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BROWN PELICANS IN CENTRAL AND NORTHERN CALIFORNIA

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As recently as 1959, Brown Pelicans (*Pelecanus occidentalis*) nested in central California during prolonged periods of oceanic warming (Baldrige 1974, Anderson and Gress 1983). They no longer nest north of Santa Barbara Channel (Fig. 1), but after the conclusion of the nesting season in southern California and Mexico, they disperse along the coast from Point Conception to northern Washington (Ainley 1972, Baldrige 1974, Anderson and Anderson 1976). Pelicans occur at these northern latitudes (35 to 46°N) at the time of year (late summer and fall) when offshore waters are warmest, but they inhabit some sections of the coast having much cooler waters and greater wind-induced turbulence than typically are encountered near pelican colonies during the nesting season (Hickey 1979, Husby and Nelson 1982). In northern California, the combined effects of winds and intense coastal upwelling produce conditions described as unsuitable for foraging by plunge-diving seabirds such as pelicans (Ainley 1977).

In the course of a 3-year study (1980-1983) in central and northern California, we focused attention on Brown Pelican populations to provide seasonal and distributional information complementary to that available for southern California (Briggs et al. 1981). Supplementary surveys of pelicans on the coast of Oregon and in selected portions of southern California in 1980 facilitated geographic comparisons. Except for Anderson and Anderson's (1976) description of general seasonality of pelicans in California and the limited data presented by Ainley (1972) and Baldrige (1974), no historical information existed prior to our study concerning geographic, seasonal, or interannual population trends north of Point Conception.

We also attempted to determine whether certain oceanographic features correlated with the presence of Brown Pelicans at sea. Ocean temperatures and unusual wind conditions have been cited as correlates of the magnitude of post-nesting dispersal in southern California and the desert southwest (Anderson and Anderson 1976, Anderson et al. 1977, Briggs et al. 1981). Additionally, Anderson (1973) recorded food

shortages, possibly related to an intense “El Niño” event (Cushing 1981), which affected Brown Pelican nesting success in the Gulf of California. Fortuitously, our study included a period of environmental warming related to the onset of a very strong “El Niño” event in the tropics.

STUDY AREA AND METHODS

Oceanographic conditions.—The coastline from Point Conception to the California/Oregon border is relatively linear and is oriented approximately north-south (Fig. 1). The continental shelf (water depth <200 m) varies in width from about 5 to 75 km and is broadest in 3 areas: Point Conception to Point Piedras Blancas, Monterey Bay to Bodega, and north from Cape Mendocino. Significant islands and banks include the Farallon Islands, Cordell Bank (25 km northwest of the Farallones), and St. George Reef, which extends 15 km west from Crescent City. The continental slope, defined by us as encompassing depth ranges from 200 to 1999 m, comprises about 41,500 km² compared to about 20,000 km² of shelf. Farther offshore we sampled waters up to 3200 m deep (about 101,000 km²) over which flows the main axis of the California Current.

Bolin and Abbott (1963) described the hydrography of Monterey Bay in terms of 3 somewhat variable periods: the Upwelling season, the Oceanic season, and the Davidson Current season. Recent research has somewhat altered this scheme as it applies elsewhere along the central California coast. At Point Sur, it appears that winds and currents are either from the north, and therefore favorable to coastal upwelling (late winter through late summer), or they are predominantly from the south and unfavorable for upwelling (the fall-winter Davidson Current period) (L. C. Breaker, pers. comm.). North of Cape Mendocino, nearshore hydrographic conditions also appear to be “monsoonal” (Hickey 1979). In many locations the late-summer Oceanic season of Bolin and Abbott (1963), when Brown Pelicans visit the study area in maximum numbers, does not appear to be a distinct season. Rather, it marks the transition between upwelling and Davidson Current regimes when the prevalence of upwelling decreases as the strength and frequency of northwest winds diminish. At this time, relatively warm, stratified eddies of California Current water often appear at the edge of the shelf (Bernstein *et al.* 1977, Hickey 1979, L.C. Breaker, pers. comm.).

Sea surface temperatures (SST's) generally are lowest (8–11°C) in coastal upwelling centers in mid-spring and are highest (15–17°C) offshore in August through October. Our data show that during the upwelling season SST is correlated positively with distance from shore (due to upwelling) and inversely with latitude. At other times of the year, SST may be lower offshore than near the coast, and complex patterns of SST arise where warm eddies approach the coast (frequently seen off Point Buchon, southwest of Monterey Bay, off Point Arena, and sometimes off Eureka).

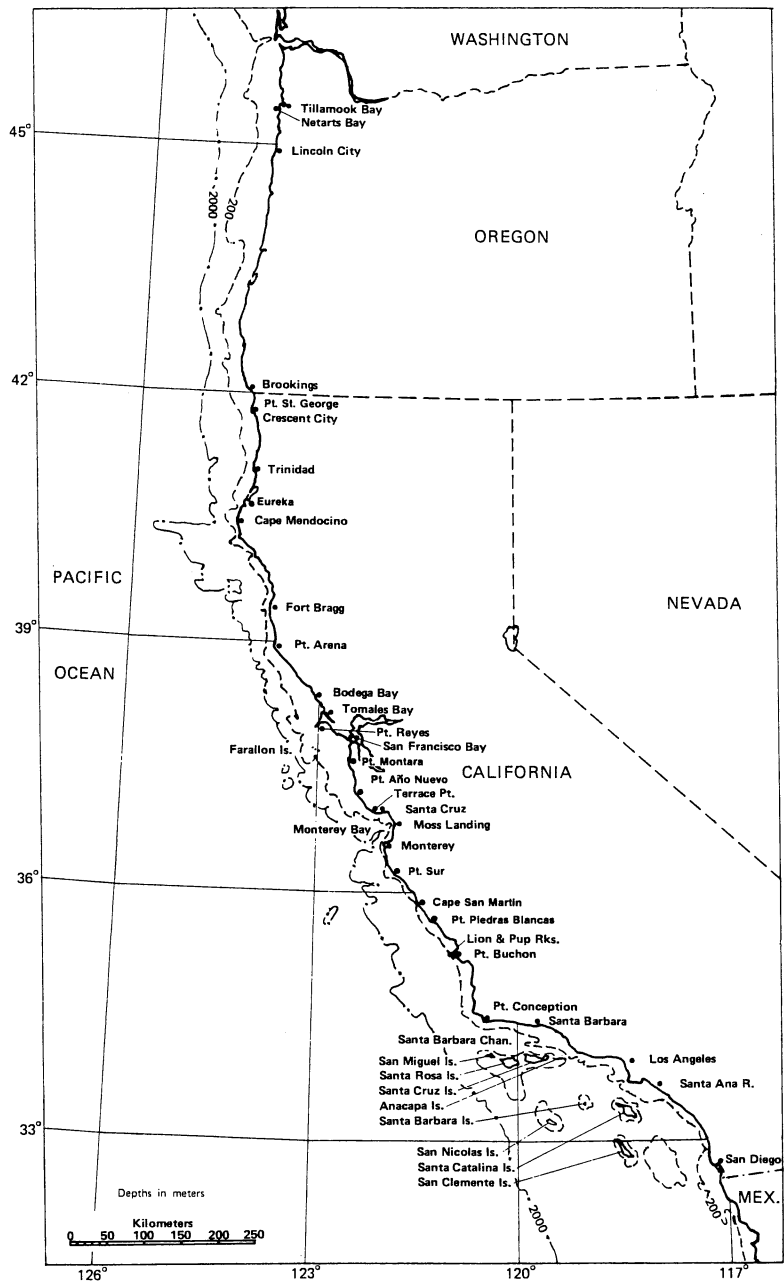


FIGURE 1. Map of California and Oregon showing general bathymetry and place names mentioned in text.

