

Point Conception and Point Arguello, 15 in the Santa Barbara Channel, and five in San Pedro Channel. Oil and gas operations are scheduled to continue on some of these platforms for more than a decade. Commercial ships, including oil tankers, pass through the area en route to and from SCB ports. Three major oil tanker and commercial ship transport lanes pass through the SCB to enter Los Angeles and Long Beach harbors, and significant tanker traffic and oil volume pass through the San Diego and Estero Bay-Avila Beach areas. Oil spills along the California, Oregon, and Washington coasts have resulted in significant losses to local seabird populations (Burger and Fry 1993, Carter 2003, USDI Fish and Wildlife Service 2005). The 1969 Santa Barbara oil spill in the northern SCB was the largest oil spill in the region and led to recognition of oil spill effects on seabirds (Carter 2003). Seabird mortality also has been documented for spills from offshore platforms, pipelines, onshore oil facilities, tankers, and military and commercial shipping (Anderson et al. 1993, Carter 2003). The region is used extensively by the military; in particular, the sea-test range of the Naval Air Systems Command covers a large portion of the southern California offshore zone. Additionally, several military bases are located along the mainland coast of southern California and on San Nicolas and San Clemente islands. Although little seabird mortality has been documented from military operations in southern California (i.e., missile and target-drone testing, low-level aircraft flights, and naval fleet maneuvers), seabirds may be disturbed during such activities (Carter et al. 2000).

METHODS

AERIAL SURVEY METHODOLOGY

Surveys were conducted from a high-winged, twin-engine Partenavia PN 68 Observer aircraft following methods developed for seabird observation by Briggs et al. (1985a, b; 1987). We flew surveys at 60 m above sea level at 160 km/hr ground speed and flew coastline (mainland and island) transects 300 m from shore. In ecologically sensitive areas (e.g., larger seabird nesting and roosting sites, and marine mammal rookery and haul-out sites), we flew 400 m from shore. Observers sat on each side of the aircraft and scanned the sea surface through bubble windows. Each observer counted and identified seabirds occurring within a 50-m strip on one side of the aircraft for a total strip width of 100 m when both observers were surveying simultaneously. At least one observer surveyed at all

times, but individual effort was discontinued when glare obscured >25% of an observer's field of view. To ensure that we maintained a strip width of 50 m, we estimated sighting angles from the aircraft to the water using clinometers. Observers rechecked sighting angles with a clinometer several times during each survey.

Seabird observations were recorded on audiotape with hand-held tape recorders (VSC-2002, Model No. 14-1158, Tandy Corporation, Fort Worth, Texas). We used tape recorders instead of recording directly to computers (see dLog program below) because they recorded more quickly, especially for mixed-bird flocks, and provided a backup to the data. For each observation we recorded: species or nearest taxon, number of individuals (i.e., exact counts for small groups and estimated numbers for groups >10 birds), time to the nearest second, behavior (e.g., flying or sitting on water), and flight direction.

Each observer transcribed data from audiotapes onto standardized data forms and entered data into the computer program SIGHT (Micro Computer Solutions, Portland, OR) which had preset data entry protocols that helped to ensure accuracy. Two people checked data entry accuracy by comparing printed SIGHT data with hand-transcribed forms.

Location for each observation and tracked survey lines were determined using a Garmin® 12 Plus global positioning system (GPS; Garmin Ltd., Olathe, KS) connected to a laptop computer that was operated by a third observer. The program dLog (R. G. Ford Consulting, Portland, OR) recorded aircraft position (waypoint) from the GPS unit every 5 sec into a log file. We chose an interval of 5 sec to allow adequate spatial coverage of the trackline (225 m is traversed every 5 sec at our survey speed of 160 km/hr) and to limit the size of data files. We synchronized observer hand watches with the computer clock twice each survey day.

Following each survey, trackline log files were plotted in the geographical information system program ArcView (Version 3.3, ESRI, Redlands, CA) and checked for GPS errors or missing trackline data. For transects with missing trackline data (e.g., from occasional computer errors or momentary loss of satellite coverage), we created transect lines based on known waypoints and constant airspeed with interpolation programs written in the SAS statistics program (SAS Institute 1999). After correcting trackline files, we calculated the position of each sighting based on observation time with the program INTERPD (R. G. Ford Consulting, Portland, OR).

