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Final Report

Burrowing Owl Population Size in the Imperial Valley, California: Survey and Sampling Methodologies for Estimation

Submitted to:

Imperial Irrigation District
333 E. Barioni Boulevard
Imperial, California
92251

Submitted by:

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April 15, 2009

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Disclaimer: The authors designed, analyzed, and interpreted the results herein to the best of their abilities. As of the date of this report, the information herein is accurate to the best of the authors' knowledge, and reflects their best recommendations for monitoring the abundance of burrowing owls in the Imperial Irrigation District's Service Area in the Imperial Valley, California USA. The authors are not responsible for problems that may arise during the implementation of the recommended protocols or for new information or interpretations that may change the understanding of the results or recommendations presented herein.

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FOREWARD

Jeffrey A. Manning produced this report under a subcontract between Bloom Biological, Inc. and Manning Biological Research, dated March 10, 2007 and in accordance with the Final Detailed Study Approach for a Burrowing Owl Population Study submitted to the Imperial Irrigation District (IID – Operational Headquarters, 333 E. Barioni Blvd., Imperial, CA 92251), dated January 31, 2007. This report was prepared as part of the IID's mitigation program for the San Diego/ IID Water Transfer project. The study was funded by the Water Transfer project Joint Powers Authority, and the study was conducted under the direction of the Water Transfer Implementation Team.

This report stems from a collaborative effort by Jeff Manning, Bloom Biological, Inc., and the Wildlife Research Institute, Inc. Having conducted more than 40 years of research on southern California Burrowing Owl populations and other raptors, Bloom Biological Inc. contributed baseline natural history information that was used to develop the original research proposal and provided the financial and administrative infrastructure for the project. Jeff Manning developed the study designs, field protocols, and methods of data collection (with reviews and recommendations by W. R. Gould, B. Manly, and others), was the principle field investigator, performed the analyses (with the collaborating coauthors of respective chapters), and authored the reports. He also selected, trained, and supervised field biologists. The Wildlife Research Institute, Inc. hired the selected field biologists, provided information on Burrowing Owl natural history during the 2006 pilot study, and assisted in the training of field biologists. Their senior biologists also assisted in the collection of data during the 2006 pilot study.

I, with Bloom Biological, Inc. and the Wildlife Research Institute, Inc., would like to especially thank Mary Coolidge, Paula Graff, and Scott Thomas for their work as Field Crew Managers, and Caren Goldberg and Stacie Robinson for their work as Statistical Analysts; they all provided recommendations that greatly improved various aspects of field activities, assisted in training field biologists, and spent endless hours to creative problem solving that contributed greatly to the success of the project. Jason Bone of CH2M Hill provided digital data on the IID's rights-of-way. Jeff Tupen of CH2M Hill provided valuable insight into interpreting aspects of the HCP and facilitating and coordinating communications with the Water Transfer Implementation Team. Caren Goldberg provided valuable comments on the general readability of earlier versions of this report. Lastly, this project would not have succeeded without the dedication and hard work of the 66 field biologists listed in Appendix I, who collected standardized survey, behavioral, and experimental field data during the 3 year-period. We thank them all.

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EXECUTIVE SUMMARY

The western Burrowing Owl (*Athene cunicularia hypugea*) is one of 18 New World Burrowing Owl subspecies, only 2 of which are found in North America (Haug et al. 1993). It is listed by the U .S. Fish and Wildlife Service as a Bird of Conservation Concern in every USFWS Region it occurs in and on the National list (USFWS 2002, Klute et al. 2003). It is listed as threatened or endangered in several U.S. states and has been listed as a species of special concern in 16 other U.S. states, including California (Remsen 1978, James and Espie 1997, Sheffield 1997, USFWS 2002). The Imperial Valley of California supports the largest concentration of Burrowing Owls in its range (Desante et al. 2004), and is the site for the Imperial Irrigation District's (IID – Operational Headquarters, 333 E. Barioni Blvd., Imperial, CA 92251) Colorado River Water Conservation and Transfer Project (Final EIR/EIS, dated June 2002). In response to requirements in the draft Habitat Conservation Plan (HCP) and other authorizations associated with the Water Conservation and Transfer Project, the IID issued a request for proposals (Qualifications Request 531) to design and implement a Burrowing Owl population investigation. The overall objective was to estimate the relative abundance and distribution of Burrowing Owls throughout the non-submerged portions of the 500,000-acre HCP Study Area, which encompasses the agricultural matrix of the Imperial Valley. These surveys for Burrowing Owls in the HCP Study Area were to focus on the IID's rights-of-way and service areas that parallel irrigation canals, drains, and ditches, including the All American Canal, and be considered as the initial phase of a 3-phase "Effective Monitoring" strategy described in section 4.5.2 of the HCP.

The proposal for this work was submitted under a partnership between Peter H. Bloom of Bloom Biological, Inc (13611 Hewes Avenue, Santa Ana, California 92705), Jeffrey A. Manning of Manning Biological Research (1868 Conestoga Rd., Moscow, Idaho 83843), and Jeff Lincer of the Wildlife Research Institute, Inc. (18030 Highland Valley Road, Ramona, California 92065). On February 1, 2006, the IID awarded Bloom Biological, Inc. a contract to further design and conduct a proposed stratified random sampling mark-recapture survey methodology for Burrowing Owls developed by Jeffrey A. Manning. The scope of that work entailed the development and implementation of detailed survey and sampling methods during 2 consecutive spring seasons, from which to provide estimates of population size and a validated method to survey for Burrowing Owls within the HCP Study Area in subsequent years. This was later amended by the Water Transfer Implementation Team (IT) on March 20, 2006 to include a pilot study during April and May, 2006, prior to implementing the originally proposed 2-year effort. The objective of the pilot study was to assess probabilities of detection and determine the best survey method (mark-recapture versus removal), times of day, and minimum number of repeat sampling occasions that would be necessary to balance accuracy of abundance estimates with effort (cost) during the 2-year population study.

This final report was developed in accordance with guidance from the IT, the requirements of the HCP and other Water Transfer related authorizations, and includes findings from a series of retrospective studies and field experiments (including a pilot study) conducted on Burrowing Owls during daylight hours in the HCP Study Area. These studies were conducted during the prehatch stage (April) of the Burrowing Owl breeding cycle in 2006, 2007, and 2008. Retrospective studies and their associated analyses followed rigorous scientific methods based on applying the information theoretic approach with multiple working hypotheses (Chamberlin 1890, 1965; Burnham and Anderson 2002), novel techniques that were tested and validated, random sampling or complete censuses, and/or bootstrapped simulations. Field experiments involved experimental controls, randomly assigned treatments, random sampling, and replication.

All surveys were conducted by biologists with a minimum of a bachelor's degree in biology or related field, formal training in the scientific method, 1 years experience conducting avian surveys, or demonstrated abilities conducting wildlife population surveys. All field biologists received extensive classroom and field training in order to standardize the collection of survey data.

The topics presented here correspond to those listed in the detailed study approach titled "Final Detailed Buow Study Approach Section 5.2 of QR 531," included in the IID's Work Order No. 2 (8100000664), dated January 31, 2007, as amended.

The primary objectives were to:

1. Provide accurate annual estimates of relative Burrowing Owl abundance and distribution in the HCP Study Area over a 2-year study period.

2. Develop and validate a repeatable sampling and analysis methodology that optimizes the accuracy of annual estimates of population abundance and distribution while minimizing costs.

Amendments to the approaches used to achieve the above objectives were made after independent peer reviews were provided by Dr. W. Gould (New Mexico State University, Las Cruses; January 8, 2007) and B. Manly (West, Inc, Cheyenne, Wyoming; August 22, 2007) and as new information was made available. These amendments include:

1. Use of a grid with a standardized 3x3-Km grid cell size to evaluate spatial autocorrelation in abundance of owls in lieu of linear IID right of ways. These grid cells would also represent standardized sampling units for all subsequent analyses. This approach was approved by the Water Transfer IT on May 9, 2007, and the size of grid cells approved by Brad Norling of the IID on August 22, 2007 and also by the IT in September 2007.

2. Use of a 110-m buffer to surround point-coordinate-based Burrowing Owl locations for estimating unbiased estimates of male Burrowing Owl population sizes from point-coordinate-based closed capture-recapture data. The approach to examine the most appropriate buffer size was approved by the IT on May 9, 2007, and the 110-m buffer size was approved by Brad Norling of the IID on August 22, 2007 and (by email) by the IT on Sept 17, 2007.

3. Use of remote sensing crop data as a correlate of male Burrowing Owl territory abundance. The initial approach of analyzing remote sensing crop data was part

of the approved detailed study approach, but final approval to use the results to predict abundance was emailed by the IT on September 17, 2007.

4. Disturbance experiment approved by Bruce Wilcox of the IID, April 2008

5. Comparison of double and single drain surveys (in response to requests made by the IT and Dr. W. R. Gould's independent review and recommendation, dated 8 January 2007 and the IT's request).

6. Use of summed estimates of local population abundances to validate long-term stratified sampling monitoring design (in response to Dr. W. R. Gould's independent review and recommendation, dated 8 January 2007).

This report is divided into 20 chapters, with subsequent chapters building upon information from former chapters. Due to the numerous novel scientific approaches applied by individual experts here, the format of this report follows that widely used and accepted by the scientific community, including a listing of authors under each chapter heading (e.g., see Barclay et al. 2007. Proceedings of the California burrowing owl symposium, November 2003. Bird populations monographs No. 1. The Institute for Bird Populations and Albion Environmental, Inc., Point Reyes Station, CA).

In Chapter 1, I provide a general introduction, objectives, and description of the study area. In Chapters 2-9, I focused on the development of an efficient survey method that produced unbiased, precise estimates of abundance. Chapter 10 involved the calculation of maximum likelihood estimates of local male Burrowing Owl territory abundance for each 3x3 km grid cell across the study area in 2007. In Chapters 11-13, I identified correlates of abundance and occupancy with the intention of evaluating the efficacy of using those correlates as surrogates of abundance for stratifying the HCP Study Area prior to subsequent population surveys. In Chapters 14-19 I developed, tested, validated, and recommended a stratified random sampling methodology with the survey method embedded into it to improve precision of population estimates and reduce costs. Chapter 20 provided a brief list of recommended future research directions divided into two sections: 1) those intended to improve the accuracy and reduce costs of population monitoring, and 2) those intended to improve the understanding of the status of the Burrowing Owl population and factors that potentially limit or regulate it.

Key points from this study include the following:

1. Diurnal home ranges of male Burrowing Owls ranged from 0.01 to 2.14 hectares (to 5.30 acres), with an average of 0.32 +/- 0.09 hectare (~0.80-acre). Males restricted 97% of diurnal movements to less than 110 m from their burrow site. Diurnal home ranges were distinct and non-overlapping.

2. Availability of Burrowing Owls (which differs from the probability that an owl was detected, given that it was available for detection) was best explained by temperature, with "availability" decreasing as temperature increased.

3. We recommend single-stop car surveys over two-stop car surveys (surveying both sides of drain feature) or foot-based surveys. Surveying from one side of a drain is recommended over surveying from both drain sides, as the latter produces no substantial reductions in bias over the former (both had about 20% bias range).

4. We recommend a three-pass (e.g., 3 survey occasion) closed population capture-recapture approach over the four-pass approach used in 2007 and 2008: the fourth pass provided only limited additional power, and is not justifiable given the additional effort required. Survey passes are conducted on separate days.

5. Of many potential environmental correlates of owl abundance investigated, the best-fit model (i.e., best correlates) included number of available burrows and presence of alfalfa three years prior to the 2007 survey effort. Based on these results, we initially recommended that these two variables could be used to stratify the study area in future survey efforts. However, after additional analyses in the later chapters, we concluded that it would not be advantageous to use these two variables in stratifying the HCP Study Area, and provided an alternative.

6. Abundance of Burrowing Owls in the study area was estimated at 3,557 male owl territories (= breeding pairs) in 2008. This represented a 27% decline from the 2007 estimate of 4,879 territories. These numbers are considerably lower than prior estimates by other researchers (e.g., Desante et al. 2004 estimated approximately 6,000 territories). The decline in abundance between 2007 and 2008 was detected in most (n=206, 75%) of the 274 3x3 km grid cells used to estimate local abundances across the study area. Substantial abundance declines (>50%) between 2007 and 2008 were detected in over 20% of the grid cells.

7. We present the minimum number of grid cells (of total n=274 in Imperial Valley) to be sampled in future burrowing owl surveys to detect a targeted percent-change in abundance. For example, the abundance estimate resulting from surveying 119 randomly-selected grid cells would produce estimates that would be within 10% of the true population size. This would allow the detection of a change in abundance as small as 20% between survey periods. However, stratified random sampling improved the ability of detecting a change to as low as about 10%.

8. The stratified random sampling methodology requires that the study area be re-stratified prior to each population survey. The best method to stratify is based on BUOW abundance, which can be obtained by a valley-wide single-pass census of owls just prior to selecting a random sample to complete capture-recapture surveys. After this single census, the sample of grid cells to be surveyed (e.g., 119) could be randomly selected and surveyed with only 2 additional passes. By combining census data with the data from the 2 additional passes, a total of 3 survey passes (occasions) would occur in the randomly selected grid cells. With a sample of 119 grid cells, this could produce an estimate that would enable detection of a 10% change in between-year abundance of male Burrowing Owl territories.

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Chapter 1

GENERAL INTRODUCTION AND STUDY AREA

JEFFREY A. MANNING

GENERAL INTRODUCTION

The western Burrowing Owl (*Athene cunicularia hypugea*) is listed by the U .S. Fish and Wildlife Service as a Bird of Conservation Concern in every USFWS Region it occurs in and on the National list (USFWS 2002, Klute et al. 2003). It is listed as threatened or endangered in several U.S. states and has been listed as a species of special concern in 16 other U.S. states, including California (Remsen 1978, James and Espie 1997, Sheffield 1997, USFWS 2002). The Imperial Valley of California, USA (32° 58' N, 115° 31' W) supports the largest concentration of Burrowing Owls in its range (Coulombe 1971, Desante et al. 2004), and is the site for the Imperial Irrigation District's (IID – Operational Headquarters, 333 E. Barioni Blvd. Imperial, CA 92251) Colorado River Water Conservation and Transfer Project (Final EIR/EIS, dated June 2002). As part of that project, a draft Habitat Conservation Plan (HCP) was prepared, and the Burrowing Owl was included as a covered species in the HCP.

The HCP specified measures to avoid, minimize, and compensate for potential impacts to Burrowing Owls resulting from the IID's activities, and specified Burrowing Owl monitoring requirements. However, the status and trends in the Burrowing Owl population within the HCP Study Area are largely unknown. Only one study has estimated the size of the Burrowing Owl population in this region (Desante et al. 2004). They surveyed 6% of the Imperial Valley, and estimated the population to be between 3,405 and 7,795 pairs. Because accuracy of abundance estimates is important for species-specific monitoring plans (Atkinson et al. 2004) and making well informed adaptive management decisions, increased accuracy is needed in estimating the Burrowing Owl distribution and population size in the HCP Study Area.

Prior to initiating a long-term population monitoring program for Burrowing Owls along the IID's rights-of-way and service areas that parallel irrigation canals, drains, and ditches within the non-submerged portions of the proposed 500,000-acre HCP area (HCP Study Area), a standardized sampling design that minimizes the required sample size, optimizes the allocation of survey effort, and reduces costs while maintaining high levels accuracy at all stages of the survey is needed. Although range-wide surveys have been recommended (Holroyd et al. 2001), no statistically rigorous broad-scale Burrowing Owl population estimation has been conducted, except for a statewide survey by Desante et al. (2007). Guidelines for conducting standardized visual surveys prior to development in an area have been developed by numerous non-governmental organizations and regulatory agencies across the southwest (California Burrowing Owl Consortium 1997, Arizona Game and Fish Department 2007, New Mexico Department of Game and Fish 2007), but these guidelines are not suitable for determining the appropriate level of sampling and surveying needed to minimize cost while maintaining accuracy in a large area with a high abundance of owls like that found in the HCP Study Area. Additionally, factors that affect detection of owls during the breeding season have been reported for populations in the northwest and central United States (Conway et al. 2008), but because the range of environmental conditions determined to be important in that study differ dramatically from that found in the Imperial Valley, these results should not be inferred to the HCP Study Area. Additionally, while Conway and Simon (2003) provide a rigorous comparison of detection probabilities among three methods of surveying for Burrowing Owls, other survey methods are available, and the applicability of using these survey methods in the HCP Study Area has yet to be evaluated.

Two sources of error that influence the precision of population estimates are measurement error and sampling error (Cochran 1977). Measurement error occurs when an observer fails to detect an animal that was available for detection during a survey, also referred to as detection probability (Diefenbach et al. 2007). This source of error can be attributed to habitat and/or environmental conditions, animal behaviors, observer fatigue, and survey methodology, among numerous other factors. Methods of estimating abundance commonly adjust raw counts by an estimated detection probability (Diefenbach et al. 2007), but lower detection probabilities coincide with lower precision of abundance estimates. Measurement error can be reduced by implementing a variety of techniques, including the use of skilled observers, application of standardized survey protocols, selection of survey times to maximize visibility and minimize misidentification of target animals, training to increase consistency and accuracy, and use of field instruments with high accuracy.

Sampling error is associated with experimental design and sampling of a population (Kuehl 1994). Time and money limitations typically constrain population surveys to a sample of areas that represent a fraction of the area occupied by the population of interest. Here, each area represents an areal sampling unit, and sampling error refers to the variability in abundance of animals among these sampling units. In these situations, a carefully selected experimental design can reduce sampling error and improve statistical power (Kuehl 1994). Designs such as cluster sampling, randomized block design, and stratified random sampling reduce sampling error by classifying sampling units according to their similarity or dissimilarity and estimating abundance in each class separately. These designs generally assume that population counts in sample units are without measurement error, which is why it is still important to reduce measurement error when using them.

Steidl et al. (1997:274) provide an elegant example that illustrates the gains in power when an efficient experimental design and appropriate statistical model for analysis are used. The remainder of this paragraph is an excerpt from that paper. “The effect of recreation on breeding bald eagles … was investigated by measuring brood behavior of eagles with people camped at distances of 500 and 100 m from nests (Steidl 1995). Assuming these data were collected with a completely randomized design, the null hypothesis of no difference in the percent day that eagles spent brooding with people camped at these 2 distances could not be rejected … However, power to detect a 20% effect with this design … was low …, indicating that the results were inconclusive.

Eagle nesting behavior changes rapidly as nestlings mature (Steidl 1995), and [the] completely randomized design [above] did not account for this known source of variability. Instead, a crossover design was used (Jones and Kenward 1989), where both treatment and control were applied in succession to the same experimental unit (nest). This design eliminated variability due to nestling age between nests. The null hypothesis of no difference in behavior between distances [people were camped] was rejected with this approach …, indicating that eagle behavior changed when people camped near nests."

Because abundance of owls is expected to be unevenly distributed across the HCP Study Area, a simple random sample of areas would likely lead to imprecise population estimates of male Burrowing Owl territories (Caughley 1977:27; Williams et al. 2002:247). An accurate estimate of population size can be obtained with sampling designs that account for the size, shape, number, and placement of sampling units across areas where abundance is unevenly distributed (Caughley 1977:27; Williams et al. 2002:247). This is a critical issue in population monitoring because increased precision translates to an increase in the ability to detect changes in population size. Imprecise estimates only allow for detection of large changes in a population.

A commonly used design to estimate the size of wildlife populations in large areas where abundance is unevenly distributed is stratified random sampling (Caughley 1977:27; Williams et al. 2002:249). The area supporting the total population of interest is subdivided into areal sampling units, and these are categorized according to their similarity in animal abundance (e.g., low, medium, and high). These categories are referred to as strata, and a random sample of units is drawn separately from each stratum. Animals are counted in the randomly sampled units and the strata abundances are summed to estimate a total population size. This stratification of units into similar abundances reduces sampling error within strata and the estimated total population estimate.

This report provides the results from a series of retrospective and experimental studies conducted over a 3-year period in the HCP Study Area, beginning with a pilot study in 2006. Our general objective was to develop and validate a repeatable stratified random sampling and analysis methodology that optimizes the accuracy of annual estimates of population abundance and distribution while minimizing costs. Secondarily, we provide unbiased estimates of local and HCP-wide Burrowing Owl abundance and distribution and demonstrate an application of these estimates in calculating annual rates of population change over the last 2 years of the study. Except where otherwise emphasized, this study focused on observations of individual owls, with inference drawn to nests and territories where appropriate. For retrospective and survey-based analyses, my general approach was to use the information theoretic approach to test multiple working hypotheses (Chamberlin 1890, 1965; Burnham and Anderson 2002); but, in some cases where inferential statistics were applied, and a P-value of <0.1 was used for determining significant differences. Field experiments used inferential statistics with a P-value of <0.05, unless otherwise stated.

This study was funded by the IID, with oversight provided by the IT. Bloom Biological, Inc. held the contract with the IID, established subcontracts with Jeff Manning and the Wildlife Research Institute, Inc., and provided information on the natural history of owls. Jeff Manning developed the study designs, field protocols, and methods of data collection (with reviews and recommendations by W. R. Gould, B. Manly, and others), was the principle field investigator, performed all analyses (with the collaborating coauthors of respective chapters), and authored all reports. He also managed purchases and the budget and selected, trained, and supervised field biologists. The Wildlife Research Institute, Inc. hired the selected field biologists, provided input during the pilot study, and assisted in the training of field biologists. Their senior biologists also assisted in the collection of data during the pilot study.

GENERAL DESCRIPTION OF STUDY AREA

This study was conducted in the agricultural matrix of the Imperial Valley of California, USA (32° 58' N, 115° 31' W), an important region for Burrowing Owls that supports the largest population in North America (Coulombe 1971, Desante et al. 2004). Specifically, the HCP Study Area included all non-submerged portions of the 500,000-acre HCP Study Area, and surveys were conducted where the IID's rights-of-way and service areas paralleled irrigation canals, drains, and ditches, including the All American Canal.

Extensive landscape change occurred in this desert ecosystem during the 20th century, with a large portion of the Imperial Valley cultivated for agricultural production with irrigation water supplied by the Colorado River (Bailey 1994). During this study, fields were intensively managed year-round for irrigated agricultural production, with alfalfa (*Medicago sativa*), Sudan grass (*Sorghum bicolor*), Bermuda grass (*Cyondon dactylon*), and wheat (*Triticum* spp.) as the dominant crops. Agricultural fields were routinely flood irrigated, irrigation drains, canals, and ditches were dredged and maintained for water conveyance, and access roads were graded. Within this agricultural landscape during the course of this study, Burrowing Owls nested almost entirely within or along irrigation drains, canals, and ditches.

Chapter 2

SPACE USE AND AVAILABILITY OF BREEDING MALE BURROWING OWLS DURING DIURNAL POPULATION SURVEYS

JEFFREY A. MANNING, CAREN S. GOLDBERG, PETER H. BLOOM, AND SCOTT E. THOMAS

ABSTRACT. Formulating a baseline understanding of Burrowing Owl space use during the day in the HCP Study Area and the implications of this information on conducting diurnal surveys is important. Here, we showed that male Burrowing Owls occupied small, spatially distinct, diurnal home ranges, restricted 97% of their activities to <110 m from the nest, and remained closest to their nest burrow during mid-afternoon while females were in the burrow. We also found that an increase in nest density coincided with a decrease in diurnal home range size and that diurnal home ranges remained spatially distinct (i.e., no change in the level of inter-home range overlap) when the density of nests increased. We also found that their availability for detection decreased on the mid-day. We concluded that these patterns in diurnal space use would minimize the risk of double counting owls or pairs during diurnal population surveys conducted in the prehatch stage of the breeding cycle and that surveys should be avoided in the mid-day until an estimator of abundance that incorporates availability becomes available.

INTRODUCTION

Like many highly mobile species, Burrowing Owls utilize various locations across their home ranges throughout a 24-hr period. This variation should be identified and accounted for to improve the accuracy of estimates derived from population surveys. For example, the probability of being available for detection (which differs from the probability that an animal is detected, given that it is available for detection) throughout the day (e.g., due to being in a burrow) is likely not to be constant; depending on when a survey is conducted, this variation can bias population estimates (Diefenbach et al. 2007). Many of the current methods used to estimate populations, like distance sampling, double-observer, and sightability (Williams et al. 2002), assume that the probability that an animal is available for detection is 1.0. Thus, information on the availability of individuals for detection and home range use and overlap can be useful in developing standardized survey protocols that increase the accuracy of population estimates, as is specified under the HCP.

Burrowing Owls use their nest burrow as a central place, with activities emanating outward like that of a central place forager (Orians and Pearson 1979, Schoener 1979). During the breeding season, male Burrowing Owls actively defend the immediate vicinity of the nest during the day (Coulombe 1971, Thomsen 1971, Martin 1973, Moulton et al. 2004) and expand their space use at night, with nocturnal home ranges measured at 45 to 184 ha (Gervais et al. 2003, Rosenberg and Haley 2004). Low detection probabilities during nocturnal surveys (Haug and Didiuk 1993, Conway and Simon 2003) may be due to these extensive movements, as owls may be absent from the area being surveyed. This is a concern for population monitoring because low detection probabilities decrease precision of population estimates (Seber 1982).

Surveys conducted while owls are occupy small diurnal home ranges may avoid these issues and produce highly accurate population estimates if movements of individual owls are short and home ranges show little overlap. However, the probability that an owl is available for detection throughout the day may change, which can bias estimates (Diefenbach et al. 2007). For example, low availability of Burrowing Owls during mid-afternoon surveys in northern California biased population counts 90% below the known population size (Thomsen 1971). Due to these behaviors, sampling throughout the day in northern latitudes, as recommended by Conway et al. (2008), may not provide reliable estimates of population size if this variability is not accounted for.

In this chapter, we focused on formulating a baseline understanding of Burrowing Owl space use and the implications of such on conducting surveys in the HCP Study Area. We estimated the size and level of overlap of diurnal Burrowing Owl home ranges during the prehatch stage of the breeding cycle and explored how these parameters varied with nest density. We further estimated the availability of Burrowing Owls throughout the day, and demonstrated how availability can influence population estimates derived from diurnal sampling.

METHODS

Data Collection

Spatial use of diurnal home ranges

We surveyed resident male Burrowing Owls during the breeding season from 1 April to 1 May 2007. We chose these dates because they corresponded with the prehatching stage of the nesting cycle, when males move little and remain sentinel around the nest entrance while females incubate (Martin 1973, Plumpton and Lutz 1993). We randomly selected 5 linear areas along the irrigation system that contained neighboring owl nests ($n = 40$ nests). We counted all active burrows in each of the 5 areas that contained sign of Burrowing Owl use (e.g., an owl that retreats or flushes from burrow, regurgitated pellets, feathers, nest lining, whitewash, or footprints with an absence of cobwebs; Conway et al. 2008). We considered the burrow entrance with the greatest amount of sign in the vicinity of each male to be the primary burrow entrance, and recorded its Geographic Positioning System (GPS) location. We used the distance between nest burrows that were at each end of a sampling area to estimate the density of nest sites.

We captured 94 resident owls with noose carpets, Bal-Chatris traps, Havahart traps, and mist nets (Collister 1967, McClure 1984, Bloom 1987, Bloom et al. 2007; Federal Bird Marking and Salvage permit 20431 and California Scientific Collector's Permit 801176-02). Each owl was fitted with metal U.S. Fish and Wildlife Service and colored plastic polyvinyl chloride, alphanumeric leg bands. We used the apparent absence of brood patches to assign sex to each banded owl, and verified that the male at each nest site was banded by conducting visual surveys the following day when we anticipated that females would be incubating eggs in the nest burrow. We used this information and that from counting active nests to derive a true number of active nests. We were unable to capture and band owls in eight nests, but we retained these for observations because they were situated between nests with banded owls, thus enabling us to distinguish them.

We continuously tracked each male for 13 consecutive hours between sunrise and sunset and mapped perch locations every 15 minutes. Observations were conducted with binoculars and a spotting scope, range finder, compass, and GPS unit. Observations were made from vehicles parked at a distance that we believed would not disturb owls (ca. 160 m). We recorded the GPS location of the observer and used the distance and bearing to the owl to map 15-minute owl locations, which were determined during a pilot study to be accurate to <3 m. The flat agricultural landscape enabled us to maintain sight of owls even when they traveled far distances. But, if an observer was unable to locate or verify identification of an owl 1 minute before or after a 15-minute time stamp, the location was not recorded.

Availability throughout the day

We conducted time budget surveys of resident Burrowing Owls in the vicinity of eight randomly selected, individual active nests during the prehatching stage of the nesting cycle, from 7-17 May 2006. We surveyed continuously from 06:30-19:30 (PDT), except between 12:30 and 13:30, and recorded the number of minutes within each hour when 1 owls were available for detection (e.g., not in a burrow). Again, due to the flat agricultural landscape, we were able to maintain continuous sight of owls even when they traveled far distances.

We examined the relative importance of ambient air temperature, wind speed, and time of day on the probability that Burrowing Owls were available for detection. We included the 2 weather variables because past authors suggested that they reduce detection probability (Shyry et al. 2001, Conway et al. 2008). We recorded ambient temperature (°C) and wind speed (km hr^{-1}) frequently throughout each survey hour with a Kestrel 3000 Pocket Weather Monitor, from which we computed hourly averages throughout the day. Ambient temperature varied from 17 to 41°C, and wind speed varied between 0 and 17 km hr^{-1}.

Diurnal population surveys

To examine how availability of owls throughout the day may affect estimates of population abundance, we counted the number of Burrowing Owl pairs in 12 randomly selected linear areas along the irrigation system between 16 April and 20 May 2006. These areas were independent from those used to assess space use in 2007. Each area was approximately 6.5 km long and was surveyed completely during each hour throughout the day (06:30-18:30 (PDT), except for 12:30-13:30). Surveys were completed by one observer and one driver in a vehicle that traveled 11 km hr^{-1}. We used the same make and model vehicle during all surveys, and positioned vehicles so the observer had an unobstructed view of the nesting habitats. We followed the same path and direction during each hourly survey. To reduce double counting owls, the observer maintained a field of view in the direction of travel and did not look behind the vehicle. We stopped the vehicle at each owl and mapped the location with a GPS unit. Because females and males typically remain close the burrow during this period of the nesting cycle (Thomsen 1971, Martin 1973), we considered owls <12 m apart to be a nesting pair and recorded them as a single observation.

Statistical Analyses

Spatial use of diurnal home ranges

We measured the distance between an owl's primary nest burrow and its 15-minute locations using ArcGIS 9.2 (ESRI, Redlands, CA). To evaluate distance moved through time of day, we divided these values by the farthest distance an owl moved. We fit a 95% fixed kernel home range utilization distribution to each owl's set of 15-minute locations (Worton 1989), and considered these as diurnal home ranges. We used likelihood cross validation smoothing because it has been shown to be a better procedure for small sample sizes and for obtaining more accurate and consistent estimates in high use areas (Blundell et al. 2001, Horne and Garton 2006).

We assessed the proportional difference in size of diurnal home ranges relative to nocturnal use areas (x = 45.3 ± 18.2 ha) measured within our study area (Rosenberg and Haley 2004). We also computed the probability that an owl would cross into a neighboring home range as ½ of the volume of overlap between neighboring diurnal home ranges. To examine if distinct boundaries of diurnal home ranges were maintained at various densities, we used unpaired, two-tailed Student's *t*-tests to determine if the size of diurnal home ranges or the probability of crossing into a neighboring home range differed when density of home ranges increased by 114% (7 owls km^{-1} vs. 15 owls km^{-1}). Statistics were computed using R (Ihaka and Gentleman 1996), *P*-values <0.1 were considered significant, and estimates are presented ± 95% confidence limits.

Availability throughout the day

We computed the proportion of each hour that 1 owls were available for detection in a home range throughout the day, and applied an arcsin square root transformation. We fit seven *a priori* linear mixed effects models to these data, and used Akaike's Information Criterion (AIC) to evaluate the relative strengths of the models (Akaike 1973, Burnham and Anderson 2002; Table 2.1). Statistics were computed using R (Ihaka and Gentleman 1996).

Diurnal population surveys

We used the raw counts to compute the proportion of the largest number of nesting pairs observed in the corresponding area during each hourly survey. Estimates are presented ± 95% confidence limits.

RESULTS

Spatial Use of Diurnal Home Ranges

We recorded 1401 diurnal locations of 40 male Burrowing Owls during the prehatch nesting stage in April 2007. Diurnal home ranges (95% fixed kernel) ranged from 0.009 to 2.14 ha ($x = 0.32 \pm 0.09$ ha; Figure 2.1), and averaged <1/100th the size of nocturnal use areas previously reported in our study area. Male Burrowing Owls moved short distances through the day, with the shortest occurring in mid-day (e.g., 12.0 ± 3% as far as the maximum diurnal distance moved) and the longest close to sundown (Figure 2.2).

The probability that an owl was present at increasing distances from its nest burrow followed the pattern of a central-place forager, and reached almost 100% at 110 m from a nest burrow (Figure 2.3). Overlap among neighboring diurnal ranges was minimal ($x = <0.001 \pm 0.000001$ ha), and did not differ where density of burrows was doubled (Student's $t_8 = 1.34$, $P = 0.20$). However, the size of diurnal ranges where density was high (0.38 ± 0.30 ha) was only 39% of that where the density was low (0.98 ± 0.65 ha, Student's $t_{18} = 1.82$, $P = 0.08$).

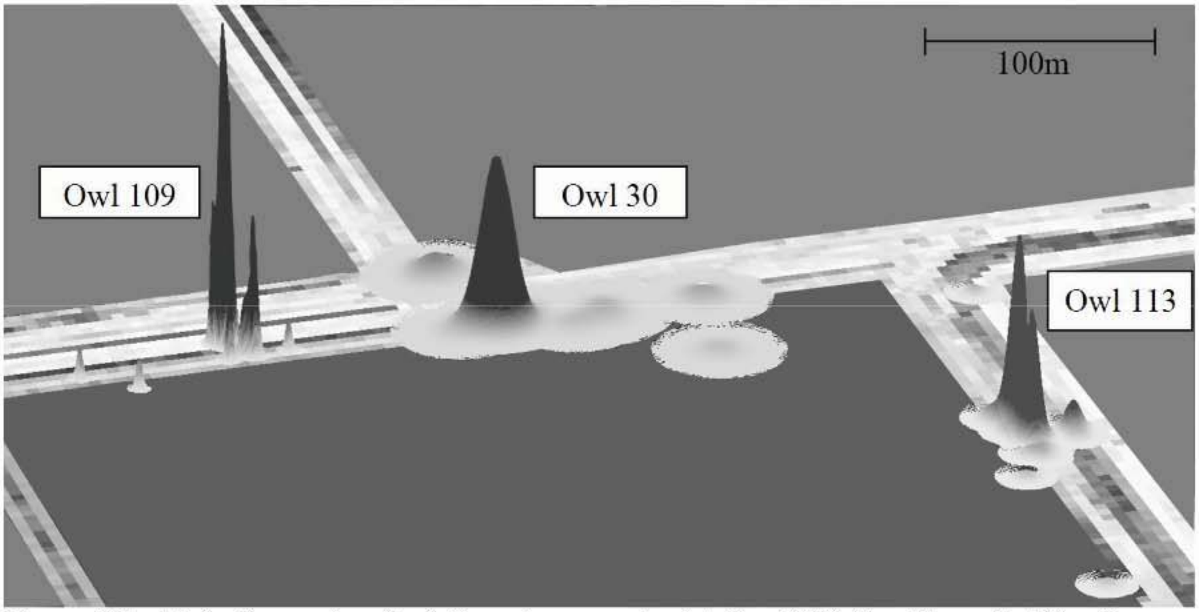

Figure 2.1. Male Burrowing Owl diurnal ranges depicted as 95% fixed kernel utilization distributions along linear irrigation drains (light grey) paralleling dirt roads (white) during the prehatch stage of the nesting cycle in the Imperial Valley, California, April 2007. Solid grey polygons represent agricultural fields.

Availability Throughout the Day

We recorded 142 time budget records in eight home ranges from 16 April 20 May 2006. The best mixed effects model predicted the probability that one owls was available for detection during a given hour of the day in a diurnal home range as a negative function of temperature [availability = $(\sin(2.13 - 0.03 \text{ x temperature}))^2$, $R^2 = 0.34$, Table 2.1]. The next best model (AIC = 3.6 predicted availability as a 2nd-degree polynomial function of time of day. Availability decreased in mid-afternoon, was lowest (58%) between 1530 and 1630h, and increased to 92% by 17:30 (Figure 2.4).

