



Size of the California Brown Pelican Metapopulation During a Non-El Niño Year

Daniel W. Anderson, Charles J. Henny, Carlos Godinez-Reyes, Franklin Gress, Eduardo L. Palacios, Karina Santos del Prado, and James Bredy



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Size of the California Brown Pelican Metapopulation During a Non-El Niño Year

Daniel W. Anderson¹, Charles J. Henny², Carlos Godinez-Reyes³, Franklin Gress⁴, Eduardo L. Palacios⁵, Karina Santos del Prado⁶, And James Bredy⁷

Abstract

Overall, we estimated a total metapopulation within the geographical range of the California brown pelican subspecies (*Pelecanus occidentalis californicus*) as about $70,680 \pm 2,640$ breeding pairs (mean \pm SD). Little change in at least three decades is indicated in the total metapopulation south of the Southern California Bight (SCB) subpopulation, but significant improvements in the breeding subpopulation size in the SCB reported elsewhere, support the present high numbers observed in this northernmost subpopulation. The largest breeding aggregation within the entire range (consisting of three immediately adjacent sub-colonies), at the San Lorenzo Archipelago, consisted of about 17,225 breeding pairs, or about 24.4% of the metapopulation in 2006. Other, smaller colonies are no less important, however, although each subpopulation defined by us seemed to have a single or small number of large “core” breeding colonies, plus many smaller colonies (for example, in 2006, one colony consisted of only 2 breeding pairs). Small colonies (< about 70 nests) comprised about 35.6% of the total occupied colonies, but only about 0.87% of the total estimated numbers (values corrected for detectability). The modal colony-size throughout the range was much smaller (about 230 to 1,300 breeding pairs, depending on subpopulation), indicating that small, scattered colonies and sub-colonies, especially on the range peripheries, function in brown pelican population dynamics and are no less important from a conservation viewpoint. These smaller breeding colonies probably represent some colonies of antiquity, but also range expansions and contractions that occur within the typically-defined metapopulation, and local manifestations of source-sink phenomena. Given such dynamics, even unoccupied islands within the range in 2006 have conservation importance from the viewpoint of such dynamics as potential alternate nesting sites. Natural variations in the estimated population levels seem to be related to the natural cycles of El Niño/Southern Oscillation (ENSO) phenomena where very low breeding populations (as low as no nesting in many areas) might be expected to occur in these same areas censused in 2006 at least 40% of the time. From the 2006 aerial survey, extensive commercial and sport-fishing activity, resort/tourist developments and associated human activities along the coastal areas and at offshore islands, and extensive aquacultural (and to a lesser degree, agricultural) developments seen from the Río Colorado Delta region, Sonora, south at least through San Blas, Nayarit (the southern terminus of our 2006 aerial survey) may result in substantial loss of breeding habitat. Juvenile (young of the 2005 breeding season) plus subadult brown pelicans comprised $28.1\% \pm 0.33\%$ (mean \pm 95% CI) of the total numbers in age-ratio samples. Thus, our overall metapopulation estimate for *P. o. californicus* in 2006 was $195,900 \pm 7,225$ individuals.

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Keywords

California brown pelican, *Pelecanus occidentalis californicus*, breeding pairs, El Niño, metapopulation estimate, subpopulation estimates, survey bias, distribution, range.

Introduction

The California Brown Pelican Metapopulation

Anderson and King (2005) reviewed key metapopulation concepts as they likely applied to the American White Pelican (*Pelecanus erythrorhynchos*). Here, we apply essentially those same definitions to the presumed California brown pelican metapopulation (*P. occidentalis californicus*) (Figure 1), but urge the reader to review Anderson and King (2005) and references therein for more detail. Essentially, our use of the term here has been defined by Newton (1998) as: "...any population composed of a number of discreet and partially independent subpopulations that live in separate areas but are linked by dispersal", and as defined by Morris and Doak (2002:375): "...sets of discrete, largely (but not entirely) independent populations whose dynamics are driven by local extinction and recolonization via movement from other populations..." For example, breeding recruitment from individuals originating in the Gulf of California was documented in the Southern California Bight (SCB) subpopulation of California brown pelicans during a period when SCB breeding colonies were severely declining and classified as "endangered" under the Endangered Species Act (Gress and Anderson 1983). Numbers later recovered (see Anderson et al. 1975, Anderson and Anderson 1976, Anderson and Gress 1983; Gress et al. in preparation, and others), and recruitment of breeding birds into the SCB, from colonies with higher productivity in Mexico likely enhanced that recovery. Anderson and Gress (1983, their Figure 2) also showed that within a region, numbers of breeders at Anacapa Island and Los Coronados (see Appendix 1), shifted in predictable "runs" between these two major breeding colonies in the SCB, probably in response to local variations in predictable food availability (Anderson et al. 1982). Smaller named sub-divisions within the California brown pelican metapopulation, again as suggested by Anderson and King (2005), are given in Table 1.

Effects of El Niño

A well-known and significant cause of year-to-year variation in numbers of breeding seabirds, their productivity, and even survival at times is seen in the El Niño/Southern Oscillation oceanographic phenomenon (ENSO)(e.g., Ainley

et al. 1988). It is not our intent here to review ENSO and seabird demography, but only to relate various key specific observations to the numbers of *P. o. californicus* as applied to this specific 2006 survey, to help better interpret our estimates, and evaluate potential variability that might be expected in metapopulation estimates from year-to-year. We do not consider historical frequencies of ENSO to be causes of severe, long-term population declines, but rather a normally-encountered oscillation to which numbers and productivity of brown pelicans, for example, must compensate with a "flexible" demography. Anderson and Gress (1983) demonstrated that in the SCB (and other subpopulations), variable proportions of available adults in the subpopulation attempt to nest from year-to-year. This was partly related to ENSO effects although adult body condition and reproductive rates, as expected, are even more closely tied to the ENSO phenomenon (for example, see Velarde and Ezcurra 2002, Velarde et al. 2004). Near the southern range periphery of the California brown pelican, Sarmiento (1994) described a short year-to-year variation in breeding numbers in his study plots at Isla de Pájaros, Sinaloa: during the 1991-92 cycle (an ENSO), he reported 69 completed nests in contrast to 1992-93 (non-ENSO) when he reported 334 nests. This represented a 79% reduction in nesting attempts. At Isla Piojo, Baja California Norte (and considered representative of the Gulf of California nesting subpopulation), Anderson et al. (2006) demonstrated that breeding attempts varied between 0 and 1,430 from 1969 through 2005 (Mean \pm 95% CI = 432 ± 114 , CV = 73%, n = 32 years of data in 36 years). In this same region in the Gulf of California, Velarde and Ezcurra (2002) reviewed and reported similarly high annual variations in breeding attempts and reproductive success of other species nesting in proximity to brown pelicans. In the 36-year period reported by Anderson et al. (2006), using standardized, normally distributed Southern Oscillation Indices (SOIs) from the literature (and conversions similar to those of Velarde and Ezcurra 2002), they calculated that ENSO conditions of varying strength occurred about 38% of the time. Based upon several brown pelican colonies studied since 1970 (Isla Piojo, Isla Animas, Isla San Lorenzo Sur, Puerto Refugio, and Isla San Luis-Appendix 2), 2006 represented a year of near-maximum breeding attempts (DWA, unpublished field notes). In the Southern California Bight area, Anderson and Gress (1983) indicated that from 1972-1979, about 20-70% of the available adults in the region bred; the lowest proportion of breeding adults (19%) was in 1977, a "mild" ENSO year, whereas the proportion of adults in the total numbers remained relatively constant through the same period (from 64 to 86%; mean = $72 \pm 8\%$, mean \pm 95% CI; CV = 14%). The highest proportion of adults was in 1978, when fewer young were expected. Therefore, we considered the 2006 estimates to be optimal numbers (non-ENSO year) on which to compare lesser numbers expected during those years potentially affected by interactions of ENSO conditions and potential future population changes from other causes.

