A Meta-Analysis of Bald and Golden Eagle Productivity Accounting for Spatial and Temporal Studies

Mark C. Otto*

Abstract
When it is not possible to obtain direct survey estimates needed, it can be possible to obtain robust estimates using meta-analysis. As part of a larger effort to update and improve demographic parameters used in eagle population modeling efforts, Brennan and Millsap (2016) compiled a dataset of contemporary productivity information for bald and golden eagles, *Haliaeetus leucocephalus* and *Aguila chrysaetos* respectively, across the U.S. from 1995–2014. As in many ecological studies, individual surveys are done over multiple areas and/or multiple years. To obtain a representative estimate over areas and years, the variation over areas and years must be accounted for within the individual studies. Centered random effects accounted for separate spatial and temporal effects within studies so that overall estimates are apart from the individual study area and year variation. A random-effects meta-analysis model estimated the predictive distributions for bald eagle and golden eagle productivity. Differences between models were accounted for by differences in AIC. Bald eagle productivity differed by region with lower productivity in the Southwest (mean = 0.77, SE = 0.249) than in the rest of the continental U.S. (mean = 1.15, SE = 0.252), whereas golden eagle productivity did not differ by region (mean = 0.55, SE = 0.087). Apart from the fixed stratum differences for bald eagles, the best-supported models included standard errors for the random effects for study, area (bald eagles only), year given study, and overdispersion; the extent to which the random effect credible intervals overlapped zero varied by species.

Key Words: Meta-Analysis, Bayesian estimation, Random Effects Model, Over-dispersion, AIC

1. Introduction

Meta-analyses combine results of different studies of the same subject in order provide stronger and more robust inferences (Borenstein et al. 2010). Meta-analyses are often used in the medical field to combine clinical trial data. Just as medical trials may have different methodologies, target populations, and sampling designs and selections, so do wildlife demographic studies (Johnson 2002) and (Koricheva et al. 2013). There are two main types of meta-analyses: fixed and random effect. Fixed effect models are used when the studies are thought to be functionally equivalent, whereas the random effect model assumes that they have common characteristics but are not the same (Borenstein et al. 2010). Thus a fixed effect model assumes that a single value is common to all studies, in contrast to a random effects model which assumes that the values belong to a common distribution (Higgins et al. 2009).

Summarizing a range of studies over different areas and time spans, accounting for the study, area, and annual components of variation also complicates the analysis with decisions on how to separate and characterize the different forms of variation. Rather than estimate the common value (in our case productivity), Higgins et al. (2009) recommend using predictive distributions. They also recommend for a small number of studies, using the t-distribution with k minus 4 degrees of freedom (k is the number of studies), instead of the normal distribution. Due to the combined complexities of deciding on the proper prediction variance and other model choices, we used the classic normal distribution for this analysis. The approach is similar to what is presented in New et al. (2015) for the prior

*U.S. Fish and Wildlife Service, Migratory Bird Program, Laurel, MD

parameters for the eagle example where the authors created a mixture distribution from the small number of projects available and estimated parameters for a common distribution from the mixture. Our methods here similarly yield a common predictive distribution for productivity from the projects available.

2. Material and methods

2.1 Data

Brennan and Millsap (2016) searched the published literature for bald and golden eagle productivity data and compiled datasets for each species from studies within the U.S. from 1995–2014. From their well-curated studies, we categorized the target populations for the included studies in terms of area and time span and accounted for separate values for multi-area and multi-year data. We used sample size (the number of nesting territories or nests), number of fledglings, productivity values, and standard errors reported in the studies. When not reported, We back-calculated sample size from number of fledglings and productivity. In one case where only the productivity value was reported, the sample size became the inverse of the productivity value—resulting in one fledgling in the study and the smallest weight possible given to that study.

There were 18 studies included in the bald eagle analysis: one multi-area study, nine multi-year studies, and two multi-area and multi-year studies. In cases where studies included multi-area or multi-year data, We used random effects for area or year nested within study. The data did not support interactions between area and year in the 2 multi-area and multi-year studies. There were 12 studies included in the golden eagle analysis: nine multi-year studies but no multi-area and multi-area, multi-year studies. This limited the golden eagle analysis to only considering study-to-study and year-to-year variation.

2.2 Model

The productivity random effects model is a Poisson log-normal hierarchical model (although a gamma distribution could replace the log normal). The data are the number of successful fledglings in each study (with values separated by areas and years in multi-strata studies). The log sample sizes, S_{ijkl} number of nesting territories, are treated as offsets but are shown here on the original scale,

$$F_{ijkl} \sim Poisson\left(R_{ijkl} S_{ijkl}\right).$$

F_{ijkl} is the number of fledglings in the k^{th} area and l^{th} year of the j^{th} study in the i^{th} region. Not all subscripts are necessary if it is not multi-area and multi-year study. R_{ijkl} is the estimated random effect productivity estimate, and S_{ijkl} is the sample size in number of occupied nesting territories. Since the model conditions on occupied nesting territories, we only make the basic assumption that the likelihood occupied nesting territories were observed was not linked to the productivity rate. If the chances of detecting an occupied nesting territory early, even if it later fails, are good then the potential for such detection bias should be low. Log productivity is affected by the region, the study within that region, and if applicable a year within a given study.

$$\log(R_{ijkl}) = \mathrm{N}\left(r_i + \psi_{j|i} + \alpha_{k|ij} + \tau_{l|ij}, \sigma^2_{\text{Overdispersion}}\right).$$

Study, $\psi_{j|i}$; area, $\alpha_{k|ij}$; and year, $\tau_{l|ij}$, are nested random effects, with study nested within region, and area and year nested within study; there were no multi-region studies. The overdispersion variance is $\sigma^2_{\text{Overdispersion}}$.

The random effects use an `Ottomert` transformation that converts $n-1$ random variables into n centered variables with the same standard deviation and the same correlations among all the effects. See the appendix for a description. The transformation corrects for the under-estimation of the standard deviation caused by generating and centering n random variables. The area in multi-area random effects and year in multi-year random effects are nested within study, so their effects are centered within each study.

$$\begin{aligned}
\psi_{j|i} &= \text{Ottomert}\left(Study_j|Region_i)N(0,\sigma^2_{Study}\right) \\
\alpha_{k|ij} &= \text{Ottomert}\left(Area_k|Study_j)N(0,\sigma^2_{Area}\right) \\
\tau_{l|ij} &= \text{Ottomert}\left(Year_l|Study_j)N(0,\sigma^2_{Year}\right)
\end{aligned}$$

Because studies are nested within region, the area and year effects are also nested within region. We assumed the study, area, and year variation were the same across regions. For bald eagles, there was only one multi-year study representing the Southwest and only one study representing the East for golden eagles.

