Early reproductive success of western bluebirds and ash-throated flycatchers: a landscape-contaminant perspective

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"Capsule": Comparison of the reproductive success of two similar cavity-nesting bird species that differ with development rate in relation to various soil contaminants.

**Abstract**

Eggshell quality, clutch size, sex ratio, and hatching success of western bluebirds (Sialia mexicana) and ash-throated flycatchers (Myiarchus cinerascens) were studied on a landscape-soil contaminant gradient at Los Alamos National Laboratory (LANL) in New Mexico from 1997 to 1999. A variety of contaminants (heavy metals, chemicals, insecticides, polychlorinated biphenyls (PCBs), organochlorines, and radioactive isotopes) range across different spatial scales and concentrations on LANL land. This study is an example of a monitoring program over a large area with varying degree of contamination that is used to highlight locations of concern for future research. There were two locations where the flycatcher had a lower hatching success. The bluebirds at Sandia wetland, a location of concern for PCBs, had a thinner eggshell thickness index (RATCLIFFE) and the eggs were smaller than at other locations. The flycatcher had thinner eggshells than bluebirds, which could add to sensitivity to exposure to contaminants. There was no variation in clutch size or sex ratio between locations or areas closer to contaminant release sites for both species. Percent females in the clutch ranged from 0 to 100% in the WEBL and from 33 to 67% for ATFL. © 2002 Elsevier Science Ltd. All rights reserved.

**Keywords:** Western bluebird; Ash-throated flycatcher; Sex ratio; Eggshells; PCBs

1. Introduction

Understanding how chronic exposure to soil contamination affects both individuals and populations is crucial for remediation efforts. However, this can be a difficult challenge when the contamination is uncharacterized and contains a mixture of contaminants including chemicals, radionuclides, and heavy metals. Understanding exposure response relationships are key to (1) assessing the implications for the exposure of management endpoints, (2) designing and implementing effective remediation strategies, and (3) for documenting post-remediation recovery. Because few data exist on the additive and differential effects of mixed waste, ecological risk assessments based on the responses of individual species to a single toxicant may be uninformative. It may be necessary to begin effects monitoring before the nature and extent of contamination is fully documented and before toxicity reference values are compiled for all potential contaminants of concern. Waiting until efforts to characterize contaminant nature and extent are complete may leave little time or funding to describe ecosystem responses to environmental stressors, causing the entire process to suffer from this added uncertainty. An alternative approach is to use hypothesized distributions of contaminants based on available release information, and knowledge of environmental processes affecting redistribution to design ecological effects monitoring surveys.

Inherent in this alternative approach would be to develop a monitoring network of several species across the gradient of contaminated areas, focusing on individual life-history traits that can have population-level
impacts. Reproductive traits of a species such as hatching success that figure directly into population size and growth may be affected by numerous contaminants available in the environment. We studied eggshell quality, clutch size, sex ratio, and hatching success of the cavity-nesting western bluebirds (Sialia mexicana) and ash-throated flycatchers (Myiarchus cinerascens) on a landscape-soil contaminant gradient in order to estimate the overall reproductive health of these species.

This study was conducted at Los Alamos National Laboratory (LANL) in northern New Mexico. Many activities and operations at the Laboratory have used or produced liquids, solids, and gases that contain radioactive or nonradioactive hazardous materials. A variety of contaminants (heavy metals, chemicals, insecticides, PCBs, and radioactive isotopes, and organochlorines) range across different spatial scales and soil concentrations on LANL land. Potentially contaminated sites are located in a clumped distribution across the landscape at LANL, with no overall specific contaminant that is inherently everywhere. Wildlife at LANL may be exposed to various mixtures of contaminants that could affect animal populations by reducing reproduction or survival. It is crucial to have information that is biologically relevant (i.e. able to be extrapolated to meaningful effects) concerning ecological risks faced by migratory birds that breed on potentially contaminated lands.

