CALIFORNIA BROWN PELICAN *PELECANUS OCCIDENTALIS* COMMUNITY SCIENCE PROJECT: POTENTIAL FOR POPULATION MONITORING

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ABSTRACT

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From 2016 to 2019, we monitored the distribution, abundance, and age structure of California Brown Pelican *Pelecanus occidentalis californicus* at nearshore communal roosts along the U.S. West Coast. This effort used "snapshot" surveys during spring and fall, simultaneously engaging up to 111 "community science" participants, i.e., volunteers, on single dates. Volunteers surveyed up to 89 sites and found as many as 22,000 Brown Pelicans. We derived abundance and population structure indices from these data and sought relationships to annual breeding season metrics and large-scale oceanographic indices in the California Current System (CCS). The proportion of immature birds increased during the study period, reflecting improved Brown Pelican productivity in the Southern California Bight after several years of low reproductive output. This increase in productivity coincided with a rise in the abundance of their primary prey, the Northern Anchovy *Engraulis mordax*. The proportion of immature Brown Pelicans observed in this survey was related to anchovy abundance. Compared to historical records, pelican distribution during fall had shifted north—consistent with climate change predictions—with a hotspot around 37°N. No single environmental driver explained the inter-annual variation in pelican abundance, which was affected by complex ecological dynamics and variable migration of pelicans from the Gulf of California, Mexico. The distribution of pelicans in the CCS suggested a coarse relationship with moderate upwelling and sea surface temperatures, in accord with habitat preferences of the anchovy, although we did not attempt to capture fine-scale predator-prey associations. Our results suggest that resuming the binational community science survey with some protocol improvements will be a valuable, inexpensive, and inclusive way to assess the general status of California Brown Pelicans. Population structure indices are likely to reflect annual variation in prey availability and pelican productivity in the CCS, while changes in total abundance will be more challenging to interpret and will require long-term datasets.

Key words: pelican, anchovy, community science, distribution, abundance, monitoring, *Pelecanus occidentalis californicus*

INTRODUCTION

Monitoring the distribution and abundance of migratory seabirds can identify critical non-breeding habitats, impacts of environmental changes, and the consequent conservation status of species. Community science efforts such as the Audubon Christmas Bird Count (CBC), Breeding Bird Atlas, and eBird have played a substantial role in monitoring avian demographics and distribution over large geographic areas (Butcher et al., 2005; Root & Schneider, 2002; Smith et al., 2017; Soykan et al., 2016; Walker & Taylor, 2020). These initiatives often offer the most comprehensive data available for coastal bird species that are underrepresented in at-sea surveys, and they frequently cover a much larger geographic area than traditional research studies (Dunn et al., 2005; Link & Sauer, 1999; Walker & Taylor, 2017). For example, CBC data have been used to assess migratory dynamics and long-term population trends of Brown Pelicans *Pelecanus occidentalis* in the California Current (Anderson & Anderson, 1976), and more recently, to analyze trends using a 34-year dataset spanning four states (Evans et al., 2023).

Brown Pelicans were among the first species to be officially listed by the United States Fish and Wildlife Service (USFWS) under the 1970 Endangered Species Act, due to declines caused by pollution. Notably, they are also one of the few species to be delisted, in 2009, following significant amelioration of pollution and a subsequent recovery across their range (USFWS, 2009a). The draft post-delisting plan for the Pacific coast subspecies *P. o. californicus*, which nests in southern California and Mexico (Anderson et al., 2013), included surveys in both the breeding and non-breeding range (USFWS, 2009b). However, the plan was not immediately implemented due to higher-priority federal initiatives. Soon after delisting, there was an extended period of low nesting effort, poor reproductive success (Anderson et al., 2017; Parker et al., 2022), and a series of unusual mortality events (Nevins et al., 2011). These events coincided with a sharp decline in the central subpopulation of Northern Anchovy *Engraulis mordax* in the California Current System (CCS; MacCall et al., 2016; Thayer et al., 2017), a primary prey for Brown Pelicans (Anderson et al., 1982; Szoboszlai et al., 2015). Another key prey species, Pacific Sardine *Sardinops sagax*, began to decline around 2006 and had collapsed by 2015, following a brief recovery from the fishery's earlier collapse in the 1950s. In the CCS, sardine populations—which historically fluctuate in opposite but complementary patterns to anchovy populations—are not expected to recover for decades (Koenigstein et al., 2022). Conservation concerns prompted the USFWS to simultaneously fund Brown Pelican breeding colony monitoring in the Southern California Bight (SCB) at Channel Islands National Park in 2016–2020 (Parker et al., 2022) and work with the West Coast Audubon network to utilize community volunteer observers to monitor Brown Pelicans elsewhere in their contiguous U.S. west coast range.

The Community Science Pelican Survey (hereafter, "CSPS") sought to determine variation in Brown Pelican distribution, abundance, and population structure by engaging volunteers to conduct simultaneous, biannual counts at designated non-breeding communal roosts across the species' U.S. range. Surveys followed a standardized online protocol and were conducted during two key seasonal periods: in May, aligning with the approximate peak of the SCB breeding season (Spring survey), and in September, coinciding with the expected peak of post-breeding dispersal (Fall survey). The California-based effort ran from 2016 to 2019 but was halted after four years due to the COVID-19 pandemic. Portland Audubon (now Bird Alliance of Oregon) continued surveys in Oregon and Washington through 2021, after which they were also discontinued. Prior to any possible re-initiation of the Pacific coast survey, we sought to summarize results from the eight surveys conducted over four years and evaluate how effectively the effort met its stated objectives: to define the distribution and abundance of Brown Pelicans and track shifts in population structure.

Breeding distribution and migratory patterns of California Brown Pelicans are well known. However, the temporal distribution within the non-breeding range has not been consistently monitored except at a few sites (e.g., Ainley, 1977). The subspecies nests primarily in Mexico, on islands in the Gulf of California and along the west coast of Baja California, as well as on the U.S. Channel Islands. In 2006, the population estimate was 196,000 birds, with 76% of the total nesting in the Gulf of California, 17% in the SCB, and the remainder in the Southern Baja Pacific (SBP; Anderson et al., 2013). Brown Pelicans from more southerly breeding subpopulations move north seasonally into productive waters in the CCS to forage on small coastal pelagic fish species, where they mix with individuals from the northernmost subpopulation (Anderson & Anderson, 1976; Briggs et al., 1983). Some Brown Pelicans range as far north as British Columbia during the non-breeding season (Shields, 2002). Inter-annual variation in ocean circulation and sea surface temperatures, such as those driven by both the warm and cold phases of El Niño Southern Oscillation (ENSO), can strongly influence the distribution and abundance of forage fishes. In turn, these fluctuations influence annual Brown Pelican breeding effort, productivity, and seasonal dispersal (Ainley, 1988; Anderson et al., 2017; Briggs et al., 1981; Capitolo et al., 2012). Away from breeding colonies, Brown Pelicans circulate between foraging areas and adjacent diurnal roosts along the coastline, frequenting a smaller number of generally larger, but dispersed, more secure traditional night roost sites (Briggs et al., 1983). Pelicans spend much of their time onshore at these roosts. Doing so provides the opportunity to collect point count data, thereby deriving an index of pelican use of a larger marine region. Brown Pelicans are long-lived and progressively attain adult plumage over three to four years (Schreiber et al., 1989). Therefore, the age structure of birds gathered at communal roosts can vary greatly. However, with adequate sample size and breadth (both spatial and temporal), age ratios collected at roosts should provide an integrated measure of meta-population structure in any given year (Schreiber & Schreiber, 1983). These data on age structure are important because they can inform the interaction between breeding success at multiple colonies and post-breeding dispersal and survival, data that are otherwise difficult to obtain. This is because breeding colony data are not routinely collated across the subspecies' entire breeding range.