We ran glm and glmer models in `R` (R Core Team 2014) to discriminate among models using AIC and then estimated the best-supported models using Stan (Stan Development Team 2015), which is equivalent to a Bayesian estimation with non-informative priors. We included overdispersion by adding a random effect where the effect was different for every observation and tested models for an overall mean only and an overall mean with overdispersion. We also calculated simple estimates of productivity by aggregating the fledged and occupied territory counts for each area and year of each study by region then taking the ratio.

3. Results

Overdispersion gave a vast reduction in AIC (ΔAIC) for both the bald eagle and golden eagle models (-118.49 and -35.37, respectively). For bald eagles, the best-supported model was a random effects model with overdispersion that included a fixed effect for region (separating the Southwest from the rest of the U.S.; Table 1). The Southwest had lower overall productivity (Table 2) than the rest of the U.S., but there was wide overlap between the predictive distributions (Figure 1). Both prediction distributions are right skewed and leptokurtic, therefore the best way to use the productivity information as part of a demographic model is to sample the posterior simulations.

All of the random effects (study, area, year, and overdispersion) were important to the model (-25.68); the estimates of the standard errors for the random effects are in Table 3. The random effects from the final model were more spread out than the simple estimates for both regional distributions (Figure 1). Normally we would expect random effects estimates to shrink or be less spread out, but the differences are small and likely due to separating out the study, area, and year random effects. The study, area, and year effects are all significant and the credible intervals do not overlap zero. The total random effect variance is the sum of the variances of all the random effects (Table 2).

For golden eagles, the best-supported model was the random effects model with overdispersion (Table 1). The study and year random effects were important to the model (-4.02), but there were no multi-area studies so We did not include area random effects. We explored models with a regional effect (e.g., Eastern U.S., Western U.S., Alaska) but there was no support for including any regional differences (-3.56 for 4 degrees of freedom; Table 6) so the final model estimated an overall productivity for the entire U.S. including Alaska (Table 2). The overall prediction estimate along with the 95% prediction intervals is shown in Figure 4. The estimates from the final model are a bit lower than simple estimates taken by aggregating the fledged and occupied territory counts then taking the ratio (Figure 4). Explaining this will require further exploration. The distribution is right skewed, skewness = 2.09, and is highly leptokurtic, kurtosis = 22.59, therefore sampling the posterior simulations is the best way to use the productivity estimates in other models, since they do not fit a common distribution.

The estimates of the standard errors for the random effects are in Table 2. The study and year random effects had low variation (medians 0.1 and 0.29, respectively), and all random effect credible intervals overlap zero (Figure 5). The non-significance of the study and year effects and the significance of the overdispersion reinforce the AIC differences observed in the model comparisons. The productivity estimates from the random effects model by study include the region effects and the study random effects; they vary from 0.48 to 0.57 (Table 5). The random effect model estimates which include the study, area, and year random effects for each study and year combination are included in Brennan and Millsap (2016) along with the simple productivity ratios.

4. Discussion

We conducted this modeling effort with the specific goal of rapidly producing a usable predictive distribution for productivity that could be used in subsequent population modeling efforts. Though the approach was logical, there were a number of decisions that could be explored further. We only included the study random effect variances in the predictions. Though this is consistent with most meta-analysis models, it is unusual to have the additional complexities of multi-area and multi-year studies. An alternative approach may be to include both random effects and overdispersion in the prediction variation along with the additional consideration of using a *t*-distribution instead of a normal distribution. However all of this would make the already large prediction intervals larger, possibly to the point of no longer being useful. The current approach used to estimate the predictive distribution is consistent with other meta-analysis models and sampling the posterior simulations will provide reasonable productivity estimates given the data available.

REFERENCES

Borenstein, M., L. V. Hedges, J. P. T. Higgins, and H. R. Rothstein. 2010. A basic introduction to fixed-effect and random-effects models for meta-analysis. Research Synthesis Methods 1:97–111.

Brennan, M., and B. A. Millsap, 2016. Literature Review and Data Compilation. Pages 36–39 *in* Bald and Golden Eagles: Population demographics and estimation of sustainable take in the United States, 2016 update. Division of Migratory Bird Management, Washington D.C., USA.

Higgins, J. P. T., S. G. Thompson, and D. J. Spiegelhalter. 2009. A re-evaluation of random-effects meta-analysis. Journal of the Royal Statistical Society 172:137–159.

Johnson, D. H. 2002. The importance of replication in wildlife research. Journal of Wildlife Management 66:919–932.

Koricheva, J., J. Gurevitch, and K. Mengersen, editors. 2013. Handbook of Meta-analysis in Ecology and Evolution. Princeton University Press, Princeton, NJ. URL `http://www.jstor.org/stable/j.ctt24hq6n`.

New, L., E. Bjerre, B. Millsap, M. C. Otto, and M. C. Runge. 2015. A collision risk model to predict avian fatalities at wind facilities: an example using golden eagles, *Aquila chrysaetos*. PLoS One 10(7):e0130978. URL `http://dx.doi.org/10.1371/journal.pone.0130978`.

R Core Team. 2014. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. URL `http://www.R-project.org/`.

Stan Development Team. 2015. Stan Modeling Language Users Guide and Reference Manual, Version 2.8.0. URL `http://mc-stan.org/`.

Appendix

Centered Random Effects

The Ottomert transformation both centers and returns effects that have a given variance. The transformation takes the form, $T\sigma$, were T is the correlation matrix, and σ is the standard error.

$$T = \begin{bmatrix} -a & -a & \cdots & -a \\ b-c & -c & \cdots & -c \\ -c & b-c & & \vdots \\ \vdots & & \ddots & -c \\ -c & \cdots & -c & b-c \end{bmatrix}.$$

To center the effects, the columns must sum to zero. The crossproduct matrix, $T'T$, must be uncorrelated, so the off-diagonal elements are zero and the diagonal are all equal to the correlation with each other, $n/(n-1)$. Here n is the number of random effects. To return the given correlation matrix, TT', must have ones on the diagonal and $-1/(n-1)$ for the off-diagonal correlations. Solving these equations for a, b, and c yields: $a = \frac{1}{\sqrt{n-1}}$, $b = \sqrt{\frac{a^2-n+1}{2-n}}$, and $c = \frac{b-a}{n-1}$. The matrix is easy to program in R, JAGS, or Stan.

