(unpubl. data) reported increased populations of several species, including Brown Pelicans, cormorants, and Western Gulls (*Larus occidentalis*), but decreased populations of Cassin's Auklets (*Ptychoramphus aleuticus*) and Xantus's Murrelets compared with surveys conducted in the 1970s.

Collectively, these changes in oceanography and human activities prompted a need for updated information regarding at-sea populations of seabirds in southern California using techniques that would allow comparison with previous seabird surveys conducted by Briggs et al. (1987). In 1975–1978 and 1980–1983 (hereafter 1975–1983), Briggs et al. (1987) conducted the first replicated, quantitative assessment of the distribution, abundance, and diversity of seabirds off California using aerial-survey techniques. Surveys in the SCB were conducted from 1975–1978 and off central and northern California from 1980–1983. More than two decades later (1999–2002), we used similar aerial-survey techniques to provide updated information and examine trends in the at-sea distribution and abundance of seabirds in southern California.

Study Area

The study area encompassed continental-shelf and slope waters from 35° 35′ N (off the city of Cambria, San Luis Obispo County, California) south to 32° 32′ N (the Mexican border), and from the mainland shoreline west to 122° W at the northern boundary, and to 119° 30′ W at the southern boundary (Fig. 1). In this area, most of the coastline and seafloor are oriented north to south. Like most parts of the California coast, the continental shelf gradually slopes westward before dropping precipitously to depths >3,000 m. At Point Conception, the coastline and bottom topography abruptly turn eastward to southeastward and transition to a southward orientation between Los Angeles and San Diego.

For this study, we considered that the SCB extended from Point Conception to just south of the Mexican border. Off Point Conception and

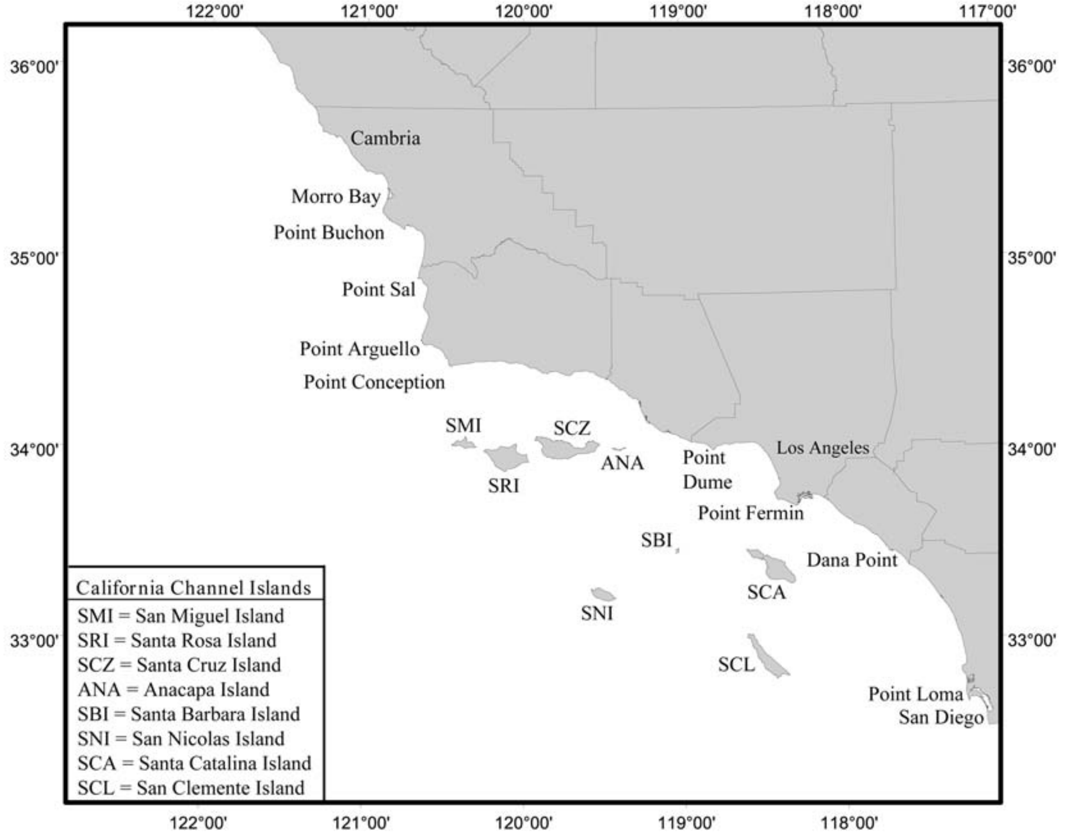

FIGURE 1. Map of central and southern California showing locations of county boundaries, major cities, coastal points, and islands.

to the north, shelf currents and water properties respond to strong, persistent upwelling-favorable winds, whereas in the SCB and offshore, flows consist of eddies, jets, and fronts which show no relation to local winds (Harms and Winant 1998). These unique conditions result in a transition zone between warmer subtropical waters to the south and colder nutrient-rich waters to the north (Hunt et al. 1980). As a result, the SCB and adjacent waters host a diverse avifauna that includes species typical of both temperate and tropical climates. Several seabird species have their northern or southern distribution limit in this region.

