CEE review 09-005

HOW DO THINNING AND BURNING TREATMENTS IN SOUTHWESTERN CONIFER FORESTS IN THE UNITED STATES AFFECT WILDLIFE DENSITY AND POPULATION PERFORMANCE?

Systematic Review

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Summary

1. Background

After a century of fire suppression, logging, and grazing, conifer forests in the southwestern United States have undergone a dramatic departure from conditions that existed prior to Euro-American settlement. Today's ponderosa pine and mixed conifer forests are characterized by homogenous, dense, small-diameter stands that are susceptible to stand-replacing crown fires. There is now an emphasis on ecological restoration in the Southwest, whereby forests are thinned, burned, or both to approximate presettlement structural conditions. Ecological restoration treatments expose wildlife species to short- and long-term alterations to their habitat. Treatments are an effort to return forest structure and composition to within the range of natural variability, which should benefit native wildlife species. However, both thinning and burning treatments are being implemented across thousands of acres of forest in the southwestern United States, with limited quantitative data regarding wildlife responses. Individual species have been studied, but no review exists that quantitatively examine the effects of thinning and burning treatments on multiple wildlife species in a systematic review framework.

2. Objectives

Primary objective: How do thinning and burning treatments in southwestern conifer forests in the United States affect wildlife density and population performance?

Secondary objective: Which wildlife species are most vulnerable to habitat alteration? How do the impacts of thinning and burning treatments compare to those of selective harvesting, wildfire, and overstory removal?

3. Methods

To identify studies relevant to our review, we searched databases supported by Northern Arizona University during September-December 2008, using a defined combination of search terms. We then eliminated papers, first based on title, then abstract, then full text, based on a set of criteria that specified the review subject (wildlife species in southwestern conifer forests), intervention (small-diameter tree removal, burning, thin and burn, selective harvest, wildfire, or overstory removal), comparator (untreated control), and outcome (density, abundance, or reproductive response variable, including recruitment, number of offspring, percent offspring survival, etc.). We assessed study quality based on whether the study was replicated and/or peer-reviewed, and applied a weighting factor (sampling area) to data used in the quantitative analysis. Other covariates included treatment, forest type, time since treatment, species, study type, density estimation method, replication, quality of study, and study (identifying the origin of the data). We identified data that met the requirements of meta-analysis, calculated effect sizes using the response ratio metric, built generalized linear models to predict effect size based on covariates, and identified the most parsimonious model using a model selection approach. Each

covariate in the best-fitting model was examined via forest plots by calculating mean effect sizes with bootstrapped confidence intervals. Data that were not appropriate for meta-analysis were analyzed using vote-counting techniques.

4. Main results

Our review identified 56 relevant studies, which were dominated by avian studies and generally occurred less than 10 years post-treatment. Although the qualitative analysis resulted in broadly neutral or positive responses to treatments in terms of species abundances, the meta-analysis revealed a pattern of generally positive density responses to the restoration-like treatments (small-diameter removal, burning, and thin/burn) and negative responses to the high-severity treatments (wildfire and overstorey removal). We recorded more positive responses by individual species to the high-severity treatments using the qualitative analysis compared to the meta-analytic approach. Reproductive responses were generally positive in the restoration treatments and negative in the high-severity treatments, but were compromised by low numbers of observations. Overall, thinning and/or burning did not negatively affect species' abundances or densities compared to unmanaged forest stands, and were less detrimental than overstorey removal or wildfire.

5. Conclusions

This review suggests that thinning and prescribed burning of southwestern ponderosa pine and dry mixed conifer forests will benefit passerine birds and small mammals. Based on the existing literature, small-diameter removal and/or burning does not negatively affect species' densities compared to unmanaged forest stands, and is less detrimental than overstorey removal or wildfire. However, no one treatment benefitted all species, at least in the short term. Thus, a combination of various treatments in a patchy arrangement in time and space across the landscape is likely to result in higher diversity than any one treatment.

The majority of studies in the analysis examined responses of birds to treatment, and we suggest that existing studies be carefully consulted before initiating similar research in order to eliminate duplication of effort. Other under- or unrepresented taxa include reptiles and amphibians, rare birds and small mammals, medium and large mammals, including both predators and ungulates, and birds of prey. Furthermore, the lack of studies that assess reproductive responses across all species indicates a paucity of research on this important fitness parameter. Finally, studies need to be conducted at larger temporal and spatial scales in order to understand both short- and long-term implications of treatments at the landscape level.

Main Text

1. Background

After a century of fire suppression, logging, and grazing, conifer forests in the southwestern United States have undergone a dramatic departure from conditions that existed prior to Euro-American settlement (Covington and Moore, 1994, Swetnam et al., 1999, Cooper, 1960). Today's ponderosa pine (*Pinus ponderosa*) and mixed conifer (*Abies lasiocarpa, P. flexilis, P. ponderosa, Populus tremuloides, Pseudotsuga menziesii*) forests are characterized by homogenous, dense, small-diameter stands that are susceptible to stand-replacing crown fires (Fulé et al., 1997, Cocke et al., 2005). This differs from the natural fire regime that occurred on a 2-25 cycle at low intensity, which would maintain forests by removing small diameter trees, freeing up space and resources (Moore et al., 1999). The results was an open, patchy forest structure of mostly mature trees with a herbaceous ground cover (Covington and Moore, 1994, Waltz et al., 2003). There is now an emphasis on ecological restoration in the Southwest, whereby forests are thinned, burned, or both to approximate presettlement structural conditions.

Ecological restoration treatments expose wildlife species to short- and long-term alterations to their habitat. In the short-term, both mechanical harvesting of trees and prescribed fire are disturbance events that have immediate effects on the environment: removing or killing live trees, reducing shrub and herbaceous ground cover, altering structural components such as snags and downed woody material, and creating sites susceptible to colonization by invasive plant species (Chambers and Germaine, 2003). In the long term, successful restoration treatments should create a forest with a decreased density of trees compared to today's conditions, but increased heterogeneity in tree sizes and overall greater basal area due to the prevalence and growth of large, mature trees with a fairly open canopy (Moore et al., 1999, Cooper, 1961). In addition, such treatments should increase understory plant cover and species diversity (Waltz et al., 2003). This increased spatial and temporal heterogeneity should diversify the composition and structure of habitat available for wildlife (Allen et al., 2002).

Wildlife responses to forest treatments vary widely; generally, it is assumed that treatments which restore conditions consistent with those animals have experienced over evolutionary time will have more beneficial effects than treatments that create novel conditions (Noss and Csuti, 1994, Lindenmayer and Franklin, 2002, Soule, 1985). High severity disturbances such as clearcutting and wildfire (Anthony and Isaacs, 1989, Grialou et al., 2000, Cunningham et al., 2002) and unnaturally dense or open conditions (Brown and Davis, 1998, Shick et al., 2006) can have negative impacts on animal species, particularly in the short term, because of habitat alteration. Ecological restoration treatments are an effort to return forest structure and composition to within the range of natural variability, which should benefit native wildlife species (Allen et al., 2002).

Due to the urgent need to implement restoration treatments to reduce fire risk, both thinning and burning treatments are being implemented across thousands of acres of forest in the southwestern United States, but with limited understanding of the implications to wildlife. Ecological restoration treatments have only been implemented in the last 20 years, and thus the corresponding studies on wildlife are relatively recent and limited in temporal and spatial scale. Individual species have been studied, but no review exists that analyzes the existing literature across taxa. Existing reviews include summaries of impacts of thinning and burning treatments on birds (Block and Finch, 1997, Bock and Block, 2005a, Bock and Block, 2005b, Sallabanks et al., 2000) and qualitative reviews that described effects of thinning and fire on multiple wildlife species (Lyon et al., 2000, Pilliod and Bull, 2006, Chambers and Germaine, 2003). The reviews point to individual species' increases or decreases in responses to treatments, but have difficulty generalizing across studies due to the variability in response variables, treatments, sites, and species. None of these reviews quantitatively examined the effects of thinning and burning treatments on multiple wildlife species in a systematic review framework.

The objective of this review is to systematically review and evaluate the impacts of tree density-reducing treatments, including thinning and burning, on wildlife vertebrate species in conifer forests in the south-western United States. Not all thinning and burning treatments are strictly "restoration treatments," as the goal of the treatments may be to simply reduce fire risk and not necessarily to restore stands to a structure and function similar to that of pre-settlement conditions. Thus, we will separately identify the effects of thinning, burning, and thin/burn treatments, which all share some elements of restoration treatments, with the thin/burn treatments most inline with the goals of ecological restoration. We compared the treatments to controls, as well as to more severe forest treatments including highgrading, clearcutting, and high severity wildfire. This review will serve as a starting point for researchers and managers in understanding the comprehensive impacts on wildlife of ecological restoration treatments and determining future monitoring and research needs.