Methods.—From an airplane we censused Brown Pelicans along the coast from Santa Barbara Channel to the California-Oregon border during late January, early May, early July, and late October; each survey required 2.5 days, and included all significant offshore rocks and islands. Surveys were made on the same dates each year, except in 1981, when we made the autumn counts in late September, in order to obtain estimates of presumed maximum range and population size. Two observers simultaneously counted all birds on the shoreline and offshore to .5 km; coastal surveys were made at 100 m altitude and 185 km/h between 0930 and 1600. All counts were recorded orally on tape and all aggregations of birds exceeding about 15 individuals were photographed; these birds were counted later from projected transparencies. Gross age determinations based on plumage (Palmer 1962) were possible for about 35% of birds photographed along the coast and 20% of birds counted at sea.

The timing of breeding season and dispersal among Heermann's Gulls (*Larus heermanni*) provides a good indication of the general status and phenology of seabirds nesting in the Gulf of California (D. W. Anderson pers. comm.). Accordingly, we made coastal counts of this species to compare with the timing of dispersal among pelicans.

To assess the accuracy of our coastal counts we compared visual estimates and photo-counts of pelicans seen during 9 surveys at 264 roosts (6 to 5200 pelicans). The slope of the regression line of visual estimate versus photo-count was statistically indistinguishable from the expected 1:1; the coefficient of determination (R^2) was .92. Counts and estimates from individual sites occasionally differed by up to 50%, depending on observer fatigue, sighting angle, photographic conditions, and presence of other birds (which observers also estimated). To obtain the most accurate counts at each site, we carefully intermixed visual estimates and photo-counts. We believe the total error inherent in this method is negligible when applied to $10 \pm$ contiguous sightings over 1+ km of coastline.

On 28 October 1980, we made counts simultaneously throughout California and Oregon to locate general concentration areas of the pelican population near the expected time of their maximum range along the coast. A helicopter survey was conducted from Lincoln City, Oregon to the California border by D. H. Varoujean, while at the same time, we censused pelicans on the Channel Islands and along the southern California mainland from the U.S.-Mexico border to the Ventura River, at the eastern end of Santa Barbara Channel. Counts were made from the shore on the same date at 6 locations in California and at 2 sites in Oregon.

Hourly, all-day counts were made at Moss Landing on 10 dates during October 1980, while daily counts were made throughout summer 1981 at Año Nuevo Island. These shoreline counts provided information about age ratios and the seasonal and diurnal occupancy of large coastal roosts.

Pelican density at sea was assessed each month during low-altitude (65 m) aerial surveys along 38 to 42 transects extending west from the mainland between Santa Barbara Channel and Oregon. Lines extended 60 to 200 km offshore and were surveyed by methods described in Briggs et al. (1981). Recent field experiments suggest Brown Pelicans tend to avoid low-flying aircraft, flushing to beyond our 50 m corridor, and thus lowering our estimates of pelican density (Briggs et al. unpubl. data). Offshore coverage totalled 38,371 linear km in 1980, 41,394 km in 1981, and 40,282 km in 1982; in January 1983 we covered 3441 km. Pelican density was calculated each month for each 10' longitude transect segment visited; birds seen within 2 km of the mainland were considered part of the onshore population.

The results of similar surveys in southern California (Briggs et al. 1981) indicated a strong affinity of pelicans for shelf and slope waters. Accordingly, we expended about 40% of offshore survey effort over continental shelf waters. An additional 40% of effort sampled waters of the continental slope, and the remaining survey time was devoted to sampling California Current waters farther offshore.

During all months Brown Pelicans appeared to roost ashore each night and forage offshore during daylight hours; maximum dispersion along the coast and at sea could be expected from roughly 0900 to 1800. Our sampling of various offshore habitats was unbiased with respect to time of day; samples of waters as far as 200 km at sea occurred within 1.5 h of counts near the shoreline.

Selected environmental characteristics (e.g., depth, distance from land) were evaluated at the mid-point of each transect segment using appropriate National Ocean Survey charts. We measured SST from the air using a Barnes PRT-5 infrared radiation thermometer mounted through the aircraft's floor. Coupled to a chart recorder, the PRT provided a continuous record accurate to about $\pm 1^\circ\text{C}$. Contouring of surface isotherms and interpretation of temperature features were facilitated by comparison of our measurements with images of the coastal and offshore surface temperature fields made daily by the NOAA-6 weather satellite (made available by L. C. Breaker and R. Gilliland).

To arrive at estimates of the total pelican population in the study area at a given time, we combined shoreline counts with extrapolations of mean pelican density at sea. Open water density estimates from each major water depth stratum (0–199 m, 200–1999 m, >2000 m) were weighted according to the fractions of the total study area (162,500 km²) included within the respective strata, to yield an estimate of overall mean density. Standard errors for mean densities ranged from 30% to 100% of the mean due to flocking (clumping) of birds at sea and the narrow (50 m) corridor used for density estimates. The impact of sampling errors associated with density estimates upon extrapolated total population figures varies with the relative size of the population ashore; during late summer and autumn, when standard errors of density estimates were greatest, the numbers counted ashore comprised about

two-thirds of the combined onshore and at-sea total. Potential inaccuracy of this sort was proportionately greatest in winter and spring, when the ratio of birds ashore to birds at sea was lowest.

RESULTS

Annual cycle of visitation.—Brown Pelicans occupied the central California coast (Point Conception to about Bodega) at all times of the year. Farther to the north they were generally present from April or May through November. Pelicans were least numerous in central California in January through April, corresponding to nesting activities at colonies to the south. During coastal surveys in January 1980 and 1981, we found fewer than 50 birds, all south of Point Sur; we counted 400 in January 1982, with up to 45 birds at roosts as far north as Tomales Bay. Higher numbers of birds lingering in the area in 1982 clearly were remnants of the large influx of the previous summer (see below). We observed very few birds more than 1 km offshore during January through March, 1980–1983.