The western bluebird (WEBL) is a widely distributed, sexually dichromatic, and monogamous species. The ash-throated flycatcher (ATFL) is not as widely distributed or sexually dichromatic. Both species nest in secondary nest cavities, are insectivorous during the breeding season, and use small amounts of grit in their gizzards that are potentially important exposure pathways. These two species have similar life history traits, although the ATFL has a faster rate of development, fledges 4–5 days earlier than the bluebird, and has a significantly higher field metabolic rate during development (Mock et al., 1991). This difference in duration of development period could affect the relative exposure and risks to contaminants. If intake of contaminants in soil is proportional to dry matter intake as is assumed in ecological risk methodology, the higher metabolic rate for the ATFL compared to the WEBL may increase their relative risk of toxic exposure. Both species feed on similar prey items on and above the ground. Sexual dichromatism differs in the two species, with the WEBL being sexually dichromatic and the ATFL having no sexual differences. Although the specific migratory pattern of both species is unknown, WEBLs are more common in the winter months in the study area and it is thought that the ATFLs migrate farther south, even in mild winter years. Both bird species in this study readily utilized nestboxes and are common in northern New Mexico. It is not known how home ranges differ between the species.

The sensitivity of a particular species to environmental stress depends in large part on its life history characteristics, such as age at first reproduction, clutch size, and reproductive life span. Many of these parameters, such as the proportion of females reproducing in a year, can be highly variable and might be influenced by environmental conditions (Fitzgerald, 1994). The next level above the approach of this study would be to determine which life history traits most affect population dynamics. Myers (1999) analyzed factors affecting contaminant exposure, dietary strategies and foraging tactics, to identify groups of species with similar exposure potential. This type of analysis is an essential and complementary part of what is needed to more accurately predict contaminant effects. Once a broad theoretical framework about the relationships between toxicants, individual life-history traits, and population growth is established, the next step will be to estimate the relative frequencies of different life-history types in natural ecosystems.

Eggshell thinning is one of the best-documented detrimental effects of insecticides on birds (Ratcliffe, 1967; Hickey and Anderson, 1968). Laboratory and field tests suggest that heavy metals impair eggshell structure (Grandjean, 1976; Miles et al., 1993; Eeva and Lehikoinen, 1995). Acidification of the environment may also cause eggshell thinning (Giooseschenko et al., 1986; Ormert et al., 1988; Graveland et al., 1994). Therefore, in cases of uncharacterized or potential contamination, eggshell quality can be an indicator of the environmental health of birds in the area of concern. This study included this established biomarker of various contaminant exposures.

The objectives of this study were to: (1) pinpoint areas of concern for environmental restoration at LANL for birds in respect to soil contaminants; (2) establish the feasibility of using the reproductive parameters of eggshell quality, clutch size, sex ratio, and hatching success, as indicators of environmental stress; and (3) determine the effects of uncharacterized soil contamination with respect to two sympatric species with similar life-history traits.

2. Study area and methods

The 111 km² Los Alamos National Laboratory is situated on the Pajarito Plateau and consists of a series of relatively narrow mesas separated by deep, steep-sided canyons that decline east-southeast from the Jemez Mountains down to the Rio Grande River. Six major vegetation community types are found in Los Alamos County: subalpine grassland, spruce-fir forest, mixed conifer forest, ponderosa pine forest, piñon-juniper woodland, and juniper grasslands (Fox and Tierney, 1982). In general, Los Alamos has a temperate
montane climate with four distinct seasons. Average annual precipitation is 47.6 cm.

During the winter of 1997, 438 nestboxes were placed on LANL in total of 18 both potentially contaminated and reference areas (Fig. 1). Nestboxes were placed approximately 2 m off the ground on trees and spaced approximately 50–75 m apart. Boxes were placed in open ponderosa pine forest of the canyons and pinon-juniper woodland on the plateau mesas. Boxes were placed in 18 locations or areas on LANL land with an average of 29 boxes per location.