Given this ecological context, we expected that changes in Brown Pelican abundance measured by the CSPS would be influenced by a combination of Pacific coast breeding population dynamics (arising from changes in the SCB and SBP subpopulations) and variable migration from the Gulf of California, Mexico. We also anticipated that age ratios could provide insights into interpreting these patterns. For example, in 2014, during the oceanographic anomaly known as "the Blob," there was an unusually early and strong migration of primarily adult pelicans into the Pacific Northwest, accompanied by a near absence of hatch-year birds in the CCS in fall, corresponding with widespread breeding failure in Mexico (Jaques, 2016). In contrast, during a productive breeding year, we would expect to see predominantly pre-breeding-age birds north of the breeding range in spring, followed by an influx of adults and hatch-year birds in the fall.

Our objectives of this paper are to (1) summarize annual and regional patterns of Brown Pelican abundance and age-ratio distributions based on CSPS data; (2) evaluate whether age-class data collected in the non-breeding range can be used as an indicator of annual breeding productivity; and (3) relate annual survey results to biological and environmental variables of the CCS that are expected to impact broad-scale variation in abundance, distribution, and age ratios.

METHODS

Study area

The CSPS extended from the Tijuana River, near the U.S.-Mexico border, north to Grays Harbor, Washington, at nearshore non-breeding sites (i.e., effort at various islands, other than the Channel Islands, was not included; see below). Sites designated for point counts were selected based on historical communal roost site maps (Jaques et al., 2008; Strong & Jaques, 2003), eBird reports, and expert input. By the end of 2019, 115 sites were incorporated into the survey, including ten inland sites at the Salton Sea (Fig. 1). For this analysis, we divided the core survey area into four coastal regions. Three were located in California—Northern, Central, and Southern—with boundaries defined at Point Conception (34.45°W) and Point Reyes (38.02°W) (following Briggs et al., 1987). The fourth region combined Oregon and southwest Washington.

Fig. 1. Locations of Brown Pelican *Pelecanus occidentalis* roost sites that were included in the community science survey (spring and fall, 2016–2019).

Data sources

Brown Pelican abundance at roost sites

The CSPS was conducted from 2016 to 2019, with surveys on single dates, twice a year—once in spring (mid-May) and once in fall (mid-September). An exception was 2016, when the fall count was conducted in mid-October. The National Audubon Society, Bird Alliance of Oregon, and USFWS Ecological Services, Ventura, California, designed the survey protocol. The National Audubon Society science branch, field offices, and local and regional Audubon Chapters (i.e., Bird Alliance of Oregon) implemented the project.

Survey methods and data-entry instructions were provided to volunteer observers via an online portal. Procedures included combining instantaneous roost site counts with continuous counts of pelicans transiting the same general area. Observers repeated counts every 15 min for one hour before sunset and recorded the highest total observed during that period. The protocol also called for observers to distinguish between active (flying) and roosting birds and to categorize pelicans as either adult or immature based on head plumage. The immature class included hatch-year and second-year pelicans. Participants either submitted hardcopy or scanned data forms, or entered data directly online using Google Forms. Bird Alliance of Oregon collated the raw data in a Microsoft Excel file. During data proofing, we discovered data entry errors in 32% of the records and missing information in many records. We corrected mathematical errors (addition) and limited analysis to the highest instantaneous count of all pelicans at the roost site regardless of activity.

The mean number of unique community science participants in the seasonal surveys was 81 (63–111) in spring and 88 (74–109) in fall. Survey coverage (the number of sites surveyed) was considered more important than the number of participants who often worked in groups. Coverage was more extensive and consistent in fall compared to spring. Fall survey coverage increased from 77 to 85 sites during 2016–2019, while spring survey coverage ranged from 41 to 89 sites (Table 1). Sites surveyed in all four years of the study comprised 17% of the total effort in the spring and 43% in the fall. Sampling efforts also varied by region. For example, 54% of all sites were surveyed each fall in Oregon-Washington, compared to 6% in northern California. Due to this variability, we attempted to normalize the data in multiple ways for data analysis (described below).

Brown Pelican colony data

Breeding effort and productivity data for colonies at the Channel Islands for 2016–2019 were provided by the National Park Service and California Institute of Environmental Studies (CIES). Pelican breeding colony data for the outer coast of Baja California, Mexico, were collected by Grupo de Ecología y Conservación de Islas (GECI; Méndez Sánchez et al., 2022). We combined the annual maximum counts of active nests on eight islands monitored by GECI with the nest count data for the two U.S. Channel Islands. Productivity (defined as chicks fledged per nest per year) data were limited to the Channel Islands because GECI did not have annual estimates of chicks fledged for one of the four years. Numbers of chicks fledged were presented as a range by CIES (see Parker et al. [2022] for data collection methodology), so we used the midpoint of the range to generate single-point productivity estimates. We combined estimated fledge totals for the two colonies (Anacapa and Santa Barbara islands).

Prey availability

We used biomass estimates of the central stock of Northern Anchovy to investigate how pelican abundance may relate to forage fish

TABLE 1
Survey coverage and mean counts for the community science Brown Pelican *Pelecanus occidentalis* (BRPE) monitoring effort, showing the total number of roost sites included versus the total number surveyed annually[a]

Region	Total no. of roosts	2016	2017	2018	2019	Total surveys (% of potential)	No. sites surveyed, all 4 years	Percent sites surveyed, all 4 years
Spring		07 May	06 May	19 May	18 May			
SCA	44	23	19	30	35	107 (61%)	8	18%
CCA	30	21	15	24	20	80 (67%)	7	23%
NCA	17	8	2	11	3	24 (17%)	1	6%
ORWA	24	11	5	24	22	62 (65%)	3	13%
TOTAL	115	63	41	89	80	273 (59%)	19	17%
Mean BRPE		63	58	71	67			
Fall		15 Oct	09 Sep	08 Sep	14 Sep			
SCA	44	31	25	32	35	123 (70%)	20	45%
CCA	30	21	22	24	24	91 (76%)	16	53%
NCA	17	11	12	3	3	29 (43%)	1	06%
ORWA	24	14	23	24	23	84 (88%)	13	54%
TOTAL	115	77	82	83	85	327 (71%)	50	43%
Mean BRPE		199	170	269	152			

[a] Regions are abbreviated as follows: SCA = Southern California; CCA = Central California; NCA = Northern California; ORWA = Oregon and Washington. Mean BRPE is the number of pelicans counted/site surveyed.

abundance. Brown Pelicans rely heavily on anchovy during the breeding season (Anderson et al., 1980; Szoboszlai et al., 2015), and distributional data of pelicans suggests that pelicans track anchovy movements year-round (Briggs et al., 1983; Jaques, 2016). The central stock of the Northern Anchovy is typically the largest and most widespread of three subpopulations in the CCS, ranging from northwestern Baja California to north of Point Reyes, California. For this analysis, we used egg and larval data collected during the winter/spring California Cooperative Oceanic Fisheries Investigations (Thayer et al., 2024). Populations of Pacific Sardine remained extremely low in the CCS during the study period (Koenigstein et al., 2022) and were therefore not considered in the analysis.

