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Research Paper

Assessing vulnerability and threat from housing development to Conservation Opportunity Areas in State Wildlife Action Plans across the United States

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ABSTRACT

Targeting conservation actions efficiently requires information on vulnerability of and threats to conservation targets, but such information is rarely included in conservation plans. In the U.S., recently updated State Wildlife Action Plans identify Conservation Opportunity Areas (COAs) selected by each state as priority areas for future action to conserve wildlife and habitats. The question is how threatened these COAs are by habitat loss and degradation, major threats to wildlife in the U.S. that are often caused by housing development. We compiled spatial data on COAs across the conterminous U.S. We estimated COA vulnerability using current land protection status and COA threat using projected housing growth derived from U.S. census data. COAs comprise 1–46% of each region. Across regions, 28–82% of the area within COAs is vulnerable to future housing development, and 5–55% and 7–23% of that vulnerable COA area is threatened by projected dense housing and rapid housing growth, respectively. COA vulnerability is greatest in the East. Threat from dense housing and rapid housing growth is highest in the Northeast and Pacific Southwest, respectively. Results highlight that many areas identified as important for reducing wildlife listings under the U.S. Endangered Species Act may need further protection to fulfill their conservation goals because they are both vulnerable to and threatened by future housing development. Our analyses can help practitioners target local government outreach, land protection efforts, and landscape-scale mitigation programs to decrease future COA loss from housing development, and could be expanded to address additional COA threats (e.g., wildfire, invasive species).

1. Introduction

Conservation plans rely on accurate data on the distribution of species and ecosystems across a landscape as their foundation (e.g., Margules & Pressey, 2000; Margules & Sarkar, 2007). In general, these biological data are familiar and accessible to the biologists who most often write conservation plans. Spatially explicit data on development and other activities that may threaten natural resources are equally important to consider if conservation actions are to be efficient and effective (Pressey & Bottrill, 2008; Wilson et al., 2005, 2007, 2009), but data on threats are typically less familiar and accessible to biologists.

Data on the intensity and distribution of major threats, and the vulnerability of priority biological sites to those threats, are important because they can inform where actions are needed to prevent the loss or degradation of key biological resources, the timeframe within which action may be needed, and the types of actions that may be most effective in alleviating the threat (e.g., Bengston, Fletcher, & Nelson, 2004; Wilson et al., 2005; Withey et al., 2012). For example, protected areas are often effective in halting deforestation (Geldmann et al., 2013) and conversion of natural land cover (Joppa & Pfaff, 2011), but may not prevent habitat degradation resulting from nearby development (Radeloff et al., 2010). Considering data on potential threats to, and vulnerability of, conservation targets together with biological data can increase the effectiveness of conservation actions by focusing investment of limited conservation dollars on protection of biologically important areas that are both vulnerable and likely to be threatened in

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the foreseeable future.

In the United States (U.S.), habitat loss and degradation are major threats to wildlife (Wilcove, Rothstein, Dubow, Phillips, & Losos, 1998), and housing development is a major cause of both (Brown, Johnson, Loveland, & Theobald, 2005; Radeloff et al., 2010; Theobald, 2013). The construction of houses and associated roads removes and fragments habitat, and changes the structure and composition of remaining vegetation (Dale, Archer, Chang, & Ojima, 2005; Hansen et al., 2005). Housing development may also alter nutrient and disturbance regimes via, for example, increased runoff and fire suppression (Dale et al., 2005; Hansen et al., 2005). Increased human activity and vehicle traffic accompany housing development, further degrading habitat through the introduction of noise, lights, pets, and invasive species (Dale et al., 2005; Gavier-Pizarro, Radeloff, Stewart, Huebner, & Keuler, 2010; Hansen et al., 2005; Odell & Knight, 2001; Slabbekoorn & Ripmeester, 2008). Resulting effects on wildlife populations include decreased density and diversity of sensitive wildlife species (Glennon & Kretser, 2013; Lepczyk et al., 2008; McKinney, 2002), increased mortality from roads (Benitez-Lopez, Alkemade, & Verweij, 2010; Fahrig & Rytwinski, 2009; Forman & Alexander, 1998) and human-associated predators (Crooks & Soule, 1999), and decreased fitness and fecundity of sensitive wildlife species (Bonnington, Gaston, & Evans, 2013; French et al., 2017).