Our objectives were: (1) during an optimal breeding year, to obtain an estimate of total numbers of breeding pairs of

Figure 1. A diagrammatic representation of hypothesized subpopulation segments of the California brown pelican presumed metapopulation (see Anderson 1983 and further discussion in text). Short dashed lines represent subpopulation boundaries and black patches connected by arrows (movement and dispersal), colonies and sub-colonies. This diagram was generally based on natural history and geographic characteristics that would tend to separate subpopulations into more or less annually independent demographic units: SCB = Southern California Bight Subpopulation, based mainly on confines of the California Current System (Anderson and Gress 1983); SBP = Southern Baja-Pacific Subpopulation, based on isolation along the southwest Baja California coast (Gress and Anderson 1983), terminated by the tropical convergence (Anderson 1983); GOC = Gulf of California, based on the confines of the Gulf of California (Anderson 1983); MME = Mexican Mainland, Estuarine Subpopulation, based on dominant nesting and feeding habitat (mangrove dominated bays with vegetated islands) (GOC and MME populations are essentially also separated by the tropical convergence, see Anderson 1983); and, MMI = Mexican Mainland, Island Subpopulation, is essentially separated from MME by a sudden change in nesting habitat and offshore oceanographic changes. The form of this diagram is adapted from the discussions of Buckley and Downer (1996) with delineations further discussed in the text. This hypothetical diagram should be considered preliminary and subject to future testing with genetic, morphological, movement, ecological, and other studies.

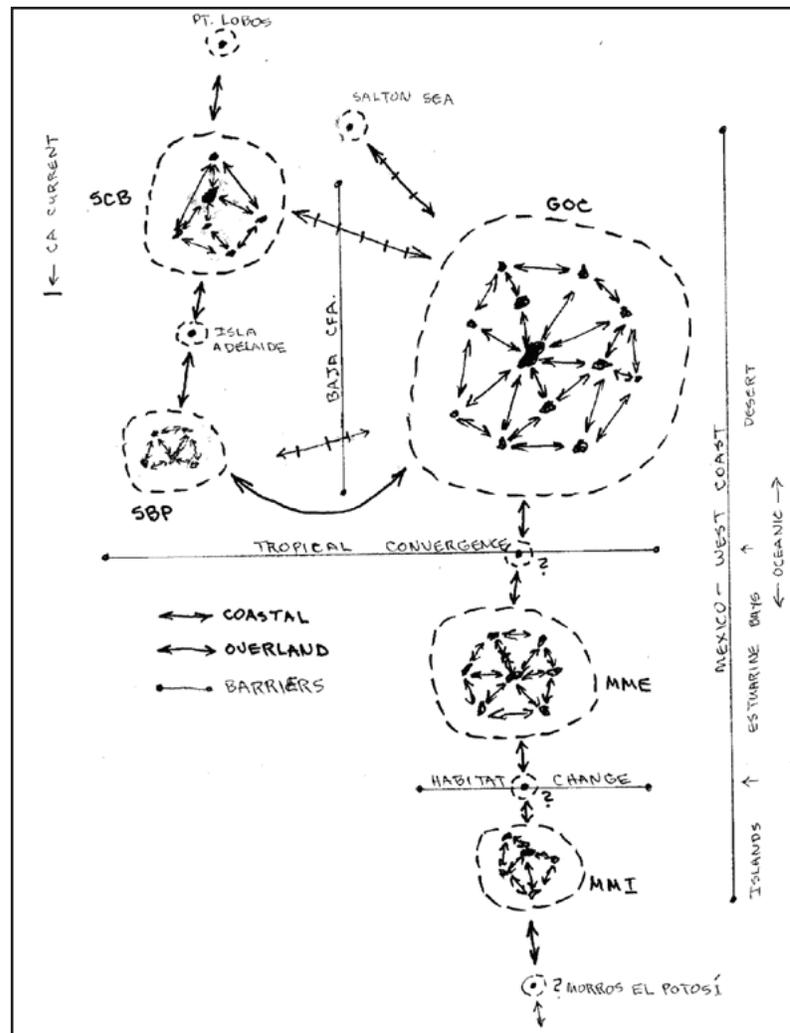


Table 1. Suggested definitions of various geographical subdivisions in the subspecies range of the California brown pelican

Geographic Scale	Suggested Term Used	Criteria
Regional	Metapopulation; <i>Pelecanus occidentalis californicus</i>	Separation by a well-defined barrier with dispersal rates very small on an inter-metapopulation (or subspecies) basis compared to intra-metapopulation movements ^a
Local, interactive	Subpopulation	Dispersal among subpopulations much greater than between subpopulations; closely sharing demographic characteristics
Single Geographic Location	Colony or Sub-colony	One or more nesting groups associated with a single geographic feature or location
Away from Breeding Colony	Flocks or Aggregations	Groups of individuals gathered anywhere away from a nesting group; further definition can be made if activity is known (i.e., feeding, loafing, migrating, moving, etc.).

^aFor the California Brown Pelican, this barrier has been previously identified (but not precisely defined) by numerous previous descriptions of the ranges and distributions of the Brown Pelican subspecies (see text for references and discussion); and it is supported by movement data based on radio-telemetry and band-recoveries (DWA unpublished data). An important description of this “barrier” has been suggested by de la Torre (1986) who has identified low relative numbers of potential nesting islands per unit of coastline, large distances between these areas, and comparative lack of estuarine habitat on the mainland, exacerbated by extensive human activities and development.

the *californicus* subspecies of the brown pelican, along with several measures of precision; (2) to accurately determine the locations of all breeding colonies for the subspecies; (3) to describe the presumed subpopulations (Figure 1) (subject to a testable hypothesis for future genetic studies) and breeding numbers; and (4) to discuss potential conservation issues.