Environmental data

In addition to direct measures of Northern Anchovy abundance, we examined the relationship between pelican abundance and oceanographic indices known to influence food web dynamics in the CCS (Checkley, 2009). We used two ENSO indices: the Oceanic Niño Index (ONI) and the Multivariate El Niño Index (MEI). The ONI is derived from sea surface temperatures (SST) (Huang et al., 2017), while the MEI incorporates multiple environmental variables from the equatorial Pacific to measure the degree of ENSO conditions (Kobayashi et al., 2015). For both indices, values of +0.5 or higher indicate El Niño and values of -0.5 or lower indicate La Niña. Oceanographic data from the National Oceanographic and Atmospheric Administration (NOAA) Physical Sciences Laboratory and the NOAA National Weather Service Climate Prediction Center (NOAA, 2024a, 2024b). We calculated the average MEI and ONI values for 2–3-month periods including and surrounding each survey month.

To examine the relationship between pelican distribution and abundance along the coast to an oceanographic index that serves as a proxy for potential food web impacts at a more spatially refined scale, we used the Biologically Effective Upwelling Transport Index (BEUTI). BEUTI quantifies vertical mixing and the associated nitrate flux (Jacox et al., 2018). For each survey, (i.e., spring, April and May; fall, August and September), we used the BEUTI values from both the current and previous months, binned by 1° latitude to match the resolution of the pelican survey data (https://mjacox.com/upwelling-indices/).

Data analysis

All statistical analyses were conducted in R (R Core Team, 2020), with maps produced in ArcGIS.

Objective 1: Summarize Brown Pelican abundance and age class distribution

Because survey effort varied across years, we evaluated whether abundance index patterns based on the full data set were consistent by considering three different metrics, analyzed separately by season: (a) raw total counts, (b) total counts from the subset of roosts that were consistently surveyed each year, and (c) mean number of Brown Pelicans per site surveyed (mean BRPE), calculated for both the full dataset and the consistent subset. To estimate the percentage of immature birds, age ratio samples were summed by region and calculated as the total number of birds classified as younger than adult, divided by the total number of birds sampled in the two age categories. We used Spearman's rank correlation and Kruskal-Wallis rank tests to compare abundance and age ratios across years and between regions.

Objective 2: Evaluate whether age class data can be used as an indicator of breeding productivity in the SCB

We compared the percentage of immature (one- and two-year old) pelicans counted annually during the fall survey, by region, with the cumulative number of chicks fledged over the previous two years (i.e., the survey year and the preceding year) from the Channel Islands colonies using linear regression. To investigate the influence of prey abundance on apparent breeding productivity, we conducted simple linear regression between anchovy biomass and the annual regional proportion of immature Brown Pelicans.

Objective 3: Compare annual seasonal abundance and distribution to habitat conditions

To explore annual correlations within each season, pelican survey results were plotted using mean BRPE, along with biological and physical variables.

We further investigated potential relationships between yearly mean BRPE counts at consistently counted roosts and environmental variables (ONI, MEI, BEUTI, and SST), prey availability (anchovy biomass), and breeding effort (number of nest attempts), using the Spearman rank correlation (r). Spearman's rank correlation coefficient assesses how closely related two variables are, ranging from -1 (a perfect negative relationship) to +1 (a perfect positive relationship), with 0 indicating no correlation. Following Obilor & Amadi (2018), we classified correlations as moderate when r was between -0.40 and -0.60 or +0.4 and +0.6, and strong when r was less than -0.6 or greater than +0.6 (Obilor & Amadi, 2018). We calculated and plotted Spearman rank correlation coefficients using the *ggpairs* function in the GGally library in *R* (Schloerke et al., 2021).

For variables with only one value per survey (nests, anchovies, MEI, and ONI), we conducted simple linear regressions to assess their relationships with annual mean BRPE counts. For variables with multiple values per survey (BEUTI and SST), we used generalized additive models (GAMs) to investigate relationships between pelican abundance (raw counts) and environmental conditions, as exploratory plots indicated a non-linear relationship. GAMs were conducted using the "mgcv" package (Wood, 2017), with Restricted Maximum Likelihood (REML) smoothness estimation used in all models. To assess collinearity between BEUTI AND SST, we calculated variance inflation factors (VIFs), which quantify how much a variable's variance is inflated by its correlation with another variable. We applied a conservative threshold, considering VIF values < 3 to indicate no strong collinearity (Zuur et al., 2012). After confirming collinearity, we first ran GAMs with both BEUTI and SST, then separately for each variable. We ran all models twice to compare Poisson and negative binomial distributions. We selected the best-fitting and most parsimonious model using Akaike Information Criterion (Akaike, 1998) (Venables & Ripley, 2002), and we examined residual plots to ensure model fits.

RESULTS

Abundance and age ratio summaries (Objective 1)

Distribution and abundance by season and region

CSPS counts were relatively low in spring ($\bar{x}$ = 4,509; standard deviation [SD] = 1,700). In fall, average abundance was nearly four times greater ($\bar{x}$ = 16,121; SD = 4,234). Abundance trends across the study years were similar when analysis was limited to consistently surveyed sites (Fig. 2). The total number of pelicans was notably higher in 2018 compared to other years, in both spring and fall.

In spring, Brown Pelicans were concentrated in Southern California (Figs. 3, 4), with these sites contributing 50%–85% of the total spring count across years. Mean aggregation size was highest in Southern California, particularly at 34°N, which included the Santa Barbara Channel coastline between Point Conception and Point Mugu. Few pelicans were observed north of Point Reyes in May (range = 31–821 total birds annually). The spring count in Oregon-Washington was exceptionally high in May 2018 (712 birds).

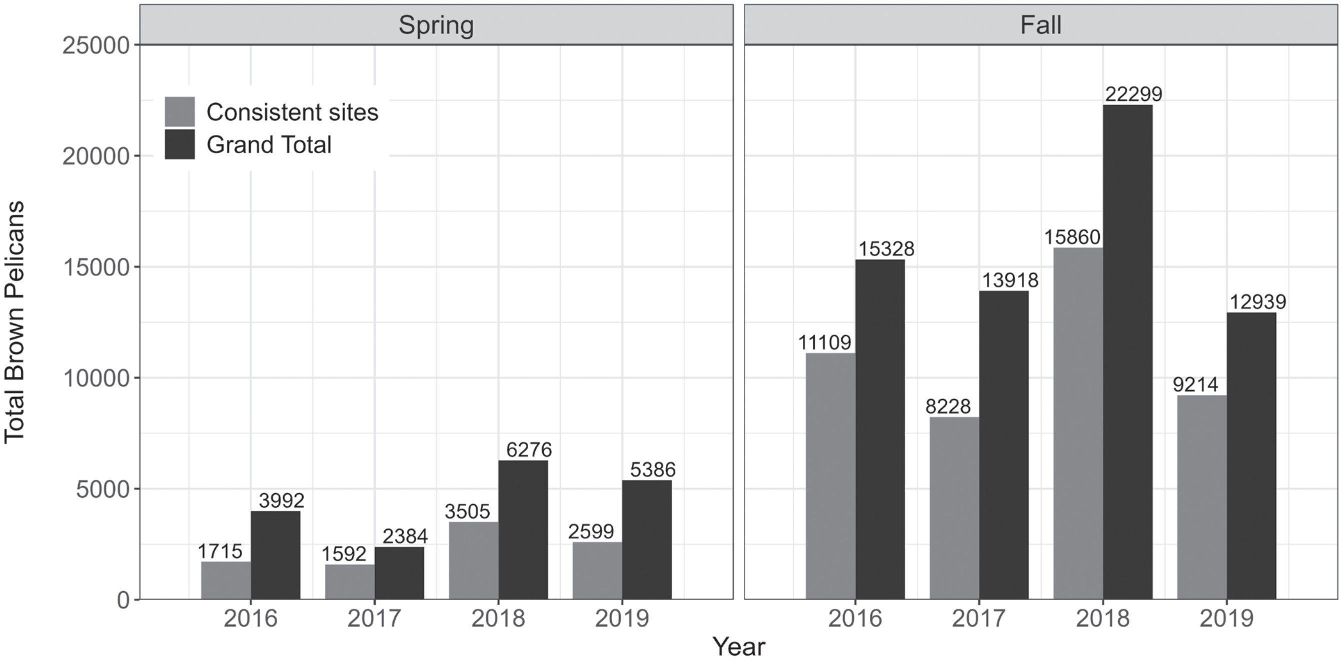

Fig. 2. Community science survey totals by year (2016–2019), shown for spring and fall. Bars represent overall total counts compared to counts from the sites that were consistently surveyed in all four years for each season. "Grand totals" include surveys at the Salton Sea, while totals for "consistent sites" do not.

