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BROWN PELICANS IN SOUTHERN CALIFORNIA: HABITAT USE AND ENVIRONMENTAL FLUCTUATIONS

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ABSTRACT.—The population size, distribution, and habitat affinities of Brown Pelicans (*Pelecanus occidentalis*) were investigated during 1975–1978 using monthly aerial, ship, and ground surveys throughout the Southern California Bight. Pelican numbers are lowest during spring, when most birds are found near the relatively small nesting colonies at Anacapa Island and Islas Los Coronados. The annual post-breeding migration from Mexican colonies augments the local population during summer and autumn; estimated peak populations of 65,000 to 94,000 birds occurred in September and October. Throughout autumn and early winter, pelicans regularly occurred as far offshore as Cortés Bank, 75 km seaward from the nearest island and 175 km off the mainland. Adults predominated offshore and near the California Channel Islands all year, but immature birds outnumbered adults along the mainland shore during autumn and winter.

Brown Pelicans occurred at sea in highest densities in areas of shallow, warm water within about 30 km of shore. During August and December, however, migrating birds showed no discernible affinity for particular sets of environmental conditions. The distribution of spawning northern anchovies, the principal prey of Brown Pelicans during the nesting season, was not a good indicator of bird density distribution. The effects of a two-year warming trend on pelican numbers are discussed.

The California Brown Pelican (*Pelecanus occidentalis*) breeds primarily on islands in the Gulf of California and along the west coast of Baja California (A.O.U. 1957). The northernmost nesting location is presently Anacapa Island (34°00'N, 119°28'W), although pelicans nested at Pt. Lobos, Monterey Co. (36°35'N, 121°58'W) as late as 1959 (Baldrige 1974). Much research has been directed towards documenting pelican population status in western North America, where a decline in nesting population size in the northern colonies coupled with very low reproductive output at several colonies has been linked with pollution by chlorinated hydrocarbons (Risebrough et al. 1971, Jehl 1973, Anderson and Anderson 1976) and human intrusion into colonies (Jehl 1973, Anderson and Keith in press). These

studies provide a record of nesting behavior and phenology, reproductive success and colony status during 1968–1978, but they furnish no systematic estimates of the total numbers of birds present or of patterns of habitat use away from the colonies. Our primary purpose here is to provide information on population size and distribution of the Brown Pelican in the Southern California Bight (SCB) based on data gathered during the period 1975–1978. We also discuss the occurrence of pelicans in relation to oceanographic events in the SCB.

STUDY AREA AND METHODS

STUDY AREA

The Southern California Bight and the section of the California Current immediately to the west include approximately 90,000 km² of open ocean and coastal

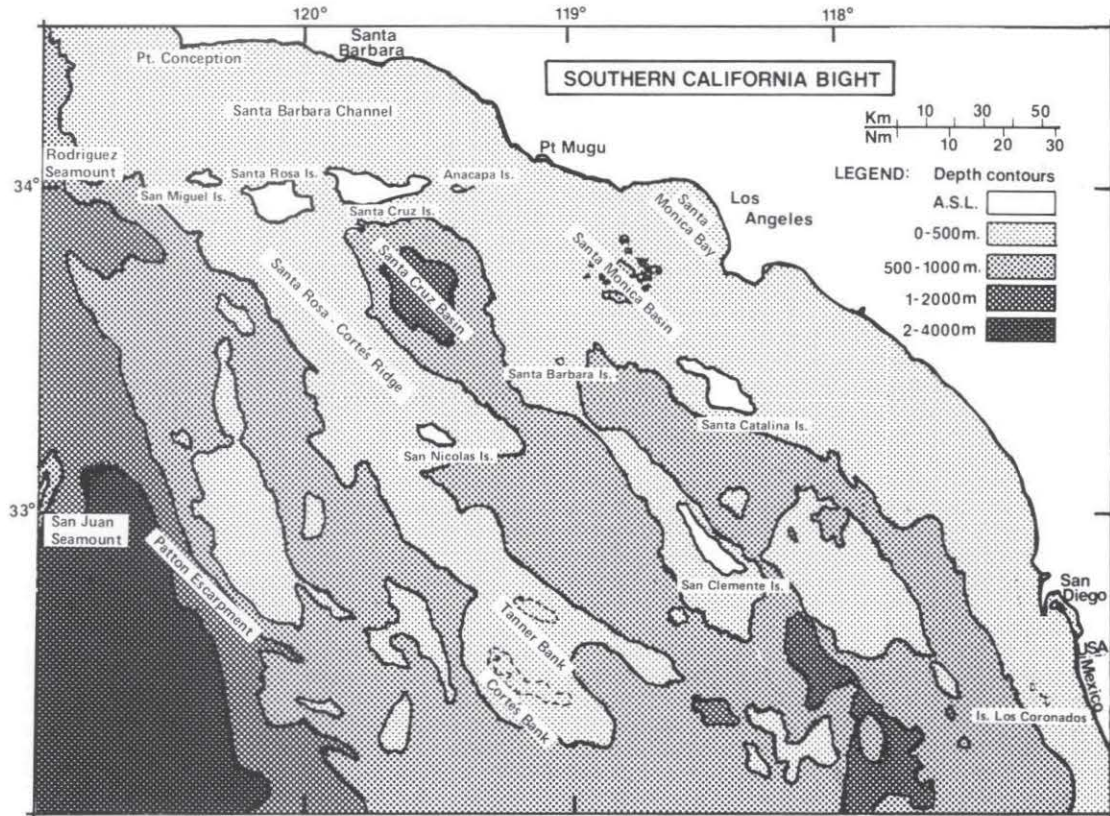


FIGURE 1. Map of the Southern California Bight study area showing major features of submarine topography (adapted from Shepard and Emery 1941).

waters, nine islands or island groups (the eight California Channel Islands and *Islas Los Coronados*), and about 460 linear km of mainland coastline (Fig. 1). We surveyed the area along the mainland shore from Pt. Conception to the U.S.-Mexico border and offshore for approximately 180 km (to beyond the 2,000 m isobath).

Unlike the relatively simple, narrow continental shelf typical of most of the California coast, the seafloor of the SCB consists of a series of ridges and basins paralleling the coastline, similar in shape and structure to the mountains and valleys of the adjacent mainland. Undersea ridges break the surface as islands or offshore rocks (Shepard and Emery 1941). Brinton (1976) characterized the region as having some of the most intense upwelling within the California Current. The California Current itself is the wide, slow, cool eastern boundary current of the North Pacific Gyre, flowing southeasterly along the west coast of North America from approximately 45°N to 30°N latitude. Upwelling of cool, nutrient-rich subsurface waters is typical of such boundary currents.

Upwelling affects local seasonal temperature variation within the SCB, but this effect is relatively minor when compared to the cooling brought about by the influx of colder, northern water in the winter and spring (January through June), and warming associated with intrusion of southern water in the summer and autumn. Surface temperatures vary annually from about 11°C to more than 20°C. Surface waters throughout the SCB are cool and well-mixed in the winter and spring. In summer, surface water in the eastern sector heats rapidly, while waters to the west remain relatively cool. Temperature differs as much as 7°C between the southeastern and the northwestern extremities of the SCB.

METHODS

Data were collected during a three-year study of all seabirds and marine mammals of the SCB; this study was not specifically designed to answer ecological questions about Brown Pelicans. Data were collected in three primary habitats: mainland beaches, island coastlines, and open-water. In each habitat, we determined total numbers by direct count or by sampling. Gross age composition, behavior, environmental conditions, and associations with other birds, mammals, or human activities were noted. We visited all parts of the study area with approximately equal frequency, and replicated coverage in space and time as much as possible to permit quantitative seasonal and yearly comparisons.

Mainland beach surveys. From April 1975 through March 1978 we censused live birds along 14 southern California beaches (Table 1). Beach censusers recorded total numbers and age ratios (adult, sub-adult, juvenile) of all birds onshore and those on and over the water out to 200 m. We regard these counts as rough indices of abundance and age composition because censusers were also responsible for tallying dead birds, and census times and conditions were variable. Further, we suspect (unpubl. data; D. W. Anderson, pers. comm.) that pelicans may concentrate in harbors and along jetties (which we did not sample); sampling open beaches probably underestimates the magnitude of mainland pelican populations.