TRANSECT LOCATION DESIGN

Previous studies indicated greatest densities of seabirds in southern California occurred near the northern Channel Islands which include San Miguel, Santa Rosa, Santa Cruz, and Anacapa islands (hereafter the core area; Hunt et al. 1980; H. Carter, unpubl. data). Briggs et al. (1987) flew similar survey lines in this core area, and this also was the area of greatest offshore oil development in the study area (Fig. 2). Therefore, we designed transect lines to concentrate survey effort in the core area to account for spatial variation and obtain data on local breeders during the breeding season (Fig. 3). At-sea transects in the core area were oriented predominantly north-to-south (perpendicular to bathymetric contours) and were spaced at intervals of 10' of longitude (~15 km). Outside the core area, transect lines were designed to survey the wide range of habitats and bathymetry changes throughout southern California. In order to cover

the core area were oriented east-to-west and spaced at intervals of 15' of latitude (~27 km). Whereas all at-sea and coastal transect lines within the core area were replicated each survey month, transects outside the core area were surveyed only once per survey month. We conducted the replicate survey of the core area 5-10 days after the initial survey.

SURVEY TIMING DESIGN

A total of nine aerial surveys were conducted in January, May, and September, beginning in May 1999 and ending in January 2002. Fixed transect lines were located both at sea and along all mainland and island coastlines in southern California (Fig. 3). Coastal transects included the mainland shoreline from Cambria, California (35° 35' N, 121° 07' W) to the Mexican border (32° 32' N, 117° 07' W) and the shorelines of the eight major Channel Islands. January, May, and September were selected for survey months because these months usually coincide

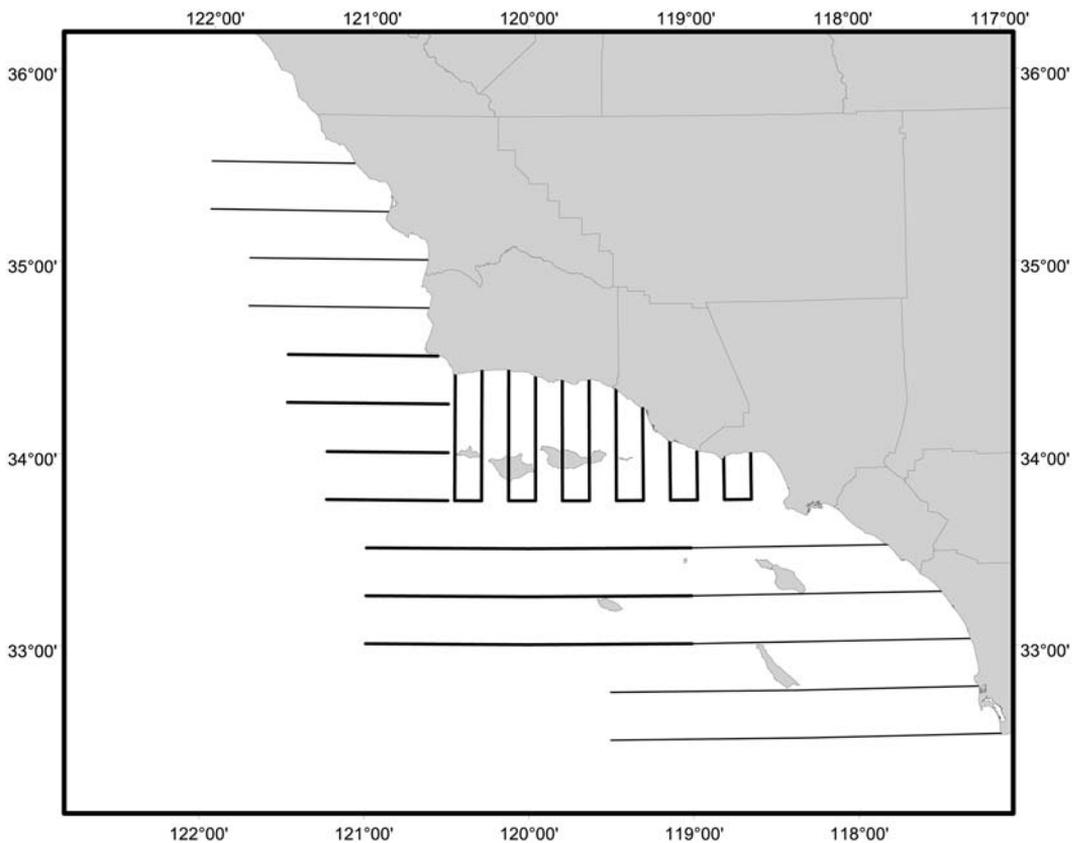


FIGURE 3. Map of central and southern California showing locations of core area and non-core area transect lines. Core area transect lines are represented by thicker lines. Non-core area transect lines are represented by thinner lines. The core area was surveyed twice each survey month from 1999-2002.

with over-wintering, breeding, and post-breeding dispersal, respectively, for many species of seabirds in southern California (K. Briggs, unpubl. data; Briggs et al. 1987; H. Carter, unpubl. data).