Figures and Tables

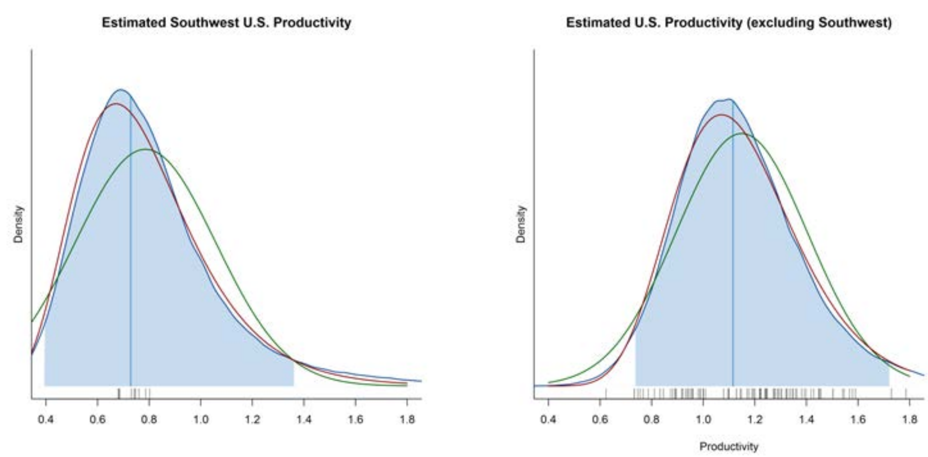


Figure 1: Bald eagle productivity for the Southwest U.S.(left) and the U.S. excluding the Southwest (right). The blue curve is the empirical density distribution of the estimates—which are shown via the rug just above the x-axis. The vertical blue line is the median with the area within the 95% credible intervals shaded blue. The red and green curves represent the log normal and normal distributions (respectively) defined by the estimated means and standard deviations.

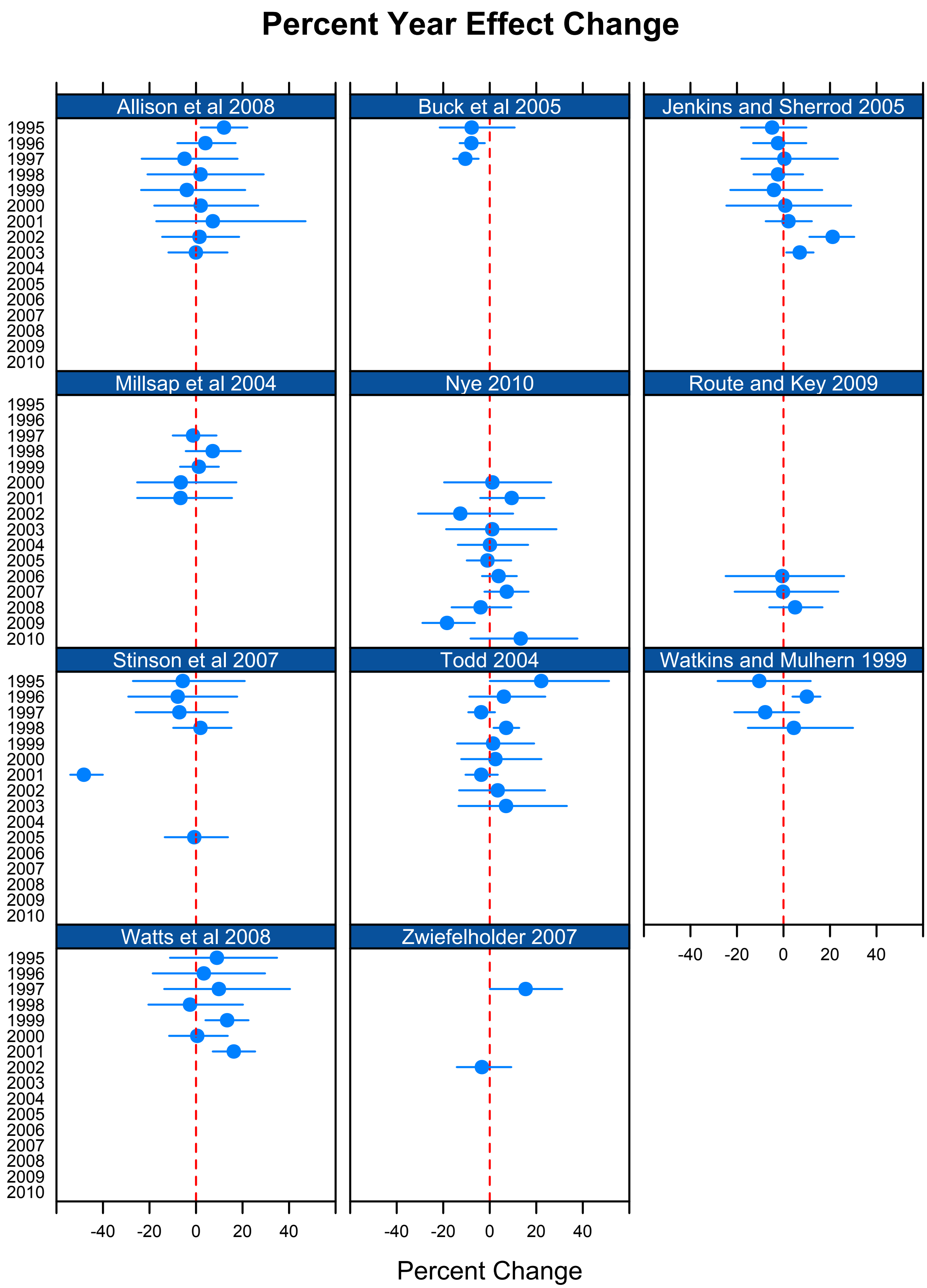
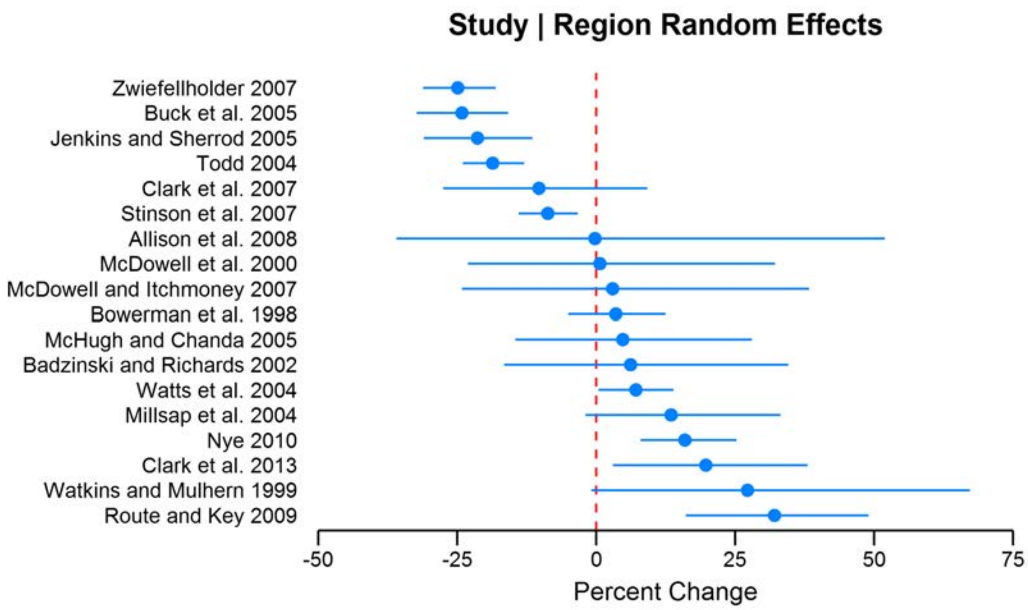