Island surveys. We censused all birds on beaches, cliffs, and inshore waters of the Channel Islands nearly every month by means of ship and aircraft surveys. During ship surveys, we slowly circumnavigated each island 0.3 to 1.0 km offshore and counted all birds with-

TABLE 1. Comparison of mean monthly pelican counts along 14 selected southern California beach areas.

Beach	Las Varas	Devereux	Arroyo Burro	Pitas Pt.	McGrath	Pt. Miguel/P.B.T.C.	Malaga/Redondo Dockweiler	Bolsa Chica	Huntington	Crystal Cove	San Onofre/Fenelon	South Carlsbad/Leucadia	Silver Strand	Border Field	Sum of Monthly Means
Beach No.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	
Km Surveyed	3.2	2.3	1.6	1.8	5.3	4.8	4.0	4.8	3.2	3.2	20.9	1.7	4.8	1.7	
Month: April	2.0	1.0	0.0	1.0	2.0	-	0.0	0.0	1.0	3.0	0.0	0.0	0.0	0.0	10.0
May	0.0	7.0	1.0	4.0	2.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.0
June	2.0	16.0	2.0	6.0	60.5	43.5	0.7	0.0	1.0	0.0	5.7	0.0	0.3	1.7	139.4
July	16.0	39.0	1.0	12.0	60.0	16.5	34.3	1.5	2.3	0.0	1.3	16.0	6.7	2.3	208.9
August	15.0	5.5	3.0	1.5	43.3	78.0	6.7	4.0	0.3	0.0	0.0	0.3	5.0	4.0	165.6
September	41.0	67.5	15.5	25.0	117.5	198.5	24.3	17.5	18.3	5.0	0.5	4.0	6.0	0.5	541.6
October	8.0	56.0	13.0	16.0	149.0	271.0	19.7	8.5	6.0	10.5	2.3	6.3	22.5	28.0	616.8
November	39.0	111.5	19.5	92.0	102.0	144.7	53.3	0.0	3.7	4.5	3.3	7.3	8.3	1.3	590.4
December	16.0	3.5	6.0	25.5	50.5	25.0	134.3	0.0	15.5	7.0	1.0	1.0	1.0	2.7	289.0
January	8.5	17.5	0.0	0.5	1.0	24.0	2.7	2.5	11.3	2.0	1.0	1.3	0.0	0.0	72.3
February	12.5	2.5	2.0	0.0	4.3	7.7	5.7	0.0	1.3	0.5	14.0	0.0	0.0	0.3	50.8
March	3.5	1.5	0.0	0.0	1.7	6.5	1.0	0.0	0.3	1.5	0.0	0.0	2.7	0.0	18.7
$\bar{X}/mo.$	13.6	27.4	5.3	15.3	49.5	68.1	23.6	2.8	5.1	2.8	2.4	3.0	4.4	3.4	
$\bar{X}/km/mo$	4.3	11.9	3.3	8.5	9.4	14.2	5.9	0.6	1.6	0.9	0.1	1.8	0.9	2.0	

in 200 m of the shoreline. Only the four northern islands (San Miguel, Santa Rosa, Santa Cruz, and Anacapa) and Santa Barbara Island were surveyed from shipboard on a regular basis. Counts of nests and nesting adult pelicans on Anacapa Is. and Scorpion Rock, Santa Cruz Is., were provided by P. Kelly and F. Gress (pers. comm.).

More complete island coverage was afforded by low-altitude (100–150 m) aerial surveys made in a high-winged, twin-engine Cessna 337. During aerial surveys one observer reported orally on a cassette recorder while a photographer filmed all aggregations of more than 15 birds. We made bird counts from approximately 25,000 of the resulting color transparencies.

Open-ocean sampling. We designed our open-water sampling series to obtain estimates of bird density in all offshore habitats. Most sampling effort was devoted to the region inshore of the Santa Rosa-Cortés Ridge—that area containing all of the islands and lying east of the main flow of the California Current. This region harbors most, if not all, of the Brown Pelican population of the study area. Cruise and flight paths (Fig. 2, described below) traversed all habitat types within the area of sampling.

To ensure that the sample of offshore habitats was representative, we compared frequency distributions of environmental variables found along cruise and flight paths ("sampled" variables included water depth [WD], bottom slope [SLOPE], distance to the nearest point of land [DNL], distance to the mainland [DML], and surface water temperature [WTMP]) with the distributions of these variables in 1,285 blocks in a 5' by 5' latitude/longitude grid of the entire study area (the "expected" frequency distributions). The ship track was found to oversample waters lying between 18.5 and 37.0 km from nearest land, while underrepresenting intervals farther from shore (Kolmogorov-Smirnov two-

tailed test of goodness of fit; $D_{max}DNL = 0.167$, $P < 0.05$; Sokal and Rohlf 1969). Distributions of WD, SLOPE, DML, and WTMP sampled along the ship track were statistically indistinguishable from expected distributions of these variables ($D_{max}WD = 0.063$, $P > 0.10$; $D_{max}SLOPE = 0.080$, $P > 0.10$; $D_{max}DML = 0.066$, $P > 0.10$; $D_{max}WTMP = 0.111$, $P > 0.10$). The distributions of all variables sampled along aerial tracks were indistinguishable from the expected distributions ($D_{max}DNL = 0.103$, $P > 0.10$; $D_{max}WD = 0.055$, $P > 0.10$; $D_{max}SLOPE = 0.117$, $P > 0.10$; $D_{max}DML = 0.099$, $P > 0.10$; $D_{max}WTMP = 0.119$, $P > 0.10$). Oversampling of waters lying at intermediate distances from shore could bias estimates of offshore populations when pelicans are concentrated at particular distances; the magnitude of such errors should be proportional to the relative influence of the variable DNL on pelican density distribution during a given season (discussed in Results). However, aerial surveys alternated with vessel surveys in all seasons (in some months both types of survey were made), providing estimates of bird density free from such systematic bias.

Eight standard ship surveys (800 m strip transects divided into 102 segments of 7.4 km length) were conducted each year along a fixed transect path east of the Santa Rosa-Cortés Ridge (Fig. 2). Five additional ship surveys of the waters west of longitude 120°30'W in September 1975, January and October 1976, and January and April 1977 confirmed that pelicans do not regularly visit waters to the west of the replicated ship track.

Aerial strip transects were also surveyed about eight times per year. These surveys routinely extended farther offshore than the area sampled from the ship (Fig. 2). Observations were made from 65 m above the water at 165–175 km/h. Aerial transect corridor width was 50

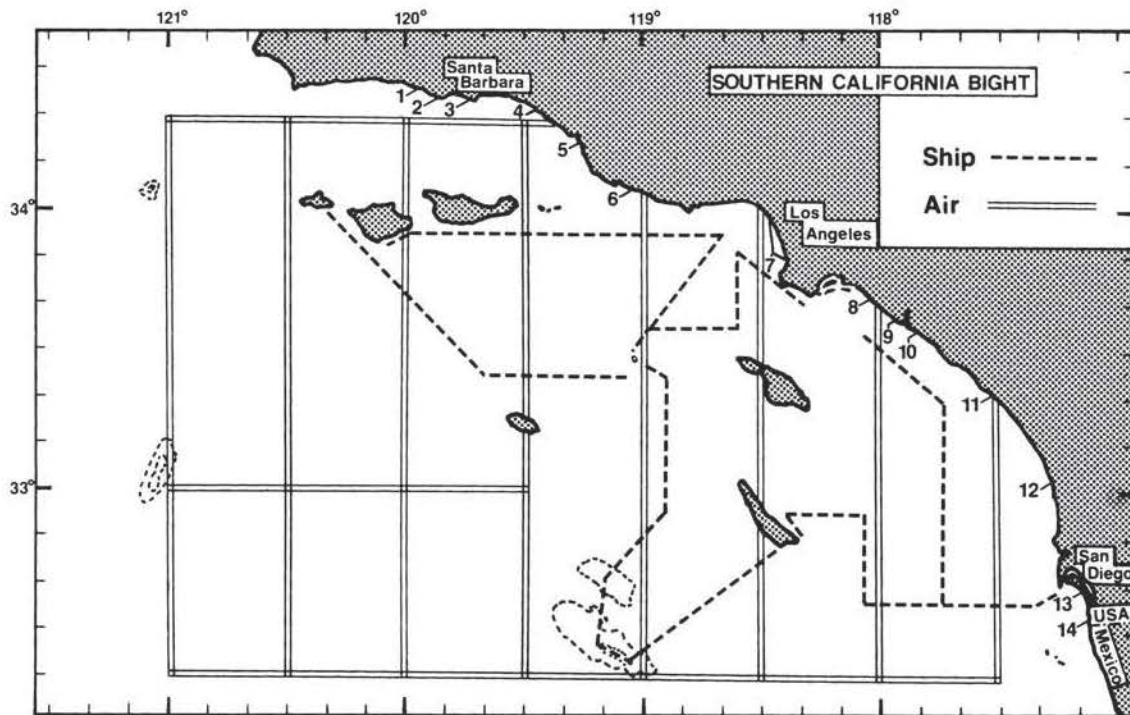


FIGURE 2. Standard transect paths followed by shipboard and aerial observers, and mainland beaches surveyed. See Figure 1 for place names (numbered beach names appear in Table 1).