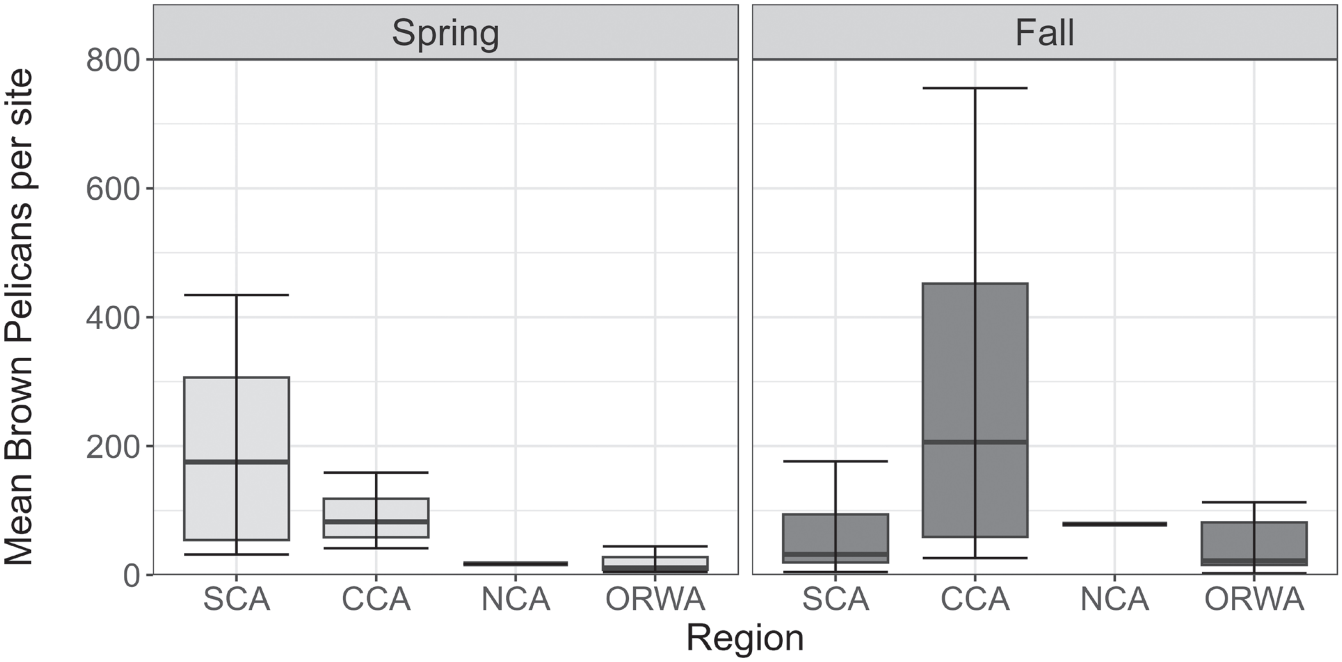

Fig. 3. Distribution of mean Brown Pelican *Pelecanus occidentalis* abundance by season and coastal region across all years (2016–2019) for sites that were consistently counted. Values represent the median, and the 1st and 3rd quartiles. Regions are ordered south to north: Southern California (SCA), Central California (CCA), Northern California (NCA), and Oregon and Washington (ORWA).

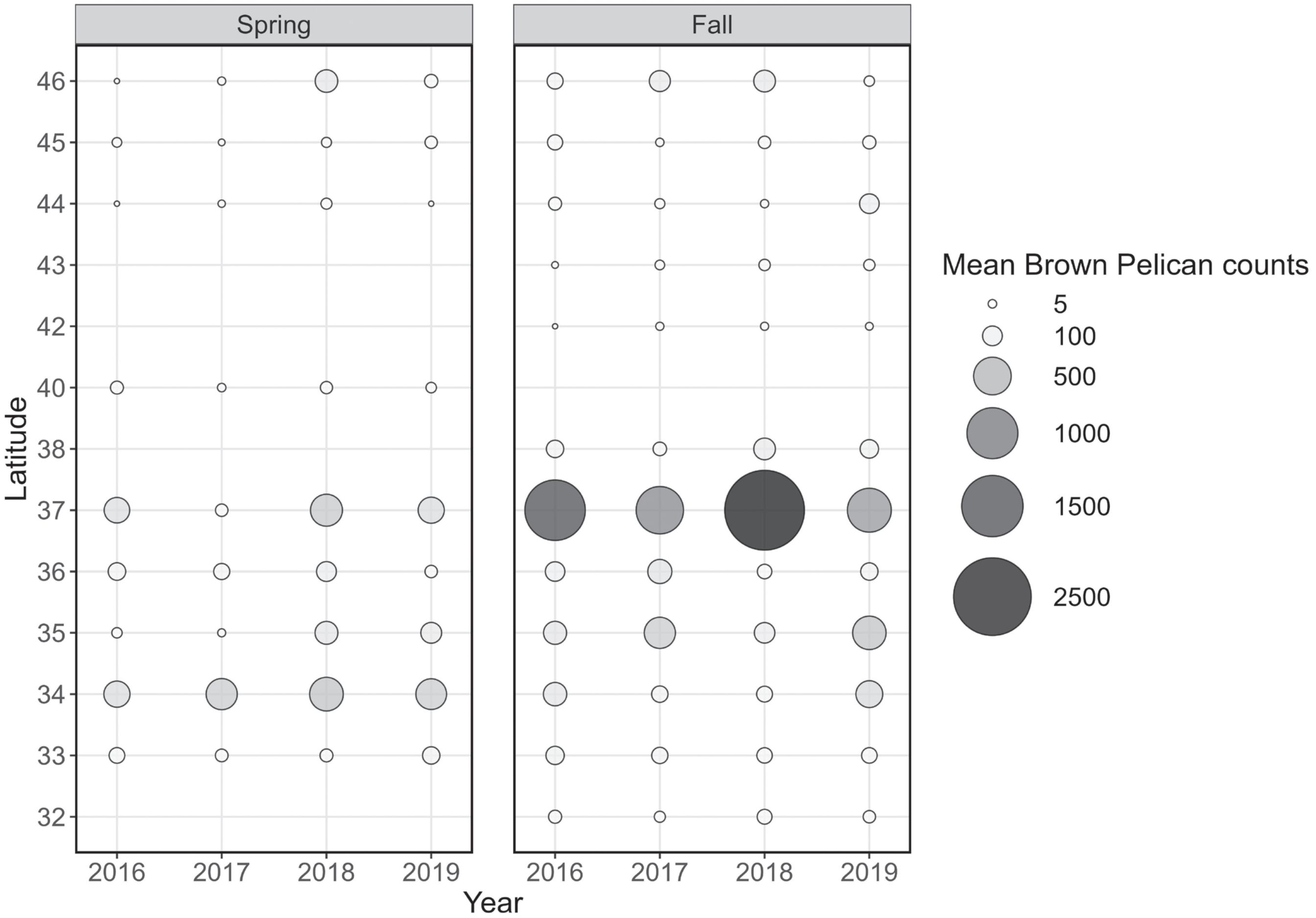

Fig. 4. The abundance of Brown Pelicans *Pelecanus occidentalis* within each season and region across latitudes using data only from sites that were surveyed in a season across all four years (excluding Salton Sea locations). Brown Pelican abundance increased at these surveyed roosts and their distribution shifted northward during fall.