By mid-spring each year, pelicans began to occupy central California roosts in increasing numbers. In May 1980 we counted 276 birds; the population was centered from Point Conception to Point Piedras Blancas, with lower numbers from Point Sur to Bodega, and none farther north. We saw more birds (736) in May 1982, but distribution was similar. Peak spring numbers (1008) were recorded in May 1981. Over half of these birds were found from Monterey to Bodega. Pelicans were scarce in the southern region, while over 200 were counted north of Eureka. In these months, offshore sightings were restricted to waters near heavily occupied roosts.

Immigration from the south increased rapidly in early to mid-summer, following fledging of young at Mexican colonies (Anderson and Anderson 1976, Anderson *et al.* 1977). In July 1980, we counted about 4700 Brown Pelicans on central and northern California roosts, while in July 1982 the count was 7700. In both years, nearly two-thirds of the total was seen between Point Lobos (15 km southwest of Monterey) and Bodega (Figs. 1, 2). However, in 1980 most of the remainder (25%) were at southern roosts, while in 1982 over 1200 birds were found north of Cape Mendocino. In contrast, we counted almost 15,500 birds in July 1981, continuing the trend of augmented pelican numbers seen earlier in that year. At that time (July) the coastlines between Point Sal (46 km south of Point Buchon) and Point Piedras Blancas, and from Point Montara to Bodega, harbored nearly 60% of the birds. At Año Nuevo Island daily counts revealed a gradual increase from 25–30 birds in May, to 100–300 in late June, and 2500–3000 in mid-July.

The general trends in post-nesting visitation to the California coast by Heermann's Gull were similar to those we noted for pelicans (Fig. 2). Numbers of Heermann's Gulls were higher in July–September 1981 than in 1980 and 1982, and the general areas of concentration were similar to those of the pelicans. This suggests that early dispersal of

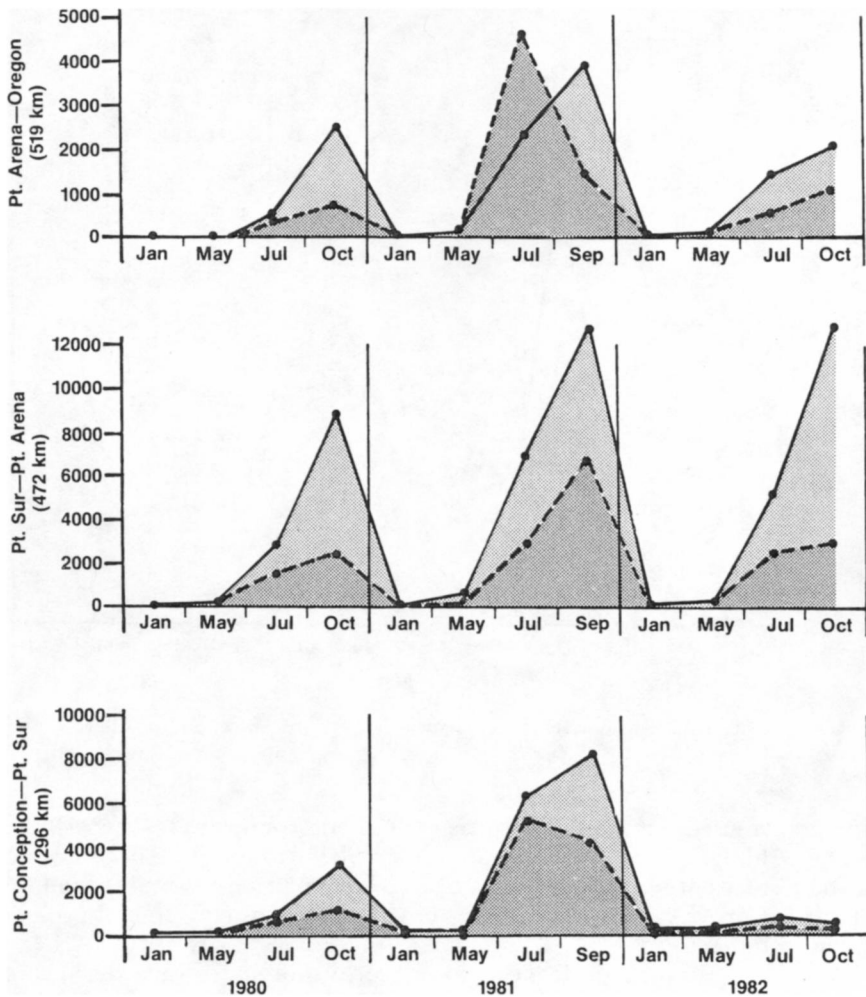


FIGURE 2. Censuses of Brown Pelicans (solid lines) and Heermann's Gulls (dashed line) along the central and northern California coast, 1980–1982.

Brown Pelicans and Heerman's Gulls was the result of widespread environmental features, generally affecting seabirds at Gulf of California colonies.

Pelican population peaks were attained in September–October each year; combined numbers ashore and at sea totalled about 23,000 in 1980 and 1982 and almost 34,000 in 1981 (Figs. 3, 4). The area from Point Lobos to Bodega consistently harbored the greatest numbers of pelicans each fall, accounting for 50% to 80% of the total estimated numbers. Numbers south of Point Piedras Blancas were highly variable,

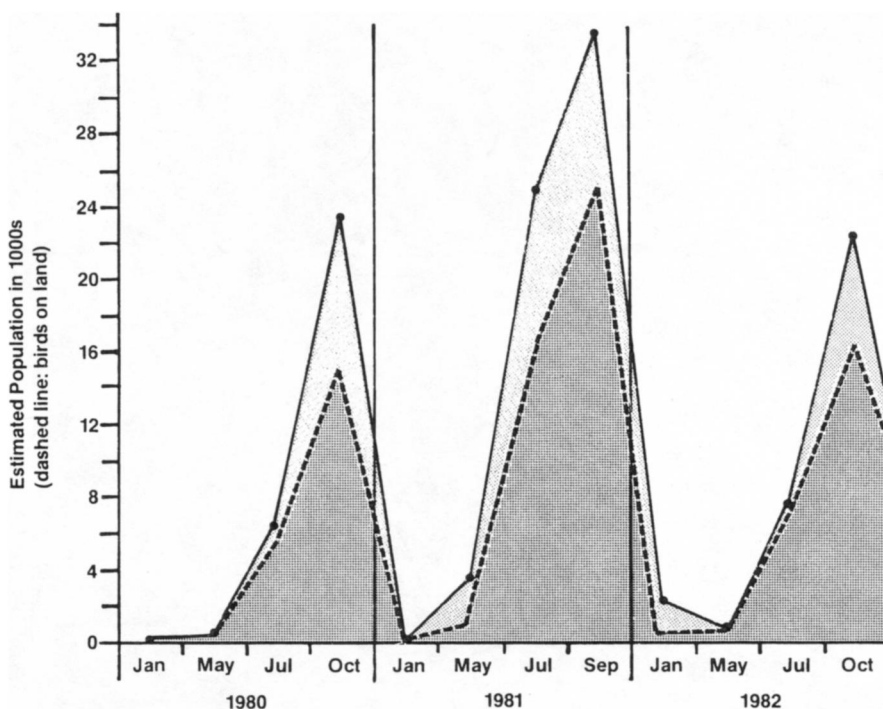


FIGURE 3. Estimated total population of Brown Pelicans in central and northern California, 1980–1982.

ranging from fewer than 500 birds (3% of the total) in October 1982 to over 7000 birds (29%) in September 1981. Counts north of Point Arena consistently accounted for about 15% of the pelicans present; the birds were far more widespread in this region during the fall, than during other seasons.