Figure 2: Bald eagle productivity model random effects (percent change) and 95% credible intervals due to year given study.



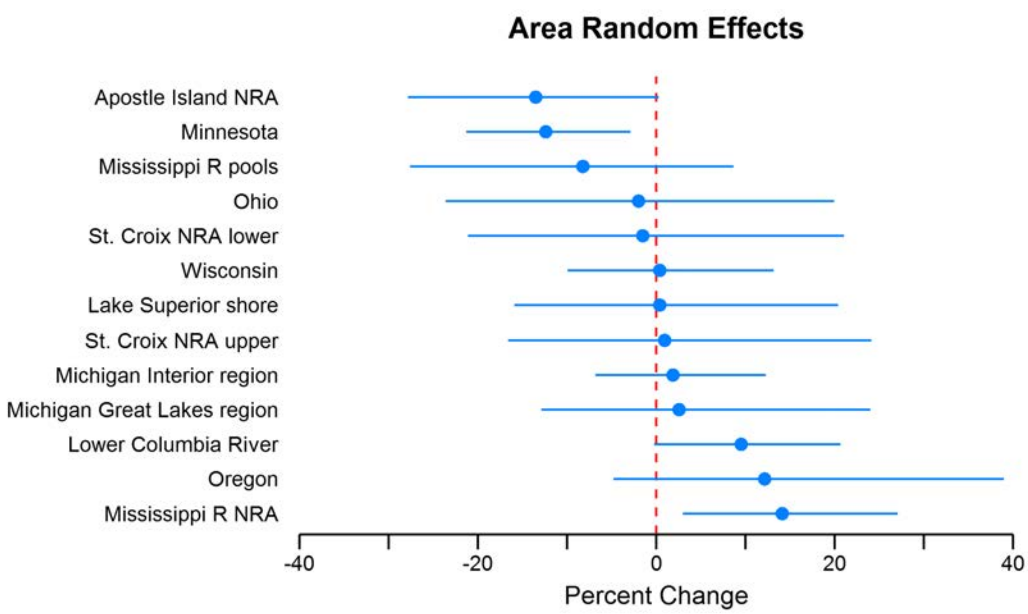


Figure 3: Bald eagle productivity model random effects (percent change) and 95% credible intervals due to study after accounting for regional (top) and area (bottom) differences in the model (see Table 6 for the full list of studies with the associated region, area, and year). The effects have wide credible intervals, some of which do not overlap zero.

Table 1: AIC values for bald and golden eagles from glm and glmer models which included overdispersion, study, area, year, and region effects with a mean. Region included Alaska, the Southwest (SW), the conterminous U.S. excluding the Southwest (Lower 48) and the entire continental U.S. (Overall) for bald eagles. Region included Eastern U.S. (East), Western U.S. (West), Alaska (AK) and Overall for golden eagles.

Species	Over-dispersion	Fixed-Effects	Random-Effects	Difference-DoF	AIC
Bald Eagle		Overall	None	1	1,449.50
	x	Overall	None	2	924.08
	x	Alaska+Lower48+SW	None	4	907.00
		Alaska+Lower48+SW	All	6	999.81
	x	Overall	All	4	883.57
	x	Lower48+SW	All	6	881.75
	x	Alaska+Lower48+SW	All	7	881.32
Golden Eagle		Overall	None	1	688.50
	x	Overall	None	2	506.56
	x	Alaska+East+West	None	4	510.01
		Alaska+East+West	All	5	541.47
	x	Overall	All	4	502.53
	x	East+West	All	5	504.20
	x	Alaska+East+West	All	6	506.09

Table 2: Regional prediction means, standard errors (SE), medians, and lower and upper limits (LCL, UCL) of the 95% credible intervals from the random effects models for bald and golden eagle productivity. The bald eagle model included a fixed effect for region and estimated productivity for the U.S. excluding the Southwest (U.S.–SW) and the Southwest (SW). The golden eagle model is an overall random effects model.

Species	Region	Mean	SE	Median	(LCL–UCL)
Bald eagle	U.S.–SW	1.15	0.252	1.12	(0.73–1.72)
	SW	0.77	0.249	0.73	(0.40–1.36)
Golden eagle	Overall	0.55	0.087	0.54	(0.40–0.75)

Table 3: Productivity model random effect standard errors with 95% credible intervals. Productivity model random effect standard errors and lower and upper limits (LCL, UCL) of the 95% credible intervals for a) bald eagles and b) golden eagles. The total standard error is the square root of the sum of all the random effect variances.