In November 2001, H.R. 2217 was signed into law (P.L. 107-63), initiating the current State Wildlife Grants Program and requiring all U.S. states and territories to develop comprehensive wildlife conservation strategies. Development of the plans represented a national initiative to decrease future listings of wildlife species under the U.S. Endangered Species Act (16 USC §1531-1544). The plans, now commonly called State Wildlife Action Plans (SWAPs), identify wildlife species of greatest conservation need, the specific actions needed to conserve these species and their habitats, and priority actions for implementation. Federal guidelines required states to provide information on eight elements in their SWAPs: 1) the distribution and abundance of wildlife, 2) the habitats and natural communities essential for their conservation, 3) potential threats to both, along with needed research and survey efforts, 4) proposed conservation actions and implementation priorities, 5) proposed species, habitat, and effectiveness monitoring plans, 6) procedures for future plan review, 7) plans for coordinating plan development, implementation, review, and revision with major federal, state, and local agencies and Indian tribes, and 8) inclusion of broad public participation in developing and implementing the plan (Teaming with Wildlife Committee, 2003). Each state developed their plan in light of their own policies and priorities using approaches and methods best suited to their resources and context. Plan products ranged from general land cover maps to identification of spatially-explicit priority areas based on species richness, habitat quality, threats, proximity to existing protected areas, and other factors (Lerner, Cochran, & Michalak, 2006). More than 950 million dollars were distributed to states from 2001 to 2017 to support implementation of conservation actions identified in SWAPs (Association of Fish and Wildlife Agencies, 2017).

States were required to conduct a ten-year review of their SWAPs, and updates were due in September 2015 (US Fish and Wildlife Service, 2010). Many states updated their plans to include new information and address shortcomings of the original plans (Lerner et al., 2006). Guidance was also provided to states regarding best practices for the revision process, including goals of achieving greater consistency among plans, spatially depicting priority conservation areas, increasing the transparency and repeatability of methods, improving data accessibility, and considering new information and changing environments, including climate change (Association of Fish and Wildlife Agencies, 2012). The revised SWAPs now provide an up-to-date suite of locally generated conservation plans across the U.S.

One outcome of inclusive planning processes is that the resulting plans tend to contain many priority areas (Cowling et al., 2003; Lerner et al., 2006), often far more than conservation organizations and natural resource management agencies can secure and manage. Accordingly, conservation practitioners need to understand the extent to which priority areas identified in each plan are vulnerable, and either already threatened or likely to be threatened in the foreseeable future, in order to prioritize conservation actions. Protecting areas that are not likely to be threatened is not an efficient use of conservation dollars (Bottrill et al., 2008; Marone, Rhodes, & Gibbons, 2013).

Our goal was to assess the extent to which Conservation Opportunity Areas (COAs) identified by states across the U.S. are vulnerable to and threatened by future housing development. We had three objectives: 1) compile, analyze, and share the most recent data available for spatially-explicit COAs identified in SWAPs across the conterminous U.S. and evaluate implementation of two associated best practices, 2) quantify vulnerability of COAs across regions, and 3) quantify the intensity and extent of threat to COAs posed by future housing development. Our results provide new data to support regional and nationwide conservation efforts and highlight biologically important areas that are both highly vulnerable and highly threatened, providing key information that policy makers and practitioners need to act efficiently within and across states to conserve wildlife species of greatest conservation need.

2. Methods

2.1. Conservation Opportunity Areas in State Wildlife Action Plans

States originally developed SWAPs in 2005 and were required to review their plans by 2015 (US Fish and Wildlife Service and Association of Fish and Wildlife Agencies, 2007). As a result, many states now have newly updated SWAPs. We contacted each state in the conterminous U.S. in October 2015 and again in June 2017 by email, and asked 1) if their original SWAP identified spatially-explicit COAs, 2) if their current SWAP identifies spatially-explicit COAs, and 3) if they were able to share these spatial data. Through these inquiries and multiple follow-up communications with individual SWAP coordinators, we sought to acquire and interpret spatial COA data from each state. When more recent data were not available, we used spatial data on the location of COAs in states' original 2005 SWAPs (or early revisions/additions to them completed through 2008) compiled and published through the LandScope America Project (www.landscope.org). We did not consider point and line COA data as they have no defined spatial area. We documented basic metadata and data processing steps for each state's COA data, including clipping data to the state boundary to exclude offshore areas and any rules for combining individual data layers and subsetting the data to identify priority areas. Spatial COA data from all states that agreed to share their data are now available both by state and as a compiled nationwide map service at LandScope.org.

As we acquired COA data from states, we also evaluated implementation of two recommended best practices for revision of the SWAPs: 1) spatially depict COAs, and 2) create a GIS portal for conservation partners to access and download plan-related data (Association of Fish and Wildlife Agencies, 2012).