Diurnal Population Surveys

We counted 93 pairs of Burrowing Owls during hourly surveys in 12 6.5-km nesting areas. Numbers of pairs declined with increasing temperature (Figure 2.4a), which also roughly corresponded with that predicted by our best model for availability throughout the day (Figure 2.4). Numbers of pairs also followed availability throughout the day, declining to the lowest numbers in the mid-afternoon (Figure 2.4b).

Table 2.1. Linear mixed models predicting the proportion of time one Burrowing Owl is available for detection at a nesting territory as a response to time of day or weather in the Imperial Valley, California April 16-May 20, 2006. Time budget surveys were based on 11-hr observations of 8 nesting home ranges, home ranges were considered random effects, and availability was arcsin square root transformed.

Model	# Parameters	AIC_c
Linear trend (temperature)	2	0
2nd-degree quadratic (time of day)	3	3.6
Linear trend (time of day)	2	5.4
Linear trend (temperature + wind)	3	6.9
Linear trend (wind)	2	7.0
Linear trend (time of day + wind)	3	12.1
2nd-degree quadratic (temperature)	3	12.7

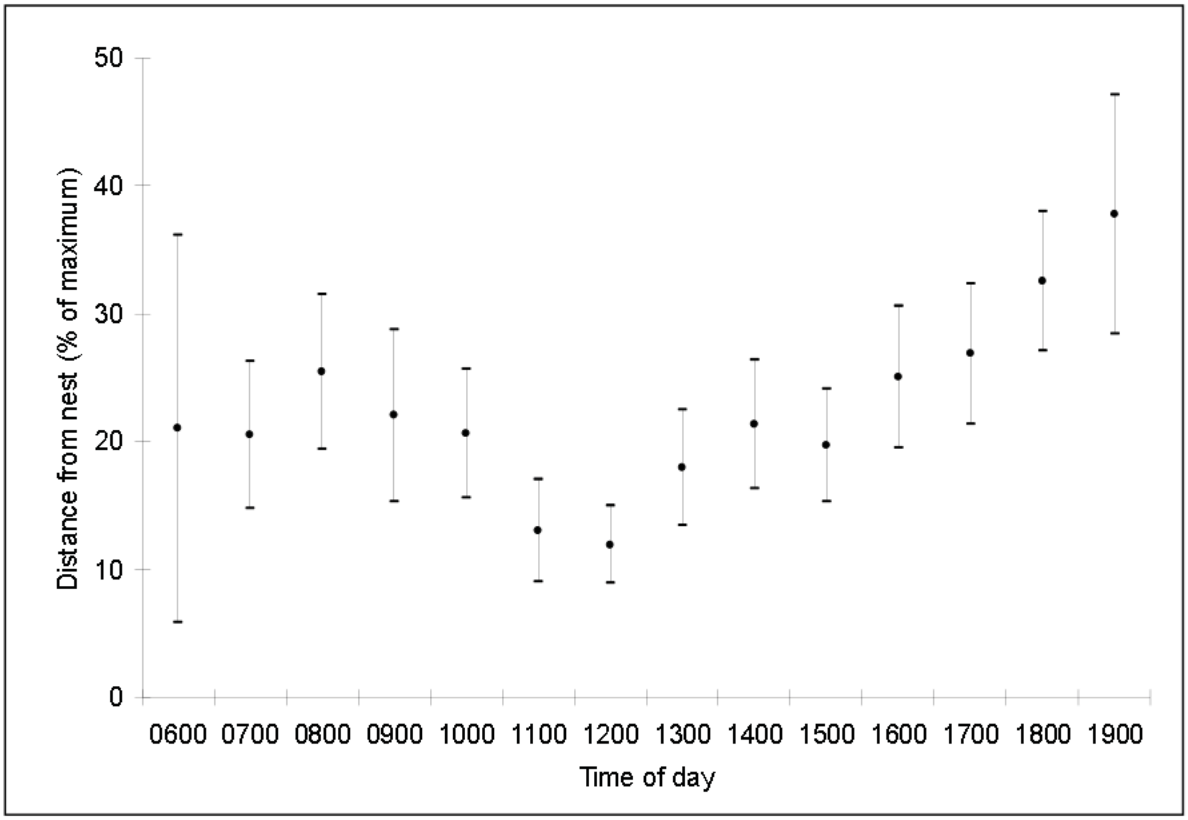

Figure 2.2. Distance (distance/maximum distance) that male Burrowing Owls moved from their nest burrows through time of day during the prehatch stage of the nesting cycle in the Imperial Valley, California, April 2007. Percentages are from 15-minute observations (*n* = 1,401) of 40 male owls recorded during 13 continuous hours (0600-1900). Error bars represent 95% CI.

CONCLUSIONS AND RECOMMENDATIONS

Spatial use of home ranges by Burrowing Owls was not uniform throughout the day. As suggested by other studies (Thomsen 1971, Moulton et al. 2004), male Burrowing Owls in our study occupied small, spatially distinct, diurnal home ranges. During the day, males restricted 97% of their activities to <110 m from the nest, and remained closest to their nest burrow during mid-afternoon while females were in the burrow. Diurnal activities were confined to <1% of nocturnal use areas as measured in a previous study on Burrowing Owls in this area (Rosenberg and Haley 2004). Our results support Moulton et al.'s (2004) findings that male Burrowing Owls during the breeding season appear to defend a relatively small portion of their nocturnal foraging areas during daylight hours. The small diurnal home ranges we observed may be due to males remaining close to their nest burrows to protect their mate from predation and from unmated males (Thomsen 1971). An alternative explanation is that nest burrows in agricultural landscapes like the Imperial Valley may function as a primary source of escape cover against aerial predators, as we occasionally observed owls entering their burrows when aerial predators (*Buteo, Falco, or Circus* spp.) were present.

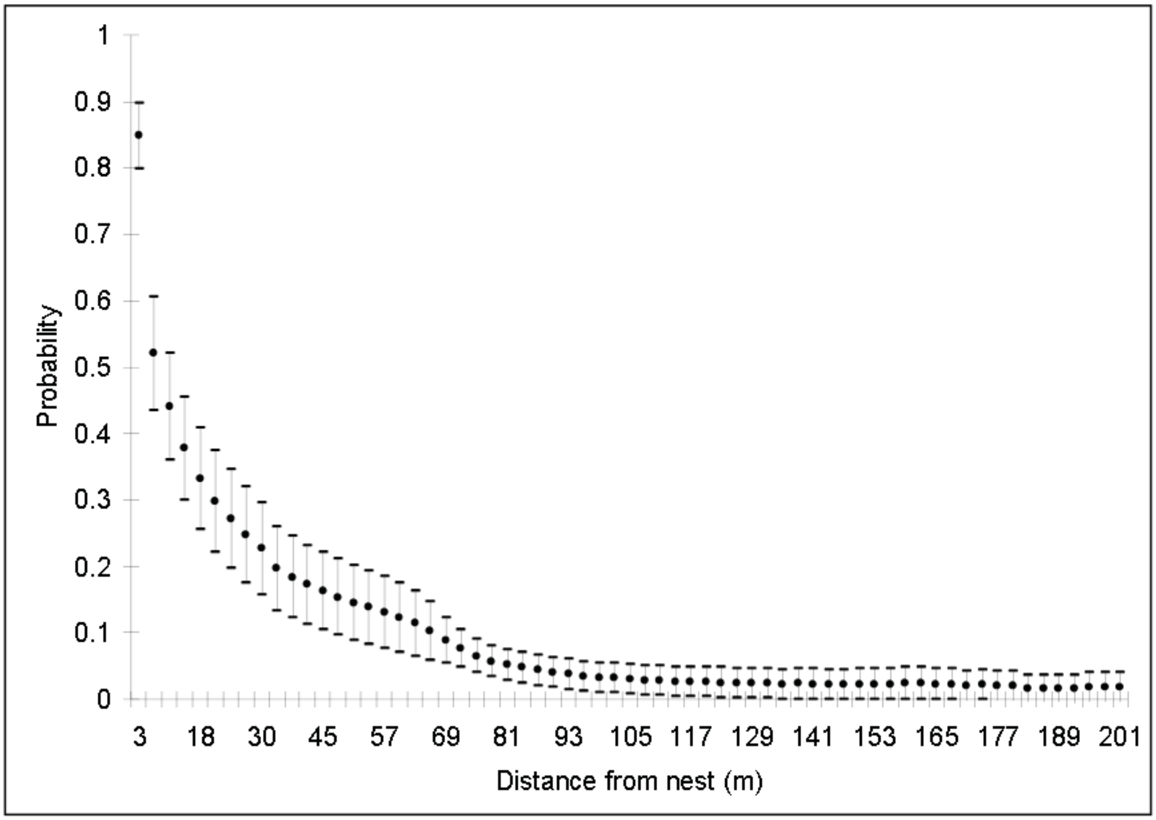

Figure 2.3. Probability that a male Burrowing Owl was present at increasing distances from its nest burrow throughout the day during the prehatch stage of the nesting cycle in the Imperial Valley, California, April 2007. Probabilities are from 95% fixed kernel estimates computed with 15-minute observations (*n* = 1,401) of 40 male owls recorded during 13 continuous hours (0600-1900). Error bars represent 95% CI.

Although previous studies reported that the number of neighboring nests did not account for the size of nocturnal home ranges during the breeding season (Gervais et al. 2003), we found that an increase in nest density coincided with a decrease in diurnal home range size, as suggested by Haug et al. (1993). We further found that diurnal home ranges remained spatially distinct (i.e., no change in the level of inter-home range overlap) when the density of nests increased. Similarly, Thomsen (1971) reported that Burrowing Owl pairs in northern California with the shortest distance to another nesting pair had the smallest home ranges. Although we did not investigate whether the density of breeding home ranges translated to density dependent demographic rates, we suspect that the spatially distinct diurnal home ranges and high use <110 m from nests we observed may maximize reproductive fitness, as nests <110 m from neighboring nests in Oregon were shown to have lower reproductive success than nests farther apart (Green and Anthony 1989).

Because many population estimation procedures assume that the probability that an animal is available for detection is 1.0 (Otis et al. 1978, Diefenbach et al. 2007), it is important to identify and account for probabilities of availability not otherwise accounted for when conducting population surveys. Estimates of Burrowing Owl abundance from previous studies have been based on detection probabilities where the probability that an owl was observed was confounded with the probability that an owl was available for detection (e.g., Rosenberg and Haley 2004, Conway et al. 2008). We found that the availability of Burrowing Owls in home ranges throughout the day in the HCP Study Area was best explained by a temperature, although our next best model predicted it as a 2nd-degree polynomial function of time of day, but there was no support for wind.. Availability was highest when temperatures were low (mainly in the morning and late afternoon), and declined as the temperature increased. Availability declined to its lowest level (58%) when it reached the hottest temperatures generally in mid-afternoon. The proportion of the population counted during our independent surveys followed this pattern with temperature and time of day closely, indicating that probabilities of availability <1.0 throughout the hotter afternoon periods bias estimates of Burrowing Owl population abundance based on counts. Likewise, Thomsen (1971) reported that availability declined to its lowest level in the mid-afternoon, and that surveys during that time estimated only 10-25% of the population.

Burrowing Owls maintain small, distinct, non-overlapping diurnal home ranges at various densities during the prehatch stage, when they are most readily surveyed. However, population estimates derived from surveys conducted during the hotter afternoon period will be biased low, as owls are least available for detection during this relatively hot period. We recommend that surveys of Burrowing Owls either incorporate appropriate correction factors for this variability or be conducted in the morning and late afternoon during the prehatch stage to produce the most accurate estimates of population size.

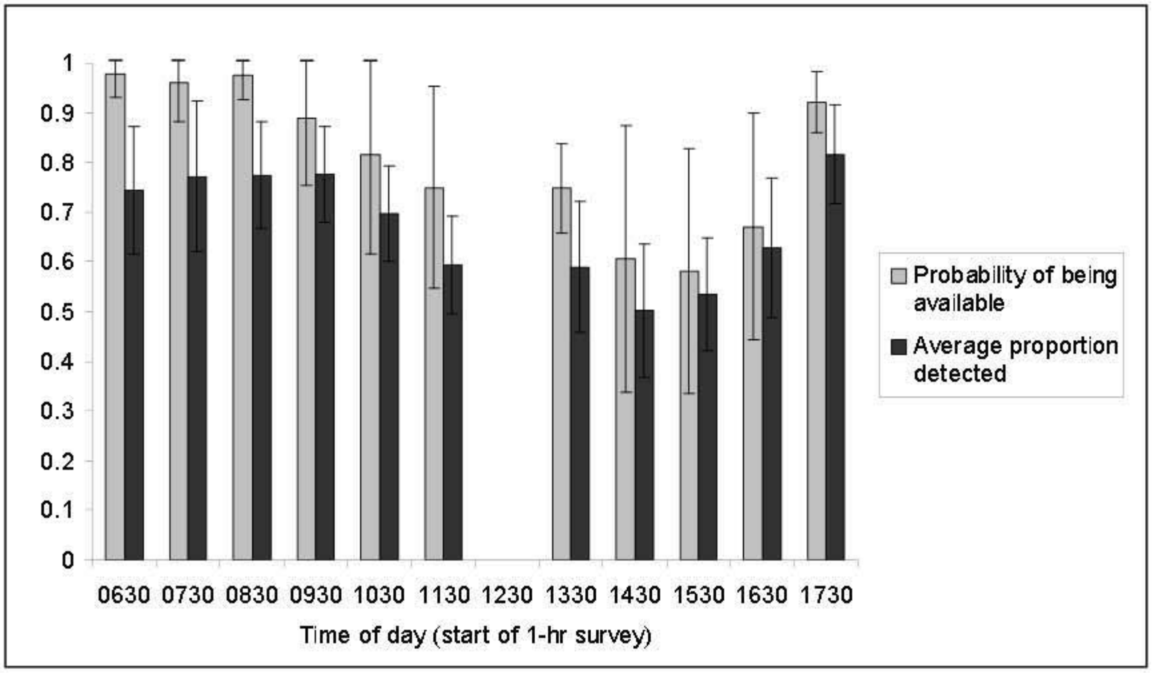

Figure 2.4a. Hourly percentage of time male Burrowing Owls ($n = 8$) were available for detection (e.g., not in their nest burrow) and hourly average number of breeding pairs ($n = 93$) detected throughout the day during the prehatch nesting stage in the Imperial Valley, California. Percentages are from time budget surveys and number detected from automobile-based survey counts. Error bars represent 95% CI.

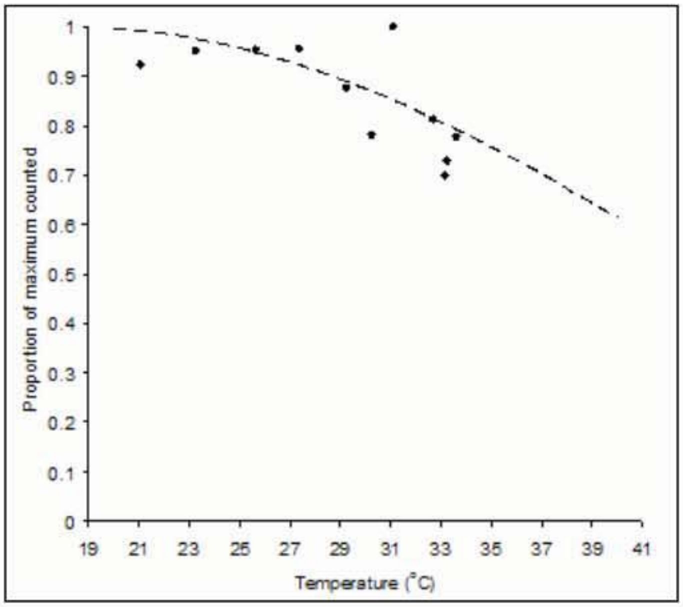

Figure 2.4b. Hourly proportion of maximum Burrowing Owl pairs ($n = 93$) counted throughout the day from automobile-based survey counts as a function of temperature during the pre-hatch nesting stage in the Imperial Valley, California. Dashed line depicts the best linear mixed model predictions of availability (availability = $(\sin(2.13 - 0.03 \times \text{temperature}))^2$) derived from independent time budget surveys. Temperature is arcsine square-root transformed.

Chapter 3

EFFECTS OF SURVEY METHODS ON BURROWING OWL BEHAVIORS

JEFFREY A. MANNING AND ROBB S. A. KALER

ABSTRACT. Information on the behavioral responses of Burrowing Owls to various methods of surveying in the HCP Study Area would be useful for the development of survey protocols. As part of Amendment 4, we compared the effects of 4 survey methods against an experimental control (no survey) on short-term behavioral responses of Burrowing Owls during the prehatch stage of the breeding cycle. The 4 survey methods included a 2 car that drove by an owl twice and stopping both times, representing the double sided drain surveys described in the HCP. Another involved a car that drove by and stopped once, representing the method we used for conducting the population surveys. We found that an owl was 5 times more likely to be displaced by a passing survey car, 15 times more likely to be displaced by a walking surveyor, 16 times more likely to be displaced by a single car survey stop, and 27 times more likely to be displaced by a double car survey stop. We recommend the single car stop for conducting population surveys across the HCP Study Area because they are more efficient than walking and may reduce short-term responses compared to double car stops, which may help minimize bias associated with double counting.

INTRODUCTION

Due to the large extent of the HCP Study Area, we proposed that surveys be conducted from slow moving (7 mph) vehicles. This approach provides an efficient sampling method because burrowing owls nest and forage near roadsides (Brenckle 1936, Ratcliff 1986, Plumpton and Lutz 1993), with the majority of nests in the HCP Study Area occurring <15 m from the banks of water conveyance structures that parallel roads (Desante et al. 2004, Rosenberg and Haley 2004). Additionally, the HCP made reference to surveying both sides of drains (essentially requiring a vehicle to pass on both sides of a water conveyance structure). However, there is some evidence that locomotion and alertness of Burrowing Owls are correlated with vehicular traffic (Plumpton and Lutz 1993). Thus, multiple passes by a vehicle could disturb owls by flushing them (Plumpton and Lutz 1993), which may increase the probability of inter-territorial overlap we reported in chapter 2. Such disturbances could lead to unintended double counting of unmarked owls, resulting in a positive bias in population estimates.

There is a paucity of studies in the literature regarding the effects of various survey methods (e.g., surveyors with or with vehicles, vehicles that stop versus not stopping when owls are detected) on behaviors of owls. Information regarding how owls respond to various population survey methods can help elucidate possible sources of bias associated with estimates of population size. Survey methods that minimize disturbance may reduce movements, which should reduce double counting and its associated influence on bias while also reducing stress and other ecologically important rates (e.g., predation by aerial predators or energy expenditure) for owls. This chapter presents the results from a field experiment we conducted in the HCP Study Area, where we compared the effects of 4 survey methods against an experimental control (no survey) on short-term behavioral responses of Burrowing Owls during the prehatch stage of the breeding cycle.

METHODS

Data Collection

We conducted a field experiment with 1 control (no survey) and 4 methods of surveying owls as experimental treatments (Table 3.1). Between April 25-May 1, 2008, we randomly selected 395 owls along IID-maintained water conveyance structures across the HCP Study Area and randomly assigned one of the above 4 treatments or control to each of the owls, following a balanced design (*n* = 79 for each treatment group and control). We chose this period because it corresponded with the prehatching stage of the nesting cycle, when females incubate and males remain sentinel outside the nest entrance (Martin 1973, Plumpton and Lutz 1993).

Eight survey teams of 3 biologists in 2 vehicles applied treatments and recorded behavioral responses. One vehicle was designated as the ‘observation’ vehicle and included a single observer. The second vehicle was designated as the ‘treatment’ vehicle and included two surveyors. With the exception of color, all vehicles were identical and were required to keep lights off and windows rolled up during treatments.

Upon locating a randomly selected owl, the observer positioned their vehicle along the right-of-way at a vantage point ~50 m from the owl and signaled (via punctuated illumination of the vehicle’s taillights) to the surveyors in the treatment vehicle positioned >150 m behind to move to ~100 m behind the observation vehicle. Based on previous observations, we believed that these distances would minimize disturbance to the owl. After the treatment vehicle was in position, both vehicles remained stationary for a 5-minute pre-treatment period to allow the owl to acclimate to the observer vehicle. If during the 5-minutes pre-treatment period the target owl appeared to be disturbed by the presence of the vehicles (head bobbing, multiple flights, repeated looking in the direction of the vehicles), then that owl was excluded from the study.

At the end of the 5-minute pre-treatment period, the treatment vehicle applied the randomly selected treatment. After the survey vehicle departed, the observer remained in the other vehicle for up to 20 minutes and recorded the location of the perch that was at the maximum distance the owl was displaced from its original perch where the treatment was first applied. If the owl returned to <10 m from its original perch <20 minutes after the treatment was applied, we also recorded the time it was displaced and that it returned to its original perch. If the owl did not return within the 20-minute post-treatment period, the observer recorded the location of the perch associated with the maximum distance and time (20 minutes) displaced and ended observations. If an owl departed from the observers view during the treatment or 20-minute post-treatment period and could not be

Table 3.1. Survey methods (treatments) randomly assigned to Burrowing Owls in the HCP Study Area, May 2008.

Survey Method	Description
Control	No surveyors or vehicles present; observed owl from observation vehicle (see below).
Car pass	Vehicle traveled 7 mph and paused for 2 minutes where owl was located before traveling away at 7 mph; the engine remained on and surveyors remained inside vehicle.
Walk	A single surveyor walked along the right-of-way surveying for owls with binoculars.
Single car stop	Survey vehicle traveled 7 mph along right-of-way, stopped at owl, and two surveyors exited the vehicle to record location data for 2 minutes, then resumed driving away from the owl.
Double car stop	This treatment represented the double survey pass initially proposed in the HCP; survey vehicle traveled 7 mph along right-of-way, stopped at owl, and 2 surveyors exited the vehicle to record location data for 1 minute, followed by the departure of the vehicle with the surveyors and the subsequent return of the vehicle within a few minutes to repeat the above for 1 minute (regardless of the owl had moved), at which time the vehicle and surveyors resumed driving away from the owl.

resighted, the observation was abandoned and excluded from the study. If the owl traveled out of the observer's view by going into a burrow, the observation continued until the owl (if ever) reappeared from the burrow, or to 20 minutes, whichever was shorter. For the control, there was no treatment vehicle and the observer recorded the maximum displacement location of the owl during a 20-minute observation period. In addition to above-ground locations, we considered standing on the ground, at burrow entrances, or in burrows as perch locations. All location data were recorded using a Trimble GeoXM, range finder, and compass, with <3-m accuracy.

Statistical Analyses

We used ArcGIS 9.2 (ESRI, Redlands, CA) to measure the maximum distances that owls were displaced. We used a logistic model with a binomial response (displaced, no response) to assess whether the probability that an owl was displaced differed among survey methods. We used the area under a receiver operating characteristic (ROC) curve to assess how well the model parameters predicted when an owl would be displaced (Hanley and McNeil 1982, Heagerty et al. 2000). We used odds ratios to compare how much more likely it was for an owl to be displaced by one survey method over another (Hosmer and Lemeshow 1989).

We used analysis of variance (ANOVA) to assess if the duration of time or distance that an owl was displaced differed among treatments and our control. We $\log_e$ (x + 0.1) transformed distance displaced. When the ANOVA indicated a $P<0.1$ difference among treatments, we used Tukey-Kramer HSD multiple comparison tests based on alpha = 0.05 to determine which treatments differed between each other or the control.

We also conducted a post-hoc analysis to assess if car color had a differential affect on the distance or time an owl was displaced by a car survey pass. We $\log_e$ (x + 0.1) transformed both variables.

All statistical analyses were performed using Program JMP 7.0.1 (SAS Institute, Inc., Cary, N.C.).

RESULTS

The probability that an owl being displaced during a survey differed among survey methods (whole model test: $^{2}_{4} = 82.2$, $P<0.0001$). The model performed fairly well at predicting when an owl would be displaced (area under the ROC curve = 0.74). Odds ratios indicated that, compared to the control group, an owl was 5 times more likely to be displaced by a passing survey car, 15 times more likely to be displaced by a walking surveyor, 16 times more likely to be displaced by a single car survey stop, and 27 times more likely to be displaced by a double car survey stop. A double car survey stop was 1.7 times more likely to displace an owl than a single car survey stop, a single car survey stop and walking surveyor were equivalent, but 3 times more likely to displace an owl than a passing survey car. Raw data for the proportion of owls displaced during each treatment are shown in Figure 3.1.

The time an owl was displaced differed between survey methods ($F_{4,390}=10.84$, $P<0.0001$), with owls responding to the control and car pass equally and at a shorter duration than that due to the remaining 3 survey methods that involved the presence of a surveyor (Tukey-Kramer HSD, $P<0.05$; Figure 3.2).

The distance an owl was displaced also differed between one or more treatments ($F_{4,390}=19.63$, $P<0.0001$), with owls responding to the control and car pass equally, but at a shorter distance than that moved in response to the remaining 3 survey methods (Tukey-Kramer HSD, $P<0.05$, Figure 3.2).

Car color did not have a differential affect on the time or distance an owl was displaced ($F_{4,74} = 2.26$, $P = 0.07$, $F_{4,74} = 2.41$, $P = 0.06$, with Tukey-Kramer HSD not detecting any differences at $P<0.05$).

CONCLUSIONS AND RECOMMENDATIONS

Compared to the control and car pass, the presence of a surveyor outside of a vehicle was the common factor among the 3 survey methods that led to significant increases in the probability of owls being displaced as well as the distance traveled and time spent while displaced. Double car stops increased the probability that owls would be displaced, as well as the median distance traveled by the displaced owl (although the latter was not a statistically detectable difference due to high levels of variation). Surveys based on the car pass method could minimize disturbance and decrease bias associated with accidental double counting of due to movements, however, accurately recording an owl's location and surroundings from inside of the vehicle would be problematic. We recommend single car stops for conducting population surveys across the HCP Study Area because they are more efficient than walking and may reduce short-term responses compared to double car stops, which may help in minimizing bias associated with double counting.

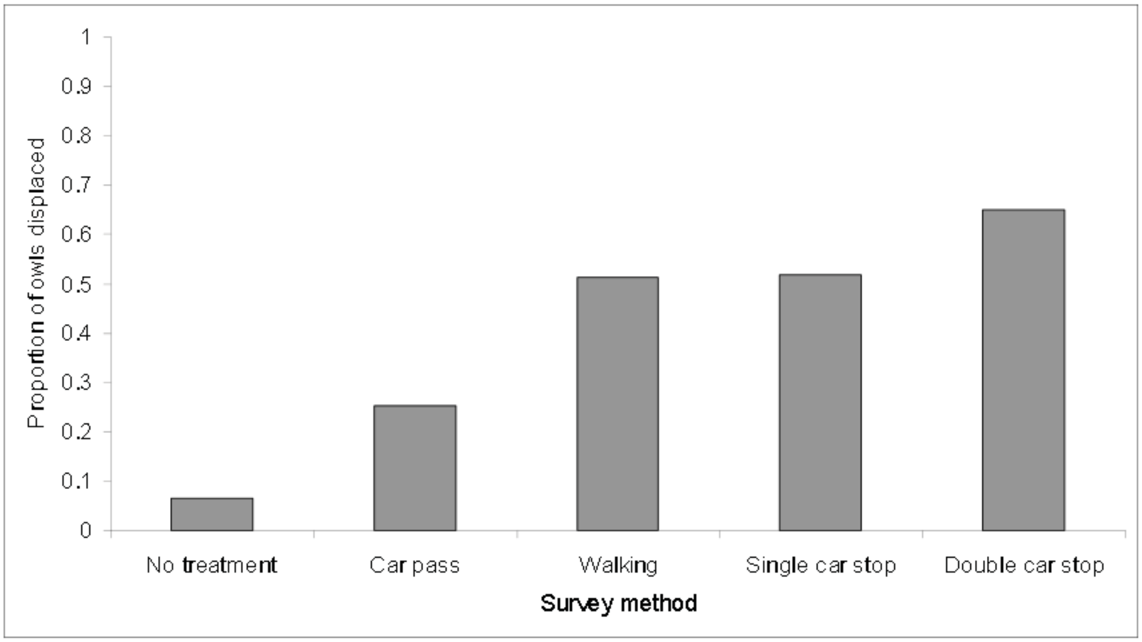

Figure 3.1. Proportion of owls displaced from a perch <20 minutes after a survey method was applied during the prehatch stage of the breeding cycle; no treatment represented an experimental control, Imperial Valley, California 2008.

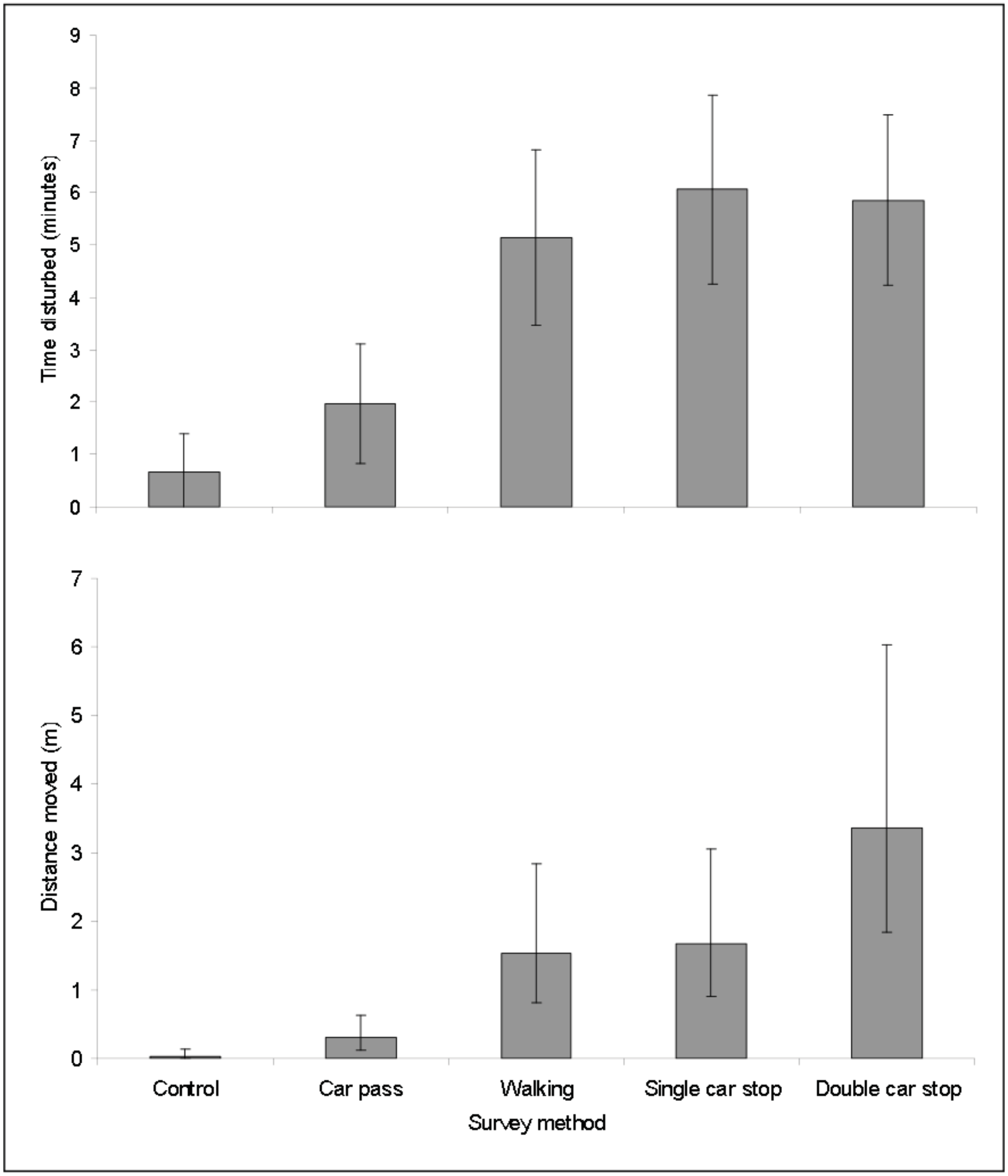

Figure 3.2. Average time and median distance that owls were displaced by a survey method during the prehatch stage of the breeding cycle, Imperial Valley, California 2008. Vertical bars are 95% confidence intervals.

Chapter 4

SINGLE VERSUS DOUBLE SURVEY PASSES

JEFFREY A. MANNING

ABSTRACT. Information on the reliability of surveys conducted from single versus double survey passes can aid in making decisions that balance cost and accuracy of population estimates. In response to Amendment 5, I present the results from a study that compared estimated population sizes, magnitudes of bias, and levels of precision between single and double pass surveys along water conveyance structures containing a known number of active Burrowing Owl territories in the HCP Study Area. I showed evidence that there is no appreciable difference in detection rates or abundance estimates between 1 versus 2 survey passes. Because the cost of 2 survey passes would be nearly twice that of a single survey pass and restricted access to both sides of numerous drains and canals across the HCP Study Area would lead to unequal levels of effort when using the 2 survey pass method, which would introduce an unknown level of error in population estimates that may fluctuate between grid cells and years based on access and maintenance, I concluded that 1 survey pass provides an adequate and consistent method of surveying for male Burrowing Owl territories in the HCP Study Area.

INTRODUCTION

The IT requested that we evaluate the differential effects of single versus double survey passes on bias and precision of population estimates. In chapter 3, Manning and Kaler compared short-term behavioral responses by Burrowing Owls to 4 methods of surveying owls and an experimental control. In that study, we used double car stops along the same side of the drain as a surrogate for two survey passes where each would occur on either side. We found that although not statistically significant, double car stops at Burrowing Owls during the prehatch stage of the breeding cycle were shown to increase the probability and distance of displacement. We concluded that these increases could lead to accidental double counting of owls, which can bias population estimates high. In this study, single and double pass surveys along water conveyance structures containing a known number of active Burrowing Owl territories were conducted during the prehatch stage of the breeding cycle. From these data, I computed population estimates, magnitude of bias, and level of precision between these 2 survey methods.

METHODS

I randomly selected 4 irrigation drains (Rice, Central, Strout, and Date drains) in the southern portion of the HCP Study Area (Figure 4.1), and conducted point-coordinate capture-recapture surveys (see chapter 7 for detailed description of survey method) along a randomly selected 4-km length (route) of IID rights-of-way along each drain. I focused on that portion of the HCP Study Area due to logistical constraints, but believe that the results can be inferred to irrigation drains throughout the HCP Study Area because environmental conditions, habitat characteristics, and owl numbers and distribution appear to be similar along drains in the north and south portions. Surveys were completed during the prehatch stage of the breeding cycle, between 26 April and 2 May, 2007, which lies within the period previously recommended for conducting population surveys.

Each drain route was surveyed on both sides along IID rights-of-way in opposing directions 3 times (occasions), following the survey methods described in chapter 7 along the same path. When a survey was completed on one side, the surveyors waited >15 minutes at the end of the survey route to allow owls to resume normal behaviors and perching that may have been disturbed by the first survey pass. This produced the first, third, and fifth survey passes in the same direction on the same side of a drain, and the second, fourth, and sixth passes on the opposing side and direction of the corresponding drain.

I combined the first, third, and fifth survey pass data (which were in the same direction) along a route, and considered these to represent 3 single pass survey occasions. I further combined the first and second passes that were in opposing directions along each route, and considered these as the first double pass survey occasion, and applied this to the remaining 2 groups of opposing passes to produce the 2nd and 3rd double pass survey occasions. These groupings enabled me to develop capture-recapture encounter histories from single pass surveys and separately for double pass surveys along the same randomly selected drains.

I used estimated the abundance of owls from single and double pass surveys in each drain separately. I fit 2 maximum likelihood, multinomial, closed-population models to these data with a sin link function using Program MARK (Otis et al. 1978, White et al. 1982, Cooch 1999, White and Burnham 1999). One assumed constant detection probabilities and the other assumed that detection varied among survey occasions. I applied an information theoretic framework (Burnham and Anderson 2002) to select the best model for each drain separately because the goal was to obtain the most reliable estimates of abundance.