In fall, the population center shifted north and abundance in Southern California was less than in spring (Figs. 3, 4). The greatest regional counts occurred in Central California, particularly at 37°N, which represents the Gulf of the Farallones coastline between Santa Cruz and Point Reyes (including San Francisco Bay). Central California sites accounted for 63%–78% of the fall totals across the years. Mean aggregation size using all data across years was nearly 500 pelicans per site in Central California compared to 55 pelicans per site in Southern California. Median values were much lower using only the consistently sampled sites (Fig. 3). Outliers included mega-roosts of > 1,000 birds at Año Nuevo Island, Pillar Point Harbor, and the Alameda Breakwater in San Francisco Bay. A night roosting aggregation of 8,086 pelicans at Alameda was responsible for 47% of the 2018 count in central California and was the highest count obtained at a single site. Oregon and Washington had the second-highest abundance of the four regions in the fall, with a peak count of 2,857 birds in 2018.

Age class composition

On average, observers were able to document the age of 77% and 72% of the pelicans counted in spring and fall, respectively. Immature birds comprised 32%–37% of the spring samples, except in 2016, when 80% were classified by age as immature (Table 2). Immatures comprised 22%–54% of the fall total counts, and the relative proportion of immature birds increased significantly over the four years (rho = 0.79, $P = .004$). There were no significant differences in age ratios across regions when data for all four years were combined ($\chi^2 = 15$, $P > .05$).

Immature proportion as proxy for productivity (Objective 2)

There was a strong positive correlation between the proportion of immature plumaged pelicans counted in the pelican survey in the fall and the estimated two-year cumulative number of chicks fledged on the Channel Islands (Fig. 5; $F_{(1,15)} = 9.38325$, $Adj.\ R^2 = 0.3438$, $P = .008$). There was also a significant relationship between the proportion of immature Brown Pelicans and anchovy biomass in the same year ($F_{(1,18)} = 4.66$, $Adj.\ R^2 = 0.21$, $P = .045$).

Brown Pelican trends with ecological conditions (Objective 3)

Our exploratory analysis found a non-significant positive correlation between spring pelican abundance and (a) the outer Pacific coast nest effort and (b) central subpopulation anchovy biomass (Fig. A1, Appendix A1, available on the website). The highest spring counts (2018) corresponded to negative ONI and MEI values (cooler, La Niña conditions). In fall, there was a weak positive correlation between pelican counts, anchovy biomass, and the fall ONI and MEI (warmer waters). The highest fall pelican counts, recorded in 2018, coincided with the greatest anchovy biomass estimate and

TABLE 2
Brown Pelican *Pelecanus occidentalis* age ratio sampling by the community science survey showing percentage of birds classified as immature, by region and year[a]

Region and season[b]	Percent immature					Number of birds aged, *n*
	2016	2017	2018	2019	$\bar{x}$	
Spring (May)						
SCA	79.2	37.6	19.1	12.2	37.0	9,173
CCA	84.1	32.0	69.9	60.7	61.7	3,727
NCA	59.5	0.0	76.0	65.6	50.3	163
ORWA	91.0	10.0	47.9	47.9	49.2	668
Total % immature	80.3	36.8	34.8	31.5		
Number aged, *n*	2,288	2,204	4,681	4,558		13,731
Fall (September[c])						
SCA	31.1	37.4	34.8	65.9	42.3	5,636
CCA	22.7	31.7	33.5	53.1	35.3	35,445
NCA	14.4	18.9	60.8	61.6	38.9	2,413
ORWA	7.3	41.8	32.6	34.8	29.1	4,289
Total % immature	22.2	32.4	34.1	54.3		
Number aged, *n*	11,710	6,321	19,605	10,157		47,793

[a] Total % immature includes the whole sample pooled.

[b] Abbreviations: Southern California (SCA), Central California (CCA), Northern California (NCA), Oregon and Washington (ORWA)

[c] In 2016, the count took place in October

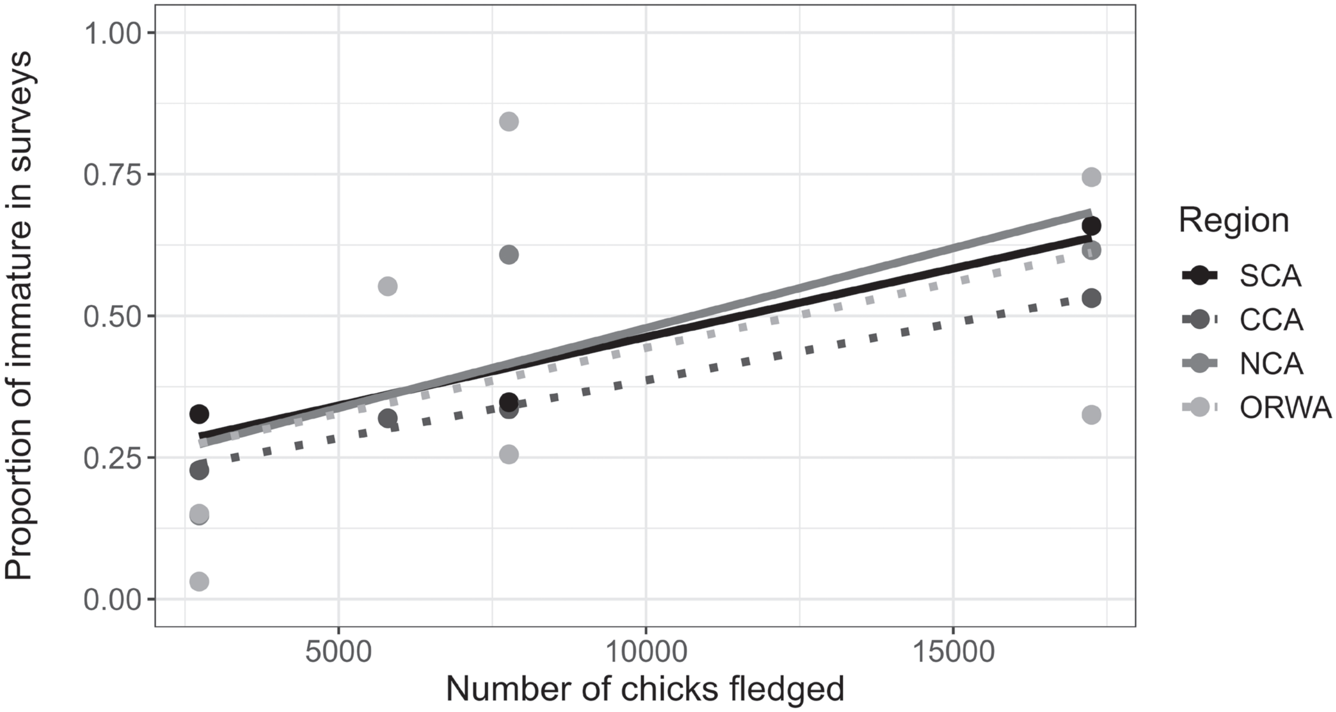

Fig. 5. Relationship between the percent of Brown Pelicans *Pelecanus occidentalis* that were aged as immature in the community science survey (all surveys included) each fall by region, and estimated number of chicks fledged from the U.S. Channel Islands, during the past two breeding seasons (i.e., the same and previous year as the survey). Regions include Southern California (SCA), Central California (CCA), Northern California (NCA), and Oregon and Washington (ORWA).

development of weak to moderate ENSO conditions. There was no apparent relationship between fall pelican abundance and the total number of nests on the outer Pacific coast during the previous spring-summer.