2. Objectives

2.1 Primary objective:

How do thinning and burning treatments in south-western conifer forests in the United States affect wildlife density and population performance?

2.2 Secondary objective

Which wildlife species are most vulnerable to habitat alteration? How do the impacts of thinning and burning treatments compare to those of selective harvesting, wildfire, and clear-cutting?

3. Methods

3.1 Question formulation

We contacted 20 wildlife managers and scientists from a range of government and academic institutions, including Northern Arizona University (NAU), Arizona Game and Fish Department, U.S. Fish and Wildlife Service, and the U.S. Forest Service. We sent them an email questionnaire giving them specific criteria with which to evaluate and modify our proposed question. We received 9 responses that helped us revise the question. In addition, the team of authors representing the Ecological Restoration Institute, Northern Arizona University School of Forestry, and Arizona Game and Fish Department further refined the question.

3.2 Search strategy

We searched databases supported by Cline Library, NAU, during September-December 2008, and then again in December 2009, including:

- Academic Search Premier
- Biological Sciences
- BioOne
- Environmental Science & Pollution Management
- Plant Science
- Springer Link
- Wiley Interscience
- Zoological Record
- JSTOR
- Forest Science Database
- Dissertation and Theses Full Text
- Cline Library
- ISI Web of Science
- We also searched government and agency websites and libraries (US Forest Service TreeSearch, Ecological Restoration Institute library, Arizona Game and Fish website and library, US Fish & Wildlife Service website)

Search terms included all combinations of the following:

- Wildlife, bird*, reptile*, amphibian*, mammal* AND
- Western forest*, ponderosa pine AND
- Restoration, thinning, prescribed burn*, fuel reduction, fire, logging, clearcut*, harvest, treatment*

3.3 Study inclusion criteria

After conducting the databases search we eliminated papers if they did not meet the following criteria:

- **Relevant subject(s):** Vertebrate species that live in ponderosa pine or mixed conifer forests in the southwestern United States, including
    - Birds
    - Mammals
    - Reptiles
    - Amphibians

- **Types of intervention:**
  - Small-diameter removal (removal of small-diameter trees; included thinning and shelterwood treatments)
  - Burn (low-to-moderate severity prescribed fire)
  - Thin and burn
  - Selective harvest (individual tree selection, highgrading)
  - Wildfire (high severity fire)
  - Overstory removal (clearcut)
- **Types of comparator:**
  - Experiments with controls (dense forest) and treatments (thinned/burned forest), either control-impact (C-I) or before-after (BACI)
- **Types of outcome:**
  - Abundance
  - Density
  - Reproductive output, as defined by number of successful nests, number of offspring, and/or survival rates of offspring

We considered all types of studies, include peer-reviewed, grey literature (government documents and theses), and observational and qualitative studies. The primary reviewer conducted the initial database searches, and eliminated irrelevant papers based on title, using the above criteria. The resulting list was examined by both the primary and a secondary reviewer, who eliminated irrelevant articles based on abstracts. Agreement between reviewers was evaluated by an inter-rater agreement (Kappa) test (Altman, 1990). The primary reviewer then eliminated studies based on the full text papers.

Among studies, there is heterogeneity in the distribution of species across different forest types, elevation, and topography in conifer forests in the southwestern U.S. There is also variation in the application of thinning and burning treatments, including intensity, spatial extent, and duration. This variability was addressed using multiple predictor variables (see Section 3.5).

3.4 Study quality assessment

For the qualitative and quantitative analysis, we identified three covariates that assessed study quality: abundance or density estimation method (with or without detection probability), replication, quality of study (peer-reviewed or not). In the qualitative analysis, we presented summary statistics of the number of studies that did and did not fall into these categories.

For the quantitative analysis, we used the covariates as predictor variables in our model selection analysis to determine if they had an effect on the response variable (see section 3.6). Furthermore, we applied a weighting scheme to our models to account for the reliability of results from large versus small studies. In most meta-analyses the inverse of the standard deviation is used to weight studies; however, in wildlife studies, the standard deviation between replicate means is often (1) unreported, (2) unavailable because sample size is one, or (3) not meaningful because the size of a replicate varies dramatically from study to study. Here, we used the natural log of the area sampled as a biologically meaningful weighting scheme, similar to Mosquera et al. (2000). Further methods involving the weighting scheme are provided in section 3.6.

3.5 Data extraction

We built a database to record the data extraction process for the analysis; this helped determine which papers (of the final set) were relevant to qualitative versus quantitative analysis. The primary reviewer read the full text of each study and recorded the species evaluated, density or reproductive output data, and covariates including treatment, forest type, time since treatment, species, study type (BACI or C-I), density estimation method (with or without detection probability), replication (replicated or not), quality of study (peer-reviewed or not), and study (where each study was assigned a unique identifier, since some studies have multiple observations) (Appendix 1). Data were separated by year and site whenever possible. If some data were missing from a paper we attempted to contact authors to acquire it. Studies lacking quantitative data were assigned to the qualitative analysis.

3.6 Data synthesis

We used vote counting to incorporate the results of studies that could not be incorporated into the meta-analysis, and tabulated the number of observations that produced positive, neutral, or negative responses to the treatments and reported the "winner" across the categories. For the individual species (abundance and reproduction response variables), we summed the positive responses (each given a value of 1) and negative responses (each given a value of -1) for an overall score; this was to improve readability of our results, but also because many "neutral" results (each given a value of 0) were attributable to a lack of data, not a true neutral response to treatment. In addition, we eliminated all species for which there was only a single observation across all studies, in order to improve data quality.

For the meta-analysis, we calculated effect sizes using the response ratio metric: ln(treatment mean/control mean) (Hedges et al., 1999). Using JMP 8.0.2 (SAS Institute Inc. 2009), we built generalized linear models, weighted using the natural log of the area sampled (see Section 3.4), to predict effect size based on covariates (see Section 3.5). We developed *a priori* models hypothesized to best predict effect size, and then used a model selection approach to identify the most parsimonious model (Burnham and Anderson, 2002). This allowed us to address non-independence of data, as the "study" effect was assessed relative to the other covariates. We compared models using Akaike's Information Criterion adjusted for small sample sizes (AIC_c) to assess the overall strength of each model, ranked the models from highest to lowest according to their ΔAIC_c values, and then chose those models with $\Delta AIC_c < 2$ as the final set to be used for inference (Burnham and Anderson, 2002). We performed separate analyses using weighted and unweighted generalized linear models. There was no difference in the results; thus, we reported only unweighted model results. We calculated the Akaike weight (w_i) for each model as a measure of model support. Each covariate in the best-fitting model(s) was examined using Metawin software

(Rosenberg et al., 2000), with which we calculated mean effect sizes with bootstrapped confidence intervals using forest plots (Adams et al., 1997).

4. Results

4.1 Review statistics

All studies retrieved were stored in a RefWorks reference manager database (www.refworks.com, supported by NAU) and assigned and YES or NO ranking after each stage of culling. The initial database search produced 6,908 studies. The primary reviewer performed a cull using our criteria (Section 3.3) based on the titles, which produced 367 studies. At this point, we made the decision to focus only on southwestern conifer forests, due to the volume of papers and variety of species involved in multiple geographic regions. We identified 229 studies after eliminating those not conducted in the Southwest.

The primary reviewer then culled based on abstract which produced 76 studies. A second reviewer performed the same cull on 30% of the studies, with a Kappa statistic of 0.79 (out of 1.00) which is considered "good" agreement (Altman, 1990). We then read all remaining full text articles, and used our data extraction form (Appendix 1) to determine if the studies were appropriate for the qualitative or quantitative analysis. A total of 36 studies were removed at this stage. We added studies based on leads in other papers' literature cited sections and the literature reviews we examined, and sent our draft reference list to several agency stakeholders to review for omissions. A total of 16 additional studies were identified.

4.2 Description of studies

Our review produced 56 relevant studies. We determined that 22 studies reported density and were suitable for meta-analysis (number of observations [N]=1,095); 39 reported abundance or presence-absence response variables that were not appropriate for the meta-analysis (N=1,580), and 12 reported reproductive response variables (N=59) (Table 1). The number of observations is different than the number of studies because many studies reported multiple species, treatments, years, and/or response variables, and thus resulted in multiple observations. Appendices 2 and 3 list studies used in qualitative and quantitative analyses, respectively.

Table 1. Number of observations per response variable for all studies used in the qualitative and quantitative analyses.