2.1. Hatching success and hatch date

Starting in May 1997, nestboxes were visited and nests with eggs were considered active and visited every 2 days until the first eggs hatched (day = 0). Then after day 0, nests were visited again on day 5, 10, 15, and 20. Hatch date was recorded for each nest because seasonal variation in reproductive success is a common phenomenon in many species and is considered to be an important life history trait for birds that is affected by the environment (Siikamaki, 1998). Each nestling was handled for less than five minutes in accordance with the Guidelines for the Use of Wild Birds in Research (Gaunt and Oring, 1997). The animal care and use committees of both LANL and the University of Missouri-St. Louis approved all protocols. Data were collected for the summer breeding seasons of 1997, 1998, and 1999.

2.2. Eggshell quality

Unhatched eggs were collected from the nestboxes when the nestlings were past the age of 10 days. Hatched eggs were not available due to the rapid disposal of eggshells by both species. Eggs were stored in a refrigerator until measurements were taken (1–10 weeks). Egg volume was measured by water displacement and greatest length and breadth were measured for each egg. Eggshells were opened, rinsed, and dried. All dirt, uric acid, or other materials were cleaned away. The contents were stored at −30°C for future residue analysis. Eggshell thickness was measured at four points along the equator on each half of the shell plus membrane, using a Starrett 1010M dial gauge micrometer graduated in units of 0.01 mm, and then averaged for each egg. Eggshells were air-dried for several weeks before weighing. A modified RATCLIFFE (Ratcliffe, 1967) shell-thickness index [shell weight (g) × 100/length × breadth (mm)] was calculated for each eggshell (Morrisson and Kiff, 1979). The shape index is the reciprocal (breadth/length) of the more usual length/breadth measurement, which gives a higher value the more rounded egg (a perfect sphere is 1.0; Brooker and Brooker, 1991). In the year 2000, eggs that went on to hatch were measured in the field to compare to the previous three years of unhatched eggs that were collected.

2.3. Sex ratio

The sex of the WEBLs was determined by plumage color identification of nestlings' 15 days or older. On days 10 and 15 of age, blood (ca. 70 μl) was collected from the brachial vein of the wing in both heparinized and non-heparinized microcapillary tubes, which were kept at room temperature. In addition, one drop (6 μl whole blood) was added to 600 μl of cell lysis solution (Purgene™, Gentra Systems, Minneapolis, MN) in an eppendorf tube and then stored at room temperature until analysis. The sex of ATFL nestlings was determined by polymerase chain reaction (PCR) amplification of a CHD gene (Griffiths and Dijkatra, 1996). This gene is present in two genomic copies of which one is Z-linked and present in both sexes and the other is W-linked and present only in females.

2.4. Data analysis

The Statistical Analysis System (SAS Institute, 1987) was used for all statistical analyses, and assumptions for parametric statistics were examined. Analysis of covariance was used for all comparisons between locations and potentially contaminated areas (PROC GLM). Means for each treatment were compared with Duncan's Multiple Range Test. Data not normally distributed or having heteroscedastic variances were compared with Kruskal-Wallis nonparametric tests. Eggshell thickness was compared between species using egg volume as a covariate to control for thickness being correlated with egg size. Elevation was also used as a covariate in all analysis of variance (ANOVA) models. If multiple eggs were collected from nests, then "nests" was treated as the random error term for testing location or species effects to avoid pseudoreplication.

Using a soil contamination database maintained by LANL, potentially contaminated sites were identified based on proximity to potential release sites (PRS). All nestbox locations were obtained using a non-differentially corrected GPS (Garmin GPS III Personal Navigator™, Olathe, KS, USA) with real-time FM correction. Locations were checked for accuracy, and contaminant data were accessed using ArcView™ (ESRI, 1996) with locations of PRSs. Distances from PRSs for all nestboxes were normally distributed (W = 0.90, Shapiro-Wilk test). Due to the lack of contaminant concentration soil data that could be used as a continuous variable in analyses, categories of distances were established. The main experimental design was to have a similar number of boxes located near potentially contaminated areas and also farther away in reference areas. This gave a bimodal distribution with a large
number of boxes near a PRS, a large number a large distance away and then, a smaller number of boxes that were in-between. Thus, three distance categories could be clearly delineated. All nestboxes located greater than 308 m from a PRS were categorized as potentially contaminated and greater than 1300 m were classified as reference areas. Locations within 60 m of a PRS were considered to be within a foraging distance (J. Fair, unpublished data). Categories were clearly delineated when box distances were graphed. When using distance to PRS as a continuous variable instead of the above categories, a nonlinear regression model was selected specifying an intercept (PROC NONLIN, SAS).