When data were limited to sites consistently surveyed within each season and analyzed using mean counts per site, no significant trends over time or associations with environmental variables were detected over four years of pelican surveys (Fig. 6).

Both local BEUTI and SST conditions explained some of the variability in pelican counts within the survey region during spring and fall (20.7% and 25%, respectively; Fig. 7). In spring, SST was a stronger predictor of abundance, with higher counts observed during moderate SST and low to moderate upwelling conditions (BEUTI). Upwelling conditions were a stronger predictor during fall, with higher pelican abundance corresponding to moderate BEUTI and SST. Notably, in both seasons, uncertainty was high under stronger upwelling conditions due to limited data collected at locations and times with elevated upwelling values. A similar limitation was observed for high SST during spring.

DISCUSSION

The CSPS was a wide-ranging, coordinated effort to monitor California Brown Pelicans in their non-breeding range and was conducted without public funding. This novel approach allowed simultaneous sampling across the species' range on a single day, twice a year. Prior surveys in the non-breeding range relied on aerial surveys and roost site counts and were more geographically constrained or temporally spread. In contrast, the CSPS benefited from strong volunteer participation, with up to 89 communal roost sites covered in the fall. Although the COVID-19 pandemic interrupted the program and limited the time series available for analysis, the resulting data were informative. Concurrent breeding colony monitoring in the SCB and SBP allowed for meaningful comparisons, and these colony-based monitoring efforts have continued.

The 2016–2019 surveys took place during a period of oceanographic variability characteristic of the CCS, including a strong El Nino in 2015–2016 and a mild El Nino in 2018–2019, which appeared to influence prey availability for some species (Amaya et al., 2020; Bond et al., 2015; Di Lorenzo & Mantua, 2016). A marine heat wave (MHW) in 2019 produced similar ENSO-like effects. In this context, the strong recovery of the Northern Anchovy central subpopulation was particularly notable. After a prolonged decline from 2009–2015, the population rebounded to record-high biomass estimates in 2018–2019 (Kuriyama et al., 2022; Sydemann et al., 2020; Thompson et al., 2019). In 2018, bongo tows off Southern California documented the highest abundance of larval anchovy since the mid-1960s, with central California reaching record highs in 2019 (Thompson et al., 2019).

The decline in pelican nest attempts on the Channel Islands during 2010–2015, which prompted the initiation of monitoring efforts, was followed by a resurgence in breeding efforts and success in the SCB during 2016–2020 (Parker et al., 2022). This pattern aligns with findings from previous studies linking pelican productivity to anchovy stock abundance (Anderson et al., 1980). Brown Pelican nesting effort also increased on the west coast of Baja California, Mexico, from 2014 to 2019 (Méndez Sánchez et al., 2022). In contrast, breeding colony results from the Gulf of California have not been summarized since the unusual warming period of 2014–2016, commonly referred to as "the Blob," which led to unprecedented breeding failures and possible northward range shifts by pelicans (Anderson et al., 2017).

Demographics, breeding productivity, and prey

Fall age ratio data from the CSPS tracked a consistent upward trend in chick production at the Channel Island colonies. The positive correlation between the percentage of immatures counted in the nonbreeding range and the estimated number of chicks fledged suggests that the program can effectively monitor important shifts in population structure and prey availability. In 2018 and 2019, the CSPS recorded the highest proportion of immatures, reflecting increased breeding productivity on the Channel Islands and higher biomass of the central stock of Northern Anchovy. In 2019, the number of chicks fledged per nest on the Channel Islands was exceptionally high (Parker et al., 2022). The same year, 54% of the pelicans aged during the CSPS fall survey were classified as immature compared to just 10% in 2014, a year of poor breeding associated with the low point in anchovy stock (Jaques, 2016; Sydeman et al., 2020).

Age ratios recorded in the fall reflect the productivity of the broader, mixed meta-population that congregates in the CCS. This suggests that either productivity in Mexico was also increasing during the study period, or that the signal of increased fledging success from the Channel Islands remained detectable despite potential dilution by adult birds migrating from more southerly breeding areas. The immature age ratio captured by the CSPS encompasses at least two age classes, combining recruitment from the previous two breeding seasons with the overwinter survival of second-year birds. Incorporating photographic sampling and expert analysis could refine this sampling into four distinct plumage classes, allowing identification of the hatch-year cohort and increasing the survey's precision and statistical power. Distinguishing immature plumage type could strengthen correlations between between colony productivity and the prevalence of "immatures" observed. It would also provide valuable information on annual recruitment and survival of previous-year cohorts, enabling more detailed comparisons with prey conditions.

Spatiotemporal changes and subpopulation exchange

An important finding from the CSPS was a continued northward shift in the fall distribution of pelicans within the CCS compared to historical patterns. Pelicans appear to be using the SCB less during fall, favoring more northerly areas. For example, between 1999 and 2002, Brown Pelican densities along the coastline south of Point Conception nearly doubled from May to September (Mason et al., 2007). This is opposite the seasonal trend at coastal roosts during the 2016–2019 CSPS surveys, when mean pelican counts in Southern California in September were about half those recorded in May. Earlier aerial roost surveys also documented this shift. In the fall of 1987–1992, fewer Brown Pelicans were observed in Southern California compared to similar surveys in 1975–1983, with a noticeable shift northward into the Pacific Northwest (Briggs et al., 1987; Jaques et al., 1994).

Compared to the period from 1975–1983, a decline in overall seabird density in the coastal region south of Point Mugu (34°N,

