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Planktivorous auklet *Ptychoramphus aleuticus* responses to ocean climate, 2005: Unusual atmospheric blocking?

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[1] In spring-summer 2005, anomalous atmospheric-oceanographic coupling caused unprecedented reproductive failures and redistribution of a planktivorous marine bird in both central California (37°N) and southern British Columbia (50°N). At SE Farallon Island, CA, the birds abandoned the breeding colony *en masse* between 10–20 May, a unique behavioral response; for the first time in 35 years, reproductive success was zero. At Triangle Island, B.C., only 8% of the nesting pairs were successful, the worst year on record. Surveys of birds at sea revealed a peak in relative abundance south of Point Conception (34°N) in summer and fall, suggestive of emigration from the north. Prey (euphausiid crustacean) biomass in the Gulf of the Farallones was reduced, but remained high south of Point Conception. Change in predator and prey may be explained, in part, by unusual atmospheric blocking in the Gulf of Alaska in May, which caused the jet stream to shift southwards resulting in poor upwelling-favorable winds and anomalously warm SST. This study demonstrates the deleterious consequences of this climate event for a top marine predator in the central-northern California Current System. **Citation:** Sydeman, W. J., R. W. Bradley, P. Warzybok, C. L. Abraham, J. Jahncke, K. D. Hyrenbach, V. Kousky, J. M. Hipfner and M. D. Ohman (2006), Planktivorous auklet *Ptychoramphus aleuticus* responses to ocean climate, 2005: Unusual atmospheric blocking?, *Geophys. Res. Lett.*, *33*, L22S09, doi:10.1029/2006GL026736.

1. Introduction

[2] The global ocean and atmosphere co-vary over multiple temporal scales, from weeks to decades [*Hickey*, 1979; *Mantua and Hare*, 2002]. Marine birds, secondary and tertiary consumers in marine ecosystems, are responsive to these changes in climate [*Durant et al.*, 2004; *Lee et al.*, 2006]. At the interannual time scale, many North Pacific large marine ecosystems are affected by El Niño-Southern Oscillation (ENSO) variability [*McGowan et al.*, 1998]. In the central-northern California Current System (CCS), El Niño events can reduce ocean productivity [*Lenarz et al.*, 1995]. In 2005, ecosystem dynamics were altered by changing atmospheric-oceanographic conditions, but the forcing was apparently extra-tropical in origin [*Kosro et al.*, 2006; *Schwing et al.*, 2006; T. Strub, personal communication, 2006]. Off northern California, 35 years of information on the productivity (breeding success) and food habits of marine birds is available from SE Farallon Island (SEFI) [*Sydeman et al.*, 2001]. Cassin's Auklet, *Ptychoramphus aleuticus*, feeds primarily on *Euphausia pacifica* and *Thysanoessa spinifera* and some larval fishes [*Abraham and Sydeman*, 2004]. Off southern British Columbia (B.C.), auklets forage on large calanoid copepods and euphausiids [*Bertram et al.*, 2001]. Timing of breeding, offspring growth, and breeding success has been linked to the abundance zooplankton prey. In this paper we consider how anomalous climate in 2005 affected predator and prey (see also J. Jahncke et al., Ecosystem responses to short-term climate variability in the Gulf of the Farallones, California, submitted to *Progress in Oceanography*, 2006, hereinafter referred to as Jahncke et al., submitted manuscript, 2006).

2. Methods

[3] We studied auklet productivity by monitoring breeding birds in nest boxes and burrows from 1971–present (SEFI) and 1994–present (Trinagle Island, B.C.). *Abraham and Sydeman* [2004] and *Bertram et al.* [2001] provide methods, which were similar at both colonies. Breeding success was scored '1' if fully developed (feathered) young left nesting burrows/boxes at $\geq$35 d of age, and '0' if eggs were broken or abandoned or if chicks disappeared at <30 d of age. We calculated annual productivity as the mean number of chicks fledged per breeding pair (Figure 1). Abandonment was calculated as the proportion of breeding pairs which permanently left eggs during incubation. We surveyed seabirds at sea as part of the California Cooperative Oceanic Fisheries Investigations/California Current Ecosystem LTER program (CalCOFI/CCE LTER; 30° to 35°N). *Hyrenbach and Veit* [2003] provide methods. Bird abundance data was tabulated as density (auklets km^{-2}).