2.2. Vulnerability of Conservation Opportunity Areas

Vulnerability is in essence an entity's level of susceptibility or exposure to possible harm from a threat. We calculated vulnerability to future housing development by quantifying the area of COAs not already permanently protected. We defined protected lands as those with GAP status 1, 2, or 3, all of which provide some level of legal conservation protection (U.S. Geological Survey, 2016). We compiled publicly available protected lands data in GIS format from two sources: 1) permanently protected areas (U.S. Geological Survey, 2016), and 2) permanent conservation easements (National Conservation Easement

Database, 2016). A total of 2,593,102 km^2 across the U.S. are permanently protected, comprising 33% of the nation's area.

2.3. Threats to Conservation Opportunity Areas

A threat is an entity or process that is likely to cause damage or harm. We quantified threat to COAs from residential development by quantifying the area of COAs that are projected to contain dense housing or experience rapid housing growth over the next several decades. To do this, we first projected housing densities from 2010 through 2050 based on 2000 and 2010 U.S. Decennial Census data at the partial block group scale (Hammer, Stewart, Winkler, Radeloff, & Voss, 2004; Radeloff et al., 2010). Partial block groups are slightly larger than census blocks, but provide information on when housing units were built, thereby allowing analysis of past housing growth (Radeloff et al., 2010). The mean size of partial block groups across the U.S. is 2.32 km^2 (range 0–11,727 km^2, n = 3,473,770). In partial block groups that partially contained protected areas (with the exception of easements and tribal reservations), we assumed that the protected areas have no houses and increased the housing density in the remainder of the partial block group accordingly.

To project housing density for 2020 to 2050 for partial block groups, we combined housing data from the 2000 and 2010 censuses (US Census Bureau, 2012a,b) with county household projections for 2020 to 2050 generated by Woods and Poole Economics, Inc. (2015). We 1) calculated county level housing growth rates between 2000 and 2010 using housing data from the 2000 and 2010 decennial censuses, 2) adjusted those growth rates by the Woods and Poole (2015) household projections, and then 3) applied the adjusted growth rates back to each partial block group to estimate the number of housing units in 2020 through 2050.

We first calculated the number of housing units in 2000 and in 2010 for each partial block group based on census block level housing densities after accounting for changes in census block boundaries (for details on the block boundary adjustment see Radeloff et al., 2018). We then calculated each partial block group's absolute growth from 2000 to 2010 (2010 units – 2000 units) and added that change in housing units to the number of 2010 units to project 2020 housing units, and subsequently to project 2030 housing units, and so forth out to 2050. These initial growth estimates reflect an assumption of constant growth; the growth estimates are then adjusted in a subsequent step (see below). We then summed census projected housing units by county.

Second, we calculated the ratio of housing units to households at the county level using block level data from the 2010 census. Housing units include seasonal homes and unoccupied houses, which is why their number is larger than that of households. We made this conversion so that we could compare our projected housing units to the Woods and Poole (2015) household projections for 2020, 2030, etc. We multiplied Woods and Poole household projections by the ratio of housing units to households in the 2010 census to estimate housing units in each county based on the Woods and Poole data for each decade out to 2050.

Finally, we calculated partial block group adjustment rates for each county and for each decade from 2020 to 2050 as the ratio of Woods and Poole (2015) county totals versus census-based projection totals. We applied the county adjustment rates to each individual partial block group and calculated the final housing unit projections for each partial block group from 2020 to 2050, thereby helping to ensure realistic overall growth rates at the spatial resolution of partial block groups.

We considered four metrics of threat based on projected future housing development: areas of current (2010) and future (2030, 2050) dense housing, and area with rapid housing growth from 2010 to 2030. For each metric, we considered both threat intensity and threat exposure (Wilson et al., 2005). To quantify intensity, we defined thresholds for dense housing and rapid housing growth. Because COAs are considered to be areas with substantial future opportunity for conservation action, including land protection, we are most interested in the point at which housing densities within COAs are projected to move from very low values (representing primarily wildlands or rural landscapes) to higher values representative of exurban areas (defined as densities of 6–247 housing units/km^2 [between 1 housing unit per 40 acres and 1 housing unit per acre], Brown et al., 2005). We used a minimum threshold of 6.18 housing units/km^2 (equivalent to 1 housing unit per 40 acres) in a partial block group, to identify dense (exurban) housing. This threshold has been used to separate developed areas from wildland areas (Carter et al., 2014; Radeloff et al., 2005) and exurban housing from rural lands (Brown et al., 2005), and is also commonly used to classify rural land uses at local levels (e.g., Town of Woodville, 2012). This housing density also corresponds roughly with the distances at which houses, roads, and other infrastructure may negatively affect wildlife: effect distances of houses may reach 300–500 m (Odell & Knight, 2001; Theobald, Miller, & Hobbs, 1997), while effects of roads and other infrastructure may extend to a kilometer for birds and five kilometers for mammals (Benitzez-Lopez et al., 2010). We used a housing growth threshold of ≥50% increase in housing density in a partial block group between 2010 and 2030, which we refer to as rapid housing growth. This threshold is greater than average housing growth rates near protected areas (20% per decade) and across the nation as a whole (13% per decade, Radeloff et al., 2010). We calculated threat exposure by calculating the area of each COA that is both vulnerable and threatened using one or more threat metrics.