Response Variable	#Observations
Qualitative analysis: abundance	**1,580**
Adult survival	1
Home range size/% of time spent in treatment	12
Presence-absence	27
Abundance	1,540
Qualitative analysis: reproduction	**59**
Recruitment (juveniles/ha)	1
# Cubs	3
% Cub/chick survival	3
% Females producing cubs	3
# Nests/roosts	7
# Fledged per nest	8
# Nestlings per nest	13
# Successful nests	21
Quantitative analysis	**1,095**
Density	1,095

We also tallied the number of observations per class (bird, mammal, or reptile) and found that the literature was dominated by avian studies (90% of the total observations), mostly focused on songbirds (Table 2). The reptile observations consisted solely of lizard studies, and the mammal observations consisted mostly of rodents (58% of the mammal observations; Table 2).

Table 2. Total number of observations used in the review by class and order.

Order	#Observations
Birds	**2,473**
Fowl	6
Owls	24
Nightbirds	29
Pigeons and doves	60
Hummingbirds and swifts	62
Birds of prey	105
Woodpeckers	264
Songbirds	1,923
Reptiles	**68**
Lizards	68
Mammals	**193**
Insectivores	2
Bats	2
Lagomorphs	3
Carnivores	21
Ungulates	54
Rodents	111

4.3 Study quality assessment

For the qualitative analysis, we found that most studies were replicated (Table 3). Most studies did not consider detection in their abundance or reproductive output estimates, and were not published in the peer-reviewed literature (Table 3).

Table 3. Number of qualitative studies that met conditions of the three covariates that assessed study quality.

Characteristic of study	Yes	No
Considered detection	208	1,431
Peer-reviewed	475	1,164
Replicated	851	788

For the quantitative analysis, the three covariates that assessed study quality (abundance or density estimation method, replication, whether the study was peer-reviewed) used as predictor variables did not have an effect on the response variable in our model selection analysis (see section 4.5).

4.4 Qualitative synthesis

Data that spanned 1-25 years post-treatment were available for the qualitative analysis. Across the studies that assessed some measure of abundance, the small-diameter removal, burn, thin/burn, and wildfire had mostly neutral effects on wildlife, and the second-most commonly observed effects were positive (Figure 1). The selective harvest and the overstory removal had mostly positive effects. Across the reproduction studies, the small-diameter removal elicited mostly neutral responses while the second-most commonly observed effects were negative; the burn, selective harvest, and wildfire produced mostly negative responses, and the thin/burn resulted in mostly positive responses (Figure 2). We found no studies on reproductive responses to overstory removals.

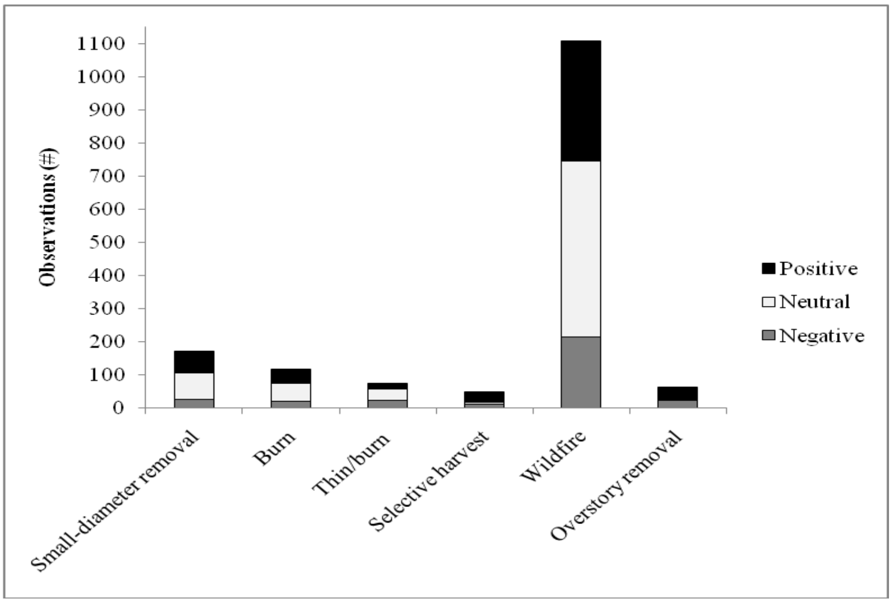

Figure 1. Number of observations that reported positive, neutral, or negative effects in response to treatment in the qualitative abundance studies.

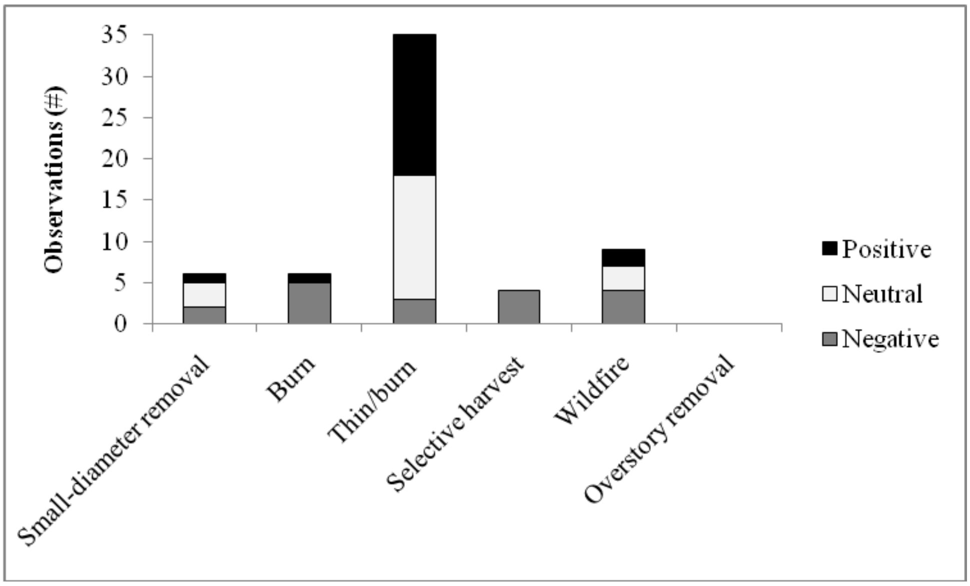

Figure 2. Number of observations that reported positive, neutral, or negative effects in response to treatment in the qualitative reproduction studies.

In response to the combined small-diameter removal, burning, and thin/burn (restoration) treatments we found that 27 species exhibited a positive response, 11 a neutral response, and 18 a negative response (Table 4). In response to the high-severity treatments (wildfire and overstorey removal), 68 species demonstrated a positive response, 14 a neutral response, and 28 a negative response (Table 4). Special status species included one with a positive response to high severity treatments (northern goshawk), two with neutral responses (Mexican spotted owl and Peregrine falcon), and one with a negative response (flammulated owl) (Table 4).

Table 4. Species' abundance responses to restoration (small-diameter removal, burn, and thin/burn) and high-severity (wildfire and overstory removal) treatments in terms of the sums of responses, followed by the total number of observations. Species are ordered by most positive to negative response to restoration and then high-severity treatments.

	Restoration Treatments		**High-severity Treatments**	
Species[1]	**Response**	**#Observations**	**Response**	**#Observations**
Birds	**43**	**252**	**125**	**1055**
Hairy woodpecker	9	13	18	23
Western bluebird	9	11	16	18
Western wood-pewee	7	8	8	18
Clark's nutcracker	5	5	12	18
Broad-tailed hummingbird	4	6	16	18
Chipping sparrow	4	8	-5	18
Pygmy nuthatch	4	9	-14	19
Northern flicker	3	5	9	17
Plumbeous vireo	3	7	-1	17
Violet-green swallow	3	5	3	17
Brown-headed cowbird	2	2	13	17
Common raven	2	5	-1	18
Dark-eyed junco	2	21	4	18
House wren	2	3	20	20
Mourning dove	2	5	4	16

