

Breeding Birds on EBMUD Horse-logging Areas 2002-2018: An Analysis of Area Census Surveys

by Lee S. Friedman

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Cover Photograph: A mother Black-headed Grosbeak feeding its fledgling a red berry, taken in the EBMUD horse-logging area on June 5, 2020. No Black-headed Grosbeaks were observed in the 2002-2009 portion of the survey. © Lee S. Friedman

Acknowledgments: Many people have contributed importantly to this study. Most of all, former EBMUD Supervising Biologist Roger Hartwell was the guiding force behind EBMUD's participation. Without his support and enthusiasm in initiating the study and overseeing its implementation in the early years, there would be no study design to follow nor data for analysis. EBMUD's Fisheries and Wildlife Division has continued to provide crucial logistical support. Special thanks are due to current Supervising Biologist Bert Mulchaey, and to Biologist Jonathan Price for his help in geotagging the study plot locations and in combing through EBMUD's archives to provide and to organize all available historical documentation and data for this study. There also would be no study without the dedication of Mark Lamoureaux not only in conducting many of the surveys himself during all years of the study, but in marshalling other volunteer surveyors (including myself) to achieve very substantial coverage of the survey areas for over 15 years. Other contributors include volunteer surveyors Marty Morrow, Sara Mathews, Jim Allen, John Brenneman, Karen O'Rourke, Ellen Barth and Maggie Clark. I am grateful to Johan Langewis and Douglas Vaughan for helpful comments on an earlier draft. Should there be any errors in this analysis and report, I take sole responsibility for them.

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#### Abstract

This paper analyzes the effectiveness of a public agency's managerial decision intended to promote biodiversity on the lands that it owns. The agency is the East Bay Municipal Utility District (EBMUD) that provides water to most of the eastern San Francisco Bay Area. In the 1940s, it planted non-native Monterey Pines on a 366 acre parcel by the San Pablo Reservoir referred to as the horse-logging area. Late in that century, it decided that the nonnative Monterey Pines were not consistent with its goal of promoting biodiversity on the lands that it stewards, and that these lands should be allowed to return gradually and naturally to their native oak woodland. By the turn of the century, many of the Monterey Pines were weak and dying. Starting in 2002, EBMUD allowed these lands to be regularly surveyed to assess the breeding bird population in them. This paper analyzes the survey data from 2002-2018 to consider how the bird population has changed and if the change is one that promotes biodiversity. The paper finds that biodiversity has increased significantly by multiple measures. The paper rejects two alternative hypotheses to explain the biodiversity increase: (1) that it could be part of a broader regional trend of avian biodiversity increase, and (2) that it could be an artifact of the survey methodology. EBMUD's decision to allow these lands to return gradually to their native vegetation was effective; it has resulted in a significant increase in avian biodiversity. This increase includes the presence in 20102018 of important species that were not present in 2002-2009, including migratory species like the Olive-sided Flycatcher, Ash-throated Flycatcher, and Black-headed Grosbeak. More generally, the evidence in this study supports the idea that native vegetation promotes biodiversity.


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## Executive Summary

Going Native Significantly Increases Avian Biodiversity

The East Bay Municipal Utility District (EBMUD), which provides water to most of the eastern portion of the San Francisco Bay Area, owns and is the steward of substantial watershed lands around its reservoir system. It manages these lands to achieve two primary purposes: to protect water quality and biodiversity. This includes a 336 acre parcel by the San Pablo Reservoir referred to as the horse-logging area. In the 1940s, non-native Monterey Pines were planted in this area, a decision that was reversed many decades later in favor of gradual and natural regeneration of the native oak woodlands. It was expected that this management strategy would increase the area's biodiversity. By the late 1990s, many of the Monterey Pines were reaching the end of their lives. Starting in 2002, area census surveys of the breeding birds in this area were undertaken by volunteers following the protocols of the Point Reyes Bird Observatory (PRBO) and have continued annually through the present. The intent of this survey is to find out how the gradual, natural regeneration affects the bird population of the horse-logging area.

This paper analyzes all available data from these surveys from 2002-2018. Each of five $1+$ acre plots was intended to be surveyed three times per year during the breeding season. There are missed or missing censuses, but there are 152 completed censuses that provide $62 \%$ of complete coverage. Biodiversity measures based on the 2002-2009 period ( 85 censuses) are compared to those from 2010-

2018 ( 67 censuses). The analysis finds evidence of significantly increased biodiversity over time by multiple measures. Richness, or the number of different breeding species observed, increased from 51 to 59. The Shannon Diversity index, the Simpson Dominance index and the Pielou Evenness index all show significant increases in diversity. The increases include both new migratory species like the Ashthroated Flycatcher, Orange-crowned Warbler and Black-headed Grosbeak, as well as new resident (year-round) species like California Quail, Wild Turkey and Western Bluebird.

As a check on whether the observed increase might be occurring generally within the same region (and therefore not due to EBMUD's managerial policy of natural regeneration on the horse-logging areas), the results here were compared with those from an adjacent, independent survey: the Moraga Breeding Bird Survey sponsored by the U.S. Geological Service. The Moraga Survey data over a comparable time frame show a decline in species abundance, effectively ruling out this possible alternative explanation.

Another possible alternative explanation for the results would be if some of the observed differences were artifacts caused by detection variation among the different surveyors. Several important factors rule out this artifactual possibility. First, the biodiversity increases occur across the four most heavily surveyed plots, two of them with one continual surveyor and the other two with a multiplicity of surveyors with overlap in both time periods. Second, some of the species contributing to the increase are among the easiest to detect (i.e. they would have been detected by the volunteers in the earlier years). The California Quail, Wild Turkey, and Western Bluebird mentioned above were all detected by multiple surveyors, and the first two are among the easiest to detect. Third, there is good supplemental photographic evidence to further document the biodiversity level in the more recent years. Appendix D contains photographs of 28 species taken in Areas A and B during the 2016-2019 breeding seasons,
including the Ash-throated Flycatcher and Black-headed Grosbeak, new migratory birds mentioned above.

The management decision to allow the horse-logging area to gradually return to its native state has increased avian biodiversity significantly in the 2010-2018 period compared to the earlier 2002-2009
period. EBMUD's managerial policy has been effective in promoting its avian biodiversity goal.
More generally, the evidence in this study supports the idea that native vegetation promotes biodiversity.

# Breeding Birds on EBMUD Horse-logging Areas 2002-2018: <br> An Analysis of Area Census Surveys 

by Lee $S$. Friedman ${ }^{1}$

## Introduction

The East Bay Area Census Survey of breeding birds was originally initiated by the Point Reyes Bird Observatory (PRBO, now Point Blue) and began in the early 2000s at most of its sites. The study design included two EBMUD areas, as well as a number of other important Bay Area bird habitats. ${ }^{2}$ Soon after it started, PRBO found it necessary to discontinue its sponsorship due to inadequate resources. However several of the people involved in the EBMUD part of the survey decided to continue it. These included Roger Hartwell, then EBMUD's Supervising Biologist and Mark Lamoureaux, one of the original volunteer surveyors who continues to this day to marshal the surveying effort.

The original survey design included two types of EBMUD habitat: the horse-logging areas by the San Pablo Reservoir that had been planted with non-native Monterey Pines during the 1940s, and other EBMUD property with native habitat (oak woodland). Mark Lamoureaux was part of the team assigned to the horse-logging areas, and it is these areas that have continued to be surveyed in accordance with the protocols of the original PRBO study design. ${ }^{3}$ There are 5 relatively small plots, each 1.1-1.8 acres (.4-. 7 hectare), that comprise the sampled habitat,

[^0]and these are referred to as Areas A, B, C, D and E. ${ }^{4}$ Figure 1 uses Google Earth to show the
location of these plots on the east side of the San Pablo Reservoir (and east of the Lower Lake
Road, so none abut on or include the Reservoir itself). They roughly spread from south to north,

Figure 1: The Five Area Census Plots in the EBMUD Horse-logging Area


[^1]and this analysis assumes they were chosen to be representative of the avian wildlife within the entire horse-logging area, approximately 336 acres. ${ }^{5}$ Each year during the breeding season, each plot is intended to be surveyed three times with an interval of about one month between each instance.

EBMUD is a public agency that manages its lands to achieve two primary goals: to protect water quality and biodiversity. The non-native Monterey Pines, outside of their normal coastal fog belt, are generally weak and nearing the end of their life cycles. EBMUD's management policy, intended to promote biodiversity, is to remove them gradually and to allow the native vegetation to succeed them naturally. Their removal has generally been done by horse, as an environmentally benign method, up until about 2015. Hence the areas are referred to as the "horse-logged oak woodland regeneration sites", or OWRE in the PRBO documents. ${ }^{6}$ A main question for our analysis is how EBMUD's policy of the gradual pine removal and natural restoration of native habitat affects the bird population. This is the "treatment" for which we would like to estimate the effect. Ideally, the survey analysis would include data from both the horse-logging areas and the EBMUD native vegetation areas (referred to as EBMU in PRBO documents). Then any changes observed over time in the horse-logging areas could be separated statistically into those happening generally in all EBMUD areas, and those due only to

[^2]the gradual removal of the Monterey Pines. However, there is no evidence that the planned PRBO area census survey of the native-vegetation EBMU areas ever took place. Nevertheless, with about 15 years of data, some population trends may be observed, and secondary sources may be useful for understanding any broader regional effects acting on the horse-logging area. ${ }^{7}$

Before turning to the avian data, it is useful to offer at least a rough impression of the extent of the habitat change from the beginning of the survey until today. A good analysis of this is beyond the scope of our data and this paper. However for each of the five survey areas, we have used Google Earth to provide comparative pictures of it historically in October 2002 and currently from June 2020.

Each of the comparative photographs shows essentially the same striking change. Figure 2 shows the photographs for Area A as an example; the other area photographs are in Appendix B. Each area has substantially reduced tree canopy, ranging from approximately $30 \%$ to $55 \%$ of its acreage over this time period. Essentially, in 2002 the areas would be described as forested with a canopy primarily of Monterey Pine covering on the order of $65-95 \%$ of each area (about 75\% for Area A shown in Figure 2). In 2020, most if not all of these areas are better described as savannas rather than forest-they appear as mixed woodland-grassland with enough space between trees that the canopy does not close. Figure 2 shows tree coverage in Area A down to about $20 \%$ of its acreage. The reduction in tree coverage and corresponding natural growth in

[^3]grassland is due to the demise of Monterey Pines. The remaining Monterey Pines are still the predominant tree but they are very weak and continue to diminish while the relatively small number of native oak trees has been at least stable.