Methods

Study Area and Survey Methods

Gress and Anderson (1983) provided the original suggested subpopulation delineations used in this report (but with some minor modifications)(Figure 1). Additional historical insights and distributional/numeric data for brown pelicans were derived from Bent (1922), Grinnell (1928), Grinnell and Miller (1944), Wetmore (1945), Hutchinson (1950), A.O.U. (1957), Palmer (1962), Gress (1970), Anderson and Anderson (1976), Anderson and Gress (1983), Johnsgard (1993), and A.O.U. (1998). And, recent general surveys and estimates of nesting brown pelicans throughout their range have been reported by Anderson et al. (1976), Everett and Anderson (1991), and Velarde and Anderson (1994). General distributional information, especially to the south, has also been broadly summarized by Howell and Webb (1995) and Wilbur (1987). The major questions emerging from a review of these references include: (1) what are the sizes (number of breeding pairs) and distribution of individual breeding colonies within the total metapopulation (*P. o. californicus*), (2) what are the sizes of various subpopulations and breeding colonies within the range of the subspecies, and (3) can more detail be provided on the relatively unknown or not recently-described southern peripheral subpopulation of the subspecies?

Through several methods, we surveyed the entire range of the California brown pelican with a total of 97 known active or historical breeding colonies of highly variable size. We conducted aerial surveys from 23 March through 1 April 2006 ($n = 68$ colonies over-flown by us in 10 days = 70.1% plus $n = 9$ colonies not flown due to inclement weather or extreme distance with tenuous gasoline levels = 9.3%; total = 79.4%), and supplemented our aerial surveys with additional ground-based surveys through the nesting season of 2006. In the northern subpopulation (Figure 1), our estimates were obtained through ground counts ($n =$ the 8 northernmost colonies without aerial surveys = 8.2%), in the Gulf of California by ground surveys conducted by members of our own team, and in the extreme south only through a literature review and cooperator information ($n = 11$ potential colonies = 11.3%). Our final estimates of numbers of breeding pairs were based largely on the aerial survey data, but also four additional sources of quasi-double-sampling at some sites (surveys by boat at selected sites, information obtained from co-operators at some sites, surveys of recent and historical records compiled by DWA, and literature

sources where no other information existed or to supplement our 2006 observations; all collectively termed here: ground-truth). Final estimates were frequently based upon ground-truth data, either our own or from cooperators, which were selected over the aerial survey results because those values were considered to be more complete and accurate. Ground-truth were compared to aerial survey data, where comparisons could be made (27 of 59, 2006-occupied colonies = 45.8%), to gain insights on sources of variability, to correct aerial estimates where no ground-truth data were available, and to help estimate our overall precision. We summarized, and attempted to correct if deemed necessary, possible biases related to: detectability, phenological variation, observer error, and inaccessibility due to such factors as inclement weather and hazardous flying conditions, so that a future survey solely by air might ultimately be attempted. More details on the aerial survey and its coverage were reported by Henny et al. (2007).

Aerial surveys for the most northern colonies of California brown pelicans of the Southern California Bight subpopulation (see Gress and Anderson 1983) within the state of California, USA (the northern range periphery) were not attempted by us because of expected large phenological differences from nesting colonies to the south (i.e., the survey dates planned for Mexico in 2006 would have been “too early” in the nesting season for this population-segment). Furthermore, we were aware that FG, ELP, and colleagues (cited in Appendix 1) were surveying those colonies from boats in 2006. However, colonies in this SCB subpopulation, south of the U.S./Mexico border, were aerially surveyed and later compared to those more accurate and complete boat and ground surveys in California and northwest Baja California to examine the potential for phenological bias had we not initiated this collaboration and conducted only a one-time, large survey of many degrees latitude. The total previously-known breeding range of *P. o. californicus* roughly extends from about 17° North latitude to about 36° North latitude, or more than 4,800 km of coastline (see Palmer 1962:275). Godínez-Reyes et al. (2006) describe the current Mexican monitoring plan (termed here the Salud Project) for these subpopulations, of which this project was a part.

As stated, we did not survey the extreme southernmost colonies, and therefore only a tentative subpopulation estimate is given (with no estimates of precision), based entirely on literature sources and personal communications (Appendix 5). No detailed studies were conducted in that subpopulation’s range in 2006. Documenting this very small subpopulation will be a future goal of the Salud Project.

Double-crested Cormorants (*Phalacrocorax auritus*) and Brant’s Cormorants (*P. penicillatus*) were also recorded in the Gulf of California (our survey was far too early in the breeding season to detect nesting cormorants in the Southern California Bight (FG and ELP). The mixing of Double-crested with Neotropical Cormorants (*P. brasillianus*) south of about Guaymas, Sonora precluded a summary until further ground-truthing can be conducted to determine species ratios in nesting colonies from Sonora south. Therefore, data on cormorants in this

report must be considered preliminary and subject to revision and further analysis. Estimated Double-crested Cormorant numbers are, nonetheless, included in this report as Appendix 6.

Statistical Analysis

Statistical tests and summaries were performed using MINITAB 15.1 (Minitab Inc., www.minitab.com/).

In estimating precision, we considered all ground-truth data equally and began by choosing those values as superior over aerial estimates because of their completeness. We also related aerial values to ground-truth values where available to approximate corrections (correction factor or CF) in instances where no ground-truth data were available. On the colonies where we had no double-sampling and where estimates used 2006 aerial data only, colonies of about <800 nests (CF <1.06) were not corrected, those of greater number as estimated from the air were corrected using the conversion factors derived from regressions of n_a on n_g (n_a = numbers of nests estimated from the air, n_g = ground-truth estimates; correction factor [CF] = n_g/n_a , slope of regression used to approximate CF) (a similar calculation was termed aerial visibility factor by Henny et al. 2007). Overall, and given a large sample of ground-truth data, only 4 estimates of colony-size out of 59 total colonies enumerated by us from the air (= 6.8%) required this conversion and most of our values were therefore derived from our best estimates (those having some type of comparative ground-truth) from multiple-sampling, or where no other information existed, estimates from previous years (those data remained uncorrected, as well). Where only other-year records were available (11 of 59 2006-occupied/or presumed-occupied colonies, or 18.6% of the total number of colonies seen and/or known) (for example Isla San Pedro Martír, Appendix 3; and Isla Cedros, Appendix 2), we had no choice but to use those older (or in one instance, newer) estimates (e.g., Isla San Gerónimo, Appendix 1).

In estimating variance, we used double-sampled data and assumed that the smaller of the numbers in ground-truth versus aerial comparisons were the values seen by both sources (aerial versus ground, or aerial versus aerial-photograph, or aerial versus ground-truth provided by a cooperator). Our best aerial estimate of colony-size was either larger or smaller than the best estimate of ground-truth, but we always accepted ground-truth as the value of our final estimate. Calculations of estimated variance were first assumed to be binomial and then calculated with the formula suggested by Pollock and Samuel (1987) (and essentially the same as that used by Henny et al. 2007), and reduced (because of the large numbers involved) as follows:

$$\hat{v} = \frac{(n_a)(n_g)(n_a - m)(n_g - m)}{(m)^3}$$

where m = smallest number of the double-estimate.