Additionally, I pooled the 4 routes into 16 km of surveyed irrigation drain, and pooled the resulting encounter histories into 2 groups based on single and double pass surveys. I fit maximum likelihood, multinomial, closed-population models with a sin link function available in Program MARK (Otis et al. 1978, White et al. 1982, Cooch 1999, White and Burnham 1999) to these data, and applied an information theoretic framework (Burnham and Anderson 2002) to assessing differences between single and double pass surveys. I developed an *a priori* set of multiple working hypotheses that involved similarities and differences in detection probabilities and/or abundances between single and double pass surveys, and constructed a separate model for each hypothesis. I used Akaike's Information Criterion adjusted for small samples (AIC_c) with a cutoff of 2.0 and the principle of parsimony to determine the best model (Akaike 1973, Burnham and Anderson 2002). I assessed the lack-of-fit of the best model here and in the prior closed-population analyses to the data by examining a plot of its deviance residuals. A symmetric and narrow pattern of deviance residuals close to zero would suggest a good fit to the data, whereas a wide pattern around zero would suggest poor fit due to extra-binomial variation.

To estimate the true number of male Burrowing Owl territories along the survey routes, I used all nest locations from the surveys that were located >40 m apart. I chose this distance because owls occupy non-overlapping diurnal home ranges and spend >80% of the time within 40 m of their nest (as shown in Chapter 2). I assumed that nest locations closer together than 40 m represented additional burrows in a complex occupied by a single pair.

RESULTS

Based on our count of owl nests that were >40m apart, there were a total of 57 male Burrowing Owl territories in the 4 drain routes. A single survey pass produced estimates of abundance for each drain route that was 5 to 25% biased below the true number of territories believed to be present (Figure 4.2), whereas the bias associated with 2 survey passes ranged from -7 to 12% (Figure 4.2). Population estimates from 2 survey passes produced less bias in each of the 4 drain routes, the single survey pass was consistently below the true number, and both survey methods were similar in their precision (i.e., the range in bias for the 1 survey pass was 20% and that of 2 survey passes was 19%).

The comparison of multiple closed-population models fit to the larger dataset that was created by pooling the 4 replicate drain routes led to 3 competing models that best explained the variation in the data (AIC_c<2.0; Table 4.1). Based on the principle of parsimony, the simplest of those 3 models [p=c(.) N(.)] represented the hypothesis that capture and recapture probabilities did not differ between 1 and 2 survey passes and the estimated abundances also did not differ between them. Based on AIC_c weights, that model had the highest level of support, and there was 50% more evidence for it being the best model over replicated datasets compared to the next best model (Table 4.1). This model fit the data well (deviance residuals followed a narrow and symmetric pattern surrounding zero), and the model estimated capture and recapture probability for both methods to be 0.77 (SE = 0.03) and the abundance estimates were 49 (95% CI: 48-56) for 1 survey pass and 55 (95% CI: 55-59) for 2 survey passes.

CONCLUSIONS AND RECOMMENDATIONS

The comparison of multiple working hypotheses with the information theoretic approach over the combined dataset provided evidence that there is no appreciable difference in detection rates or abundance estimates between 1 versus 2 survey passes. When the data was analyzed individually for each survey route, 2 survey passes produced less bias in estimated abundance for each of the 4 drain routes. The 2 survey pass method produced estimates that were sometimes positively and sometimes negatively biased, while the single survey pass was consistently below the true number when drains were analyzed surveyed.

One explanation for the difference in bias between the 2 levels of survey effort when examining the data at the level of short drain routes may be due to the poor performance of capture-recapture models with small sample sizes like those present in each drain route. In this situation, the estimator did not correct for visibility bias efficiently with the small observed samples to adequately correct estimated abundance. This is especially important for the single pass data because the assumption is that all territories are not counted in every pass, but that this will be corrected for by the capture-recapture model. For the 2 survey pass method, the number of counted territories should be closer to the true number present, and the capture-recapture model should not inflate the estimate as much. The analysis with the pooled data is likely more representative of the results that may be obtained when sampling 3x3 km grid cells or larger areas in the HCP Study Area. The similar levels of precision from 1 and 2 survey passes suggests that both may be adequate for monitoring changes in the size of the population or relative differences among grid cells in the HCP Study Area.

Some other differences between conducting 1 and 2 survey passes that were not examined here include cost and consistent levels of effort across the HCP Study Area in order to obtain comparable estimates of abundance among local areas or grid cells. Cost would approximately double if two survey passes were conducted instead of one. Additionally, restricted access to both sides of numerous drains and canals across the HCP Study Area would lead to unequal levels of effort. This would introduce an unknown level of error in population estimates that may fluctuate between grid cells and years based on access and maintenance. For these reasons, it is reasonable to conclude that 1 survey pass provides an adequate and consistent method of surveying for male Burrowing Owl territories in the HCP Study Area during the prehatch stage of the breeding cycle. Although this method may slightly underestimate the number of territories along large drains, this bias should be small and consistent between years, allowing for accurate detection of changes in population size.

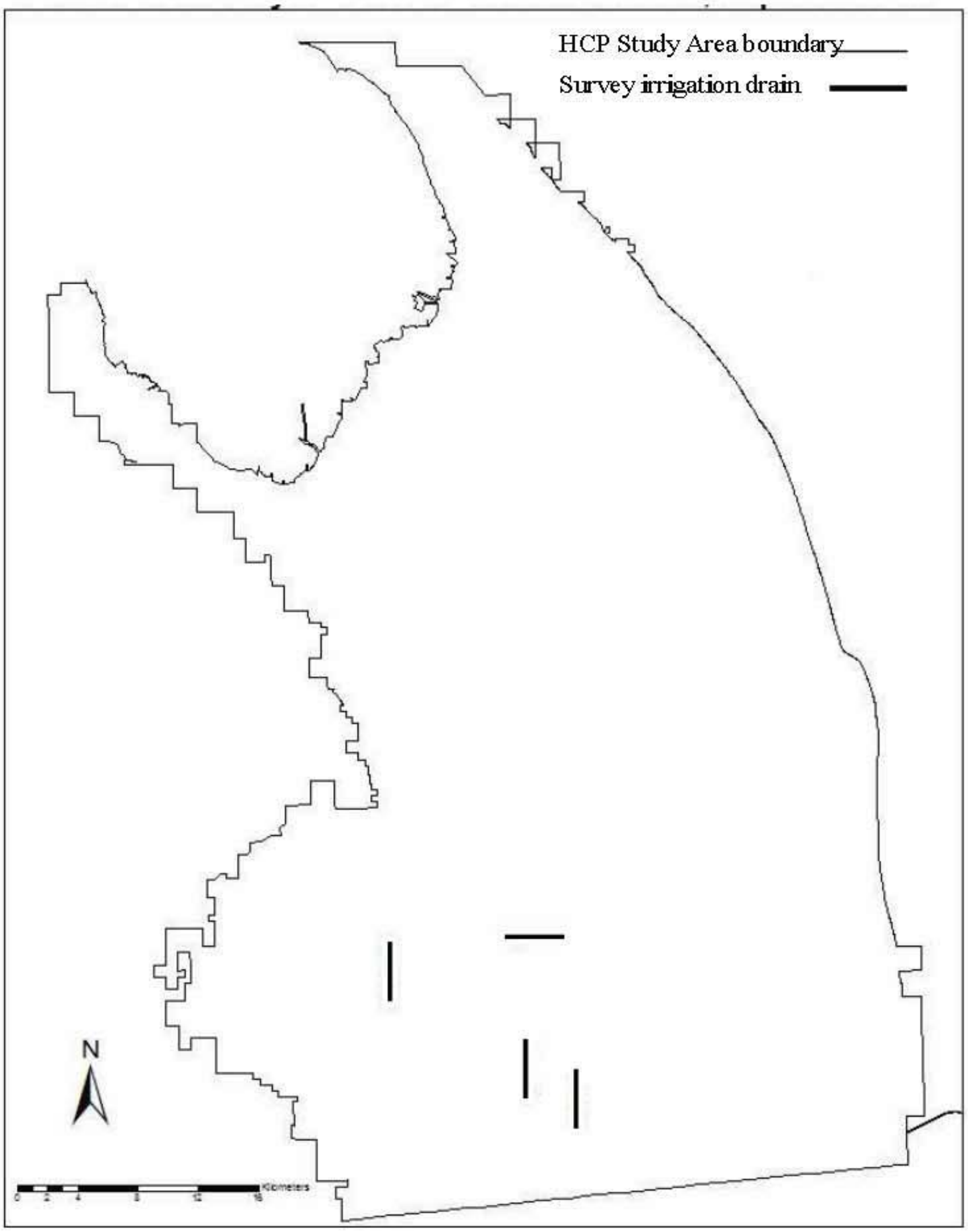

Figure 4.1. Locations of four randomly 4-Km lengths of irrigation drain where point-coordinate capture-recapture surveys were conducted for male Burrowing Owl territories using 1 and 2 survey passes in the HCP Study Area, Imperial County, California, 26 April - 3 May, 2007.

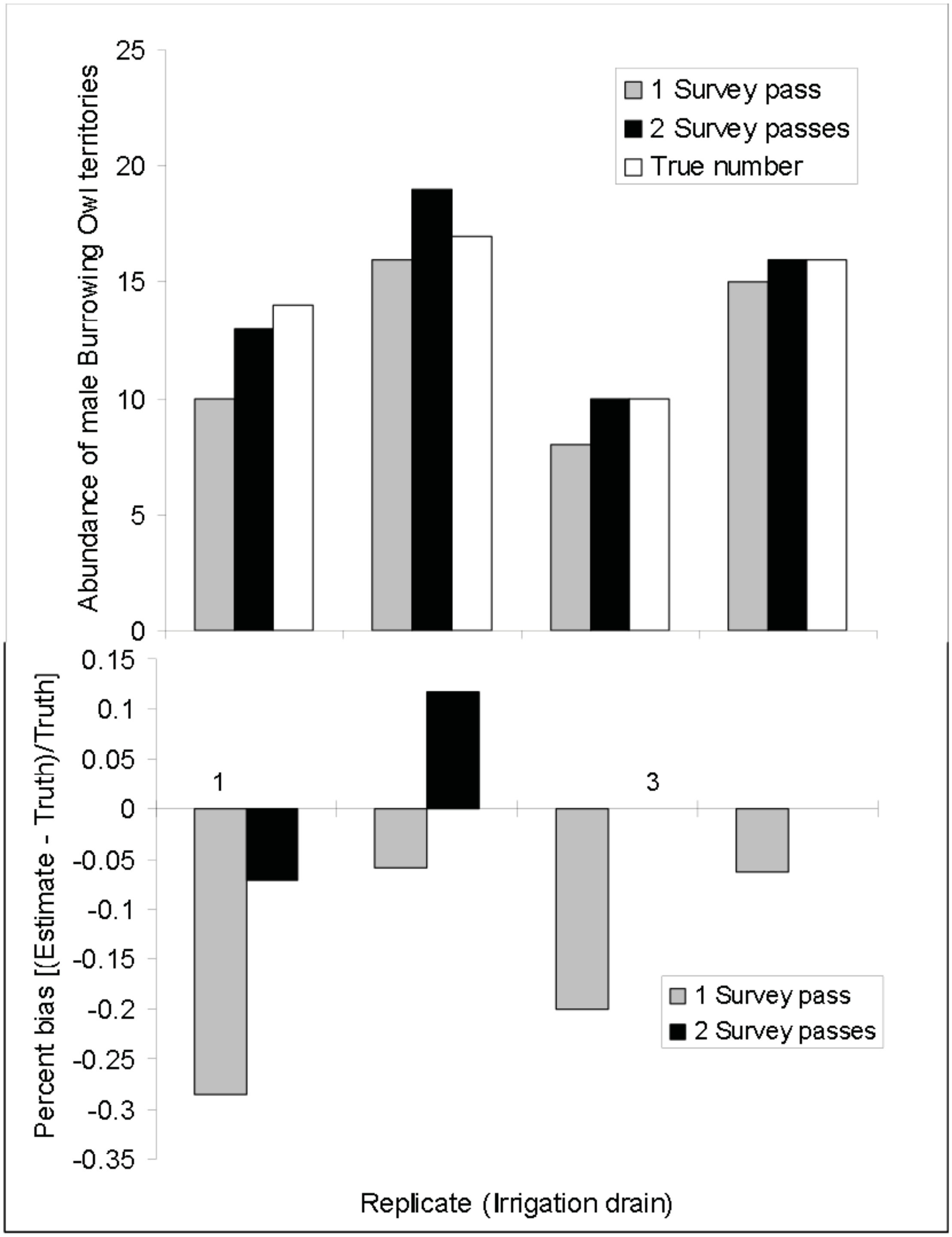

Figure 4.2. Abundance (A) and associated percent bias (B) of estimated male Burrowing Owl territories from 1 or 2 survey passes along 4 randomly selected 4-Km lengths of irrigation drain in the HCP Study Area, Imperial County, California, 26 April - 3 May, 2007.

Table 4.1. Maximum likelihood closed-population models applied to point-coordinate capture-recapture data of male Burrowing Owl territory encounter histories to assess differences in detection [capture (p) and recapture (c)] probabilities as well as abundance between single and double survey passes during the prehatch stage of the breeding cycle in the HCP Study Area, Imperial County, California, 26 April - 2 May, 2007. Models were constructed with the sin link function in Program MARK, and model syntax followed Otis et al. (1973) and White and Burnham (1999).

Model	ΔAICc	AICc Weight	Likelihood	No. of Estimated Parameters	Deviance
N(.) p=c[1](.)	0.00	0.31	1.00	2	21.70
N(survey type) p=c(survey type)	0.72	0.22	0.70	3	20.38
N(.) p=c(survey type)	0.84	0.21	0.66	3	20.50
N(survey type) p=c(.)	2.03	0.11	0.36	3	21.69
N(.) p=c(t)	2.36	0.10	0.31	4	19.97
N(survey type) p=c(t)	4.42	0.03	0.11	5	19.96
N(survey type) p=c(survey type × t)	7.12	0.01	0.03	7	18.49
N(.) p=c(survey type × t)	7.23	0.01	0.03	7	18.60

[1] capture and recapture probabilities were modeled to be equal

Chapter 5

POINT-COORDINATE CAPTURE-RECAPTURE TECHNIQUE TO PRODUCE UNBIASED CLOSED CAPTURE-RECAPTURE ESTIMATES OF MALE BURROWING OWL TERRITORY ABUNDNANCE

JEFFREY A. MANNING AND CAREN S. GOLDBERG

ABSTRACT. Due to the extent of the distribution and high abundance of Burrowing Owls in the HCP Study Area, an efficient and reliable method of surveying is needed. Here, we address Amendment 2, and present the results from developing a closed-population capture-recapture survey technique that relied on a swift recording of each Burrowing Owl's location. We developed this method to provide a cost effective method of surveying owls in the HCP Study Area, where other methods of surveying could be costly or hampered by the high density of owls. We formalized, tested, and validated the technique, showing that it produced unbiased estimates of male Burrowing Owl territory abundance.

INTRODUCTION

Many methods used to obtain abundance estimates for wildlife populations involve some form of closed-population capture-recapture sampling (Williams et al. 2002). Capture-recapture methods stem from a strong statistical and theoretical foundation and long history involving mobile animals (Petersen 1896, Otis et al. 1978, Williams et al. 2002). The general principle of capture-recapture methods is to uniquely tag individuals in a first capture occasion and record the proportion of tagged individuals in subsequent recapture occasions, with information about the detectability of organisms obtained from the recapture information of individuals (Williams et al. 2002). However, the intensive effort required to capture and tag individual animals (e.g., see Seber 1982:93 for a list of methods) can render capture-recapture methods cost prohibitive in some cases (Otis et al. 1978, Pollock et al. 1990, Petitt and Valiere 2006). Moreover, these techniques may be impractical in instances where tagging is difficult or when the population is widespread or abundance spatially variable, and the disturbance of capture activities may be incompatible with conservation strategies for sensitive species (Royle and Nichols 2003, Royle 2004). Alternatives to physically capturing and tagging animals in capture-recapture studies may reduce effort and cost, thus enabling conservation and management programs, such as that proposed for the Burrowing Owl in the HCP Study Area, to conduct annual population monitoring.

As an alternative to physically marking Burrowing Owls in the HCP Study Area, we proposed collecting point coordinates of burrowing owls during multiple occasions to generate capture-recapture encounter histories (Section 5.2 of Qualification Request #531: Final Detailed Study Approach for a Burrowing Owl Population Study). This novel approach does not require that individual owls be physically marked, but rather their point coordinates recorded and used to generate 'new' captures and recaptures. A primary concern with this technique is the effect of misidentifying individual owls because owls move within their home ranges among survey occasions. Here, misidentification consists of 2 types of error: intrusion by neighbors and misidentifying recaptures as 'new' individuals. However, Kendall (1999) found that closed-population methods are robust to completely random movement by individuals in and out of a study area, and that estimates remain unbiased under this scenario. Equivalently, if the types of misidentification associated with using point coordinates are random, unbiased estimates of burrowing owl abundance may be attainable from encounter histories generated from point-coordinate-based survey data in the HCP Study Area.

We assessed the effects of these sources of misidentification on population estimates obtained from capture-recapture analyses computed from point-coordinate-based encounter histories. The objective of this study was to assess the probability that a 'recapture' was recorded when a pair was not seen in the buffer and effects of buffer size, detection probabilities, and owl density on the bias and precision of population estimates computed using encounter histories developed from point-coordinate data. We were particularly interested in identifying a standardized buffer width that could be used to surround each point coordinate to generate capture-recapture encounter histories.

We thank Dr. Bryan Manly (West, Inc., 2003 Central Avenue, Cheyenne, WY 82001, bmanly@west-inc.com) for his review and suggestions to perform simulations, which greatly improved the analysis. He also provided a letter to Brad Norling of the Imperial Irrigation District, dated August 22, 2007, concluding that the recommendations provided in this chapter represent the best approach.

METHODS

1. Collected field data between April 11-May 2, 2007
2. 40 individual burrowing owls from 40 breeding territories (Figure 5.1).
3. Individuals were believed to be males because they were visible much of the time during the peak period when females were anticipated to be on eggs.
4. Leg-banded most, but not all, individuals with unique numbers before April 11.
5. Conducted 13-hr continuous observations (0600-1900)/individual.
6. Recorded point coordinates of owl perch locations every 15 minutes when visible (n=1,400) using a Trimble GeoXM GPS, rangefinder, and compass with <3m accuracy. The flat agricultural landscape enabled us to maintain sight of owls even when they traveled far distances.
7. Considered the burrow entrance with the greatest amount of sign (e.g., excrement, pellets, feathers, tracks) in each territory to be the primary burrow entrance, recorded its GPS location, and used ArcGIS 9.2 (ESRI, Redlands, CA) to measure the distance between each owl's location and its primary nest burrow entrance.
8. Computed 95% fixed kernel home range utilization distributions for each owl, based on likelihood cross validation smoothing because likelihood cross-validation has been shown to be a better procedure for small sample sizes and for obtaining more accurate estimates in high use areas then other methods (Horne

and Garton 2006). This was intended to assess the level of overlap among neighboring owls.

9. Created 15 Monte Carlo datasets (each containing 4 survey occasions) by bootstrapping the original field sample to mimic our actual 4-occasion survey effort across the HCP. We decided on using 15 subsamples rather than the originally proposed 30 because variances with 15 were sufficiently small. We applied a constant detection probability (0.7), based on the average probability during diurnal periods (see Chapter 2), by randomly removing 12 of the 40 observations from each occasion.
10. These bootstrapped data were used to create capture-recapture encounter histories by buffering point coordinates with various buffer radii, generating centroids for each individual, and using the buffer radius specified to assign the latter occasion's point coordinates as existing or new individuals by the following rules:
    a. Owl point coordinate locations recorded on occasion 1 were considered as new individuals.
    b. Owl locations from occasion 2 were determined to be recaptures if they were the closest location of a location in occasion 1 and buffers from each location overlapped. All other owls from occasion 2 were considered as new individuals.
    c. We computed a center location (centroid) for owls that were observed in both occasions.
    d. Owl locations from occasion 3 were determined to be recaptures if they were the closest location to a centroid or a location from occasions 1 or 2 that were captured only once and buffers from the previous and new location overlapped. All other owls were considered to be new individuals.
    e. We computed a centroid for all owls that were captured in 2 or more occasions.
    f. Owl locations from occasion 4 were determined to be recaptures if they were the closest location to a centroid or location from occasions 1, 2, or 3 that were captured only once and buffers from the previous and new location overlapped. All other owls were considered to be new individuals.
11. Calculated the probability that encounter histories would contain misidentified owls (owls identified as their neighbor due to their location and neighbor's non-detection).
12. Computed closed-population, capture-recapture estimates of population size ($\hat{N}$) for each bootstrapped sample using the standard model structure [*N*(subsample) *p*=*c*(.)]; models were developed using the closed captured model with the sin link function available in Program MARK (Cooch 1999, White and Burnham 1999).
13. Computed mean estimates of population size and 95% confidence intervals for each buffer size and compared them to true (known) numbers.
14. Conducted additional simulations to test for the effects of detection probability on population estimates given the optimal buffer size.
15. Tested the effects of owl density on point-coordinate capture-recapture population estimation using additional Monte Carlo simulations with the same parameters as

for the full dataset for 2 survey routes of different densities (7 owls/km and 15 owls/km).

Figure 5.1. Point coordinate locations (n=1,400) of 40 individual burrowing owls at 8 randomly selected locations, Imperial Valley, California 2007.

RESULTS

The mean maximum distance between all locations of each owl was 89.2 m (95% CI: 66.9 to 111.5 m), the mean maximum distance moved (MMDM) from a nest was 58.4 m (95% CI: 46.2 to 70.5), and densities ranged from 7-15 nests/km.

Likelihood Cross Validation Fixed Kernel Home Range Sizes of Burrowing Owls and Volume of Overlap by Neighboring Owls

We used the 15-minute diurnal locations to compute fixed kernel home ranges, from which we assessed volume of home range overlap for neighboring owls. We found that on average, the amount of overlap that occurs between neighboring territorial Burrowing Owls is negligible (Mean = 0.8%, 95% CI = 0-1.9%). Such a low level of overlap suggests that misidentification of neighboring owls while using the point-coordinate-based closed capture-recapture approach used here may not occur often in the Imperial Valley agricultural matrix.

However, portioning the 2 sources of misidentification out into its constituent parts showed that the probability that a correct owl (i.e., the owl actually occupying the territory being sampled) is present for detection rapidly decreased with distance from its nest burrow, and that probability approximated zero at 110 m from the burrow (Figure

5.2). As expected, the probability that a wrong owl (i.e., neighboring owl) is present for detection in the territory being sampled increases with distance from the correct owl's nest (Figure 5.2). In other words, the closer an owl was to an active burrow when detected, the higher the probability that it was the correct owl and the lower the probability that the owl was the wrong owl, as suggested by the utilization distributions presented in chapter 2.

This expected interaction between these 2 sources of misidentification with buffered point-coordinates was the impetus for the following bootstrapping analyses.

Probability that a Recapture is Recorded when the Breeding Pair is Unavailable for Detection in the Buffer

Given a constant buffer radius approximately equal to the MMDM (55 m), a constant detection probability (0.7), 4 encounter occasions, and 40 original owls, there were 48 instances in each Monte Carlo simulation where a breeding pair was unavailable for detection.

Monte Carlo simulations indicate that the mean probability that a 'recapture' would be recorded when a pair is not available for detection, given the simulation conditions, is 0.085 (N = 15, SE = 1.1). This occurred when the correct owl was not observed, but a neighboring owl was falsely identified as the missing owl. Overall, for a survey under these conditions, the probability of this form of misidentification occurring is 0.025 (N = 15, SE = 0.3) for each observation.

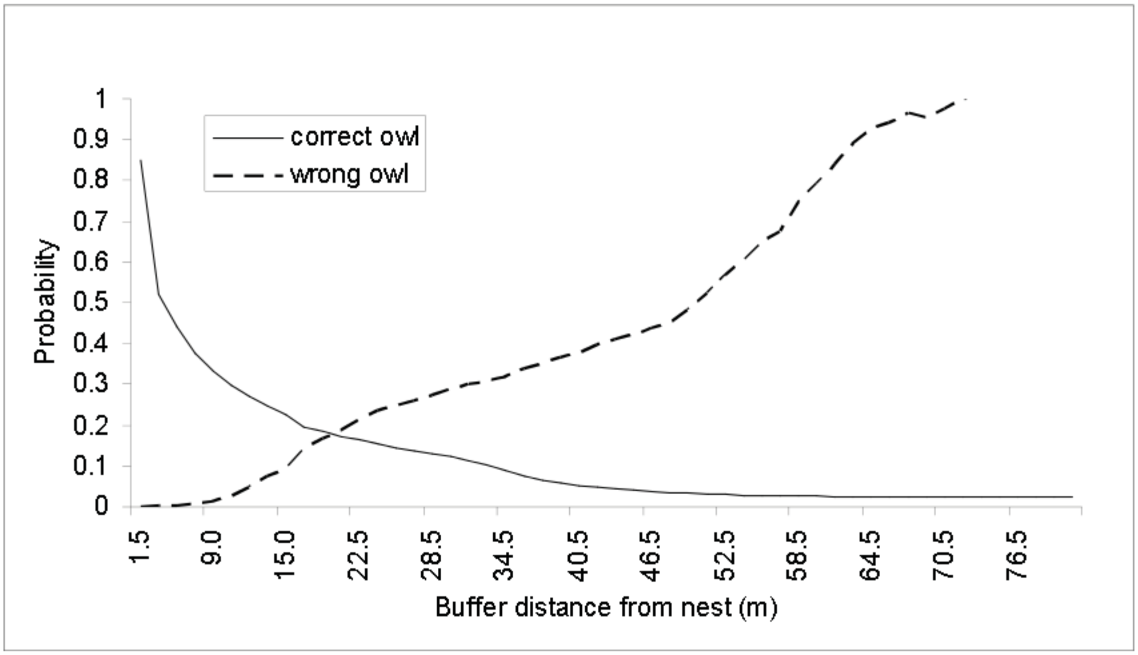

Figure 5.2. Probabilities that the correct and wrong male Burrowing Owls are present and available for detection at increasing distance from the correct owl's nest, Imperial Valley, California, April 2007.

Effects of Buffer Size on Population Estimates

Monte Carlo simulations with a constant detection probability of 0.7 indicated that the buffer radius that produced highly precise and unbiased population estimates was 55 m, approximately equal to the MMDM (Figure 5.3). These results also suggest that the effect of misidentification of individual owls as neighbors is minimal on population estimates relative to effects of misidentifying a recapture as a 'new' individual.

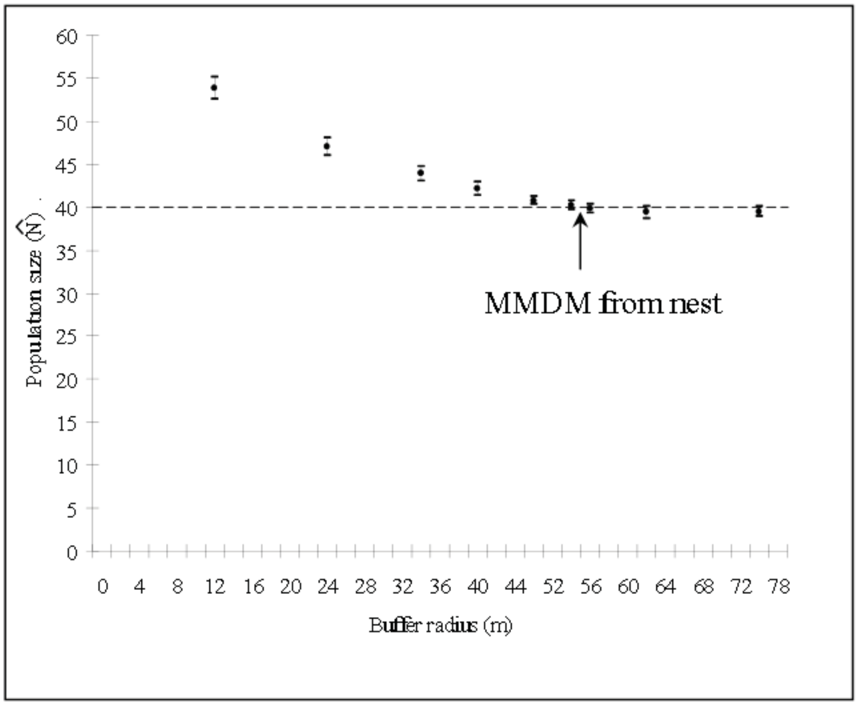

Figure 5.3. Effects of buffer size (radius) surrounding burrowing owl capture-recapture point coordinates on closed-population estimates, Imperial Valley, California. Dotted line represents true N. Vertical bars are 95% CI. Estimates are from closed-capture models [N(rep) p(.)=c(.)]; data bootstrapped from 15-min locations (with p-hat=0.7) recorded consecutively from 0600-1900 for 40 male breeding burrowing owls from April-May, 2007.

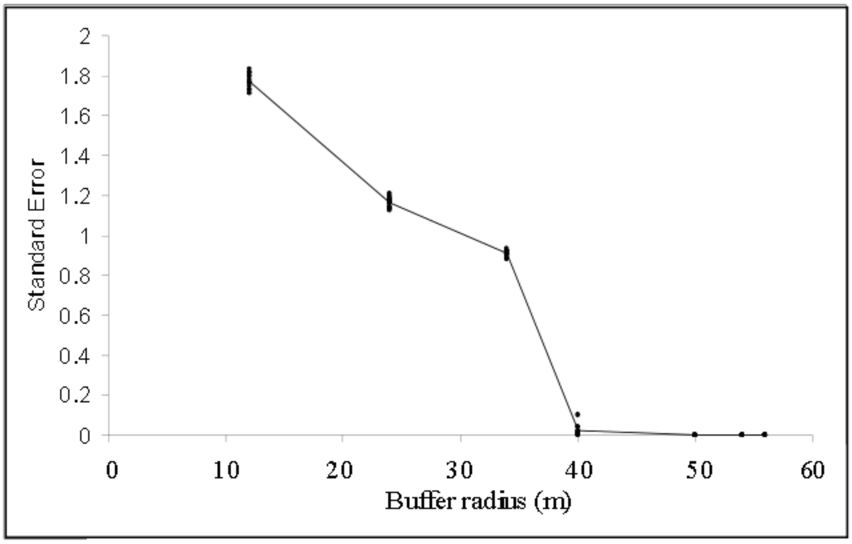

Figure 5.4. Effects of buffer size (radius) surrounding capture-recapture point coordinates of male Burrowing Owls on the standard error of closed-population estimates, Imperial Valley, California. Vertical bars are 95% CI. Estimates are from closed-capture models [N(rep) p(.)=c(.)]; data bootstrapped from 15-min locations (with p-hat=0.7) recorded

Effects of Detection Probabilities on Population Estimates

We found that the high level of accuracy obtained by buffering point coordinates with a buffer radius equal to the MMDM was robust to varying detection probabilities between 0.6 and 0.9, yielding relatively unbiased, precise estimates of male Burrowing Owl territory abundance (Figure 5.5). Detection probabilities near 0.6 may produce slightly biased low (~1%) population estimates and 0.9 slightly biased high (~1%) from the true number, but the true number fell within all 95% CIs (Figure 5.5).

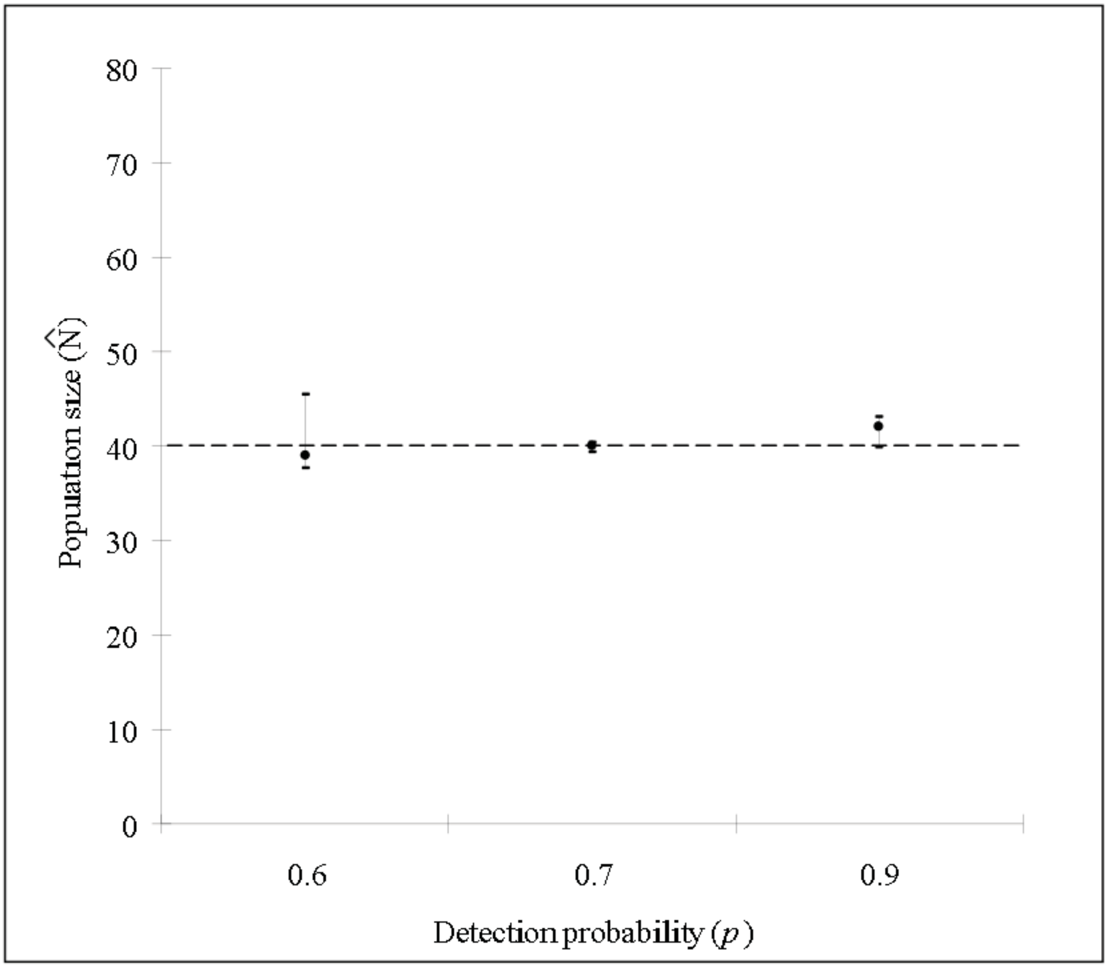

Figure 5.5. Effects of detection probabilities on burrowing owl population estimates based on a 55 m buffer surrounding capture-recapture point coordinates, Imperial County, California 2007. Dotted line represents true N. Vertical bars are 95% CI.

Effects of Density on Population Estimates

The following results are based on a fixed buffer = 55 m and a constant detection probability (0.7) and used a Monte Carlo simulation as above to create datasets representing 4 capture survey occasions along these 2 routes.

Low density (6 adjacent owls where the linear density = 7 owls/km)

Mean $\hat{N}$ = 6.1, 95% CI: 5.8 to 6.5

This $\hat{N}$ approximates the true N = 6 with reasonably good precision that encompasses the true N.

High density (7 neighboring owls where the linear density = 15 owls/km)

Mean $\hat{N}$ = 7.1, 95% CI: 6.8 to 7.5

This $\hat{N}$ approximates the true N = 7 with reasonably good precision that encompasses the true N.

CONCLUSIONS AND RECOMMENDATIONS

We found that buffering burrowing owl point coordinates with a 55 m radius circle yielded relatively precise, unbiased estimates of burrowing owl abundance that we believe are adequate for estimating annual burrowing owl abundances across the HCP on an annual basis. The 55 m radius circle essentially enabled us to identify locations from subsequent survey occasions that were the closest within 110 m from previous locations as recaptures, which corroborates with the results presented in figures 2.3 and 5.2. Our results suggest that the misidentification errors due to using point-coordinate-based encounter histories in capture-recapture analyses are random and therefore do not introduce bias into estimates of population abundance (Kendall 1999). This is because when a neighboring owl is misidentified as a recapture in its neighbor's buffer when its neighbor is undetected, the misidentified pair receives a 'zero' in its encounter history, thereby maintaining the constant probability of detection for the cohort in that occasion.

This technique produces encounter histories that provide unbiased, precise population estimates from currently available capture-recapture models. Consequently, in combination with the low level of measurement error associated with acquiring point-coordinate locations (see Appendix II for details), we believe this approach is well suited for population-level analyses. However, use of point coordinates recorded by observing vagile species like owls leads to shifting of encounters among neighboring individuals in an occasion, which can lead to unreliable estimates of detection probabilities at the level of individual animals. Thus, we (and Dr. Bryan Manly, personal communication) do not advocate the use of point coordinate capture-recapture encounter histories for estimating parameters in individual-based analyses (e.g., use of individual covariates).