m (estimated by inclinometer). As with shipboard observations, aerial data included bird numbers, age, behavior, and direction of travel. We made observations only on the shaded side of the aircraft when glare conditions were bad; significantly fewer birds are seen by observers looking into glare than by observers with a shaded view (Briggs and Hunt 1976). Aerial transect lines were divided into segments of 18.5 km length; typical monthly coverage included about 1,800 linear km.

The replicability and efficiency of the open-ocean density estimation techniques we employed have been investigated by ourselves and other authors (Briggs and Hunt 1976, Wiens et al. 1978). In general, the rapidity and breadth of coverage of aerial surveys and the relative emancipation of aerial observers from surface weather conditions provided a nearly "instantaneous" sample of pelican numbers and distribution throughout the study area. Surveys from ships, on the other hand, provided details of age composition, behavior, and environmental conditions not obtainable from the air. Standard errors of density estimates derived from replicated aerial samples are 10% higher than those from estimates taken from shipboard data; both techniques yield very similar figures on species composition when samples are taken at the same place and time and very similar mean density values for birds as large and conspicuous as pelicans.

Analysis procedures. Data concerning pelican numbers on land and at sea were entered into a computer and stored on magnetic tape. We calculated pelican density for each segment of ship and air track by dividing observed numbers by the area included within the search corridor; no corrections were made for detectability (Wiens et al. 1978). Densities calculated for these segments were plotted on a 10' latitude/longitude grid. When more than one segment fell within a grid block during a given trip, all density calculations for that block were averaged.

The relationships between pelican density and various environmental features were analyzed by stepwise multiple regression procedures (Kim and Kahout 1975). Bird density in transect segments (dependent variable) was regressed against DNL, DML, SLOPE, WD, WTMP and distance to the nearest pelican nesting colony (DNC). On occasion, vessels of the California Department of Fish and Game conducted intensive acoustic (side-scan sonar) surveys of the distribution of northern anchovies (*Engraulis mordax*) in the study area. When their surveys coincided with ours, we regressed pelican density against the estimate of anchovy school biomass (ANCH) in the same manner as the other independent variables (Mais 1974, and unpublished cruise reports of the CDFG provided maps of anchovy distribution). In cases where a multiple regression equation explained a significant portion of variance in bird density at sea, the equation was used to extrapolate numbers from our sample to the entire study area according to the distribution of the statistically significant environmental variables.

An estimate of the size of the Brown Pelican population in the SCB must integrate estimates for the several habitats in which the birds occur. We combined our mainland, island, and open-water data to derive a population estimate for each survey. Extrapolation of mainland counts from our 41 to 58 km of coverage to the 460 km coastline yielded a minimum mainland population. Island counts were used directly without manipulation. We manipulated data taken along transects at sea to obtain two estimates of offshore pelican populations: 1) the observed mean density for each trip was multiplied by 60,000 km² (the area from which density was sampled and roughly the area occupied by Brown Pelicans when maximally abundant). Confidence limits of 95% of mean density estimates were proportional to the magnitude of the mean, varying from 15% to 50% of the mean. 2) We summed the numbers for the 1,285 grid-cells that were estimated from

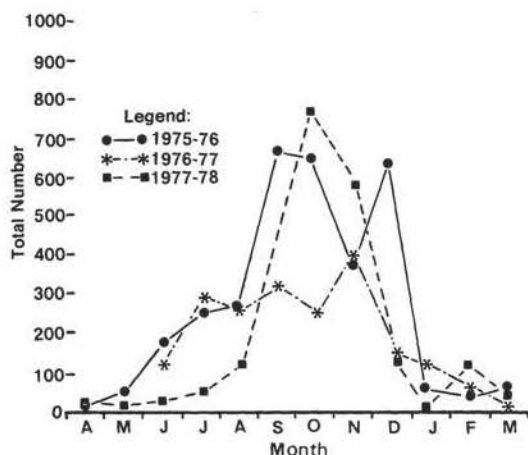


FIGURE 3. Total counts of Brown Pelicans recorded along mainland shores during 1975-1978.

regression equations relating bird density to environmental variables. Confidence limits for these extrapolations varied in proportion to the standard error of beta, amounting to 22% to 67% of the extrapolated mean density for the study area.

Since our ship surveys, like pelicans, were farthest from the nearest land at noon each day and were closer to islands at dawn and dusk, it is possible that biases in estimating population size by adding ship transect data to island counts might occur. The logistics of aerial sampling differed importantly in this respect, however, because island surveys were interspersed randomly with open-water surveys. Thus, the temporal distribution of samples far offshore was statistically indistinguishable from island visits. For this reason, we feel that open-ocean and island population estimates generated from aerial data can be combined to yield estimates of the total population off the mainland coast.

RESULTS

The population of Brown Pelicans in southern California varied seasonally in size; total numbers were lowest in the period February through May, highest in August through October, and at intermediate levels in early summer and early winter (Figs. 3-5 show population trends in each of the three study years and each habitat division).

Although we found considerable variability in numbers at given locations during surveys spaced as little as ten days apart, the overall censuses of mainland beaches, island beaches and roosts, and open-water areas within one- to two-month periods showed broad trends of population increase or decline. Modest variations between years occurred in the timing of attainment of peak numbers in the fall, but the curves are remarkably similar overall. Winter declines appeared to be more abrupt and less variable in timing (e.g., Fig. 5) than the build-up of numbers in the spring and summer.

These seasonal changes in population size correspond well with the known influx

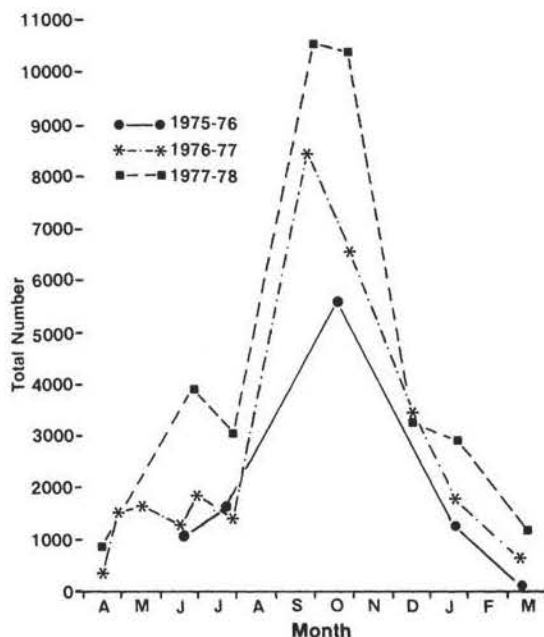


FIGURE 4. Total counts of Brown Pelicans recorded along island shores during 1975-1978.

into the SCB of birds from Mexican breeding colonies in late summer and return migration through and beyond the SCB in early winter. Populations were lowest each year during the breeding season of Mexican birds (February through May); this is the only time when SCB-nesting pelicans comprise the majority of the population in the study area (Anderson and Anderson 1976).

We estimated peak autumn populations at between 65,000 (1975) and 94,000 (1977) individuals (Fig. 5). Our winter estimates of 1,800 to 5,000 birds reasonably account for the local breeders and immatures, and Mexican stragglers expected to be present then. The striking increase in peak numbers between 1975 and 1977 will be discussed below. Although no estimates of the total size of the California Brown Pelican population have yet been published, it appears that during autumn 1977, a very large segment of the entire population was present in or passed through the SCB.