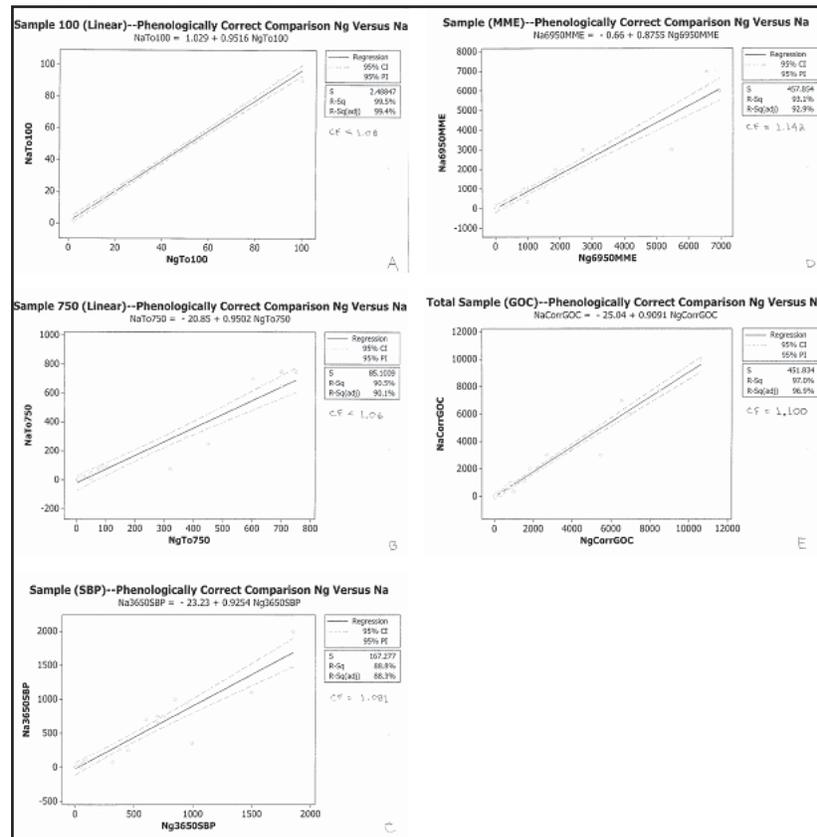
These estimates were applied only to two subpopulations (GOC and MME) because we only had phenologically-correct, double-samplings including ground-truth data from those areas. Since this was the largest sample to estimate variance from the entire metapopulation, the combined GOC and MME variance was also applied to the total metapopulation estimate. Given the large sample of ground-truth data for these estimates ($n = 27$ of 59 colonies = 45.8%), the implied high levels of precision in the estimates seem warranted.

In our estimates of variance for the two subpopulations, SCB and SBP, we applied the variances derived from regressions of our aerial/ground-truth comparisons, calculated separately for each of these subpopulations and based on a regression that included the total estimate for each of the subpopulations. The regression lines for each of these subpopulations were: SCB = 10,000 (Figure 2E); SBP = 2,000 (Figure 2C) (because no intermediate data at this level were available for 3,000). These estimates were as near those numbers as the available data-set allowed. These error estimates derived from the regressions of n_a on n_g were applied to our values for the SCB and SBP subpopulations, assuming that had we flown those areas at the phenologically-correct time, our precision would have been approximately the same. That this is reasonable was indicated by Henny et al. (2007), in Osprey (*Pandion haliaetus*) surveys conducted by CJH and DWA on this same aerial survey flight, in showing remarkable consistency among three similar surveys conducted from 1977 to 2006, where the observers were attempting to detect single, large nests.

All estimates of variance were then further converted to standard deviations (SDs) for each subpopulation and then for the total estimate based on the three non-peripheral subpopulations (Appendices 2-4) and applied to the entire sample as a crude measure of precision. Because the northern subpopulation estimates (Appendix 1) were based almost solely on ground counts, and correction factors would have been rather high based on ground-truth/aerial comparisons had we used them (Figure 2), we assumed that the SCB totals were the most precise of all our estimates (Appendix 1), but had no way to provide a value, other than to use our own regression-based precision estimates from the remainder of the metapopulation. We believe, therefore, that for the SCB subpopulation, we have over-estimated variance. It was also obvious that in instances where we had n_a and n_g sampling, our precision estimates were proportionately lower than estimates interpolated from regression data at different sample (colony)-sizes, perhaps by a factor by as much as 1/5 (Table 2). For the southern periphery population (MMI-Appendix 5), given that estimates used were potentially quite out-dated and incomplete, we must emphasize that we cannot provide any estimates of precision for this potentially important subpopulation, and even the total number of estimated nesting-pairs must be considered very crude until more precise surveys can be conducted in that region.

Henny et al. (2007) indicated that Osprey nests in this same survey (large birds with single, large nests) had an average detection probability of 0.57 (converted by us from their aerial visibility rate for 2006). We assumed this value would

Figure 2. Linear regressions of 2006 aerial estimates (na) on 2006 ground-truth estimates (ng) where matched data were available and at different largest-breeding-colony levels, and where phenology differences between the date of aerial survey and ground-truth surveys were small (i.e., the aerial survey was timed correctly for an accurate estimate): A. colony-sizes <101, B. colony-sizes <751, C. colony-sizes <2, 000 (data in this area of the regression were not available for colonies < about 4000), D. colony-sizes <7,000, and E. colony-sizes <11,000 breeding pairs. The conversion factors presented (CFs) were used to correct estimates in instances where only aerial estimates (na) were available. The corrected values are marked with an asterisk (*) in the Appendices where done (2-4) and four estimates were corrected using these CFs.



have been similar for single brown pelican nests. In examining detectability (assumed to be largely a function of colony-size [Pollock and Kendall 1987], as our aerial surveys took us over all likely nesting locations throughout the aerial survey areas except where inclement weather prevented us to do so, but where we made our estimates from other data-sources), we applied a simple linear function and predicted the number of nests required to achieve a detection probability of approximately 1. To determine a rate of increase in detection probability with larger colonies sampled, we used an estimated but crude function of 10/11 (our detection rate of colonies of about 60 or less) to estimate the rate of increase to 1, and then used this simple rate to crudely approximate the colony-size where probability of detection would be near one.

Results

Detectability of Small Colonies

Detectability for pelican colonies based on size (numbers of nests) rapidly approached 1 (Figure 3). A linear projection predicted that colonies of >63 nests were almost certain to be detected in our survey which covered all or almost all available nesting habitat. Based on these data (admittedly crude) (Figure 3), we estimate that (based on the mean colony-size of all colonies detected that were >63 nests) about 5 small colonies were undetected during the survey, or about 0.66% of all nests--but about 27.1% of all small colonies. Corrected for reduced detectability, these small colonies (say, < about 70 nests) still comprised about 35.6% of the total occupied colonies, but only about 0.87% of the total estimated numbers (Table 2). Thus, small groups of nesting brown pelicans

Table 2. Estimated subpopulation and metapopulation sizes of *Pelecanus occidentalis californicus* and their general characteristics, based largely on the 2006 aerial and ground-truth surveys.