The SCB contains a variety of bathymetric and land features that combine to form a highly complex oceanographic region. Eight major islands, 11 deep-water basins, three major banks and seamounts, and at least 13 major submarine canyons bisect the SCB (Dailey et al. 1993, Hickey 1993). These features strongly affect local circulation patterns of the California current, which turns from its more typical flow toward the equator to a flow toward the pole in the central-southern SCB, with a predominant counterclockwise eddy south of the northern Channel Islands (Hickey 1993). The strong coastal upwelling off the northern and central California coasts is much reduced in the southern portion of the SCB, resulting in warmer and less productive waters.

Human activities in southern California have affected seabirds. The southern California coast is one of the most densely populated coastal areas in the U.S. and this has led to highly modified coastal habitats. Various pollutants, including oil, sewage, agricultural runoff, pesticides, and other chemicals have affected coastal waters (Schiff 2000). Several offshore oil leases for commercial oil development are located off Point Conception and the Santa Barbara and San Pedro channels; several other lease sales remain undeveloped (Fig. 2). In southern California, four active offshore oil platforms exist off

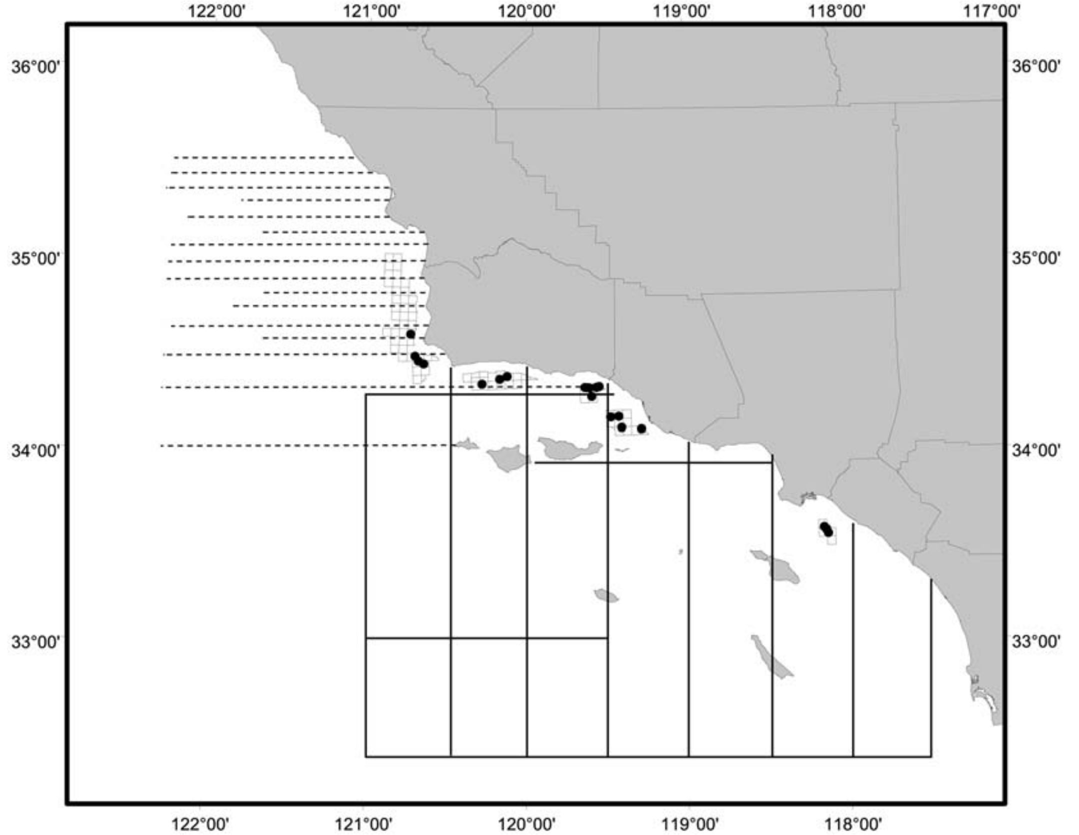

FIGURE 2. Map of central and southern California showing oil lease and platform locations and survey lines flown by Briggs et al. (1987). Oil leases are represented by squares. Platforms are represented by solid circles within lease areas. Lines surveyed in 1975–1978 are represented by solid lines. Lines surveyed in 1980–1983 are represented by dotted lines.

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).