This point coordinate technique is suitable for surveying Burrowing Owls in the HCP because it:

1. produces: A. unbiased, precise estimates of abundance,

2. is robust to: A. variable probabilities of detection among encounter histories and
B. variable densities, and

3. assumes: A. high probabilities of detection (>0.6)

The Imperial Valley agricultural matrix supports conditions that meet these assumptions. Thus, we believe that the point-coordinate capture-recapture technique is an efficient technique to obtain unbiased estimates of male Burrowing Owl territory abundance in that area.

Chapter 6

NUMBER OF SURVEY OCCASIONS

JEFFREY A. MANNING AND CAREN S. GOLDBERG

ABSTRACT. Cost benefit information is always beneficial in designing population monitoring programs. We evaluated the minimum number capture-recapture survey occasions needed in the HCP Study Area to calculate accurate estimates of population size. We found clear evidence that a minimum of 3 survey occasions were necessary when using the point-coordinate capture-recapture technique to achieve an acceptable level of accuracy in estimating the abundance of male Burrowing Owl territories. Three survey occasions nearly doubled the precision of population estimates compared to using only 2 occasions, and a retrospective power analysis showed that ¬4 occasions provided little improvement over the 3, indicating that an increase in the number of surveys beyond 3 did not appreciably improve power, and doing so would only be at an unnecessary expense.

INTRODUCTION

To ensure accuracy of estimated owl abundances in the HCP Study Area while minimizing costs, it is essential that detection probabilities, level of effort, and sampling/analysis methods be carefully selected prior to starting the formal population-level study. To reduce cost while maintaining accuracy, it is important to determine the minimum amount of effort necessary to achieve an acceptable level of accuracy.

One type of field sampling effort associated with the approach we proposed for estimating abundance relates to the number of repeated surveys (occasions) needed to obtain accurate estimates of population size each year. As described in the original proposal, repeated survey occasions are a necessary part of the proposed closed population capture-recapture method. The original proposal called for 2 occasions. However, further insight into the existing literature on Burrowing Owls led to recommending alternatives to using only 2 occasions, as described in the letter from Bloom Biological Inc. to Bruce Wilcox dated February 24, 2006, one of which was the addition of a pilot study.

We conducted a pilot study of point-coordinate capture-recapture surveys of Burrowing Owls across approximately 412 randomly selected km of IID right-of-way in the HCP Study Area to assess the minimum number of sampling occasions required to obtain accurate estimates of population size. This was followed by prospective power analyses to elucidate the statistical power behind the minimum number of repeat sampling occasions that we identified. We assessed the accuracy of population estimates ($\hat{N}$) by their corresponding coefficients of variation ($CV(\hat{N})$). The $CV(\hat{N})$ reflects precision, and an acceptable level of precision for reliable scientific studies is considered to be 0.1 (White et al. 1982).

These initial analyses were based on 20-m buffer around each owl location to generate capture-recapture encounter histories, followed by fitting maximum-likelihood, closed-population models (Cooch and White 2006) to each capture-recapture encounter history dataset. These preliminary analyses led us to initially conclude that 4 capture-recapture survey occasions were necessary to achieve reasonably accurate estimates of male Burrowing Owl territory abundance. However, an independent peer reviewer raised several concerns regarding this buffer size, which instigated our development of the Monte Carlo simulations of the point-coordinate capture-recapture technique in 2008, as described in Chapter 5.

In order to determine the minimum number of repeat sampling occasions required to achieve accurate estimates of population size, in this chapter, we reanalyzed the 2006 data using the new analytical point-coordinate capture-recapture technique, with the mean maximum distance moved (55m) as the buffer radius (see Chapter 5 for details).

METHODS

Field Surveys

We conducted diurnal, capture-recapture surveys for Burrowing Owls from April 16-May 20, 2006 using the following detailed methods:

1. Randomly selected 64 replicate survey routes (each approximately 6.4 km in length; Figure 6.1).
2. Conducted surveys for approximately 1-hour in each replicate route at approximately the same time of day (between 0630-1830, excluding 1230-1330) for 6 consecutive days (occasions).
3. Used 1 vehicle/route (each having a driver and observer) to conduct visual surveys at 7 mph. Vehicle was positioned so observer was closest to drain/canal, observer surveyed passenger side of vehicle, and driver provided incidental observations from in front of vehicle.
4. Stopped at every 1 Burrowing Owl(s), and recorded the following information:

    A. Date
    B. Time
    C. Location, based on:
        i. GPS coordinates (Trimble GeoExplorer XM with GPS slider set halfway to balance productivity with precision and postprocessed differential correction)
        ii. Compass heading to owl/nest from observer (Suunto Handheld Directional Compass)
        iii. Distance to owl/nest from observer (Opti-Logic Laser Rangefinder with ±1 m accuracy)
    E. Type of location (nest burrow, no nest, flying, perched)
    F. Number of owls (1, 2, 3, …n)

5. Avoided errors in detection by not looking past the vehicle after stopping at an owl (except to track an owl that moved in order to avoid double counting) and not backtracking route.

Data Processing and Analyses

Processing and analyses of Burrowing Owl closed-population capture-recapture data entailed 3 general steps:

1. Development of capture-recapture encounter histories

    A. We used the point coordinate technique with a 55m radius buffer (which corresponds to the mean maximum distance moved (see Chapter 5))
    B. Created 5 individual encounter histories from the 64 routes:
        i. Encounter history dataset 1: First 2 occasions
        ii. Encounter history dataset 2: First 3 occasions
        iii. Encounter history dataset 3: First 4 occasions
        iv. Encounter history dataset 4: First 5 occasions
        v. Encounter history dataset 5: First 6 occasions

2. Closed population modeling

    A. Fit maximum-likelihood, closed-population models (Cooch 1999) to each capture-recapture encounter history dataset.
    B. Used the sin link function to link model coefficients to matrices because it allows for better estimation of the number of estimable parameters and of the shape of the log-likelihood function at its maximum, while constraining its parameter to be within 0-1 (White and Burnham 1999).
    C. Used deviance plots to heuristically assess model fit.

3. Minimum number of repeat sampling occasions needed to achieve accurate estimates of population size

    A. Computed coefficients of variation (CV) for each population estimate and plotted them against the number of survey occasions (Figure 6.2).
    B. Determined the minimum number of repeat survey occasions necessary for obtaining reliably precise estimates by identifying the number of survey occasions needed to achieve a $CV(\hat{N})$ 0.1. We chose this cutoff because "reliable scientific studies … should try for a $CV(\hat{N})$ 0.1" (White et al. 1982:50).
    C. Performed retrospective power analyses (Kuehl 1994, Steidl and Thomas 2001) with a specified range of effect sizes (changes in annual population size) to assess the relative statistical power of detecting a change in population size between the 5 encounter history datasets (2, 3, 4, 5, and 6 occasions). We used a one-tailed test (because adaptive management would be triggered only when the population would decline), an =0.05,

and empirically based estimates of population size associated with the 5 encounter history datasets. We chose a range in population changes to yield power curves that would illustrate differences among sampling design scenarios and various changes in annual population sizes since an acceptable level of population change has yet to be determined for the demographic study (section 4.5.3 of the HCP Plan, dated June 2002).

RESULTS

Capture-recapture Results

We successfully computed CV($\hat{N}$)s and $\hat{N}$s for 300 of the 320 possible encounter histories (1 encounter history file for 2, 3, 4, 5, and 6 repeat sampling occasions x 64 routes). The 20 that were not estimated were generally those corresponding to low numbers of occasions (and hence low effective sample sizes), preventing the convergence of model likelihoods. The average detection probability was 0.63.

Minimum number of repeat sampling occasions needed to achieve accurate estimates of population size

1. Minimum number of repeat survey occasions to achieve a CV($\hat{N}$) 1 was 3.
2. Statistical power of detecting a change in the Burrowing Owl population increases with an increase in survey occasions; there was a marked increase in power from >2 occasions (Figure 6.3A).
3. Statistical power began to asymptote at 3 occasions (Figure 6.3B).

CONCLUSIONS AND RECOMMENDATIONS

We found clear evidence that a minimum of 3 survey occasions are necessary when using the point-coordinate capture-recapture technique in order to achieve an acceptable level of accuracy in estimating the abundance of male Burrowing Owl territories in the HCP Study Area. Three survey occasions nearly doubled the precision of $\hat{N}$ compared to using only 2 occasions. This high level of precision stemmed from our using 3 capture-recapture occasions on a species with high detection probabilities. For example, given the average detection probability/occasion we found here (0.63), the probability of that we <u>did</u> <u>not</u> detect a territory 1 times during the 3 occasions was 5.0% [i.e., $(1\text{-}0.63)^3$]; thus, the probability that we <u>did</u> detect a territory 1 times over the 3 occasions was 95.0% [i.e., $1\text{-}(1\text{-}0.63)^3$].

Our prospective power curve analyses showed that 3 occasions provided a marked increase in statistical power to detect a change in the annual Burrowing Owl population size compared to using 2 occasions. For example, the power curve associated with 2 occasions consistently provided the least power to detect a change at any level, and the addition of 1 more survey occasion increased power by as much as 11%. Coinciding with this increase, 4 occasions provided little improvement over 3, indicating that an increase in the number of surveys beyond 3 did not appreciably improve power, and doing so would only be at an unnecessary expense (effort). Additionally, we advise against the use of only 2 occasions because that level of effort does not allow for the complex testing of assumptions and subsequent selection of a model from which to obtain unbiased estimates. Furthermore, the power curves began to asymptote at 3 occasions, substantiating the minimum number required to obtain the highest power to detect a change in abundance.

Prospective power analyses like these can aid in the development of future Burrowing Owl capture-recapture sampling designs because they provide a probability that a specified change in annual population change could be detected (Peterman 1990). Based on our results, we conclude that all vehicle-based point-coordinate capture-recapture surveys of Burrowing Owls (following our protocols) in the HCP should conduct 3 consecutive occasions. Fewer than 3 may provide poor accuracy and more than 3 may be an unnecessary expense.

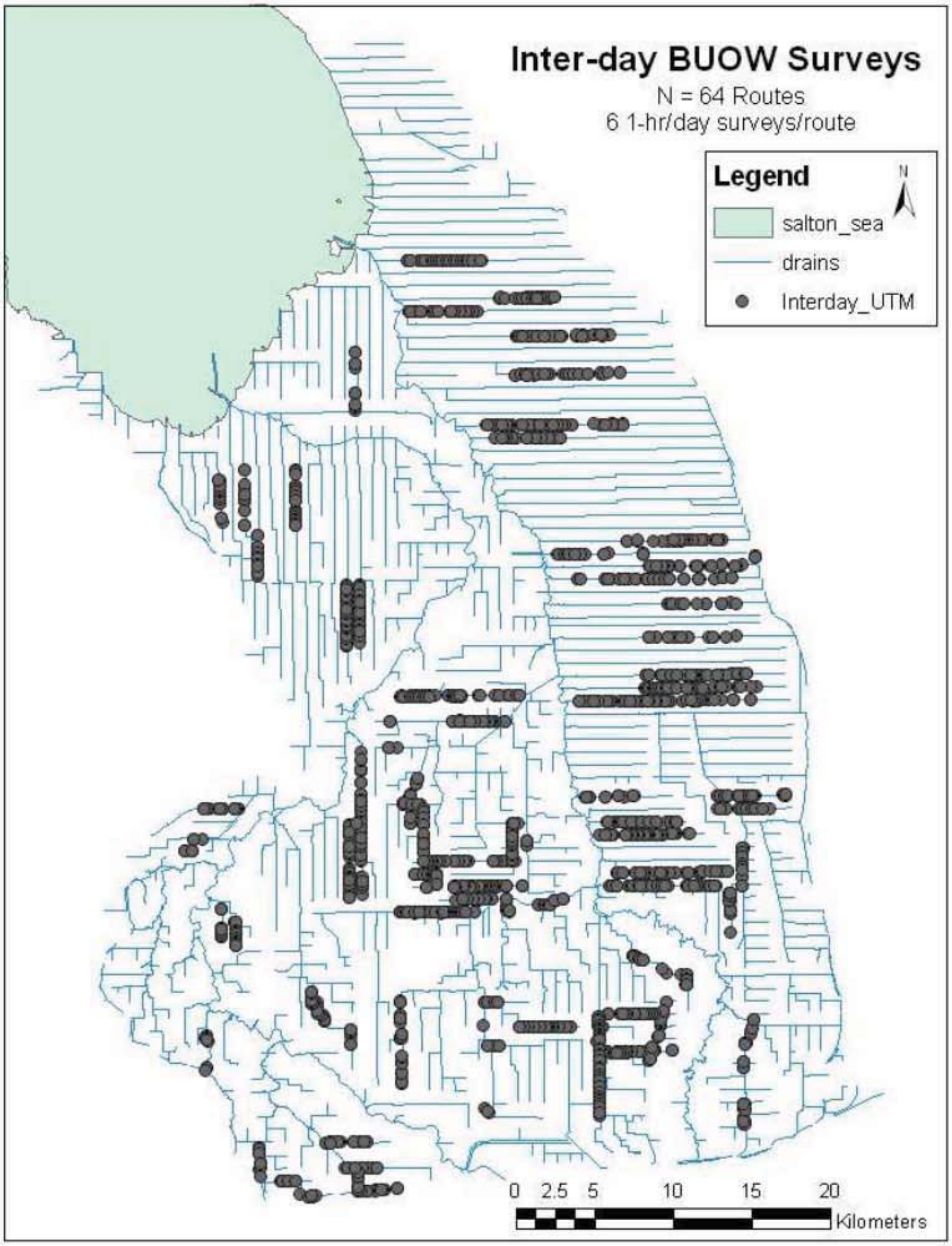

Figure 6.1. Routes where 6 consecutive days of diurnal, capture-recapture surveys were conducted for Burrowing Owls in the HCP Study Area, Imperial County, California. Points represent individual owl locations, April 16-May 20, 2006.

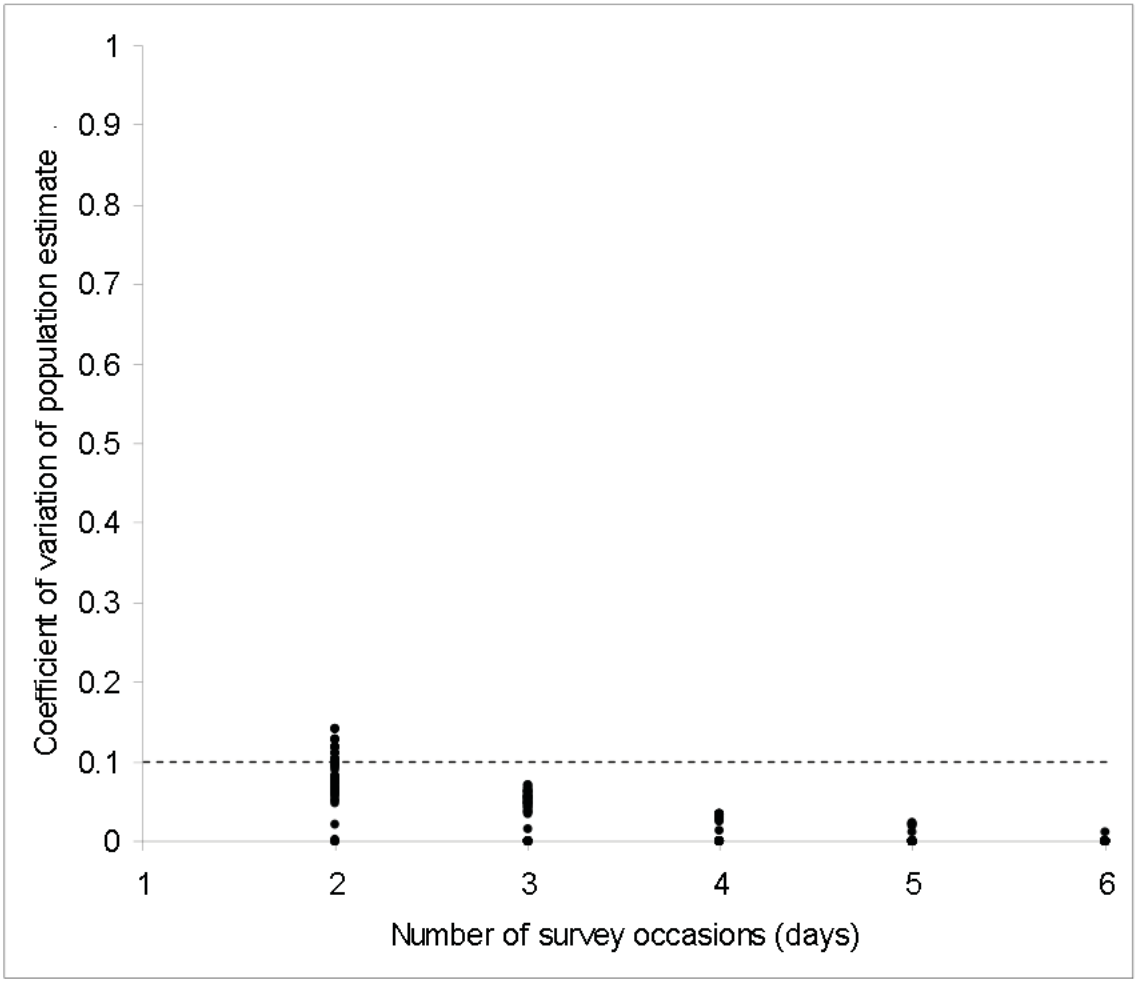

Figure 6.2. Coefficients of variation of population size as a function of the number of repeat survey occasions for male Burrowing Owl territories in the HCP Study Area, Imperial County, California, April 16-May 20, 2006. "Reliable scientific studies … should try for a CV($\hat{N}$) 0.1" (White et al. 1982:50).

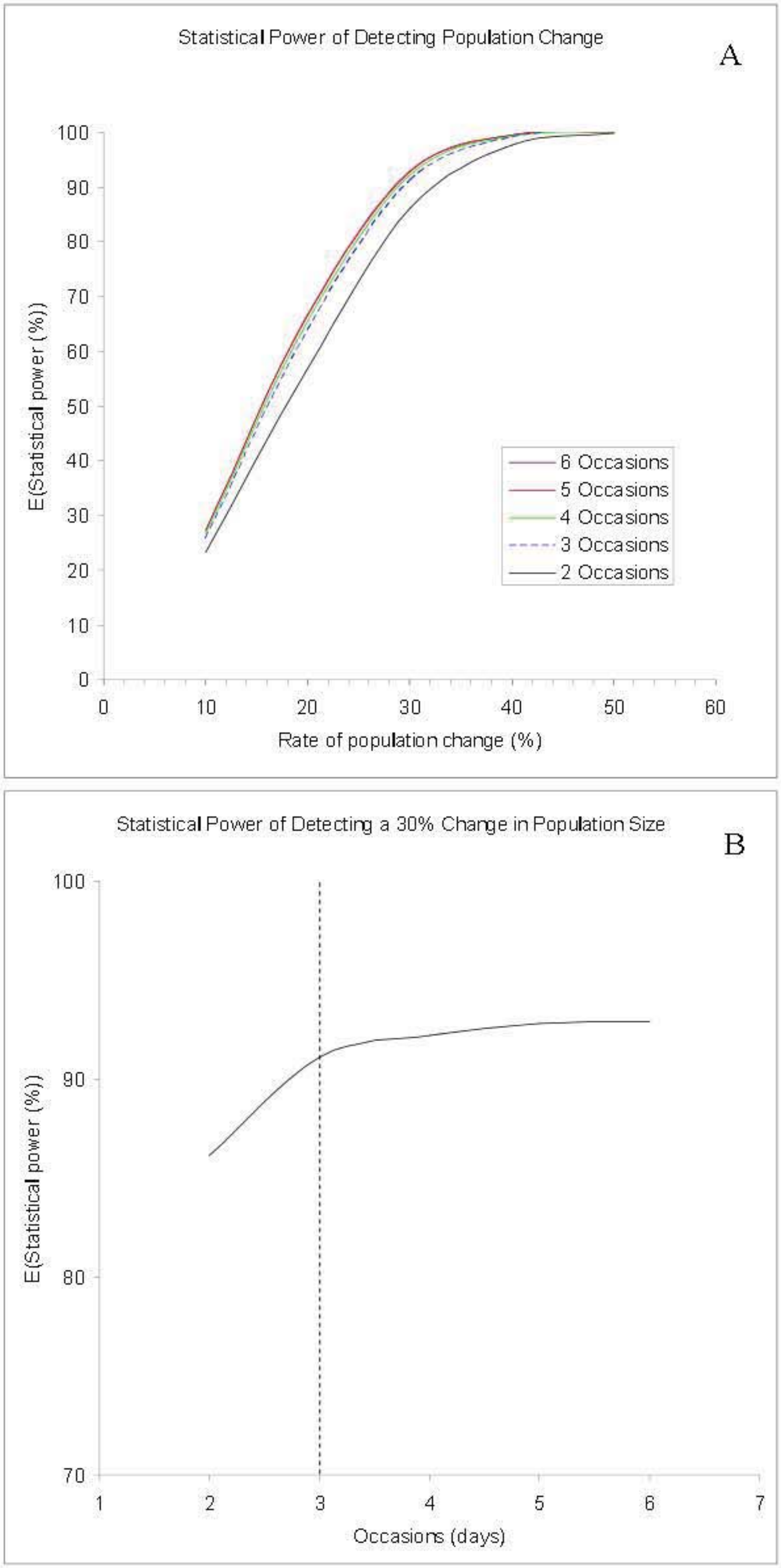

Figure 6.3. Retrospective power curves for various rates of Burrowing Owl population change (indexed by changes in population size) in the HCP Study Area, Imperial County, California, April 16-May 20, 2006. Power curves are in vertical order listed in legend.

Chapter 7

CLOSED-POPULATION CAPTURE-RECAPTURE SURVEYS IN 2007

JEFFREY A. MANNING

ABSTRACT. In this chapter, I present the results from conducting a complete census of male Burrowing Owl territories in the HCP Study Area during the prehatch stage of the breeding cycle in 2007 using the point-coordinate capture-recapture technique.

INTRODUCTION

Closed-population, capture-recapture methodology is a powerful approach for estimating the abundance of male Burrowing Owl territories in the Imperial Valley. This technique is based on marking and recapturing animals during repeated survey occasions. Repeated surveys are required to increase probabilities of detecting male owl territories and accuracy of population estimates (Otis et al. 1978). Generally, greater numbers of survey occasions increase the accuracy of population abundance (Otis et al. 1978, White et al. 1982). There is an optimal number, beyond which additional surveys would not improve accuracy appreciably and thus would constitute wasted effort. Based on preliminary analyses from a pilot study in 2006, we initially suggested that 4 occasions were appropriate; we therefore completed 4 survey occasions in 2007. However, as we reported in Chapter 6, a recent reanalysis of that data led us to recommend that the application of the point-coordinate capture-recapture survey technique to estimate the size of the owl population in the HCP Study Area requires only 3 survey occasions to achieve an optimal level of effort when following our survey protocols.

Achieving accurate population estimates from closed-population sampling methods depends on meeting the critical assumption of population closure (no emigration, immigration, births, or deaths) (White et al. 1982). We met this assumption demographically by conducting point-coordinate surveys in a brief period (30 days from April 2-May 3), which coincided with the prehatch stage of the breeding cycle, when females incubate and males remain sentinel outside the nest entrance (Martin 1973, Plumpton and Lutz 1993). This period began after migrant owls were thought to have departed from the Imperial Valley, ended prior to resident owls fledging young, and coincided with minimal movements of resident males away from burrows. The majority of resident females should have already been pair-bonded with males by the start of this period, and have been spending the majority of their time in the burrow. Thus, we minimized the risk of biasing estimates of male owl territories in the HCP Study Area by avoiding migrant and fledgling owls and surveying when males were expected to exhibit minimal movements away from nest burrows while females were unavailable for accidental double counting.

METHODS

We conducted diurnal, capture-recapture surveys for Burrowing Owls from April 2 – May 3, 2007 using the following detailed methods:

1. Conducted 4 point-coordinate survey occasions (1 occasion/day) along every IID right-of-way that paralleled an aboveground water conveyance structure (canal and/or drain) in the HCP Study Area. During each survey occasion, the vehicle traveled one side of an isolated drain or canal Where 2 water conveyance structures paralleled multiple access roads within a single right-of-way and the field of view could be compromised by distance between the water conveyance structures (roughly 60 m) or topography, a survey was conducted on >1 of the roads to ensure complete survey coverage of the right-of-way while care was taken to not survey the same water conveyance structure twice (i.e., each water conveyance structure was surveyed from only one side).
2. Conducted diurnal, visual surveys by traveling the same direction during all 4 surveys.
3. Conducted the 4 surveys at approximately the same time of day (½-hr after sunrise to 1130 and 1600 to ½-hr before sundown) to avoid issues with reduced availability of owls during midday:
   April 2-11: 0700-1130 and 1600-1830
   April 12-23: 0650-1130 and 1600-1845
   April 24-May 3: 0640-1130 and 1600-1850

4. Randomly partitioned the HCP Study Area into 6 routes (where a consecutive number of survey occasions completed along a route was considered to be a survey session; Figure 7.2), and completed each session with 1 vehicle (each having a driver and observer) traveling 7 mph in 4 days (e.g., 4 survey occasions/route). Vehicles were positioned so the observer was closest to drain/canal, observer surveyed passenger side of vehicle, and driver provided incidental observations towards the front of vehicle.
5. Stopped at every 1 Burrowing Owl(s), and recorded the following information (in 2 minutes) for the 1st owl detected at that stop and separately for any owl(s) >20 m from the first owl detected or in addition the first 2 owls seen:

   A. Date
   B. Time
   C. Location of burrow entrance <20m from the owl(s) that contained the highest number of signs of activity (e.g., an owl that retreats or flushes from burrow, regurgitated pellets, feathers, nest lining, whitewash, or footprints with an absence of cobwebs; Conway et al. 2008) or the closest burrow if multiple burrows revealed an equal amount of signs of activity. Location of owl, if no burrow is evident within 20 m.
      i. GPS coordinates (Trimble GeoExplorer XM with GPS slider set halfway to balance productivity with precision and postprocessed differential correction)

  - ii. Compass heading to owl/nest from observer (Suunto Handheld Directional Compass)
  - iii. Distance to owl/nest from observer (Opti-Logic Laser Rangefinder with ±1 m accuracy)
- D. Detection method
- E. Observed behavior (Flush/flying)
- F. Fate
- G. Type of location (nest burrow, no nest, flying)
- H. Number of owls (1 or 2)
- I. Type of perch:
  - i. At burrow entrance -- within the burrow entrance
  - ii. On bare ground -- on bare ground (with no veg or debris)
    -- on cement liner (with no veg or debris)
  - iii. Flying only -- never seen on the ground (wings flapping)
  - iv. On pppwdfh -- on fence post or stake
    -- on horizontal pipe
    -- on utility pole
    -- on utility or fence wire
    -- on debris pile (cement, dirt, gravel, other)
    -- on farm equipment
    -- on head gate

  - v. In or on vegetation -- in live or dead vegetation
    -- on live or dead vegetation
  - vi. In agricultural field -- in vegetated agricultural field
  - vii. On hay bale(s) -- on hay bale(s)
  - viii. Other -- any other structure or substrate, described
- J. Texture within an approximated 8-degree radius circle centered on the detected owl from observer's view. This was based on a 6-m radius circle surrounding an owl at 21 m from the observer because many vantage points for detecting owls were approximately 21 m from where owls often perched (across the water conveyance structure).
- K. Vegetation cover in the same circle used for measuring texture:
  - i. 0%
  - ii. 1-25%
  - iii. 26-50%
  - iv. 51-75%
  - v. 76-100%
  - vi. No vegetation because owl was silhouetted above horizon
  - vii. No vegetation because owl was detected in flight
- L. Leg band status:
  - i. Banded
  - ii. Unbanded
  - iii. Unknown
- M. Number of squirrels detected since previous owl location

6. Avoided errors in detection by not looking past the vehicle after stopping at an owl (except to track an owl that moved in order to avoid double counting) and not backtracking route in order to obtain detections primarily from the moving vehicle. If an owl was detected while not in the moving vehicle, the above information was recorded and a note that it was not detected from the moving vehicle.
7. Standardized observations by having the vehicle lights off, windows rolled up, come to a stop after passing detected owl to avoid flushing it forward into areas yet to be surveyed, and engine turned off upon stopping; also required all field biologists to participate in extensive training and field exercises; did not use cell phones, radio, and cameras while surveying.

This survey method essentially 'marked' or 'captured' each territory on the first date observed using global positioning system (GPS) coordinates. 'Recaptures' were successive recordings of GPS coordinates during subsequent sampling occasions, identified using the method described in Chapter 5.

RESULTS

We conducted 4 capture-recapture survey occasions along 3,960 Km of IID right-of-way that paralleled an above-ground irrigation canal and/or drain. We observed 3,461 male Burrowing Owl territories on the first capture-recapture occasion; on the second, we observed 3,685, the third 3,737, and the fourth had 3,748 (Figure 7.1). Owl locations by survey session are portrayed in Figure 7.2.

Obstacles that led to delays in our traveling along the IID right-of-ways included locked gates, farm equipment, piled hay bales, erosion, mud, sand, and restricted access to private property.

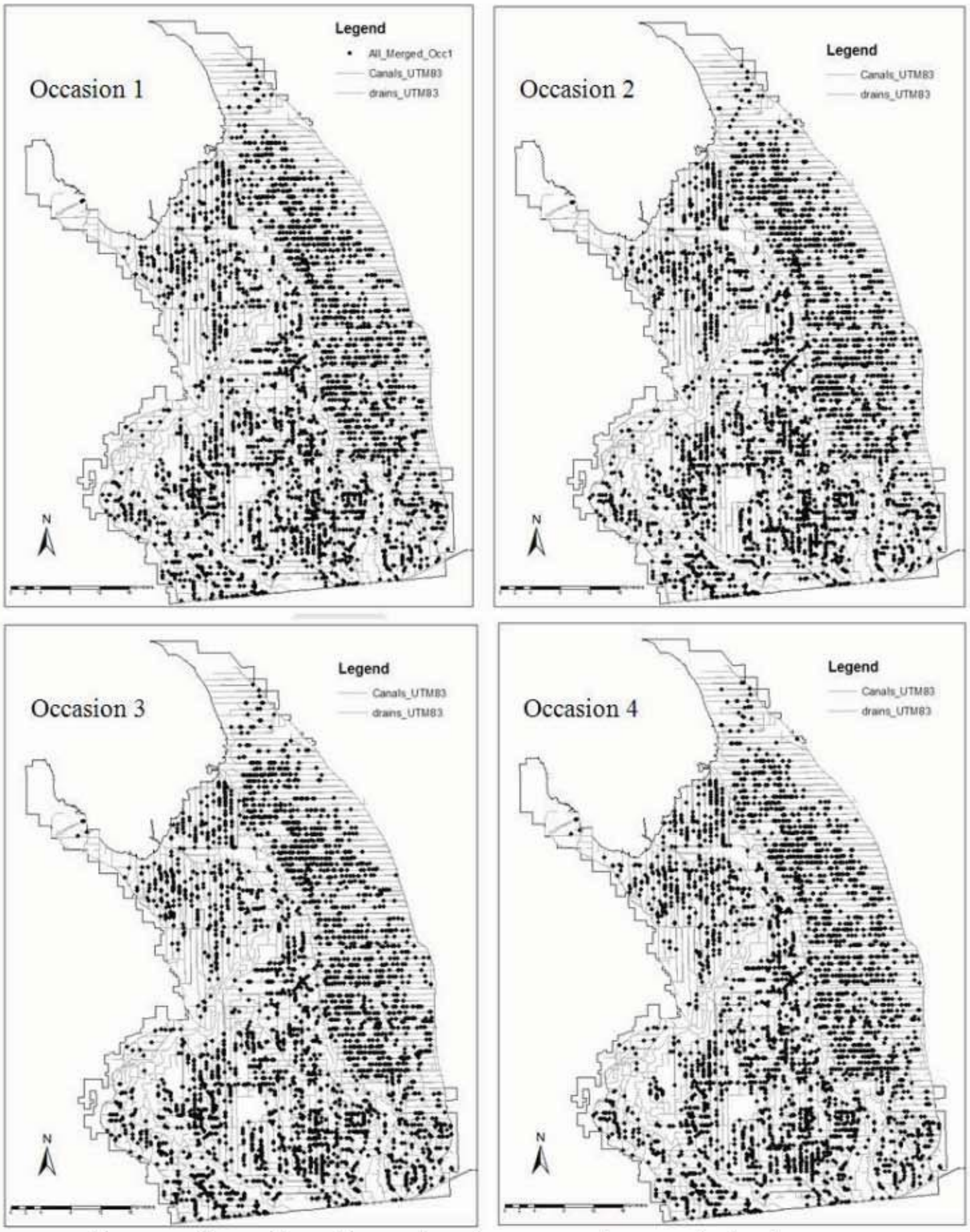

Figure 7.1. Point coordinate locations of male Burrowing Owls during capture-recapture survey occasions 1, 2, 3, and 4 from April 2-May 3, 2007.

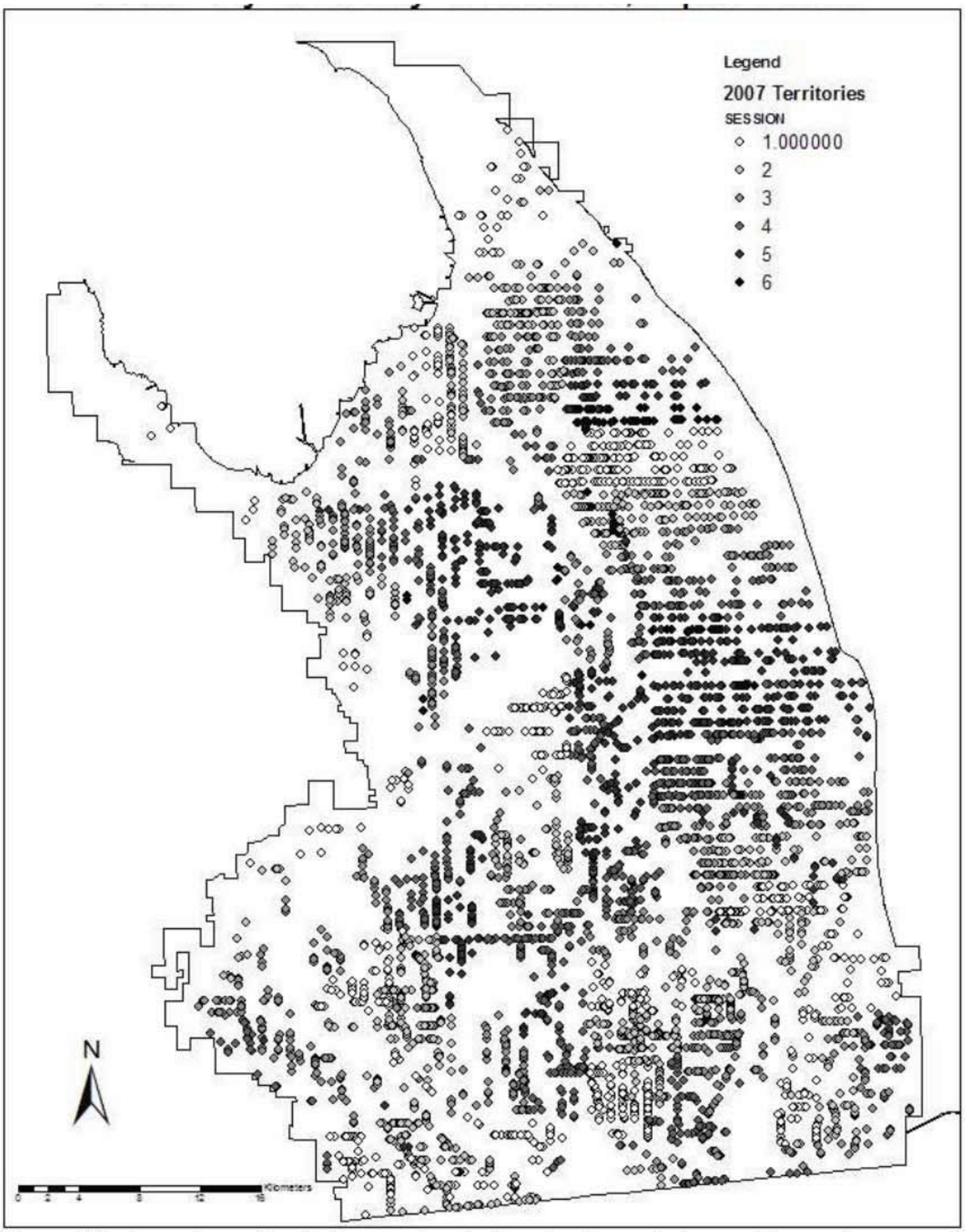

Figure 7.2. Locations of male Burrowing Owl territories coded according to 6 separate 4-occasion survey sessions during the prehatch stage of the breeding cycle across the HCP Study Area, Imperial County, California, 2007.