AT-SEA SUB-AREAS

We divided the at-sea study area into five sub-areas to facilitate comparison of our 1999–2002 and 1975–1983 data sets (Fig. 4). In general, these five sub-areas reflect major geographic regions in southern California, with differing oceanography and proximity to islands and the mainland. We also tried to make these similar in size and large enough for accurate density measurement for comparison of mean densities to each other. We positioned sub-area boundaries to bisect the distance between contiguous parallel transect lines (i.e., sub-area boundaries were equidistant from adjacent parallel transect lines). Briggs et al. (1987) surveyed farther offshore than we did; thus, we restricted statistical

comparisons to data collected only within our study area during both studies.

Sub-area 1 (S1) extended from Point Piedras Blancas to north of Point Conception and seaward 108 km. The southern boundary was along the edge of the transition zone between colder, up-welled waters of central California and the warmer waters of southern California (Chelton 1984, Lynn and Simpson 1987). This area represented the southern portion of the area surveyed by Briggs et al. (1987) in 1980–1983.

Sub-area 2 (S2) extended south from 34° 30' N to 33° 40' N and from 120° 30' W seaward to the western edge of the study area 117 km west of San Miguel Island. This area represented the offshore zone west of the northern Channel Islands. It was downstream and slightly offshore from the central California upwelling zone and was largely outside the foraging areas for most Channel Islands seabirds during the breeding season.