[4] In the Gulf of the Farallones, we conducted surveys of krill biomass from May to October 2004 and February to October 2005. Our survey consisted of 9 parallel lines, running perpendicular to the coastline, covering much of the outer shelf/shelf-break region northwest of SEFI where auklets are known to forage [*Yen et al.*, 2004]. We used a multi-beam, hull-mounted SIMRAD EK-60 echosounder, equipped with 38, 120 and 200 kHz transducers (Jahncke et

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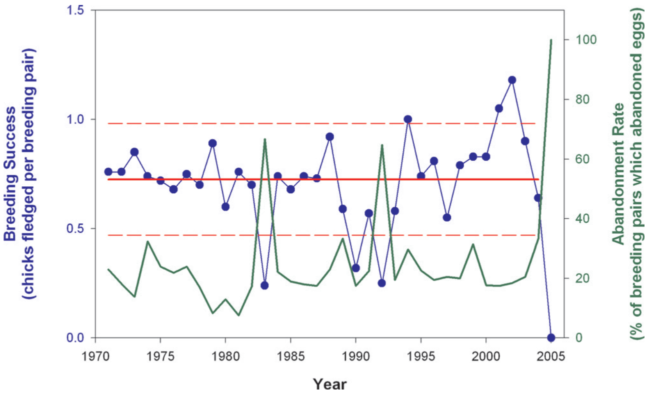

Figure 1. Interannual variability of Cassin's auklet breeding success and abandonment rate at Southeast Farallon Island, California (1971–2005), showing the long-term mean breeding success (solid red line) ±80% confidence intervals (dashed red lines).

al., submitted manuscript, 2006). Following previous studies, we assumed that 38 kHz detects large organisms and negligible amounts of krill, while the 120 and 200 kHz detect mostly krill [*Coyle et al.*, 1992; *Fiedler et al.*, 1998; *Lawson et al.*, 2004]. We omitted data below −81 dB to eliminate backscatter attributable to non-biological sources and organisms smaller than krill [*Croll et al.*, 1998]. We calculated an index of krill biomass by averaging volume backscatter from 120 and 200 kHz and subtracting backscatter from organisms larger than krill detected at 38 kHz. We report average backscatter volume (dB/m3) for the upper 200 m. Off southern and central California, euphausiids were collected at standardized stations during springtime CalCOFI/CCE LTER cruises with a metered 71-cm diameter, 505-μm mesh bongo net towed obliquely in the upper 210 m of the water column, while maintaining a wire angle close to 45°. *Brinton and Townsend* [2003] provide methods. Herein only night-time samples are considered for spring cruises in the years 1987–2005. Samples for the Southern California region include CalCOFI lines 80 through 93, onshore of station 70 (inclusive), while Central California samples are from CalCOFI lines 60 through 70, onshore of station 90 (inclusive). We report biomass as organic C based on length-C relationships [*Ross*, 1982] from individual life history stages.

3. Results

[5] In 2005, we witnessed unprecedented auklet abandonment for the Farallon Island colony, coupled with complete breeding failure, heretofore unobserved in 35 years