CONCLUSIONS AND RECOMMENDATIONS

These surveys of 3,960 Km of IID right-of-way that paralleled above-ground water conveyance structures during 6 4-day survey sessions over a 30-day period demonstrates that a complete census of the HCP Study Area during the prehatch stage of the breeding cycle is possible. The successful completion of these surveys was largely due to the absence of significant delays or postponements through intensive preplanning and training, and the cooperation and support of the IID staff. The IID staff informed private landowners in advance and during our surveys of the survey effort, provided gate keys upon our encountering locked gates, and shared additional support. Such collaboration would be essential for the success of any future HCP-wide census.

We conducted these 4 survey occasions prior to the new information we presented in chapter 6, which suggested that only 3 survey occasions are necessary to compute reliable estimates of population size in the HCP Study Area. The first 3 survey occasions of Burrowing Owl point-coordinates presented here provide the basis for constructing point-coordinate capture-recapture encounter histories, as described in Chapter 5, that will be used in chapter 8 to compute maximum likelihood estimates of male Burrowing Owl territory abundance in the HCP Study Area.

Chapter 8

MAXIMUM LIKELIHOOD ESTIMATE OF MALE BURROWING OWL TERRITORY ABUNDANCE IN THE HCP STUDY AREA IN 2007

JEFFREY A. MANNING

ABSTRACT. Maximum likelihood estimates of population size are widely considered to be the most reliable estimates attainable by wildlife scientists. Here, I present a maximum likelihood estimate of male Burrowing Owl territory abundance in the HCP Study Area using the data presented in Chapter 7. The data were pooled into a single capture-recapture encounter history and categorized according to six separate periods when the 3 survey occasions occurred. In the absence of sampling error or sampling units, this analysis estimated the population to be 4,998 (95% CI=4,946-5,081).

INTRODUCTION

The HCP specified the need to obtain annual estimates of the population of male Burrowing Owl territories in the HCP Study Area. One approach to achieve this would be to sample the HCP Study Area and extrapolate those results to the remainder of the area that was not sampled. Alternatively, a complete census could be used to estimate a single estimate. The latter approach is not cost effective on an annual basis. But, because our approach to develop a validated survey method relied on 2 consecutive years of complete censuses, we had the unique opportunity to utilize those data to compute annual estimates for those years. This chapter presents the estimated population size of male Burrowing Owl territories during the prehatch stage of the breeding cycle along the IID's rights-of-way in the HCP Study Area in 2007.

METHODS

I combined the encounter histories from all male Burrowing Owl territories across the entire HCP into a single encounter history dataset, and stratified it by 6 survey sessions, as described in Chapter 7. I used the closed-capture capture-recapture models with the sin link function available in Program MARK to fit 6 maximum likelihood models to these data (Table 8.1, Otis et al. 1978, White et al. 1982, Cooch 1999, White and Burnham 1999). All models estimated abundance for the portion of the HCP Study Area that was surveyed in each session, and assumed that detection and recapture probabilities were equal and either constant [$\hat{p} = \hat{c}$ (.)], vary across occasions [$\hat{p} = \hat{c}$ (t)], vary among sessions [$\hat{p} = \hat{c}$ (session)], or vary by the interactive effects of session and occasions ($\hat{p} = \hat{c}$ (session x t)). I used Akaike's Information Criterion adjusted for small sample sizes (AIC$_c$) to determine the most parsimonious model and considered this to be my best model (Akaike 1973, Burnham and Anderson 2002). I obtained estimates of abundance for each session ($\hat{N}_s$) from this model, and considered the sum of the abundance estimates for the sessions $\left(\sum_{i=1}^{6}\hat{N}_s\right)$ as the approximate true population size of male Burrowing Owl territories in the HCP Study Area in April 2007. I assessed the lack-of-fit of this model to the data by examining a plot of its deviance residuals. A symmetric and narrow pattern of deviance residuals close to zero would suggest a good fit to the data, whereas a wide pattern around zero would suggest poor fit due to extra-binomial variation.

Although I had initially proposed to include individual covariates (e.g., percent vegetation and texture) into the models, our approach of using buffered point coordinates restricted their use at this stage of analysis, as described under the conclusions and recommendations in Chapter 5.

RESULTS

The most parsimonious model showed that detection probabilities varied through time differently within each session (Table 8.1). This model fit the data well (deviance residuals followed a narrow and symmetric pattern surrounding zero), and estimated a total of 4,998 (95% CI=4,946-5,081) male Burrowing Owl territories in the HCP (Table 8.2).

Table 8.1. Closed-population capture-recapture models fit to male Burrowing Owl Territory encounter histories and their corresponding AIC_c-values, Imperial Valley, California, April 2007.

Model Syntax	AIC_c	AIC_c weight	No. of Parameters	Deviance
$\hat{p} = \hat{c}$ (session x time[1])	0	1.00	24	298.628
$\hat{p} = \hat{c}$ (session)	234.53	0.00	12	557.218
$\hat{p} = \hat{c}$ (time)	276.98	0.00	9	605.68
$\hat{p} = \hat{c}$ (.)	294.78	0.00	7	627.487

[1] Time refers to days (n=3), as a survey occasion occurred on each of 3 days.

Table 8.2. Estimates of detection and abundance of male Burrowing Owl territories during the prehatch stage of the breeding cycle in the HCP Study Area, Imperial County, California, 2007. Estimates are from the best closed-population model in Table 8.1.

	Detection and recapture probabilities (p=c) (SE)			
Session[1]	Occ. 1	Occ. 2	Occ. 3	$\hat{N}_s$ (95% CI)
1	0.71 (0.02)	0.67 (0.02)	0.79 (0.01)	897.4 (890.3 - 909.2)
2	0.68 (0.01)	0.69 (0.01)	0.77 (0.01)	1161.4 (1152.5 - 1175.1)
3	0.58 (0.02)	0.62 (0.02)	0.72 (0.01)	1102.1 (1088.2 - 1121.5)
4	0.64 (0.02)	0.78 (0.01)	0.52 (0.02)	985.7 (974.1 - 1002.6)
5	0.70 (0.02)	0.68 (0.02)	0.68 (0.02)	758.4 (749.9 - 771.8)
6	0.60 (0.05)	0.71 (0.05)	0.70 (0.05)	92.8 (90.7 - 100.4)
Entire HCP Study Area				4998.0 (4948 - 5081)

[1] Refers to 3 consecutive survey occasions in 6 different geographic portions of the HCP Study Area.

CONCLUSIONS AND RECOMMENDATIONS

Based on the closed-population point-coordinate capture-recapture estimation procedure used there, the estimate of 4,998 (95% CI=4,946-5,081) best approximates the true population size of male Burrowing Owl territories in the HCP Study Area in April 2007.

Chapter 9

EVALUATION OF SPATIAL AUTOCORRELATION IN MALE BURROWING OWL TERRITORY ABUNDANCE AND THE DETERMINATION OF A STANDARDIZED SAMPLING GRID

JEFFREY A. MANNING AND STACIE ROBINSON

ABSTRACT. A standardized sampling grid across the HCP Study Area would standardize a population of sampling units that could be sampled annually for estimating and comparing Burrowing Owl population sizes. We present the results on an analysis of spatial autocorrelation in owl abundance to identify an appropriate resolution of a standardized sampling grid intended for use in sampling the HCP Study Area for Burrowing Owls in subsequent years. In accordance with Amendment 1, and based on the needs of the analytical survey and sampling methods, we determined that a 3x3 km grid cell resolution was appropriate for establishing a standardized grid.

INTRODUCTION

The original HCP document required that the relative abundance and distribution of owls be determined (section 4.5.2.2). In order to evaluate relationships between correlates and abundance, a standardized unit to measure abundance is needed. Such sampling units should be independent from one another. Since levels of Burrowing Owl abundance are believed to vary across the HCP Study Area, we suspect that abundance may be spatially auto-correlated, in which case independence has a spatial component to it. Fortunately, spatial statistics can be used to evaluate at what resolution spatial independence of male Burrowing Owl territory abundance may occur in the HCP Study Area. We initially proposed using the linear distance of the IID's rights-of-way for this analysis, but later proposed and received approval for an amendment to this (see executive summary), which entailed the evaluation of grids of various grid cell sizes to evaluate spatial autocorrelation. The intent of such an analysis is would be to determine a standardized sampling grid.

A standardized sampling grid would standardize a population of sampling units that serve the purpose of making comparisons between annual population estimates over the 75-year permit of the HCP. Data currently available and suitable for an evaluation of grid cell sizes comes from the owl surveys presented in the previous chapter. These data are from a census of the HCP Study Area, the methods were thorough and standardized, and they provide an opportunity to assess possible relationships in spatial patterns of owl abundance. Because these data are empirical, their use comes with the assumption that they are from a population of owls that exhibit an approximate distribution and pattern of local abundances typical to that expected to be present over the life of the HCP.

Spatial patterns provide information about the processes that affect ecological communities (Fortin and Dale 2005), as well as information to best model systems where data are not spatially random (Haining 2003). Assessing spatial autocorrelation is a basic, but critical, step in assessing data structure and describing spatial patterns. Spatial autocorrelation describes the degree to which similarity in data values is dependent on spatial proximity (Haining 2003). The extent of spatial dependence can be used to describe ecological structure and define the extent of biological communities (Fortin and Dale 2005, Heywood 1991). The definition of ecological neighborhoods based on the extent of spatial autocorrelation has even been used to define units for conservation and reserve design (Diniz-Filho and Telles 2002).

Sampling designs and distributions of selected sampling units can affect the spatial pattern observed in the data, and may influence a researcher's ability to infer the true spatial structure in an ecological system (Tobin 2004). This is especially true of complex ecological systems like the Imperial Valley, where numerous environmental factors may combine to affect the spatial distribution of Burrowing Owls (Legendre and Fortin 1989). The census of owls across the HCP Study Area that were conducted in the IID's rights-of-way (see previous chapter) does not represent a sample and therefore should not affect the spatial pattern we observe. We are confident that the data enables us to capture the true patterns in the distribution of male Burrowing Owl territories.

In looking at the abundance of male Burrowing Owl territories across the Imperial Valley, we needed to decide on an areal unit of analysis in which to compute abundance. The definition of analysis units and the scale of spatial analysis can substantially affect the extent and intensity of spatial pattern observed (Turner et al. 1989, Wiens 1989). The manner in which we divide the study area into sampling units to assess abundance could therefore influence the spatial patterns (i.e. the degree of spatial autocorrelation) we observe. We chose square sampling units because they have smaller perimeter lengths per unit area than rectangular units and therefore less potential for error in including individuals in a unit. Square units are generally easier to map out than rectangular ones. Square units can also be used to easily subdivide a study area into non-overlapping areas without excluding areas, which is not the case with circular units.

It has long been established that spatial analyses should be carried out at multiple scales to get the most accurate picture and to detect confounding influences of scale on spatial patterns (Mead 1974). In order to assess scale effects and decide upon an areal unit of analysis for computing owl abundance, we performed spatial analyses at multiple resolutions using variable grid cell sizes to partition the study area.

METHODS

Autocorrelation – Moran's *I* Correlogram

1. Used the maximum number of owls observed during the 4 occasions for grid cell counts.
2. Grid cell sizes were 1x1 km, 2x2 km, 4x4 km, 8x8 km, 10x10 km, 11x11 km and 12x12 km.
3. Computed density of owls in grid cells as count/km of IID linear right of way.

4. Constructed Moran's *I* correlogram.
    A. Moran's *I* provides an autocorrelation measure that is similar to a Pearson's correlation coefficient, and ranges from -1 to 1 (Moran 1950).
    B. A negative Moran's *I* would suggest that similar densities were over-dispersed, or spread farther than expected at random.
    C. A positive Moran's *I* would indicate that similar densities were clustered or closer together than expected at random.
    D. The correlogram is a graph of the Moran's *I* coefficient calculated at multiple distance thresholds (i.e. Moran's *I* is first calculated according to all pairs of nearest neighbors, then all pairs of 2nd order neighbors, then 3rd, 4th etc.). In this way we graphed the decay of spatial dependence between neighbors as the distance separating them increased (Fortin and Dale 2005, Haining 2003, Rangel et al. 2006).
5. Used program SAM – Spatial Analysis for Macro-ecology (Rangel et al. 2006)
    A. Number of distance classes used coincided with 80 km [the approximated longest distance across the HCP divided by grid cell size (i.e., the number of neighbors expected to span the maximum distance across the HPC)].
    B. Used Queen's adjacency scheme (included neighbors on all sides and corners)

Autocorrelation - Variogram

1. Constructed semivariograms (refered to as variograms)
2. The variogram plots variance between sampled pairs against distance
3. The variogram can be seen as a compliment or inverse of the correlogram – where as the correlogram shows the breakdown in correlation at increasing distance, the variogram graphs the increase in variance between sampled pairs as the distance between them increases (Cressie 1991, Fortin and Dale 2005, Haining 2003, Ribeiro et al. 2003)
4. The variogram curves upward as long as the variance between samples increases with distance, at some point the curve levels off where distance no longer influences the variation between samples – this point is called the sill
5. Calculated variograms using geoR (Ribeiro et al. 2003), a package in the R statistical environment (Ihaka and Gentleman 1996)
6. Both classical and modulus models were used for completeness (Cressie 1991)

Determination of a Standardized Sampling Grid

We received a joint assessment of our results from the above analyses by Dr. Manly (WEST, Inc., Laramie, WY). His assessment required the further analyses at intermediate grid cell sizes (Figure 9.2). In light of the need to establish a grid that would be appropriate for stratified random sampling, this assessment was based on the following issues:

1. Large enough to support reasonably sized numbers of owls for capture-recapture modeling.

2. Large enough to support a range of abundances (including zero) for estimation purposes.
3. Small enough to support a large population of cells necessary for stratified random sampling.
4. Small enough to reduce washing out variation in covariates of abundance.

We developed a standardized sampling grid in ArcGIS 9.2 (ESRI, Redlands, CA) based on the assessment from Dr. Manly and laid it over the HCP Study Area. In doing this, some grid cells along the border of the HCP Study Area encompassed non-HCP Study Areas; to avoid inclusion of these areas, we refined the geographic extent of that grid by clipping it to the boundary of the HCP Study Area. However, clipping led to non-square cells along the boundary. In order to maintain grid cells of approximately equal size (which is advantageous for survey logistics and with the stratified random sampling framework described in Chapter 15), we combined some of these individual cell fragments that contained IID water conveyance structures to approximate the size of the standardized cell size. We removed cells that lacked any IID water conveyance structures, as these were not surveyed during this study.

RESULTS

We found that the abundance of male Burrowing Owls was spatially autocorrelated across the HCP at all grid cell resolutions we examined (Figure 9.1). Based on the subsequent assessment with Dr. Bryan Manly (Figure 9.2), it was determined that the 3x3 km grid cell provided a fairly large number of cells (*n* = 274), which contained reasonable numbers of owls for capture-recapture modeling and should be sufficient for stratified random sampling. This size reflected a balance of assessed issues; larger cell sizes reduced the number of cells available for stratification and smaller cells reduced sample sizes for capture-recapture modeling. The final, refined, standardized sampling grid produced 274 grid cells, with some clipped and combined cell fragments along its border approximating the 9 km^2 cell size (Figure 9.3).

CONCLUSIONS AND RECOMMENDATIONS

Based on the presence of spatial autocorrelation in the abundance of male Burrowing Owl territories across the HCP Study Area, we did not find a grid cell size that eliminated the autocorrelation among sampling units. Recognizing the need to establish a standardized grid from which to sample owls from so comparable estimates can be made in subsequent years, we chose to focus on the additional needs to adequately stratify the HCP Study Area. Based on Dr. Manly's assessment, we conclude that a 3x3 km grid cell would be appropriate for performing the current analyses and future surveys and analyses of male Burrowing Owl abundance.

This grid is intended for use in future surveys through the 75-year period of the HCP, from which a new random sample of grid cells should be obtained each year. This conclusion is based on our analyses of empirical owl data collected in 2007, and assumes that the data represent the typical distribution and abundance of owls across the HCP in subsequent years. As recommended by Dr. Manly, because spatial autocorrelation is inevitable, it needs to be assessed and accounted for the final model used to estimate abundance of male Burrowing Owls in the HCP Study Area.

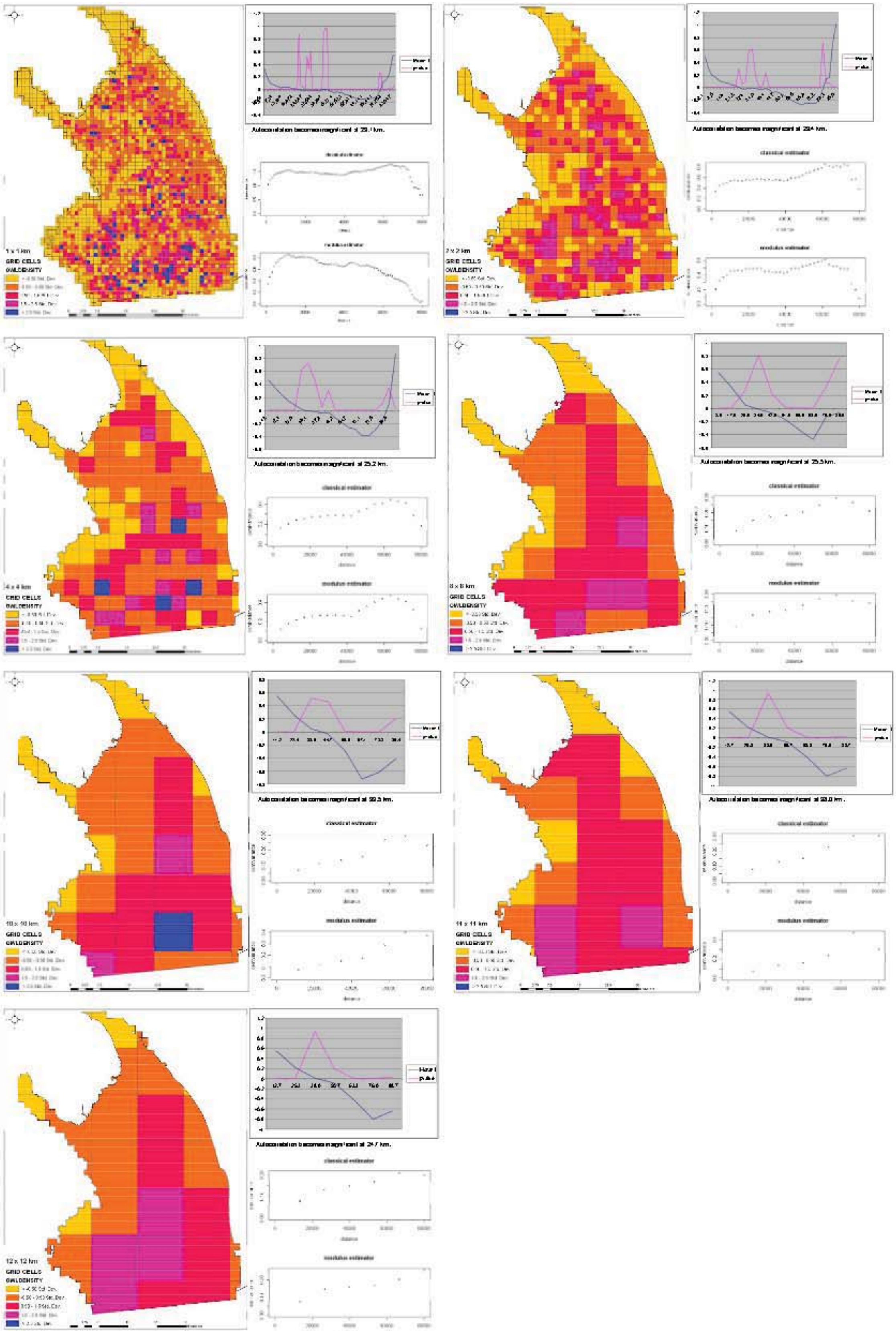

Figure 9.1. Spatial autocorrelation Moran's I, correlogram, and variogram results.

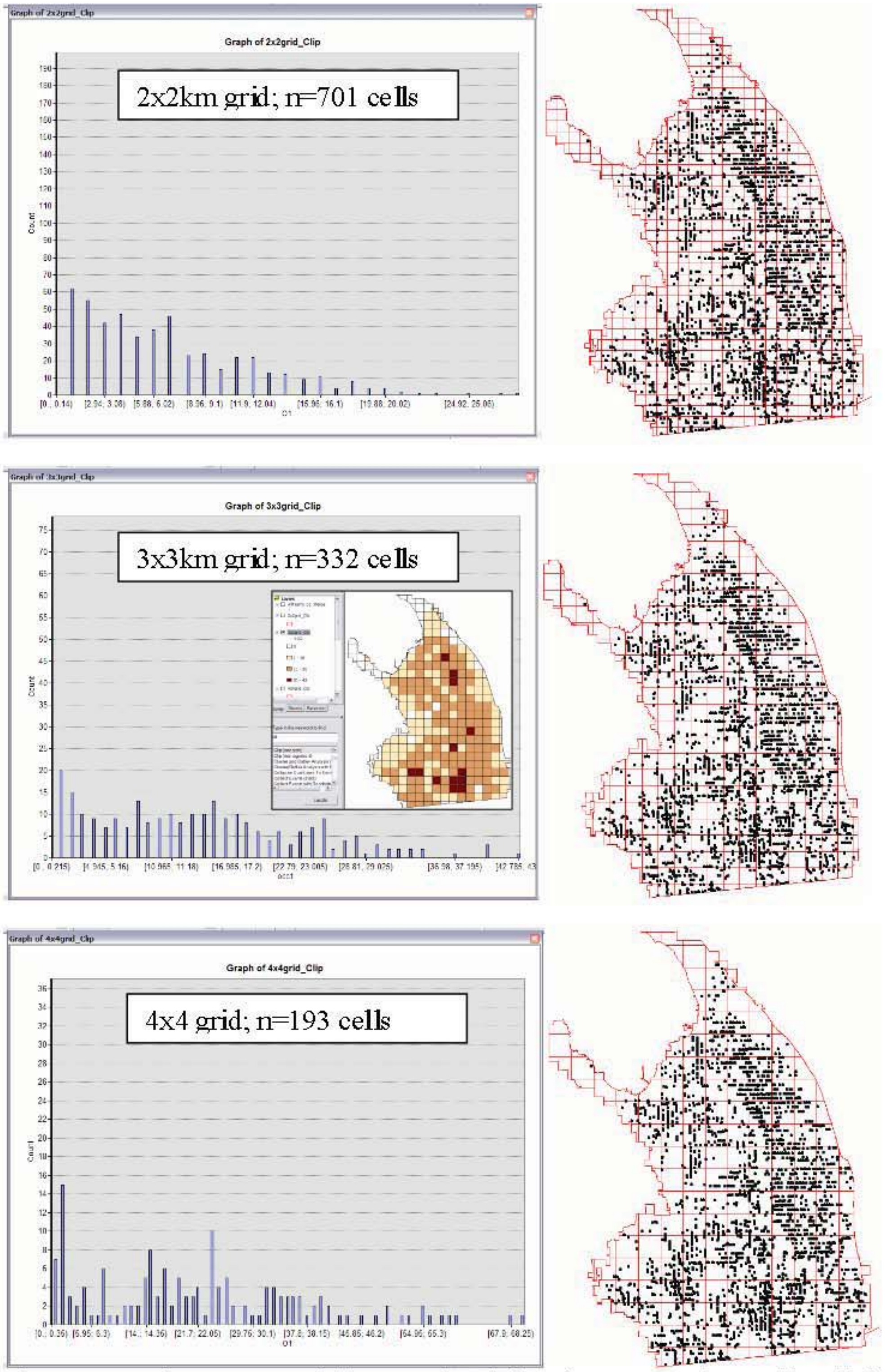

Figure 9.2. Histograms and figures of owl abundance at various grid cell sizes included as part of an assessment of results by Dr. Bryan Manly (WEST, Inc., Laramie, WY).

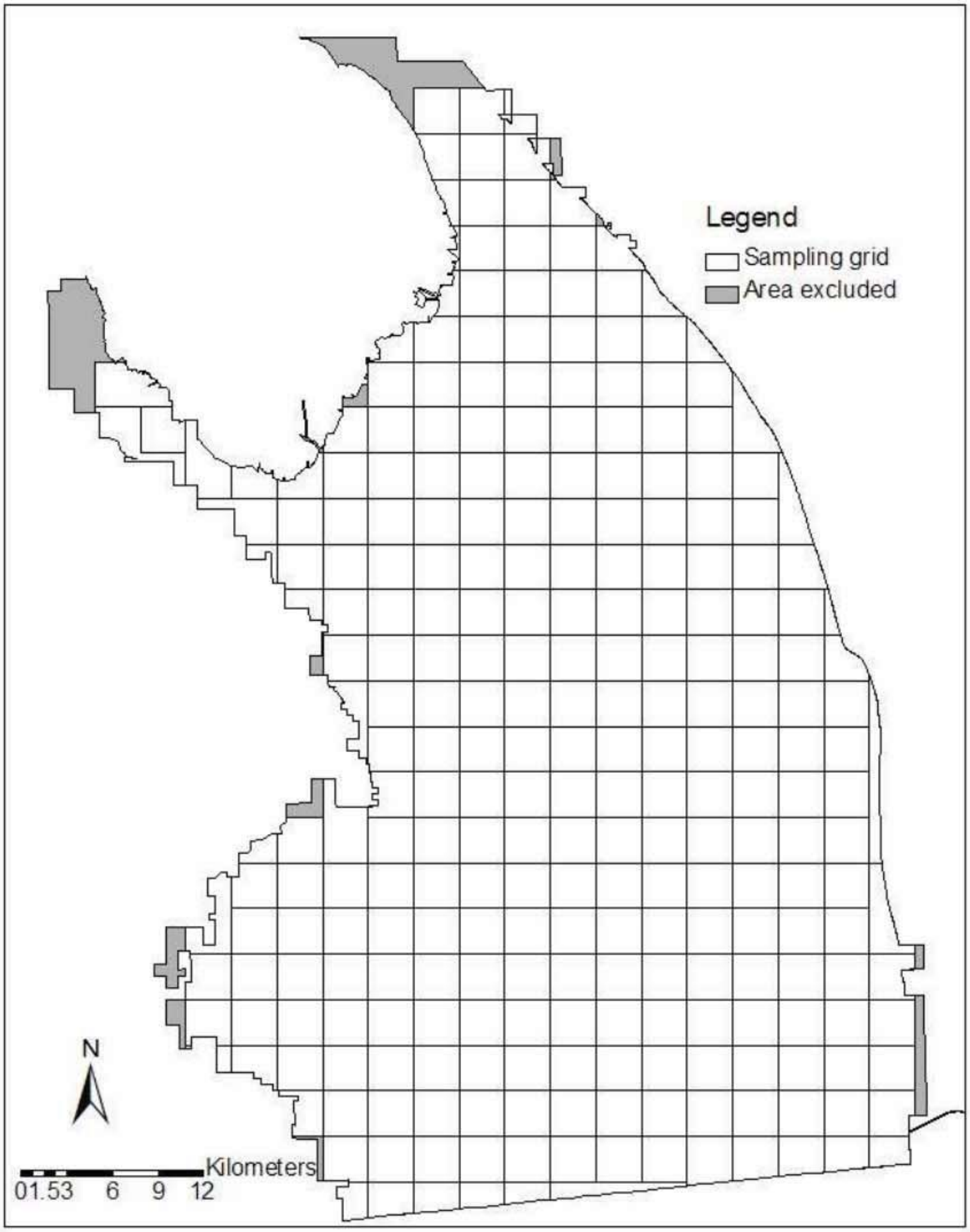

Figure 9.3. Standardized grid of 274 3x3 km sampling units for surveying Burrowing Owls in the HCP Study Area, Imperial County, California. Excluded areas are those where IID water conveyance structures were absent at the time of this survey, April 2007. Some cells along the boundary approximate 9 km^2 due to clipping and combining.

Chapter 10

MAXIMUM LIKELIHOOD ESTIMATES OF LOCAL MALE BURROWING OWL TERRITORY ABUNDANCE IN 2007

JEFFREY A. MANNING

ABSTRACT. Individual grid cells across the HCP Study Area can be used to adequately represent local Burrowing Owl territory abundances for comparisons across the area and annually. I calculated maximum likelihood estimates of local male Burrowing Owl territory abundance for each 3x3 km grid cell in 2007. To satisfy Amendment 6 and provide a total population estimate that could be compared as an approximation to the true population size to estimates calculated from sampling the data (as done in later chapters), I summed the abundances among the grid cells. Local abundances varied from 0-54 territories, and the approximated true population size was 4,879 (95% CI: 4,847 - 5,387).

INTRODUCTION

The HCP specified the need to obtain annual population estimates of male Burrowing Owl territories in the HCP Study Area. A complete census conducted annually could be used to obtain annual population sizes. However, such an extensive annual effort would be cost prohibitive and would still have to account for errors attributable to detection below 100%. A more practical and cost effective approach commonly applied by wildlife scientists would be to randomly sample portions of the HCP Study Area and extrapolate those results to the remainder of the area that was not sampled. This is because a random selection of sample units from an available population of units can yield statistically and biologically reliable population estimates. It is important to note that the population of Burrowing Owls is not the same as the population of grid cells referred to here for sampling. In order to have a population of sampling units to draw random samples from and compute local abundances annually, we developed the grid of 3x3 km cells in the previous chapter.

The goal to develop a validated long-term survey methodology (as proposed in Tasks 5 and 6 under Objective 2 of the final detailed study plan, dated January 31, 2007) relied on the acquisition of empirical estimates of population abundance (i.e., local abundance) in each grid cell. I intended to repeatedly draw random samples of cells from the 2007 census of grid cells to determine an optimal level and allocation of sampling that could be used in subsequent surveys to achieve a population estimate that would approximate that which could be obtained from a census of all grid cells (as presented in Chapter 15).

The power of such a sampling approach depends on the successful reduction in measurement error while surveying for owls in grid cells. This is because the analytical tools available for analyzing stratified random sampled data assume perfect counts in sampling units (no error in counts). Those tools, however, do account for the variation in abundance among grid cells, which is referred to as sampling variance. Thus, an important objective in surveying owls for the purpose of determining local abundances must be to minimize measurement error during surveys. Fortunately, the field methods presented in Appendix II can be used with the point-coordinate capture-recapture analytical technique presented in Chapter 5 to achieve negligible levels of measurement error in estimates of local abundance. Here, I present maximum likelihood, point-coordinate, capture-recapture estimates of local male Burrowing Owl territory abundance in 3x3 km grid cells across the HCP Study Area and discuss their associated estimates of measurement error. Per amendment 6, I also used these data to calculate an approximate true number of Burrowing Owl territories in the HCP Study Area that is appropriate for comparing HCP Study Area-wide abundance estimates derived from random samples drawn from the population of grid cells.

METHODS

I considered a single survey pass along an IID right-of-way on a single day as a survey occasion, and consecutive occasions as a survey session (e.g., see Chapter 7). Thus, each of the 6 survey sessions described in Chapter 7 were comprised of a distinct set of survey occasions (i.e., 6 survey sessions, each in a distinct portion of the HCP Study Area, comprised of 4 single-day occasions = 24 days of surveys). Because the 6 sessions also corresponded with 6 different portions of the HCP Study Area that were surveyed at different days, I tested for time effects separately in grid cells according to each session.

Because the stratified random sampling approach to developing a long term survey protocol for owls is reliant on reducing measurement error when survey for owls inside grid cells, I used the point-coordinate capture-recapture technique (presented in Chapter 5) in analyzing owls survey data. I used the following methods to compute local, maximum likelihood, closed-population estimates of male Burrowing Owl territory abundance:

1. Applied the point-coordinate capture-recapture technique to the first 3 survey occasions, using the 55 m radius MMDM buffer recommended in Chapter 5. My use of only the first 3 occasions was based on the results presented in Chapter 6. This technique developed centroids associated with individual, point-coordinate-based, capture-recapture encounter histories.

2. To meet the HCP's requirement to estimate the abundance of breeding male territories and because I showed that owls in the HCP Study Area have a high probability of being detected during our surveys (95%; Chapter 6), I removed individual encounter histories from the dataset where a single owl was observed on only 1 of the 3 occasions and without a nest (Table 10.1). This is because owls had a high probability of being detected near their nests (see results, this chapter), and I assumed that such observations were of non-breeding owls that were not maintaining breeding territories at the time of our survey, or owls that were away from their territories at the time of observation. I considered the remaining centroids established above to be those of territorial males.

3. Overlaid the grid of 274 cells (see Figure 9.3 for grid details) onto the centroids of male Burrowing Owl territories and associated capture-recapture encounter histories determined above, and assigned each encounter history to its corresponding grid cell. I therefore used the 3x3 km grid cell as the areal unit to calculate local abundance estimates.

4. Determined in which of the 6 sessions the majority of a grid cell was surveyed, and grouped grid cells by the 6 sessions, and applied closed-population models with the sin link function available in Program MARK (Otis et al. 1978, White et al. 1982, Cooch 1999, White and Burnham 1999) to each grid cell and tested for time effects (among occasions) separately among the 6 survey sessions. Within each session, I fit models to each cell's set of encounter histories that assumed that detection and recapture probabilities were equal and constant [$\hat{N}$ (grid cell) $\hat{p} = \hat{c}$ (.)] or varied through time [$\hat{N}$ (grid cell) $\hat{p} = \hat{c}$ (time)], where time referred to occasions 1, 2, and 3. I used Akaike's Information Criterion (AIC$_c$; Akaike 1973, Burnham and Anderson 2002) to determine the most parsimonious model for a grid cell, and considered it to be the best model for that cell. I assessed the lack-of-fit of the model to the data by examining a plot of its deviance residuals. A symmetric and narrow pattern of deviance residuals close to zero would suggest a good fit to the data, whereas a wide pattern around zero would suggest poor fit due to extra-binomial variation.

5. Added the associated estimates of abundance and standard error from the best models into the corresponding grid cell in the GIS grid layer. Here, the standard error was a measure of precision that represented the error attributed to the point-coordinate capture-recapture surveys, which can be appropriately referred to as measurement error.

Although I initially proposed the inclusion of individual covariates (e.g., percent vegetation and texture) in models, the point-coordinate capture-recapture technique restricted their use at this stage of analysis, as described under the conclusions and recommendations in Chapter 5.

In order to have an estimate of the total population for comparisons with estimates obtained from sampling, I summed the local estimates from all 274 sample grid cells.

RESULTS

Raw counts during single survey occasions ranged from 3,451-3,726 (Table 10.1). The best capture-recapture models for most survey sessions represented the hypothesis that detection probabilities varied through time (day; Table 10.2), and most of these models fit the data fairly well (deviance residuals followed a fairly narrow and symmetric pattern surrounding zero). Estimates of male Burrowing Owl territory abundance ranged from 0 to 53.96/3x3 km grid cell (SE = 1.26), and those with a lower estimated abundance tended to be from smaller samples of owls and models having relatively greater spread in the deviance residuals. The mean abundance of the 274 cells was 17.8 owl territories (St

Dev = 13.2), and 18 cells were estimated to not contain owls during our surveys (Figures 10.1 and 10.2).

The majority of local abundance estimates had small standard errors, indicating small measurement errors. Nearly half of the grid cells, those cells where abundance was estimated to be 20 territories, contained very low standard errors, suggesting either negligible measurement error or poor performance of the capture-recapture models fit to those cells (Figure 10.1).

By summing the local abundances obtained from this method, we estimated the total population of male Burrowing Owl territories in the HCP Study Area in 2007 at 4,879 (95% CI: 4,847 - 5,387).

Table 10.1. Number of Burrowing Owl detections by survey occasion during the prehatch stage of the breeding cycle in the HCP Study Area, Imperial County, California, 2007. Owls detected once and without a nest were removed from the data.