(a) **Bald Eagle**

Random Effect SE	Mean	SE	Median	(LCL–UCL)
Study	0.21	0.047	0.20	(0.14–0.32)
Area	0.13	0.056	0.12	(0.05–0.26)
Year	0.14	0.020	0.14	(0.11–0.18)
Overdispersion	0.02	0.016	0.02	(0.01–0.06)
Total	0.26	0.041	0.25	(0.19–0.35)

(b) **Golden Eagle**

Random Effect SE	Mean	SE	Median	(LCL–UCL)
Study	0.11	0.079	0.10	(0.00–0.30)
Year	0.27	0.132	0.29	(0.02–0.49)
Overdispersion	0.31	0.120	0.32	(0.07–0.51)
Total	0.47	0.059	0.46	(0.36–0.60)

Table 4: Bald eagle productivity model median random effects (and lower and upper limits, LCL and UCL, of the 95% credible intervals) apart from region. The effect medians are presented in descending order. Fledged and nest counts are aggregated over all areas and years for each study. Ratio is the simple ratio of the total fledged to the total occupied nesting territories across all areas and years.

Study	Ratio	Median	(LCL–UCL)	Fledged	Occupied Nesting Territories
Allison et al. 2008	0.74	0.73	(0.64–0.83)	234	317
Zwiefelholder 2007	0.84	0.84	(0.78–0.92)	836	998
Buck et al. 2005	0.93	0.85	(0.76–0.94)	766	828
Jenkins and Sherrod 2005	0.88	0.88	(0.78–0.99)	241	274
Todd 2004	0.92	0.91	(0.87–0.96)	1,916	2,091
Clark et al. 2007	0.97	1.00	(0.81–1.24)	62	64
Stinson et al. 2007	1.04	1.03	(1.00–1.05)	8,074	7,784
McDowell et al. 2000	1.16	1.12	(0.84–1.49)	29	25
McDowell and Itchmoney 1997	1.21	1.16	(0.84–1.57)	17	14
Bowerman et al. 1998	1.21	1.16	(1.08–1.25)	1,817	1,497
McHugh and Chanda 2005	1.21	1.17	(0.95–1.45)	64	53
Badzinski and Richards 2002	1.24	1.20	(0.93–1.53)	41	33
Watts et al. 2008	1.26	1.20	(1.16–1.25)	4,001	3,181
Millsap et al. 2004	1.32	1.28	(1.10–1.49)	158	120
Nye 2010	1.31	1.30	(1.22–1.37)	1,540	1,178
Clark et al. 2013	1.38	1.35	(1.15–1.55)	177	128
Watkins and Mulhern 1999	1.71	1.42	(1.09–1.86)	41	24
Route and Key 2009	1.55	1.48	(1.30–1.67)	254	164

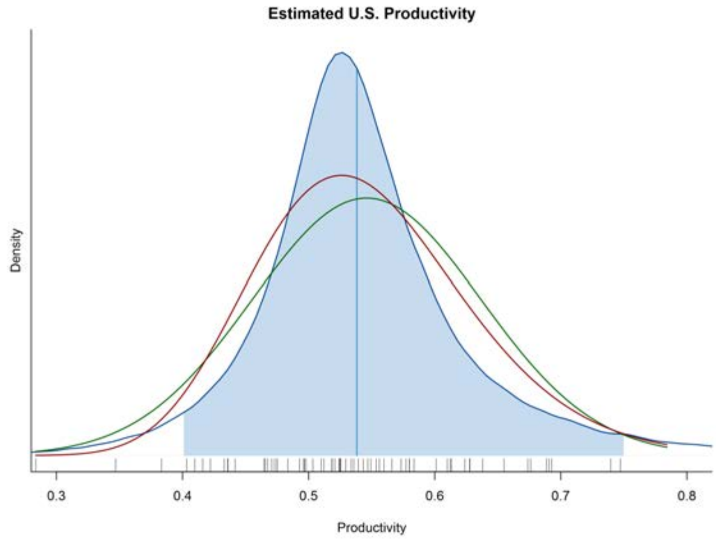


Figure 4: Golden eagle productivity for the U.S. The blue curve is the empirical density distribution of the estimates—which are shown via the rug just above the x-axis. The vertical blue line is the median with the area within the 95% credible intervals shaded blue. The red and green curves represent the log normal and normal distributions (respectively) defined by the estimated mean and standard deviation.

Table 5: Golden eagle productivity model median random effects (and lower and upper limits, LCL and UCL, of the 95% credible intervals) apart from region. The effect medians are presented in descending order. Fledged and nest counts are aggregated over all areas and years for each study. Ratio is the simple ratio of the total fledged to the total occupied nesting territories across all areas and years.

Productivity random effects	Ratio	Median	(LCL–UCL)	Fledged	Occupied Nesting Territories
Hopi Navajo 2013	0.51	0.49	(0.40–0.58)	362	715
Hawkwatch International 2009*a*	0.50	0.51	(0.41–0.60)	257	510
Morneau et al. 2012	0.49	0.53	(0.40–0.67)	24	49
Hawks Aloft 2002	0.50	0.53	(0.41–0.68)	38	76
McIntyre and Schmidt 2012	0.61	0.53	(0.46–0.62)	692	1,140
Preston 2014	0.56	0.54	(0.44–0.65)	149	264
Hawks Aloft 2006	0.64	0.54	(0.43–0.75)	27	42
McIntyre and Adams 1999	0.61	0.54	(0.44–0.69)	112	184
Isaacs 2011	0.60	0.54	(0.43–0.73)	169	280
Berengia 2014	0.60	0.55	(0.45–0.69)	117	196
Ritchie et al. 2003	1.18	0.56	(0.45–0.87)	13	11
Hawkwatch International 2009*b*	0.92	0.58	(0.47–0.84)	85	92