It should not be surprising that this striking change in the habitat will have consequences for its avian population. We turn now to a description of the survey process by which the avian data has been collected. We also discuss some limitations of this data.

The survey protocol limits the time conducting each census to 20 minutes, a time thought to be enough to cover each area. From 2002-2018, 152 censuses were conducted by 10 volunteer surveyors (almost always one surveyor per census, but two in a few instances). 1669 birds were observed, averaging 10.8 birds per 20-minute census (or 8.7 birds per acre), and representing 67 different species. While this is an extensive record over a long time period, it is an imperfect one. There are some gaps in terms of the available censuses. For all five areas, there are no censuses from 2012-2013. Areas $A$ and $B$ also have no censuses from 2004-2006, although areas D and E have complete coverage for this period. Areas D and E are missing the 2003 census, although areas $A$ and $B$ do have coverage for this year. Areas $A, B, D$ and $E$ do have extensive if imperfect data coverage, with 133 censuses out of the 198 that would reflect complete coverage, or 67 percent. ${ }^{8}$

[^4]Figure 2: A Google Earth View of the Change in Habitat in Area A from 2002 to 2020
Area A 10/2002


Area A 6/2020


The least studied area is C, which has nearly complete coverage only for 2007-2011, with nothing before 2007 and sporadic coverage from 2014-2018. Area C has 19 censuses, only about $20 \%$ of the 96 that would completely cover 2003-2018. This will have little to no effect on the analysis if the community of birds in Area C is not too different from the average of the other areas-we will examine this later in the analysis. The original PRBO instructions specify that "All search areas at a given site should be the same size and of the same habitat type." 9 But in recognition of varying terrain features, the instructions do provide flexibility: "the most useful criteria in setting up the size of plots" is that it "can be easily covered and birded thoroughly over a 20 minute period." In other words, it is understood that the five plots are not expected to be homogeneous; if they were, then the lack of data from one plot like C would be the same as randomly missing data. All of the plots are part of the horse-logging decaying Monterey Pine habitat, and collectively they should be representative of its avian population. The missing data from $C$ could affect this representativeness, unless it turns out that $C$ is like the average of the other four.

Another factor addressed by the protocol is the time of day for the survey. Because bird activity generally varies with the time of day, with mornings being more active, the protocol will usually try to ensure some degree of consistency of the survey time across different visits. In this survey, the protocol states that "typically three plots should be covered in a single morning" and recommends starting as early as possible and finishing within three hours after sunrise. Virtually all censuses in this survey began sometime after 7:30AM, and for those starting later,

[^5]almost all were completed by 10:30AM. Each census also has entries for the temperature, wind speed, and degree of cloud cover, variables that can also affect the activity level of birds. Of course a few birds are nocturnal, like most owls and poorwills, and morning surveys when they are inactive are not the ideal time for spotting (or hearing) them.

It should be noted that the area census survey methodology is distinct from another common bird census methodology, the point count. The area census, because it involves a survey of a relatively small, well-defined and fixed area, can be conducted by volunteers and birders of diverse skill levels. All birds within the area at the time of the census are assumed to be detected, so that the data does not require adjustment for degree of a bird's detectability. By contrast, the point count requires the surveyor to follow a predefined route and stop briefly at particular points to record the birds that can be seen or heard from that point, usually requiring some estimate of the distance from the point of each bird recorded. Indeed, one of the main scientific sources of data used to estimate North American bird populations are the 4600+ point count survey routes sponsored by the U.S. Geological Survey. These surveys began in 1966, and have grown to cover much of North America, with each route intended to be surveyed annually (in 2018, 3291 routes of 4641 or $70.9 \%$ provided the survey data). ${ }^{10}$

For example, the Moraga Breeding Bird Survey-of some interest here because one section of its route includes the west side of the San Pablo Reservoir—is one of the USGS sponsored ones

[^6]and follows a route that is about 24.5 miles long with 50 stops or points spaced a half-mile apart (beginning in Moraga and ending near the Pinole-Martinez border). The surveyor stops for only 3 minutes at each point, recording all birds seen or heard within .25 mile. Obviously not all birds within that area will be seen or heard within the three minute observation period, so the observations need to be adjusted for the detectability of each species in order to make any inferences about the bird populations. As one example, because it is believed that it is primarily the male bird that is heard singing, most population estimates from these surveys double the raw count (the "pair adjustment") on the assumption that the birds are primarily in pairs with the female undetected. ${ }^{11}$ The survey is done annually on one day each year (usually in June), beginning before sunrise and taking about 5 hours to complete. Clearly, a point-count survey like this requires a surveyor with a very high level of birding skill to provide good observations: the surveyor has 3 minutes to bird approximately 126 acres, compared to 20 minutes to bird about 1.5 acres in this study. ${ }^{12}$

This introduction provides the context for data examination. The data from each of the 152
available census reports has been entered into an Excel spreadsheet, and is the database from

[^7]which the analysis in this paper is drawn. Let us turn now to the analysis, beginning with some summary statistics and then delving into time trends.

## Summary Statistics for the Sample

No single ecological measure adequately captures avian biodiversity. The density of birds may be different from one area to the next, as may be the variety of birds in terms of number of different species, and the dominance or lack of it of any particular species. This study utilizes a variety of measures in order to offer a reasonably comprehensive picture of this diversity. The measures of Richness, Diversity, Dominance and Evenness are standard measures that emphasize different aspects of the avian population (see note for exact definitions). ${ }^{13}$ Table 1 contains the summary statistics from the entire sample that characterize the avian biodiversity of Areas A, B, C, D and E separately and collectively. It also includes some other useful summary statistics: the number of birds reported, the average number of birds per census, and the average number of birds/acre. ${ }^{14}$

[^8]The summary statistics for the different areas provide some initial sense of differences across them. However, even rough impressions need to be drawn carefully because some of the statistics are not directly comparable-largely because they are based on unequal numbers of censuses. Richness is an increasing function of how many censuses have been performed (up to the limit of the true number of species in the area) and thus should not be directly compared across areas having substantially fewer or greater censuses. Diversity and Dominance, however, depend on the number of birds of each species relative to the total number of birds observed, and thus do not depend directly on the number of censuses (an additional census might lower or raise either measure). Evenness decreases somewhat with the number of censuses, and this also limits any direct comparison of it across the areas. In general, the higher the number for any measure, the more diverse is the area by that measure.

Table 1: Summary Statistics 2002-2018

|  | A | B | C | D | E | All Areas |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| Richness | 53 | 54 | 34 | 33 | 37 | 67 |
| Diversity <br> (Shannon) | 3.52 | 3.46 | 2.89 | 2.69 | 2.90 | 3.45 |
| Dominance <br> (Simpson) | 23.09 | 22.01 | 9.43 | 7.96 | 9.28 | 16.86 |
| Evenness | .89 | .87 | .82 | .77 | .80 | .82 |
| \# of censuses | 28 | 27 | 19 | 39 | 39 | 152 |
| \# of individual <br> birds | 529 | 440 | 189 | 242 | 269 | 1669 |
| Average <br> birds/census | 18.89 | 16.30 | 9.95 | 6.21 | 6.90 | 10.98 |
| Average <br> birds/acre | 12.60 | 14.81 | 5.24 | 5.17 | 5.75 | 8.41 |

With these qualifications in mind, Areas $A$ and $B$ have been surveyed almost the same number of times. They are roughly equal in their biodiversity, with approximately the same number of species (Richness) observed in each, and with similar distributions of these species (Diversity, Dominance, Evenness). Areas A and B do seem to have somewhat greater diversity than Areas D and E (Richness in D and E is lower even though it is based upon more censuses), which also appear roughly equal to one another. Area C seems to be in the middle: like Areas D and E in terms of Diversity and Dominance and Average birds/acre, but unlike them in achieving a similar Richness based upon far fewer censuses and with a somewhat greater Evenness. In sum, it seems like the southern-most horse-logging areas ( $A$ and $B$ ) have the most diversity, which decreases somewhat as one moves northward (to D and E ).

Of course no single area has exactly the same features as any of the others, and differences across the areas in an area census survey are not unusual. Area A, for example, has a very small vernal pool-an area that fills with water during the rainy season, and usually dries out before the next rainy season-enough to attract the occasional Mallard or Wood Duck that (as of yet) have not been seen in pondless Area $B$. Areas $A$ and $B$, as the southern-most areas within the horse-logging territory, may be closer to more substantial oak woodland habitat than Areas C, D and E , perhaps leading to greater exploration of them by neighboring birds. All of the areas contribute to the picture of the avian diversity in the horse-logging area generally (the last column of Table 1). ${ }^{15}$

[^9]
## Time Trends: Statistical Analysis

The earlier section reviewed the dataset, which has some occasional gaps but nonetheless offers extensive coverage over time. It is helpful that, except for no data in the two years 20112012, all other years have coverage of at least some of the areas. It is also important to keep in mind the limits on the quality of the data. The volunteer surveyors are generally quite good birders, but they are not expected to have the considerable expertise of those qualified to undertake point-count surveys. Even though the census areas have been designed to allow for thorough coverage within the 20-minute limit of the protocol, from a single census one cannot know for sure whether some avian occupant may have been overlooked or another misidentified. The most reliable evidence is that which is pooled across multiple areas, multiple surveyors, and multiple time periods. This pooling is the most common practice in the analysis of avian area census surveys. ${ }^{16}$

Still, the question of most interest is about change over time: does the strategy of allowing the horse-logging areas to return gradually to their native vegetation affect the bird populations that live there? If there is change in the bird populations, it also would be expected to occur gradually over time. Any change from one year to the next might or might not be reflective of a longer-term trend. Bird populations from year to year can be substantially affected by recent

[^10]climate conditions (e.g. a severe drought year, or a particularly bountiful one in terms of food abundance), and for migrating birds the relevant climate might be that of their wintering rather than EBMUD breeding grounds. Thus the best use of the data is to pool it as much as possible over the years but in a manner that allows an answer to the time trend question. I divide the data into two roughly equal time periods to form two large pools: the 2002-2009 "early" period (spanning 8 years), and the "later" 2010-2018 period (spanning 9 years). If the EBMUD policy of allowing the Monterey Pines to be gradually dissipated and replaced by native growth is having an effect on the bird populations, it should show up as a difference in the area's biodiversity between the early and later period.