	Survey Occasions		
Type of detection	1	2	3
Once without nest	165	221	232
All other detections	3,286	3,447	3,494
Mean/cell[1]	9.8	10.7	10.6
Standard deviation/cell[1]	12.6	13.4	13.6

[1] Calculated with total detections from all 274 3x3 km grid cells.

Table 10.2. Best closed-population capture-recapture models and detection estimates by session. These best models have AIC$_c$-values = 0; their AIC$_c$-values that are not comparable to each other because AIC$_c$ was used to select each of them from another model separately for each session, and those models are not included here.

		Survey Occasion		
Session	Best model	1	2	3
1	$\hat{p} = \hat{c}$ (time[1])	0.71 (0.02)	0.70 (0.02)	0.79 (0.01)
2	$\hat{p} = \hat{c}$ (time)	0.69 (0.01)	0.70 (0.01)	0.78 (0.01)
3	$\hat{p} = \hat{c}$ (time)	0.61 (0.02)	0.67 (0.02)	0.73 (0.01)
4	$\hat{p} = \hat{c}$ (time)	0.67 (0.02)	0.76 (0.01)	0.58 (0.02)
5	$\hat{p} = \hat{c}$ (.)	0.70 (0.01)	0.70 (0.01)	0.70 (0.01)
6	$\hat{p} = \hat{c}$ (.)	0.76 (0.06)	0.76 (0.06)	0.76 (0.06)

[1] Time refers to days, as a survey occasion occurred on each of 3 days.

CONCLUSIONS AND RECOMMENDATIONS

The use of 3 closed-population point-coordinate capture-recapture survey occasions resulted in a high probability (97.6%) of detecting a male Burrowing Owl territory 1 times over the 3 occasions, which is similar to that reported in Chapter 6. Specifically, given the average detection probability over occasions and sessions ($\hat{p}$ = 0.71), the probability that a territory was detected 1 times over the 3 occasions was 97.6% [i.e., 1-$(1\text{-}0.71)^3$].

This approach did not allow for modeling effects of individual covariates (e.g., amount of vegetation or type of drain or canal bank) on detection probabilities (see Chapter 5 for further details). However, given the high overall high detection probability from 3 survey occasions, such an analysis, if possible, may not have provided a marked improvement in bias or precision.

The low standard errors associated with estimates where territories numbered <20/grid cell (Figure 10.1) were likely due to the performance of the closed-population capture-recapture models that were fit to the data in Program MARK. Although this may lead to slightly biased low abundances when the number of owls is small within a grid cell, capture-recapture methods produce encounter histories for each individual owl, even if they are missed on all but one of the occasions, leading to a 97.6% chance that each territory will be accounted for. Unlike capture-recapture, which utilizes these repeated occasions to increase the number of individuals detected and thereby account for imperfect probabilities of availability when numbers are high enough, other survey methods which can minimize measurement error due to visibility bias (e.g., distance sampling, point counts, and sightability) do not correct for availability bias. This is problematic with species where availability may vary throughout the day like the Burrowing Owls in the HCP Study Area (i.e., see Figure 2.4). Variation in availability among days can also be a problem, as we found that the raw counts associated with the capture-recapture occasions conducted here were variable among days. Given the standardized and constant levels of effort applied only days apart during the owl surveys, it is unlikely that the 6% difference in counts among the 3 occasions was due primarily to visibility bias, but rather also imperfect availability of individuals among the days. Currently, capture-recapture is one of the more powerful methods to estimate abundance from species like the Burrowing Owl where visibility and availability bias affects measurement error, and hence population estimates. Until advances are made with methods that rely on a single survey occasion that will correct for imperfect availability as well as detectability while producing precise, unbiased estimates, capture-recapture methods are recommended for estimating local abundances in the HCP Study Area.

Closed-population models in Program MARK are widely accepted in wildlife science, and they allow for evaluating variable detection probabilities. The program also incorporates the ability to compare models using the information theoretic approach. One alternative to using Program MARK while maintaining the use of capture-recapture methods with such small sample sizes would be to use the model developed by Chao (1989). This model is unavailable in Program MARK. Currently, I am unaware of any statistical-based closed-population platforms that include the Chao estimator, other than Program CAPTURE, which does not have a reliable model selection procedure. Thus, applying the Chao (1989) model would preclude modeling variable detection probabilities or comparing multiple working hypotheses, which in itself could lead to imprecise, biased estimates. It also does not perform as well as other closed-population models with larger samples.

In order to accomplish the proposed objective of evaluating the level of bias associated with various sampling methods and randomly drawn samples (to be completed in Chapters 15 and 17), an estimated abundance that best approximates the true total population size in the HCP Study Area is needed. Although we provided a maximum likelihood estimate of male territories in the HCP Study Area in Chapter 8, that estimate was calculated by pooling the complete census data into a single dataset and partitioning and analyzing it by survey session without considering the standardized sampling grid. Those data and analytical methods differ from those that will be used in future surveys, which will rely on surveys in grid cells that are to be randomly drawn from the standardized sampling grid. As suggested by Dr. W. R. Gould (New Mexico State University, Las Cruses) in his independent review, dated January 8, 2007, those differences preclude using the estimated population total from Chapter 8 as a basis for comparing estimates obtained from sampling the HCP Study Area. Because the sampling grid is intended for future surveys and will be the basis for drawing random samples in simulations intended to test different sampling methods and levels of random sampling in Chapters 15 and 17, the sum of the local 2007 abundances in grid cells [4,879 male Burrowing Owl territories (95% CI: 4,847 - 5,387)] is an appropriate estimate of the true population size for comparing with the simulated sample estimates.

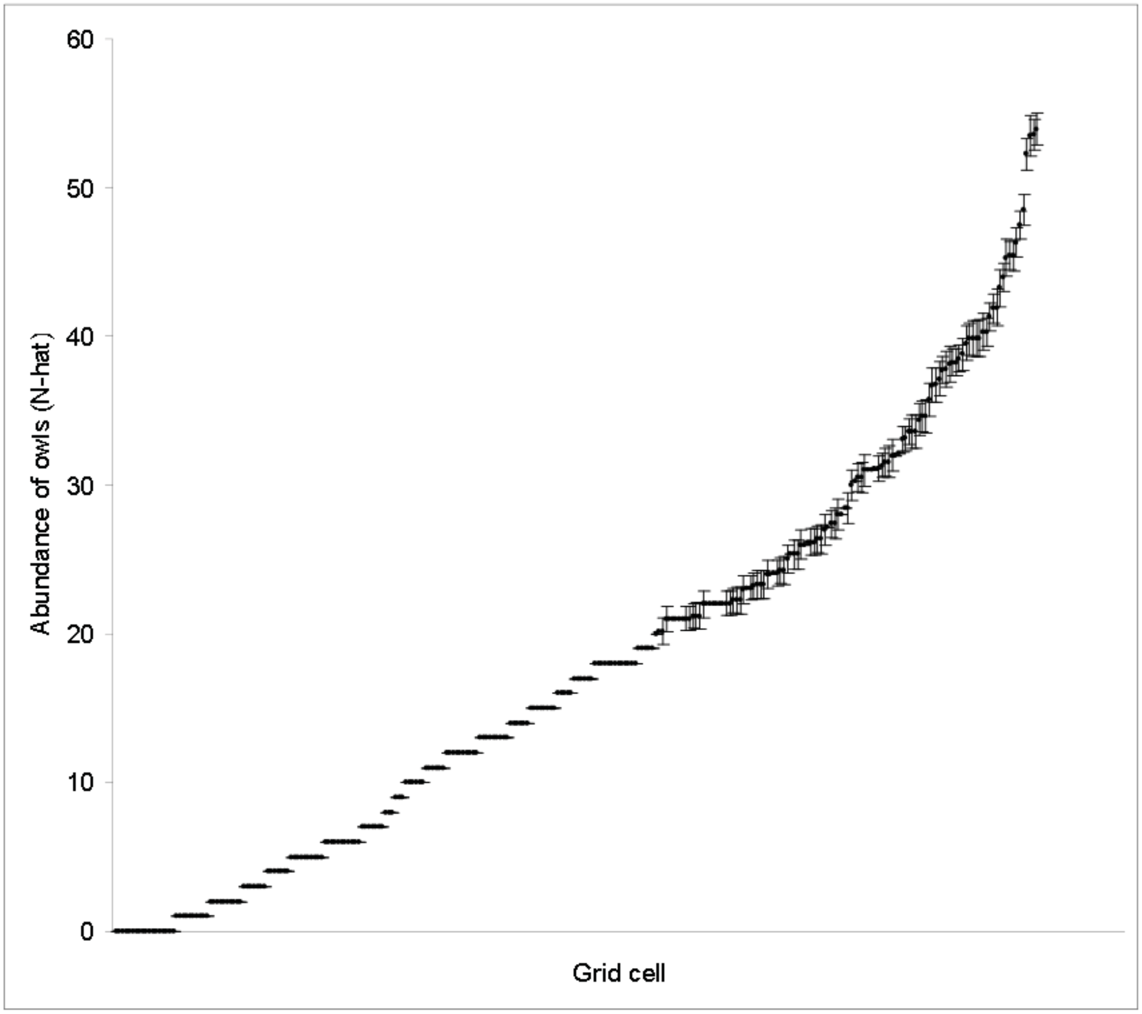

Figure 10.1. Estimates of local male Burrowing Owl territory abundances in 3x3 Km grid cells in the HCP Study Area, Imperial County, California, 2007. Data are presented according to increased abundances. Vertical bars are standard errors.

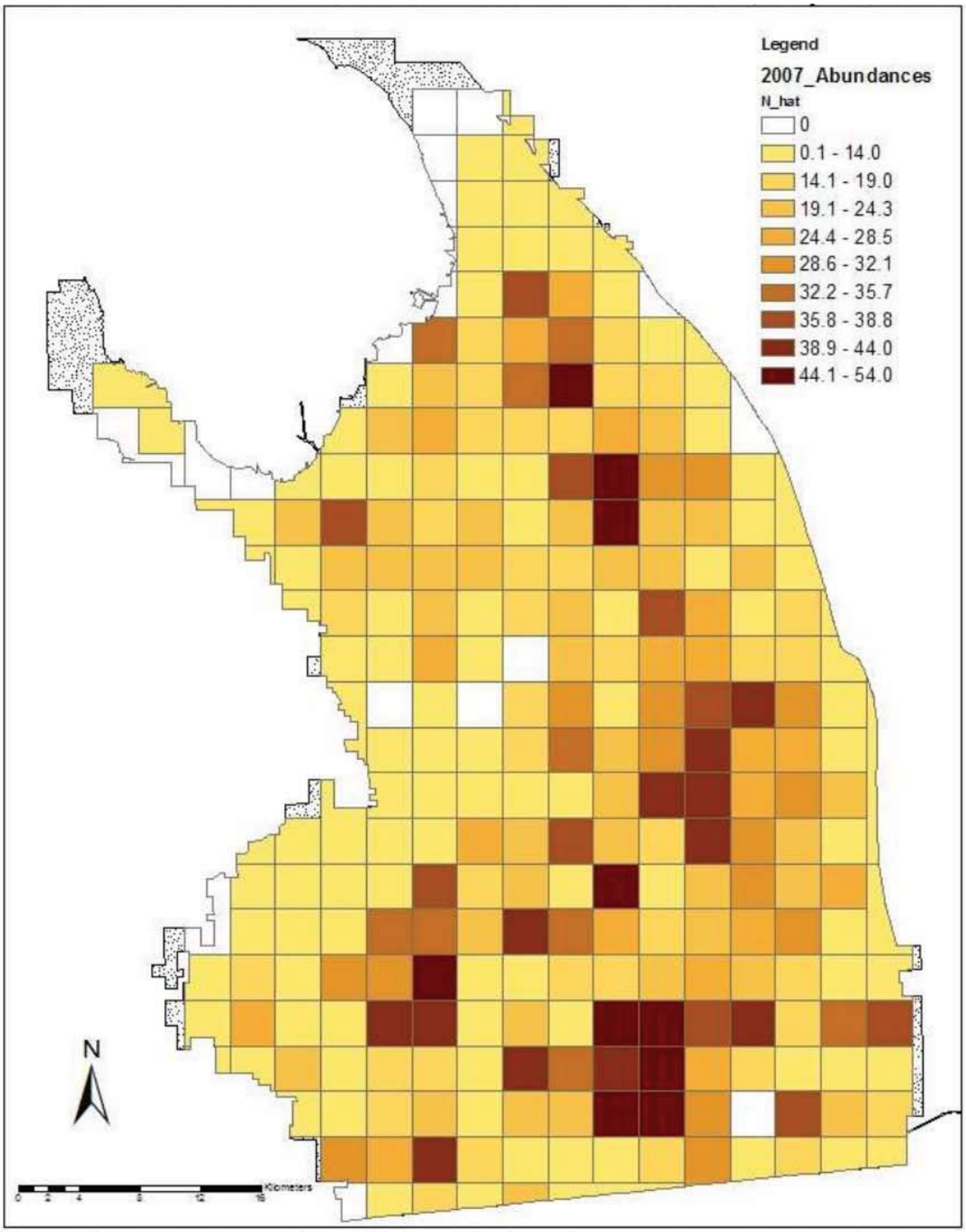

Figure 10.2. Closed-population point-coordinate capture-recapture estimates of local male Burrowing Owl territory abundance in 3x3 km grid cells in the HCP Study Area, Imperial County, California, April 2007. Stippled areas were not surveyed due to the absence of above-ground water conveyance structures.

Chapter 11

DATASETS OF POTENTIAL CORRELATES OF LOCAL MALE BURROWING OWL TERRITORY ABUNDANCE IN 2007

JEFFREY A. MANNING

ABSTRACT. Knowledge of potential environmental correlates of Burrowing Owl abundance is important in the development of survey protocols because using such correlates to stratify the HCP Study Area prior to future surveys could reduce logistical effort and costs by improving the precision of population estimates. Here, I describe spatial datasets of environmental and biological variables intended for comparing their individual and additive potential as correlates of local male Burrowing Owl territory abundance. These datasets included soils, IID maintenance activities, number of suitable nesting burrows, type of water conveyance structure, and agricultural crops.

INTRODUCTION

The identification of factors (i.e., habitat characteristics and IID maintenance activities) that may be suitable correlates of Burrowing Owl abundance was based on existing biological information and on availability of data that extends across the HCP Study Area. The latter basis was important because the intended purpose of suitable correlates was to stratify the HCP Study Area in order to optimally allocate future annual survey efforts. Thus, suitable correlates must be measurable and available across the entire HCP Study Area each year prior to conducting owl surveys.

Several factors have been hypothesized as important correlates of Burrowing Owl nest burrows, and hence possibly abundance of male territories. These include soils, maintenance activities, sympatric fossorial (burrowing) mammals, surrounding vegetation (in the HCP Study Area, this referred largely to agricultural crops), and type of bank (cement-lined or earthen) along water conveyance structures. We obtained data on each one of these factors in order to incorporate them into our analyses to test for their relative importance in predicting owl abundance

METHODS

Soils

Soft, friable, loamy soils have been hypothesized to be an important correlate of Burrowing Owl nest burrows (MacCracken et al. 1985, Green 1983). Thus, soils that deviate from this soil type are anticipated to coincide with fewer numbers of owls.

Soil information was obtained from the USDA Natural Resource Conservation Service (NRCS) geodatabase of soils (NRCS 2005). These data were derived from a digital soil survey developed by the National Cooperative Soil Survey, and was the most detailed level of soil geographic data available. It was prepared by digitizing maps, compiling information onto a planimetric-correct base and digitizing from it, and/or revising digitized maps using remotely sensed information (NRCS 2005). National Cooperative Soil Survey standards and procedures were used in the classification of soils, design and name of map units, and location of special soil features in this dataset (NRCS 1993, NRCS 1995, NRCS and NSS undated current issue).

These data were clipped from: "Categorical ranking of soils in the Imperial Valley," California according to their suitability for burrowing owls. We measured the following soil classes in each 3x3 km grid cell for use as correlates (Figure 11.1):

1. proportion of poorly suited soils (continuous variable)
2. proportion of suitable soils (continuous variable)
3. proportion of well suited soils (continuous variable)
4. proportion of suitable and well suited soils (continuous variable)
5. dominant soil class (poorly suited, suitable, well suited; ordinal variable)

Imperial Irrigation District's maintenance activities

Section 4.5.2.2 of the HCP specified that "the Burrowing Owl population data will be linked to or combined with spatial information on the IID's maintenance activities..." This is because maintenance of water conveyance structures (i.e., dredging) is believed to possibly affect nest burrows. Thus, the location, year, and type of maintenance activities should also be assessed as possible determinants of owl abundance.

I met with maintenance personnel at the IID in April 2007 and obtained Microsoft Excel spreadsheets and GIS vector features of maintenance activities that occurred over the past 4 years. In most cases, the data were not detailed (e.g., not specific to a location on a canal, but rather named the entire canal, or a general definition for a maintenance activity was used). I counted the frequency of specific maintenance activities performed by the Imperial Irrigation District along irrigation canal and drain right-of-ways within each 3x3 km grid cell by year. Original drain and canal data were obtained by CH2M Hill, Sacramento, California. These data were further reduced to 12 general types of maintenance activity that were anticipated to possibly impact burrowing owls (as classified by the IID):

1. W03 = Concrete lined channel repair
2. W04 = Concrete lined channel brush and weed control by machine
3. W06 = Drain brush and weed control by machine
4. W08 = Earth channel machine clearing
5. W11 = Concrete canal structure maintenance
6. W12 = Drain structure maintenance
7. W13 = Earth canal structure maintenance
8. W17 = Concrete channel bank maintenance-road grading
9. W18 = Drain bank maintenance-road grading
10. W19 = Earth channel bank maintenance-road grading

11. W28 = Flood control
12. W29 = Pipeline maintenance

These general types of activities were summed for each canal or drain (vector), and divided by the total length of that water conveyance structure (across grid cells); this was multiplied by the total length of that structure in each cell, and summed across all water conveyance structures in the cell to produce grid cell-level estimates (Figure 11.2).

Availability of potential nest burrows

The presence of sympatric, fossorial mammals has been identified as an important correlate of Burrowing Owl nests (Thomsen 1971, Martin 1973, Zarn 1974, Wedgwood 1978, Haug 1985, Haug et al. 1993, Klute et al. 2003). This is because Burrowing Owls depend on the burrows from these mammals for nesting. Various species of fossorial mammals occupy the HCP Study Area, including the California ground squirrel (*Spermophilus beecheyi*), round tailed ground squirrel (*Spermophilus tereticaudus*), and Antelope ground squirrel (*Ammospermophilus leucurus*). The number of burrows dug by these mammals along the IID's right-of-way may be suitable for predicting the abundance of owl territories.

A complete count of burrows that were 'potentially suitable' as nest burrows for Burrowing Owls was conducted along the IID's rights-of-way. A burrow/hole was considered to be potentially suitable if it entered into an earthen surface, space within a debris pile, or pipe with an entrance between 3.5-15 inches in diameter that was flush with the ground. All burrows/holes that met this criteria were counted, even if occupied by a small mammal, and burrows/holes <20 m apart were considered as a single count because these data were intended to predict the number of male Burrowing Owl territories, and a single Burrowing Owl can occupy such a complex.

Vehicle-based surveys for potential burrows were completed from March 23-27, 2007, days before capture-recapture surveys were conducted for Burrowing Owls, following these procedures:

1. An observer and driver surveyed by vehicle
2. Vehicles were positioned so observers were closest to drains/canals
3. Traveled at 10 mph
4. Observers visually detected burrows while traveling in the vehicle, and used a handheld tally counter to record the number of burrows/complexes.
5. Observers set the Trimble GeoExplorer XM to record continuous vectors in order to map linear segments of the IID's right-of-way traveled in association with burrow counts.
6. Vehicles stopped every 0.5 miles to discontinue recording each previous vector, recorded the number of tallied burrows in the Trimble GeoExplorer XM data dictionary for each vector.

I summed the tallied number of burrows in each 0.5-mile within each 3x3 km grid cell in the GIS layer (Figure 11.3), and considered this summed count as a continuous variable in our correlative analyses of Burrowing Owl abundance.

Surrounding agricultural crops

The type of vegetation surrounding Burrowing Owl nest burrows may be correlated with abundance of male territories (Rich 1986, Green and Anthony 1989, Haug and Oliphant 1990, Plumpton and Lutz 1993), and thus may aid in predicting the abundance of owls across the HCP Study Area. For example, an intensive radio-tracking study of a small sample of owls in the Imperial Valley found 9 crop types were used, and that owls selected for barren ground near (<1,980 ft) and hay far (>1,980 ft) from nests (Rosenberg and Haley 2004). Furthermore, section 4.5.2.2 specified that "the burrowing owl population data will be linked to or combined with spatial information on … crop types in the HCP Study Area."

Relating crops to Burrowing Owl abundance is challenged by how and when owls tend to establish and maintain territories. Like many raptors, Burrowing Owls tend to establish territories and then occupy them for years, barring no major disturbances or nest failures. This complicates using current crop information to predict the current distribution of owl abundance because abundances may have been due to crop types present in the past. For example, older owls in the current population likely selected their territories farther back in the past than younger owls. If older owls represent the larger age class in the current population, and may have selected sites based on crops that are not currently present at those sites, a pattern between current crops and current owl abundance across the HCP Study Area may not emerge. In the absence of demographic data, methods to ascertain patterns between crops and current estimates of owl abundance warrant a multiple working hypotheses (Chamberlin 1890, 1965) approach based on comparisons of annual crop information (e.g., over the previous 5 years) and local estimates of abundance across the current Burrowing Owl population.

I took a retrospective approach to determine what crop(s) and how many years in the past the dominant age class in the current owl population may have selected their territories. If successful, this method could also possibly provide an indirect measure of the dominant age class in the Burrowing Owl population during the 2007 owl surveys. It may also be valuable in identifying the type of crop and how many years previous from a proposed population survey crops should be examined in order to adequately stratify the HCP Study Area and efficiently allocate survey efforts over the 75-year HCP permit.

This remote classification of the agricultural crops is presented separately in Appendix III. Here, those results were further used to assign a crop-related value to each 3x3 km grid cell separately each year. I computed the richness (number) of unique crops in a grid cell, and the proportion of each grid cell in the following cover types (Figure 11.4):

1. Level II grass
2. Level II bare ground and fallow

3. Level II broadleaf
4. wheat
5. fallow
6. Sudan
7. alfalfa
8. Bermuda
9. bare ground

These specific cover types were chosen because of their suggested importance in the literature (e.g., Rosenberg and Haley 2004) or expected similarity to those suggested to be important.

Type of water conveyance structure bank

Abundance of owl nests is anticipated to differ between canals, drains, and interceptors (Rosenberg and Haley 2004). Because a single or combination of these water conveyance structure(s) can occur within any stretch of the IID's rights-of-way, I had initially proposed to assign one of up to 10 different categories to each right-of-way. After reviewing the IID's canal and drain GIS feature layers, I was able only to assign only 2 categories (cement lined or earthen). I used these data to assign the proportion of cement-lined right-of-way to each 3x3 km grid cell (Figure 11.5).

RESULTS

The following figures display the GIS-based spatial datasets of selected environmental variables intended for use in assessing their potential as correlates of Burrowing Owl abundance.

CONCLUSIONS AND RECOMMENDATIONS

The resulting datasets were used in the following chapter to assess their relative importance as correlates of male Burrowing Owl territory abundance.

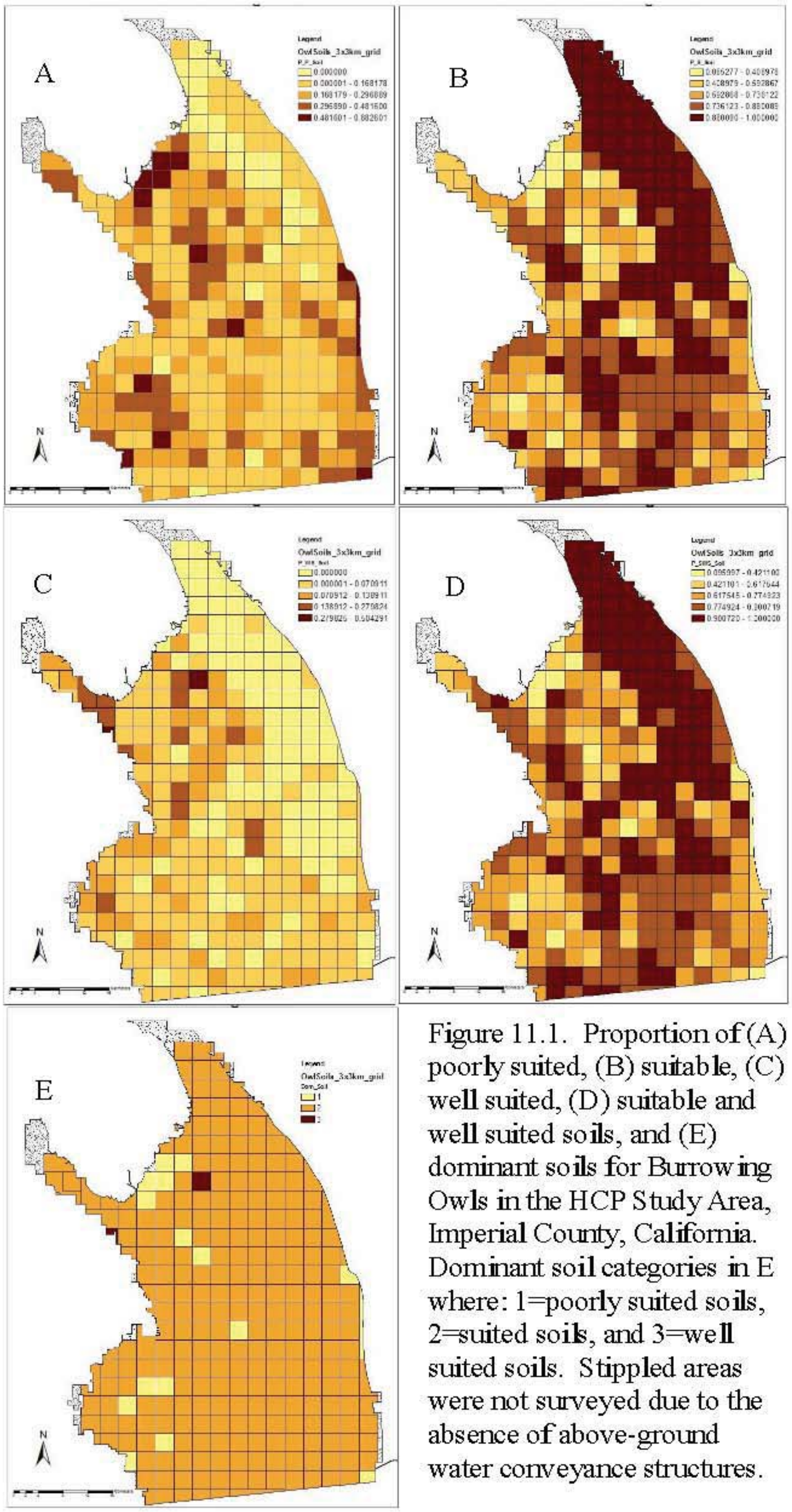

Figure 11.1. Proportion of (A) poorly suited, (B) suitable, (C) well suited, (D) suitable and well suited soils, and (E) dominant soils for Burrowing Owls in the HCP Study Area, Imperial County, California. Dominant soil categories in E where: 1=poorly suited soils, 2=suited soils, and 3=well suited soils. Stippled areas were not surveyed due to the absence of above-ground water conveyance structures.

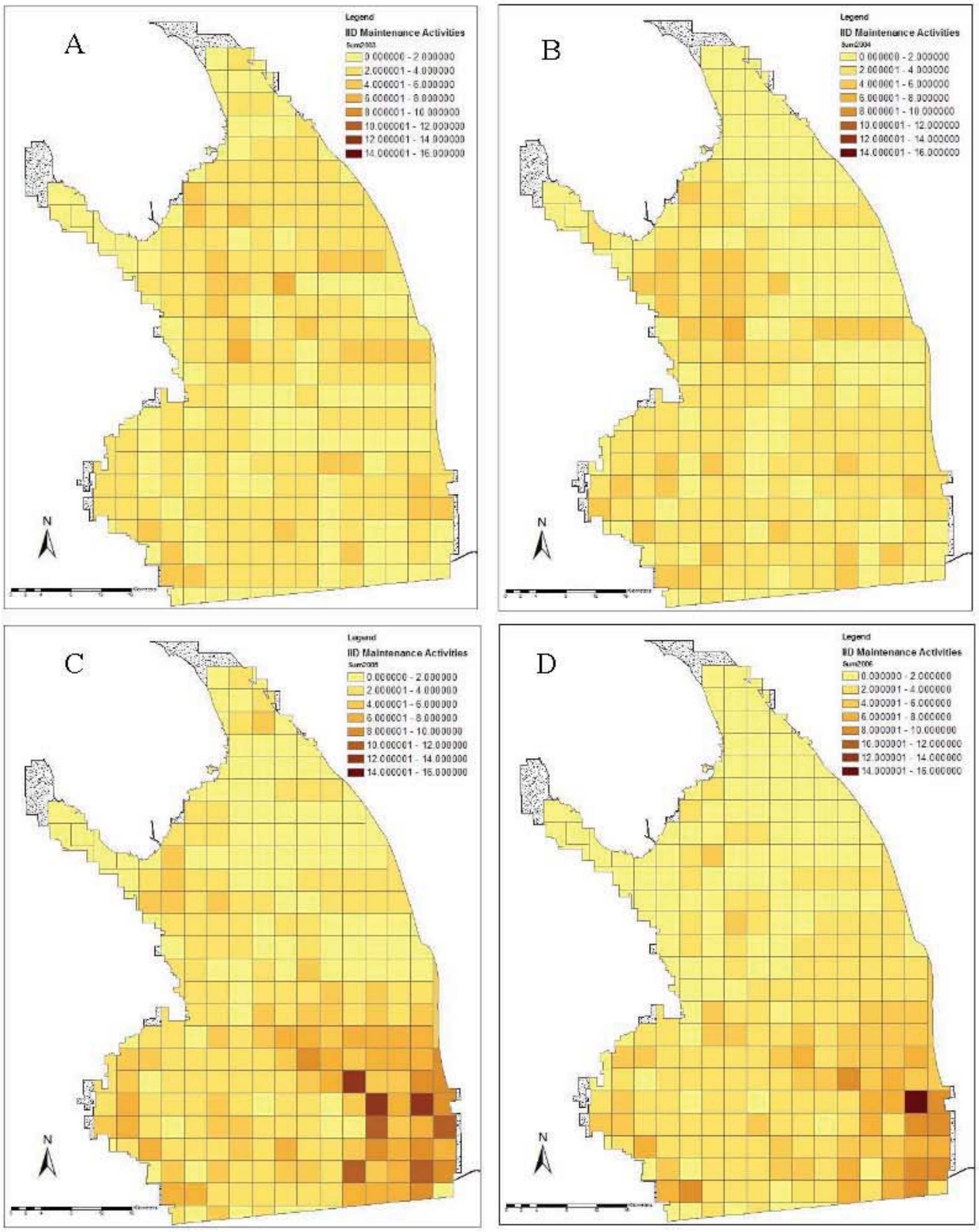

Figure 11.2. Frequency of the IID's maintenance activities in (A) 2003, (B) 2004, (C) 2005, and (D) 2006, Imperial County, California. Stippled areas were not surveyed due to the absence of above-ground water conveyance structures.

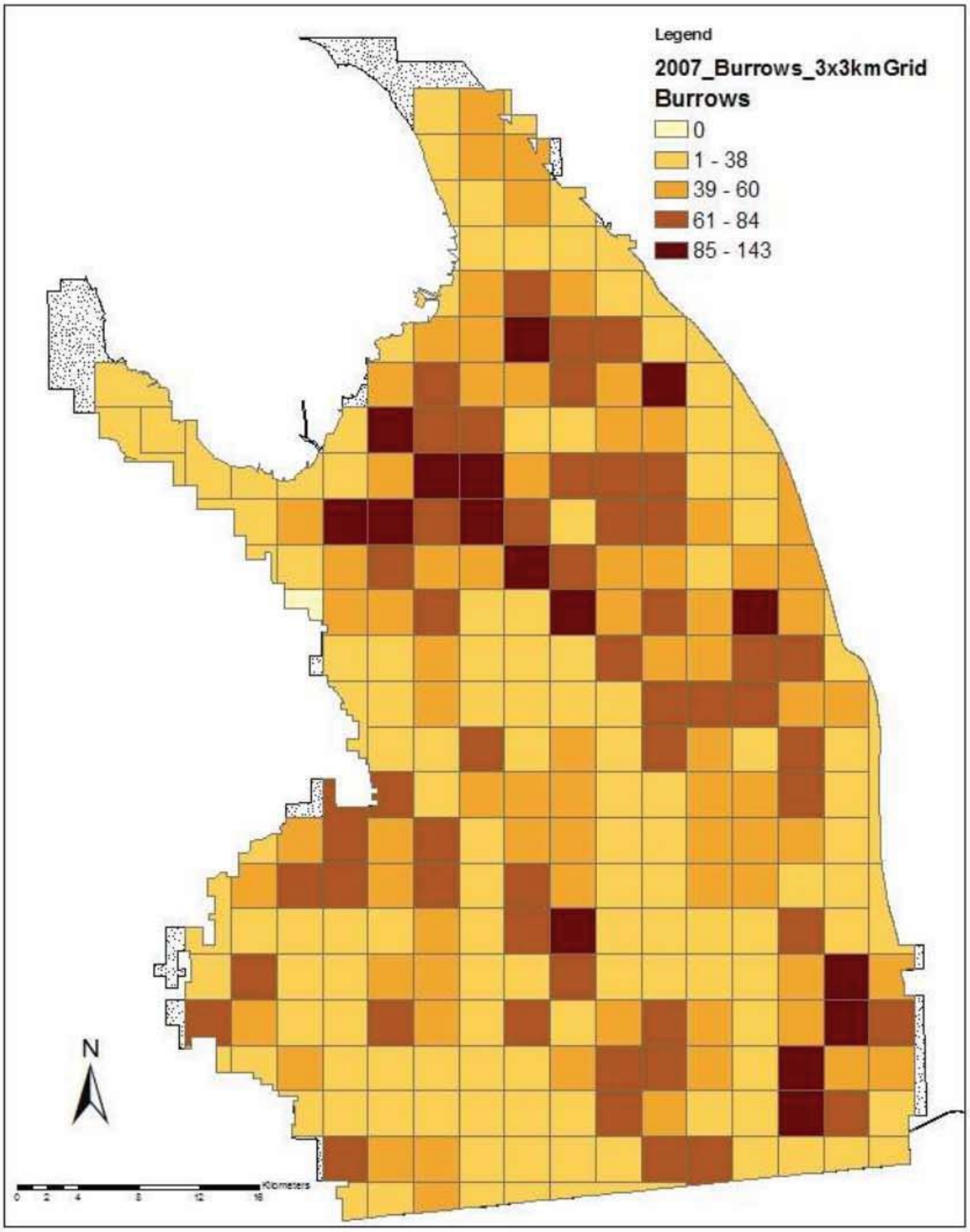

Figure 11.3. Number of potential Burrowing Owl nest burrows in the HCP Study Area, Imperial County, California, April 2007. Stippled areas were not surveyed due to absence of above-ground water conveyance structures.