We performed all spatial analyses in ArcGIS 10.3.1 (ESRI 2015). We present most results by region, using a slight modification of the regional boundaries of the U.S. Fish and Wildlife Service (US Fish and Wildlife Service, 2017) that uses the state borders of California and Nevada as the boundary between the Pacific and Pacific Southwest regions and excludes offshore and non-continental areas. States are sensitive to the potential for misinterpretation of results summarized at state levels, and a region-based summary also supports calls to facilitate greater regional coordination (Meretsky et al., 2012).

Table 1
Availability of spatial Conservation Opportunity Area (COA) data for the conterminous United States.

Region	Number of states in region	Number of states with new or updated spatial COA data	Number of states for which spatial COA data compiled by Landscope ca 2005 was the most recent available	Number of states with no spatial COA data	Area (%) of region currently within mapped COAs
Pacific[1]	3	1	1	1	26%
Pacific southwest	2	2	0	0	28%
Mountain prairie	8	7	1	0	46%
Southwest	4	1	0	3	1%
Midwest[1]	8	8	0	0	34%
Southeast[1]	10	9	0	1	30%
Northeast [1]	13	9	2	2	31%
Total	48	37	4	7	30%

[1] Data were collected for the conterminous portions of these regions only and exclude offshore areas.

3. Results

3.1. Conservation Opportunity Areas in State Wildlife Action Plans

We able to acquire spatially-explicit COA data from 41 states (Table 1). COA data from 37 states had been created or updated since they completed their original SWAP, and COA data from four other states were available from their original 2005 SWAP via LandScope.org (NatureServ, 2017). Because all SWAPs were required to be reviewed by 2015 (US Fish and Wildlife Service, 2010), COA data from all 41 states were treated as the best available information for that state. In one case, a state said specifically that it uses other priority conservation areas as COAs (i.e., New York's use of data from the Nature's Network project [Tracey & Fuller, 2017]), and thus we considered and mapped these data as COAs for New York for this project. Seven states do not currently have spatial COA data available, and four states with either no existing spatial data or data only from their original SWAP are currently involved in state or regional efforts to identify spatially-explicit conservation focus areas. Two states noted that they purposefully either did not spatially depict COAs, or decided to define very large and inclusive COA boundaries, because a more spatially targeted effort would not be helpful or feasible in their political climate. Spatial COA data from 20 states were freely available for direct download via a publicly accessible website, and all 37 states with updated spatial COA data were able to provide those data to us quickly and easily.

In summary, 41 of the 48 states in the conterminous U.S. have mapped COAs in either their 2005 or 2015 SWAP, ranging from a low of 25% of states in the Southwest region to 100% of states in the Mountain Prairie, Midwest, and Pacific Southwest regions (Table 1). The amount of land within mapped COAs varied regionally, from a low of 1% in the Southwest to a high of 46% in the Mountain Prairie region (Fig. 1).

3.2. Vulnerability of Conservation Opportunity Areas

We found that 68% (1,509,104 km^2) of the area in COAs across the conterminous U.S. is vulnerable to future development because it is not permanently protected. Vulnerability varied regionally, from a low of 28% in the Southwest to a high of 82% in both the Southeast and Northeast (Table 2, Fig. 2).

3.3. Threats to Conservation Opportunity Areas

On average, 17% (379,953 km^2) of the area in COAs across the conterminous US already contained dense housing development as of 2010 (Table 2, Fig. 3). COAs in the Northeast had the largest area in dense housing as of 2010 (51%), and COAs in the Mountain Prairie and Southwest regions had the lowest area (2%). Looking ahead, 28% (419,420 km^2) and 29% (433,896 km^2) of the nationwide vulnerable COA area is threatened by projected dense housing development by 2030 and 2050, respectively (Table 2, Fig. 3). Threat from projected dense housing for both time periods (2030 and 2050) showed similar patterns, being highest in the Northeast region and lowest in the Mountain Prairie region (Table 2, Fig. 3). The pattern of threat differed when considering a different threat metric: threat to COAs from projected rapid housing growth from 2010 to 2030 was highest in the Pacific Southwest and lowest in the Northeast (Table 2, Fig. 3). The nationwide COA area threatened by rapid housing growth (13% of the vulnerable area in COAs) was less than that posed by dense housing but essentially non-overlapping, thus representing additional, and often spatially distant, areas of potential threat.