Designated subpopulation	Estimated size of breeding population (\pm SD) ^a	Proportion of meta-population	Dominant breeding substrate	Dominant feeding habitat during breeding	No. of known colonies ^b	Occupied colonies in 2006	Mean colony size (CV) ^c	Median colony-size	Range: colony-size
Southern	11,695 \pm 450**	16.6%	vegetated	offshore, pelagic	14 (11)	79%	1,063 (131%)	250	10 to 4,000
California Bight			oceanic island, ground-nests						
Southern Baja-Pacific	3,100 \pm 170**	4.4%	oceanic desert island ground nests	offshore, pelagic; estuarine	11 (5)	45%	620 (121%)	350	100 to 1,950
Gulf of California	43,350 \pm 230*	61.5%	oceanic desert island, ground-nests	offshore, pelagic	42 (24)	57%	1,806 (164%)	525	5 to 10,625 ^d
Mexican Mainland-Estuarine	10,540 \pm 270*	14.9%	estuarine island, tree/bush nests	estuarine; some offshore, pelagic	15 (11)	73%	958 (216%)	90	2 to 6,950
Mexican Mainland-Island	1,845	2.6%	vegetated oceanic island, tree/bush nests	Offshore, pelagic	15 (8)	53%	231 (127%)	98	25 to 850
Total meta-population estimate	70,680^e \pm 2,640** (or \pm 485*)	100.0%			97 (64)^e	66%	1,314 (176%)	320	2 to 10,625^d

^aValues given represent the best maximum estimates of numbers of breeding pairs from multiple-samplings and various data sources (cited in the text and appendices), with SD (= standard deviations) given as an estimate of precision. * indicates SD based on binomial distribution and ** indicates SD based on regression estimates.

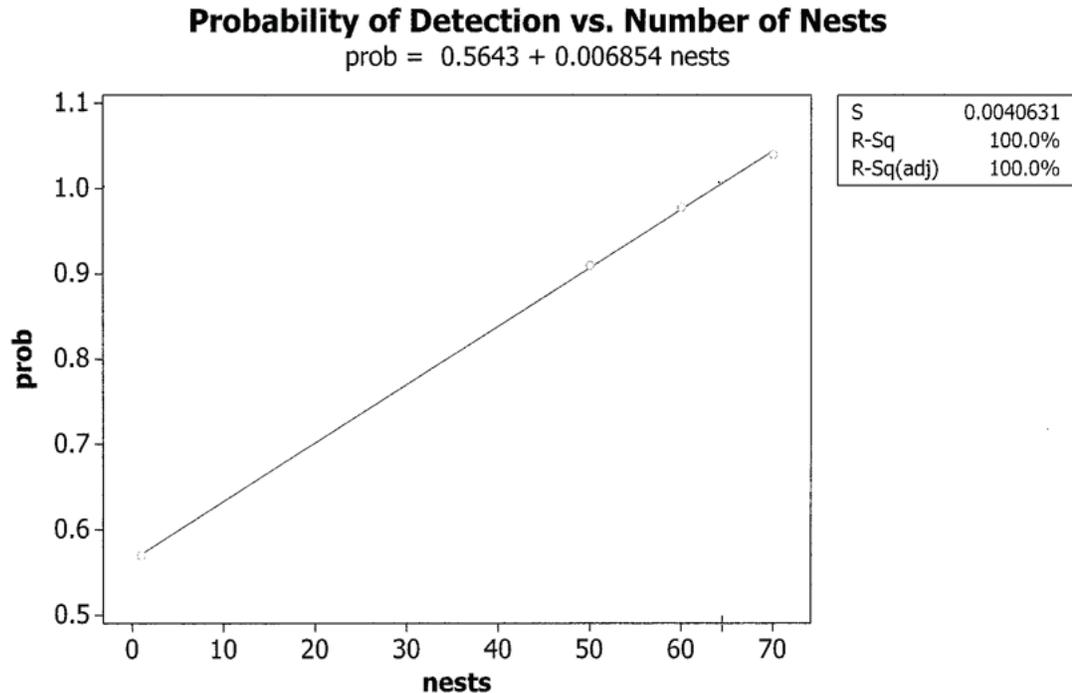
^bThe values given represent the total number of known sites with current or previously-known Brown Pelican nesting ("historical"). The numbers in parentheses represent the number of active colonies or sub-colonies seen in 2006. All known, historical colonies would not be expected to be occupied in a single year (see text) and that percentage for 2006 is given in the next column (6). None of the subpopulation values were significantly different from one-another (P=0.41, Chi2-test).

^cCV = coefficient of variation.

^dThe largest numbers of breeding pairs on a single island are found at Isla San Lorenzo Norte (Animas) in the Gulf of California (Appendix 3); but three islands in very close proximity, Islas Salispuedes, San Lorenzo Norte, and San Lorenzo Sur, actually comprise the largest single breeding colony, 17,225 nests in 2006, determined from ground-truth data.

^eThis value was corrected for the estimated reduced detectability of small (<63) colonies, adding about 150 pairs and 5 occupied colonies to the total.

Figure 3. Estimated aerial detectability of small colonies of brown pelicans.



occur commonly throughout the range, commonly enough that these small colonies are likely important for an understanding of metapopulation dynamics, source/sink phenomena, and dynamics of local extinctions/establishments. Yet, due to the high overall aerial detectability of brown pelican concentrations and colonies, augmented by the usually large sizes (>63) of breeding colonies, which include large birds conspicuous in, over, and near occupied nesting substrate (or on the ground in large flocks), usually also “marked” with large, white patches of fresh guano (in contrast to pinkish or yellowish patches, which would be from previous years), we do not believe these small, rare occurrences of nesting brown pelicans are consequential to total metapopulation or subpopulation estimates reported here (we estimate a correction for detectability would add about 150 nests and only 5 more colonies to the overall estimate, which are included only in the totals in Table 2). Given the degree of other known sources of variation that potentially confound overall precision (namely phenological differences, observer error, and even methods and assumptions used to estimate precision), small colonies are of minor importance to the overall estimate. However, small colonies are nonetheless biologically important in metapopulation dynamics, but documenting this phenomenon was not an objective of this report.

Sampling Bias

Sampling biases associated with potential phenological differences over a wide range of latitudes (about 11° of

latitude in ten days for the aerial survey portion alone) and observer error are perhaps the most perplexing potential problems. It can be seen that as colony-size becomes larger, aerial estimates tend to steadily and increasingly underestimate ground-truth values (Figure 2), a tendency commonly noted in aerial surveys, but correctable (previous discussion).

Phenology Bias

For the Southern California Bight (SCB) subpopulation (on northern range periphery) (Appendix 1), it was obvious that our flight occurred too early in 2006 to be useful by itself (Figure 4), but a CF of 1.487 is provided for possible adjustments to future surveys of this nature. Yet, given the high expected year-to-year variations in the nesting cycle, even within a subpopulation (see Anderson and Gress 1983, their Figure 4), a correction based on one year’s data may be of limited use.