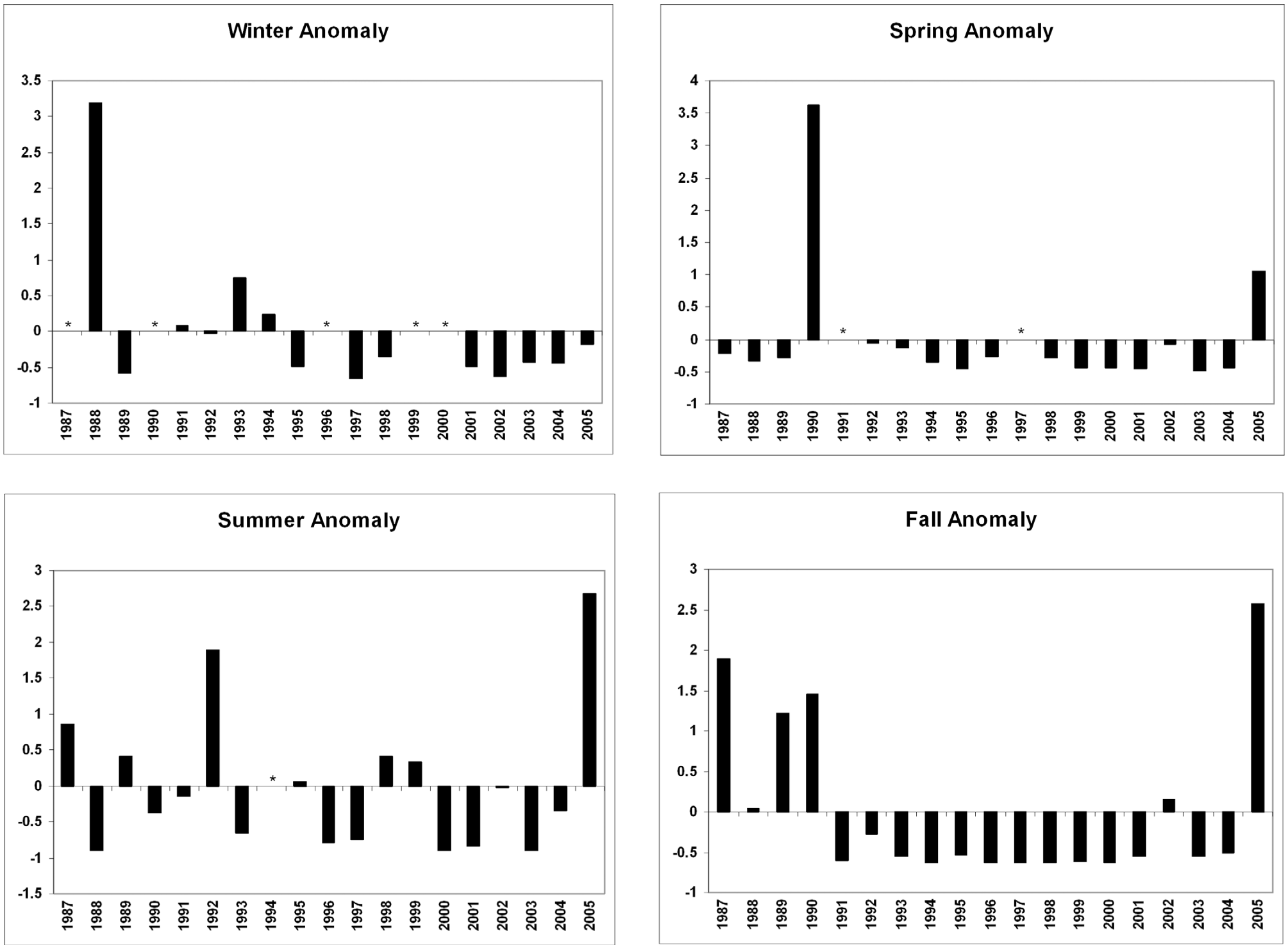

Figure 2. Normalized seasonal anomalies of Cassin's auklet density (no./km^2) at sea within the CalCOFI study area, off southern California (1987–2005).

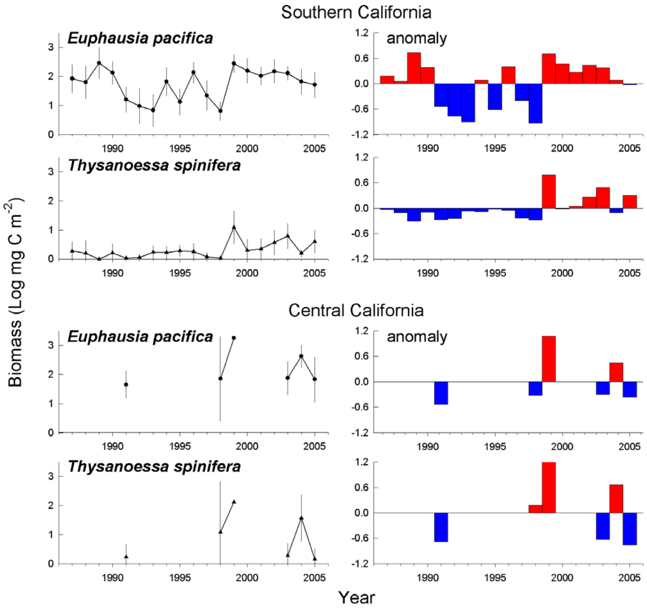

Figure 3. Interannual variability in spring-time biomass of *Euphausia pacifica* and *Thysanoessa spinifera* in (top) the Southern California region and (bottom) the Central California region. Right hand panels illustrate the anomalies from the long-term mean for 1987–2005. Means 95% ± C.I. for the log-transformed values.