Species[1]	Restoration Treatments		High-severity Treatments	
	Response	#Observations	Response	#Observations
White-breasted nuthatch	2	9	2	19
White-crowned sparrow	2	2	2	2
Black-headed grosbeak	1	5	0	18
Black-throated gray warbler	1	2		
Orange-crowned warbler	1	2	-5	16
Pine siskin	1	6	-1	18
Rufous hummingbird	1	2		
Virginia's warbler	1	3	-11	17
Western tanager	1	6	5	16
Acorn woodpecker	0	2	6	13
Brown creeper	0	5	-5	18
Bushtit	0	3	-1	2
Cordilleran flycatcher	0	5	-1	16
Hepatic tanager	0	2	1	3
Olive-sided flycatcher	0	4	10	18
Wilson's warbler	0	2		
American robin	-1	7	-2	19
Buff-breasted flycatcher	-1	2	2	2
Empidonax flycatchers	-1	2	-15	17
Red crossbill	-1	2	-3	16
Red-breasted nuthatch	-1	6	3	9
Red-naped sapsucker	-1	2	1	6
Yellow-bellied sapsucker	-1	2	-2	3
Grace's warbler	-2	8	-3	17
Ruby-crowned kinglet	-2	3	-8	15
Spotted towhee	-2	4	7	18
Steller's jay	-2	7	4	19
Townsend's solitaire	-2	5	1	17
Yellow-rumped warbler	-2	9	-5	20
Hermit thrush	-3	5	-14	16
Warbling vireo	-3	7	3	18
Mountain chickadee	-4	8	-17	18
American kestrel			9	16
American three-toed woodpecker			9	16
Green-tailed towhee			7	15
White-throated swift			7	10
Cassin's finch			6	17
Evening grosbeak			6	16
Mountain bluebird			6	16
Canyon wren			4	6
Lark sparrow			3	3
Lewis's woodpecker			3	6
Purple martin			3	3
Vesper sparrow			3	3
Greater pewee			2	2
Red-tailed hawk			2	12
Saw-whet owl			2	2
Scrub jay			2	5
Turkey vulture			2	10
Band-tailed pigeon			1	16
Blue-gray gnatcatcher			1	5

	Restoration Treatments		High-severity Treatments	
Species[1]	Response	#Observations	Response	#Observations
Common nighthawk			1	11
Common poorwill			1	5
Great horned owl			1	7
House finch			1	6
Northern goshawk[2,3,4]			1	11
Northern pygmy owl			1	6
Pinyon jay			1	6
Red-headed woodpecker			1	5
Sharp-shinned hawk			1	11
Cassin's kingbird			0	6
Cooper's hawk			0	16
Downy woodpecker			0	5
MacGillivray's warbler			0	5
Mexican spotted owl[3,4,5]			0	2
Peregrine falcon[2,3,4,6]			0	5
Rock wren			0	11
Yellow warbler			0	5
Ash-throated flycatcher			-2	11
Cedar waxwing			-2	2
Flammulated owl[4]			-2	2
Lesser goldfinch			-2	17
Townsend's warbler			-2	2
Williamson's sapsucker			-2	11
Golden-crowned kinglet			-6	13
Mammals	**-1**	**34**	**6**	**14**
Deer mouse	2	7		
Brush mouse	1	3		
Chipmunks	0	4		
Elk	0	4	1	2
Deer	0	12	2	2
Pinyon mouse	-4	4		
Coyote			0	3
Gray fox			0	3
Black bear			3	4
Reptiles	**0**	**6**	**23**	**60**
Sagebrush lizard	2	2		
Eastern fence lizard	0	2	4	4
Western skink	-2	2		
Little striped whiptail			3	4
Tree lizard			3	4
Collared lizard			2	4
Plateau striped whiptail			2	4
Sonoran spotted whiptail			2	4
Western whiptail			2	4
Banded gecko			1	4
Desert-grassland whiptail			1	4
Gila spotted whiptail			1	4
Great plains skink			1	4
Short horned lizard			1	4
Clark's spiny lizard			0	4
Lesser earless lizard			0	4
Madrean alligator lizard			0	4

1 Species' scientific names provided in Appendix 4.
2 US Fish and Wildlife Service Species of Concern
3 Arizona Species of Concern
4 US Forest Service Sensitive Species
5 Federally threatened
6 New Mexico threatened

Reproductive data indicated that 3 species responded positively, 1 neutrally, and 2 negatively to restoration treatments; 2 species responded negatively to high-severity treatments; however, the number of observations was low for most species (Table 5). One special status species, the Mexican spotted owl, responded negatively to high-severity treatments in terms of reproduction.

Table 5. Species' reproductive responses to restoration (small-diameter removal, burn, and thin/burn) and high severity (wildfire and overstory removal) treatments, followed by the total number of observations and the overall response.

Species[1]	Positive	Neutral	Negative	Total	Overall Response
Restoration Treatments					
Tassel-eared squirrel			1	1	-
Dark-eyed junco	1		5	6	-
Wild turkey		1		1	**0**
Plumbeous vireo	6		1	7	+
Western bluebird	11	17	3	31	+
Western tanager	1			1	+
High-severity Treatments					
Black bear	2	3	3	8	-
Mexican spotted owl[2,3,4]			1	1	-

1 Species' scientific names provided in Appendix 4.
2 Arizona Species of Concern
3 US Forest Service Sensitive Species
4 Federally threatened

4.5 Meta-analysis

The model ($\Delta AIC_c<2$) that best predicted wildlife response to treatments with 83% of model weight included the variables treatment, species, time since treatment, and study (Table 6). The second best model with 17% of model weight also included the study design variable.

Table 6. Model selection analysis; all *a priori* candidate models (model), number of parameters (K), AIC value corrected for small sample size (AIC_c), difference in AIC_c between models (ΔAIC_c), and the relative weight of each model (w_i).

Model	K	AIC_c	ΔAIC_c	w_i
Treatment, Species, Time, Study	75	5902.65	0	0.83
Treatment, Species, Time, Study, Study Design	77	5905.76	3.11	0.17
Global: Treatment, Species, Time, Study, Study Design, Forest Type, Density Estimation Method, Replicated, Peer-Reviewed	85	5922.56	19.91	3.93E-05
Treatment, Species, Time	53	5957.85	55.20	8.52E-13

Treatment, Species, Time, Study Design	55	5960.19	57.54	2.64E-13
Treatment, Species	52	5990.33	87.68	7.53E-20
Study	23	6347.46	444.81	2.12E-97
Null (intercept only)	1	6410.10	507.45	5.3E-111

Mean effect sizes (MES) for treatments showed that species responded positively to the small-diameter removal and the burning treatment, negatively to the wildfire and overstorey removal treatment, but did not differ from zero for the thin/burn and selective harvest (Figure 3). We conducted the same analysis for 11 species for which there were data available for every treatment (American robin, chipping sparrow, dark-eyed junco, western bluebird, mountain chickadee, Steller's jay, western tanager, yellow-rumped warbler, pygmy nuthatch, white-breasted nuthatch, and hairy woodpecker), and found a similar pattern (Figure 3).

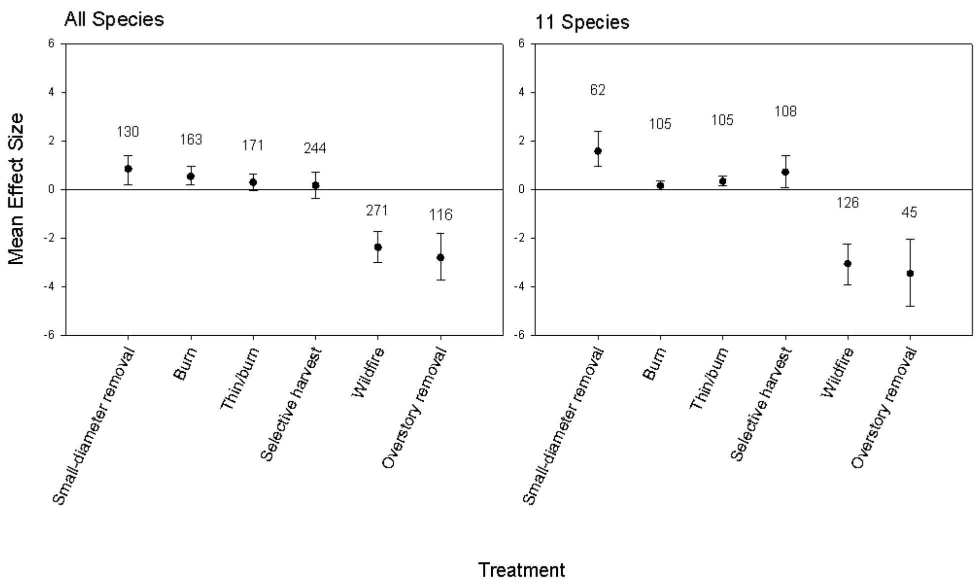

Figure 3. Mean effect size, bootstrapped confidence interval, and number of observations, a) across all species for the 6 treatment types, and b) for only the 11 species for which data were available in each of the 6 treatment types. See section 3.3 for a full description of the treatments.