3. Results

3.1. Hatching success and eggshell quality

Western bluebirds and ash-throated flycatchers had similar hatching success, which was the proportion of eggs hatched in successful nests, over the three years ($F_{1, 216} = 0.33, P = 0.52$) and there was no species x year
interaction ($F_{2, 216} = 0.87, P = 0.42$). The average hatching success for the WEBL was 70.5% ($\pm 2.9$ S.E., $n = 168$) and for the ATFL was 75.7% ($\pm 4.9$ S.E., $n = 54$; Fig. 2). Hatching success was not correlated with elevation, Julian hatch date, distance to nearest PRS, the type of PRS, or between areas closer than 300 m or farther away for either species. There was no variation in percent hatching among the different areas for the WEBL, but in two areas ATFL had below average hatching success (Technical Area 33 and Los Alamos Canyon). Nests that were started and then abandoned by the parents were not in more often in any specific location ($n = 30$).

A total of 91 eggs did not hatch and were collected from 1997 to 1999 for the WEBL and ATFL (Table 1). More eggs were collected in 1998 than other years. Table 2 contains ANOVA results for all egg variables measured. The wet weight, volume and shape of the eggs did not differ between species or years. The wet weight and shape of the eggs also did not vary with elevation, locations, potentially contaminated or reference sites, or distance to a PRS. However, egg volume varied between locations ($F_{1, 92} = 8.45, P = 0.003$). The ATFLs had higher dry weight of the eggshells than WEBLs ($F_{1, 80} = 72.46, P < 0.0001$). Dry weight did not vary with location for WEBLs ($F_{11, 47} = 1.69, P = 0.10$) or ATFLs ($F_{4, 19} = 0.39, P = 0.81$). Locational dry weights for the WEBL ranged from 0.147 to 0.243 g for all locations containing more than four eggs collected. At the Sandia location, a wetland of concern below the county landfill and where PCBs were found in the soil and small mammals (Bennett et al., 1999), eggshells had an average dry weight of 0.147 (10% less than other locations) for the WEBL (no ATFLs nested in this location). There were no difference between years for the number of nests that were complete but not used and there were locations that contained significantly more empty nests.

The ATFL eggs were longer than the WEBL eggs ($F_{1, 94} = 7.19, P = 0.009$). The main difference in the eggs of the two species was the thickness and eggshell thickness index ($F_{1, 95} = 72.4, P < 0.0001$) and ($F_{1, 80} = 50.31, P < 0.0001$).

### Table 1
Mean (S.E.) egg variables for western bluebird and ash-throated flycatchers for 1997–1999 at Los Alamos National Laboratory

<table>
<thead>
<tr>
<th>Egg variable</th>
<th>Western bluebird</th>
<th>Ash-throated flycatcher</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1997 ($n = 10$)</td>
<td>1998 ($n = 35$)</td>
</tr>
<tr>
<td>Wet weight (g)</td>
<td>2.09 (0.15)</td>
<td>1.81 (0.12)</td>
</tr>
<tr>
<td>Dry weight (g)</td>
<td>0.16 (0.005)</td>
<td>0.17 (0.003)</td>
</tr>
<tr>
<td>Shape</td>
<td>0.76 (0.006)</td>
<td>0.75 (0.005)</td>
</tr>
<tr>
<td>Length (mm)</td>
<td>20.43 (0.29)</td>
<td>20.74 (0.23)</td>
</tr>
<tr>
<td>Volume (ml)</td>
<td>2.58 (0.12)</td>
<td>2.65 (0.09)</td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td>0.191 (0.01)</td>
<td>0.225 (0.003)</td>
</tr>
<tr>
<td>Eggshell index</td>
<td>12.07 (0.57)</td>
<td>12.5 (0.20)</td>
</tr>
</tbody>
</table>