4. Discussion

Many states have recently updated their SWAPs, providing a unique opportunity to examine vulnerability to and threats from housing development in COAs across states and regions. We compiled data on spatially-explicit COAs in SWAPs for 41 of the 48 states in the conterminous U.S. We found that the area encompassed by mapped COAs ranged from a low of 1% of the Southwest region to a high of 46% of the Mountain Prairie region. Vulnerability ranged from a low of 28% in the Southwest to a high of 82% in both eastern regions. Threat from projected dense housing was also highest in the east, peaking at 55% of the vulnerable COA area in the Northeast. However, threat from rapid housing growth was greatest in the Pacific Southwest (23% of the vulnerable COA area). Our findings provide important information for targeting and coordinating conservation actions within and across states to more efficiently protect threatened COAs, and highlight that many COAs may need further protection to meet their long term conservation goals given their high levels of both vulnerability to and threat from projected future housing development.

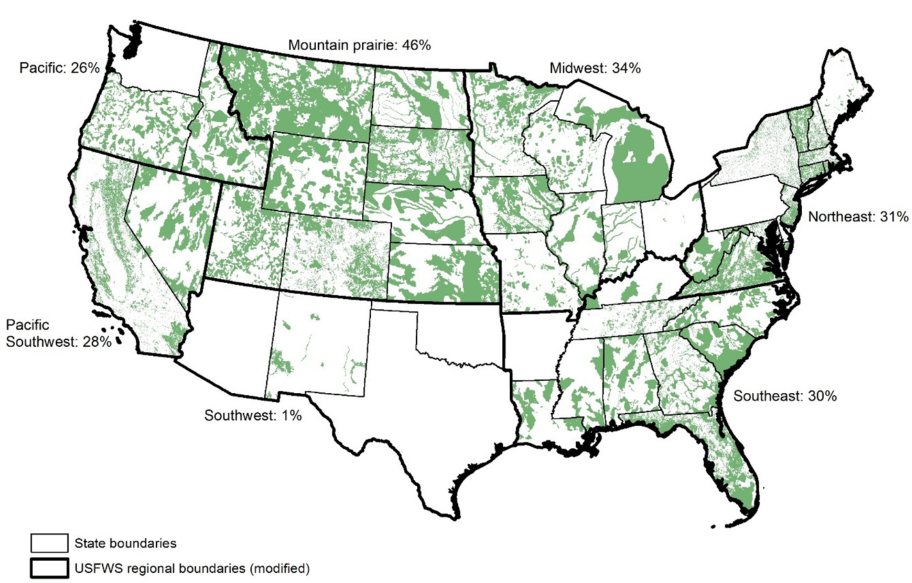

Fig. 1. Mapped Conservation Opportunity Areas in State Wildlife Action Plans across the conterminous United States. Percentages reflect the area of the region encompassed by mapped Conservation Opportunity Areas for which data were available for this study.

Table 2
Area of Conservation Opportunity Areas (COAs) in each region of the conterminous United States that is vulnerable to future housing development, limited by current dense housing, and projected to be threatened by future dense housing development by 2030 or 2050, or by rapid housing growth by 2030.

Region	Area of COAs vulnerable to future housing development	Area of COAs limited by current (2010) dense housing	Area of COAs both vulnerable and threatened by projected dense housing in 2030	Area of COAs both vulnerable and threatened by projected dense housing in 2050	Area of COAs both vulnerable and threatened by rapid housing growth
Pacific[1]	34% (58,501 km^2)	4% (7,356 km^2)	14% (8,296 km^2)	16% (9,391 km^2)	14% (8,051 km^2)
Pacific southwest	32% (61,364 km^2)	6% (12,194 km^2)	21% (13,137 km^2)	23% (13,954 km^2)	23% (14,369 km^2)
Mountain prairie	68% (605,573 km^2)	2% (21,338 km^2)	4% (27,055 km^2)	5% (30,108 km^2)	13% (81,524 km^2)
Southwest	28% (4,486 km^2)	2% (333 km^2)	8% (339 km^2)	7% (335 km^2)	14% (631 km^2)
Midwest	79% (317,702 km^2)	28% (112,306 km^2)	39% (123,787 km^2)	40% (126,952 km^2)	8% (25,271 km^2)
Southeast[1]	82% (303,809 km^2)	35% (128,572 km^2)	47% (142,315 km^2)	49% (147,884 km^2)	16% (47,959 km^2)
Northeast	82% (157,670 km^2)	51% (97,856 km^2)	54% (104,492 km^2)	55% (105,271 km^2)	7% (12,677 km^2)
Total	68% (1,509,104 km^2)	17% (379,953 km^2)	28% (419,420 km^2)	29% (433,896 km^2)	13% (190,482 km^2)

[1] Data were collected for the conterminous portions of these regions only and exclude offshore areas.