Two points on Figure 5 (November 1975 and November 1976) that lie well below estimates for both the preceding and the subsequent months require explanation. The open-ocean estimates for these months came from ship surveys that did not sample in Santa Barbara Channel, a region of known high pelican densities. Ship-generated figures for these periods were below aerial figures that included the Channel with other sectors of the SCB. The solid

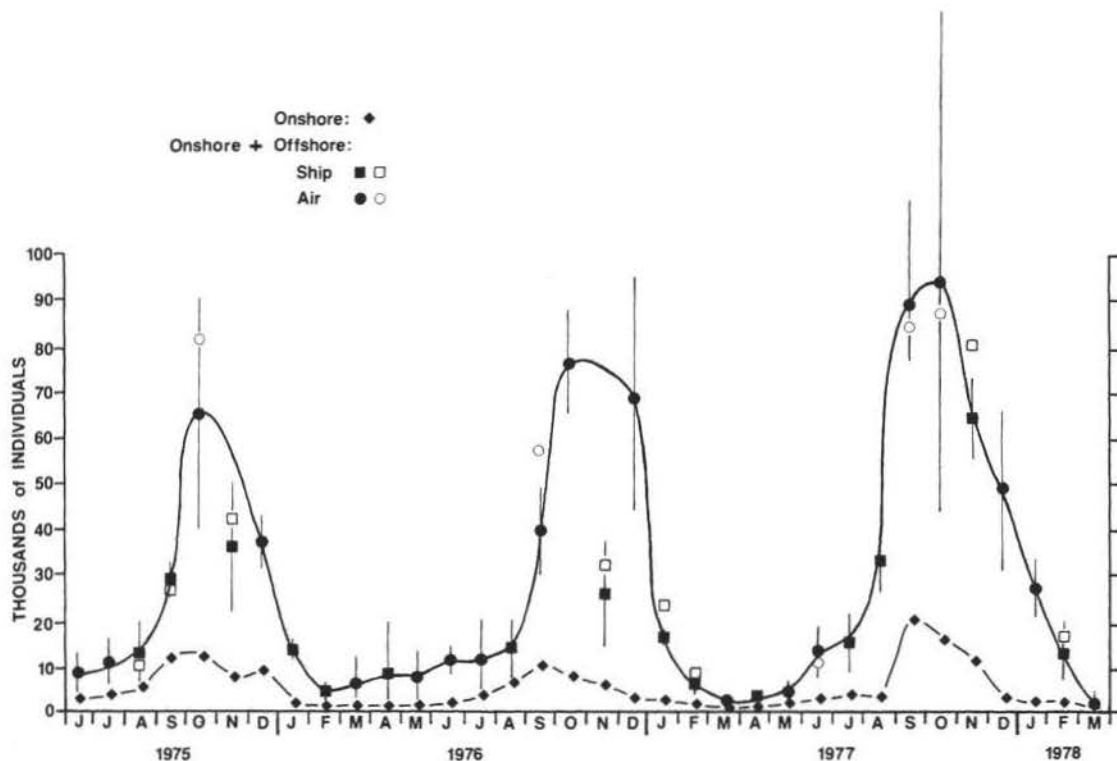


FIGURE 5. Estimated total Brown Pelican population (upper curve) in southern California waters during 1975–1978. The lower curve represents onshore populations from island and mainland coasts. The upper curve combines onshore and offshore estimates (vertical lines indicate 95% confidence intervals). Solid points on upper curve result from extrapolated mean densities (mean density \times area), while open points result from computer extrapolation based on regression results.

lines connecting October and December estimates in these years represent our best approximation of the population curve.

AGE STRUCTURE

Because of lack of uniformity of age determinations by our beach-walk observers, and high speed and unfavorable sighting angles characteristic of aerial observations, we limited our analysis of age structure to two plumage classes, “adult” (white crown, grey back, and completely dark underparts) and “immature” (all other plumage classes) (Palmer 1962), and considered only vessel survey data for the open waters of the SCB. Despite these limitations, we found significant differences in age composition of the pelican population between habitats and between seasons.

Three-month moving averages of age composition from mainland beach counts are plotted in Figure 6a. Adults constituted from 16% to 59% of all birds identified as to age, averaging about 35% to 45%. Generally, adults were in the majority on the mainland in spring and early summer, declined in August and held at about 40% to 50% through autumn and early winter. Figures

for March indicated a preponderance of immatures.

In contrast, adults comprised from 42% to 90% of all pelicans censused among the islands, and constituted 75% or more of the population found there from August through November each year (Fig. 6b). Proportionately fewest adults occurred on the islands in March through May and the fewest immatures during the autumn population peaks. As on the mainland, proportionately fewer adults were seen in winter 1976 than in 1977 or 1978. Age ratios fluctuated more widely on individual islands, particularly when populations were low and on those islands lying close to the mainland (Anacapa and Santa Catalina). In almost all numerically-large island counts, however (those exceeding 1,000 birds), adults comprised more than 65% of the total.

Age ratios obtained at sea parallel the island data; in all three years adults constituted about 50% to 70% of the population during June through August, then became increasingly predominant until reaching a peak of 75% to 85% of the birds at sea after October (Fig. 6c).

Taken together, data from all habitats in-

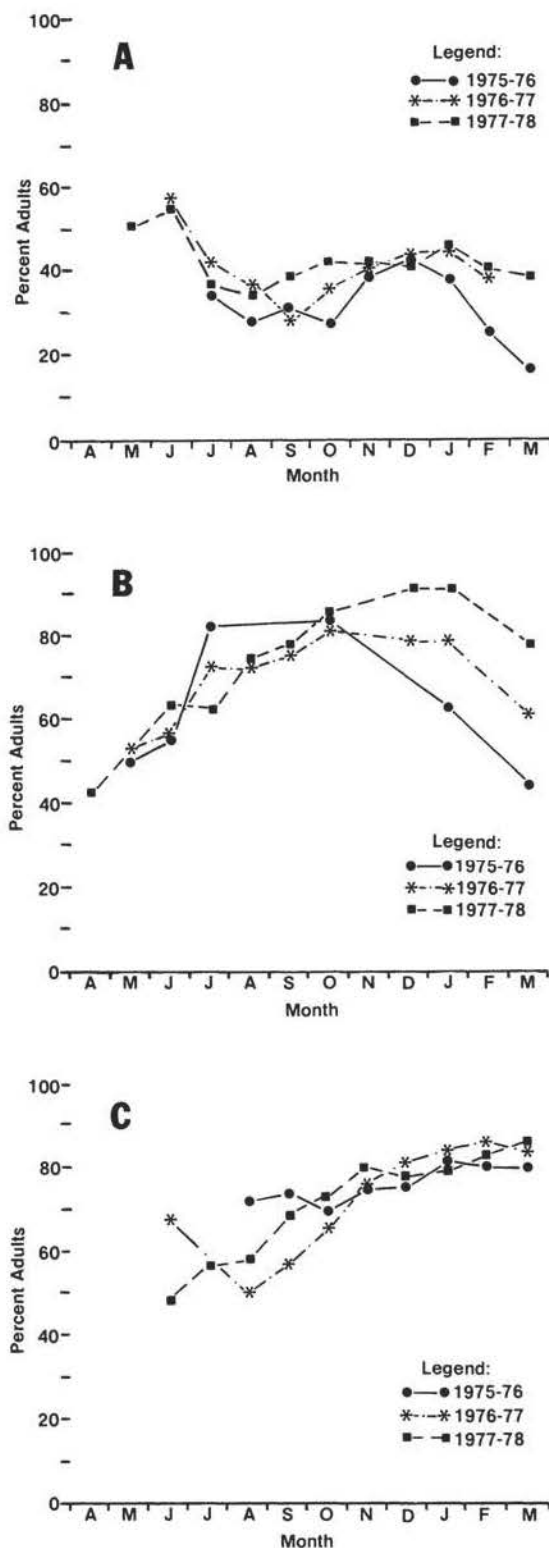


FIGURE 6. Comparison of age composition curves for three habitat divisions (three-month moving average): a) mainland censuses; b) island censuses; c) open-ocean waters.

indicate a ratio of about a 1.2:1 adults to immatures during April through June or July. This ratio declined along the mainland for the remainder of the year but increased to values of 8:1 to 10:1 on the islands and at sea by late autumn. Immatures constituted a slightly greater proportion of the population in March than earlier in the winter.