### Table 2
ANOVA results for egg variable differences for western bluebirds and ash-throated flycatchers for years 1997–1999

<table>
<thead>
<tr>
<th>Source</th>
<th>d.f.</th>
<th>Egg variables</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Weight (g)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$F$ value</td>
</tr>
<tr>
<td>Species</td>
<td>1</td>
<td>0.80</td>
</tr>
<tr>
<td>Year</td>
<td>2</td>
<td>0.01</td>
</tr>
<tr>
<td>Elevation</td>
<td>1</td>
<td>4.7</td>
</tr>
<tr>
<td>Location</td>
<td>13</td>
<td>0.92</td>
</tr>
<tr>
<td>Contaminated vs. PRS</td>
<td>2</td>
<td>0.41</td>
</tr>
<tr>
<td>PRS distance</td>
<td>1</td>
<td>0.00</td>
</tr>
</tbody>
</table>
For both species, egg length did not vary between locations ($F_{1, 92} = 3.06, P = 0.14$). Western bluebirds had a much thicker shell than the ash-throated flycatcher. Using egg volume as a covariate for measured thickness, bluebird eggs still had thicker shells ($F_{1, 54} = 17.06, P = 0.0001$). Both of the thickness variables did not vary with elevation, contamination site categories, or distance to PRS for both species. There appears to be more variation with the eggshell index for the bluebirds in regards to location, ranging from 11.3 to 18.2 ($F_{6, 72} = 3.33, P = 0.007$).

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Sandia wetland contains eggs with an average eggshell index 9% thinner than the other six locations with more than four eggs collected (Duncan's Multiple Range Test). The only egg parameter that varied with year was eggshell thickness, with 1997 eggs being thinner than 1998 and 1999 for both species. Overall, Sandia wetlands had 13% smaller eggs than all other locations but did not differ from other locations in hatchability. The egg parameter with the highest coefficient of variation was the wet weight of the egg that ranged from 27 to 61%, which is intuitive since the eggs had been left in the nests before collecting for variable times under varying conditions. Therefore the wet weights of eggs were left out of further analysis. The length of the eggs varied very little from 3 to 6%, and all other parameters varied from 7 to 21% for both species. The lengths of the unhatched eggs collected from 1997 to 1999 did not differ from the hatched eggs measured in the field in 2000 ($F_{3, 59} = 0.84, P = 0.48$). This was also the case for the width of the eggs ($F_{3, 59} = 1.54, P = 0.22$). Egg width did not vary between locations ($F_{1, 92} = 0.77, P = 0.42$).

### 3.2. Julian hatch date

Julian hatching date was unrelated to elevation (1897–2186 m) in both the WEBL ($F_{1, 218} = 0.91, P = 0.34$) and ATFL ($F_{1, 43} = 1.15, P = 0.29$) and there was no species×year interaction. Ash-throated flycatcher clutches hatched an average of 10 days later than those of WEBLs ($F_{1, 151} = 20.38, P < 0.0001$; Fig. 3). Western bluebird hatch dates did not vary among years ($F_{2, 137} = 0.47, P = 0.63$), however, ATFLs bred earlier in 1998 ($F_{2, 42} = 5.01, P = 0.01$). The mean hatch date for WEBL was day 164 (ca. June 12; ± 14.4 S.D.) and was day 177 (ca. June 25; ± 12.3 S.D.) for the ATFL. There were no differences in mean hatch date between locations for WEBL ($F_{15, 84} = 1.11, P = 0.36$) or for ATFL ($F_{2, 35} = 0.94, P = 0.49$). There were also no differences in hatch date for both species in areas within foraging distance of a PRS, areas between 60 and 308 m, or areas located greater than 308 m from a PRS ($F_{2, 132} = 0.17, P = 0.85$) or distance to a PRS ($F_{2, 220} = 0.04, P = 0.96$).