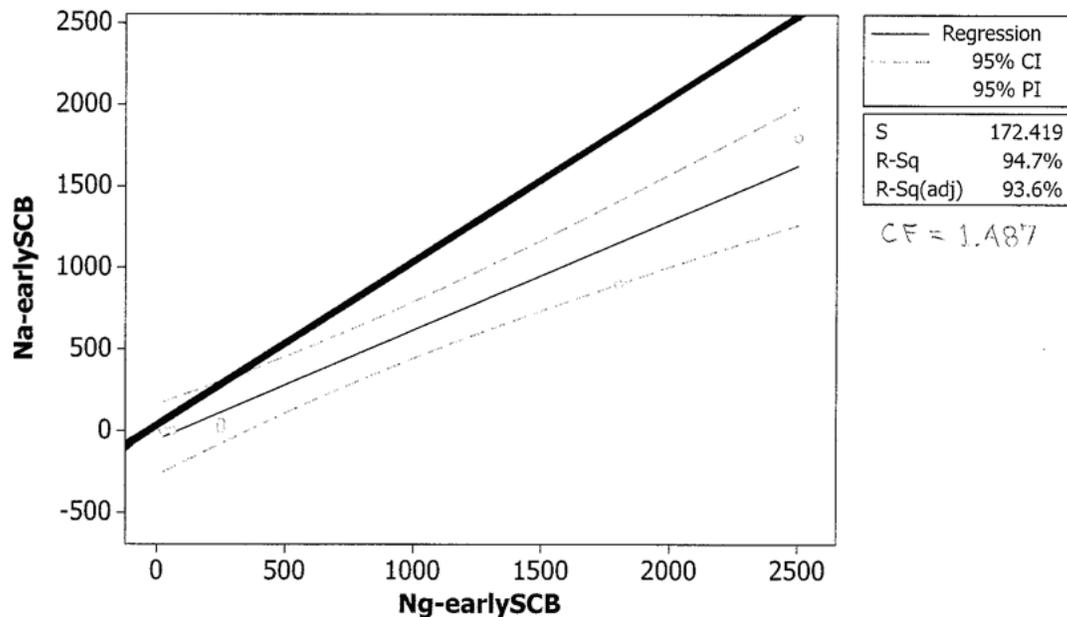
Overall Distribution and Delineation of Metapopulation and Subpopulations

Personal field work and accumulated records by DWA were summarized here only to record a location as a known site for breeding pelicans sometime in the past. Furthermore, the published literature (see methods and additional citations) was reviewed to supplement the total record (Figure 5A, 5B).

Figure 4. Linear regression of aerial estimates (n_a) on ground-truth determinations (n_g) where matched data were available, but phenology differences between the date of aerial survey and final colony-size estimates were large, resulting in an aerial survey too early in the nesting season for an accurate estimate.

Total Sample--Phenologically INCORRECT Comparison Ng Versus Na

$$Na\text{-earlySCB} = -54.42 + 0.6726 Ng\text{-earlySCB}$$



Southern California Bight (SCB) Subpopulation

This subpopulation (Figure 5B, Appendix 1) is defined mainly by the bounds of the California Current System (Anderson and Gress 1983) and includes the mid- and south-coast of California plus the northwest coast of Baja California south to Isla San Gerónimo, Baja California. The most southern, known seabird nesting location, Isla San Gerónimo, was also a potential nesting location for brown pelicans in this zone in 2006. Due to its remoteness and distance from gasoline supplies, Isla San Geronimo was not surveyed by us from the air in 2006. However, ELP and H. Carter (personal communication) observed about 200 nests there in April 2007; that value was used for 2006. Gress (1970) conducted the most comprehensive early review of nesting status of brown pelicans in the SCB. General surveys and estimates of nesting brown pelicans throughout their range were reported by Anderson et al. (1976), Everett and Anderson (1991), and Velarde and Anderson (1994). The general distribution, especially to the south, has also been summarized by Howell and Webb (1995) and Wilbur (1987), with specifics provided in Appendix 1.

Southern Baja-Pacific (SBP) Subpopulation

This subpopulation (Figure 5B, Appendix 2) includes the mid- and southern- Pacific coast of Baja California, south

from Isla San Gerónimo, Baja California (29° 47.5' N), to the south end of Isla Creciente (southern Magdalena Bay, 24° 17' N). Hutchinson (1950:122-133) documented the nesting of brown pelicans (but with no estimate of numbers) in this area and farther south into Mexico. A potential nesting location in this region for brown pelicans, Isla Adelaide (28° 40.2' N, 114° 16.7' W) is not listed in Appendix 2 because brown pelican nesting has never been confirmed, although thousands of Brandt's Cormorants (*Phalacrocorax penicillatus*) regularly nest on this island with 400-500 brown pelicans usually found loafing in the area. Isla Adelaide was reported once to DWA (K. Nishikawa, personal communication) to have possible, sporadic, but very low numbers of nesting brown pelicans, but it was unconfirmed, although the island is often mentioned by many of the authors cited above as an important nesting location for other seabirds (see "X" in that area, Figure 5A). Our name for this subpopulation was changed slightly from that given by Gress and Anderson (1983) ("Southwest Baja California Coastal Population") to avoid name confusion with the SCB subpopulation. No nesting records of brown pelicans have been reported for the outermost island groups of western Baja California, the Islas Revillagigedos (Wehtje et al. 1993) and Isla Guadalupe (Jehl and Everett 1985).

Gulf of California (GOC) Subpopulation

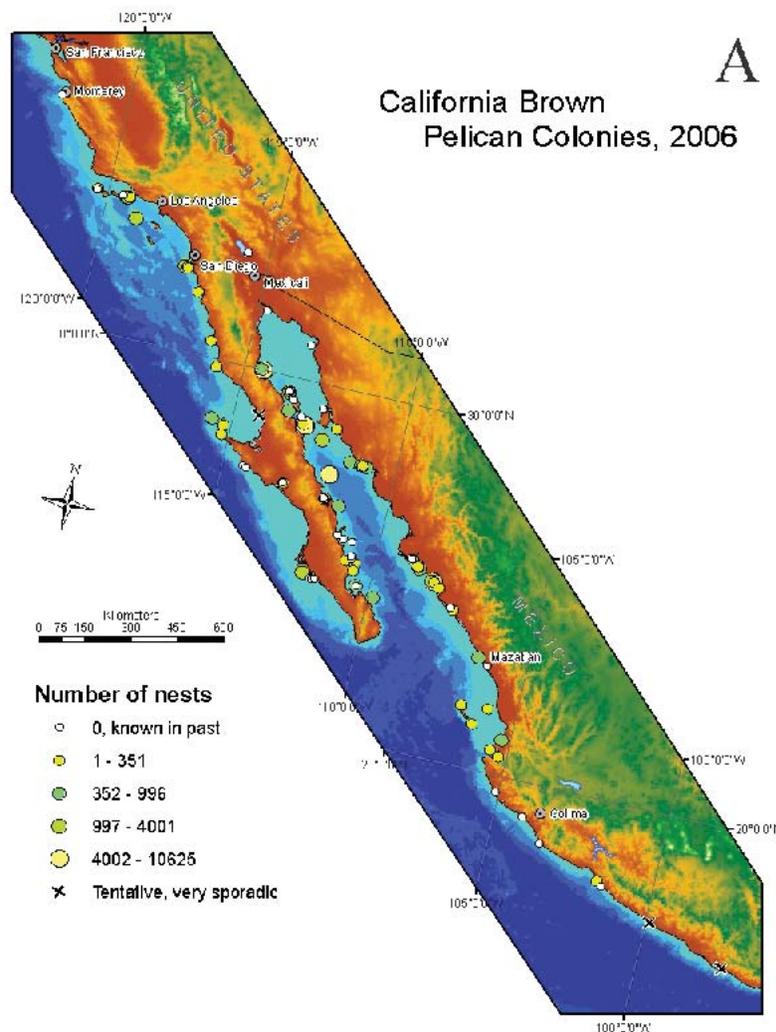
This subpopulation was always known as the largest (Gress and Anderson 1983) and includes the Gulf of California, north from Isla Cerralvo, Baja California Sur (24° 14.6' N, 109° 51.4' W) and north from Punta Calavaras (near Guásimos), Sonora (27° 53.4' N, 110° 40.8' W) (Figure 5B, Appendix 3). A large gap in brown pelican nesting distribution occurs from about the southern terminus of Bahía de Magdalena (24° 20.0' N) south and around Cabo San Lucas to the first nesting colony on Isla Cerralvo, in the southwestern Gulf of California (Figure 5A, 5B). South of Punta Calavaras, subpopulation designation is based mostly on dominant