4.1. Conservation Opportunity Areas in State Wildlife Action Plans

Our first objective was to compile, analyze, and share spatially-explicit COA data and to evaluate implementation of two related best practices emerging from the ten-year SWAP review: 1) to identify spatially-explicit COAs, and 2) to make COA data available for direct download (Association of Fish and Wildlife Agencies, 2012). Mapping spatially-explicit COAs helps states target conservation investments and coordinate actions with diverse partners (Stoms, Davis, & Scott, 2010). We were able to compile spatially-explicit COA data for 41 of the 48 states in the conterminous U.S. Of the remaining states, some (e.g., Oklahoma) are still in the process of identifying COAs, and others decided against mapping COAs and are pursuing other approaches. For example, Washington state is identifying priority conservation actions for each ecosystem or habitat type in the state rather than identifying specific locations in the state that are a conservation focus (John Pierce, personal communication, June 6, 2016). In total, the COA data that we compiled provide information on priority conservation areas for 80% of the conterminous U.S. However, we were only able to acquire COA data for one of the 4 states in the Southwest region (Table 1), substantially limiting the value of our vulnerability and threat estimates for that region.

Spatially-explicit COA data were available for direct download from 20 of the 41 states that currently have such data. Many states have limited conservation staff and funding (Stoms et al., 2010), and thus may have had difficulty implementing this practice. NatureServe has committed to hosting and maintaining the updated COA data on LandScope.org to facilitate future viewing, analysis and use by conservation planners and practitioners at all levels, providing states with an additional option for sharing their data.

Regional differences in the area covered by COAs were, at least in part, related to methodological differences among states in identifying COAs. Some states identified COA boundaries using an expert-based process (e.g., Wisconsin), while others used more quantitative approaches (e.g., California). Several states used multiple SWAP data layers simultaneously, sometimes also considering priority areas

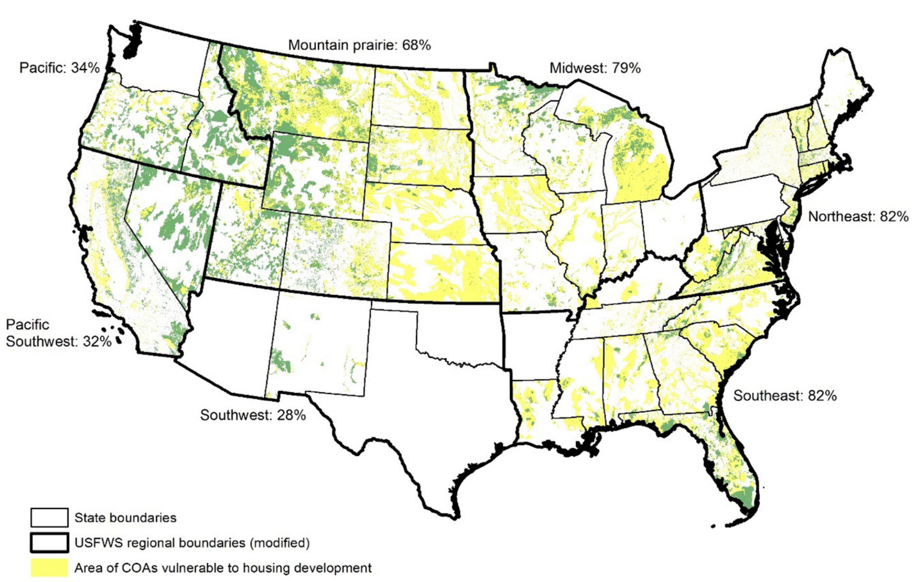

Fig. 2. Percentage of the area within mapped Conservation Opportunity Areas in State Wildlife Action Plans across the conterminous United States that is vulnerable to future development because it is not currently permanently protected.