of study (Figure 1). The Farallon population initiated egg-laying ~26d later than average between 1 and 13 May (Jahncke et al., submitted manuscript, 2006), but all birds left study sites by 20 May. A very small second pulse of egg-laying was observed in late June, again followed by rapid colony abandonment. The long-term mean breeding success ("climatology" of productivity) for this population is 0.70 chicks pair^{-1}. Significant negative anomalies in breeding success occurred in 1983, 1990, 1992, but complete failure was never observed in the past. The abandonment rate during the El Niño events of 1983 and 1992 was high, with roughly 65% of the breeding pairs leaving over an extended period of time. In 2005, this rate reached 100%, and the birds abandoned within a week. At Triangle Island, breeding success was close to zero (see supplementary material[1]) and was the worst year on record since 1994. Off southern California, auklet densities were anomalously *high* in 2005. During winter, the normalized anomaly was close to zero (Figure 2), but in spring, and especially summer and fall the anomalies were positive. Summertime anomalies were positively correlated with the abandonment rate at the Farallones (rho = 0.423, P = 0.08).

[6] Estimates of euphausiid biomass in the Gulf of the Farallones showed a 52% decrease from May 2004 to May 2005, and a 56% decrease between years for July (supplementary material). Net sampling of euphausiids revealed negative anomalies of biomass of both *E. pacifica* and *T. spinifera* off central California in spring 2005 (Figure 3, bottom plots); these measurements were made ~120 km to the south of the region studied by hydroacoustics. The biomass of *T. spinifera* in central California was the lowest in the six sampled springs. In contrast, off southern California, where auklet abundance was anomalously high, *T. spinifera* showed a positive anomaly in spring 2005 (note: log scale), while *E. pacifica* showed biomass at the long term mean (Figure 3, top plots).

4. Discussion

[7] The colony abandonment exhibited by the auklets in 2005 reflects a fundamental marine bird life-history strategy to abandon current reproductive efforts (eggs and chicks) when the costs threaten survival and future breeding opportunities [*Erikstad et al.*, 1998]. We observed large-scale abandonment in other years (1983, 1992), though not to the degree observed in 2005. Although auklet breeding success has been previously associated with El Niño [*Ainley et al.* 1995], there are considerable event-to-event differences in these impacts. The strongest El Niño conditions during the last 3 decades occurred in 1982–83 and 1997–98. In both of these periods there was a decrease in auklet breeding success (Figure 1), but the magnitude of this decrease was much greater in 1983. The more moderate El Niño of 1992 was characterized by auklet breeding success similar to that observed in 1983 (~0.25 fledglings pair^{-1}), which was considerably higher than the complete failure we observed in 2005. Timing of events may explain these differences. In 2005, data from in southern B.C. and central California revealed almost identical reproductive success suggesting regional coherence in the bird's demographic response to this climate anomaly (Figure 2).

[8] Auklet abundance at-sea off southern California was also anomalous in 2005, but showed an opposing "positive" response (Figure 2). This result suggests that the ecological effects of the climate anomaly of 2005 were north of Point Conception. This hypothesis is corroborated by other biological time series, which indicate that ecological effects were found mainly in the northern CCS [*Brodeur et al.*, 2006; D. L. Mackas et al., Zooplankton anomalies in the California Current System before and during the warm conditions of 2005, submitted to *Geophysical Research Letters*, 2006]. Variability in euphausiid biomass underscores the spatial extent of ecosystem effects to the north of Point Conception (Figure 3). Auklets also breed in the Channel Islands (CI), California, and southwards to the San Benitos Islands off Baja California. At the Benitos, productivity was reduced in 2005 (S. Wolf, personal communication, 2006), but the time series there extends only to 2000. No information is available from the CI.

[9] Although weak El Niño conditions were observed in the tropical Pacific (Climate Prediction Center Climate diagnostics bulletin, 2005, Available at www.cpc.ncep.noaa.gov/products/analysis_monitoring), with pole-ward flow during the first half of 2005 (T. Strub, personal communication, 2006), that was probably insufficient to cause the altered wind vectors [*Kosro et al.*, 2006], decreased upwelling and ocean warming [*Schwing et al.*, 2006], and reduced primary productivity [*Thomas and Brickley*, 2006] observed in the CCS this year. We hypothesize that an unusually late occurrence of *atmospheric blocking* in the Gulf of Alaska [*Higgins and Mo*, 1997;

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[1] Auxiliary materials are available in the HTML. doi:10.1029/2006GL026736.