WITHIN-HABITAT USE

Habitat use is categorized first in terms of differential regional use (mainland beaches, islands, open waters), then in terms of those oceanographic features that correlated with density variations at sea.

Mainland beaches. We found a fairly consistent concentration of pelicans in the northwestern half of the study area (Santa Barbara, Ventura, and Los Angeles counties) as compared with beaches to the southeast (Orange and San Diego counties). The Point Mugu - McGrath State Beach area, in particular, consistently harbored sizeable numbers of birds. Individual monthly counts at beaches south of Huntington Beach never exceeded 60 birds and the monthly means never exceeded 30 (Table 1). This localization was most apparent in the periods of peak numbers (August through November), when up to 90% of the total mainland pelican count was from Ventura and Los Angeles county beaches.

Island shorelines. Yearly population counts along the shores of the California Channel Islands are presented in Figure 7. Although the *total* island counts were consistently highest each autumn and lowest in late winter and spring, neither were the islands uniformly populated during most seasons, nor were annual census curves consistent from year to year for several islands. For example, numbers were low in April through June each year on some islands, while spring "peaks" occurred, at least occasionally, on others. In the cases of Santa Cruz and Anacapa Islands, spring populations represented nesting colonies and birds roosting adjacent to these sites. Populations increased during December and/or January on three islands in 1976-77 and on four islands in 1977-78. These oscillations did not precede larger than average spring populations at these same islands. They probably indicate only that pelicans move roost locations in response to changes in environmental conditions, such as food availability.

Open-ocean. Brown Pelicans were seen from near the mainland shore to about 180 km offshore; the most remote location at

which they were regularly found was Cortés Bank, 175 km west of San Diego and 75 km southwest of the nearest island, San Clemente. Distributional limits and patterns of abundance varied seasonally and annually.

During the main portion of the southern California breeding season (March through July) pelicans were most numerous within 20 km of the nesting islands. Birds were occasionally encountered offshore as far as San Clemente and Santa Barbara Islands, although densities for individual 10' blocks of latitude/longitude seldom exceeded one individual/km². Santa Barbara Channel was used relatively more than any other open-ocean area, though populations there were small compared to the numbers seen during autumn. The typical pelican distribution pattern during May is illustrated in Figure 8a.

During August through September pelicans were found throughout the SCB east of the arc extending from Rodriguez Seamount to San Nicolas Island. The distributional pattern typical of late summer is illustrated in Figure 8b. Although pelicans were occasionally seen near Tanner and Cortés Banks during summer, most birds were found much closer to shore, especially in Santa Barbara Channel. Densities ranging from two to five individuals/km² were frequently noted in Santa Barbara Channel and Santa Cruz Basin; occasionally densities above 15 individuals/km² were recorded in shallow waters near the mainland. Usage of the waters east of Santa Catalina and San Clemente Islands was variable; in 1975 and 1976 densities remained below one bird/km² during August and September, while in 1977 density averaged more than 1.4 birds/km² in August, but dropped to less than 0.2/km² by late September.

Brown Pelican density at sea was generally high in September and October although main areas of concentration shifted southeastward thereafter. Concentrations of birds were most frequent in the northwestern and central thirds of the study area in early autumn, but large numbers were most frequently encountered west of San Diego in November and December (Fig. 8c). Usage of the Cortés Banks area and Santa Barbara Channel remained high through early December.

In 1977 and 1978 pelicans were widely distributed at sea during January and February (Fig. 8d), but few birds were observed offshore in this season in 1976. As winter progressed, pelicans rapidly became scarcer at sea and distributional patterns late in the

period indicated aggregation near the nesting islands (Anacapa and Los Coronados).

Environmental correlates. We wished to determine which features of the marine environment were the best predictors of pelican distribution and numbers at sea. We approached the problem in two ways. The first concerned the "instantaneous" distribution of pelicans throughout the SCB. The second concerned whether those environmental features shown to be most important as predictors of instantaneous distribution significantly correlated with the *seasonal* or *annual* variation in pelican numbers in the SCB.

Twenty-seven cruises and flight series contained pelicans in a sufficient number of segments (more than 10) to permit multiple regression analysis. Statistically significant regression equations were obtained for 17 of these data sets. Table 2 presents results of these analyses, indicating dates of surveys and independent variables found to be significant predictors of pelican density distribution at sea.

Distance to the mainland (DML) was found to account for the greatest amount of variation in pelican density on nine occasions. In all cases in which DML was statistically significant, pelicans decreased in abundance the farther from the mainland. The slope of the regression lines varied, as did the y-intercept, but the frequency with which this variable was statistically significant indicates that distance from the mainland or an unmeasured and closely correlated factor was of primary importance in determining pelican distribution at sea. Pelicans were also found to concentrate over shallow water, warm water, and near their nesting islands. Only once, out of seven occasions for which anchovy distribution data were available, was the biomass of schooling anchovies (the principal prey of Brown Pelicans in the SCB during the nesting season; Anderson and Anderson 1976) an important variable.

During several periods when pelicans were fairly abundant at sea, multiple regression analysis indicated that none of the independent variables accounted for significant amounts of density variation. This in turn showed a high degree of randomness of pelican densities relative to the environmental variables considered.

Of the environmental variables tested, surface water temperature (WTMP) was the only one that both changed seasonally and correlated *within data sets* with geographic variation in pelican density. Data pooled

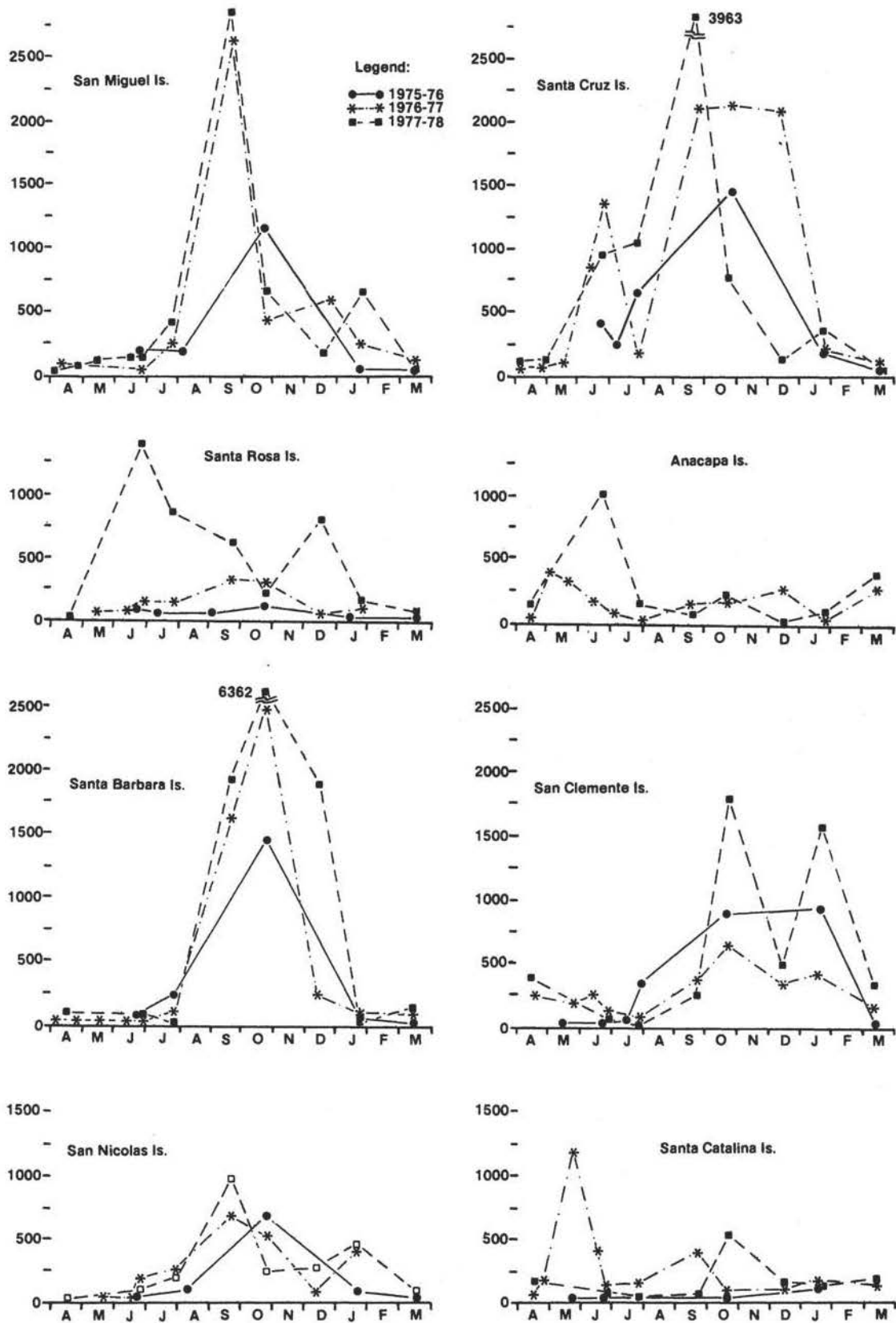


FIGURE 7. Comparison of total Brown Pelican counts made from each of the eight California Channel Islands during 1975 through 1978.