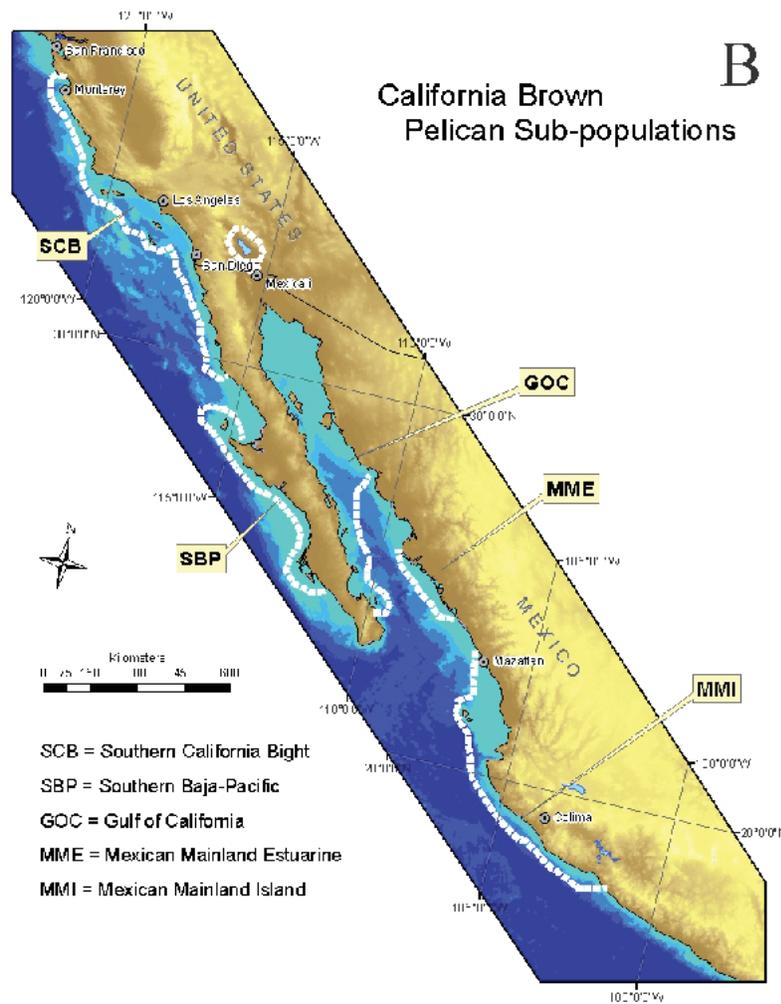
nesting habitat association (estuaries) and distance (physical gap) from the more northern and pelagic GOC brown pelican nesting colonies. Much additional information on the GOC subpopulation and the subpopulations farther south is provided by Velarde et al. (2005).

Mexican Mainland, Estuarine (MME) Subpopulation

There is another large gap in the distribution of brown pelican nesting to the south from about Punta Calavaras (near Guásimos), Sonora (27° 53.4' N, 110° 40.8' W) south to about

Figure 5. The ranges of the California brown pelican (Basemap data source: NGDC, USGS, ESRI, coordinate system WGS 84, created by K. Keightley and M. Ferrell). A. Nesting colonies on the West Coast of North America plotted by size (yellow circles of various sizes) and occupancy (black and white versus yellow circles). B. Hypothesized subpopulations and their boundaries.





Boca las Piedras at the mouth of the Río Fuerte Nuevo ($25^{\circ} 49.1' 109^{\circ} 25.6'$) (= about 400 km) where a distinct change in available and utilized nesting substrate (to mangrove and vegetated, estuarine islands) occurs. This subpopulation nests mostly in mangrove habitat south to about Peninsula Quevedo ($23^{\circ} 54.9' N, 106^{\circ} 58.2'$) (Figure 5B, Appendix 4).

This (MME) subpopulation is also apparently characterized by significant shifting amongst the various bays and islands (details in footnotes, Appendix 4). With nesting colonies frequently shifting location, the numerous presently unoccupied islands of the region (no current colonial waterbird nesting activity seen in 2006) may nonetheless be important for waterbird and biodiversity conservation. The isolated barrier islands, large bays, and extensive mangrove habitats with large numbers of islands along Mexico's west coast are important for many waterbird species.

Mexican Mainland, Island (MMI) Subpopulation

This subpopulation is found nesting mostly in bushes and trees on offshore islands, south of a gap starting at about Mazatlan ($23^{\circ} 16' N, 106^{\circ} 28' W$), and ending at about Isla Grande ($17^{\circ} 40.6' N$) (Figure 5B, Appendix 5). The southern limits of this subpopulation (and the subspecies) are not well defined or well-known. Also evident from a computer "over-flight" on "Google Earth", extensive shoreline development and tourist, agriculture, and mariculture activity characterizes much this area's coastline; and it is possible, but unknown, if larger numbers of brown pelicans nested along this current geographical gap in earlier times.

MMI subpopulation designation is based mostly on dominant nesting habitat association (offshore islands in pelagic zones), distance (physical gap) from the more estuarine-inhabiting MME nesting colonies of Appendix 4, and several reliable correspondents and references. Knoder et al. (1980) conducted eight aerial censuses of variable coverage from the Guatemala border north into Mexico from 1971-1979 and

reported (personal communication, 1980) “no pelican colonies to speak-of” south of Puerto Vallarta, Jalisco. Gonzalo Gaviño de la Torre (personal communication, 1978) reported “little or no brown pelican nesting south of Isla Grande”, Guerrero (see also references under these names).