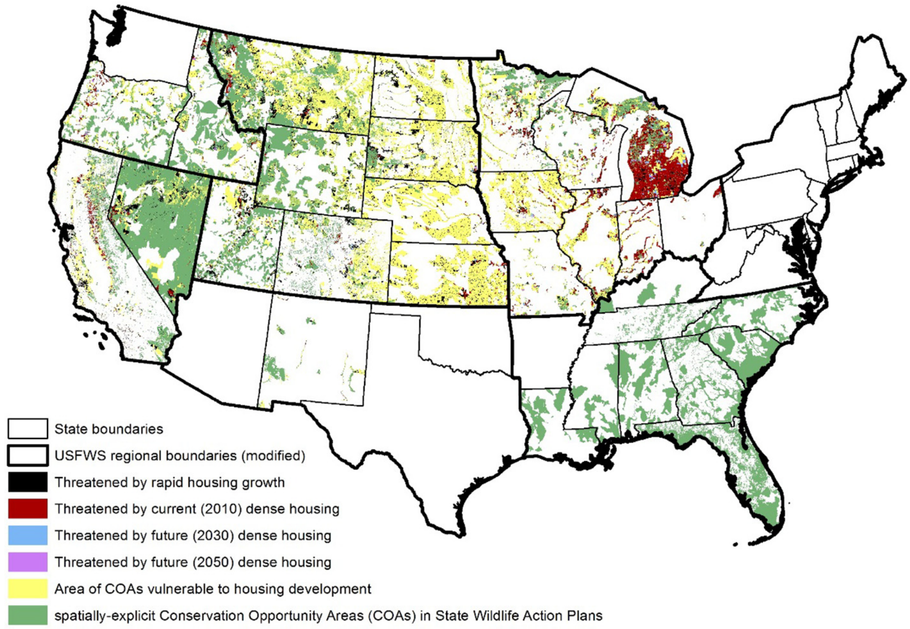

Fig. 3. Areas of mapped Conservation Opportunity Areas in State Wildlife Action Plans in each region across the conterminous United States that are both vulnerable to future development and are threatened by current (2010) dense housing, by projected future dense housing by 2030 and 2050, and by rapid housing growth.

identified through other planning efforts (e.g., West Virginia). Some states included as COAs both high quality areas that are a focus for protection and more degraded areas that are a focus for restoration efforts. Other states (e.g., Colorado) have COA data consisting of a continuous range of values for all areas in the state, and we worked with those states to identify an appropriate threshold that defines COA boundaries for our analysis. Overall, some states identified large portions of their state as COAs (e.g., 89% in Michigan), while COAs in other states are very targeted (e.g., comprising 5% or less of the states of both New Mexico and Ohio). These different approaches reflect state-by-state differences in priority resources, available conservation tools, and effective conservation strategies, and illustrate potential challenges in seeking to standardize plans (Association of Fish and Wildlife Agencies, 2012) whose development is driven by an open, flexible, inclusive, state-based approach to conservation planning.

4.2. Vulnerability of Conservation Opportunity Areas

Our second objective was to quantify COA vulnerability across regions. We found that COAs in the central and eastern US are quite vulnerable to future housing development because of a lack of existing permanent protection, with COA vulnerability peaking at 82% in both the Southeast and Northeast regions. Jenkins, Van Houtan, Pimm, and Sexton (2015) also found that priority areas for conservation (defined based on species endemism and range size) were highly vulnerable to threat in the southeastern U.S. (defined broadly, extending west into parts of the Southwest region and north into a portion of the Northeast region) and along the West Coast. Vulnerability of COAs in our study was lower in the West, where much more land is permanently protected (e.g., 86% of the Pacific Southwest consists of protected areas, compared to 15% of the Northeast).

High state or regional vulnerability may also reflect and be influenced by the approach states used to identify COAs. For example, one state (North Carolina) used watershed boundaries to define COAs. Such an approach to identifying COAs could skew vulnerability scores upward if, for example, a portion of the watershed is already urbanized (i.e., the urbanized area is technically vulnerable because it is not permanently protected, but it is also not in fact threatened because it is already developed). Other states may purposely not have considered existing protected areas to be major opportunities for future conservation action, as is common in the conservation planning literature (e.g., Margules & Pressey, 2000). This approach to identifying COAs would tend to skew vulnerability scores downward compared to states that included existing protected areas when identifying COAs. However, excluding existing protected areas from consideration as potential COAs is likely uncommon because conservation actions in SWAPS are diverse, extending well beyond permanent land protection to include actions such as collecting and analyzing data, restoring species assemblages, and managing invasive species (Association of Fish and Wildlife Agencies, 2011), some of which may be priorities within existing protected areas.

4.3. Threats to Conservation Opportunity Areas

Our final objective was to quantify the intensity and extent of threat to COAs across the U.S. posed by future housing development. Quantifying threats consistently was another recommendation for improving the revised SWAPs (Association of Fish and Wildlife Agencies, 2012; Lerner et al., 2006). We evaluated all COAs according to four nationally consistent threat metrics, and found that potential threat to priority areas from future housing development differed substantially by region and by metric. COAs in the Northeast are already affected by dense housing within their boundaries and exposed to the greatest threat from potential future dense housing. Conversely, COAs in the Pacific Southwest are exposed to the greatest threat from rapid housing growth. Threat from future housing development tended to be lower in much of the American West, as many of these lands are public and not subject to residential housing development. However, it is important to note that our threat metrics do not account for other types of development, such as mines, quarries, conventional and renewable energy development (e.g., oil, gas, wind, solar), recreational development, and associated transportation infrastructure, that are occurring on many multiple-use (GAP status 3) public lands managed by the Bureau of Land Management and U.S. Forest Service in the western U.S. (Leu, Hanser, & Knick, 2008; Theobald, 2010; Venter et al., 2016).