Our late autumn data do not show a consistent southward flight direction by pelicans as might be expected in a coordinated, rapid population movement, but we did record a second peak in density at sea in November or December each year. Birds were seen almost exclusively within 10 km of shore at this time which, together with dwindling numbers ashore, indicated a near-coast migration route and general lack of foraging farther offshore.

Important coastal sites.—The number of roosts occupied by Brown Pelicans varied from 10 or fewer in January to more than 150 in September–October. When pelicans were present in large numbers (July–late autumn), anywhere from 10 to 40 roosts harbored more than 100 birds each. Only a few roosts (Shell Beach Rocks, Elkhorn Slough, Año Nuevo Island, Southeast Farallon Island, Bird Island) were consistently used by more than 500 birds during daylight surveys; the middle 3 of

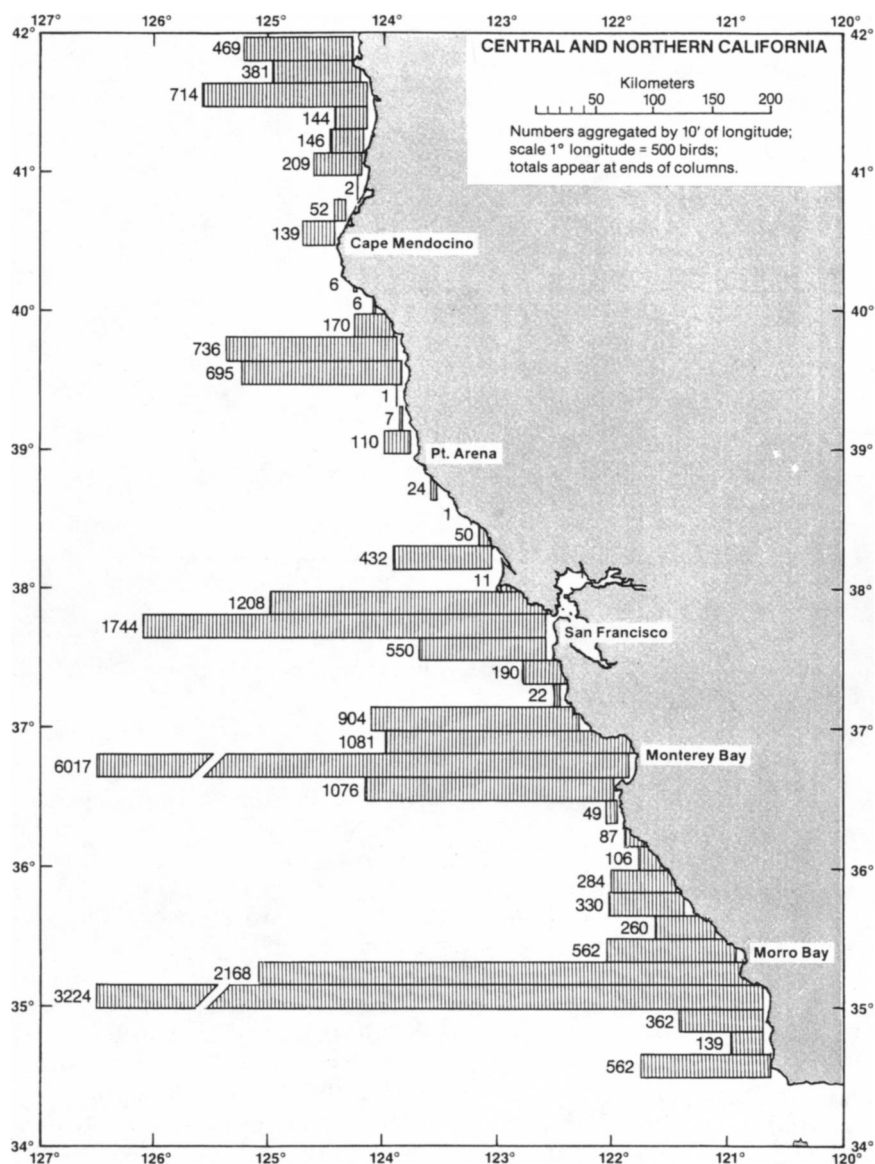


FIGURE 4. Distribution of Brown Pelicans at coastal roosts, 28–30 September 1981.

these are important nocturnal roosts that attract up to several thousand birds from surrounding areas (D.A.C. this study; A. SOWLS pers. comm.). The pattern of occupancy at these sites is illustrated by hourly counts at Moss Landing during October 1980; bird numbers were highest there

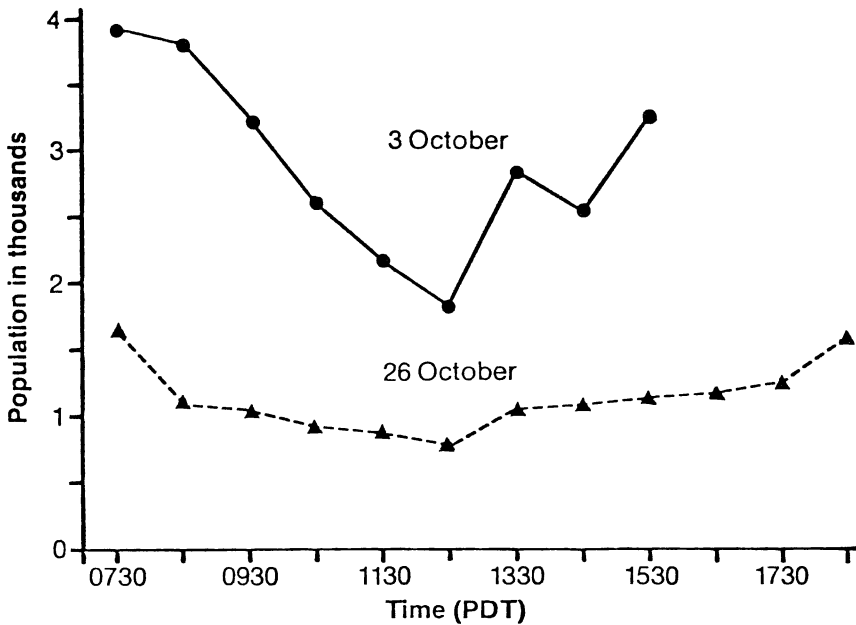


FIGURE 5. Hourly counts of Brown Pelicans at Elkhorn Slough, Monterey County, California during October, 1980.

at dawn and dusk each day (and lowest at midday—when the aerial survey was conducted) and many birds were observed arriving after sunset (Fig. 5).