The brown pelicans that breed in Central America, perhaps as far north in the presumed large gap between *P. o. californicus* and *P. o. carolinensis* (= approximately 1500 km), such as the colony reported in 1971 at Laguna Chacahua (Appendix 5), was likely no more than a sporadic, temporary northern colony of *P. o. carolinensis*, especially given that those brown pelicans were also reported nesting in estuarine mangroves and not on a pelagic, offshore island as seems more characteristic of this subpopulation (Table 2). Importantly, brown pelican nesting is not reported by Binford (1989), the most authoritative author on the birds of Oaxaca, and we must therefore conclude that the Laguna Chacahua record (but based on a reliable source, ref. 28, Appendix 5) must at best be no more than a sporadic, northern record for *P. o. carolinensis* (see also Thurber et al. 1987:128-129). Furthermore, the Laguna Chacahua area has been a National Park (Parque Nacional Lagunas de Chacahua) with constant annual monitoring, but no known brown pelican nesting reported since at least the early-1970s (J. E. Mendoza, personal communication; FG, field notes). We doubt that this record at the range peripheries of both subspecies represents a regular location for nesting brown pelicans. Howell and Webb (1995:126), also recognized authorities for this region, indicate that the first “regular” brown pelican colony to the south of Isla Grande (Appendix 5) is located in the Gulf of Fonseca (about 13° 16' N, 87° 42' W), near the border of El Salvador and Nicaragua.

Genetic studies are certainly needed from both north and south of this area, and ecological studies may provide useful information regarding isolating barriers for the two subspecies. Jehl (1974) conducted pelagic seabird surveys from the offshore areas in this region (see Figure 5) and commented on the general rarity of brown pelicans. Thus, the available information indicates that the coast of Guerrero (about 17° 40' N) likely represents the southern limits of nesting for the California brown pelican subspecies as well as the MMI subpopulation, although as suggested in Figure 5 and Appendix 5, small, perhaps no more than sporadic brown pelican nesting colonies may occasionally be found somewhat farther south, although the two resident breeding subspecies of the larger region (western North America), normally widely separated, may commonly mix as non-breeders (see Thurber et al. 1987), or even rarely breed in this region.

Numbers of Breeding Pairs by Subpopulation and Totals for the Sub-species

Overall results of the survey are presented in Table 2, and summarized by subpopulation in Figure 5B. The entire metapopulation (subspecies) is comprised of about 70,680 ± 2,640 breeding pairs (Table 2). The largest subpopulation within the

subspecies' range is in the Gulf of California (about 43,400 breeding pairs) and the largest single breeding aggregation is presently located in the Midriff Region of the Gulf of California on the San Lorenzo Archipelago (Table 2, Appendix 3). Age-ratio estimates from our 2006 aerial survey for the entire metapopulation indicated 71.9% adults (white-heads) and 28.1% immatures (brown-heads) (mostly comprised of young produced in the two years preceding 2006) (total n = 71,287 individuals categorized). Given these age-ratios, we therefore estimate the total California brown pelican metapopulation in 2006 (an exceptional season preceded by about five years of high production and survival of subadult birds; DWA, field notes), at about 195,900 ± 7,225 individuals.

Discussion

Our total estimate for the subspecies was about 70,680 breeding pairs (Table 2). The Archipelago of San Lorenzo contained the largest colony (comprised of three sub-colonies) with a ground-truth census of about 17,200 breeding pairs (= 24.4%). Yet, no subpopulation breeding colony average (expressed in various ways in Table 2) approaches that level, with considerably smaller colonies more typical. Also, each subpopulation seems to contain at least one or two colonies or colony-areas which dominate subpopulation numbers, and perhaps act as central dispersal areas: SCB, Anacapa Islands Archipelago plus Santa Barbara Island = 9,000 nests (77.0% of the subpopulation); SBP, Isla Santa Margarita = 1,950 nests (62.9%); GOC, San Lorenzo and San Luis Archipelagos plus Isla Tortuga = 31,485 nests (72.6%); MME, Archipelago Isla Pájaros (Bahía Santa Maria) = 9,050 nests (85.9%); and MMI, Isla de Pájaros (Mazatlán) plus Isla la Peña = 1,350 nests (73.2%).

De la Torre (1986) has aptly pointed-out that from about Nayarit and south (the MMI subpopulation), offshore nesting islands are very scarce, and rarely does one encounter breeding brown pelicans. Thus, he concludes (and we agree, see Anderson et al. 1976 and 2006) that such smaller and more widespread breeding colonies are no less important in conservation, but perhaps more vulnerable, than those larger colonies to the north (Appendices 3 and 4, for example). This importance would seem especially true for such nesting colonies at Isla Peña and Isla Grande. From literature reviews for this region (Appendix 5), we are confident that subpopulation numbers are very low, but perhaps even lower than estimated here.

We have not specifically evaluated trends in this report or conducted a specific Population Viability Analysis (see Beissinger and McCullough 2002), but in most instances where long-term data are available, this metapopulation should be considered similar to when it was more crudely estimated by Gress and Anderson (1983:9,176), at “55,000-60,000 pairs”, except that the SCB population has increased (recovered) greatly in numbers since the early-1980s (Gress

et al., in preparation). Gress and Anderson (1983:11) stated: The number of pairs breeding in the SCB from 1969 through 1981 ranged from 339 to 3,510 (average = 1,228). Our 2006 estimate of about 11,700 (Appendix 1, Table 2) indicates an increase over the earlier average by almost one order of magnitude (a factor of approximately 9.5). If one subtracts the SCB early/late difference (10,470) from our 2006 metapopulation total, the remainder is about 60,200, a value remarkably close to an earlier estimate by Gress and Anderson (1983). Reclassification of the California brown pelican under the Endangered Species Act as first proposed in 1985 (Letter from L. L. Leschner, Chair Pacific Seabird Group, to U.S. Fish and Wildlife Service, 18 March 1986) was partly postponed until some assurances that the large, viable segment of the overall metapopulation to the south of the California Current had assurances for conservation. Indeed, conservation has made significant strides in Mexico since that time (Carabias-Lillo et al. 2000), so that now, a formal petition to re-classify or delist has been put forward (U.S. Fish and Wildlife Service 2006). We consider our estimate as a maximum estimate; numbers in other years, likely to be less than this number, are likely to be most influenced by ENSO conditions and the effects of human development pressures and disturbances (e.g., Anderson and Keith 1980, Tershy et al. 1999, and Primavera 2005) along the Mexican coastlines of the subspecies' range, especially from the Colorado Delta region south to the southern limits of its range along the coasts of Western Mexico. Maricultural, agricultural, and tourist activities in this region are extensive and may result in substantial loss of breeding habitat leading to decreased brown pelican and waterbird populations. The Mexican Mainland Estuarine subpopulation and its habitat are especially dependent on the persistence of estuarine/mangrove habitats and estuarine/mangrove nesting islands. Much

of this habitat also represents significant habitat for wintering waterfowl (shorebirds, ducks, geese, coots). Further descriptions, threats, and conservation (along with waterfowl census data) have been provided by Saunders and Saunders (1981), Kramer and Migoya (1989), Wilson and Ryan (1997), and Pérez-Arteaga et al. (2002).

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