4.4. Conclusion

States worked closely with local partners, stakeholders, and the public to produce their original Wildlife Action Plans in 2005 (Stoms et al., 2010), and to review and revise their plans by 2015. A number of reports and publications have summarized findings from the original and revised SWAPs, ranging from connectivity analyses (Lacher & Wilkerson, 2013) to adaptive management (Fontaine, 2011) to consideration of plants (Stein & Gravuer, 2008), invertebrates (Bried & Mazzacano, 2010; Mawdsley & Humpert, 2016), and aquatic species (Mawdsely, Palmeri, & Humpert, 2017). To our knowledge, however, this is the first effort since 2008 to compile, analyze, and share the spatial data associated with these comprehensive conservation plans. Collectively, these COAs are considered by states and their stakeholders to be the most important areas for conserving wildlife species of conservation concern and preventing future endangered species listings across the conterminous U.S.

States have received more than $950 million in support of their SWAPs (Association of Fish and Wildlife Agencies, 2017), and funded projects have improved habitat quality and increased populations of some wildlife species (Association of Fish and Wildlife Agencies, 2011). When presented with a large suite of areas of high conservation value, targeting conservation action toward those sites that are both vulnerable and threatened in the short term is a recommended strategy (Visconti, Pressey, Bode, & Segan, 2010; Wilson, McBride, Bode, & Possingham, 2006). Our results thus provide a stronger foundation for conservation practitioners to prioritize future conservation actions within and across state and other jurisdictional boundaries using consistent, spatially-explicit data.

Our vulnerability analysis also provides a baseline assessment and approach for evaluating the effectiveness of future land purchases and conservation easements in reducing the vulnerability of COAs to future housing development. As protected area and conservation easement databases are updated over time, this analysis can be repeated to identify where and under what circumstances practitioners have been most effective in reducing COA vulnerability, which is one measure of the effectiveness of conservation actions in achieving natural capital outcomes (Bottrill & Pressey, 2012).

Our threats assessment provides information practitioners can use to target and coordinate near-term (e.g., 5 year) and mid-term (e.g., 10–15 year) conservation strategies and actions designed specifically to abate threats from future housing development. For example, greater outreach to local planners has been highlighted as a compelling conservation need (Stoms et al., 2010), and areas containing COAs that are expected to experience rapid housing growth within the next 15 years may be priority places for biologists to meet now with local governments and land use planners to 1) ensure that everyone is aware of the high conservation value of the COAs within their jurisdiction, 2) provide the locations of COAs to them in usable electronic formats, and 3) discuss how they might work proactively to guide planned development toward areas on the landscape where it is most suited (e.g., through comprehensive plans or zoning ordinances). Non-governmental organizations might use detailed maps of areas that have high conservation value, high vulnerability, and high threat to focus near-term efforts to purchase development rights from willing landowners (Bengston et al., 2004). Conservation developments, in which residential housing subdivisions are designed to preserve a significant footprint of natural cover within their boundary, are one tool for maintaining some sites of conservation value within areas that are projected to undergo significant residential housing development (Milder & Clark, 2011). Local governments can encourage conservation developments by passing local ordinances that allow for and guide their design (Reed, Hilty, & Theobald, 2013). Vulnerable areas of COAs that are highly threatened may also serve as priority locations for landscape-scale mitigation efforts, which seek to offset wildlife habitat losses from current development by requiring conservation actions (such as land protection) elsewhere on the landscape (e.g., Clement, Belin, Bean, Boling, & Lyons, 2014).

Our approach also provides a framework for analyzing other major threats to wildlife habitat in the U.S. Nationwide datasets exist that could be used to quantify potential future threat to COAs from fire (Wildfire Hazard Potential, Dillon, 2018), invasive species (National Insect and Disease Risk Map, Krist, Ellenwood, Woods, McMahan, Cowardin, Ryerson, & Romero, 2014), and land use change (e.g., Radeloff et al., 2012; Lawler et al., 2014). Conducting additional broad-scale threat assessments using our approach, and monitoring changes in vulnerability and threat metrics as indicators of the implementation and effectiveness of conservation actions, can help states move forward efficiently in conserving priority habitats for rare and declining wildlife species.

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