If each of the five survey areas were censused equally (i.e. each contributing 20 percent of the censuses), then two large pools distinguished only by their respective time periods should give an unbiased estimate of the overall changes in biodiversity. Unfortunately, that is not quite the case. Table 2 shows the number and percentage of censuses that come from each of the five areas in each of the two broad time periods.

One can see from Table 2 that Areas D and E contributed 59\% of the censuses in the early period (rather than $40 \%$ ), with their share dropping to $42 \%$ in the more recent period. Recall that these two similar areas had lower biodiversity than the other areas for the entire study period (Table 1). Simply calculating the various diversity indices (to be discussed shortly) for all five areas in the aggregate would overweight $D \& E$ in the early period relative to the more recent one. Even if there were no actual change in biodiversity in any of the areas, in the

Table 2: Number and Percentage of Censuses from each Area, 2002-2009 and 2010-2018

|  |  | A | B | C | D | E | Total |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\begin{aligned} & 2002- \\ & 2009 \end{aligned}$ | Number of | 11 | 12 | 12 | 25 | 25 | 85 |
|  | Censuses |  |  |  |  |  |  |
|  | Percent* | 12.9 | 14.1 | 14.1 | 29.4 | 29.4 | 100.0 |
| 2010- | Number of | 17 | 15 | 7 | 14 | 14 | 67 |
| 2018 | Censuses |  |  |  |  |  |  |
|  | Percent* | 25.4 | 22.4 | 10.4 | 20.9 | 20.9 | 100.0 |

* Row numbers may not add to 100 due to rounding.
aggregate it might appear that biodiversity increased somewhat simply because of this change in weighting. On the other hand, it may be that the unequal sampling has little impact on the overall diversity indices to be calculated. We utilize two complementary approaches to dealing with the unequal sampling. One approach is to examine the components of the whole area to see if changes within them are consistent with the aggregate picture, or if some areas seem to be changing in one direction while others are either not changing or changing in an opposite direction. The second approach is to reweight the observations from each area to ensure that each area is weighted equally when aggregating them to calculate the whole area (or "all area") diversity indices. We discuss the rationale for each of these approaches briefly.

The first approach to this problem is to break down the pooled data a bit more so that only similar areas and/or equally-sampled areas (in this case both) are being aggregated for statistical comparison over time: pooled data for similar Areas A and B, pooled data for similar Areas D and E , and Area C by itself since its biodiversity is somewhere in the middle between the other areas. In other words, we will be able to see clearly whether or not diversity has changed within the area $A+B$, within the area $D+E$, and within area $C$. This disaggregation removes the problem of unequal weighting by areas. It is also illuminating to see whether or not there are differences across these areas in whether and how they are changing. Its weakness is that it does not present one comprehensive picture of overall change within the whole horse-logging area.

The second approach does offer a comprehensive picture of overall change. It uses all of the data from all of the censuses, but corrects for the unequal sampling across the five areas. In order to correct the data, one must reweight each area so that each of the five count equally in the whole area diversity measures. ${ }^{17}$ In words, we do this by using from each area its average number observed of each species across all visits (censuses), and its average number of birds observed of all species across all visits. Then the reweighted probability of observing a species in the whole area is found by dividing the sum across areas of the five averages for that species over the sum across areas of the five averages for number of birds observed of all species. The corrected Shannon, Simpson and Evenness indices are then computed by using these

[^11]reweighted probabilities. This process does not change the total number of species observed, so that the Richness number itself is unaffected.

Mathematically,

$$
\begin{gathered}
p_{i}=\sum_{j=A}^{E} S_{i}^{j} / \sum_{j=A}^{E} n_{j} \\
p_{i}^{w}=\left(\sum_{j=A}^{E} S_{i}^{j} / V_{j}\right) / \sum_{j=A}^{E} n_{j} / V_{j}
\end{gathered}
$$

where
$p_{i}=$ the uncorrected probability of observing species $i$ in the whole area
$p_{i}^{w}=$ the corrected probability of observing species $i$ in the whole area
$S_{i}^{j}=$ the total number of birds of species $i$ observed in area $j$
$V_{j}=$ the number of visits (censuses) in area $j$
$n_{j}=$ the total number of birds observed in area $j$
$i=1,2, \ldots \mathrm{k}$ species
$j=\mathrm{A}, \mathrm{B}, \ldots \mathrm{E}$ areas

Note from Table 2 that the 2010-2018 data by itself is quite balanced across the areas. The well-studied areas A, B, D and E each comprise just over 20 percent of the sample, with only Area C underweighted at 10.4 percent. If Area $C$ remains in the middle not just geographically but by the different biodiversity indices for the 2010-2018 period, then giving it somewhat more weight will not have much impact on the overall calculation. Thus even with the
reweighting, there is no reason to expect much change from the unweighted indices for 20102018. It is the 2002-2009 data that is less well-balanced. If the reweighting does cause a difference, it should be more pronounced in comparing the unweighted and weighted indices for 2002-2009.

All of the calculations rely upon dividing the observations into two broad time periods and examining them to see if avian diversity has changed significantly from the earlier period to the more recent one. Instead of this pooling process, one could consider alternatively a time series analysis and try to detect finer year-by-year effects. In my opinion, the simpler pooling method compensates more effectively for any missed censuses and for any uncontrolled sources of year-to-year variation. The latter may arise from exogenous factors like those of climate mentioned previously. It also may arise from unknown differences in the detecting accuracy among surveyors, as well as skill differences over time in any single surveyor. ${ }^{18}$ In other words, these differences due to uncontrolled factors are getting pooled and likely minimized by the simpler method, whereas a time series analysis with important uncontrolled factors risks confounding the estimated treatment effect with the missing exogenous variables. It is better to detect with confidence an average treatment effect over two broad time periods than risk error in trying to estimate an annual treatment effect.

[^12]Table 3: Change over Time in Areas A + B, C, D + E and All Areas

|  | $A+B$ | C | $D+E$ | All Areas ${ }^{\circ}$ | All Areas <br> Weighting Corrected |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 2002-2009 Only |  |  |  |  |  |
| Richness | 42 | 26 | 32 | 51 | 51 |
| Diversity (Shannon) | 3.12 | 2.59 | 2.65 | 3.01 | 3.06 |
| Dominance (Simpson) | 14.24 | 7.33 | 7.66 | 10.13 | 10.99 |
| Evenness | . 83 | . 79 | . 77 | . 76 | . 78 |
| \# of censuses | 23 | 12 | 50 | 85 | 85 |
| \# of individual birds | 364 | 152 | 332 | 848 |  |
| Average birds/census | 15.83 | 12.67 | 6.64 | 9.98 |  |
| 2010-2018 Only |  |  |  |  |  |
| Richness | 54*** | 19** | 33* | 59*** | 59*** |
| Diversity (Shannon) | 3.54*** | 2.81*** | 2.88*** | 3.56*** | 3.55*** |
| Dominance (Simpson) | 26.24*** | 15.04*** | 10.46* | 24.69*** | 24.30*** |
| Evenness | .89*** | .96*** | .83* | .87*** | .87*** |
| \# of censuses | 32 | 7 | 28 | 67 | 67 |
| \# of individual birds | 605 | 37 | 179 | 821 |  |
| Average birds/census | 18.90 | 5.29 | 6.39 | 12.25 |  |

Table 3 presents the main results of dividing the data into the two broad time periods and examining the change in biodiversity over time. The first three numerical columns show the data separately in Areas $A+B, C$ and $D+E$. The last two columns show the unweighted and weighted "All Area" biodiversity measures. It is clear from all columns in Table 3 that the avian biodiversity of EBMUD's horse-logging areas has increased substantially over time. For each of
the four biodiversity measures shown, all show increases over time in each of the columns. Indeed, the null hypothesis of no significant increase over time is rejected statistically for all four of the species diversity measures, using the bootstrap method, in all columns. ${ }^{19}$ Normal practice is to consider highly significant any p -value less than $1 \%$ (denoted ${ }^{* * *}$ in the table), significant any $p$-value less than $5 \%$ (denoted ${ }^{* *}$ ), and weakly significant any $p$-value less than $10 \%$ (denoted ${ }^{*}$ ).

Looking at the area components in the first three columns, by level of significance the increases appear strongest in Area $A+B$, next strongest in Area $C$, with Area $D+E$ showing less sizable but still statistically relevant increases. It is also true that within each period, Area $A+B$ is generally the most diverse, Area $D+E$ the least diverse, and Area $C$ in the middle. Thus it does appear that the increases in biodiversity are occurring throughout the horse-logging area, but are strongest in the southern-most sections. Looking at the whole area calculations in the last two columns, as expected the weighting correction does result in modest increases in the diversity indices for the 2002-2009 period, but only very minor changes in the 2010-2018

[^13]period. Even after making the weighting corrections, all indices show highly significant increases over time.

Note that there are significant increases in Richness. As pointed out earlier, Richness itself cannot be compared across observations that have unequal sampling efforts (number of censuses in the early and later periods). Table 3 reports the standard way of comparing Richness by computing Menhinick's Index for each of the two time periods, and then performing a bootstrap test to see if the difference between them is significant. ${ }^{20}$ The Area C test provides a good illustration. The ordinary Richness measure, the number of species recorded, declined from 26 to 19 . But there were a good number more censuses conducted in the early period (12 versus 7). Menhinick's Index is 2.109 for the early period, whereas it increases to 3.124 for the later period (reversing the direction of change from the raw numbers that take no account of the differential sampling effort). The difference of 1.015 is tested to see if it has statistical significance. Based on the 10,000 bootstrap replications that assume the null hypothesis, there were only 306 instances in which the replicated difference was equal to or greater than the observed difference. In other words, there is only a .0306 chance ( $p$-value) that a difference as large as 1.015 could occur if the 2010-2018 period really had no greater richness than the earlier period. Richness in Area C has increased significantly ( $p<.05$ ). Table 3 also reports a highly significant increase in Richness for Area $A+B$, and a weakly significant

[^14]increase for Area $D+E$. Thus Richness has increased throughout the horse-logging area, and the overall increase to 59 species versus 51 in the earlier period (which had more censuses) is a reasonable aggregate indicator. ${ }^{21}$

Richness is primarily about the number of species, but does not distinguish between equally "rich" communities in which one has $90 \%$ of the birds belonging to one species and another in which no species has more than $10 \%$ of the birds. The other measures, like the Shannon index of Diversity, are designed to account in some way for the relative abundance of each species. In this study, the 2010-2018 period shows highly significant increases in the Shannon Diversity Index overall and in all component areas, including Area D + E. The Simpson Dominance index can also be tested for differences across the two time periods, and it shows highly significant increases overall and in Areas A + B and in Area C, with a weakly significant increase in Area $D+$ E. It is interesting that the increase in Area $\mathrm{D}+\mathrm{E}$ in the Simpson Index is not as strong as the increase in the Shannon Index. The Simpson Index is less sensitive to Richness change and more sensitive to differences in the equality of abundance across species.