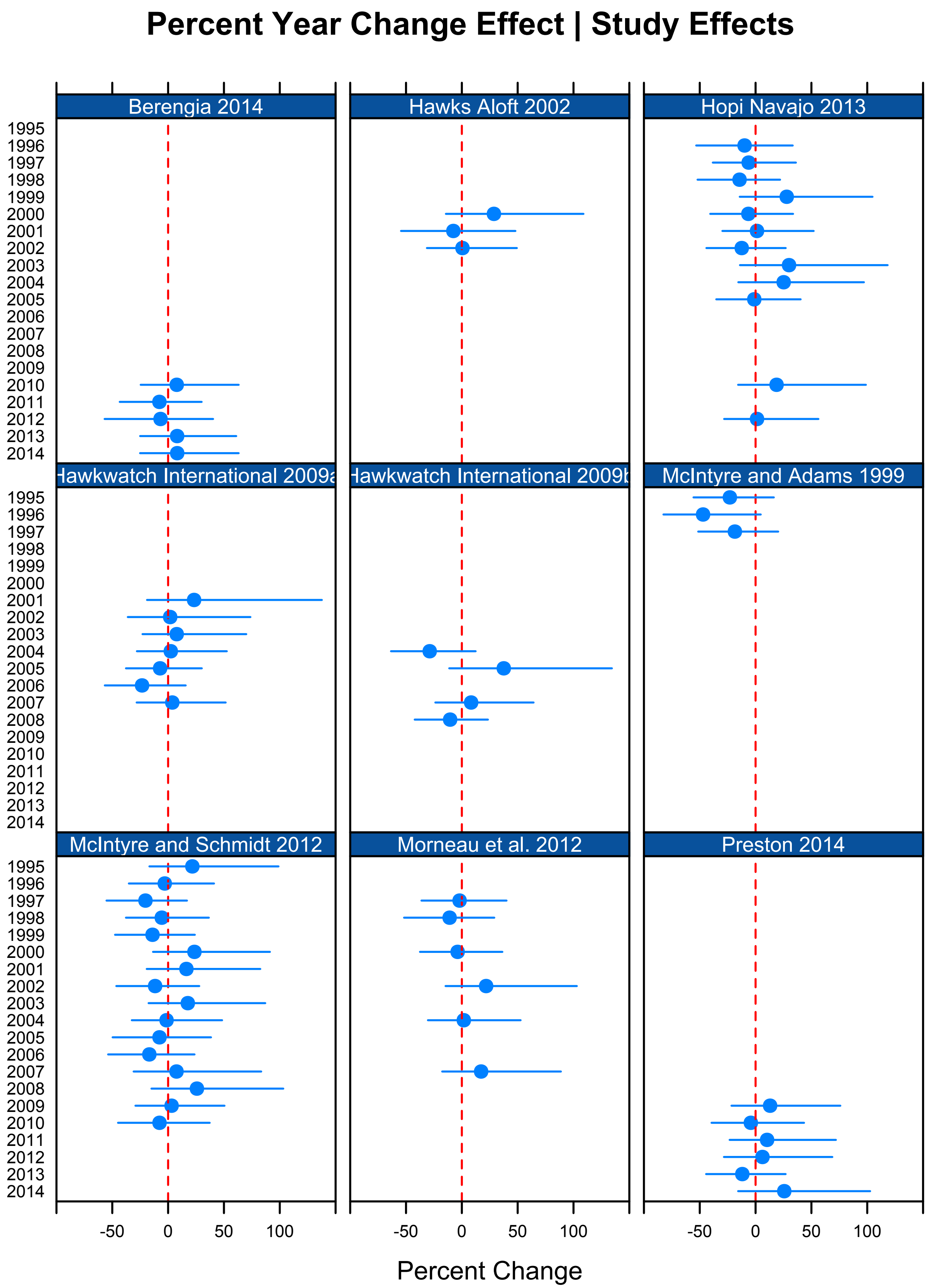


Figure 5: Golden eagle productivity model random effects (percent change) and 95% credible intervals due to year given study. The random effect credible intervals all overlap zero.

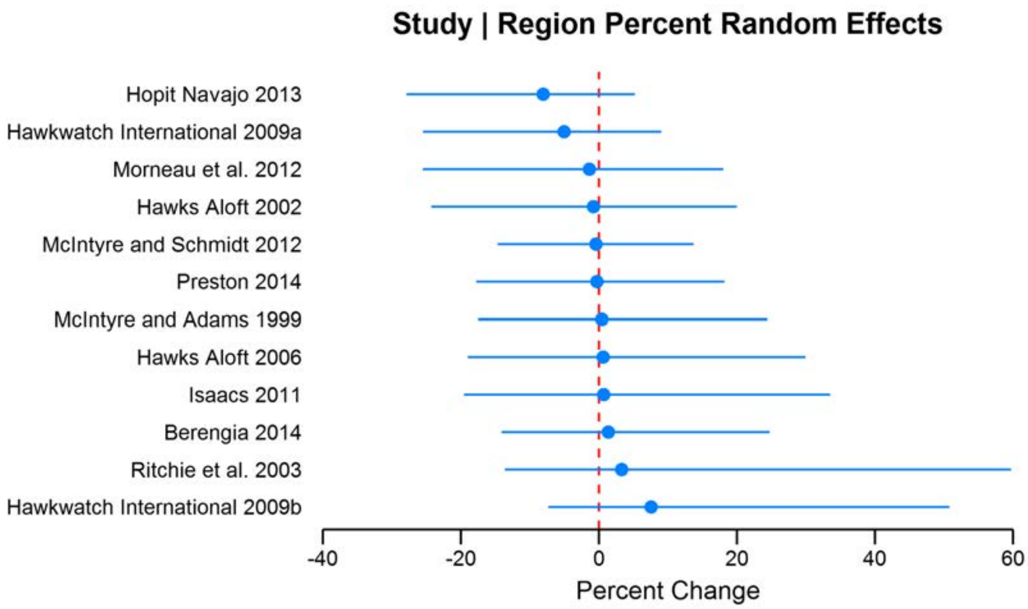


Figure 6: Golden eagle productivity model random effects (percent change) and 95% credible intervals due to study after accounting for regional differences in the model (see Table 7 for the full list of studies with the associated region and year). The credible intervals all overlap zero.

Table 6: Bald eagle studies included in the analysis, their simple productivity ratios, and the final random effect model median estimates for each area and year combination of the studies.

Study	Region	Area	Year	Fledged	Sample Size	Productivity	Model Median
Watts et al. 2008	Other		1997	227	416	1.40	0.624
Allison et al. 2008	SW		2003	25	42	0.60	0.677
Allison et al. 2008	SW		2000	23	38	0.61	0.680
Allison et al. 2008	SW		1998	21	34	0.62	0.692
Allison et al. 2008	SW		1997	23	32	0.72	0.722
Buck et al. 2005	Other	Lower Columbia River	1997	32	54	0.59	0.737
Buck et al. 2005	Other	Lower Columbia River	1996	39	48	0.81	0.741
Allison et al. 2008	SW		1996	23	30	0.77	0.742
Todd 2004	Other		1996	141	203	0.69	0.747
Allison et al. 2008	SW		2001	28	36	0.78	0.748
Buck et al. 2005	Other	Lower Columbia River	1995	22	35	0.63	0.759
Allison et al. 2008	SW		1995	23	28	0.82	0.764
Jenkins and Sherrod 2005	Other		1996	13	25	0.52	0.778
Allison et al. 2008	SW		1999	31	36	0.86	0.780
Jenkins and Sherrod 2005	Other		1999	20	32	0.63	0.796
Allison et al. 2008	SW		2002	37	41	0.90	0.800
Zwiefelholder 2007	Other		1997	368	460	0.80	0.812
Jenkins and Sherrod 2005	Other		1998	21	28	0.75	0.836
Jenkins and Sherrod 2005	Other		1997	19	26	0.73	0.837
Zwiefelholder 2007	Other		2002	468	538	0.87	0.875
Todd 2004	Other		2000	205	234	0.88	0.884
Jenkins and Sherrod 2005	Other		2000	29	33	0.88	0.891
Todd 2004	Other		2003	273	309	0.88	0.891