### 3.3. Clutch size

Western bluebirds had significantly larger clutches than ATFLs in all 3 years ($F_{1, 218} = 12.71, P = 0.0004$; Fig. 4). However, there was no species×year interaction, and clutch size did not differ between years ($F_{2, 218} = 0.29, P = 0.74$). Clutch size decreased over the breeding season for both WEBL ($F_{1, 136} = 32.15, P < 0.0001, r^2 = 0.20$) and ATFL ($F_{1, 44} = 19.22, P < 0.0001, r^2 = 0.30$) and the rate of clutch size decline was much faster in the ATFL ($F_{1, 150} = 29.12, P < 0.0001, ANCOVA$). Elevation and distance to the nearest PRS had no effect on clutch size for both species. Clutch size for both
species also did not vary with the type of PRS or between potentially contaminated sites and sites farther away. There was also no variation in clutch size among locations for both species. Ash-throated flycatchers had no second clutches in the 3 years while an average of 4% of bluebird nests each year produced double clutches.

3.4. Sex ratio

A total of 11 ATFL nests were fully characterized for sex ratio in 1999 as were 85 WEBL nests over all 3 years. Sex ratios were only included in the analysis for nests in which all eggs hatched and sexes was known. Both species had mean percentages of females in the nest of 52%, which was not different from a 1:1 ratio. The percent of females did not differ between species (F1, 92 = 0.03, P = 0.87) or years (F1, 92 = 0.90, P = 0.41; Fig. 5). Julian hatch date, elevation, and distance to nearest PRS did not affect sex ratio for either species. There were also no differences in sex ratio among PRS types or potentially contaminated areas. Among locations, percent females ranged from 0 to 100% for WEBL and from 33 to 67% for ATFL. There were no differences among locations for ATFL (F9, 86 = 0.24, P = 0.90). Using only locations with a nest sample size greater than six for analyses, there were no differences for WEBL (F6, 68 = 1.09, P = 0.38). Unfortunately, locations that contained nests with either all females or no females contained small sample sizes (1–3 nests per location) and therefore were not included in the analysis.

4. Discussion

There were no major effects of PRSs or locations on any of the nest success parameters. That is, by the measures of hatching success, sex ratio, or abandoned nests, there is no evidence of environmental risk for these population-level reproductive variables for the bluebirds and flycatchers at LANL in spite of the presence of contaminants (Table 3). Like Ormerod et al. (2000) we hypothesized that any marked toxicological effects, including endocrine disruption, would be detectable as altered clutch-size, hatching success, clutch size, eggshell quality or sex ratio. Although this study did not demonstrate large impacts of contaminants on two similar cavity-nesting species, it is a useful example of the importance of reproductive endpoints in that can be used within an ecological risk assessment using a life history framework. By comparing species in similar environmental conditions, we can gain more insight into how specific life history traits are affected. Since exposure could not be measured directly, it cannot be known whether the contaminants are not bioavailable or that the contaminants are in accessible quantities but do not affect these particular measures of potential risk. Regardless, large effects on reproductive traits that are biologically significant to these species and that would need immediate attention were not found, thus giving environmental management a better assessment of LANL lands as a whole. A third alternative could be that the contaminants are so widely distributed that all of the birds are exposed, although this is probably unlikely due to the clumped distribution of contaminants, the types of contaminants, and the small foraging area of the birds. Other life history traits that can factor significantly into overall reproductive success such as nesting growth, survival and immune response are presented elsewhere (Fair, 2000).

In respect to our first objective of determining locations of concern using the reproductive endpoints, the most significant finding was variability in eggshell quality. Sandia wetlands, an area of concern for PCBs contained smaller eggs and had a thinner eggshell thickness index for the WEBL than other areas at LANL. One category of contaminants of concern for eggshell thinning is the PCBs (Frumkin, 1994). Numerous studies have investigated the effects of chlorinated hydrocarbons on eggshells (Ratcliffe, 1967; Hickey and Anderson, 1968; Anderson and Hickey, 1970; Blus et al., 1972; Cooke, 1973; Morrison and Kiff, 1979; Weimer et al., 1984; Lundholm, 1987; Fair et al., 1994). Fernie et al. (2000) also found that water content and eggshell thickness were not affected by PCB exposure but that yolks in the PCB-contaminated eggs were heavier and suggest that the contaminated eggs have relatively more lipid and less protein available for embryonic development. None of the unhatched eggs