Finally, we have the Evenness measure which, like the Simpson Index, shows highly significant increases overall and in Area $A+B$ and Area $C$, with a weakly significant increase in Area $D+E$.

[^15]Thus for all four of the species diversity measures, the 2010-2018 period shows significant increases in avian biodiversity. This conclusion holds for the overall area (with and without the weighting correction) as well as for the subarea components.

While these diversity changes are the prime focus of this study, we offer a brief comment about overall abundance. This issue has risen to prominence since the 2019 publication of a major new study in Science that finds the North American bird population has declined by $29 \%$ since 1970. ${ }^{22}$ Area census surveys are not normally used to estimate absolute bird populations; this is the province of the larger-area point-count surveys like those discussed earlier, and for smaller areas the much more labor-intensive mist-net studies often involving bird banding and enumeration. However, given the length of our data series and knowledge of the land area covered (6.9 acres), it is interesting to see what the data imply about abundance. They are inconclusive about any change in overall abundance, but perhaps the figures might serve as a crude benchmark for comparison with other studies. Although the survey reports more birds/census and birds/acre in the more recent period, this is due in good part to the uneven sampling of areas across the two periods. To correct abundance numbers for this uneven sampling, we use the same corrective weighting as explained previously to calculate the average number of birds across all five areas (giving equal weight to each area). This is simply the sum of the average number of birds reported in each area:

Weight-corrected Average Number of Birds All Areas 2002-2009: 57.88 (or 8.39/acre)
Weight-corrected Average Number of Birds All Areas 2010-2018: 55.91 (or 8.10/acre)

[^16]The difference between these two numbers is very small, and the decrease is due completely to the decline in birds per census in Area C from 12.67 to 5.29 , with the latter figure coming from only 7 censuses. Put differently, based on an equal weighting of the much more heavily sampled areas A, B, D and E, the average number of birds excluding Area C would increase over time from 45.21 to 50.62 or from 9.04/acre to 10.12/acre. So we regard the evidence as inconclusive about any true trend in overall abundance. The numbers suggest there were roughly 8-9 birds/acre in the early period, and with more uncertainty, perhaps 8-10 birds/acre in the more recent period as a reasonable interpretation. ${ }^{23}$

There are reasons to believe that, at least to some extent, the absolute counts above are underestimates of the true population. For example, recall some of the reasons discussed earlier why the raw counts from the BBS surveys are adjusted upwards in making population estimates. One bird heard singing is assumed to be a male accompanied by an undetected nonsinging female, so that the raw counts are doubled (the standard "pair adjustment"). In the Area Censuses, there are birds detected by song alone, so perhaps they have unheard and unseen partners. As another example, the surveyors during 2010-2018 often reported hearing the calls or songs of several California Quail, although these birds are typically in a flock that could number 10-12 and hide when they perceive some intrusion. The raw point counts from

[^17]the BBS surveys are also generally adjusted upwards unless they occur at the peak time for singing, with the adjustment factor increasing the further the actual time of the count is from the peak. Not all of the Area Census surveys occur at the peak, so they may also miss some of the birds that have become quieter and less active than during the peak. Still, keeping in mind that the search areas have deliberately been kept small so that visual observation is far more likely than in the BBS surveys, the raw survey counts may only have a relatively small degree of underestimation.

## Time Trends: Observations about Specific Species

To give more meaning to the aggregate numbers above, it is helpful to look in a bit more detail at changes at the species level. For example, the overall increase in richness of 8 species arises in the following way. There were 16 species not seen at all in 2002-2009 but seen in 2010-2018. There were 8 species seen in 2002-2009 but not seen at all in 2010-2018. Table 4 shows both sets of species, and the numbers observed of each.

Table 4: Species observed in only one of the two time periods

| Species only in 2002- <br> 2009 | Number Observed | Species only in 2010- <br> 2018 | Number Observed |
| :--- | :--- | :--- | :--- |
| Double-crested <br> Cormorant | 6 | California Quail |  |
| White-tailed Kite | 4 | 70 |  |
| Barn Swallow | 3 | Tree Swallow | 25 |
| Wilson's Warbler | 3 | Western Bluebirda,b | 20 |
| Cliff Swallow | 2 | Wild Turkey ${ }^{\text {a }}$ | 14 |
| Cooper's Hawk | 2 | Ash-throated <br> Flycatcher | 11 |
| Osprey | 2 | Band-tailed Pigeon | 11 |
| Rufous Hummingbird | 1 | Orange-crowned <br> Warbler | 8 |


|  |  | Swainson's Thrush | 5 |
| :--- | :--- | :--- | :--- |
|  |  | American Crow | 3 |
|  |  | Hutton's Vireo | 3 |
|  |  | Snowy Egret | 2 |
|  |  | Mallard ${ }^{\text {a }}$ | 1 |
|  |  | Red-winged Blackbird | 1 |
|  |  | Violet-green Swallow | 1 |
|  | Wood Duck | 1 |  |

${ }^{\text {a }}$ Photographed in Area A, ${ }^{\text {b }}$ Photographed in Area B

Probably the most spectacular change is the strong prevalence of the California Quail, not present at all in 2002-2009 but with 70 observations of them in 2010-2018. This is likely the result of the growing grasses and shrubbery that provide suitable habitat for them. Very similarly, the Wild Turkey also likes tall grasses to hide itself in, and that is surely a factor in the observation of 14 during the 2010-2018 censuses compared to none in the earlier period. Like the Quail and Turkey, the Western Bluebird is a year-round resident in the Bay Area. But unlike them, it prefers an open wooded habitat, perching on low branches near grass while foraging. It appears that the gradual thinning of the horse-logged areas, as the Monterey pines slowly give way, has attracted this species. The Tree Swallow is another resident that seems to be finding the horse-logging area newly attractive. ${ }^{24}$

It is especially important to note the new presence of the Ash-throated Flycatcher, the Orangecrowned Warbler, and the Black-headed Grosbeak. All three of these species are migrating birds that return to the Bay Area each spring in order to breed, and then fly north in the fall. They can only do this if they have suitable habitat in both their summering and wintering areas.

[^18]None of these species can be described as abundant in the Bay Area, so that suitable habitat is a very important resource for them, and it seems like the horse-logging area is becoming more welcoming to them.

It is also worth noting that, of the species observed only in the earlier time period, none of them were observed very often. The Double-crested Cormorant is a water bird and it was observed 6 times, largely flyovers; it continues to be easily observed at the San Pablo Reservoir itself. Three of the other species are raptors that were observed a few times each: White-tailed Kite, Cooper's Hawk and Osprey. The raptors generally hunt over fairly large territories, so there may be no special significance to the lack of sighting of these particular raptors during the 2010-2018 censuses. Red-tailed Hawks had the same abundance in each period, while Redshouldered Hawks had a somewhat increased abundance in 2010-2018. The Osprey, like the Cormorant, has been observed numerous times in recent years at the San Pablo Reservoir. The Cooper's Hawk has been observed breeding on abutting EBMUD lands in recent years, and similarly the Cliff Swallows have a healthy breeding colony that nests each spring and summer (at least through 2019) at the bottom of the Briones spillway (also adjacent EBMUD land). The only somewhat puzzling observation is that of the Wilson's Warblers: they are still frequently observed on the EBMUD lands adjacent to the horse-logging sites, and I would have expected more sightings of them during the censuses as the land gradually regenerates with native vegetation.

Figures 2 a and 2 b provide another way of examining the changing biodiversity between the two time periods. Figure 2a shows a chart of the 10 most abundant species per census in the 20022009 period, whereas Figure 2 b shows the equivalent chart for the 2010-2018 period. We use these charts to look for changes in the relative abundance of species, and caution that they must be used carefully. One species, for example, might drop in its ranking even if exactly the same number of members are observed in each period. Or note that the top species in both charts is the Dark-eyed Junco, even though its absolute abundance has fallen from 2.6 individuals per census to 1.4. The charts are designed to show the relative prevalence of one species to another.

Perhaps most importantly, note visually how close the bars in each chart are to one another. In the early period, the bars are more spread out, whereas they are closer in size to each other in the more recent period. This is showing us the increased biodiversity in a slightly different way: the top 10 species in abundance are sharing the areas more equally in the recent years than in the earlier ones.

There has been substantial change in terms of which species are in the top 10, although it is not obvious how to interpret this. Comparing these two charts, we see that four species are among the most abundant in both time periods (Dark-eyed Junco, Chestnut-backed Chickadee, Mourning Dove and House Wren). No longer among the most abundant species are the Pacificslope Flycatcher, Steller's Jay, Red-breasted Nuthatch, California Towhee, Nuttall's Woodpecker and Brown Creeper. They have been displaced from the top of the abundance rankings by the

Figure 2a: Abundant Species 2002-2009


Figure 2b: Abundant Species 2010-2018


California Quail, House Finch, Canada Goose, Acorn Woodpecker, Tree Swallow and Lesser Goldfinch. To some extent, this is purely a relative phenomena, for example, there is little change in the absolute abundance of the Brown Creeper (. 24 individuals/census early, .19 recent) or the California Towhee (. 32 early, .30 recent) across these periods. On the other hand, there has been a real increase in the abundance of the Acorn Woodpecker (. 07 early, . 45 recent), but this mirrors pretty well the increase in its abundance throughout Contra Costa County for the same time periods (.20-. 30 per eBird checklist during May and June of the early years, compared to .70-1.20 during May and June of the more recent years).