The relative importance of individual roosts appeared to vary both seasonally and among years. This is illustrated by considering the principal roosts between Point Sur and Point Arena, where variability was lowest. The 10 “most important” roosts accounted for 50% to 90% (\bar{x} = 71.5%) of the pelicans present in this region during July and September/October. Early July counts in the 3 years at Double Point, Año Nuevo Island, and Bird Island, (near Double Point), varied by 310%, 300%, and 380%, respectively, while counts in late October 1980 and 1982 at the same sites varied by 160%, 305%, and 560%. Elkhorn Slough, which harbored from 2 to 425 birds and was regionally unimportant in July, varied by only 2% at about 1200 birds in October 1980 and 1982 but had almost 5300 in fall 1981. At Double Point and Bird Island, numbers in July were highest in the year (1981) when the regional population was largest, but at Año Nuevo and Elkhorn Slough numbers were highest in 1982. From a different perspective, 19 individual roosts in this region ranked among the “most important” at least once during our 3 September/October counts but only 5 of these were important during 2 fall counts, and only 3, Elkhorn Slough, Año Nuevo Island, and Southeast Farallon Island, were important every year. South of Point Sur, 23

sites harbored large numbers of birds during at least one fall count, but only one site was important each fall. North of Point Arena, no site was consistently important. Thus, with the possible exception of long time-series observations at major nocturnal roosts, single site data are of questionable value in assessing general population trends in central and northern California.

On a different scale, however, that which probably corresponds to the range of daily movements by foraging pelicans, several general patterns are discernible. In the southern region of the study area, pelicans usually frequented roosts between Point Sal and Point Piedras Blancas; on average, 75% of the pelicans south of Point Sur could be found in this stretch (data for specific roosts in Table 1). Largest numbers were found within 20 km of Point Buchon. During autumn, this high-use zone extended south to Point Conception and north to Cape San Martin.

The 2 shoreline areas of highest pelican numbers were Point Lobos to Point Año Nuevo and from Point Montara to Bodega. During July each year the most heavily used roosts were those along the shoreline of the Gulf of the Farallones; on average, these roosts comprised 43% of all pelicans noted on roosts. During autumn the Monterey Bay area and the Gulf of the Farallones were equally important; together they accounted for 50 to 80% of all pelicans present (Fig. 2, Table 1).

The 280 km coastline between Bodega and Trinidad generally harbored the fewest pelicans, averaging less than 10% of the total birds in each census. Roosts within 25 km north of Fort Bragg reached moderate levels during the fall (Table 1). In July the largest numbers of pelicans in the northern region were found from Trinidad to the Klamath River, and during autumn from Trinidad to the Oregon border.

On all coastal censuses, the age ratio was variable from location to location but averaged 2.4 adults : 1 immature. This contrasts with data from the southern California mainland, where juveniles and subadults predominate through most of the year (Briggs et al. 1981).

Occurrence at sea.—We saw Brown Pelicans offshore of all sections of the coast; their seasonal numbers and latitudinal distribution paralleled patterns of occupancy of coastal roosts. Sightings were few north of Cape Mendocino during November–July; at all times densities there were lower than we noted in shelf areas to the south. Birds occurred in most months off Bodega–Monterey and Point Piedras Blancas–Point Conception; peak densities were attained in late summer through December.

The curve of monthly mean pelican densities (>2 km from shore) is bimodal each year (Fig. 6); a late summer density peak is followed by 1–3 months of lower densities and a second peak in November to December. Except in local concentrations near major roosts, maximum mean densities south of Point Reyes, where pelicans were most numerous, were always below 1.0 birds/km².

Sightings of pelicans at sea were heavily concentrated within the first 20 km; 451 of 587 (77%) pelicans seen on offshore transects were no

TABLE 1. Counts of Brown Pelicans at 27 important roosts in California.

Site	North latitude	\bar{x}_j	$\bar{x}_{s/o}$	n > 100	n > 500	Maximum count (month)
Castle Rock	41°45'	0	207	2	0	314 (9/81)
False Klamath Rock	41°35'	1	264	1	1	657 (10/80)
Klamath River	41°32'	2	180	2	0	293 (9/81)
White Rock ¹	41°30'	101	124	3	0	396 (9/81)
Redding Rock	41°20'	92	24	2	0	155 (7/81)
Big Lagoon	41°10'	244	1	0	1	731 (7/81)
Flatiron Rock	41°03'	130	46	2	0	221 (7/82)
Soldier Frank Point	39°45'	31	150	2	0	304 (9/81)
Kibesillah Rock ¹	39°34'	0	249	1	1	674 (9/81)
Arched Rock	38°26'	276	206	5	0	430 (7/81)
Bird Rock	38°13'	526	362	3	2	1265 (7/82)
Bolinas Lagoon	37°55'	485	38	1	1	992 (7/81)
Double Point Rocks	37°50'	348	369	5	1	562 (7/81)
Bird Island	37°49'	533	145	4	1	1026 (7/81)
Southeast Farallon Island	37°41'	105	2856	2	3	3967 (10/82)
Point San Pedro	37°35'	118	311	3	1	533 (10/82)
Año Nuevo Island	37°06'	201	1148	4	1	2328 (10/82)
Elkhorn Slough	36°48'	142	2555	2	3	5288 (9/81)
Salinas River ¹	36°44'	124	25	1	0	200 (7/81)
Bird Island	36°30'	68	797	2	2	1538 (10/82)
Islay Creek ¹	35°16'	3	301	0	1	855 (9/81)
Lion Rock ¹	35°13'	150	358	4	1	743 (10/80)
Pecho Rock	35°10'	140	13	1	0	370 (7/80)
Point San Luis	35°09'	209	149	4	0	328 (9/81)
Shell Beach Rocks	35°09'	631	575	1	2	1683 (7/81)
North Pismo Beach	35°07'	167	133	1	1	500 (7/81)
South Point Sal Rocks	34°53'	94	59	2	0	170 (1/82)

¹ Includes adjacent mainland. \bar{x}_j is the average for 3 July surveys. $\bar{x}_{s/o}$ is the average for 3 September and October surveys.

n > 100 is the number of surveys with greater than 100 birds (12 total surveys).

n > 500 is the number of surveys with greater than 500 birds (12 total surveys).

more than 16 km out while only 27 birds were offshore more than 40 km. Due to the high correlation between water depth and distance from shore in central and northern California (varying from $r = .61$ to $r = .79$ among our sampled transect lines), pelican sightings also generally occurred in waters of less than 150 m depth. Birds were occasionally seen at the edge of the continental shelf and over the continental slope; single individuals were observed as far offshore as 88 km (west of Monterey) and in water depths exceeding 3100 m. The slope areas from west of Bodega to Monterey, off Point Sur, and off Point Piedras Blancas to Point Conception were the foci of offshore foraging.