Sub-area 3 (S3) comprised the area surrounding the northern Channel Islands from

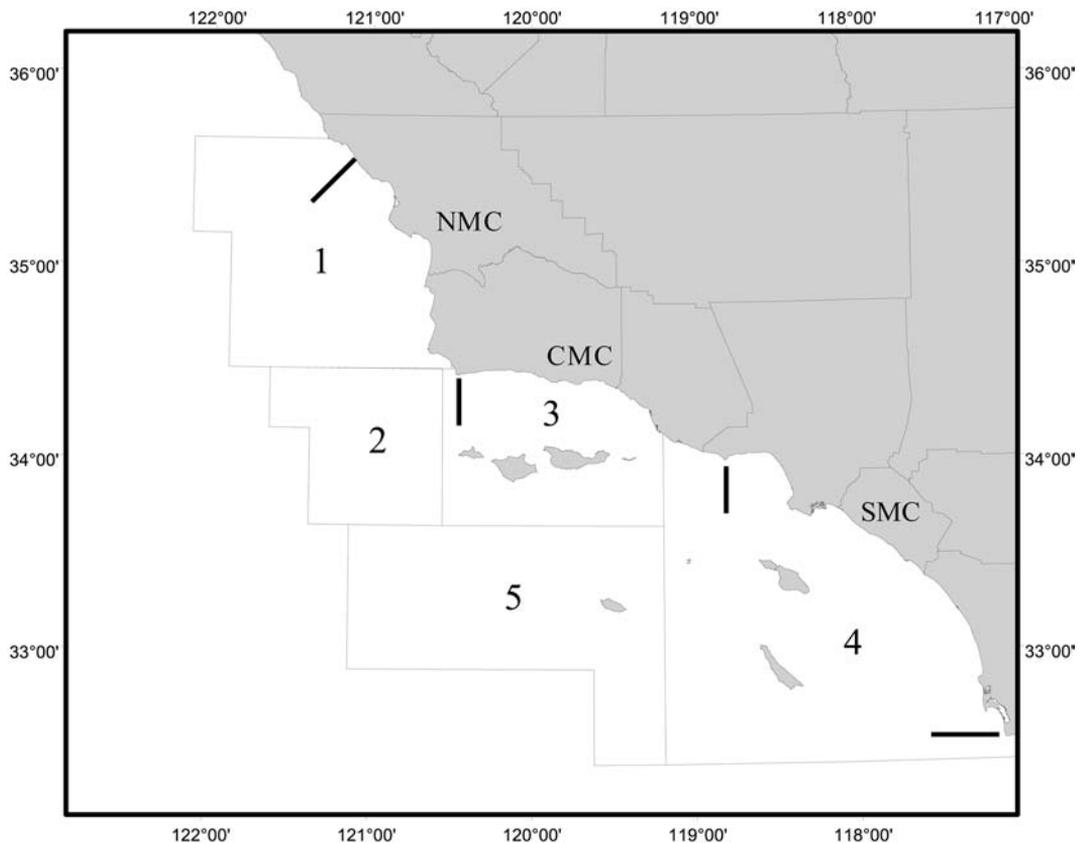


FIGURE 4. Map of central and southern California showing locations of at-sea and coastal subareas. At-sea sub-areas are numbered 1–5. Coastal sub-area boundaries are denoted by bars. NMC = northern mainland coast. CMC = central mainland coast. SMC = southern mainland coast.

Point Conception east to Point Mugu. Main ecological features of this area included the Santa Barbara Channel and the northern Channel Islands seabird-breeding habitat. Significant upwelling (Point Conception upwelling plume) from S1 becomes entrained in the western half of S3 (Denner et al. 1988, Harms and Winant 1998).

Sub-area 4 (S4) comprised the eastern SCB and was less influenced by coastal upwelling and had fewer breeding seabirds relative to S3 (H. Carter, unpubl. data). Sub-area four contained breeding and roosting habitat provided by Santa Barbara, Santa Catalina, and San Clemente islands and complex bathymetry with several deep basins and the Santa Rosa Ridge.

Sub-area 5 (S5) represented the offshore portion of the southwestern SCB and contained large expanses of open, deep ocean as well as ocean ridges and banks. The northern section of S5 was influenced by the Point Conception upwelling plume, but compared with S1, S2, and S3, waters were generally warmer, more saline, and less nutrient enriched (Harms and Winant 1998). San Nicolas Island provided breeding and roosting habitat in S5.

COASTAL SUB-AREAS

Coastal at-sea areas along the mainland and Channel Islands also were divided into five sub-areas—three mainland sub-areas and two island coastline sub-areas (Fig. 4). We created coastline sub-areas to represent biologically distinct regions and attempted to equalize transect length within each sub-area. Coastal sub-areas were not intended to match at-sea sub-areas because factors affecting abundance and distribution of avifauna on coastal and at-sea transects are known to differ for many reasons including different prey types, water masses, and use of roosting habitats (Briggs et al. 1987, Baird 1993).

Northern mainland coast (NMC) included the northern portion of the mainland coastline extending from Cambria to Point Arguello. The NMC was oceanographically similar to the central California coast and characterized by strong, upwelling-favorable winds. Coastlines are highly exposed and a mixture of rock and beach, with deep water close to shore.

Central mainland coast (CMC) included the central portion of the mainland coastline from Point Arguello to just east of Point Dume and included Point Conception, the northern Santa Barbara Channel coastline, and Mugu Lagoon. Coastlines are rocky until Santa Barbara then undergo transition to sandy beach, with a large, relatively shallow shelf off Ventura.

Southern mainland coast (SMC) included the southern portion of the mainland coastline just east of Point Dume to the Mexican border and included Santa Monica Bay, Palos Verdes, Dana Point, and Point Loma. Coastlines are mainly sandy beaches with moderate shelf.

Northern island coast (NIC) included the northern Channel Islands with mainly rocky coastlines, deep water close to shore, and large and small seabird colonies.

Southern island coast (SIC) included the southern Channel Islands (Santa Barbara, San Nicolas, Santa Catalina, and San Clemente islands). Coastlines are mainly rocky and include mainly small seabird colonies with deep water close to shore.

SPATIAL ANALYSIS METHODS

Trackline data files were used to generate point and line coverages in ArcInfo (ESRI, Redlands, CA). In order to estimate the areas surveyed for calculating seabird densities, we buffered the tracklines based upon the number of observers (50 m for one, 100 m for two). These buffered transects were then overlaid on the entire study area and divided into 1' × 1' and 5' × 5' latitude and longitude grid cells. Each transect section was labeled with a unique grid identifier. We separated strip transect data into coastal versus at-sea areas.

Observation points were then divided into these transect sections. Databases included seabird observations and the area surveyed within each grid cell at both 1' and 5' scales. These data were then analyzed with SAS programs to calculate species densities per cell. We originally collected data in geographic coordinates (NAD 27) and later re-projected data into the California Teale Albers projection to ensure accuracy of distance and area calculations. Track log GPS data collected during aerial surveys were reformatted with SAS programs to create formatted text files. We processed text files with an ArcInfo macro language program to create point and line coverages.