Finally, five of the species observed during the survey deserve special attention because they are on federal and California lists of conservation concern. ${ }^{25}$ These species, without additional conservation actions, are those at risk of becoming listed under the Endangered Species Act. The five species are Allen's Hummingbird, Rufous Hummingbird, Nuttall's Woodpecker, Olivesided Flycatcher, and Oak Titmouse. The two hummingbird species are migratory and were only seen rarely during our survey, with one sighting of each in the 2002-2009 period and one sighting of the Allen's in the 2010-2018 period. No trend is discernible from this.

[^19]There are trends with the other three species. Both the migratory Olive-sided Flycatcher and the resident Oak Titmouse have been observed more frequently during the most recent period: the Olive-sided has gone from 3 to 11 individuals observed, and the Oak Titmouse from 1 to 6 individuals. This is good news. On the other hand, the resident Nuttall's Woodpecker was seen much more frequently during the early 2002-2009 period (26 individuals) than in the 2010-2018 period (4 individuals). This is likely due to the significant influx of another resident, the Acorn Woodpecker. The Acorn is twice the weight of the Nuttall's, and while both species are partial to oak, the Acorn may be better adapted to the pine-oak mixture that characterizes the horselogging area during its transition. ${ }^{26}$

This discussion of specific species has sought to be informative, particularly in terms of the types of residential and migratory species that have become increasingly attracted to the horse-logging area as it regenerates. It is also possible that the discussion will be helpful in causing us to refocus upon the central question: is the general increase in avian biodiversity that we have observed due to EBMUD's decision to allow the horse-logging area to return gradually and naturally to its native oak woodland roots? It may be tempting to think otherwise. I have stated, for example, that the increase in Acorn Woodpeckers observed here is part of a broader regional phenomenon. Perhaps the Wild Turkey also fits that pattern, and other species as well. If so, then the biodiversity increase we have observed would not be due

[^20]to EBMUD's decision. However, one cannot answer this question by reference to a few species; one must seek more general evidence. Let us consider more carefully possible alternative explanations for the biodiversity increase.

## Alternative Explanations for the Results of Increased Biodiversity?

The hypothesis of interest in this study is whether EBMUD's managerial decision to allow the horse-logging areas to return gradually to their native oak woodland habitat has caused the increase in biodiversity that we have documented. Could these results be due to something other than this treatment effect? We consider, but find reason to reject, two alternative explanations. One very plausible alternative explanation is that the diversity increase we have observed is a more general phenomenon that has happened both in the horse-logging areas and in the surrounding environments. A second alternative explanation is if the results themselves could somehow be an artifact of the survey methodology—perhaps, for example, if the surveyors in the more recent period were more experienced bird detectors than those in the earlier period? We consider in turn each of these two alternative explanations, a broader diversity increase in the immediate region and variation in surveyor bird detection ability.

## Alternative Explanation \#1: Is Diversity Increasing in the Immediate Region of the Horse-logging Area?

One alternative explanation for the results found here could be that they are part of a general trend in the region and have nothing to do with EBMUD's policy of allowing the horse-logging
area to gradually return to its native habitat. That is, perhaps the general area surrounding the EBMUD lands has experienced a similar diversity increase over the same time period. However, there is reasonable secondary evidence available to reject this possible explanation. I mentioned earlier the Moraga Breeding Bird Survey (BBS) sponsored by the U.S. Geological Survey. Figure 3 shows a map of the Moraga BBS relative to EBMUD's horse-logging area. They are very close to one another: a good portion of the BBS Survey parallels the west side of the San Pablo Reservoir, just across from the horse-logging area on the east side of the Reservoir. Public data from the Moraga BBS begins in 1998. It is intended to be conducted annually, with actual survey results available for 12 years through 2015. If there has been a trend of increasing avian diversity in the general area, it should show up in the results of the Moraga BBS.

Figure 4 shows a key graph taken from the Moraga BBS Data Summary (available through the California Avian Data Center hosted by Point Blue Conservation Science). The Data Summary offers the same four measures of diversity as analyzed in this study, although these results are aggregated over all twelve years and all 50 points or transects of the Survey. But for the Richness measure (109 species in the aggregate), the Summary provides annual data on the Mean Species Richness/point. Figure 4 shows a graph of this data. It is quite clear that the trend was generally of increasing richness from 1998-2005, no data for 2006-2008, but a sharp falloff in 2009 and 2010, with a further falloff in the last three years of 2011, 2014 and 2015. In numerical terms, the Mean Species Richness/point was generally between 9 and 10 from 19982005, but only between 5 and 6 from 2011-2015, a substantial decrease.

Figure 3: Map of Moraga Breeding Bird Survey Route Relative to EBMUD Horse-logging Area


While there is no direct comparison of these numbers with our data, a close relative comparison is to calculate from our data the Mean Species Richness/census. We do this for our two periods to show that the trend is the opposite from the Moraga BBS. In the EBMUD horselogging areas, the unweighted 2002-2009 Mean Species Richness per census is 5.39 , whereas it is 6.96 in the later 2010-2018. These numbers overstate the increase somewhat due to the
unequal sampling of areas across the two time periods, but this can be corrected as we did previously by adjusting the weights so that each area counts equally. The weighting-corrected calculation leads to the same conclusion: Mean Species Richness is 6.12 in 2002-2009, increasing to 6.42 for 2010-2018. In other words, over approximately the same time frame the Richness/point is decreasing substantially in the Moraga BBS while the Richness/census is increasing in the nearby EBMUD horse-logging area. This supports the key hypothesis: avian diversity has increased over time in the EBMUD horse-logging area because of EBMUD's decision to allow these areas to return gradually to their native habitat.

Figure 4: Moraga Breeding Bird Survey, Annual Mean Species/Point, 1998-2015


## Alternative Explanation \#2: Could the Diversity Increase Be An Artifact of the

## Surveyors?

Recall that area census surveys assume all birds are detected accurately within each area, so here we are questioning that assumption. Surveyors may vary in terms of their bird identification skills, and perhaps those with more limited skills are also more cautious in terms of their identifications. Still, if there are many surveyors and they are distributed randomly throughout, differences among them would not cause the result of increased diversity over time that we have observed. Similarly, if the same group of individuals perform the surveys in both the earlier and more recent periods, then it is also very unlikely that there would be detection differences between the two groups. ${ }^{27}$ While neither of these conditions hold for our entire survey sample, they can be said to hold for substantial subsamples. Therefore we can check these subsamples to see if they show diversity increases over time. If they do, then we can reject the hypothesis that the increases for the whole horse-logging area are primarily artifacts of different detection abilities among the surveyors.

It turns out that we have two subsamples that meets these surveying conditions. Areas D and E provide the simplest subset, in that these two areas have been surveyed by the same surveyor in both time periods. Areas A + B also form a subset with an unbiased pattern of surveyors. These two areas have been surveyed by multiple surveyors, 7 different surveyors during 2003-

[^21]2009 and 5 different surveyors in 2010-2018 (4 overlapping with the earlier period). Both the multiplicity and overlap of surveyors for these two areas also makes it unlikely that there will be any average difference in surveyor bird detectability across the time periods. Thus we have two subsamples that should not vary in surveyor detection abilities across the two time periods, and we can examine the change in diversity observed in each. The only data not being used here are the surveys in Area C, because one individual did the lion's share (8) of the 12 surveys in the earlier period, whereas a different individual did all 7 of the surveys in the more recent period. This does not mean, of course, that the results in Area C are due to detection differences over time; this area simply cannot be tested for this.

Table 3 already reports the diversity measures calculated separately for the combined area $A+B$ (multiplicity of surveyors with substantial overlap across the time periods) and for the combined area D+E (single surveyor for all of the censuses). As we have seen, both of these combined areas show statistically relevant diversity increases over time in all four measures. Since these areas also represent surveying by "equal surveyor teams" across the two time periods, we can reject the alternate hypothesis that our findings of increased avian biodiversity could be due to unequal surveyor abilities over time. These results also support the key hypothesis: the gradual regeneration to native oak woodland is driving the increase in avian diversity in the EBMUD horse-logging land.

There is some additional evidence worth mentioning that also supports rejecting the alternative explanation that variation in surveyor bird detection abilities could explain the result of
increasing diversity over time. For this alternative explanation to be true, there would have to be some combination of under-reporting in the earlier period and/or over-reporting in the later period. However, consider some of the species that were fairly common in the later period and not seen at all in the early period. The California Quail and the Wild Turkey are among the species that are most easy to detect, both visually and by call-it is simply not plausible that these species were actually there during the early period and simply missed by all of the surveyors. Somewhat similarly, the Western Bluebird and the Ash-throated Flycatcher were detected by multiple surveyors in the more recent period, and for that reason it seems unlikely that multiple earlier surveyors would have missed them if they were actually there-especially when these same surveyors were successfully observing the Pacific-slope Flycatcher, somewhat harder to detect than its vocal and larger cousin the Ash-throated Flycatcher and the colorful Western Bluebird.

In terms of possible over-reporting in the more recent period, recall that Table 4 footnotes a number of the species seen only in 2010-2018 for which there is supplemental photographic evidence. Pictures of these birds in the Census areas during the survey periods rule out the possibility that they were not there (e.g. if a Spotted Towhee were mistaken for a Black-headed Grosbeak). In fact there are photographs of many of the species in Areas A and B from the 2016 - 2019 breeding seasons, documenting their presence in addition to the survey reports. These photographs are included as Appendix D to this report. In sum, the available evidence supports the hypothesis of the treatment effect and does not support the alternative artifactual explanation.

## Conclusion

The data in this analysis show a healthy increase by multiple measures in the biodiversity of the avian population in the EBMUD horse-logging areas over the years 2002-2018. Furthermore, this increase does seem due to the EBMUD managerial policy of allowing these areas gradually and naturally to return to their native oak woodland. Alternative explanations for the increase, either based on a broader regional increase in diversity or an artifact caused by differences in surveyor detection abilities, are not supported by the available evidence. EBMUD's management strategy has been effective with regard to the biodiversity of the avian population. More generally, the evidence in this study supports the idea that native vegetation promotes biodiversity.