Species' overall effect size averaged across the small-diameter removal, burning, and thin/burn (restoration) treatments was positive (MES = 0.5); the overall species effect size averaged across the wildfire and clearcut was negative (MES = -2.6). Fourteen species had a strong positive response to restoration treatments, in that their confidence interval (CI) did not overlap zero; 4 species had a strong negative response to restoration treatments (Figure 4). Nine species had a strong positive response to the wildfire and clearcut; 18 species that had a strong negative response (Figure 5).

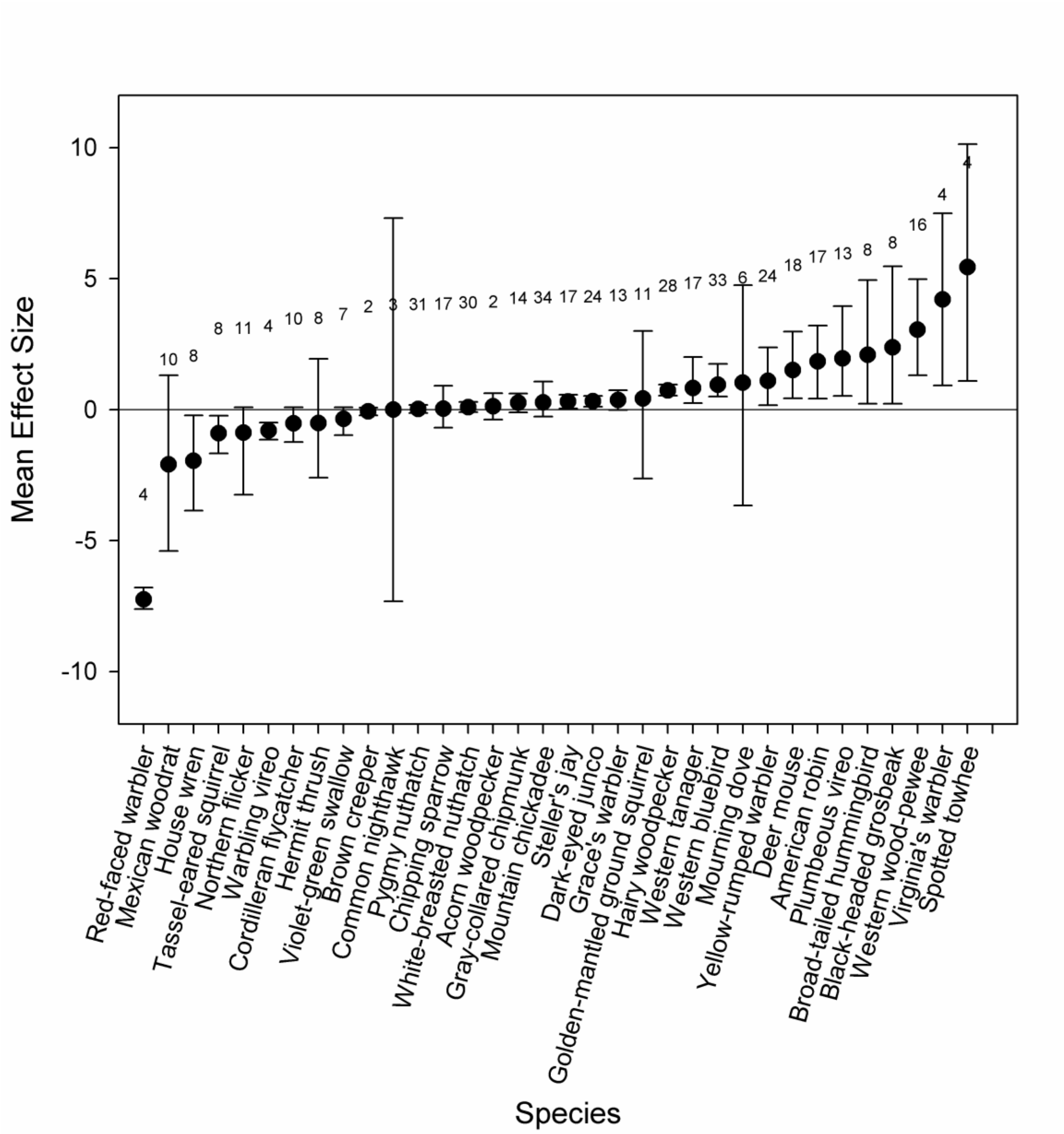

Figure 4. Mean effect size, bootstrapped CI, and number of observations for wildlife species averaged across the small-diameter removal, burning, and thin/burn (restoration) treatments. Species' scientific names are provided in Appendix 4.

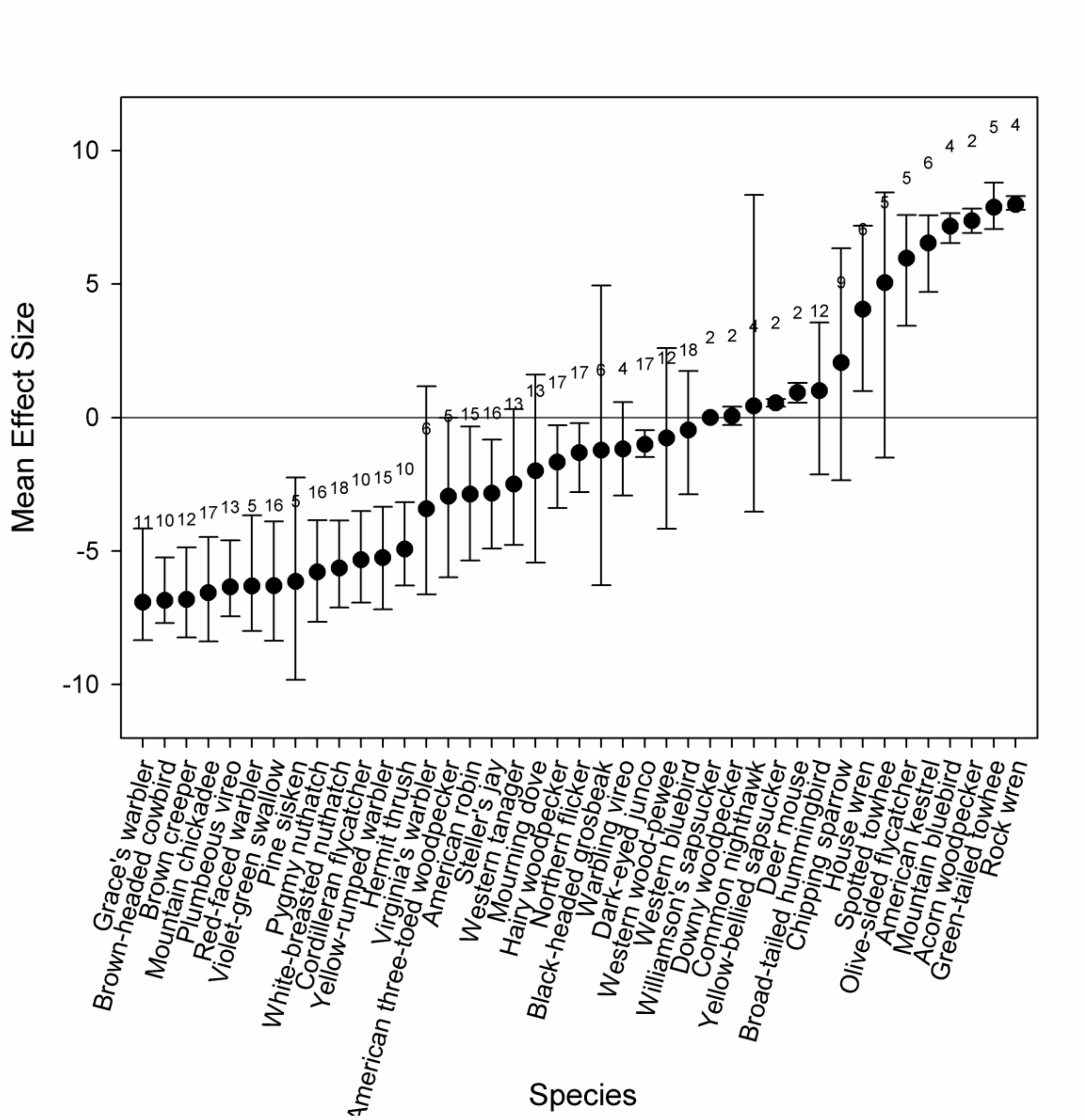

Figure 5. Mean effect size, bootstrapped CI, and number of observations for wildlife species averaged across the wildfire and overstory removal treatments. Species' scientific names are provided in Appendix 4.

Time since treatment ranged from 1 to 20 years, however most studies examined responses less than 10 years post-treatment (Figure 6). Time since treatment had an overall negative effect on species density responses (slope = -0.35; Figure 6), and a slightly negative effect on species density responses in restoration treatments (slope = -0.08).