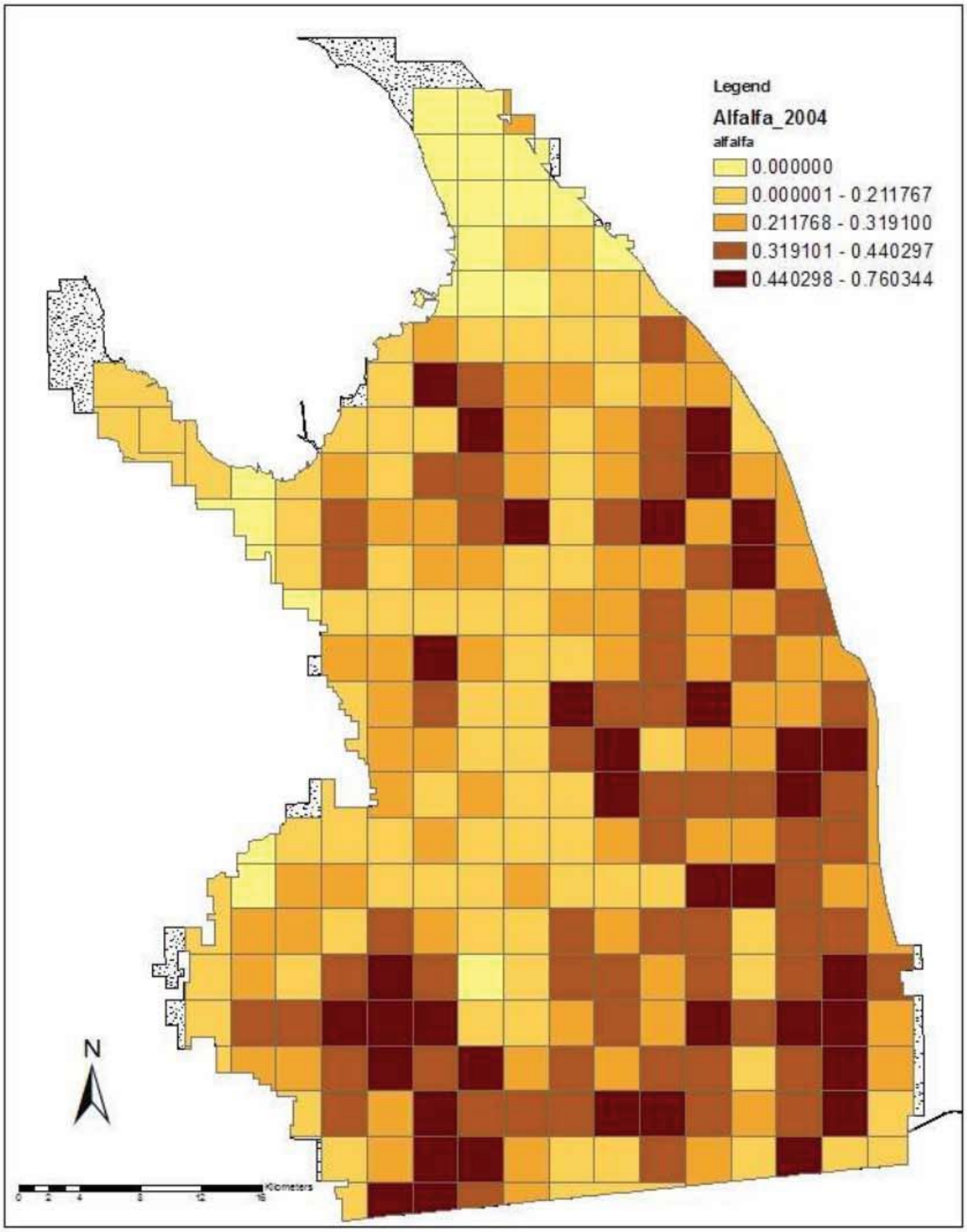

Figure 11.4. Proportion of crop class level III alfalfa in the HCP Study Area, Imperial County, California, 2004. This figure also is representative of the numerous other crop datasets generated. Stippled areas were not surveyed due to absence of above-ground water conveyance structures.

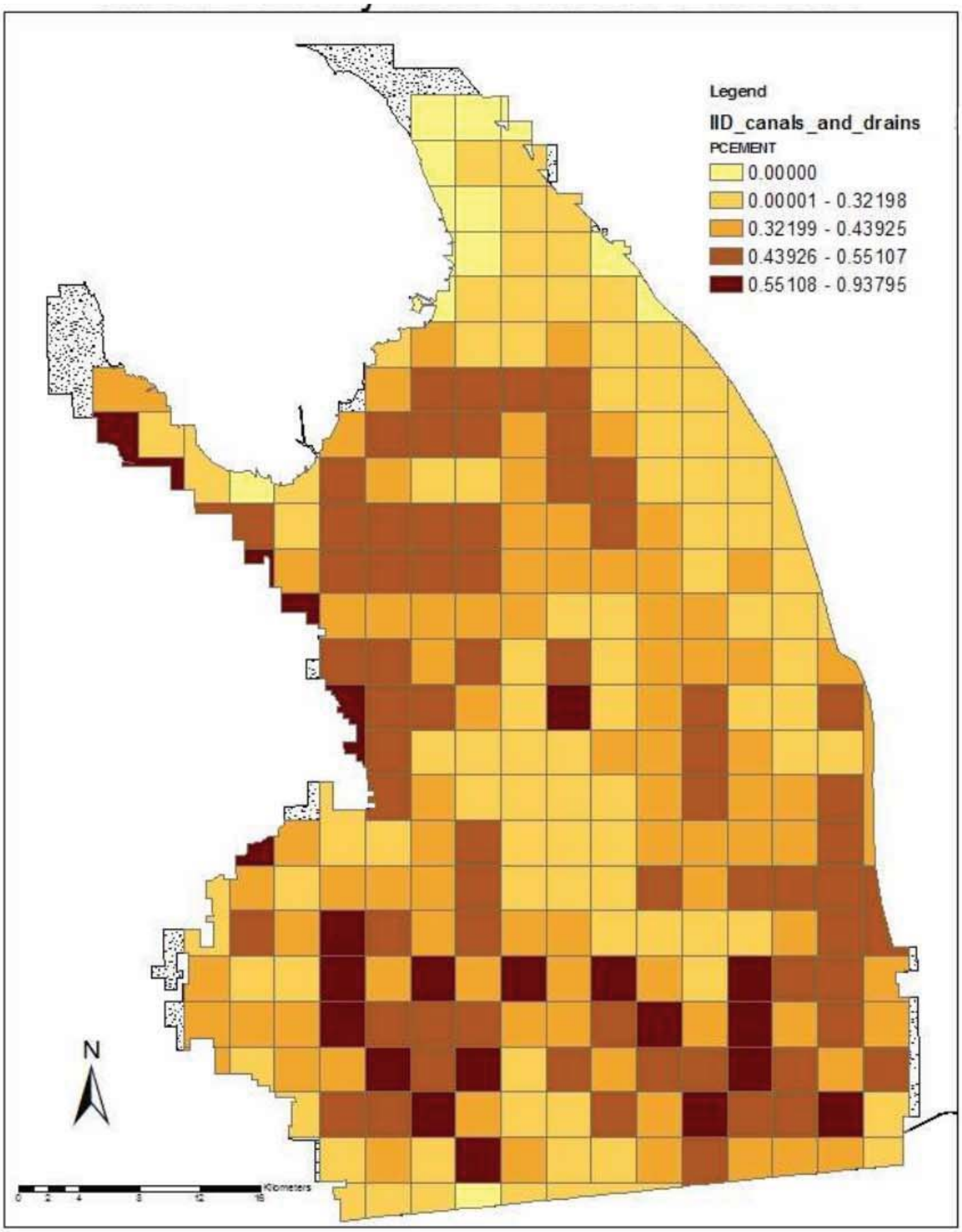

Figure 11.5. Percent cement-lined IID water conveyance structures, Imperial Valley, California, 2007. Stippled areas were not surveyed due to absence of above-ground water conveyance structures.

Chapter 12

THE RELATIVE IMPORTANCE OF POTENTIAL CORRELATES OF MALE BURROWING OWL TERRITORY ABUNDANCE

JEFFREY A. MANNING AND CAREN S. GOLDBERG

ABSTRACT. Given the large number of potential correlate datasets of Burrowing Owl abundance presented in the previous chapter, it is advantageous to assess their relative importance as correlates in order to consider only the strongest correlate(s). Here, we present modeling results from evaluating the relative importance of the potential correlates of male Burrowing Owl territory abundance in 2007. We intended that the resulting correlative model could be used to estimate the abundance of owls from its surrogate variable(s) reasonably well enough to stratify the sampling grid according to broad ranges of abundance because stratification would aid in improving the accuracy of sample estimates of abundance. We used the information theoretic approach with multiple-working hypotheses to compare 74 models, where each model represented one of the working hypotheses. The best model predicted male Burrowing Owl territory abundance as a function of the linear length of IID water conveyance structure, available burrows in 2007, and the proportion of agricultural crops in alfalfa production in 2004. We found that spatial autocorrelation was significant up to 2 nearest grid cell neighbors out, and a spatial covariate term added to the model improved the model's predictive ability.

INTRODUCTION

An important part of the long-term stratified random sampling survey method we proposed is to produce a model with environmental variables that can be used in subsequent years to determine which strata (low, medium, and high abundances of male Burrowing Owl territories) a grid cell belongs to prior to a given population survey. This stratification would be used to randomly select grid cells to be surveyed. Due to the dynamic nature of the system in the HCP Study Area, the use of this model to assign grid cells to specific strata is designed for re-stratifying grid cells each year.

Our objective here was to develop a model, using the environmental variables gathered and presented in Chapter 11, of the relative best correlates of male Burrowing Owl territory abundance in the HCP Study Area. We chose to use the estimate of local abundance in each independent sampling unit from Chapter 10 as the response variable in linear models outside of a closed-population statistical platform (e.g., program MARK; Cooch 1999, White and Burnham 1999) because the optimal allocation of effort proposed under our stratified random sampling approach required a large number of standardized sampling units (274 grid cells). This large number of units would lead to over-parameterized models in such platforms. Furthermore the extrapolation of results from future stratified random sampling to a full population estimate is currently unavailable within such a platform.

METHODS

Each single or combination of correlate(s) constituted a hypothesis represented by a statistical model, with owl abundance as the response, based on the 3x3 km grid as sampling units. Because the error surrounding each abundance estimate was expected not to be constant, we fit weighted least square regression models (Cleveland 1979, Cleveland and Devlin 1988) to the data. Weighted least squares regression is an efficient method to provide easily interpretable statistical intervals for estimation, prediction, calibration and optimization. In addition, the main advantage that the weighted least squares method has over other methods is the ability to handle regression situations where the data points vary in quality. If the variance of the random errors in the data is not constant across all levels of the explanatory variable(s), the use of weighted least squares can yield relatively precise parameter estimates.

Model structures followed that of simple linear regression (Table 12.1). We restricted additive structures to those factors that have been shown or suggested to be important for Burrowing Owls (e.g., alfalfa, bare ground, and fallow fields; Rosenberg and Haley 2004). Because the Burrowing Owl abundance data in each cell were dependent on the linear length of IID-maintained water conveyance structures, we standardized this effect by including a term for linear length of these structures as the baseline in every model we fit to the data. The inclusion of this variable in all models precluded the need to scale other explanatory variables by linear length of water conveyance structures.

We compared the relative fit of each model following a multiple-hypothesis testing framework, based a model-selection procedure with AIC (Akaike 1973). This information theoretic approach (Burnham and Anderson 2002) was intended to determine the best correlates of male Burrowing Owl territory abundance that we measured by identifying the most parsimonious model. Such correlates are necessary to develop strata classes associated with low, medium, and high abundances of male Burrowing Owl territories in the HCP Study Area for the development of a long-term sampling methodology.

We tested for spatial autocorrelation in the residuals of the best model using the Moran's *I* spatial statistic in Program Geoda95 (Spatial Analysis Laboratory, University of Illinois, Urbana-Champaign, IL). This test was used to assess spatial autocorrelation in owl abundance that explanatory variables did not account for in the model. We used a weight matrix based on Queen's adjacency scheme to identify how far out from a given cell (i.e., to what degree of neighboring cells) abundance was autocorrelated. We then accounted for this spatial covariance structure by using this distance to incorporate a term in the best model, thereby allowing the model to estimate the spatial coefficient, which is similar to methods used with mixed models (Laird and Ware 1982). This approach was recommended by Dr. Bryan Manly in his letter, dated June 5, 2007. We considered this model, which included the spatial autocorrelation term, as our 'best' model.

We validated the assumptions underlying the best model by performing graphical analyses of residuals. We plotted the innermost fitted values from the best model against observed values of the response variable to provide an overall summary of explanatory power of the model, how much variation is explained, how much remains, and evidence of lack of fit. We also plotted the innermost fitted values against the innermost residuals to assess the assumption of correct model structure.

We also used a version of *k*-fold cross validation [leave-one-out cross validation; Devijver and Kittler (1982)] to validate how well the model parameters from our best model could predict abundance in a grid cell. This validation approach involved using a single observation from the original sample as the validation data, and the remaining observations as the training data. This was repeated such that each observation in the sample was used once as the validation data. We performed these analyses in Program R (Ihaka and Gentleman 1996).

Table 12.1. Linear regression models (presented as program R code). Model names are to the left of '<-' and refer to a model's explanatory variables. Definitions of model syntax are provided at the bottom of the table.

```
03grass.lm <- lm(Nhat ~ TotLength + 03grass, data=buow, weights=Nhatwt)
03barefallow.lm <- lm(Nhat ~ TotLength + 03barefallow, data=buow, weights=Nhatwt)
03broadleaf.lm <- lm(Nhat ~ TotLength + 03broadleaf, data=buow, weights=Nhatwt)
04grass.lm <- lm(Nhat ~ TotLength + 04grass, data=buow, weights=Nhatwt)
04barefallow.lm <- lm(Nhat ~ TotLength + 04barefallow, data=buow, weights=Nhatwt)
04broadleaf.lm <- lm(Nhat ~ TotLength + 04broadleaf, data=buow, weights=Nhatwt)
05grass.lm <- lm(Nhat ~ TotLength + 05grass, data=buow, weights=Nhatwt)
05barefallow.lm <- lm(Nhat ~ TotLength + 05barefallow, data=buow, weights=Nhatwt)
05broadleaf.lm <- lm(Nhat ~ TotLength + 05broadleaf, data=buow, weights=Nhatwt)
06grass.lm <- lm(Nhat ~ TotLength + 06grass, data=buow, weights=Nhatwt)
06barefallow.lm <- lm(Nhat ~ TotLength + 06barefallow, data=buow, weights=Nhatwt)
06broadleaf.lm <- lm(Nhat ~ TotLength + 06broadleaf, data=buow, weights=Nhatwt)
07grass.lm <- lm(Nhat ~ TotLength + 07grass, data=buow, weights=Nhatwt)
07barefallow.lm <- lm(Nhat ~ TotLength + 07barefallow, data=buow, weights=Nhatwt)
07broadleaf.lm <- lm(Nhat ~ TotLength + 07broadleaf, data=buow, weights=Nhatwt)
03wheat.lm <- lm(Nhat ~ TotLength + 03wheat, data=buow, weights=Nhatwt)
03fallow.lm <- lm(Nhat ~ TotLength + 03fallow, data=buow, weights=Nhatwt)
03sudan.lm <- lm(Nhat ~ TotLength + 03sudan, data=buow, weights=Nhatwt)
03alfalfa.lm <- lm(Nhat ~ TotLength + 03alfalfa, data=buow, weights=Nhatwt)
03bermuda.lm <- lm(Nhat ~ TotLength + 03bermuda, data=buow, weights=Nhatwt)
03bareground.lm <- lm(Nhat ~ TotLength + 03bareground, data=buow, weights=Nhatwt)
04wheat.lm <- lm(Nhat ~ TotLength + 04wheat, data=buow, weights=Nhatwt)
04fallow.lm <- lm(Nhat ~ TotLength + 04fallow, data=buow, weights=Nhatwt)
04sudan.lm <- lm(Nhat ~ TotLength + 04sudan, data=buow, weights=Nhatwt)
04alfalfa.lm <- lm(Nhat ~ TotLength + 04alfalfa, data=buow, weights=Nhatwt)
04bermuda.lm <- lm(Nhat ~ TotLength + 04bermuda, data=buow, weights=Nhatwt)
04bareground.lm <- lm(Nhat ~ TotLength + 04bareground, data=buow, weights=Nhatwt)
05wheat.lm <- lm(Nhat ~ TotLength + 05wheat, data=buow, weights=Nhatwt)
05fallow.lm <- lm(Nhat ~ TotLength + 05fallow, data=buow, weights=Nhatwt)
05sudan.lm <- lm(Nhat ~ TotLength + 05sudan, data=buow, weights=Nhatwt)
05alfalfa.lm <- lm(Nhat ~ TotLength + 05alfalfa, data=buow, weights=Nhatwt)
05bermuda.lm <- lm(Nhat ~ TotLength + 05bermuda, data=buow, weights=Nhatwt)
05bareground.lm <- lm(Nhat ~ TotLength + 05bareground, data=buow, weights=Nhatwt)
06wheat.lm <- lm(Nhat ~ TotLength + 06wheat, data=buow, weights=Nhatwt)
06fallow.lm <- lm(Nhat ~ TotLength + 06fallow, data=buow, weights=Nhatwt)
06sudan.lm <- lm(Nhat ~ TotLength + 06sudan, data=buow, weights=Nhatwt)
06alfalfa.lm <- lm(Nhat ~ TotLength + 06alfalfa, data=buow, weights=Nhatwt)
06bermuda.lm <- lm(Nhat ~ TotLength + 06bermuda, data=buow, weights=Nhatwt)
06bareground.lm <- lm(Nhat ~ TotLength + 06bareground, data=buow, weights=Nhatwt)
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```
07wheat.lm <- lm(Nhat ~ TotLength + 07wheat, data=buow, weights=Nhatwt)
07fallow.lm <- lm(Nhat ~ TotLength + 07fallow, data=buow, weights=Nhatwt)
07sudan.lm <- lm(Nhat ~ TotLength + 07sudan, data=buow, weights=Nhatwt)
07alfalfa.lm <- lm(Nhat ~ TotLength + 07alfalfa, data=buow, weights=Nhatwt)
07bermuda.lm <- lm(Nhat ~ TotLength + 07bermuda, data=buow, weights=Nhatwt)
07bareground.lm <- lm(Nhat ~ TotLength + 07bareground, data=buow, weights=Nhatwt)
03CrpRch.lm <- lm(Nhat ~ TotLength + 03CrpRch, data=buow, weights=Nhatwt)
04CrpRch.lm <- lm(Nhat ~ TotLength + 04CrpRch, data=buow, weights=Nhatwt)
05CrpRch.lm <- lm(Nhat ~ TotLength + 05CrpRch, data=buow, weights=Nhatwt)
06CrpRch.lm <- lm(Nhat ~ TotLength + 06CrpRch, data=buow, weights=Nhatwt)
07CrpRch.lm <- lm(Nhat ~ TotLength + 07CrpRch, data=buow, weights=Nhatwt)
03IIDMnt.lm <- lm(Nhat ~ TotLength + 03IIDMnt, data=buow, weights=Nhatwt)
04IIDMnt.lm <- lm(Nhat ~ TotLength + 04IIDMnt, data=buow, weights=Nhatwt)
05IIDMnt.lm <- lm(Nhat ~ TotLength + 05IIDMnt, data=buow, weights=Nhatwt)
06IIDMnt.lm <- lm(Nhat ~ TotLength + 06IIDMnt, data=buow, weights=Nhatwt)
TotIIDMnt.lm <- lm(Nhat ~ TotLength + TotIIDMnt, data=buow, weights=Nhatwt)
PPSoil.lm <- lm(Nhat ~ TotLength + PPSoil, data=buow, weights=Nhatwt)
PSSoil.lm <- lm(Nhat ~ TotLength + PSSoil, data=buow, weights=Nhatwt)
PWSoil.lm <- lm(Nhat ~ TotLength + PWSoil, data=buow, weights=Nhatwt)
PSWSoil.lm <- lm(Nhat ~ TotLength + PSWSoil, data=buow, weights=Nhatwt)
DomSoil.lm <- lm(Nhat ~ TotLength + DomSoil, data=buow, weights=Nhatwt)
07Brrws.lm <- lm(Nhat ~ TotLength + 07Brrws, data=buow, weights=Nhatwt)
PCementlined.lm <- lm(Nhat ~ TotLength + PCementlined, data=buow, weights=Nhatwt)
TotLength.lm <- lm(Nhat ~ TotLength, data=buow, weights=Nhatwt)

07Brrwsplus03alfalfa.lm <- lm(Nhat ~ TotLength + 07Brrws + 03alfalfa, data=buow, weights=Nhatwt)
07Brrwsplus04alfalfa.lm <- lm(Nhat ~ TotLength + 07Brrws + 04alfalfa, data=buow, weights=Nhatwt)
07Brrwsplus05alfalfa.lm <- lm(Nhat ~ TotLength + 07Brrws + 05alfalfa, data=buow, weights=Nhatwt)
07Brrwsplus06alfalfa.lm <- lm(Nhat ~ TotLength + 07Brrws + 06alfalfa, data=buow, weights=Nhatwt)
07Brrwsplus07alfalfa.lm <- lm(Nhat ~ TotLength + 07Brrws + 07alfalfa, data=buow, weights=Nhatwt)

07Brrwsplus03barefallow.lm <- lm(Nhat ~ TotLength + 07Brrws + 03barefallow, data=buow, weights=Nhatwt)
07Brrwsplus04barefallow.lm <- lm(Nhat ~ TotLength + 07Brrws + 04barefallow, data=buow, weights=Nhatwt)
07Brrwsplus05barefallow.lm <- lm(Nhat ~ TotLength + 07Brrws + 05barefallow, data=buow, weights=Nhatwt)
07Brrwsplus06barefallow.lm <- lm(Nhat ~ TotLength + 07Brrws + 06barefallow, data=buow, weights=Nhatwt)
07Brrwsplus07barefallow.lm <- lm(Nhat ~ TotLength + 07Brrws + 07barefallow, data=buow, weights=Nhatwt)
```

Bareground referred to the proportion of a grid in a bare ground condition (i.e., no vegetation), barefallow was the proportion of a grid cell in a bare ground and fallow conditions, CrpRch was crop richness (count) in a grid cell, Brrws was the number of suitable burrows counted in a grid cell in 2007 immediately prior to the population surveys, PCementlined was the proportion of above-ground water conveyance structure in a grid cell that was cement-lined, TotLength was the total length of above-ground water conveyance structure in a grid cell, and IIDMnt was the frequency of IID's maintenance activities in a grid cell (as calculated in the previous chapter). Numeric values preceding model names referred to year.

RESULTS

The best model predicted male Burrowing Owl territory abundance as a function of available burrows in 2007 and the proportion of agricultural crops in alfalfa production in 2004, with the next model having a AIC = 1.62 ($r^2 = 0.37$, $F_{3,270} = 53.7$, $p<0.001$; Tables 12.2 and 12.3). The difference between this model and a competing one was the year of alfalfa production. Because both models had the same number of parameters and alfalfa production between any 2 years is likely to be correlated, we considered the model with the smaller AIC as the best for stratification purposes.

We used the residuals from the best model above to assess spatial autocorrelation in Burrowing Owl abundance, and found that spatial autocorrelation was significant up to 2 nearest grid cell neighbors out (Table 12.4).

We constructed an additional model that included a spatial covariate term that accounted for the mean abundance of male Burrowing Owl territory abundance out to 2 nearest grid cell neighbors away (Table 12.5). The addition of this spatial autocorrelation term improved the fit of the model, with the original model having a AIC = 59.74. The adjusted r^2 for this model was 0.51 ($F_{4,269} = 67.22$, $p<0.001$; Table 12.5), and *k*-fold cross validation indicated that the correlates in the model were not biased (slope in Figure 12.1 = 1) and explained 53% of the variation in grid cells used for validation, which were independent from the cells used for training the model.

Table 12.2. Models of abundance in grid cells and AIC values. All models included the total length of IID water conveyance structure in addition to the parameters listed.

Model Parameters	AIC
Burrows in 2007, alfalfa in 2004	0
Burrows in 2007, alfalfa in 2003	1.62
Burrows in 2007, alfalfa in 2006	5.38
Burrows in 2007, alfalfa in 2005	6.21
Burrows in 2007, bare and fallow in 2007	9.82
Burrows in 2007, bare and fallow in 2006	10.09
Burrows in 2007, bare and fallow in 2003	10.54
Burrows in 2007, bare and fallow in 2004	12.48
Burrows in 2007, alfalfa in 2007	13.16
Burrows in 2007	27.53
Grass in 2006	27.94
Burrows in 2007, bare and fallow in 2005	29.31
Bare/fallow in 2004	30.06
Bermuda grass in 2007	30.46
Alfalfa in 2004	31.03
Alfalfa in 2003	33.29
Fallow in 2007	35.71
Fallow in 2006	40.07
Fallow in 2003	40.19
Grass in 2007	40.70
Alfalfa in 2006	40.92
Bare/fallow in 2007	42.13
Fallow in 2005	43.90
Sudan grass in 2006	43.92
Alfalfa in 2005	44.21
Proportion cement-lined water conveyance structures	44.57
Bare/fallow in 2006	45.14
Bare/fallow in 2003	46.28
Grass in 2004	47.05

Bermuda grass in 2003	47.14
Bare/fallow in 2004	48.13
Grass in 2003	49.01
Broadleaf in 2003	50.27
Bermuda grass in 2004	52.69
Bermuda grass in 2005	52.83
Alfalfa in 2007	52.90
Bermuda in 2006	53.19
Broadleaf in 2004	55.69
Grass in 2005	57.38
IID Mainenence in 2006	58.56
Proportion suitable soils	59.59
Broadleaf in 2006	59.82
Broadleaf in 2007	60.06
Sudan grass in 2004	60.22
Total IID Maintenance activities, 2004-2007	61.14
Proportion suited and well-suited soils	61.39
Wheat in 2004	61.96
Crop richness in 2006	62.03
Wheat in 2003	62.50
Crop richness in 2005	62.52
IID Maintenance in 2005	62.70
Proportion well-suited soils	62.75
Wheat in 2005	63.04
Bare/fallow in 2005	63.87
Crop richness in 2003	64.34
Proportion poorly-suited soils	64.37
Length of water conveyance structures	64.40
Bare ground in 2004	64.60
Dominant soil category	64.69
Crop richness in 2004	64.74
Wheat in 2006	65.01
IID Maintenance in 2004	65.44
Sudan grass in 2003	65.67
Broadleaf in 2005	65.72
Bare ground in 2005	65.72
Sudan Grass in 2007	65.79
Bare ground in 2007	65.83
Wheat in 2007	65.97
IID Maintenance in 2003	66.23
Bare ground in 2006	66.32
Crop richness in 2007	66.35
Bare ground in 2003	66.39

Table 12.3. Summary of best linear regression model without a spatial covariate. TotLength is the total length of IID water conveyance structure (km) in a grid cell, 07Brrws is the number of available burrows counted in a grid cell in 2007, and 04Alfalfa is the proportion of a grid cell covered by alfalfa in the spring 2004.

Parameter	Estimate	Std. Error	*t*-value	Pr(>|t|)
Intercept	-3.63719	2.19056	-1.66	0.09
TotLength	0.45289	0.13106	3.456	<0.001
07Brrws	0.16371	0.02784	5.881	<0.001
04Alfalfa	22.87477	4.12668	5.543	<0.001

Table 12.4. Results from Moran's *I* analysis of spatial autocorrelation, using program GeoDa.

Nearest Neighbors	Moran's *I*	*p*-value
1	0.3011	0.001
2	0.1314	0.001
3	0.0040	0.355

Table 12.5. Summary of best linear regression model with a spatial covariate. TotLength is the total length of IID water conveyance structure (km) in a grid cell, 07Brrws is the number of available burrows counted in a grid cell in 2007, 04Alfalfa is the proportion of a grid cell covered by alfalfa in the spring 2004, and MNhat2NN is the mean abundance of male Burrowing Owl territories out to 2 nearest neighboring grid cells (Queen's rule).

Parameter	Estimate	Std. Error	*t*-value	Pr(>|t|)
Intercept	-12.5436	2.23862	-5.603	<0.001
TotLength	0.27721	0.11923	2.325	0.0208
07Brrws	0.16018	0.02492	6.427	<0.001
04Alfalfa	10.46895	3.9885	2.625	0.009
MNhat2NN	0.83916	0.10177	8.245	<0.001

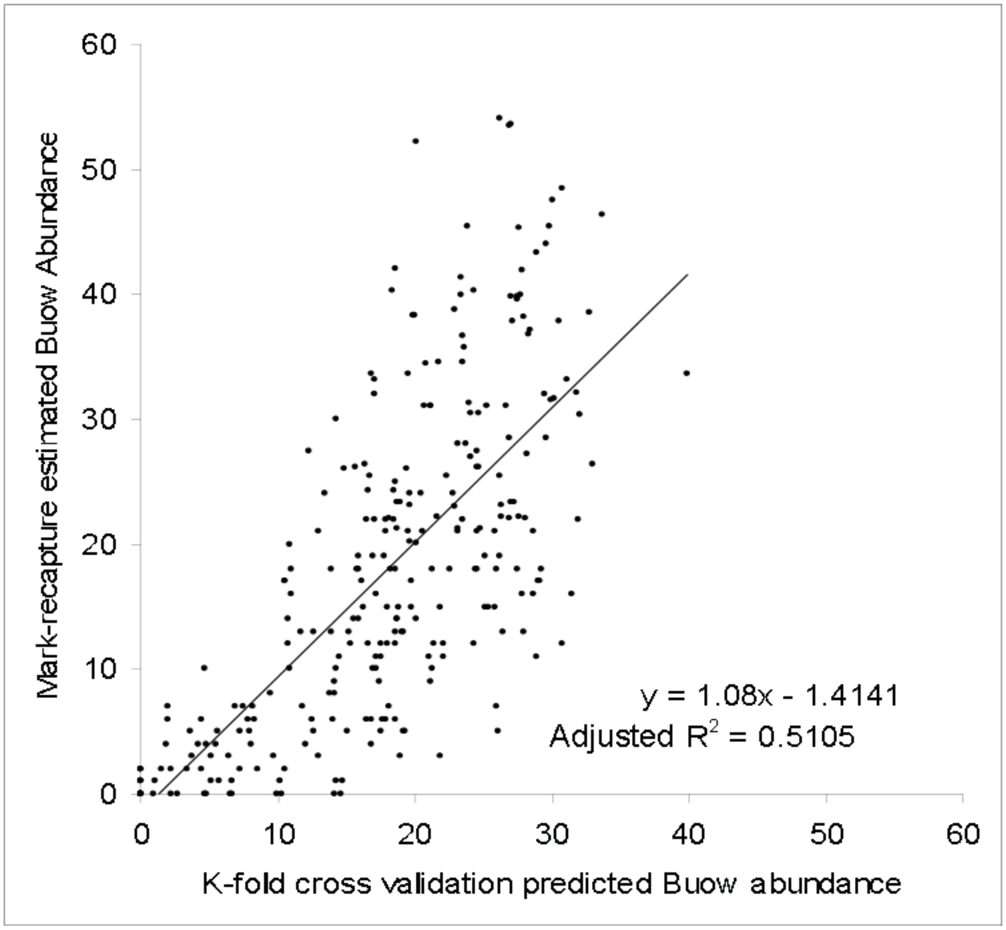

Figure 12.1. Results from *k*-fold cross validation of the best least squares weighted regression with a spatial covariate of owl abundance (Owl territory abundance = TotLength + 07Brrws + 04alfalfa + MNhat2NN) for predicting abundance of male Burrowing Owl territories, Imperial Valley, California 2007.

CONCLUSIONS AND RECOMMENDATIONS

The model representing the best correlates of male Burrowing Owl territory abundance in the HCP Study Area contained the number of available burrows and the proportion of alfalfa in grid cells three years prior to the owl survey. The competing model in our initial analysis contained alfalfa four years prior to the survey, and the four models containing only alfalfa and burrows had the best AIC rankings of all the models tested. This was not surprising given that the type of vegetation surrounding Burrowing Owl nest burrows has been suggested by others to be a possible predictor of owl abundance (Rich 1986, Green and Anthony 1989, Haug and Oliphant 1990, Plumpton and Lutz 1993). Of the 9 crop types found to be used by a small sample of radio-tagged Burrowing Owls in the Imperial Valley (Rosenberg and Haley 2004), owls selected for barren ground near (<1,980 ft) and hay far (>1,980 ft) from nests. Our results provide evidence of the importance of alfalfa as a correlate of owl abundance in the HCP Study Area.

Although the addition of a spatial covariance term improved the fit of our best model, this model explained only 51% of the variability in local owl abundance across the HCP Study Area. This may be due to a variety of factors, including the resolution of the standardized grid cells, temporal variation in the correlates themselves (e.g., crops were rotated during our owl surveys), accuracy of the remote sensing analyses that we used to derive the crop estimates, and quality of the other correlates we used. For example, the IID's maintenance data were only available for each canal or drain as a whole, with no specific location. Because some of these structures were very long and maintenance activities are often locally concentrated (Ty Mull, pers. comm.), the spatial resolution of the data was not fine enough to determine with high accuracy the amount of maintenance each grid cell received. The categorization of maintenance activities also necessitated that we pool among categories because specific activities were often referred to in the database under more general terms. Because recent information suggested that maintenance activities can directly influence Burrowing Owl survival and dispersal (e.g., Catlin and Rosenberg 2006), we suspect our generalization of that data may have diluted its accuracy, which in turn reduced our ability to adequately assess the relative importance of the IID's maintenance as a correlate of abundance. Based on our initial objective to identify the best correlates of owl abundance for use in stratifying the HCP Study Area prior to future population surveys, further investigations into correlations between specific IID maintenance activities and owl abundance may prove beneficial.

The best model identified the variables that were most correlated to owl abundance, which is a widely accepted method of choosing variables that can be used to construct strata for stratified random sampling (Cochran 1977:128). Because it did not explain all of the variation in owl abundance and its correlative power may not be stable over time (e.g., farming practices change or local owl abundances become limited by other factors), the efficacy of using this model for constructing strata needs to be tested. A validation of this correlative model with an independent dataset is essential because if the correlation between these variables and owl abundance does not remain constant or increase over time, then the stratification will become inefficient and the precision of the resulting population estimates will be reduced (Cochran 1977:100-102). In light of these concerns, chapter 17 provides a comparison of this model against alternatives to stratifying the HCP Study Area, and a recommended alternative is provided.

Chapter 13

POTENTIAL CORRELATES OF AREA OCCUPANCY BY MALE BURROWING OWLS

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ABSTRACT. The Burrowing Owl population surveys described in previous chapters could provide information on rates of occupancy in local grid cells, which could provide valuable information for conservation and management and elimination of areas from future surveys. In this chapter, we focused on identifying potential correlates of area occupancy by male Burrowing Owls. We used the information theoretic approach to compare the fit of various logistic occupancy models to the data, where each model structure included a different potential correlate and/or assumed variable or constant detection probabilities. We found that >95% of the 3x3 grid cells in the HCP Study Area were occupied, and that none of the models fit the data well, preventing us from identifying a correlate of occupancy.

INTRODUCTION

In our detailed study plan, dated 18 January 2007, we proposed to use the Burrowing Owl survey data and datasets of potential correlative factors collected for Tasks 1 and 4 under Objective 1 to estimate the probability that sampling units (grid cells) were occupied by 1 owl territories. This information was intended to supplement the distribution of owl point locations obtained from conducting the complete census under Objective 1 of the study plan. It was also to provide a GIS polygon layer of independent sampling units with probabilities of occupancy categorized according to either low and high probabilities of occupancy. This GIS layer could also be viewed as a probabilistic distribution map, and was anticipated to be generated each year, based on the correlative factor(s) determined to be the most strongly correlated to probabilities of occupancy. Here, we present the findings from this approach.

METHODS

For this study, we used the original territory locations derived from the 3 point-coordinate capture-recapture survey occasions determined from the 2007 census of 3x3 km grid cells in the HCP Study Area. We used these data to construct a multinomial occupancy encounter history for each grid cell, where a given grid cell was considered occupied (1) on a given survey occasion if 1 owl territories were detected and unoccupied (0) if no territories were detected. We applied these binomial decisions for each survey occasion.

We fit occupancy models to the occupancy encounter history using Program PRESENCE 2.2 (Hines 2006), with the goal of determining the corrected estimate of the proportion of 3x3 km grid cells occupied in the HCP Study Area. We applied an information theoretic framework to testing multiple working hypotheses (Burnham and Anderson 2002), developed a set of 28 *a priori* hypotheses, and constructed an occupancy model for each hypothesis. Our base model [ψ(.) p(.)] represented the hypothesis that the proportion of occupied grid cells (ψ) did not vary according to an environmental covariate and the probability of detecting occupancy (p) was constant among occasions. We further constructed models that differed in the environmental variable (soils, fallow land, alfalfa, maintenance activities, water conveyance structure length and type, burrows, and crop richness) hypothesized to be a potential correlate of occupancy of grid cells. We constructed simple linear models, and included only single covariates that we suspected may be important or previously reported in the literature to be important for Burrowing Owls. Because our sampling methodology involved surveying different portions of the HCP Study Area at different times over the 30 days (e.g., we would conduct 4 consecutive occasions in one portion before conducting 4 occasions in another portion, and we divided the area into 6 separate portions), we pooled the data across the different portions to create our 4-occasion encounter histories. To avoid problems with the possible confounding of time and portion of the HCP Study Area surveyed, we assumed that detection was constant in our models. We used Akaike's Information Criterion (Akaike 1973) to determine the most parsimonious model and considered it to be our best model. We assessed the fit of our global model to the occupancy encounter history data using 1,000 bootstraps for Mackenzie and Bailey's Goodness-of-fit test (Mackenzie and Bailey 2004).