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# Appendix A: Original PRBO Area Census Instructions 

PRBO<br>AREA SEARCH CENSUS<br>INSTRUCTIONS<br>May 1999

Background:
Recently adopted for the Australian Bird Count as a follow up to their completed Breeding Bird Atlas, area search censuses are time constrained bird censuses, similar to a "Christmas Bird Count" or repeated "breeding bird atlas" census. However, area search censuses differ significantly in that the census areas are defined by habitat rather than by political boundaries. This allows bird relationships to be determined and land management techniques assessed. This method is also ideal for volunteers and observers with limited identification skills. Observers are able to interact, compare notes, and chase down unfamiliar species or sounds. It is ideal for recruiting new observers in that it requires little training and allows skilled observers to train new observers. Non-birders may even participate by serving as recorders or tallying obvious species.

## 1. Choosing a site:

Any site containing a definable habitat may be chosen for a census. Riparian, oak woodland, grassland, coastal scrub, chaparral, and coniferous forests are current priority habitats of California Parmers in Flight. Area searches can be done in any habitat, Important Bird Area (IBA), or site where bird information is needed.

Each site generally consists of three separate plots or "search areas". For those of you setting up your own sites, each site should be registered with PRBO (using Table 1) and defined according to its current land use or habitat criteria (e.g. grazing, controlled burning, recreational park land, mixed riparian woodland, etc.). Habitat criteria will initially follow classifications in "California Statewide Wildlife Habitat Relationships System" (WHR) (A guide to wildlife habitats of California, 1988. K.E. Mayer and W.F. Laudenslayer editors, available from California Department of Fish and Game, CA), and/or from A Manual of California Vegetation (J.O. Sawyer and T. Keeler-Wolf, 1995). Contact PRBO if more information is needed.
2. Choosing a plot (or search area):

All search areas at a given site should be the same size and of the same habitat type. Avoid mixing habitat types, or standing water (i.e. lakes), or areas of high human activity. Standard protocol recommends 3 search areas within a given site. However, each site may have anywhere from 1 to 12 search areas, depending on volunteer availability and land access. For forested habitats, each plot should be about 3 hectares (e.g. 150 m by $200 \mathrm{~m} ; 1$ hectare $=100 \mathrm{~m}$ by 100 m ). Larger areas can be used in more open habitats (up to 10 hectares). The size of the plot should be such that it can be easily covered and birded thoroughly over a 20 minute period, and this is the most useful criteria in setting up the size of your plots. Plots may be of any shape. The different plots may have adjoining boundaries. In general the plot boundaries should be at least 25 meters from edges or different habitats; however this is frequently impossible, especially in riparian habitat, it is usually only the rule for areas containing continuous habitat. Plot boundaries should be planned and marked using permanent geographic features so that they can be relocated in subsequent visits, seasons and years, and often by different observers. These boundaries should be described in detail, and if necessary a map clearly delineating these boundaries and the plots should be made.

## 3. Conducting a census:

Each area search plot is covered in 20 minutes during a census (some exceptions may apply, i.e. 30 minute censuses). Typically 3 plots should be covered in a single moming. In general, observers cover the entire plot in the time allotted. Observers are free to stop the area search (and the clock) to investigate songs, calls, or breeding activity. This may be necessary for identifying species you are not familiar with. Do not be distracted or spend too much time looking for rare birds or nests (if you are doing nest searches, do them after the census).

Number of Observers: Number of people involved in conducting the census. Ideally should be only one or possibly two.

Start Time: Time the 20 minute census was begun.
End Time: Time the census was completed. Is not always 20 minutes after start time as interruptions may occur. Indicate below why it is not 20 minutes (i.e spent 5 minutes tracking down a bird, etc.)

Species: Use current 4-letter code from the AOU checklist as well as subspecies if discernible. If you do not know the 4 letter code please write name in full.

Tally of Individuals: Put an $S$ (song), V (visual), or $C$ (call) for each individual encountered in the following priority:

Priority is S, V, C. For example, if you first see an individual (V) then later during the census hear it call ( $C$ ), and after a few minutes hear it sing ( $S$ ), the only code recorded on the form in the end for this individual would be an S . If you hear a bird sing $(\mathrm{S})$ then see it $(\mathrm{V})$, the only code recorded would be an $S$.

Total: After each area search is complete, tally the total number of individuals of each species encountered.

Behavior: Check each column if any individual of the species is observed doing the following:
Forag: Foraging observed
Flock: Bird observed in a flock
Copul: Copulation observed
Displ: Breeding display observed
Pair: 2 birds believed to be a mated pair observed; courtship behavior observed
Mater. Carry: Individual observed carrying nest material
Food Carry: Individual observed carrying food or fecal sac
Nest: Active nest found.
Fledg: Dependent fledgling observed (being fed by adults, begging, with fledgling-length tail)
Notes and flyovers: Flyovers (birds flying above and not through the plot) are recorded here, as can be birds detected outside of the boundaries of the plot, and any other information deemed pertinent, including nest predators.

Other Observers: Give the names of the observers whose personal information is not filled out above.

# PRBO East Bay Area Search Codes 

## Station (Park) Codes

Tilden Regional Park: TIRP
Wildcat Regional Park: WCRP
Redwood Regional Park: RERP
Briones Regional Park: BRRP
Sibley Volcanic Regional Preserve: SIRP
Anthony Chabot Regional Park: ACRP
Joaquin Miller Park: JQMP
East Bay Municipal Utilities District Lands (excluding horse-logged oak woodland regeneratioin sites): EBMU
EBMUD Horse-logged Oak Woodland Regeneration Sites: OWRE

## Region (County) Codes

Alameda County: ALAMED
Contra Costa County: CONTRA

## Species Codes

Please use the species codes on the attached list, "Four letter codes and species list for birds detected in E-Bay surveys" If species does not appear in list, contact PRBO, or review the full list online at:
http://www.pwrc.usgs.gov/bbl/manual/bandsize.htm

## Area Search Cheat Sheet

Helpful hints to remember about conducting a census.

1. Area search censuses last 20 min !
2. Counts should be finished within 3 hours of sunrise. The earlier the better!
3. Each individual bird detected should be recorded with one and only one letter.
4. If you are doing only 3 visits to your plot, try to have one in May, one in June, and one in July, with equal spacing. If you are conducting more then three visits, space visits at least 2 weeks apart.
5. Things to bring:

Extra pen
Binoculars
Clip board
Hat
Sunscreen
Water
Data sheets

Four letter codes and species list for birds detected in E-Bay surveys (page 1/2)

| Species |  | CODE | TIRP | WCRP | RERP | Other | EBMU | JQMP |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Mallard | Anas platyrhynchos | mall |  |  | X | X |  |  |
| Cooper's Hawk | Accipiter cooperii | coha | X | X |  |  |  |  |
| Red-shouldered Hawk | Buteo lineatus | rsha |  |  |  |  |  | X |
| Red-tailed Hawk | Buteo jamaicensis | rtha |  | X | X |  | , |  |
| California Quail | Callipepla californica | caqu | X | X | X | X | X |  |
| Mourning Dove | Zenaida macroura | modo | X | X | X |  | X |  |
| Great Horned Owl | Bubo virginianus | ghow | X |  |  |  |  |  |
| Anna's Hummingbird | Calypte anna | anhu | X | X | X | X | X | X |
| Rufous Hummingbird | Selaphorus rufus | ruhu | X |  |  |  |  |  |
| Allen's Hummingbird | Selaphorus sasin | alhu | X | X | X |  |  |  |
| Northern Flicker | Colaptes auratus | nofl | X |  | X |  | X |  |
| Nuttall's Woodpecker | Picoides nuttallii | nuwo | X |  |  | X | X |  |
| Downy Woodpecker | Picoides pubescens | dowo |  | X |  | X |  |  |
| Hairy Woodpecker | Picoides villosus | hawo | X |  | X |  |  | X |
| Olive-sided Flycatcher | Contopus cooperi | osfl | X |  |  |  |  |  |
| Western Wood Peewee | Contopus sordidulus | wewp | X | X |  |  |  |  |
| Pacific-slope Flycatcher | Empidonax difficilis | psfl | X | X | X | X | X | X |
| Black Phoebe | Sayornis nigricans | blph | X | X |  | X |  |  |
| Ash-throated Flycatcher | Myiarchus cinerascens | atfl | X | X |  |  |  |  |
| Western Kingbird | Tyrannus verticalis | weki |  | X |  |  |  |  |
| Hutton's Vireo | Vireo huttoni | huvi | X | X | X | X | X | X |
| Cassin's Vireo | Vireo cassinii | cavi | X |  |  |  |  |  |
| Warbling Vireo | Vireo gilvus | wavi | X | X | X | X | X |  |
| Steller's Jay | Cyanocitta stelleri | stja | X | X | X | X | X | X |
| Western Scrub Jay | Aphelocoma californica | wesj | X | X | X | X | X |  |
| Common Raven | Corvus corax | cora | X |  | X |  |  |  |
| Horned Lark | Eremophila alpestris | hola |  |  |  | X |  |  |
| Tree Swallow | Tachycineta bicolor | tres |  | X |  |  |  |  |
| Violet-green Swallow | Tachycineta thalassina | vgsw | X | X |  |  |  |  |
| Barn Swallow | Hirundo rustica | bars |  |  |  | X |  |  |
| Wrentit | Chamaea fasciata | wren | X | X | X | X | X | X |
| Oak Titmouse | Baeolophus inornatus | oati |  | X | X | X | X |  |
| Chesnut-backed Chickadee | Poecile rufescens | cbch | X | X | X | X | X | X |
| Bushtit | Psaltriparus minimus | bush | X | X | X | X | X | X |
| White-breasted Nuthatch | Sitta carolinensis | wbnu |  |  |  |  |  | X |
| Red-breasted Nuthatch | Sitta canadensis | rbnu | X |  | X |  |  |  |
| Pygmy Nuthatch | Sitta pygmaea | pynu |  |  | X |  |  | X |
| Brown Creeper | Certhia americana | brar | X |  | X |  | X |  |
| Bewick's Wren | Thryomanes bewickii | bewr | X | X | X | X | X |  |
| House Wren | Traglodytes aedon | howr | X | X | X |  |  |  |
| Ruby-crowned Kinglet | Regulus calendula | rcki |  |  |  | X |  | X |