Table 6. Bald eagle studies included in the analysis, their simple productivity ratios, and the final random effect model median estimates for each area and year combination of the studies. *(continued)*

Study	Region	Area	Year	Fledged	Sample Size	Productivity	Model Median
Jenkins and Sherrod 2005	Other		1995	17	19	0.89	0.895
Todd 2004	Other		1995	176	192	0.92	0.916
Jenkins and Sherrod 2005	Other		2001	31	32	0.97	0.917
Stinson et al. 2007	Other		1995	509	558	0.91	0.917
Stinson et al. 2007	Other		1995	509	558	0.91	0.917
Todd 2004	Other		1998	189	202	0.94	0.933
Jenkins and Sherrod 2005	Other		2002	38	38	1.00	0.945
Stinson et al. 2007	Other		1996	564	599	0.94	0.946
Stinson et al. 2007	Other		1996	564	599	0.94	0.946
Todd 2004	Other		1999	207	216	0.96	0.950
Buck et al. 2005	Other	Oregon	1997	244	248	0.98	0.960
Todd 2004	Other		2002	280	290	0.97	0.962
Buck et al. 2005	Other	Oregon	1996	215	230	0.93	0.964
Todd 2004	Other		2001	266	269	0.99	0.979
Stinson et al. 2007	Other		1997	565	574	0.98	0.986
Stinson et al. 2007	Other		1997	565	574	0.98	0.986
Buck et al. 2005	Other	Oregon	1995	214	213	1.00	0.989
Todd 2004	Other		1997	179	176	1.02	0.993
Clark et al. 2007	Other			62	64	0.97	1.005
Bowerman et al. 1998	Other	Michigan Great Lakes		81	90	0.90	1.006
Jenkins and Sherrod 2005	Other		2003	53	41	1.29	1.083
Stinson et al. 2007	Other		1998	713	648	1.10	1.097
Stinson et al. 2007	Other		1998	713	648	1.10	1.097

Table 6. Bald eagle studies included in the analysis, their simple productivity ratios, and the final random effect model median estimates for each area and year combination of the studies. *(continued)*

Study	Region	Area	Year	Fledged	Sample Size	Productivity	Model Median
Stinson et al. 2007	Other		2005	925	840	1.10	1.098
Stinson et al. 2007	Other		2005	925	840	1.10	1.098
Stinson et al. 2007	Other		2001	761	673	1.13	1.127
Stinson et al. 2007	Other		2001	761	673	1.13	1.127
McDowell et al. 2000	Other			29	25	1.16	1.129
McDowell and Itchmoney 1997	Other			17	14	1.21	1.157
Bowerman et al. 1998	Other	Michigan Interior		207	176	1.19	1.168
McHugh and Chanda 2005	Other			64	53	1.21	1.174
Bowerman et al. 1998	Other	Wisconsin		694	583	1.19	1.186
Badzinski and Richards 2002	Other			41	33	1.20	1.193
Bowerman et al. 1998	Other	Ohio		38	30	1.27	1.195
Nye 2010	Other		2003	87	75	1.16	1.208
Millsap et al. 2004	Other		1998	12	12	1.00	1.213
Millsap et al. 2004	Other		1998	16	12	1.33	1.213
Watts et al. 2008	Other		1998	563	462	1.20	1.216
Millsap et al. 2004	Other		1999	13	12	1.08	1.222
Millsap et al. 2004	Other		1999	15	12	1.25	1.222
Nye 2010	Other		2005	112	92	1.22	1.235
Nye 2010	Other		2007	153	124	1.24	1.245
Millsap et al. 2004	Other		2000	15	12	1.25	1.246
Millsap et al. 2004	Other		2000	15	12	1.25	1.246
Route and Key 2009	Other	Apostle Island NRA	2007	10	9	1.10	1.249
Bowerman et al. 1998	Other	Minnesota		797	618	1.29	1.276

Table 6. Bald eagle studies included in the analysis, their simple productivity ratios, and the final random effect model median estimates for each area and year combination of the studies. *(continued)*

Study	Region	Area	Year	Fledged	Sample Size	Productivity	Model Median
Nye 2010	Other		2010	244	192	1.27	1.278
Millsap et al. 2004	Other		2001	13	12	1.08	1.280
Millsap et al. 2004	Other		2001	19	12	1.58	1.280
Nye 2010	Other		2009	223	173	1.29	1.286
Watts et al. 2008	Other		1996	490	377	1.30	1.291
Nye 2010	Other		2004	111	84	1.32	1.310
Nye 2010	Other		2008	190	145	1.31	1.311
Nye 2010	Other		2001	83	62	1.34	1.317
Watkins and Mulhern 1999	Other		1995	5	5	1.00	1.327
Nye 2010	Other		2002	94	70	1.34	1.329
Route and Key 2009	Other	Lake Superior shore	2007	18	14	1.30	1.330
Clark et al. 2013	Other			177	128	1.38	1.343
Nye 2010	Other		2000	71	51	1.35	1.347
Watts et al. 2008	Other		1995	464	340	1.40	1.347
Watts et al. 2008	Other		1999	650	472	1.40	1.362
Route and Key 2009	Other	St. Croix NRA upper	2007	28	19	1.50	1.372
Route and Key 2009	Other	St. Croix NRA lower	2007	6	4	1.50	1.378
Route and Key 2009	Other	Apostle Island NRA	2008	8	8	1.00	1.386
Watts et al. 2008	Other		2001	849	601	1.40	1.398
Watkins and Mulhern 1999	Other		1998	11	7	1.57	1.405
Millsap et al. 2004	Other		1997	17	12	1.42	1.426
Millsap et al. 2004	Other		1997	23	12	1.91	1.426
Route and Key 2009	Other	Apostle Island NRA	2006	16	11	1.50	1.440