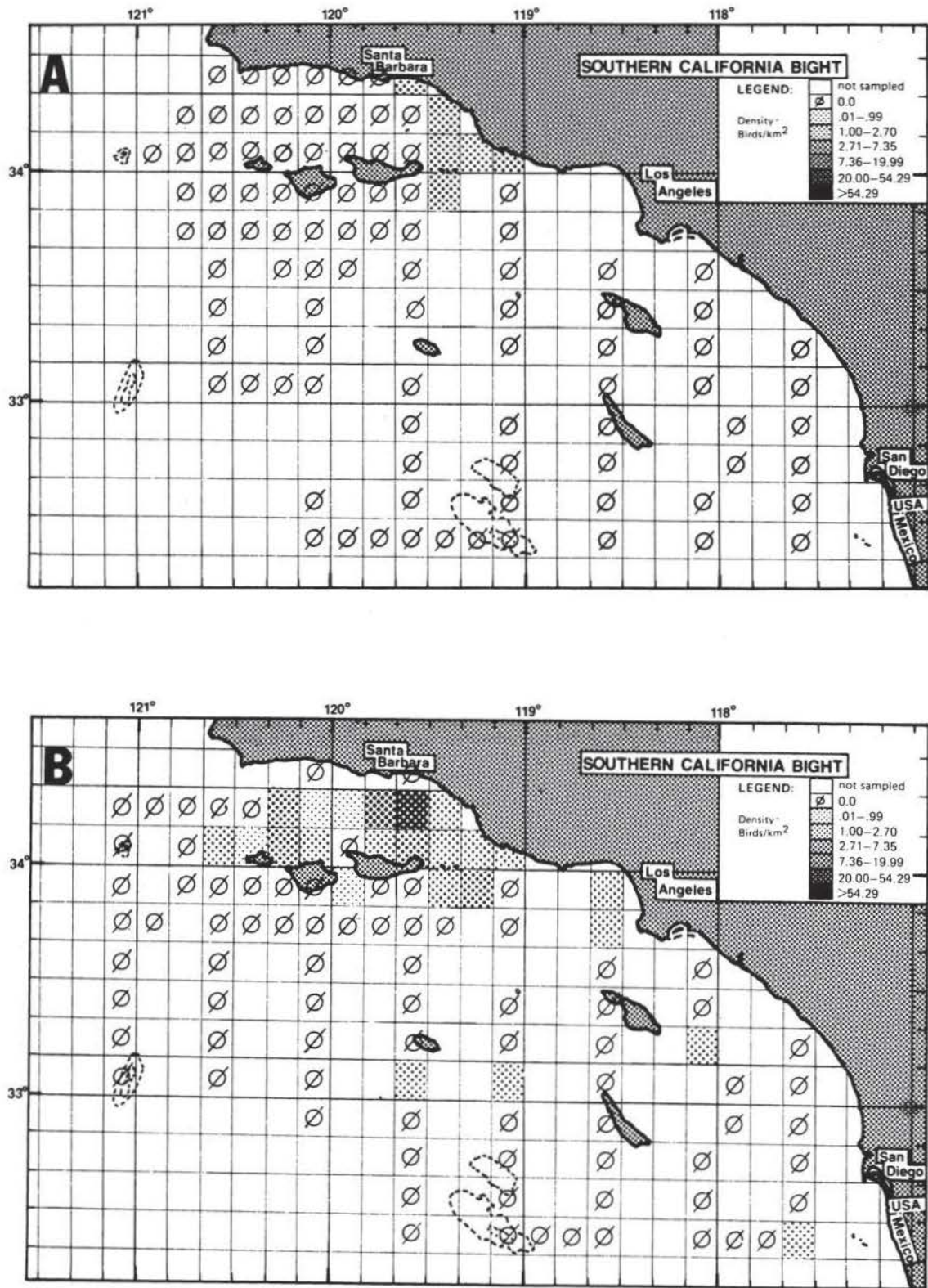


FIGURE 8. Maps of Brown Pelican density calculated from observations made during surveys of waters of the Southern California Bight: a) May 1977, aerial; b) September 1977, aerial; c) October 1977, aerial; and d) January 1977, shipboard. See Figure 1 for place names.

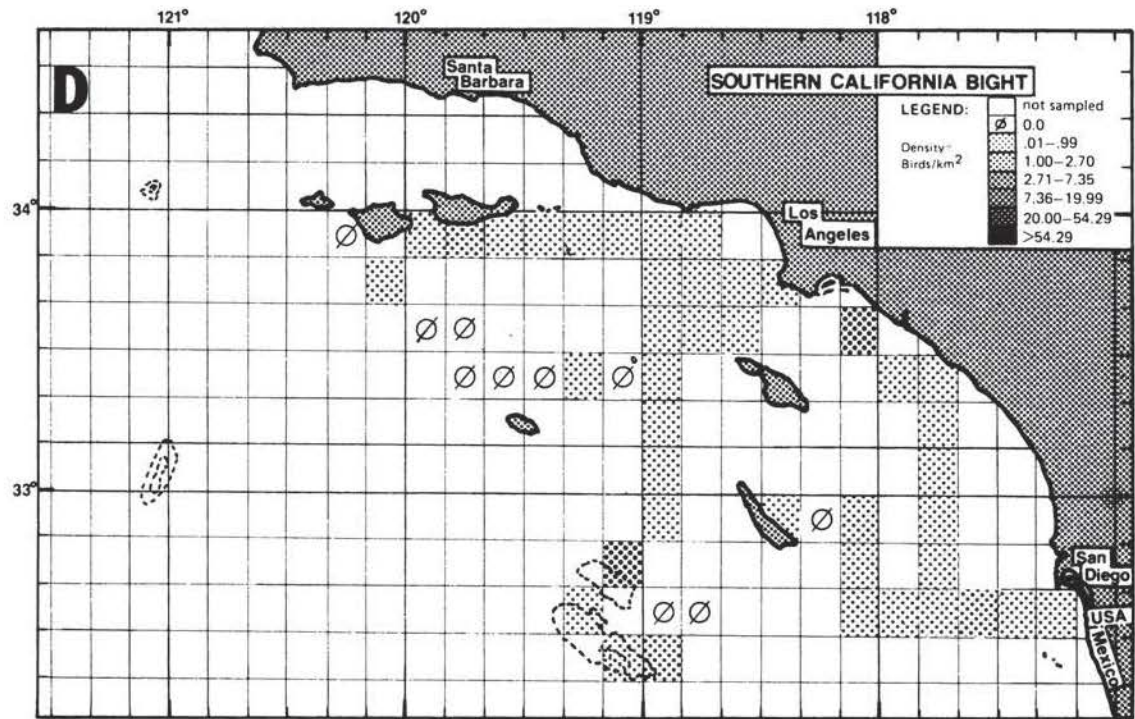
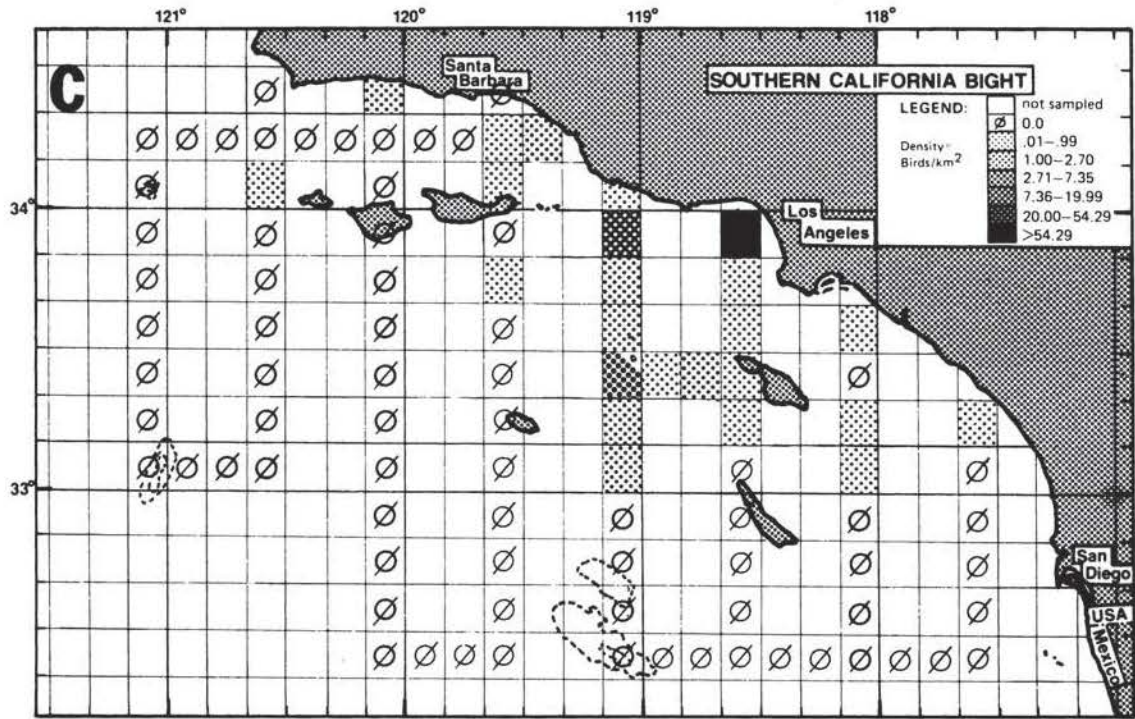


