Map of study area in the southeastern Bering Sea and locations of relevant isobaths.
Details on Methods

Study area

The study area ranged from the shallow waters of Bristol Bay over the edge of the continental shelf (≈200 m) to the Bering Sea Basin, in the southeastern Bering Sea, which is similar to the area selected in a previous study of seabird communities over the shelf [10]. The continental shelf here is unusually wide, stretching over almost 500 km, gradually increasing in depth from east to west. In contrast to our previous study, we constricted the present study area to range from the 30 m to the 500 m isobath to avoid low sample sizes from the shallowest and deepest waters. We further restricted our study of the seabird, forage fish, and zooplankton community to the summer months between 1 June and 15 September, when the water column is generally stratified where the bottom depths are 50 m and greater [1,10].

Bathymetry

We used the AlaskaRegionBathymetricDEMv1.04, provided by the Alaska Ocean Observing System (AOOS).

Sea ice

We needed a measure to quantify the timing of sea-ice-retreat in the southeastern Bering Sea. Because the southern extent of sea ice in this area is wind driven, and can easily return after disappearing for the first time, there is not necessarily a clearly defined date of ice break-up. Instead, we used the proportion of ice cover within the study area, between the 50 m isobath and the 500 m isobath, during the usual time of breakup (the month of April) as a measure of the timing of ice-retreat. A low proportion of ice-cover in April would equate to an early, warm year.

We used two sources of ice data to determine ice extent. From 1972–1994, we used weekly sea-ice concentration, on a 0.25 degree grid, which we obtained from the Joint US Russian Sea Ice Atlas (Environmental Working Group Joint U.S. Russian Sea Ice Atlas (distributed by the National Snow and Ice Data Center September 2001). Overlapping that dataset, from 1978 to the present we used data from the National Snow and Ice Data Center; their Bootstrap algorithm, on a 25 km grid (http://nsidc.org/data/docs/daac/nsidc0079_bootstrap_seaice.gd.html). These data are semi-daily before 1987, and daily after that time. We calculated the daily mean sea-ice concentration in six regions over the southeastern Bering Sea shelf from the ice concentrations of the
data-points within each region. For data before 1987, we linearly extrapolated daily ice extents from semi-daily or weekly data.

In contrast to most previous studies comparing warm and cold years in the region [1], we used three categories, late, neutral, and early sea-ice-retreat-years. We defined early-sea-ice-retreat-years as those between the 0 and 40 percentile of ice-coverage, and late years as those between the 60 and 100 percentile. Neutral years were ignored for this study. It would have been more desirable to treat the continuous variable “percentage of April sea-ice” continuously, rather than as an artificial categorical variable. Unfortunately, our sample sizes were not sufficient to calculate the mean bathymetry depth distribution of seabirds reliably on an annual basis. We therefore aggregated years over the early/late categories.

There is autocorrelation in the timing of sea-ice-retreat between years up to a time lag of 1–2 years. We do not consider this an issue for our study of summer distribution and abundance, because migration, dispersion, and displacement by sea ice will effectively reset the distribution of seabirds, fish, and zooplankton every winter.

**Zooplankton and forage fish abundance**

We estimated relative densities of zooplankton species from oblique bongo net tows sampled over the water column at predefined, regularly spaced stations during the years 2003–2010 [6]. The copepod species *Calanus marshallae* and *C. glacialis* cannot be distinguished using standard identification techniques and were therefore lumped in our analysis. Euphausiid species, which tend to be fast swimmers and escape a small zooplankton net deployed in daytime, were surveyed hydro-acoustically in eight years between 2004 and 2014 [14]. Forage fish densities were estimated from near-surface trawls that sampled the upper 15–20 m of the water column [19].

**Seabirds**

Data from seabird surveys, conducted between 1975 and 2014, were extracted from the North Pacific Pelagic Seabird Database [15]. Note that we therefore had data from several early and late ice-retreat episodes for seabirds, but much more restricted data for zooplankton and forage fish. We adjusted for differences in survey methods as described previously [10, 20]. Unidentified birds of species pairs like common and thick-billed murre, *Uria aalge* and *U. lomvia*, were pro-rated, following the scheme described in previously [10]. It is difficult to identify shearwaters *Ardenna spp.* reliably in the field. While we know the vast majority of shearwaters in the area to be short-tailed shearwaters *A. tenuirostris*, we feel that the identification challenges preclude a reliable analysis of the distribution of
the rarer sooty shearwater *A. griseus* and therefore combined both species as “unidentified shearwater”.

To gain further insights into the interactions between seabirds and forage species, we categorised seabird species into surface-foragers and pursuit-divers (table 2). While it would be desirable to have clear categories of planktivorous and piscivorous species, most of the seabird species at hand consume both fish and plankton at times. With the exception of shearwaters, all seabirds occurring within our region are easily classified into surface-foragers or pursuit-divers. Because shearwaters are of such dominant abundance and forage both on the surface and by diving, we retained them in their own category.

In contrast to the surveys on forage species, which were conducted on a regular grid, seabird data were obtained from numerous sources, resulting in heterogeneous sampling effort across the study area. To standardise for these differences in effort, we averaged seabird densities over 21 slices between logarithmically spaced isobaths. Mean seabird densities for the entire study area were then calculated by averaging all samples within each bathymetry slice and then averaging those densities over the entire study area.

The mean depth-distribution of each species was calculated as a weighted mean (mean depth of bathymetry slices, weighted by average density within the respective slice), being equivalent to the center of gravity of the respective species’ distribution.

**Supplemental Literature**

[19] Farley, EV, Murphy, JM, Adkison, MD, and Eisner, LB 2007 Juvenile sockeye salmon distribution, size, condition and diet during years with warm and cool spring sea temperatures along the eastern Bering Sea shelf. *Journal of Fish Biology* 71, 1145–1158.