Considering all offshore sightings, we most often saw pelicans during the period when SST throughout the study area was highest, but at

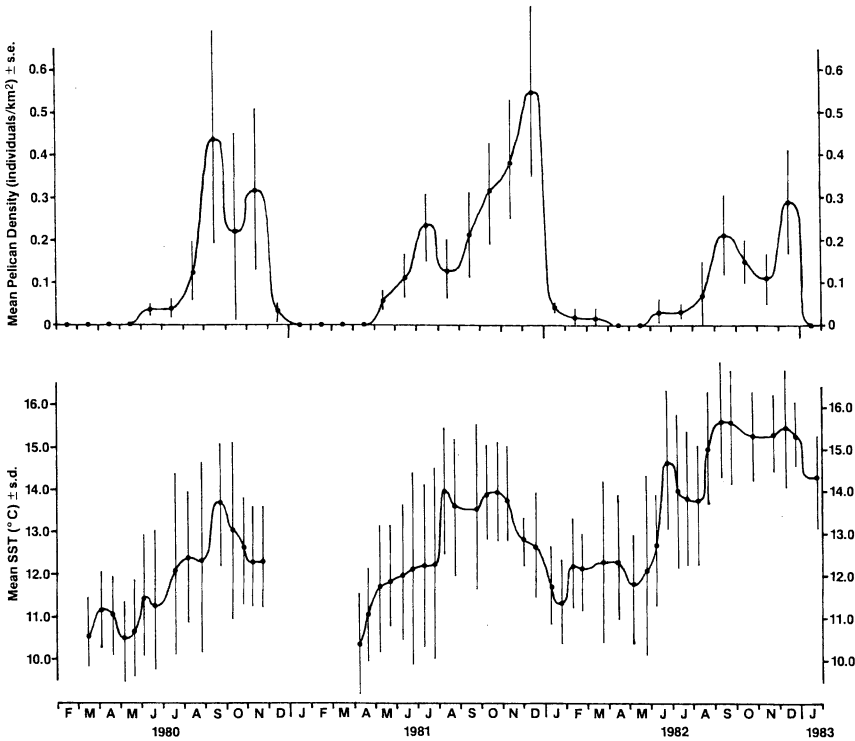


FIGURE 6. Mean pelican density over the continental shelf and slope compared to mean sea surface temperature (SST) on all transect lines sampled. Pelican data derive from monthly flights while temperature data are from the same flights and from similar marine mammal surveys. The elevated temperatures during autumn 1982–winter 1983 occurred during an “El Niño” event in the eastern tropical Pacific.

locations having relatively cool water. Within a given year, the timing of peak at-sea density correlated with the timing of peak mean SST's south of Point Reyes (Spearman rank-correlation of monthly mean bird density vs. monthly mean SST: $r_{1980} = .97$, $r_{1981} = .77$, $r_{1982} = .71$; all $P < .05$). But the magnitude of bird density was not related linearly to the magnitude of mean SST, either among months, or among locations during a given month (for all months, regression R^2 for monthly mean density vs. SST $< .08$; $P > .15$). On almost every survey, however, SST's of transects on which we observed pelicans were below the mean of all SST's in the study area. Further, during 7 surveys mean SST's from the specific locations of pelican sightings were significantly below the mean of all locations on the transects occupied by pelicans (Student's t -test, $P < .025$). We wondered if this pattern were an artifact of coastal upwelling: might we have observed pelicans over cool water while they commuted between coastal roosts and warm-water feeding areas offshore? Instead, we found that in many cases pelicans had probably com-

TABLE 2. Mean sea surface temperature (SST) within 80 km of the coast on aerial transects south of Point Reyes, compared with SST where Brown Pelicans occurred. The correlations of SST with distance from the mainland (DML) and notes on locations of pelican sightings relative to warm and cool water masses are also presented. On these seven surveys, pelicans occupied waters significantly cooler (Student's *t*-test; $P < .02$) than the mean of all SST's on occupied lines.

Month	\bar{x} SST, all locations on all lines sampled (°C)	Transect lines having pelican sightings			
		Number of occupied lines	\bar{x} SST of all locations (°C)	Correlation coefficient of SST vs DML	\bar{x} SST where pelicans seen (°C)
September 1980	15.5	6	15.3	.48	13.6
Comments: Many warm surface intrusions into cooler nearshore waters; on half the occupied lines, pelicans were found in cool water seaward of nearshore warm intrusions; most birds were seen in 12–14°C waters where SST gradients were at least moderate ($>.08^{\circ}\text{C}/\text{km}$).					
October 1980	14.6	9	14.2	.13	12.5
Comments: On all but one occupied transect, pelicans were seen in sharp SST fronts associated with cool "plumes," often with warmer, homogeneous SST's inshore.					
August 1981	14.8	6	13.7	-.06	12.1
Comments: 9 of 11 birds found in cool edges of a "plume" of upwelled water extending 100 km southwest from Point Montara and lying seaward of warmer waters in Monterey Bay.					
October 1981	15.5	6	15.3	.22	12.9
Comments: Most of 69 birds seen were off Point Montara in cool, shelf water that was contiguous with upwelling off Point Reyes, but that had complex interleaving of warmer waters. No birds were seen in the coolest waters nearshore, in warmer (16–17°C) water to the south or offshore, or in the contiguous cooler plume (10–13°C) 150 km off San Francisco.					
November 1981	16.8	5	16.5	-.05	14.1
Comments: Almost all birds seen were in edges of a warm intrusion between water upwelled near Point Montara and an extensive cool plume extending SW from Point Reyes.					
December 1981	15.8	9	15.7	.52	12.9
Comments: Almost all birds seen were in cool waters over the shelf; probably a coastal migration route.					
December 1982	15.6	11	15.3	.12	14.4
Comments: As in December 1981.					

mutated over warmer waters near the coast to forage in cooler waters farther offshore (Table 2). Pelicans were most common in areas of moderate horizontal gradients in SST ($>.08^{\circ}\text{C}/\text{km}$) bordering cool upwellings. The complex spatial interleaving of cool and warm waters within 100 km of the central California coast in July–October (Traganza *et al.* 1981, Briggs *et al.* 1983), leads to the presence of apparently suitable foraging habitat at varied distances from shore.