### Table 3

Mean (S.E.) reproductive variables for western bluebird and ash-throated flycatchers for 1997-1999 at Los Alamos National Laboratory

<table>
<thead>
<tr>
<th></th>
<th>Western bluebird</th>
<th>Ash-throated flycatcher</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>1997 (n=23)</td>
<td>1998 (n=76)</td>
</tr>
<tr>
<td></td>
<td>1997 (n=20)</td>
<td>1998 (n=16)</td>
</tr>
<tr>
<td>Percent hatch (%)</td>
<td>78.7 (7.1)</td>
<td>59.2 (4.6)</td>
</tr>
<tr>
<td>Julian hatch date</td>
<td>161.9 (4.0)</td>
<td>166.7 (2.2)</td>
</tr>
<tr>
<td>Clutch size (%)</td>
<td>4.6 (1.1)</td>
<td>4.27 (1.4)</td>
</tr>
<tr>
<td>Percent females (%)</td>
<td>0.58</td>
<td>0.47</td>
</tr>
</tbody>
</table>
that were collected at Sandia wetland exhibited embryo development so they were probably infertile.

The primary LANL use of the Sandia wetland has been disposal of liquid waste from industrial and sanitary systems. Ecological risk in the wetland is determined to come from hexavalent chromium, arsenic, and point-source PCBs. PCBs were collected from 78% of the sediment samples in the wetland with a highest concentration of 2.0 mg/kg (Bennett et al., 2001). Samples from internal organs and fat tissue of small mammals in the wetland contained detectable quantities of PCBs, including Aroclor-1260 that ranged from 49 to 19,000 g/kg and approached minimum levels for which effects have been noted (Bennett et al., 1999). This study was also conducted 7–10 years after a sulfuric acid spill in the wetlands.

Several studies have found that eggshell thickness is dependent on calcium in soil and prey (Eeva and Lehikoinen, 1995; Weimer and Schmidt, 1998) and that calcium availability limits breeding success of passerines (Johnson and Barclay, 1996; Graveland and Drent, 1997). Graveland and Drent (1997) provided the first experimental evidence of Ca availability limiting avian reproduction in regions of Ca-poor soils. In the case of contaminants, a reduced diet of calcium greatly increased the accumulation and effects of lead, cadmium, and aluminum in birds (Scheuhammer, 1996). Soils on the Pajarito Plateau are variable with respect to calcium carbonate and are considered to have comparatively higher concentrations of calcium carbonate for North America (Longmire et al., 1996). Therefore, risk to wildlife from contaminants exposure at LANL due to a paucity of calcium is not predicted.

Two other important factors involved in shell thickness may be prior exposure to DDT on wintering grounds and taxon specific response to DDT. The ATFLs migrate south from New Mexico, although it is not known specifically where they migrate. Mexico and several countries in Central America continue to use DDT pesticides that could be an exposure route to the migratory birds from North America. Banded WEBLs in this study were spotted throughout the winters on the Pajarito Plateau. Western bluebirds in the southwestern part of North America may only migrate in colder and moister years (J. Guinan, personal communication).

As in Eeva and Lehikoinen (1995), the present study found species-specific differences in eggshell thickness between two similar species between potential contaminated and uncontaminated areas. They compared one species that feeds on ground-living prey that may accumulate more heavy metals, and another species that feeds on foliage-inhabiting prey. This difference in foraging strategies may lead to calcium differences in the prey that could lead to differences in eggshell thickness between ATFLs and WEBLs. There are currently no published studies on the diet of the ATFLs, although nest remains over the three years of this study do not show obvious differences in the prey selection of insects between the two species (Fair, unpublished data). Pertaining to our third objective of comparing two similar species, if the ATFLs naturally have thinner shells, then we would predict this species would be more susceptible to contaminants than WEBLs. Due to the plethora of results linking eggshell qualities with environmental quality, eggshell quality may continue to be a useful tool to managers for the status of individual avian health.