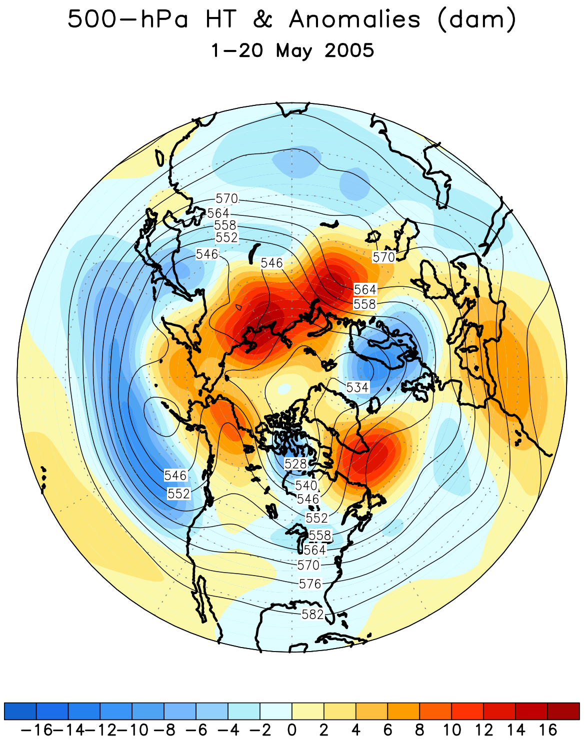

Figure 4. Mean 500-hPa heights (contours) and anomalies (departures from the 1979–1995 base period, indicated by shading) for the period 1–20 May 2005. During this period above average heights were observed at high latitudes of western North America and Siberia, while below average heights were observed over the middle latitudes of the North Pacific. Sea-level pressure shows a similar pattern of anomalies (NOAA-CPC unpublished). Associated with this pattern, the Pacific jet stream was shifted south (near the California coast) from its normal position in British Columbia. This resulted abnormal low-level southerly and southwesterly flow and elevated SST.

Carrera et al., 2004] also contributed to the physical and biological changes in the CCS during spring-summer 2005 (Figure 4). Atmospheric blocking in the North Pacific is primarily a winter phenomenon. Nearly all of the cases described by *Carrera et al.* [2004] occurred during December–March, so the blocking event during May 2005 was quite unusual. Madden-Julian Oscillation activity, although present, was not unusual for the month of May, and the weak El Niño was waning during spring (CPC 2005). During June, blocking ended and stronger low-level winds from the north-northwest contributed to enhanced upwelling and decreased SSTs coast-wide [*Kosro et al.*, 2006]. Even though the oceanographic conditions returned to normal, this shift apparently came too late to support additional reproductive attempts by the birds.

[10] Mechanistically, observations suggest that relatively short-term (e.g., weekly) climatic events, like atmospheric blocking, may cause a mismatch in prey availability for top marine predators, important during critical periods of energetic need such as egg-laying. The mismatch hypothesis has been invoked to explain climate effects on other planktivorous marine predators, including fish [*Cushing*, 1990], and has previously explained poor reproduction for seabirds in British Columbia [*Bertram et al.*, 2001]. A "miscue" hypothesis may also be advanced for our observations. In central California, upwelling-favorable conditions were not just delayed as they were off Oregon [*Schwing et al.*, 2006; *Kosro et al.*, 2006], but instead altered from positive to negative state on a quasi-monthly time scale. Month-to-month variability in atmospheric-oceanographic conditions in central California in 2005 can be characterized as follows: in February conditions were normal to anomalously windy, with cold SST; March was anomalously warm, with poor upwelling-favorable winds; April was neutral; May was anomalously warm, even more so than March (Jahncke et al., submitted manuscript, 2006). Upwelling and cold conditions and February and neutral conditions in April could have signaled the auklets to initiate breeding, but when conditions changed severely in May, they abandoned the colony.

[11] This study highlights the use of marine birds as sentinels of unusual climate variability and change. The Farallon colony abandonment was one of the first indications of the developing anomaly of 2005. As integrators of lower trophic-level constituents, the auklets demonstrated an ecosystem-level response to the weather anomaly of 2005, which was not as apparent at all trophic levels [*Thomas and Brickley*, 2006]. This response has implications for other krill predators in the CCS which are more difficult to study (e.g., salmonids, hake, herring, balaenopterid whales). In conclusion, in addition to the well-known interannual (ENSO) and interdecadal forcing, this paper highlights the importance of relatively short-term, episodic extra-tropical climate events to the structure and functioning of North Pacific marine ecosystems.

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