Four letter codes and species list for birds detected in E-Bay surveys (page 2/2)

| Species |  | CODE | TIRP | WCRP | RERP | Other | EBMU | JQMP |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Blue-gray Gnatcatcher | Polioptila caerulea | bggn | X |  |  |  |  |  |
| Western Bluebird | Sialia mexicana | webl | X | X |  |  |  |  |
| Swainson's Thrush | Catharus ustulatus | swth | X | X | X |  | X |  |
| American Robin | Turdus migratorius | amro | X |  | X | X | - |  |
| Northem Mockingbird | Mimus polyglotios | nomo |  |  |  | X |  |  |
| Califormia Thrasher | Toxostoma redivivum | cath | X |  |  |  |  |  |
| European Starling | Sturrus vulgaris | eust |  | X |  |  |  |  |
| Orange-crowned Warbler | Vermivora celata | ocwa | X | X | X | X | X | X |
| Yellow-rumped Warbler (audubon's/myrtle warbler) | Dendroica coronata | auwa/mywa unkn=uyrw |  |  |  |  |  | X |
| Townsend's Warbler | Dendroica towsendi | towa | X |  | X |  |  |  |
| Yellow Warbler | Dendroica petechia | ywar | X |  | . |  | X |  |
| MacGillivray's Warbler | Oporornis tolmiei | mgwa | X | X |  |  |  |  |
| Wilson's Warbler | Wilsonia pusilla | wiwa | X | X | X | X | X | X |
| California Towhee | Pipilo crissalis | calt | X | X | X | X | X |  |
| Spotted Towhee | Pipilo maculatus | spto | X | X | X | X | X | X |
| Lark Sparrow | Chondestes grammacus | lasp |  |  |  | X |  |  |
| Grasshopper Sparrow | Ammodramus savvanarum | grsp |  | X |  |  |  |  |
| Song Sparrow | Melospiza melodia | sosp | X | X | X | X | X | X |
| Dark-eyed Junco | Junco hyemalis | deju | X | X | X | X | X | X |
| Black-headed Grosbeak | Pheucticus melanocephalus | bhgr | X | X | X |  | X |  |
| Lazuli Bunting | Passerina amoena | lazb | X | X |  | X |  |  |
| Western Meadowlark | Sturnella neglecta | weme |  |  |  | X |  |  |
| Red-winged Blackbird | Agelaius phoenicius | rwbl |  |  |  | X |  |  |
| Brown-headed Cowbird | Molothrus ater | bhco |  |  |  | X |  |  |
| Bullock's Oriole | Icterus bullockii | buor |  | X |  |  |  |  |
| Purple Finch | Carpodacus purpureus | pufi | X |  | X | X | X |  |
| House Finch | Carpodacus mexicanus | hofi |  | X |  | X | X |  |
| American Goldfinch | Carduelis tristis | amgo | X | X |  |  |  |  |
| Lesser Goldfinch | Carduelis psaltria | lego | X | X |  | X | X |  |

TIRP $=$ Tilden Regional Park
$\mathbf{W C R P}=$ Wildcat Regional Park
RERP $=$ Redwood Regional Park
Other = Briones Regional Park (BRRP), Sibley Volcanic Regional Preserve (SIRP), and Anthony Chabot Regional Park (ACRP)
EBMU $=$ East Bay Municipal Utilites District (EBMUD) lands
JQMP = Joaquin Miller Municipal Park

It is a good idea, whether you are conducting the census alone or with other observers, to walk through and explore the plot prior to the actual census. It helps to have a good sense of the borders of the plot so it can be thoroughly covered. The "time constraint" nature of area search censuses is an important feature; never extend your time to include "just a few good birds". Carefully record your starting time when you begin, stay aware of the time throughout the census to ensure both good coverage and correct timing, and keep track of any pauses you take in the 20 minutes. With groups it may be helpful to designate one observer as timekeeper. Additionally, please try to be sensitive to the subjects of your census and in particular do not stay too long near a nest or anywhere where birds are distress calling.

Begin by filling out the observer and census information at the top of the PRBO AREA SEARCH FORM. Only one address is needed although there may be additional observers; their names go on the bottom of the form. Complete the weather information, consulting the PRBO Area Search Code Key. During the census, carefully record the name of each species seen or heard on the plot in the species column. If you know the American Ornithologists' Union 4-letter code for the bird (e.g. WIWA for Wilson's Warbler) please use that, if not record the full individual name of the bird. Fill in the Total column for each species after the census is complete. Record data as described on the enclosed PRBO Area Search Code Key. For each individual of each species, record a single letter ( $\mathrm{S}=$ song, $\mathrm{V}=$ visual, $\mathrm{C}=\mathrm{call}$ ), in the order of priority explained in the code key. You should change the data, i.e. from a call to a song, if a higher priority observation later occurs for that individual. Recording any special behaviors (such as food carries, flocking, displaying), is strongly recommended but not required; there are respective columns on the form for these observations, following breeding bird atlas methodology. Other species not recorded in the 20 minutes, observed off the plot, or exhibiting interesting behaviors, may be recorded under Notes and Flyovers or on a separate sheet of paper (such as the "Off Census Bird List and Breeding Observations" form).

Observers: At least one observer should be able to identify by sight and sound most of the species likely to be encountered. Surveying the area prior to conducting a census is recommended. Observers not familiar with the birds, habitat or methods are encouraged to participate as recorders or counters of easily identified species. Up to 6 observers per plot is acceptable under certain circumstances, but 1 or 2 is preferable. During the census, observers should keep together, act as one observer, and record all observations on the same sheet by the designated recorder. Encourage beginners to come along and learn their local birds.

## 4. Frequency

3 plots should be done in a single morning. We recommend at least 2 , and ideally 3 , censuses of each plot during the breeding season; during the winter a single census may be adequate, while during the fall migration they should probably be conducted a minimum of once a week. The same exact plots must be censused annually, and at approximately the same time of year.

## PRBO Area Search Code Key <br> May 1999

Name and Address: Contact information for primary person conducting the area search.
Date and Visit \#: Day in which census is done, and corresponding visit number (1, 2, 3, 4 etc.)
Location: County in which area search is conducted.
Site: Specific name (two-letter code unique to the county) given to the site.
Plot \#: Consecutive number or letter given to the specific area search plot within the site.
Weather (Censuses should not be conducted in bad weather, which includes high winds):
Temperature: Celsius or Fahrenheit (specify) of temperature at time of census
Cloud Cover: Percent of sky covered by clouds
Wind Speed: mph, knots, or kmph (specify) of average wind speed during census

Appendix B
Historical (2002) and Current (2020) Google Earth Images of Survey Areas B, C, D and E (see text Figure 2 for Area A photos)

Area B 10/2002


Area B 6/2020


Area C 10/2002


Area C 6/2020


Area D 10/2002


Area D 6/2020


Area E 10/2002


Area E 6/2020


## Appendix C

## A Simple Illustration of the Unequal Sampling Problem and its Correction by Reweighting

This Appendix provides a simple numerical example of why unequal sampling of areas that comprise a larger whole give biased estimates of standard biodiversity indices like the Simpson, Shannon and Evenness indices used in this paper's analysis. It also shows how this can be corrected by reweighting the observations.

Suppose we are trying to measure the avian biodiversity in one territory comprised of two survey areas $A$ and $B$. The truth is that Area $A$ is inhabited by four pairs of birds, each of a different species (finch, sparrow, woodpecker, flycatcher). The truth is that Area B is inhabited by two birds, each a different species (sparrow, woodpecker). When a survey is done of either area, the observations correspond to the truth for that area.

Thus in the whole territory, there are 10 birds consisting of 3 sparrows, 3 woodpeckers, 2 finches and 2 flycatchers. The true Simpson's index for the territory is:
$=1 /\left[(3 / 10)^{2}+(3 / 10)^{2}+(2 / 10)^{2}+(2 / 10)^{2}\right]$
$=1 / .26$
$=3.846$

Suppose in conducting surveys there was only one visit to Area A and two visits to Area B, providing three observations (here representing the problem of unequal sampling). Then calculating Simpson's
index by using all three observations (ignoring the unequal sampling problem), we have a population of 12 birds consisting of 4 sparrows, 4 woodpeckers, 2 finches and 2 flycatchers and the index is:
$=1 /\left[(4 / 12)^{2}+(4 / 12)^{2}+(2 / 12)^{2}+(2 / 12)^{2}\right]$
$=1 / .556$
$=1.799$

In other words, ignoring the unequal sampling problem causes us to overweight the less diverse Area B and biases the index downwards.

The reweighting solution uses all three observations, but only utilizes the average result from each of the two areas. In Area A the one observation is the average for it, and in Area B the average per visit is to see 2 birds, 1 sparrow and 1 woodpecker. Calculating the Simpson's index based on these average observations is identical to our first calculation and results in the correct estimate for the territory.

The above illustration simplifies by removing any variation in what is observed per visit to each area. In more realistic examples, the average accurately summarizes the estimated bird distribution across species utilizing all observations made in the area, and its use in calculating the different diversity indices corrects for any unequal sampling of the areas within the territory.

## Appendix D

Photographs by Lee Friedman

Species Observed 2016-2019 during the Breeding Season in Areas A \& B
of the EBMUD Horse-logged Oak Woodland Regeneration (OWRE) Acreage

Red-breasted Nuthatch April 21, 2016 Area A


Dark-eyed Junco 4/28/2017 Area A


Pacific-slope Flycatcher May 10, 2016 Area A


California Towhee June 8, 2018 Area B


Chestnut-backed Chicadee 6/28/2016 Area A


Song Sparrow 4/28/2017 Area A


Mallards 4/26/2017 Area A


House Wren 5/24/2017 Area A


Nuttall's Woodpecker 6/27/2017 Area A


European Starling 4/21/2016 Area B


Pygmy Nuthatch April 19, 2016 Area B


Spotted Towhee May 27, 2016 Area B


Western Bluebird 4/27/2018 Area A


White-breasted Nuthatch 4/27/2018 Area A


California Quail 4/27/2018 Area B


Bewick's Wren 5/1/2018 Area B



Steller's Jay 5/1/2018 Area B



Black Phoebe 6/8/2018 Area A


Black-headed Grosbeak 5/28/2019 Area A


Ash-throated Flycatcher 5/30/2019 Area A


Red-tailed Hawk 5/30/2019 Area A


Wild Turkeys June 8, 2018 Area A


Violet-green Swallow April 28, 2017 Area B


Lesser Goldfinch May 30, 2019 Area B


House Finch April 27, 2018 Area A


Anna's Hummingbird May 30, 2019 Area B



[^0]:    ${ }^{1}$ Professor of the Graduate School and Professor Emeritus of Public Policy, University of California at Berkeley. Contact: Ifried6@comcast.net.
    ${ }^{2}$ The other sites are all part of the East Bay Regional Park District: Tilden, Wildcat Canyon, Redwood, Briones, Sibley, Chabot, and Joaquin Miller.
    ${ }^{3}$ The original PRBO Instructions for the Area Census surveys are attached here as Appendix A.