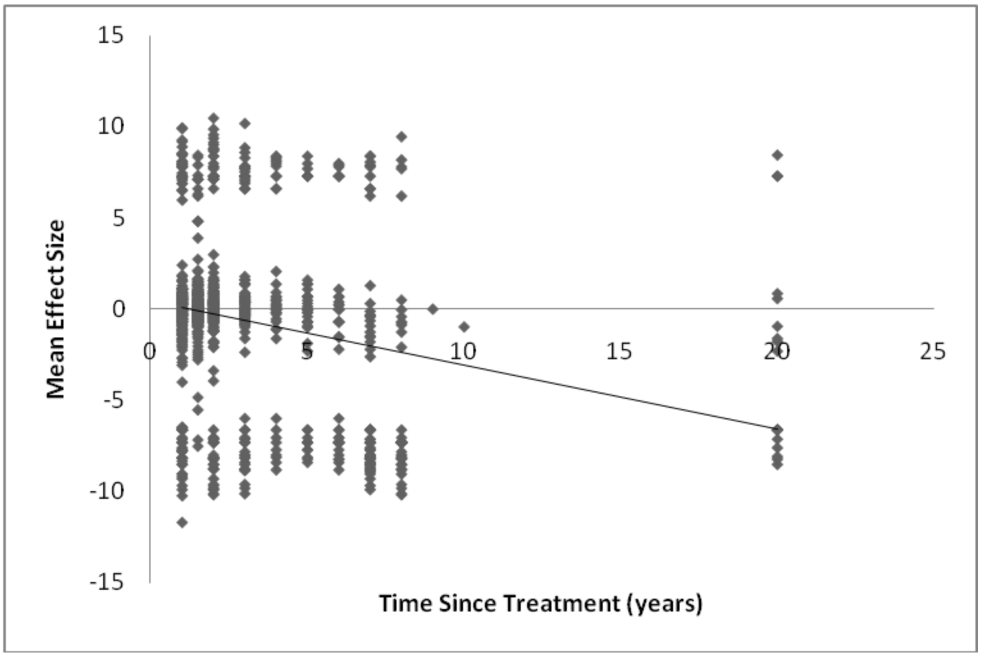

Figure 6. Mean effect size versus time since treatment across all treatment types.

The presence of study as a variable in our top model (Table 5) indicated a lack of independence among observations from the same study, similar to a site effect.

Study design was an additional variable that appeared in the second best model (Table 5); BACI designs had a higher mean effect size (MES=0.75; CI 0.39-1.15; N=203) than did C-I designs (MES=-0.94; CI -1.25 to -0.65; N=892).

4.6 Outcome of the review

Although the qualitative analysis resulted in broadly neutral or positive responses to treatments in terms of species abundances, the meta-analysis revealed a pattern of generally positive responses to the restoration treatments and negative responses to the high-severity treatments. We recorded more positive responses by individual species to the high-severity treatments using the qualitative analysis compared to the meta-analytic approach. Reproductive responses were generally positive in the restoration treatments and negative in the high-severity treatments, but were compromised by low numbers of observations. Overall, small-diameter removal and/or burning did not negatively affect species' densities compared to unmanaged forest stands, and was less detrimental than overstorey removal or wildfire.

5. Discussion

5.1 Evidence of and variation in effectiveness

The meta-analysis approach worked well in summarizing the density response of multiple species across different treatments over time at a coarse scale. We had a clear best model in our model selection analysis with 83% of the weight that contained meaningful covariates (i.e., the null and global models performed poorly in comparison). We elucidated clear patterns of density responses to treatments, with non-overlapping confidence intervals, including positive responses to thinning and burning, neutral responses to thin/burn and selective harvest, and negative responses to wildfire and overstorey removal. The qualitative analysis revealed a similar pattern except it recorded more positive response in the wildfire and overstorey removal treatments.

There was general agreement between the qualitative and meta-analysis in terms of species responses with some exceptions: the house wren, northern flicker, violet-green swallow, pygmy nuthatch, chipping sparrow, and dark-eyed junco responded negatively or neutrally to restoration treatments according to the meta-analysis, but positively according to the qualitative analysis. The mountain chickadee, Steller's jay, Grace's warbler, yellow-rumped warbler, American robin, and spotted towhee responded positively or neutrally to restoration treatments according to the meta-analysis, but negatively according to the qualitative analysis. Thus, 12 of 34 species showed inconsistent responses.

Similarly, the violet-green swallow, white-breasted nuthatch, American three-toed woodpecker, Steller's jay, western tanager, mourning dove, hairy woodpecker, northern flicker, warbling vireo, dark-eyed junco, and western wood-pewee responded negatively or neutrally to high-severity treatments according to the meta-analysis, but positively according to the qualitative analysis, while the yellow-bellied sapsucker and chipping sparrow responded positively to treatment according to the meta-analysis but negatively according to the qualitative analysis. Thus, 13 of 41 species had inconsistent results. The reason for this may be that qualitative analysis was dominated by wildfire studies compared to overstory removal (1,109 observations versus 62) and thus we may be seeing a more positive response by species that respond negatively to clearcut but positively to wildfire, especially since fire severity varied among studies.

The qualitative analysis used less rigorous statistical methods and smaller sample sizes than did the meta-analysis. Further, although vote-counting is not uncommon in the ecological literature, it can be misleading because the method has low statistical power, with the results tending toward zero as the sample size increases (Gurevitch and Hedges, 1999). Thus, we suggest that the meta-analysis produced the most reliable conclusions, and the qualitative analysis should be consulted only for species that could not be evaluated in the meta-analysis.

5.2 Review limitations

A drawback of the review is that we were unable to quantify fine-scale effects on wildlife. The model selection analysis shows that there are similarities between density responses measured in the same study and using the same site; thus, there must be other important within-site variables that we did not use as covariates in our analysis. Some may include characteristics of the control stands, post-treatment tree density or basal area, treatment intensity, seasonality of treatments, overstory composition, number of snags, and understory characteristics, as these variables were not consistently reported in the literature.

Meta-analysis was restrictive in the types of response variables that could be analyzed. Only animal density could be compared in treatments versus controls across different taxa, thus we included other responses such as home range size, abundance, and presence-absence in our qualitative analysis to the extent possible. Since fitness is often viewed as the best indicator of population performance (Bock and Jones, 2004), we compared density and reproductive output results and found that both were consistent in treatments versus controls (either both positive or both negative) for the plumbeous vireo and western tanager (Battin and Sisk, 2003), western bluebird (Wightman and Germaine, 2006, Germaine and Germaine, 2002, Hurteau et al., in press), and tassel-eared squirrel (Dodd et al., 2006). However, black bear had similar densities pre- and post-fire, and in burned areas versus control, but lower reproductive output in the burned areas (Cunningham et al., 2003). It is well-documented in the literature that density is often a misleading indication of habitat quality (Van Horne, 1983); thus, assessing wildlife density may not always be meaningful in terms of understanding changes in habitat. Yet, most studies in our review used this response variable presumably because reproductive output is more difficult, time consuming, and costly to measure.

6. Reviewers' Conclusions

6.1 Implications for management

This meta-analysis suggests that thinning and prescribed burning of southwestern ponderosa pine and dry mixed conifer forests will benefit passerine birds and small mammals. Based on the existing literature, small-diameter removal and/or burning does not negatively affect species' densities compared to unmanaged forest stands, and are less detrimental than overstorey removal or wildfire. These results support the hypothesis that thinning and burning at the landscape level are consistent with ecological restoration objectives for wildlife. However, wildfire and clearcuts have overall negative effects on wildlife density and should be used with caution. For example, clearcut fuel breaks will likely have negative impacts on species, but may prevent wildfire from spreading and thus reduce overall species loss.

No one treatment benefitted all species, at least over the short term. Even within the small-diameter removal treatment, which had the greatest overall positive effect of the six treatments on species densities, house wrens and red-faced warblers responded negatively relative to the controls. This could be due to their need for understory vegetation for foraging (house wrens) and nesting (red-faced warblers) (Wheye et al., 1988). Similarly, the negative density response of the Mexican woodrat to thin/burn treatment is likely caused by a lack of coarse woody debris and downed logs, essential for nest-building and cover (Converse et al., 2006). In response to high-severity treatments, special status species, including the northern goshawk, Mexican spotted owl, and peregrine falcon, exhibited positive or neutral abundance responses; however, flammulated owls exhibited a negative abundance response, and Mexican spotted owls had a negative reproductive response. Thus, at least in the near term, a combination of various treatments in a patchy arrangement in time and space across the landscape is likely to result in the highest diversity compared to any one treatment, at least for animals whose home ranges are restricted to the stand level. In addition, treatments can be implemented to reduce the risk of wildfire to Mexican spotted owl and flammulated owl habitat.