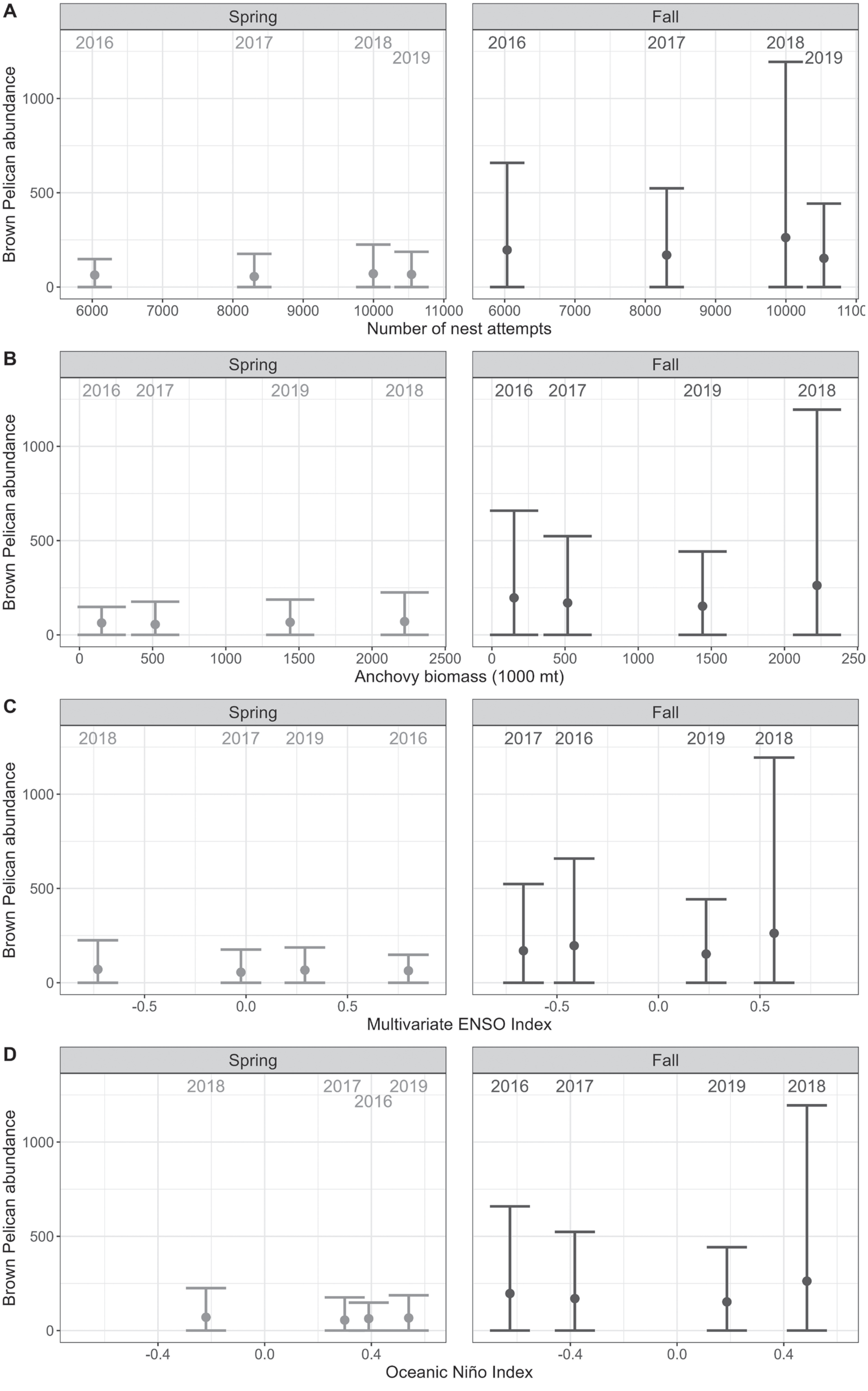

Fig. 6. Brown Pelican *Pelecanus occidentalis* counts per site (mean and standard deviation [SD]) compared with: (A) number of nest attempts in the Channel Islands, (B) anchovy biomass in the Southern California Bight, (C) Multivariate ENSO Index, and (D) Oceanic Niño Index.

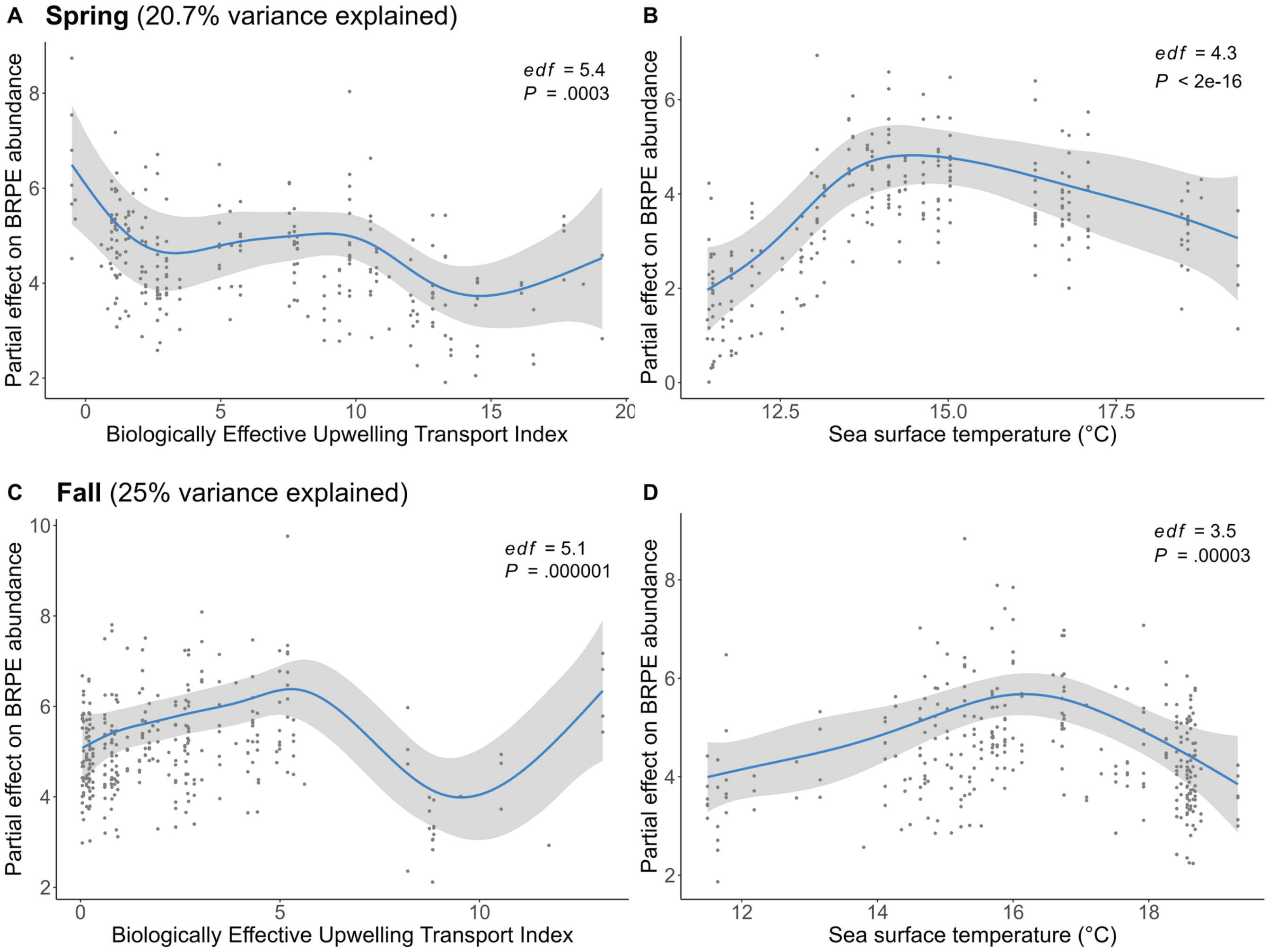

Fig. 7. Generalized additive model results showing Brown Pelican *Pelecanus occidentalis* (BRPE) using raw counts in relation to Biologically Effective Upwelling Transport Index (BEUTI) and sea surface temperature (SST), using values from the latitude nearest each site. For fall and spring, best-fit models (selected by Akaike information criterion, AIC) included both BEUTI and SST as predictors. Estimated degrees of freedom (*edf*), indicating the degree of nonlinearity, ranged from 3.5 to 5.4. Note: BEUTI plots use different scales.

-116°W) was reported by Mason et al. (2007). Northward shifts in other CCS seabirds have also been documented (Sydeman et al., 2009). Understanding how many Brown Pelicans the CCS can support in the non-breeding season, and how this baseline may be shifting temporally and geographically, has large-scale implications. Based on our data and previous studies (Sydeman et al., 2015), it is clear that prey availability plays a key role. However, the spatial distribution of roosting sites, i.e. the geographic "structure" of the population, also appears to adjust in response to interspecific competition.

Changes in both breeding and migratory phenology of Brown Pelicans have likely occurred over the last few decades, influencing seasonal abundance. Pelicans present in California from February to May have been considered part of the SCB nesting subpopulation (Briggs et al., 1981). Spring counts historically showed little variation, whereas dramatic year-to-year fluctuations in fall abundance within the CCS were attributed to variable dispersal strength from Mexico (Anderson & Anderson, 1976; Briggs et al., 1981). We suspect that our spring counts were affected by the immigration of pelicans from outside of the SCB. This suggests that birds recorded during the CSPS survey may include a substantial proportion of migrants from other subpopulations. Supporting this idea, spring abundance at consistently counted CSPS sites more than doubled between 2017 and 2018 (Fig. 2), yet pooled age ratios remained similar (Table 2). This indicates that factors other than recruitment from the 2017 SCB cohort contributed to the increased count in 2018, such as a possible surge of adults from the Gulf of California moving into the CCS in spring. Interpretation of spring counts is further complicated by reduced breeding synchrony among sites and an increasingly extended breeding period. For example, during the four-year survey, the first fledging dates at Anacapa ranged from late February (2018) to mid-June (2016) (Parker et al., 2022). As a result, hatch-year birds were likely included in the spring 2018 survey but not in the 2016 survey. Inter-annual fledge date differences, along with and long-term shifts in breeding and migratory phenology, must be considered when interpreting spring abundance data.