We observed Brown Pelicans in mixed-species feeding assemblages at various locations over the shelf and slope. A noteworthy sighting in October 1981 consisted of a concentration of pelicans in an area of 60 km diameter centered 50 km southwest of the Farallones; within this region pelicans averaged 1.12 birds/km². Feeding upon numerous shoals of baitfish, pelicans intermixed with other seabirds including phalaropes (*Phalaropus*), Buller's Shearwaters (*Puffinus bulleri*), Western Gulls (*Larus occidentalis*), Common Murres (*Uria aalge*), and Cassin's Auklets (*Ptychoramphus aleuticus*); each of these associated species exceeded 20 birds/km². This area also harbored millions of large scyphomedusae (probably *Chrysaora melanaster*), remnants of a dense bloom of "red-tide" (identified by D. Garrison as primarily *Ceratium dens*), numerous Pacific white-sided dolphins (*Lagenorhynchus obliquidens*), plus a few humpback whales (*Megaptera novaeangliae*) and killer whales (*Orcinus orca*).

In certain circumstances, we saw no pelicans more than a few km offshore, despite the presence ashore of substantial populations. Two instances are noteworthy: first, during July–October the pelicans we saw in the area from Point Arena to Cape Mendocino were very near the mainland. This area supports considerable spawning runs of night smelt (*Spirinchus starksi*) during summer; both avian and human fishermen take this fish by the tens of thousands at dusk as it enters the surf to spawn on beaches (Hart 1973, K.T.B. unpubl. obs.). Second, during December each year we saw pelicans only within 10 km of shore, generally south of Point Reyes. As mentioned earlier, this pattern suggests near-coastal, southward migration.

General abundance on the U.S. Pacific Coast.—Our October 1980 counts throughout California and Oregon provide a perspective on general areas of pelican concentration and relate the present results to data previously published for southern California. No pelicans were seen during the aerial survey of the Oregon coast on 26 October, though 2 days later 48 were seen from shore in Netart's Bay and 5 were seen in Tillamook Bay (L. Spear, pers. comm.). During 1–7 October casual censuses from the shoreline in southern Oregon revealed several hundred pelicans with peak numbers near Brookings, indicating that most birds departed Oregon waters before late October. Almost 15,000 pelicans were counted onshore in central and northern California; peak numbers appeared at Green Rock near Trinidad (650 birds; A. Sowls, pers. comm.), the Farallones (3460), Moss Landing (1201), and Lion and Pup rocks (1108). The mean density of pelicans at sea off central and northern California was $.23 \pm .23$ (SE) birds/km². In southern California we counted 10,280 pelicans on the Channel Islands; San Miguel Island was not censused due to excessive winds. These totals were near the top of the range previously reported for the islands (Briggs et al. 1981), and resulted from very high numbers at Santa Cruz and San Clemente islands (Table 3). Pelicans occurred along the coast from San Diego to the Santa Ana River in numbers (about 3.5 birds/km) similar to those reported for the years 1975 to 1978 by Briggs et al. (1981). The Los Angeles to

TABLE 3. Counts of Brown Pelicans on the California Channel Islands in late October 1980 compared with previous October censuses (Briggs et al. 1981).

Island	October 1980	October range 1975-1977
San Miguel	not surveyed	425 (1976) to 1200 (1975)
Santa Rosa	953	103 (1975) to 230 (1976)
Santa Cruz	4231	718 (1977) to 2166 (1976)
Anacapa	0	181 (1977) to 199 (1976)
San Nicolas	971	244 (1977) to 688 (1975)
Santa Barbara	738	1460 (1975) to 6362 (1977)
Santa Catalina	1368	47 (1975) to 545 (1977)
San Clemente	2019	650 (1977) to 1794 (1977)
Total (7 islands)	10,280	
Annual October totals	—	4360 (1975) to 10,595 (1977)

Santa Barbara region, where wind conditions were severe, harbored very few pelicans. Synoptic transects offshore in Santa Barbara Channel, from Santa Barbara to San Nicholas Island, and from San Clemente Island to San Diego, showed that substantial numbers of pelicans were at sea on 28 October 1980 (mean density was 2.09 birds/km² in areas within 30 km of shore and .58 birds/km² farther at sea). This paralleled the situation reported by Briggs et al. (1981) for southern California during autumn. Comparing these counts with the data available for southern California (Briggs et al. 1981), we surmise that about 83,000 to 110,000 pelicans occurred north of Mexico at this time, with 20 to 28% in central and northern California.

DISCUSSION

The results of our surveys provide the first quantitative assessment of the magnitude of Brown Pelican dispersal into central and northern California. Following a gradual build-up in numbers south of San Francisco in spring, pelicans increase in number very rapidly in June through September, dispersing northward as far as northern Oregon. Since only a few thousand pelicans nest in California, the large populations reported after the nesting season must derive mostly from Mexican colonies (Anderson and Anderson 1976, Briggs et al. 1981, Anderson and Gress 1983). Many pelicans banded as chicks on Gulf of California colonies subsequently have been reported from southern and central California during autumn (D. W. Anderson, pers. comm.).

Because of the lack of historical information with which to compare our figures, it is not yet clear how much annual variation can occur in the magnitude of northward dispersal. In addition, movements of pelicans between coastal roosts in response to changing feeding conditions compromise the usefulness of single-site data in evaluating annual

changes. Nevertheless, comparison of the peak coast-wide counts in 1980–1982 indicates that annual differences of at least 50% may occur. During the coolest autumn of our study, 22 to 28% of the estimated California population occurred north of Point Conception.

We have found that pelican populations in central and northern California peak each year at the time of peak SST's south of Point Reyes, but the magnitude of numbers offshore and of total estimated populations cannot be predicted on the basis of mean SST's. On the basis of average summer–fall temperatures, the total pelican populations were similar in the coolest year (1980) and the warmer, pre-El Niño year (1982), while numbers were highest in the year of intermediate temperatures (1981). General population trends were equally unpredictable on a regional basis. South of Point Sur, the fewest pelicans were seen in the warmest and coolest years (1982 and 1980), while the most pelicans were seen in 1981, the year with temperatures closest to the 20-year means (Auer 1981, 1982). From Point Sur to Point Arena, summer–fall temperatures were quite cool in 1980 and 1981 and were warm in 1982; pelican numbers along the coast were similar in 1981 and 1982 and were 45% higher than in 1980 (Fig. 2). These findings contrast with the situation reported by Anderson and Anderson (1976) and Briggs et al. (1981) for southern California, where general population size can be predicted from SST's. The magnitude of dispersal to central and northern California probably relates, therefore, more to previous events occurring at nesting colonies in southern California and Mexico than to proximal environmental conditions north of Point Conception.