Table 6. Bald eagle studies included in the analysis, their simple productivity ratios, and the final random effect model median estimates for each area and year combination of the studies. *(continued)*

Study	Region	Area	Year	Fledged	Sample Size	Productivity	Model Median
Watkins and Mulhern 1999	Other		1996	9	5	1.80	1.449
Watts et al. 2008	Other		2000	758	513	1.50	1.454
Route and Key 2009	Other	Mississippi River pools	2008	36	24	1.50	1.494
Nye 2010	Other		2006	172	110	1.56	1.494
Route and Key 2009	Other	Mississippi River NRA	2007	22	15	1.50	1.532
Route and Key 2009	Other	St. Croix NRA lower	2008	16	10	1.60	1.534
Watkins and Mulhern 1999	Other		1997	16	7	2.29	1.556
Route and Key 2009	Other	St. Croix NRA upper	2006	31	20	1.60	1.582
Route and Key 2009	Other	St. Croix NRA lower	2006	9	5	1.80	1.589
Route and Key 2009	Other	Mississippi River NRA	2008	30	14	2.10	1.704
Route and Key 2009	Other	Mississippi River NRA	2006	24	11	2.20	1.770

Table 7: Golden eagle studies included in the analysis, their simple productivity ratios, and the final random effect model median estimates for each year of the studies.

Study	Region	Year	Fledged	Sample Size	Productivity	Model Median
McIntyre and Schmidt 2012	AK	2002	4	73	0.05	0.296
Hopi Navajo 2013	West	2003	9	60	0.15	0.358
Hawkwatch International 2009*a*	West	2001	13	60	0.22	0.397
Hopi Navajo 2013	West	2010	6	29	0.21	0.415
Hopi Navajo 2013	West	2002	20	71	0.28	0.417
McIntyre and Schmidt 2012	AK	2003	19	71	0.27	0.420
McIntyre and Schmidt 2012	AK	2004	20	73	0.27	0.424
Hopi Navajo 2013	West	1997	7	25	0.28	0.445
Preston 2014	West	2012	15	48	0.31	0.447
Hawkwatch International 2009*a*	West	2003	26	78	0.33	0.448
Hawkwatch International 2009*a*	West	2002	23	68	0.34	0.456
Hopi Navajo 2013	West	2012	23	60	0.38	0.468
Hawks Aloft 2002	West	2002	12	33	0.36	0.474
Morneau et al. 2012	East	2007	4	14	0.29	0.474
Preston 2014	West	2011	17	44	0.39	0.480
Morneau et al. 2012	East	2002	2	8	0.25	0.481
McIntyre and Adams 1999	AK	1995	25	59	0.42	0.484
Preston 2014	West	2013	17	42	0.41	0.485
Morneau et al. 2012	East	1997	2	7	0.29	0.492
Hawkwatch International 2009*b*	West	2008	8	16	0.50	0.494
Hopi Navajo 2013	West	2001	35	75	0.47	0.496
McIntyre and Schmidt 2012	AK	1995	24	56	0.43	0.497
McIntyre and Adams 1999	AK	1996	30	62	0.48	0.504
McIntyre and Schmidt 2012	AK	2001	31	68	0.46	0.505
McIntyre and Schmidt 2012	AK	1996	28	61	0.46	0.506
McIntyre and Schmidt 2012	AK	1998	33	66	0.50	0.518
McIntyre and Schmidt 2012	AK	2005	38	76	0.50	0.520
Hawkwatch International 2009*a*	West	2004	42	84	0.50	0.520
Hopi Navajo 2013	West	1996	14	26	0.54	0.521
Berengia 2014	West	2012	21	41	0.51	0.521
Hawkwatch International 2009*a*	West	2007	34	67	0.51	0.522
Preston 2014	West	2014	29	54	0.54	0.530
Hopi Navajo 2013	West	1999	39	70	0.56	0.531
Hopi Navajo 2013	West	2004	43	76	0.57	0.535
Berengia 2014	West	2011	23	42	0.55	0.535
Hawks Aloft 2002	West	2000	12	22	0.55	0.539
Morneau et al. 2012	East	1998	3	5	0.60	0.540
Hawks Aloft 2006	West		27	42	0.64	0.542
Isaacs 2011	West		169	280	0.60	0.544
Hawkwatch International 2009*b*	West	2007	8	11	0.73	0.546
Morneau et al. 2012	East	2004	6	9	0.67	0.557
Ritchie et al. 2003	AK		13	11	1.18	0.558
Berengia 2014	West	2013	26	41	0.63	0.561

Table 7: Golden eagle studies included in the analysis, their simple productivity ratios, and the final random effect model median estimates for each year of the studies. *(continued)*

Study	Region	Year	Fledged	Sample Size	Productivity	Model Median
Berengia 2014	West	2014	26	41	0.63	0.564
Berengia 2014	West	2010	21	31	0.68	0.572
McIntyre and Schmidt 2012	AK	2010	49	75	0.65	0.575
Hawks Aloft 2002	West	2001	14	21	0.66	0.579
Hopi Navajo 2013	West	2005	59	84	0.70	0.583
Hopi Navajo 2013	West	2000	55	76	0.72	0.584
McIntyre and Schmidt 2012	AK	2008	52	75	0.69	0.585
McIntyre and Schmidt 2012	AK	2000	51	70	0.73	0.596
Preston 2014	West	2010	34	43	0.79	0.615
Hopi Navajo 2013	West	1998	52	63	0.83	0.621
Hawkwatch International 2009*a*	West	2005	67	87	0.77	0.621
Hawkwatch International 2009*a*	West	2006	52	66	0.79	0.624
Morneau et al. 2012	East	2000	7	6	1.17	0.633
McIntyre and Schmidt 2012	AK	1997	58	69	0.84	0.636
Hawkwatch International 2009*b*	West	2005	32	35	0.91	0.640
McIntyre and Schmidt 2012	AK	2007	73	81	0.90	0.658
McIntyre and Schmidt 2012	AK	2009	67	74	0.91	0.660
McIntyre and Schmidt 2012	AK	2006	76	80	0.95	0.675
McIntyre and Adams 1999	AK	1997	57	63	0.90	0.675
McIntyre and Schmidt 2012	AK	1999	69	72	0.96	0.677
Preston 2014	West	2009	37	33	1.11	0.718
Hawkwatch International 2009*b*	West	2004	37	30	1.23	0.732