[^1]:    ${ }^{4}$ The original plots had their corners marked with small poles, most of which have disappeared over the years. However, Mark Lamoureaux had surveyed each of them when the poles existed, and has continued to survey them based on his personal knowledge of the plot areas. Jonathan Price of EBMUD, Mark and I went out to each area to record the GPS coordinates of each corner of each area. Those coordinates have been used to show the plots in Figure 1 and to calculate the area of each: Area A 1.5 acres, Area B 1.1 acres, Area C 1.9 acres, Area D 1.2 acres, and Area E 1.2 acres, for a total of 6.9 acres or $2.05 \%$ of the entire horse-logging area.

[^2]:    ${ }^{5}$ The acreage comes from an internal EBMUD document, "San Pablo Reservoir Monterey Pine Management Plan Outline," March 20, 2001.
    ${ }^{6}$ A report from an EBMUD contractor Bay Area Applied Mycology dated February 7, 2015 states that "EBMUD currently utilizes horses to haul fallen trees from their property." The report describes an alternative removal method. Beginning in 2012, EBMUD with Bay Area Applied Mycology began testing an alternative method on some of the fallen pines: injection with mushroom spawn to speed the natural decomposition while retaining water to prevent fire hazard. Testing was expected to continue for a decade. See the section "Mycoforestry: decomposition of felled pine" at http://bayareaappliedmycology.com/category/projects/.

[^3]:    ${ }^{7}$ See p. 2, Table 2 in Nur, Jones and Geupel, A Statistical Guide to Data Analysis of Avian Monitoring Programs, 1999, U.S. Department of Interior, Fish and Wildlife Service, BTP-R6001-1999. It suggests 10+ years of data are needed to use area search census data to determine population trends.

[^4]:    ${ }^{8}$ To the best of my knowledge, the survey in Areas A and B did not begin until 2003, so complete coverage through 2018 would mean 96 censuses. Surveys in Areas D and E, however, began in 2002 so complete coverage through 2018 would mean 102 censuses, or 198 for all four of the areas.

[^5]:    ${ }^{9}$ P. 1 of "PRBO Area Search Census Instructions May 1999" in Appendix A.

[^6]:    ${ }^{10}$ Reported online in "North American Breeding Bird Survey: Summary of Effort in 2018," dated April 2019 and available at https://www.pwrc.usgs.gov/bbs/results/summaries/Effort Summary of 2018.pdf.

[^7]:    ${ }^{11}$ Another adjustment is based on the surveyor-estimated distance of the bird from the point, with those in a closer band coming from a smaller area (weighted more heavily) than those from more distant bands. Similarly, there is a time-of-day adjustment-all raw counts at points below the peak count for a species are adjusted upward on the assumption that some birds have stopped singing and go undetected. For more details on these surveys and the adjustments used in making population estimates from them, see Blancher et al (2007).
    ${ }^{12}$ Each of these methods have appropriate uses. An interesting comparison of them by Nalwanga et al (2012), in a specific tropical farmland setting, finds that the "timed species counts" (area census survey) is easier than and as accurate as the point-count survey in that setting. For a general introduction to bird census techniques, see Gregory, Gibbons and Donald (2004).

[^8]:    ${ }^{13}$ Their precise definitions follow. Richness = number of different species. This measure takes no account of the abundance of each species. Diversity is measured by the Shannon index $=-\operatorname{sum}\left(\mathrm{P}_{\mathrm{i}}^{*} \ln \left(\mathrm{P}_{\mathrm{i}}\right)\right.$, where $\mathrm{P}_{\mathrm{i}}$ is the proportion of birds in the census that belong to species i. For a sample with a given number of individuals and species, the index (Diversity) increases as the individuals per species approaches equality. Dominance is measured by the Simpson index $=1 /\left(\operatorname{sum}\left(\mathrm{P}_{\mathrm{i}}{ }^{2}\right)\right)$. This index is 1 when all individuals are of the same species, and increases above 1 (is more diverse) the more species are present and the closer they are to equal abundance (e.g. 10 species each with 10 individuals have Dominance = 10, whereas 10 species with 91 of 100 individuals belonging to just 1 species has Dominance $=1.21$ ). This index gives heavy weight to the most abundant (or Dominant) species in a sample; the addition of a few individuals of new species does not change the index very much. Evenness = Shannon index/In(Richness). This is a number between 0 and 1, with the index higher as the relative abundance of each species approaches equality.
    ${ }^{14}$ The latter measure is calculated using the acreage for each of the five areas given in note 4 , with the overall average calculated by weighting each area by the proportion of censuses it contributed.

[^9]:    ${ }^{15}$ Note that the aggregated view is based on a slightly unequal sampling effort of the five different areas. Rather than each area contributing $20 \%$ of the censuses, Areas D \& E each contribute $26 \%$ while Area C only contributes $12.5 \%$. Areas A \& B each contribute just under $20 \%$.

[^10]:    ${ }^{16}$ See, for example, John P. Kelly, "A Comparison of Bird Use at the Mayacamas Mountains Audubon Sanctuary Before and After the September 2004 Fire," Audubon Canyon Ranch Technical Report 10-2-1, June 2010. See also Yik-Hei Sung, Ivan Wai-Lun Tse and Yat-Tung Yu, "Population Trends of the Black-faced Spoonbill Platalea minor: analysis of data from international synchronized censuses," Bird Conservation International, 2018, V28, pp. 157167.

[^11]:    ${ }^{17}$ See Appendix C for a simple illustration of the problem caused by unequal sampling, and the correction by reweighting.

[^12]:    ${ }^{18} \mathrm{~A}$ single surveyor learns and may acquire additional birding skills over time. However, ageing can also cause a decrease in skill over time, e.g. if hearing declines. A study by Farmer et al [2014] finds significantly fewer detections among older birders relative to younger ones. If this generalization were to hold for the current study, for which early surveyors were generally younger than those in the later years, it would mean that the observed increase in biodiversity in the more recent years is an underestimate.

[^13]:    ${ }^{19}$ The preferred method of testing is to use the bootstrap both because it makes no assumption about the nature of the underlying distribution and because large numbers of bootstrap replications (that determine its power) are now easy for modern computers. The test is to see how frequently differences as large as or larger than those actually observed occur assuming the null hypothesis of no difference across the periods. The bootstrap generates random samples from the actual data under the null hypothesis for both periods, calculates the size of the index difference in the replicated data, and repeats this procedure many times. The proportion of times that the replicate difference is equal to or larger than the actual observed difference is an estimate of the probability (or pvalue) that the null hypothesis is true. Unless stated otherwise, all tests reported here have been conducted using 10,000 bootstrap replications.

    The software program used for the bootstrap tests is Seaby R. M. \& Henderson, P. A. (2006) Species Diversity and Richness Version 4. Pisces Conservation Ltd., Lymington, England. We report the results of the onesided test that the later period is more diverse than the earlier period.

[^14]:    ${ }^{20}$ Menhinick's Index is the number of species in the sample divided by the square root of the number of individuals in that sample-the higher the index, the richer is the sample population. The division by the square root of the number of individuals can be thought of as controlling for the unequal number of censuses in each period that prevents direct comparison of the Richness measure itself.

[^15]:    ${ }^{21}$ The number of species increases with the number of censuses, but only up to the limit of the true number of species in the area being sampled. With the relatively large number of censuses that we have in each period for all areas, it is reasonable to assume that we are approaching the limiting number of species that could be observed by the area census methodology. Put differently, additional censuses within each time period would be unlikely to change these aggregate Richness numbers very much, and on this measure the bias from oversampling Areas $\mathrm{D}+\mathrm{E}$ in the early period is likely to be small.

[^16]:    ${ }^{22}$ See Rosenberg et al (2019).

[^17]:    ${ }^{23}$ It is interesting that the birds/acre figures do not seem unreasonable in light of what gets reported in the literature. For example, Mills, Dunning and Bates (1991) is a study that includes breeding birds in the Tuscon Valley, Pima County, Arizona. The habitat of these birds is either Sonoran Desertscrub or Riparian Deciduous Woodland sites. They report in their Figure 1 an observed density range of approximately $50-350$ breeding pairs per 25 hectares. Converting this data from hectares to acres (and from pairs to individuals), it gives an observed density from 1.62 to 11.33 birds per acre. The higher densities are associated with the areas of higher vegetation density (the woodland). Our estimates of 8-10 birds/acre are consistent with the upper range of their observations.

[^18]:    ${ }^{24}$ There may be an additional influence of nesting boxes for them in an area adjacent to the horse-logging area on the north side of the Briones spillway; I do not know when these nesting boxes originated.

[^19]:    ${ }^{25}$ The U.S. Fish and Wildlife Service maintains a list "Birds of Conservation Concern" that represent the species with the highest conservation priorities after those already designated threatened or endangered. The California Department of Fish and Wildlife maintains a list "Bird Species of Special Concern" described as those of immediate conservation concern.

[^20]:    ${ }^{26}$ In an early study of Acorn Woodpeckers by MacRoberts (1970), he describes the Acorn Woodpeckers as supplanting the Nuttall's Woodpeckers that alit in their storage tree. In 24.5 hours of observation, he recorded 71 instances in which a Nuttall's Woodpecker was frightened off by an aggressive pass or two of the Acorn Woodpecker.

[^21]:    ${ }^{27}$ See note 17 for qualification about detection probability changes as one individual acquires more skill and as one ages.