The pelicans nesting in the Gulf of California during 1980 and 1982 experienced “normal” seasonal oceanographic and feeding conditions, raised “normal” numbers of young, and most chicks fledged during May–July: incomplete surveys in the northern Gulf during 1981 indicated very early nesting and above average numbers of nesting attempts (D. W. Anderson, pers. comm.). We assume therefore, that dispersal from Mexico was earlier in 1981 than in the other years. Enhanced numbers of pelicans south of Point Sur led to a high total for central and northern California as a whole and may have resulted both from larger numbers throughout California and from a shift in the proportion of the total population that remained in southern California. Once situated in central California, pelicans probably experienced enhanced availability of northern anchovy (*Engraulis mordax*) schools as a result of several consecutive years of increasing anchovy biomass (Stauffer and Charter 1982).

Anchovy schools migrate north to central California after late winter (Parrish et al. 1981); the tens of thousands of pelicans we saw from Point Buchon to Bodega in September 1981 probably relied substantially on these fish for food. At that time pulses of upwelling we observed at Point Arena, Point Reyes, and Point Montara (Briggs et al. 1983), may have contributed to sustaining food chains upon which anchovies depend, while alternating periods of calm winds led to the low-turbulence,

high-transparency conditions conducive to prey capture by plunge-diving pelicans (Ainley 1977). Detailed summer–fall distributional data for anchovies and other schooling fish in central California have not been published for the years of our study, so we cannot directly relate concentrations of pelicans to those of their prey. The generally high numbers of birds found from Monterey Bay to Bodega each year argue, however, that this is the area where prey abundance and availability usually are greatest.

Survival of northern anchovy larvae is strongly favored by low-turbulence conditions; spawning is heavily concentrated in southern California waters in winter–early spring. We found that pelican numbers diminished rapidly in central and northern California after mid-December, while in southern California they remain fairly abundant at sea as late as February (Briggs *et al.* 1981). Thus in winter, it is likely that pelicans find schooling (spawning) anchovies more abundant in southern California than farther north and, due to low wind-induced turbulence, much easier to detect and capture. Conversely, the lack of an equivalent, visible, shoaling bait species off central and northern California in winter (Parrish *et al.* 1981) may partially explain the seasonally-diminished Brown Pelican population along that section of coast.

Like other central and northern California seabirds, pelicans appear to respond to micro- or meso-scale habitat features (a few m to a few km). At sea, pelicans were often seen in areas of moderate or strong SST gradients ($>.08^{\circ}\text{C}/\text{km}$), especially where “plumes” of cool, upwelled water intruded into warmer, more stratified water of the California Current. We have found that these features, together with current rips and slicks, correlate with concentrations of zooplankton and planktivorous birds (shearwaters, phalaropes, some alcids; Briggs *et al.* unpubl. data). Concentration of anchovies and other pelican prey in these features seems likely. In satellite infrared imagery of SST (e.g., Parrish *et al.* 1981, Fig. 3), this type of habitat gradient often appears as a continuum of complex “scallops” and eddies over and seaward of the continental slope—the apparent outer limit of pelican foraging from mainland roosts.

In southern California, the estimated ratio of pelicans ashore to pelicans at sea during daylight hours was about 1:4 (Briggs *et al.* 1981). In contrast, we have shown that in central and northern California the ratio is usually about 3:1. Why is there such a large difference in roosting vs. foraging/flying activity between the two regions? Several possible explanations suggest why less time is spent at sea in the north. First, secondary productivity may be centered closer to pelican roosts in central and northern California than in the south, thus requiring less time for foraging flights. This phenomenon is particularly apparent with concentrations of anchovies, which are captured very close to shore in central California, both by commercial fisherman and by a variety of seabirds and marine mammals (Baltz and Morejohn 1977, Chu 1983, M. L. Bonnell, pers. comm.). Depth, upwelling, and water temperature

are much more highly correlated to distance from shore in central and northern California than in southern California (Briggs et al. 1981, Husby and Nelson 1982, this study). Second, the prevalence in northern California of storms (and of high velocity winds unrelated to storms) throughout the period of maximum pelican visitation (Husby and Nelson 1982), may lead to substantial periods when pelicans stay ashore because conditions offshore are unsuitable for foraging. Third, we found that among roosting birds in central and northern California the ratio of adults to younger birds averages 2.4:1, while Briggs et al. (1981) reported ratios of 1:8 along the southern California mainland and 4:1 on the Channel Islands. Extrapolations of these age ratios to the proportions of the population in each type of habitat indicate that in autumn young birds comprise a larger segment of the total population in southern California than in the north (September averages of 43% and 30%, respectively). If adults comprise a larger proportion of birds north of Point Conception, their greater efficiency at food gathering (Orians 1969) would lead to less time spent foraging (and thus more roosting) by the population as a whole (assuming overall similarity of food quality and availability between the regions). A fourth factor, unrelated to foraging time but which also may contribute to the relatively large number of birds seen over open water in southern California, is the interchange of non-foraging birds between island and mainland roosts. Relocations between roosts in central and northern California would be restricted to the coastal strand except near the Farallones and a small number of offshore rocks north of Eureka.

Use of coastal roosts in central and northern California appears to be highly variable; only a few sites such as Elkhorn Slough, Año Nuevo Island, and the Farallones consistently harbored hundreds or thousands of birds and served as nocturnal roosts for pelicans inhabiting larger sections of coastline. These nocturnal roosts are mostly free from human disturbances, including boat traffic, and lie close to open water areas frequented by pelicans. Elkhorn Slough is unique in that the salt evaporation pond flats occupied by pelicans lie one km inland. Tern colonies on levees there are subject to predation in summer by dogs and raccoons (unpubl. data), but because the pelican roost is situated in very flat surroundings, terrestrial predators find it difficult to approach the pelicans undetected.

Despite the presence of a relatively broad shelf north of Cape Mendocino (which correlates elsewhere with high population numbers) and an abundance of rocks throughout the region that are inaccessible to people and other terrestrial predators, relatively few pelicans roosted in the area from Point Arena to Eureka. This region is identified by Parrish et al. (1981) and Husby and Nelson (1982) as having the highest average summer wind velocity anywhere in the northeast Pacific, south of Alaska. High wind energy and concomitant offshore advection due to Ekman transport lead to strong upwelling and a deep mixed layer. These conditions militate against spawning activity by anchovies, which

spawn both to the north, off Oregon, and south of Monterey (Parrish *et al.* 1981). Additionally, highly turbulent surface waters present problems to plunge-divers who must visually locate their prey (Ainley 1977). Although this section of coast is traversed each fall by as many as several thousand pelicans, who roost on rocks north of Trinidad, few birds forage offshore here. Detailed observations may reveal whether night smelt are taken close to shore by pelicans residing in the area, or whether the birds seen here merely pass through.

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