6.2 Implications for research

The majority of observations in the analysis examined responses of birds to treatment (90%). In particular, recent studies (Dickson et al., 2009, Hurteau et al., 2008, Berk, 2007, Kotliar et al., 2007, Pope et al., 2009) assessed 1-4 year bird responses to prescribed fire and thinning using sophisticated modeling techniques, and we suggest that these studies be carefully consulted before initiating similar research in order to eliminate duplication of effort. On the other hand, there were 193 observations for mammals but most focused on rodents, and most observations were only appropriate for the qualitative analysis. Other underrepresented taxa include reptiles and amphibians, as well as rare birds and small mammals that are not easily assessed using conventional survey methodologies; for example, shrews (*Sorex* spp.) or wild turkeys. Other species under- or un-represented in this meta-analysis include medium and large mammals, including both predators and ungulates, bats, and birds of prey.

In terms of response variables, 98% of observations focused on abundance or density, but only 2% examined a measure of reproductive output. Reproductive studies are more expensive and time consuming, and generally only address one species; thus, they are more difficult to undertake and fund. At the same time, they provide much more useful information than density studies on long-term effects of treatments on population viability, and we recommend that future research efforts focus on this variable particularly for species that already have sufficient density response information. In particular, special status species are under-represented in the literature and especially in terms of reproductive responses. Studies that focus on just population size should strive to calculate density, uses sophisticated methods that model detection, so that the results can be compared across studies and regions.

Finally, studies need to be conducted at larger spatial and temporal scales in order to understand both short- and long-term implications of treatments at the landscape level. Most studies were conducted at <10 years post-treatment, and so the long-terms implications of treatments are poorly understood. Repeat measures, rather than simple chronosequences, are lacking. Further, most animals in our analysis had home ranges similar to the stand scale, and thus we were unable to draw conclusions on species that use multiple habitat types. Studies that investigate the impacts of treatments on animals with large home ranges, using a landscape of both treated and untreated areas, would greatly improve our understanding of how landscape metrics such as fragmentation and connectivity are affecting wildlife.

7. Acknowledgements

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8. Potential Conflicts of Interest and Sources of Support

The review was led by the Ecological Restoration Institute, which has funded and published studies on impacts of forest treatments on some wildlife species. We addressed the possibility of conflict of interest by including scientists from Arizona Game and Fish Department in the development of the systematic review. Another independent check is the review process through CEBC which solicits additional reviews from scientists whom are not affiliated with the Ecological Restoration Institute or Northern Arizona University.

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10. Appendices

Appendix 1. Data extraction form; if all bolded categories could not be filled but a response to a control and treatment was available, study was assigned to the vote-counting analysis.

Data Type	**Values**
Species	Common and scientific
Class	Bird, mammal, reptile, amphibian
Foraging guild	
Forest type	Ponderosa pine or mixed conifer
Treatment	Thin, burn, thin/burn, wildfire, or clearcut
Study design	BACI, CI
Time since treatment (years)	1+
Density estimation method (modeled using detection probability, or not)	Y, N
Peer-reviewed	Y, N
Replicated	Y, N
Area of treatments (acres)	#
Area of controls	#
Experimental mean	#
Control mean	#
Study	Author, year
Region	Region of AZ or NM
Density, abundance, or reproduction?	D, A, R
Meta-analysis or vote-counting?	M, V

Appendix 2. Studies used in the qualitative analysis.

Abundance studies:

BAGNE, K. E. & FINCH, D. M. (2009) Response of small mammal populations to fuel treatment and precipitation in a ponderosa pine forest, New Mexico. *Restoration Ecology*, Published online.

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Appendix 3. Studies and covariates used in the meta-analysis.

Reference	Region	Treatment	Species	Time since treatment [1] (years)	Area sampled[2] (ha)	Study design	Forest type	Density estimation method	Replicated?	Source
Wightman and Yarborough, 2006	Northern AZ	Thin/burn	Lizards[3] (5 species)	6, 7	4	C-I	PIPO	Based on abundance data	Y	Agency report
Wightman and Rosenstock, unpublished data	Northern AZ	Thin/burn	Tassel-eared squirrel (*Sciurus aberti)*	6, 7	2	C-I	PIPO	Clippings	Y	Unpublished
Battin, 2003	Northern AZ	Thin/burn	Birds (9 species)	1-4 (combined)	16	C-I	PIPO	Transects; based on abundance data	Y	Dissertation
Berk, 2007	Northern & eastern AZ, western NM	Low-to-moderate prescribed fire	Birds (5 species)	3	872 total (4 sites)	BACI and C-I	PIPO	Point counts, detection probabilities, distance sampling	Y	Thesis
Burgoyne, 1980	Northern AZ	Shelterwood	Birds (10 species)	2	110	C-I	PIPO	Older version of distance sampling (Emlen, 1971)	Y	Dissertation
Converse et al., 2006	Northern AZ	Thin (3 levels), thin/burn	Small mammal (4 species)	1 (thin); 1, 2, 3, (thin/burn)	15 (3 treatments)	C-I	PIPO	Mark-recapture	Y	Forest Ecology and Management
Converse et al., 2006b	Northern AZ, northern NM	High intensity wildfire, thin	Small mammal (3 species)	1	44 (burn), 75 (thin AZ)	C-I	PIPO	Mark-recapture	Y	Journal of Wildlife Management

Reference	Region	Treatment	Species	Time since treatment[1] (years)	Area sampled[2] (ha)	Study design	Forest type	Density estimation method	Replicated?	Source
Conway and Kirkpatrick, 2007	Southern AZ	High, moderate-low wildfire	Buff-breasted flycatcher[3] (*Empidonax fulvifrons*)	6	10,800 (high); 11,668 (mod-low)	C-I	PIPO, MC	Point counts, detection probabilites	Y	Journal of Wildlife Management
Cunningham et al., 2003	Southern AZ	Crown fire	Black bear[3] (*Ursus americanus)*	1-2 (combined)	24,000	BACI and C-I	PIPO	Petersen estimate	N	Wildlife Society Bulletin
Dickson et al., 2009	Northern & eastern AZ, western NM	Low-to-moderate intensity prescribed burn	Birds (14 species)	1-2 (combined)	872 (4 sites)	BACI and C-I	PIPO	Point counts, detection probabilities, DISTANCE	Y	Ecological Applications
Dodd et al., 2006	Northern AZ	Shelterwood	Tassel-eared squirrel	10 (combined 4 years of data at ~10-year old treatments)	3	C-I	PIPO	Clippings	Y	Restoration Ecology
Dwyer & Block (Dwyer and Block, 2000)	Northern AZ	High and moderate-low wildfire	Birds (5 species)	1	217 (2 sites)	C-I	PIPO	Point counts, simple density calc based on abundance	Y (moderate), N (high)	Conference proceedings (peer-reviewed)
Franzreb and Ohmart, 1978	Eastern AZ	Overstory removal	Birds (47 species)	1, 2	31	C-I	MC	Census	N	The Condor
Horton and Mannan, 1988	Southern AZ	Moderate-low prescribed fire	Birds (16 species)	1	95	BACI and C-I	PIPO	Point counts, modified distance sampling	Y	Wildlife Society Bulletin
Hurteau et al., 2008	Northern AZ	Moderate-low prescribed	Birds (5 species)	2	180 (3 sites)	BACI and C-I	PIPO	Point counts, DISTANCE	Y	Journal of Wildlife Management

Reference	Region	Treatment	Species	Time since treatment [1] (years)	Area sampled[2] (ha)	Study design	Forest type	Density estimation method	Replicated?	Source
		fire, thin, thin/burn								
Kotliar et al., 2007	Northern NM	High, moderate-low wildfire	Birds (21 species)	1, 2	315 (3 sites)	BACI and C-I	PIPO, MC	Point counts, DISTANCE	Y	Ecological Applications
Kyle and Block, 2000	Northern AZ	High and moderate-low wildfire	Deer mouse (*Peromyscus maniculatus*), gray-collared chipmunk (*Tamias cinereicollis*)	1	64 (2 sites)	C-I	PIPO	Mark-recapture, CAPTURE	N	Conference proceeding (peer-reviewed)
Lowe et al., 1978	Northern AZ	High severity wildfire	Birds (31 species)	1, 3, 7, 20	188 (4 sites)	C-I	PIPO	Census	N	Government document
Overturf, 1979	Northern AZ	High severity wildfire	Birds (33 species)	1, 2, 7, sampled for 2 years	62 (3 sites)	C-I	PIPO	Census	N	Thesis
Patton et al., 1985	Northern AZ	Selective harvest	Tassel-eared squirrel	1-2 (combined)	240	BACI and C-I	PIPO	Census	Y	Journal of Wildlife Management
Pope et al., 2009	Northern AZ	Low-to-moderate intensity prescribed burn	Birds (3 species)	1-2 (combined)	533	C-I	PIPO	Point counts, detection probabilities, DISTANCE	Y	Journal of Wildlife Management
Roberts, 2003	Northern AZ	Thin/burn	Pinyon mouse[3] (*Peromyscus truei*), deer mouse	1, 2	32	BACI and C-I	PIPO	Mark-recapture, CAPTURE	N	Thesis
Scott and Gottfried, 1983	Eastern AZ	Selective harvest	Birds (23 species)	1-2 (combined)	296	BACI and C-I	MC	Census	N	Government document