The WEBL eggs from nests in Sandia wetland were smaller and had a thinner eggshell index than other WEBL eggs from other areas. Many nonexperimental studies have reported a positive relationship between egg size and posthatching survival or growth in birds, and few experimental studies have demonstrated a developmental advantage of larger eggs (Bolton, 1991; Hipfner and Gaston, 1999). While in some species, parental quality can contribute as much as egg size (Blomqvist et al., 1997); areas consistently producing small eggs could indicate poor habitat. Sandia wetland should be monitored for egg and arthropod contaminant load, egg quality, and nest success.

The hatching success of these two species was lower and much more variable than reported for two similar cavity-nesting birds by Eeva and Lehikoinen (1995). They reported markedly lower hatching success closer to a factory complex producing heavy metal pollutants and less variation in hatching success farther away. Eeva and Lehikoinen (1995) also suggested that hatching failure did not result from lower fertility of the eggs, but rather from desiccation of eggs with low-quality shells from exposure to contaminants. Western bluebirds had a larger clutch size in this study than the flycatcher but the rate of decrease in clutch size was faster in the ATFL that initiated breeding later in the nesting season. While this is most probably a natural phenomenon, this decrease in the rate of clutch size throughout the season could affect the ATFL’s total fitness in late spring or early dry seasons that impact breeding initiation. There were no differences or trends in the number of completed nests that were no used which can be an indicator of contaminant or pollution stress (Eeva et al., 2000).

There was not the seasonal shift in nestling sex ratios of the earlier part of the season being biased towards males and later in the season biased towards females, as found by Smallwood and Smallwood (1998) for American kestrels (Falco sparverius). Several reported incidences of skewed sex ratios in reptiles have been reportedly caused by xenobiotics such as DDT, PCBs, and tetrachlor dibenzo-p-dioxin (TCDD), which are referred to as endocrine disrupters (Guillette et al., 1995). Miyamoto and Klein (1998) warn that effects from these contaminants should not be considered...
broad and general, due to species differences. Passerines have been found to have female-biased sex ratios (Gowaty, 1993) and this may add difficulty in the interpretation, sex ratio investigations within a species can be used in varying environments.

Sex-specific differences in exposure and uptake of contaminants (Donaldson and Braun, 1999) and effects from metabolic differences (Landis and Yu, 1995) can also lead to skewed sex ratios if nesting survival is affected by contaminants. Another important facet of sex ratio was experimentally demonstrated by Nager et al. (1999) who found that sex ratio varies with maternal condition. When female gull (Larus fuscus) condition declined, sex ratio of the offspring was skewed toward the sex with higher survival prospects. Although this can confound studies linking contaminants to sex ratios, if the sexes are not dimorphic, like the WEBL and ATFL, then no differences in survival between the sexes would be expected (Sheldon et al., 1998). In the present study, sex ratio was used in a triage approach to pinpoint areas of concern, although no differences were found for areas on LANL. Sex ratio is considered an important component of assessing population viability. Brook et al. (2000) found that sex ratio was the major difference between individual-based and matrix-based population viability analysis packages. Individual-based packages included sex ratio and predicted extinction rates were higher with sex ratio incorporated into the model. Unfortunately, the locations that did have highly skewed sex ratios for WEBLs contained small sample sizes and so they could not be included in the analyses.

The varying results of the sensitivities of the different life-history traits of different species suggest that consideration of life history may be more important for site-specific assessments. If potential hazards to anthropogenic stressors and safe environmental contaminant concentrations are to be estimated, then a life-cycle approach using numerous life-history traits for each stage is critical. The next logical step is a sensitivity analysis of population dynamics of these two species, elucidating which life-history traits are sensitive. Questions such as the importance of a clutch size decrease to population growth can be answered. Viability analyses are lacking for large or apparently healthy passerine populations.

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