The eastern boundary CCS is generally highly productive, whereas the Gulf of California, Mexico, has suffered ecologically from extended periods of reduced prey availability due to anomalously warm waters and commercial overfishing (Anderson et al., 2017; Velarde & Ezcurra, 2016). As a result, annual pelican productivity can be mismatched between these regions. The status of the Gulf of California food web is of high conservation concern for this subspecies, as ~70% of the population has historically bred there (Anderson et al., 2013). To better understand population dynamics, updated, range-wide census data, along with coordinated banding and tracking studies, are needed to assess the degree of interchange among breeding colonies and the seasonal movements of non-breeders or failed breeders from other subpopulations. Collaborative efforts are currently underway to enhance research and conservation of Brown Pelicans across the U.S./Mexico border through USFWS joint venture programs and individual researcher initiatives. One of the values of the spring survey is its ability to detect anomalies in pelican abundance and age ratios that may signal adverse environmental conditions and predict potential Brown Pelican management challenges, such as those associated with widespread starvation and aggressive scavenging.

Roost site selection for the CSPS can also significantly influence overall count totals; therefore, all traditional mega roosts should be consistently monitored in future surveys. Briggs et al. (1983) found that the 10 most important roosts accounted for 50%–90% ($\bar{x}$ = 71.5%) of the aerial survey totals in Central and Northern California. In 2018, a single site—Alameda breakwater—accounted for nearly half of the total count in Central California. Annual results would have differed substantially if data for this roost had been missing or underestimated. Fortunately, observers monitored this site each year. Beyond its methodological importance, the data also highlight the ecological value of the Alameda breakwater as critical roost habitat for pelicans foraging in the Gulf of Farallones and San Francisco Bay regions. Although this analysis focused on large-scale patterns, the CSPS data offer an untapped opportunity to highlight the comparative value of individual terrestrial roost sites, their relationship to prey distribution, their role in supporting migratory connectivity, and the conservation threats to these sites. Comparisons to historical roost site data (much of which is unpublished) on a site-by-site basis could yield valuable insights.

Abundance, distribution, and habitat indices

Total abundance estimates from the CSPS did not reveal a clear Brown Pelican response to annual variation in any single environmental variable we tested. The ecological impacts of the marine heatwaves that occurred during this study, including “the Blob” (2014–2016) (Anderson et al., 2017; Bond et al., 2015; Brodeur et al., 2019), may not be fully captured by the oceanographic indices used (Ainley et al., 1995; Holbrook et al., 2019). El Niño and other warm water events during spring are typically associated with reduced nesting effort, lowered breeding success, or even failure to breed (Anderson et al., 2017). Strong events can also trigger unusually early movements of Brown Pelicans from the Gulf of California into more productive waters of the CCS (Anderson & Anderson, 1976; Briggs et al., 1983). Despite increased anchovy biomass and higher numbers of fledged pelican chicks in the CCS during 2019, total CSPS counts were lower than in 2018. This may anecdotally suggest that the weak-moderate 2018 ENSO event prompted elevated northward emigration from Mexico in the fall of that year.

Modeling seasonal pelican abundance along the coast in relation to local upwelling and SST conditions revealed stronger correlations between CSPS counts and the marine environment. Latitudinal analysis of pelican distribution (Fig. 3) indicated a preference for moderate upwelling indices and SSTs—an optimal environmental “window” (after Cury & Roy, 1989). These SST values align with the thermal preferences of spawning Northern Anchovy, which generally ranges from 12–16 °C (Kuriyama et al., 2022). While low upwelling typically leads to low marine productivity, excessive vertical transport can also be unfavorable to coastal pelagic prey such as anchovy and sardine (Cury & Roy, 1989). The strongest coastal upwelling tends to occur between latitudes 38°N and 42°N, a region that consistently attracts fewer pelicans during spring and fall. In addition to elevated SSTs overall, climate change models predict an intensification of upwelling-favorable winds within the core of the eastern boundary current systems, and shifts in seasonal phenology of oceanographic patterns, changes that are already underway (Bakun, 1990; Poloczanska et al., 2016; Sydeman et al., 2014). Although our results indicate some correlation between environmental conditions and pelican abundance, direct measurements of prey dynamics are needed to interpret these patterns. The use of total anchovy biomass across the entire CCS may be too broad a metric to accurately describe prey-pelican dynamics. In the future, collaboration between CSPS surveys and fish stock monitoring programs (e.g., CalCOFI, National Marine Fisheries Service Rockfish Recruitment and Ecosystem Assessment Surveys, etc.) is needed for finer-scale analyses. In addition, by monitoring highly visible aggregations of communal roosting pelicans and comparing them to fish stock data, Brown Pelicans could serve as indicators of seasonal shifts in near-surface coastal pelagic prey availability—patterns that may not be captured by standard fisheries surveys. Future analyses will also benefit from survey designs that more carefully consider the spatial distribution of communal roost sites used in pelican counts.

SUMMARY

Monitoring the phenology and relative distribution of migratory seabirds is a valuable tool for understanding the impacts of oceanographic perturbations, climate change, and food web dynamics (Ainely & Divoky 2001; Ford et al., 2004; Mason et al., 2007; Veit et al., 1996). CBC data, for example, have increasingly been used to test specific hypotheses about the causes and patterns of population change (Dunn et al., 2005). Based on our exploratory analysis, we suggest that CSPS data have strong potential to track broad-scale distribution patterns and population structure of Brown Pelicans along the West Coast. Despite the inherent challenges of a large-scale community science endeavor, long-term monitoring of Brown Pelican age ratios has valuable scientific and conservation insights that complement traditional colony monitoring. In addition to offering broad-scale trends, CSPS data also capture finer-scale distribution patterns. To improve future analyses, we emphasize the need for increased collaboration and data-sharing agreements between researchers in the U.S. and Mexico. This includes sharing data from breeding colonies, as well as integrating banding and tracking programs with ongoing fish assessment surveys (e.g., NMFS, CalCOFI). Coordinated efforts between community science participants and professional biologists are essential for understanding the complex dynamics of birds moving between the Gulf of California and the CCS (Anderson et al., 2017; Veit et al., 2021; Velarde et al., 2015). Establishing an ongoing binational community science pelican survey would be an invaluable, inexpensive, and inclusive way to assess Brown Pelican status and develop time series data suitable for more rigorous analysis. Moreover, the public awareness and stewardship generated through such a survey could significantly support conservation of critical roost sites, address fisheries conflicts, and advance broader marine conservation goals.

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AUTHOR CONTRIBUTIONS

DJ & TR: Conceptualization, data curation, formal analysis, visualization, writing—original draft. JL: Conceptualization, methodology, data curation, funding acquisition, project administration, supervision, writing—review & editing. AW: Conceptualization, methodology, funding acquisition, project administration, supervision, writing—review & editing. RV: Formal analysis, writing—review & editing. DO: Methodology, resources, writing—review & editing. MP, JH, & YB: Investigation, project administration, writing—review & editing. DA: Conceptualization, writing-review & editing. DM: Project administration.

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