Reference	Region	Treatment	Species	Time since treatment [1] (years)	Area sampled[2] (ha)	Study design	Forest type	Density estimation method	Replic ated?	Source
Scott, 1979; Scott and Oldemeyer, 1983	Eastern AZ	Selective harvest	Birds (18 species)	1-2 (combined)	68	BACI and C-I	MC	Census	N	7 species in Journal of Forestry; 11 species in government document
Szaro and Balda, 1979	Northern AZ	multiple (see below)	Birds (30 species)	1, 3, 4, 6, sampled for 3 years	150 (4 sites)	BACI and C-I	PIPO	Census	N	Studies in Avian Biology
		clearcut		6						
		thin		4						
		strip cut (thin)		3						
		silvicultur-ally cut (thin)		1						

1 Different years were considered individual observations, except when the author combined results over multiple years; in these cases, we used the mean number of years as our time variable.
2 Area sampled is per species per year per study type. If there were different sites/treatments analyzed separately, that is noted in parenthesis.
3 Omitted from meta-analysis because there were < 5 total observations per species; included in qualitative analysis.

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Appendix 4. Common and scientific names of all species included in review (in alphabetical order).

Common Name	Scientific Name
Acorn woodpecker	*Melanerpes formicivorus*
American kestrel	*Falco sparverius*
American robin	*Turdus migratorius*
American three-toed woodpecker	*Picoides dorsalis*
Ash-throated flycatcher	*Myiarchus cinerascens*
Banded gecko	*Coleonyx variegatus*
Band-tailed pigeon	*Patagioenas fasciata*
Black bear	*Ursus americanus*
Black-headed grosbeak	*Pheucticus melanocephalus*
Black-throated gray warbler	*Dendroica nigrescens*
Blue-gray gnatcatcher	*Polioptila caerulea*
Broad-tailed hummingbird	*Selasphorus platycercus*
Brown creeper	*Certhia familiaris*
Brown-headed cowbird	*Molothrus ater*
Brush mouse	*Peromyscus boylii*
Buff-breasted flycatcher	*Empidonax fulvifrons*
Bushtit	*Psaltriparus minimus*
Canyon wren	*Catherpes mexicanus*
Cassin's finch	*Carpodacus cassinii*
Cassin's kingbird	*Tyrannus vociferans*
Cedar waxwing	*Bombycilla cedrorum*
Chipmunks	*Tamias* spp.
Chipping sparrow	*Spizella passerina*
Clark's nutcracker	*Nucifraga columbiana*
Clark's spiny lizard	*Sceloporus clarkii*
Collared lizard	*Crotaphytus collaris*
Common nighthawk	*Chordeiles minor*
Common poorwill	*Phalaenoptilus nuttallii*
Common raven	*Corvus corax*
Cooper's hawk	*Accipiter cooperii*
Cordilleran flycatcher	*Empidonax occidentalis*
Coyote	*Canis latrans*
Dark-eyed junco	*Junco hyemalis*
Deer	*Odocoileus* spp.
Deer mouse	*Peromyscus maniculatus*
Desert-grassland whiptail	*Aspidoscelis uniparens*
Downy woodpecker	*Picoides pubescens*
Eastern fence lizard	*Sceloporus undulatus*
Elk	*Cervus canadensis*
Empidonax flycatchers	*Empidonax* spp.
Evening grosbeak	*Coccothraustes vespertinus*
Flammulated owl	*Otus flammeolus*
Gila spotted whiptail	*Aspidoscelis flagellicauda*
Golden-crowned kinglet	*Regulus satrapa*
Golden-mantled ground squirrel	*Spermophilus lateralis*
Grace's warbler	*Dendroica graciae*
Gray fox	*Urocyon cinereoargenteus*
Great horned owl	*Bubo virginianus*

Common Name	Scientific Name
Great plains skink	*Eumeces obsoletus*
Greater pewee	*Contopus pertinax*
Green-tailed towhee	*Pipilo chlorurus*
Hairy woodpecker	*Picoides villosus*
Hepatic tanager	*Piranga flava*
Hermit thrush	*Catharus guttatus*
House finch	*Carpodacus mexicanus*
House wren	*Troglodytes aedon*
Lark sparrow	*Chondestes grammacus*
Lesser earless lizard	*Holbrookia maculata*
Lesser goldfinch	*Carduelis psaltria*
Lewis's woodpecker	*Melanerpes lewis*
Little striped whiptail	*Cnemidophorus inornatus*
MacGillivray's warbler	*Oporornis tolmiei*
Madrean alligator lizard	*Elgaria kingii*
Mexican spotted owl	*Strix occidentalis lucida*
Mexican woodrat	*Neotoma mexicana*
Mountain bluebird	*Sialia currucoides*
Mountain chickadee	*Poecile gambeli*
Mourning dove	*Zenaida macroura*
Northern flicker	*Colaptes auratus*
Northern goshawk	*Accipiter gentilis*
Northern pygmy owl	*Glaucidium gnoma*
Olive-sided flycatcher	*Contopus cooperi*
Orange-crowned warbler	*Vermivora celata*
Peregrine falcon	*Falco peregrinus*
Pine siskin	*Carduelis pinus*
Pinyon jay	*Gymnorhinus cyanocephalus*
Pinyon mouse	*Peromyscus truei*
Plateau striped whiptail	*Cnemidophorus velox*
Plumbeous vireo	*Vireo plumbeus*
Purple martin	*Progne subis*
Pygmy nuthatch	*Sitta pygmaea*
Red crossbill	*Loxia curvirostra*
Red-breasted nuthatch	*Sitta canadensis*
Red-faced warbler	*Cardellina rubrifrons*
Red-headed woodpecker	*Melanerpes erythrocephalus*
Red-naped sapsucker	*Sphyrapicus nuchalis*
Red-tailed hawk	*Buteo jamaicensis*
Rock wren	*Salpinctes obsoletus*
Ruby-crowned kinglet	*Regulus calendula*
Rufous hummingbird	*Selasphorus rufus*
Sagebrush lizard	*Sceloporus graciosus*
Saw-whet owl	*Aegolius acadicus*
Scrub jay	*Aphelocoma californica*
Sharp-shinned hawk	*Accipiter striatus*
Short horned lizard	*Phrynosoma douglassii*
Sonoran spotted whiptail	*Aspidoscelis sonorae*
Spotted towhee	*Pipilo maculatus*
Steller's jay	*Cyanocitta stelleri*
Tassel-eared squirrel	*Sciurus aberti*

Common Name	**Scientific Name**
Townsend's solitaire	*Myadestes townsendi*
Townsend's warbler	*Dendroica townsendi*
Tree lizard	*Urosaurus ornatus*
Turkey vulture	*Cathartes aura*
Vesper sparrow	*Pooecetes gramineus*
Violet-green swallow	*Tachycineta thalassina*
Virginia's warbler	*Vermivora virginiae*
Warbling vireo	*Vireo gilvus*
Western bluebird	*Sialia mexicana*
Western skink	*Eumeces skiltonianus*
Western tanager	*Piranga ludoviciana*
Western whiptail	*Cnemidophorus tigris*
Western wood-pewee	*Contopus sordidulus*
White-breasted nuthatch	*Sitta carolinensis*
White-crowned sparrow	*Zonotrichia leucophrys*
White-throated swift	*Aeronautes saxatalis*
Wild turkey	*Meleagris gallopavo*
Williamson's sapsucker	*Sphyrapicus thyroideus*
Wilson's warbler	*Wilsonia pusilla*
Yellow warbler	*Dendroica petechia*
Yellow-bellied sapsucker	*Sphyrapicus varius*
Yellow-rumped warbler	*Dendroica coronata*

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