Seabird observations were linked to track log data, output as a dBASE file (dBASE Inc., Vestal, NY), imported into ArcView, and converted to shape files. We intersected shape files with buffered strips to transfer grid identifiers to points. These data were exported as dBASE files and analyzed with SAS programs to calculate densities.

STATISTICAL ANALYSES

Seabird distribution was examined hierarchically at three taxonomic levels: species, families,

and all seabirds grouped together. Occasionally seabirds could be identified only to family or, very infrequently, only as unidentified species. The latter were excluded from species-specific analyses, but were used in the broader taxon groupings.

We analyzed at-sea and coastal-transect data separately and included both flying and non-flying birds in analyses. Unlike shipboard surveys, densities of flying birds were not corrected for the effect of flight direction (Spear and Ainley 1997). Because of the greater relative speed of the survey aircraft compared with flying seabirds, we assumed error in density calculations of flying birds to be negligible. We assessed differences among seasons (January, May, and September) and sub-areas. We compared our at-sea transect data with similar aerial-survey data collected in 1975–1978 throughout the SCB and in 1980–1983 off central California (Briggs et al. 1987). We were unable to compare coastal transect data because Briggs et al. (1987) did not conduct aerial coastal transects.

For the analysis of at-sea-transect data, mean densities and standard errors were calculated for each species separately for sub-area and season. Mean densities across grids were weighted by survey area within each grid. We estimated standard errors by the Taylor expansion method used in the SURVEYMEANS procedure in SAS. We used generalized linear mixed models (GLMM) to model species counts within grids (Poisson distribution) with means proportional to the area of buffered transect (offset variable; McCullagh and Nelder 1989) that varied according to sub-area, season, year, and replicate. Replicate variation was measured by comparing the two replicates of the survey route flown within the same month and year. We assessed effects of sub-area and season on densities and controlled for variation between replicates and years by including replicate and year as random effect variables in models.

We restricted the GLMM to test for differences in densities only for those sub-areas and seasons in which species were observed. For sub-areas or seasons in which a species was not observed, density and standard error were zero. In this case, one of two possibilities occurred: (1) the entire season or sub-area contained no individuals of a particular species causing season or sub-area to be significantly different from any other season or sub-area in which the species was observed at least once, or (2) the species was present but too rare to be observed with our survey techniques and effort. Because we had insufficient data for the GLMM to distinguish between these two alternatives, we simply identified sub-areas and seasons that

did not have observations and excluded these categories from statistical analysis.

For similar reasons, we occasionally restricted the GLMM to exclude the replicate random effect when no observations occurred for one of the replicates. Conversely, for species with suitably large densities, sufficient data were available to test for presence of sub-area and season interactions. All tests for sub-area, season, and interaction effects were conducted with F-statistics and considered to be statistically significant at the 0.05 alpha error level.

COMPARISONS TO PAST DENSITY ESTIMATES

We obtained data for Briggs et al. (1987) from (M. Bonnell, unpubl. data). Aerial survey data were collected in the SCB from 1975–1978 that corresponded to our areas S2–S5. Aerial survey data were also collected off central and northern California in 1980–1983 that corresponded to our area S1. We assigned observations from Briggs et al. (1987) to sub-areas based on latitude and longitude associated with each observation. To compare at-sea densities of seabirds between the two studies, we used Briggs et al. (1987) data that bracketed the months of our survey (i.e., observations from the December, January, and February 1975–1983 surveys were compared to our January observations; April, May, and June 1975–1983 were compared to May; and August, September, and October 1975–1983 were compared to September). We did this to account for variation in the timing of seasonal species density peaks in 1975–1983 and to ensure that, if Briggs et al. (1987) did not survey in January, May, or September in a particular year, that we could obtain data from a similar time of year. Unlike Briggs et al. (1987), we chose not to extrapolate at-sea densities to generate at-sea population estimates. Meaningful comparison of such estimates between surveys would be difficult because of the variation around estimates.

We excluded any random effects that were found to be insignificant sources of variation in the analysis of the 1999–2002 survey. If all random effects are removed from a GLMM, then the model simplifies into a generalized linear model (GLM). We used either the GLMM or GLM, depending on whether any random effects were present, to test differences in density between the 1975–1983 and 1999–2002 survey periods. We created a classification variable for both survey periods, which was included in the GLMM or GLM to test effects of period on density.