TABLE 2. Results of regression analysis of pelican density and environmental variables. Equations listed predict significant portions of variance in density ($ANOVA_{df=1,101}$; $P < 0.05$). Abbreviations as in text.

Date	Survey type	Regression equation	Multiple R
July 1975	ship	$d = 0.058 + 0.044 \text{ SLOPE}$	0.28
August 1975	ship	$d = 0.280 + 0.006 \text{ DML}$	0.31
September 1975	ship	$d = 0.831 - 0.011 \text{ DNC}$	0.31
October 1975	air	$d = 0.480 - 0.033 \text{ DNC}$	0.71
November 1975	ship	$d = -0.063 + 0.001 \text{ WD}$	0.38
January 1976	ship	$d = 0.110 - 0.031 \text{ WD}$	0.38
September 1976	air	$d = 0.792 - 0.143 \text{ DML}$	0.39
September 1976	ship	$d = 0.877 - 0.200 \text{ DML}$	0.38
October 1976	air	$d = 2.738 - 0.266 \text{ DML}$	0.31
November 1976	ship	$d = 0.780 - 0.017 \text{ DML} - 0.006 \text{ WD}$	0.34
January 1977	ship	$d = -7.393 + 0.51 \text{ WTMP}$	0.53
February 1977	ship	$d = 0.398 - 0.032 \text{ DNL} + 0.001 \text{ WD}$	0.40
July 1977	ship	$d = 0.185 - 0.011 \text{ DNC}$	0.57
September 1977	air	$d = 0.394 - 0.008 \text{ DNC}$	0.39
October 1977	air	$d = 0.496 - 0.037 \text{ DML} + 1.3 \text{ ANCH}$	0.78
November 1977	ship	$d = 0.200 - 0.003 \text{ DML} - 0.010 \text{ WD}$ $+ 0.051 \text{ SLOPE} + 0.097 \text{ WTMP}$	0.53

1) No statistically significant relationships ($ANOVA_{df=1,101}$; $P > 0.10$) were found in data sets from Dec. 1975, Aug. and Dec. 1976, Aug. 1977, and Jan. and Feb. 1978.

2) Regression analysis was not undertaken for data from April through June 1975, early Aug. 1975, Jan. through July 1976, Mar.-June 1977, or Mar. 1978 due to insufficient numbers of pelicans in the samples.

from three years of study relating pelican density to mean WTMP for the entire study area are plotted in Figure 9. The regression relationship is statistically significant, but has a large amount of scatter (high S.E. of beta). When mean WTMP and mean pelican density are arrayed along a time axis, however (Fig. 10), part of the scatter evident in Figure 9 is explained. The annual highs in pelican density at sea were attained a month later than the peak in WTMP during 1975 and 1977 and occurred just at the WTMP peak in 1976. However, the annual warm-up began in April and May each year and mean WTMP rose steadily throughout the summer. Pelican density curves, on the other hand, lagged well behind the warming curves, and numbers did not increase significantly at sea until at least mid-August. Thus, relatively few pelicans were seen as late as 1 August, despite the presence of waters with mean WTMP in the 18° to 19°C range.

Two other features of the relationships between these curves are evident. First, the autumn peak densities increased each year, as did mean WTMP, indicating a general correlation of the two. However, peak WTMP was similar in 1976 and 1977, while pelican densities were different, suggesting that mean water temperatures alone are not a good indication of the magnitude of pelican immigration from Mexican waters. Second, it appears that the annual lows in pelican density reached about the same values (0.03 to 0.08 individuals/km²) despite considerable annual variation in winter-spring water temperatures.

DISCUSSION

Our study corroborates the findings of previous workers concerning habitat usage and population structure of Brown Pelicans in the Southern California Bight. The general seasonal cycle of this species is well known for the study area, but the relatively broad temporal and spatial scope of this project enabled us to look in many places during each season and through three complete annual cycles. As a result, seasonal changes in population size and centers of concentration, and some of the environmental correlates of these features have become clear for the first time.

Brown Pelicans are found in a broader section of coastal waters in the SCB than elsewhere in their Pacific Coast range, except perhaps in the Gulf of California. We

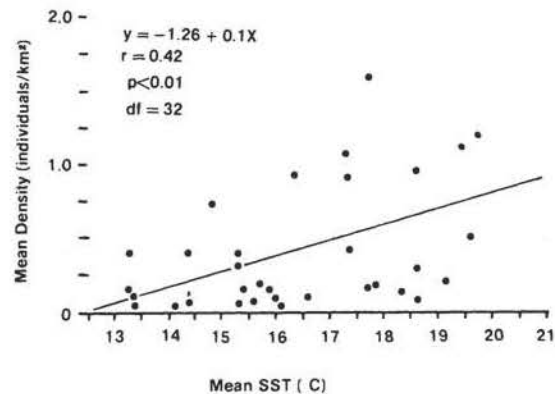


FIGURE 9. Linear regression of mean Brown Pelican density against mean monthly surface water temperature.

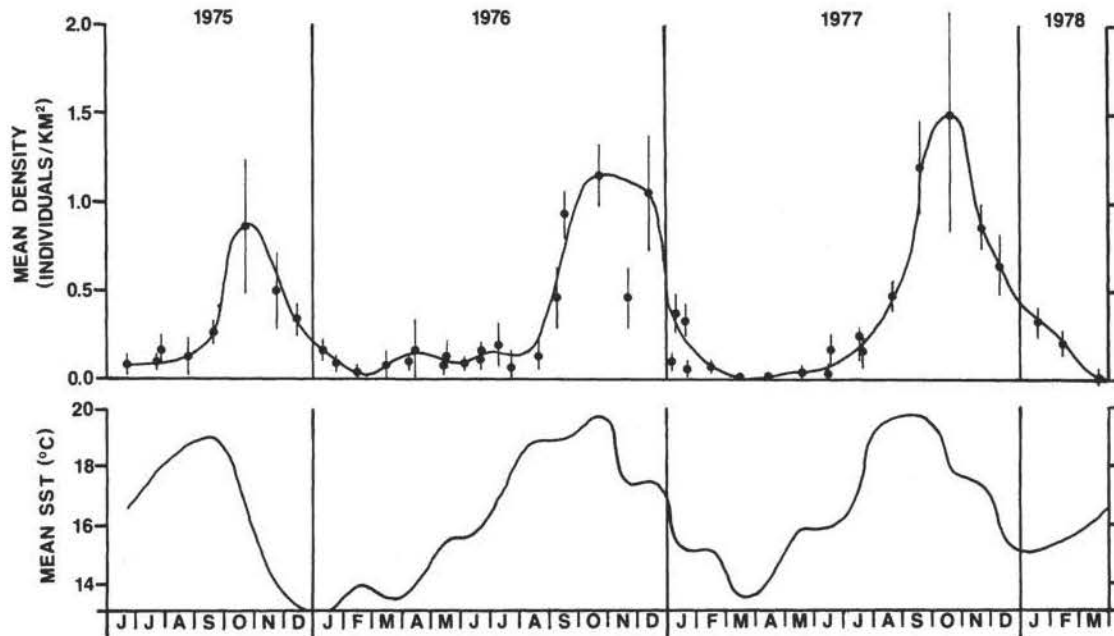


FIGURE 10. Seasonal variation in mean observed density (vertical bars indicate ± 2 S.E.) of Brown Pelicans in offshore waters of the Southern California Bight relative to mean sea surface temperature.