RESULTS

We observed 1 male Burrowing Owl territories during 1 survey occasions in 261 (95%) of the 274 grid cells in the HCP Study Area during the 2007 surveys. We did not detect territories in the remaining 5% (13) of the grid cells, making the naïve (empirical) estimate of $\psi = 0.95$, which differs from the modeled estimate of ψ and can be interpreted as the probability that any grid in the HCP Study Area is occupied. The model with the smallest □AIC hypothesized that occupancy was a function of the dominant type of soil in grid cells, and there were no competing models (the next best model had a □AIC = 181). This model estimated a very high detection probability (p) of 0.97 (SE = 0.18).

Our best model (equivalent to a global model in its number of parameters) fit the data poorly (Goodness-of-fit $X^2 = 57.2$, $P = 0.001$), predicting an unconditional ψ that was equal to the naïve estimate (0.95, SE = 0.01) in the 13 grid cells where we did not observe territories. When conditioned on the encounter histories, this model predicted no occupancies that we did not detect.

Given the poor performance of this model and the absence of competing models, we also examined the fit and ability to correctly predict occupancy from various models with covariates that we constructed and found similar problems, with none passing the Goodness-of-fit test. Although there was little support for our base model containing no covariates (□AIC = 1058.94), its estimated p was also high (0.97, SE = 0.005), and it also predicted the proportion of occupied sites equal to the naïve estimate (ψ = 0.95, SE = 0.01).

CONCLUSIONS AND RECOMMENDATIONS

Given the high probability of detecting the presence of male Burrowing Owl territories in grid cells, and the high rate of occupancy, most of 274 grid cells in the sampling grid were occupied. The discrepancy between the 18 grid cells found in chapter 10 to contain zero territory centroids and the lower number (13) found here to be unoccupied was due to our use of owl locations in estimating occupancy. Because of the 2-dimensional nature of owl territories, locations of owls that occupy territories straddling grid cell boundaries can occur in 2 grid cells, and this edge effect led to classifying 5 of the grid cells without territory centroids as occupied during these analyses.

The failure of our global model to fit the data may stem from a variety of sources, including: 1) that the size of our grid cells, coupled with high detection probabilities, ensured a high rate of observed occupancy, particularly given the density of the owl population in 2007, 2) the owl population was saturated (but see Chapter 19), 3) our set of hypotheses were not comprehensive enough which could have incidentally led us to not measure the biologically correct correlative variable(s), 4) or our model structures may not have adequately accounted for additive or multiplicative biological processes that influenced occupancy. A reduced owl population or smaller grid cells would produce more variability among grid cells and may have yielded a different result, but our objective was to use the existing standardized grid intended for drawing random samples from prior to subsequent surveys.

The prediction of high occupancy rates (0.95) by the best model in grid cells where territories were not detected was likely due to the high rate of occupancy that essentially produced a homogeneous sampling grid of occupied cells. This extremely low number of unoccupied grid cells, compared to the large number of occupied cells, provided an extremely imbalanced dataset from which to estimate occupancy rates with our models, and explains the source of the poor fit. Furthermore, this may also explain why dominant soil type was the best correlate. Dominant soils were classified into only 3 types, and suitable soils was the dominant soil type in grid cells across the HCP Study Area (Figure 7.1E), including all of the grid cells where we did not detect owls, producing a nearly homogeneous distribution similar to that of occupancy rates. Thus, the response and correlate variables lacked adequate variability necessary to model a range of occupancy rates, and unoccupied grid cells were assigned the global (naïve) probability of occupancy.

Chapter 14

ELIMINATION OF AREAS DURING FUTURE SURVEYS DUE TO THE UNLIKELIHOOD OF BEING OCCUPIED BY MALE BURROWING OWL TERRITORIES

JEFFREY A. MANNING

ABSTRACT. Balancing cost and logistical effort is always a priority in developing long-term wildlife population monitoring programs. Here, I provide a brief discussion on how to prioritize survey efforts towards grid cells in the HCP Study Area with high probabilities of being occupied to reduce costs. During the establishment of the standardized sampling grid, several grid cells were removed because they lacked any above-ground IID water conveyance structures. There removal was necessitated by our conducting surveys only along water conveyance structures. Due to the high rate of occupancy among the remaining grid cells, dynamic changes in numbers of owls that can occur, and the robust ability of the sampling methodology developed in the following chapter to account for cells that are unoccupied during a given survey, no other cells were removed.

INTRODUCTION

I originally proposed to use the 2007 census data to determine if any and which grid cells in the HCP Study Area should be eliminated from the sampling grid (see detailed study design, dated 8 January 2007). I proposed to make such a determination on a cell by cell basis using the estimated local abundance from Chapter 10 and occupancy rates from Chapter 13. The approach involved eliminating grid cells where estimated abundance and occupancy rates were simultaneously low. This was intended to prioritize survey efforts towards areas with high probabilities of being occupied and coincidently improve the accuracy of population estimates.

As part of the development of the standardized sampling grid of 3x3 km cells in Chapter 9, several grid cells were removed because they lacked any IID water conveyance structures. The remaining grid cells contained a range of abundance estimates from 0 to 57 male Burrowing Owl territories, as reported in Chapter 10. The discrepancy between the 18 grid cells we reported in Chapter 10 to contain zero territory centroids and the 13 reported to be unoccupied during our occupancy modeling in chapter 13 was due to our use of owl locations in estimating occupancy rather than centroids. Because of the 2-dimensional nature of owl territories, the locations of owls along grid cell boundaries can occur in multiple grid cells, and this edge effect can lead to classifying cells without territory centroids as occupied. Nonetheless, as was shown in chapter 13, occupancy rates were consistently high across the HCP Study Area. The absence of variability in occupancy rates compromised the originally proposed effort to use them for making decisions on the selective elimination of cells from the sampling grid.

Several of the 18 grid cells where we did not detect territory centroids in 2007 were dominated by urban developments, but they did contain above-ground water conveyance structures maintained by the IID. Such structures near other urban areas in the HCP Study Area did support territories during this study period. For these reasons, grid cells dominated by urban development that contain above-ground water conveyance structures may still contain suitable nesting habitat and could be occupied in future years. In light of the dynamic changes in the numbers and distribution of territories during the breeding season (see Chapter 19), it would not be prudent to permanently remove these grid cells from future surveys. Furthermore, because the stratified random sampling methodology presented in the following chapter is reliant on low, medium, and high owl abundances among grid cells, the few grid cells where we surveyed and did not detect occupancy in 2007 can be appropriately included into the low abundance stratum, thereby making them available for random selection in future surveys. When these grid cells are randomly selected, the resulting abundance estimates at that time can be used to appropriately calculate the overall estimate and sampling error for the low abundance stratum.

Chapter 15

DEVELOPMENT OF A STRATIFIED RANDOM SAMPLING METHODOLOGY TO SURVEY FOR AND ESTIMATE MALE BURROWING OWL TERRITORY ABUNDANCE

JEFFREY A. MANNING AND CAREN S. GOLDBERG

ABSTRACT. As with any long-term population monitoring program, a standardized sampling design that minimizes the required sample size, optimizes the allocation of survey effort, and reduces costs while maintaining high levels accuracy at all stages of the survey is needed for surveying Burrowing Owls in the HCP Study Area. Here, we present a stratified random sampling methodology for estimating the abundance of male Burrowing Owl territories. The method involved identifying a range of minimum required sample of grid cells needed to achieve estimates with specified levels of precision. It also determined the optimal allocation of grid cells to the corresponding strata by accounting for differential variances in owl abundance and costs associated with surveying each strata (i.e., based on our standardized sampling protocols, more owls equated to more stops that required more time and higher costs). We demonstrated how this sampling methodology greatly improved precision, and recommended its use.

INTRODUCTION

Prior to initiating a long-term population monitoring program for Burrowing Owls in the HCP Study Area, a standardized sampling design that minimizes the required sample size, optimizes the allocation of survey effort, and reduces costs while maintaining high levels accuracy at all stages of the survey is needed. Wildlife monitoring programs such as these generally involve choosing a desired level of detectable change in the population. Many decisions made in the early planning stages influence the power and cost of conducting surveys intended to detect that desired level. A well designed sampling approach can reduce costs while maintaining the ability to detect the desired level of population change. As described in the general introduction, reducing measurement and sampling errors can increase the accuracy of total population estimates. Reducing these errors essentially increases statistical power, and sampling design is an important mechanism by which to accomplish this objective. Statistical power can be increased by (1) establishing homogeneous strata, (2) measuring concomitant information, and (3) selecting an efficient sampling design (Kuehl 1994).

With the proper sampling design, empirical estimates of population size can be used to compute finite rates of annual population growth (λ) with a level of precision needed to achieve a desired level of detecting a change in the Burrowing Owl population. Because the HCP specified that “the appropriate significance level for … [λ] will be determined by a statistician,” a range of sample sizes that would be required to achieve a desired level of precision surrounding population estimates (or distance from the true population mean) would be advantageous prior to making such a determination. The desired precision is important because it is a function of sample size (or visa versa) which corresponds to the level of survey effort and cost. Larger sample sizes (e.g., more grid cells surveyed) are more precise, which increase the ability to detect a smaller change in the population between years than from smaller samples, but at a greater financial cost. Because management actions involve a balance between cost and reliability of biological data, determining how many grid cells would be required to attain a particular level of precision (and detectable level of population change), is a practical and efficient method to establish the annual level of survey effort in the HCP Study Area. This method of computing a population growth rate would also enable the IT to immediately assess the stability of the Burrowing Owl population and determine if adjustments to the Burrowing Owl Conservation Strategy are needed prior to the onset or completion of the demographic study referenced in section 4.5.3 of the HCP.

Time and money limitations typically constrain population surveys to a sample of areas that represent a fraction of the area occupied by the population of interest. Here, each area is represented by a 3x3 km grid cell, and sampling error refers to the variability in abundance of male Burrowing Owl territories among these sampling units. In these situations, a carefully selected sampling design can reduce sampling error and improve statistical power (Kuehl 1994). Designs such as cluster sampling, randomized block, and stratified random sampling reduce sampling error by categorizing sampling units according to their similarity or dissimilarity and estimating abundance in each class separately.

Because abundance of owls was shown to be unevenly distributed across the HCP Study Area (see Chapter 10), a simple random sample of areas would likely lead to imprecise estimates of the total size of the population (Caughley 1977:27, Williams et al. 2002:247). An accurate estimate of population size can be obtained with sampling designs that account for the size, shape, number, and placement of sampling units across areas where abundance is unevenly distributed (Caughley 1977:27, Williams et al. 2002:247).

A commonly used design to estimate the size of wildlife populations in large areas where abundance is unevenly distributed is stratified random sampling (Caughley 1977:27, Cochran 1977:87, Williams et al. 2002:249). The area supporting the total population of interest is subdivided into areal sampling units, and these are categorized according to their similarity in animal abundance (e.g., low, medium, and high). These categories are referred to as strata, and a random sample of units is drawn separately from each stratum. Animals are counted in the randomly sampled units and the strata abundances are summed to estimate a total population size. This stratification of units into similar abundances reduces sampling error among strata and the estimated total population estimate (Cochran 1977:88). As with the other designs mentioned above, this sampling design assumes that population counts in sample units are without measurement error. Because measurement error probably cannot be completely eliminated (Steenhof and Kochert 1982, Fraser et al. 1983) and is not accounted for in these methods, it is very important to reduce measurement error when using one of these designs.

In this chapter, we present the results from a stratified random sampling design we developed for sampling and estimating the total population size of male Burrowing Owl territories in the HCP Study Area. As part of this effort, we calculated a range of sample sizes that would be required to achieve a desired level of statistical precision surrounding population estimates (or distance from the true population mean), from which a determination of the desired level of change can be based. We accomplished this with the local abundance estimates from 2007, and the design relies on survey methods that minimize measurement errors, such as the point-coordinate capture-recapture survey technique presented in Chapter 5 and used in producing the local abundance estimates.

METHODS

Minimum Required Sample Size

We determined the size of random samples of grid cells that would be required to be surveyed in the HCP Study Area to achieve an estimated population mean at specified levels of precision (or distance away from the true population mean; Williams et al. 2002:64). Here, the population refers to the 274 grid cells from which a random sample would be drawn from and surveyed each year, and the mean refers to the mean owl abundance in grid cells. We based this analysis on sampling without replacement (e.g., a grid cell would be surveyed once per population survey), with an adjustment for the influence of the finite population of 274 grid cells available for sampling, using the following equations:

$$n = \left(\frac{z_{\alpha/2}}{d} CV \right)^2 \qquad \text{Equation 15.1}$$

where n is the sample size needed, α is the level of statistical significance, $z_{\alpha/2}$ is the upper $\alpha/2$ point of the standard normal distribution, d is the specified distance in multiples of the population mean, and CV is the population coefficient of variation, which we calculated from the estimated abundance in each 3x3 km grid cell. The finite population adjusted n was then computed with

$$n' = n/(1 + n/N) \qquad \text{Equation 15.2}$$

where N is the total population of grid cells (274) available for sampling.

This approach is commonly used in wildlife science to determine a minimum required sample size, and negates the bootstrapping that we originally proposed.

Stratum Boundaries

Stratification of a study area into relatively homogeneous subunits can improve the precision of population estimates (Cochran 1977). Stratification increases efficiency in sampling effort and is commonly used to improve the precision of wildlife population estimates. We determined the numerical boundaries of 3 strata (low, moderate, and high owl abundances) using the cumulative of the square-root of the frequency method, which should provide an efficient stratification (Cochran 1977:127-132). For this analysis, we used frequencies of owl abundance in increments of 5. We then used these numerical stratum boundaries to post-stratify each grid cell across the HCP Study Area by the estimates of Burrowing Owl abundance in 2007. Using this same method, stratum boundaries can be recalculated prior to each subsequent survey using owl abundance or a correlate of it, and should yield relatively precise estimates.

Optimal Allocation of Survey Effort among Strata

Optimal allocation of the minimum required sample size among the predefined strata improves precision and survey efficiency. We determined the optimal allocation of effort among strata by taking into account stratum variances, sampling costs, and stratum size (Williams et al. 2002:65-67). Sampling costs were based on cost constraints in each stratum according to the mean length of survey route and mean number of owls per grid cell in a stratum. This approach allocated samples to each stratum in a manner that minimized stratum variances given an overall cost constraint C that equaled $C_1 n_1 + \ldots + C_i n_i$ for $n = n_1 + \ldots + n_i$ available samples of grid cells. This constrained optimization had an optimum solution of

$$n_i = n \frac{(N_i \times \sigma_i)/\sqrt{C_i}}{\sum_{i=1}^{I} (N_i \times \sigma_i)/\sqrt{C_i}} \qquad \text{Equation 15.3}$$

where N_i is the total number of grid cells, σ_i is the standard deviation, and C_i is the cost constraint [($\bar{x}$ km of survey route × 0.19 minutes/km) + ($\bar{x}$ number of owls × 2 minute stop/owl)] associated with stratum *i*.

Precision of Burrowing Owl Territory Abundance Estimates by Stratified Random Sampling

When applied appropriately, stratified random sampling nearly always results in greatly improved precision of estimated means or totals than that obtained from a comparable simple random sample (Cochran 1977:98). To demonstrate how well stratified random sampling improved the precision of our estimates over simple random sampling with the same level of survey effort, we repeatedly sampled the estimates of abundance in the 274 grid cells from the entire 2007 dataset, thereby developing a series of simulated sample datasets from the original data. For each sampling method, we conducted 1,000 simulations by subsampling the grid cells, without replacement. For these simulations, we chose to use the minimum required sample size to be within 10% of the true population size that was approximated in Chapter 10 by summing the local abundance estimates from the 2007 census. For stratified random sampling simulations we also applied optimal allocation of effort among the 3 strata determined above.

Unbiased simple random sampling estimates of population size $(\hat{X}_{SR})$ for the HCP Study Area were calculated by multiplying the total number of grid cells by the ordinary sample mean $(\bar{x}_{SR})$ in the HCP Study Area:

$$\hat{X}_{SR} = N \times \bar{x}_{SR} = N \times \sum_{j=1}^{n} \hat{x}_j / n_j \qquad \text{Equation 15.4}$$

where $\hat{x}$ is the abundance estimate associated with the jth randomly selected grid cell n.

We calculated the variance of each simple random sampling estimate ($\hat{\sigma}^2_{\hat{X}_{SR}}$) with a finite population adjustment:

$$\hat{\sigma}^2_{\hat{X}_{SR}} = N^2 \times \frac{s^2}{n}(1 - n/N) \qquad \text{Equation 15.5}$$

where s^2 is the usual sample variance. We then used this variance to calculate 95% confidence intervals.

Following Steel et al. (1997:595-597), we calculated unbiased stratified random sampling estimates of population size $(\hat{X}_{ST})$ as:

$$\hat{X}_{ST} = \sum_{i=1}^{n} N_i \times \bar{x}_i \qquad \text{Equation 15.6}$$

where N_i is the total number of grid cells in the ith stratum and $\bar{x}_i$ is the mean abundance estimate associated with the ith stratum.

The variance of the estimated population mean from a stratified random sample was calculated as:

$$\hat{\sigma}^2_{\bar{x}_{ST}} = \frac{1}{N^2} \sum_{i=1}^{3} N_i (N_i - n_i) \times \frac{s_i^2}{n_i} \qquad \text{Equation 15.7}$$

We used this variance to calculate 95% confidence intervals surrounding the mean of each simulated stratified random sample and multiplied the upper and lower bounds by N to obtain the intervals surrounding each population estimate.

To compare between the two sampling methods, we calculated the 95% confidence interval width (CI) for each bootstrapped population estimate, computed the mean of those confidence interval widths $(\overline{CI})$ separately for each sampling approach, and assessed the difference in this measure of precision. All analyses were performed in R (Ihaka and Gentleman 1996).

RESULTS

We present a range of minimum required numbers of 3x3 km grid cells to be randomly sampled and surveyed to achieve specified levels of precision (Table 15.1). A minimum of 119 grid cells (43% of the HCP Study Area) would need to be surveyed using a simple random sampling approach to ensure that the population estimate is within 10% of the true population size, and 44 grid cells would be required for 20% (Table 15.1; Figure 15.1). These levels of precision also specify the minimum detectable level of annual population change under simple random sampling by multiplying them by 2; but, stratification and optimal allocation of effort can further improve these levels of precision and narrow the statistically detectable level of population change.

Our analysis of numerical boundaries for the 3 strata we selected determined the following ranges in abundance: 0 - 14.9 in the low abundance stratum, 15.0 - 29.9 in the moderate, and 30 - 54.9 in the high (Table 15.2; Figure 15.2). Based on these stratum boundaries, there were 123 grid cells in the low abundance stratum, 95 in the moderate, and 56 in the high.

The optimal allocation of effort among the 3 strata was 50.4% of the low, 32.6% of the moderate, and 48.2% of the high abundance strata (Table 15.3).

For our assessment with the simulated samples bootstrapped from the census of all grid cells, we used the minimum required sample size required to be within 10% of the true population size (119 grid cells; Table 15.1). For this selected sample size, the optimal allocation was determined to be 62 grid cells in low abundance stratum, 31 in the moderate, and 27 in the high. Based on these simulations, the precision of estimated Burrowing Owl territory abundance was improved by stratified random sampling [$\overline{CI}$ = 352.7 male owl territories (95% CI: 351.8 - 353.7)] compared to simple random sampling [($\overline{CI}$ = 977.6 (95% CI: 975.0 - 980.2)]. The $\overline{CI}$ obtained from simple random sampling represented almost 20% of the true total population size of 4,879 estimated in chapter 10 (or 10% on either side of the estimate), whereas that from stratified random sampling was 7% of the true total population size.

CONCLUSIONS AND RECOMMENDATIONS

The minimum required sample of grid cells to achieve specified levels of precision and rates of change in population size we present here were based on the survey protocols and analytical methods presented in Chapters 5, 7, and 10. Our results provide basic information needed to choose a desired level of detectable change in the population by considering the statistical precision of the population estimates. Once a minimum level of change is chosen, the minimum required sample size can be determined from Table 15.1. The smallest rate of change that can be detected with 95% certainty from simple random sampling is approximately 20% (2 x 10% of the distance each sample estimate would be from its true population size) by sampling 43% of the HCP Study Area. As an example of such a change, a 20% decline would reflect the loss of 999 of the 4,998 male territories detected in 2007. However, stratified random sampling can improve this level of precision and narrow the level of detectable rate of change.

To apply the stratified random sampling methodology, the optimal level of effort in each stratum would need to be determined for the minimum required sample size chosen. Once an optimal level of effort was determined, optimal allocation would be recalculated following the re-stratification of the sampling grid prior to each population survey. Based on our assessment with our simulated samples, that same sample size (119; but, stratified, optimally allocated, and surveyed following our methods) should provide estimates of population size that lie 3.5% from the total population size that would have been estimated if all grid cells in the HCP Study Area were surveyed. This represents a 186% gain in precision over an equal level of simple random sampling.

In theory, a stratified random sample of 119 grid cells would enable the IT to detect a 7% change in λ with 95% statistical confidence. However, our stratified random sampling methodology assumed no measurement error during surveys in our grid cells, although we believe our standardized survey protocols and number of point-coordinate capture-recapture occasions minimized it to a negligible level (Steenhof and Kochert 1982, Fraser et al. 1983). Furthermore, this sampling methodology was based on the construction of strata from the empirical frequency of owl abundance, which was the ideal variable for stratification (Cochran 1977:100). Although this currently was the best biological information available to construct strata, its application in subsequent surveys would assume that local owl abundances would change little. The next best alternative to using owl abundance would be to use a variable that is closely correlated to it (Cochran 1977:128), which is why we developed the correlative model in Chapter 12. That model determined the group of variables that were most correlated with abundance of owls in 2007, and in Chapter 17, we compare its use to stratify the HCP Study Area prior to an independent survey to other possible methods of stratification. Because that correlative model did not explain all of the variation in owl abundance and its correlative power may not be stable over time (e.g., farming practices change or local owl abundances become influenced by other factors), we expect that the precision presented here may be higher than realized in subsequent surveys (Cochran 1977:100-102). Thus, it is important to consider the results in Chapters 17 and 18 before selecting the final method to stratify the HCP Study Area prior to each subsequent survey and choosing the minimum required sample size for a specified level of detectable rate of change.

Table 15.1. Size of a simple random sample (no. of grid cells) required to ensure a population size within a specified distance from the true number of owls.

Distance from true mean (%)	Finite adjusted sample size
0	274
10	119
20	44
30	22
40	13
50	8
60	6
70	4
80	3
90	3

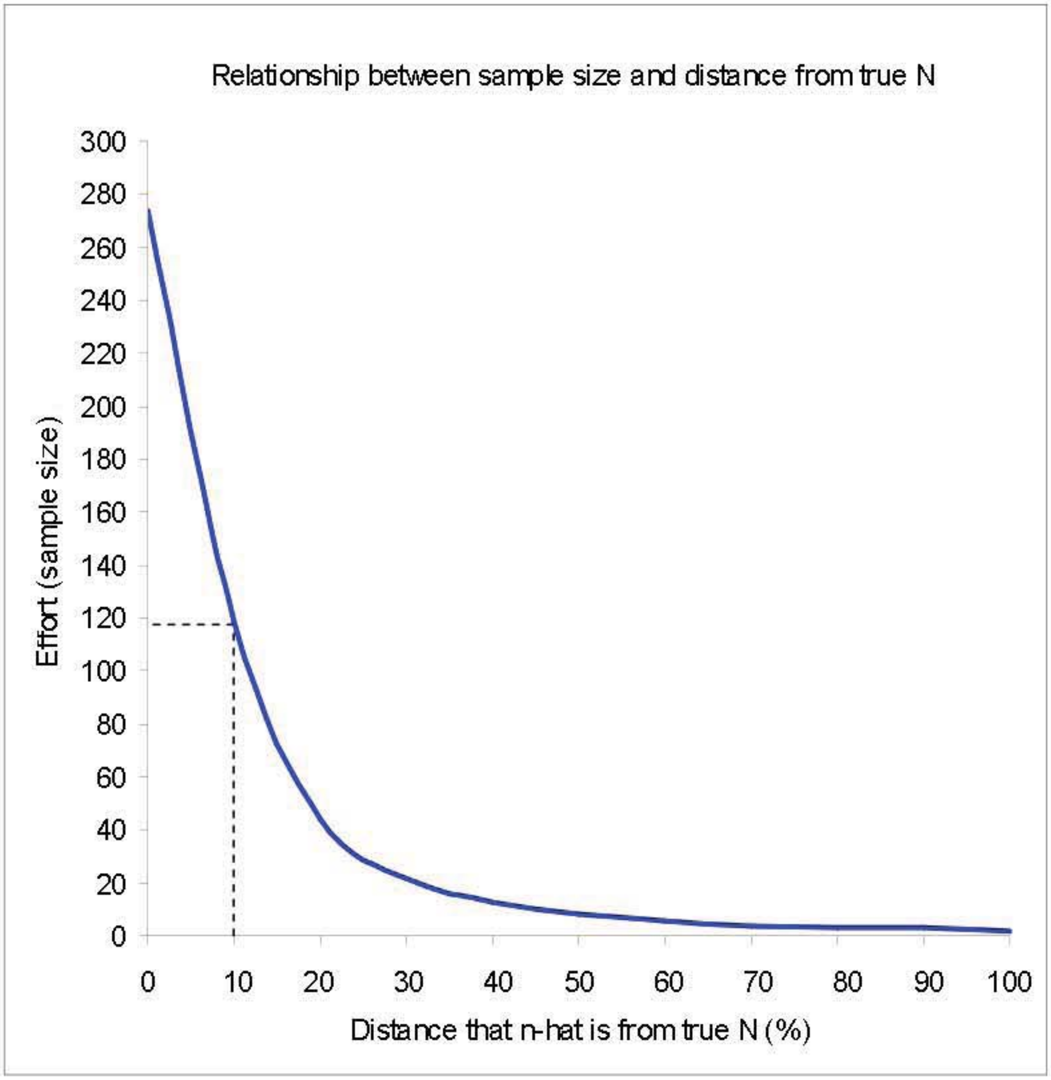

Figure 15.1. Graphical representation of Table 15.1: size of a simple random sample (no. of grid cells) required to ensure a population size within a specified distance from the true number of owls and minimum detectable population change. Dotted lines demarcate the level of simple random sampling effort (number of 3x3 km grid cells) required to detect a minimum change of 20%, which can be improved through stratification and optimal allocation.

Table 15.2. Determination of sampling strata boundaries of Burrowing Owl abundance during the prehatch stage of the breeding cycle using the cumulative square root method (Cochran 1977:127-131), Imperial Valley, California, 2007. These strata were developed as part of a long-term stratified random sampling survey method.

Abundance range	No. of cells $f(y)$	$\square\sqrt{f(y)}$	Strata	Range	Cells (N)
0-4.99	52	7.21			
5-9.99	34	13.04			
10-14.99	37	19.12	1 (low)	0-14.99	123
15-19.99	37	25.21			
20-24.99	39	31.45			
25-29.99	19	35.81	2 (moderate)	15-29.99	95
30-34.99	23	40.61			
35-39.99	16	44.61			
40-44.99	7	47.25			
45-49.99	6	49.70			
50-54.99	4	51.70	3 (high)	30-54.99	56

Stratum Boundaries	
max $\square\sqrt{f(y)}/3 =$	17.23
2xmax $\square\sqrt{f(y)}/3 =$	34.47
3xmax $\square\sqrt{f(y)}/3 =$	51.70

Table 15.3. Optimal allocation of survey effort among 3 strata of estimated local abundance for estimating the annual population size of male Burrowing Owl territories in the HCP Study Area, Imperial County, California, based on data from 2007. $\bar{x}$ indicates mean.

Strata	Number of owls ($\bar{x}$)	Average length of survey route ($\bar{x}$ km)	Cost constraint ($\bar{x}$ minutes)	Total cells	Optimal sample size of Total cells (%)
Low	6.03	12.24	76.46	123	50.4
Moderate	21.07	15.82	125.39	95	32.6
High	38.13	16.96	165.56	56	48.2

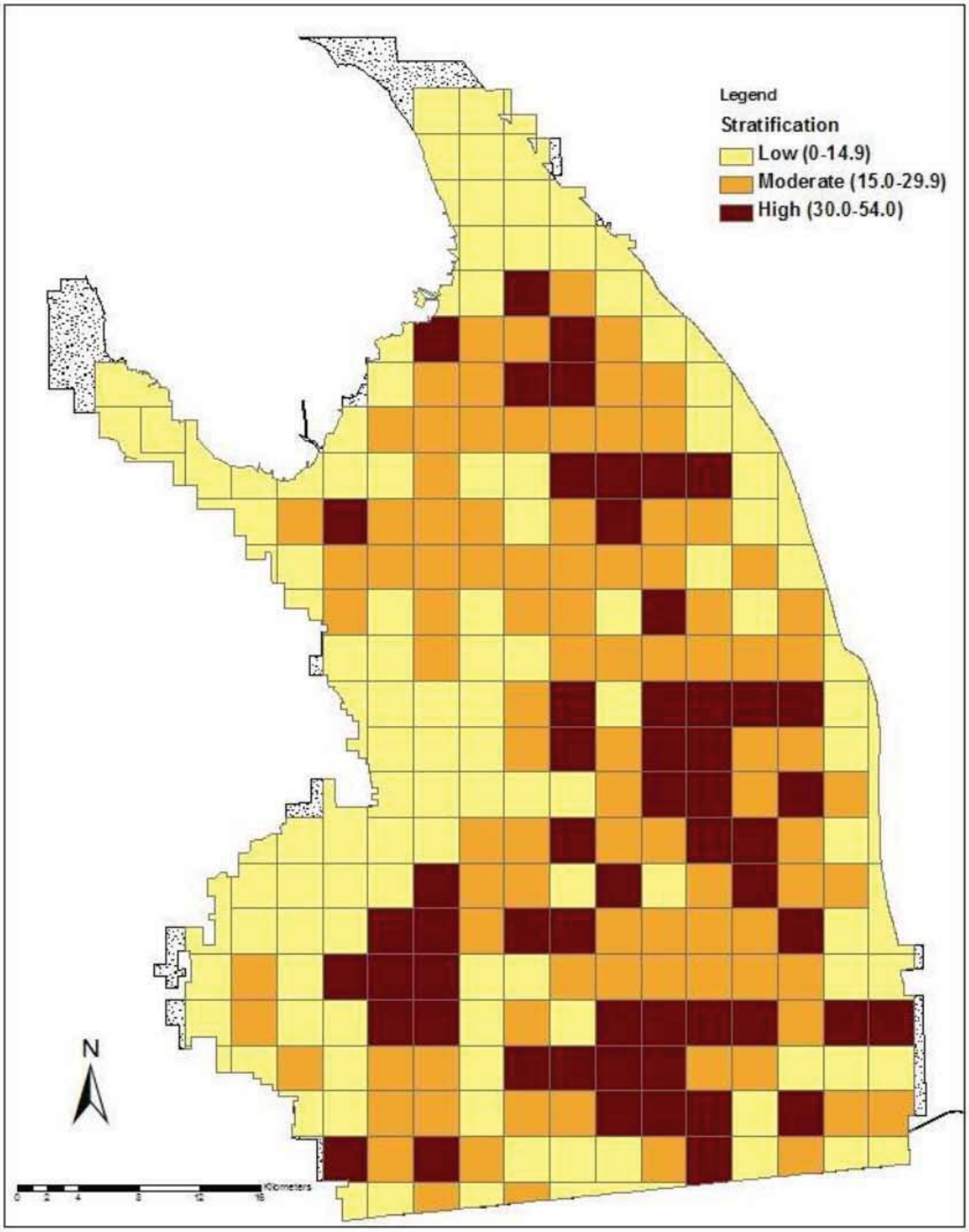

Figure 15.2. Post-stratification of Burrowing Owl abundance during the prehatch stage of the breeding cycle, Imperial Valley, California, 2007. These strata were developed as part of a long-term stratified random sampling survey method.

Chapter 16

MAXIMUM LIKELIHOOD ESTIMATES OF LOCAL MALE BURROWING OWL TERRITORY ABUNDANCE IN 2008

JEFFREY A. MANNING

ABSTRACT. Validation of models or statistical methods often includes testing those resulting tools with a dataset that is independent from the original data used to develop the tool. To validate the stratified random sampling strategy for Burrowing Owls in the HCP Study Area and the correlative model constructed for constructing sampling strata, an independent dataset was needed. I computed maximum likelihood estimates of local male Burrowing Owl territory abundance in 3x3 km grid cells from an independent dataset collected in 2008. These estimates were from point-coordinate capture-recapture survey occasions completed along the same IID rights-of-way surveyed in 2007, and following the same survey and analytical methods. By summing the grid cells, the approximated true population size in 2008 was 3,557 territories (95% CI: 3,218-3,895).

INTRODUCTION

To validate the sampling methodology developed in Chapter 15, an independent and comparable dataset was needed. In this chapter, I present the estimated local abundances calculated from a complete census of the IID's rights-of-way in the HCP Study Area in 2008.

METHODS

Between 28 March - 30 April, 2008, four point-coordinate capture-recapture survey occasions were completed along the same IID rights-of-way surveyed in 2007. Surveys and analytical methods followed those described in Chapters 5, 6, 7, and 10. The resulting male Burrowing Owl territory data from this census was used to compute local abundance estimates across the same standardized 3x3 km-resolution sampling grid applied to the 2007 census data. The sum of these grid cells was used to provide an approximated true population size in 2008.

RESULTS

Raw counts during single survey occasions ranged from 2.403-2.966 (Table 16.1), and the number of single detections without nests was similar to that found in 2007. Based on a sum of the population estimates in grid cells, a total of 3,557 (95% CI: 3,218-3,895) male Burrowing Owl territories was estimated to be present in the HCP Study Area during the prehatch stage of the breeding cycle in 2008. Local abundances within grid cells ranged from 0-55 territories, and the number of grid cells where no territories were detected increased to 21 (3 more) compared to 2007 (Figure 16.1).

Local abundances were lower on average than that found in 2007 (Figure 16.2), with 75% of the cells containing an estimated 20 territories (Figure 16.3). These low estimates of abundance coincide with counts in those cells and associated low standard errors that approximate zero (Figure 16.3), suggesting negligible measurement error or poor performance of the capture-recapture models fit to those cells.

CONCLUSIONS AND RECOMMENDATIONS

I estimated the population size in 2008 to be 3,557 (95% CI: 3,218-3,895) male Burrowing Owl territories. This estimate was derived by summing the local abundances, and can be used as the approximated true population size for comparing against sampled estimates in the following chapter.

This population size represented a marked decline compared to that estimated from the 2007 census. This coincided with slightly lower local abundances on average than that found in 2007 (see Chapter 10), and an increased number of apparently unoccupied grid cells.

Our survey protocols, level of survey effort, and analytical methods were standardized in both years, and all but one survey team in 2008 had at least 1 member from the survey teams used to complete surveys in 2007. Therefore, this difference was not due to differences in measurement error between the 2 years. Because a census was completed both years, this difference also cannot be attributed to sampling error. Furthermore, field biologists were asked to provide anecdotal reports on the presence of owls detected outside of the IID's rights-of-way in both years, and that information suggested that very few owls were outside of our survey areas during both years. Thus, this difference is largely due to a change in the total number of male Burrowing Owl territories present in the HCP Study Area.

The intended use of the 2008 census data was as an independent dataset for validating the survey methodology developed from the census data collected in 2007. That methodology was derived from a standardized grid of sampling units that were predominantly 3x3 km. This resolution was chosen, after communications with Dr. Bryan Manly, to balance the needs for an adequate number of territories in grid cells for capture-recapture modeling and a sufficient number of sampling units from which to draw random samples from each year. That decision was based from the best biological information available at that time, the census data from 2007. By using that empirical data with the intention of developing a standardized grid to be used for sampling in subsequent years, the sampling grid that was established assumed that the population data from 2007 was representative of that anticipated to be present in subsequent years. Thus, the unanticipated marked change in the total population size and local abundances between the 2007 and 2008 breeding seasons may compromise the validation of that methodology.