We compared survey periods separately for the five at-sea sub-areas. This allowed us to estimate period effects that might vary geographically without requiring sub-area to be a factor in

the model. This also allowed us to avoid potential model convergence difficulties that might result from complex interaction terms, such as a three-way season by sub-area by period interaction. We retained season as a factor in the model and allowed a season and period interaction term whenever sufficient data existed to test it. We estimated the period effect across the entire sub-area by repeating the analysis using data pooled across all at-sea sub-areas. We used contrasts to express the difference in densities between survey periods averaged across seasons and Wald's Z-test to test the significance of this contrast.

DISTRIBUTION MAPS

We averaged seabird densities for 5' grids across years and replicates for each survey month. This resulted in three maps for each species and family representing January, May, and September. To facilitate visual comparisons among maps for individual species or families, map legends were standardized for each species or family based on percentages of maximum densities observed for that species or family. The five categories were: (1) 0 (none observed), (2) >0-50% of densities, (3) >50-75% of densities, (4) >75-90% of densities, and (5) >90% of densities. Standardized density legends highlighted areas of greatest importance to individual species or families.

RESULTS

Between May 1999 and January 2002, we completed nine surveys of the entire area (102 flight days). For all surveys combined, we flew >54,600 km of transects with >20,100 km in the core area and >14,400 km along coastlines. We identified 54 species of seabirds representing 12 families and counted a total of 135,545 seabirds on transect.

Seabirds occurred in all sub-areas and in all seasons (Fig. 5). Densities (all species) averaged 33.7 birds/km² (for at-sea and coastal transects combined) and ranged from 0-12,244 birds/km². Densities for both at-sea and coastal transects were generally greatest in January (Tables 1-4), primarily due to large numbers of California Gulls (*Larus californicus*), Western Grebes (*Aechmophorus occidentalis*), Surf Scoters (*Melanitta perspicillata*) and, to a lesser extent, Black-legged Kittiwakes (*Rissa tridactyla*), Cassin's Auklets, loons, and phalaropes. In May, Western Grebes, Sooty Shearwaters (*Puffinus griseus*), phalaropes, and Western Gulls were the most abundant species in southern California. Sooty Shearwaters were the

most abundant seabird in September, followed by Western Grebes, Western Gulls, and Brown Pelicans. Maximum seabird densities for a single 5' grid occurred in September, involving large flocks of Sooty Shearwaters.

In 1999-2002, mean monthly abundance of seabirds was 981,000 ± 144,000 in January, 862,000 ± 95,000 in May, and 762,000 ± 172,000 in September. Among five at-sea sub-areas, greatest seabird densities occurred in S3 in January and in S1 in May and September. Western Grebes, California and Western gulls, and Cassin's Auklets were the most abundant species in S3 in January. Sooty and Short-tailed shearwaters, phalaropes, and Cassin's Auklets were most abundant in S1 in May, and Sooty and Short-tailed shearwaters, phalaropes, Common or Arctic terns, and Pink-footed Shearwaters were the most abundant species in September.

Among five coastal sub-areas, densities were greater along mainland rather than island coasts because of large numbers of Western Grebes, Sooty and Short-tailed shearwaters, and Surf Scoters, and to a lesser extent, terns. Greatest coastal seabird densities were found in CMC in January and May and in NMC in September (Table 5). Western Grebes, California and Western gulls, and Surf Scoters were the most abundant species in CMC in January. Western Grebes, cormorants, Western Gulls, and Brown Pelicans were the most abundant species in CMC in May. Sooty Shearwaters, Heermann's and Western gulls, Brown Pelicans, and cormorants were the most abundant species in the NMC in September.

All estimates of mean at-sea densities are presented separately by species, season, and geographic sub-area (Tables 1a-e). Mean densities that were greatest along mainland coastlines, island coastlines, and both coastline types are presented separately by species and season (Tables 2a-c). Mean densities for each coastline sub-area are presented for mainland coastlines (Tables 3a-c) and island coastlines (Tables 4a, 4b), and statistical tests of variation are summarized for seasonal (Table 5) and geographic (Table 6) differences. Random effects for year and replicate were not found to be significant ($P > 0.15$ for all species), so we compared at-sea densities between 1975-1983 and 1999-2002 surveys using GLM (Tables 7a, 7b).

Densities for all seabirds combined differed among at-sea and coastal sub-areas. Greatest densities of seabirds occurred in S3 (Table 1c) and in NMC (Tables 2-4), whereas lowest densities occurred in S5 (Table 1e) and in SIC (Tables 2-4). Densities along at-sea transects did not differ consistently among seasons, but greatest seasonal densities for at-sea transects occurred