regularly encountered birds as far offshore as Cortés Bank during late autumn, while off central and northern California and Baja California's west coast, we have seldom encountered pelicans more than 50 km from the mainland (unpubl. notes of cruises during 1970–1978). Pelicans are coastal birds, however, and the relatively great breadth of waters inhabited in the SCB probably reflects the presence offshore of the Channel Islands and sub-sea banks and ridges.

POPULATION SIZE AND SEASONALITY

Estimated total numbers of pelicans varied from approximately 2,000 to 94,000 individuals within the SCB during the three years of study. As expected, populations were smallest and least widespread during the spring nesting season and largest and most widespread during autumn. The estimated population in October 1976 and 1977 was surprisingly large, reflecting high counts of pelicans in all habitats—particularly in open-waters.

The reliability of the population estimate was largely a function of the confidence limits associated with the open-water transect samples. Estimates of error for these transects varied in proportion to the magnitude of the mean densities (95% confidence limits averaged 30% to 50% of the mean when density exceeded 0.50 individuals/km², and 30% of the mean at lower densities). Error estimates of this order are characteristic of samples of populations that occur as flocks

or herds (Eberhardt et al. 1979). In spite of this potential for error in population estimates, numbers of pelicans migrating through the SCB clearly increased from 1975 through 1977.

The most obvious environmental variable correlating with this increase was mean sea surface temperature; estimated populations were largest during a prolonged period of environmental warming. That pelicans and other marine organisms respond to such changes in hydrographic conditions has been noted by Radovich (1961), Small (1959), and Anderson and Anderson (1976). Among pelicans in the SCB, responses correlated with the warming trend included expansion of the annual influxes of pelicans from Mexican waters and a tendency for slight increases in overwintering populations near island roosts and colony locations.

In view of the changes in colony site use during the past several decades (primarily in the northern part of the nesting range) and reports of increases in pelican visitation to the California coast during "anomalous" periods of warm water in 1957–1959, 1971, 1972–1973, and during the present study, it seems likely that alternating periods of abundance and scarcity—perhaps also of breeding range expansion and contraction—are a regular phenomenon in the life history of this and other sub-tropical pelecani-forms. Interestingly, although we found a weak but significant relationship between

estimated population size and mean WTMP, the *degree* of warming in spring and summer was found to be a poor indicator of the magnitude of the October population.

HABITAT UTILIZATION AND ENVIRONMENTAL CONDITIONS

Our data indicate that during daylight hours pelicans are numerous over open-waters more than 0.5 km from land. Through most of the year, numbers found ashore on islands and on the mainland were greatest north and west of Los Angeles, while at sea the birds were concentrated near the northern island chain, near Santa Barbara Island, and in a band extending offshore approximately 25–30 km from the mainland coast.

Of the environmental variables against which pelican density was regressed, those found to explain the greatest portions of variance were distance to the mainland, water depth, surface water temperature, and distance to the nearest nesting colony. These variables are not significantly cross-correlated with one another due to the physiographic complexity of the continental margin off southern California and because WTMP varies seasonally and independently of the other environmental features. The relatively great amounts of unexplained variance in pelican density indicated by regression analysis suggests that, 1) pelicans assort themselves at sea according to other, as yet unmeasured environmental gradients (with which the variables included here are partially correlated); 2) different segments of the population (age groups or birds from different colonies, for example) react differently to a given set of environmental conditions—leading to “scatter” within the whole population’s response to environmental gradients, or, 3) there is too much variance in density resulting from the clumped population distribution to permit attainment of high coefficients of determination (r^2) in linear regression analysis.

Although the spatial distribution of pelican density during spring was very similar to the distribution of schooling anchovies, the distributions of these two populations during autumn was similar only very infrequently. Pelicans may well take a wider variety of prey during autumn than during the nesting season, and thus be less closely linked to the distribution of anchovy schools. Alternatively, since abundance and availability of prey do not necessarily equate, pelicans may react to different “maps” of prey distribution than those we analyzed.

The variables that most frequently explained significant portions of variance in pelican density at sea were expressions of the proximity of birds to shore and the depth and temperature of the water. Although pelicans are capable of rapid, long-distance flights from their roosts and colonies, they apparently do not remain at sea overnight. Thus, although we found pelicans as far offshore as Cortés Bank by 09:00 or 10:00, it is likely that the entire population was ashore after sunset. Roosts and nesting areas are almost certainly selected to maximize the likelihood of finding food with minimum expenditure of energy in foraging, while also providing for predator-free surroundings. Though pelicans tend to concentrate at a few traditional roosts, while ignoring other locations, the variables DML and DNL provide a reasonable approximation of what may be the most important variable governing offshore distribution: distance to the nearest large roost. We did not test this hypothesis statistically, but suggest that a complex variable incorporating both roost size and distance may be found to explain more variance in pelican density than the features tested.

SUMMARY

Brown Pelicans were most abundant during autumn migration, and were least so during spring, when the population of the study area was comprised almost entirely of Anacapa Island breeders, their young of the past several seasons, and a few immigrants from Mexico. Young birds predominated along the mainland coast throughout the year but were outnumbered by adults near island shores and at sea at all times. At times of maximal abundance, pelicans were estimated to number 74,000 at sea and 20,000 along island and mainland shores (in daylight hours). The population was concentrated north and west of Los Angeles, particularly near the northern Channel Islands, near Santa Barbara Island, and from 25 to 30 km offshore of the mainland coast.

Environmental variables that accounted for significant portions of variance in pelican density distribution included distance to nearest colony, distance to the mainland, and water depth and temperature. Annual increases in estimated total populations during autumn correlated with a period of environmental warming.

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RECENT PUBLICATIONS

Bird Community Dynamics in a Ponderosa Pine Forest.—Robert C. Szaro and Russell P. Balda. 1979. *Studies in Avian Biology* No. 3, Cooper Ornithological Society. 66 p. Paper cover. \$6.00 plus \$0.50 for postage and handling. Source: Allen Press, P.O. Box 368, Lawrence, KS 66044. Studies of the relationship between vegetation and populations of breeding birds have generally investigated communities offering a variety of microhabitats. This study, by contrast, examined a pure coniferous forest (in northern Arizona). It "was undertaken to measure and evaluate 1) the effects of differing foliage volume, foliage patterns, and densities of trees on the diversity, density, and behavior patterns of the breeding birds of ponderosa pine forest, and 2) the standing crop biomass, consuming biomass, and existence energy requirements of the breeding birds on each plot." The report is aimed at avian ecologists who are interested in how birds select and use forest habitats. Diagrams, graphs, references.

The Avifauna of the South Farallon Islands, California.—David F. DeSante and David G. Ainley. 1980. *Studies in Avian Biology* No. 4, Cooper Ornithological Society. 104 p. Paper cover. Source: as above. The core of this monograph is an annotated list of the birds that have been recorded on the Farallones. It is based on a unique set of data, the daily censuses conducted over eight years by biologists at the Point Reyes Bird Observatory. These and earlier published records are summarized and analyzed to show the status of each species. "From this record, quantitative descriptions are made of the migratory periods of California coastal migrants, and of the rates of visitation by landbirds to an offshore California island . . . The breeding landbirds of the California islands are then reviewed relative to this pool of potential colonists." The report is not only an avifaunal catalog but also an important contribution to the study of the dynamics of island populations. References.