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Biological Effects of the 1997/98 ENSO in Cook Inlet, Alaska

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Abstract

We have been conducting detailed studies of the biology of seabirds in relation to oceanography and forage fish ecology in lower Cook Inlet, Alaska, since 1995. This fortuitously allowed us to document biological effects of the 1997/98 ENSO in this region. Anomalously warm sea surface temperatures (SSTs) were observed in the Gulf of Alaska (GOA) beginning in June of 1997, but not in Cook Inlet until September, 1997. Warm temperature anomalies at the surface and at depth persisted until May of 1998, when temperatures returned to average in the GOA and Cook Inlet. Thus, temperature anomalies occurred outside the core window of productivity (June–August) for forage fish and seabirds in both 1997 and 1998. Abundance or production of phytoplankton, zooplankton, fish, and seabirds in lower Cook Inlet varied among years, and overall appeared to be depressed in 1998. We observed a few biological anomalies that might be attributed to ENSO effects: (1) a significant die-off of Common Murres occurred in March–May of 1998, (2) murres and Black-legged Kittiwakes were physiologically stressed during the 1998 breeding season, (3) murres failed to reproduce at one colony in 1998, (4) kittiwake breeding success was lower than usual at colonies in 1998, and (5) phenology of breeding was later in 1998 for both murres and kittiwakes. We presume that seabird die-offs, reduced productivity and delayed phenology were linked to a reduction or delay in food availability, but the mechanism by which anomalously warm water temperatures in winter reduce forage fish availability during the summer breeding season for seabirds is not known.

Oceanography

The 1997/98 ENSO was well developed at the equator by July of 1997. Anomalously warm sea surface temperatures (SSTs) developed rapidly during June in the GOA and Bering Sea, presumably via atmospheric tele-connection with the tropics. SST positive anomalies of 2°C in the GOA persisted throughout summer of 1997 (Figure 1), diminished to ~1°C in October; and persisted until May/June of 1998. Water temperatures at depth (0–250 m) differed markedly from surface temperatures during summer of 1997. Warming of deeper waters started much later (September) and peaked in February/March of 1998. In lower Cook Inlet, effects of the 1997/98 ENSO were ameliorated by upwelling and tidal mixing at the entrance to Cook Inlet. Whereas the northern GOA was well stratified during summer of 1997 and capped by warm surface layers, strong upwelling occurs around the Kodiak Archipelago and at the entrance to Cook Inlet, leading to complete mixing of the water column and reduced surface temperatures in these areas (Figure 2). Cold, mixed waters are carried north by prevailing currents far into Cook Inlet. Strong tidal mixing limits stratification to protected areas such as Kachemak Bay where river outflows create shallow lenses of warm, low-salinity water at the surface. On the west side of Cook Inlet, currents flow south and

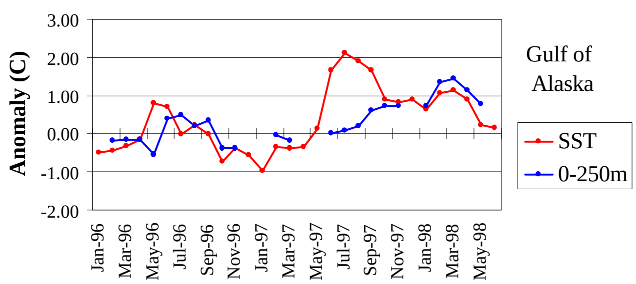


Figure 1. *Temperature anomalies at the surface and over the entire water column in the Gulf of Alaska from January 1996 to May 1998.*

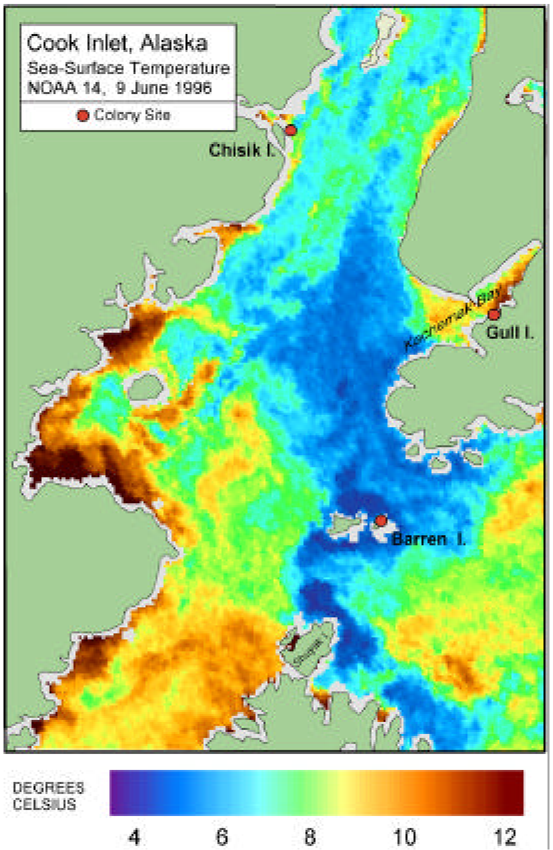


Figure 2. *AVHRR image showing sea surface temperatures in Cook Inlet and seabird colonies under investigation.*

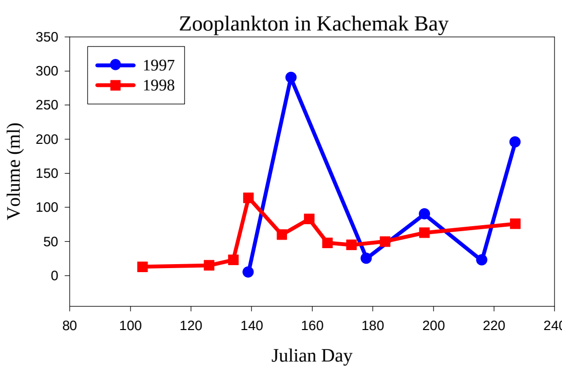
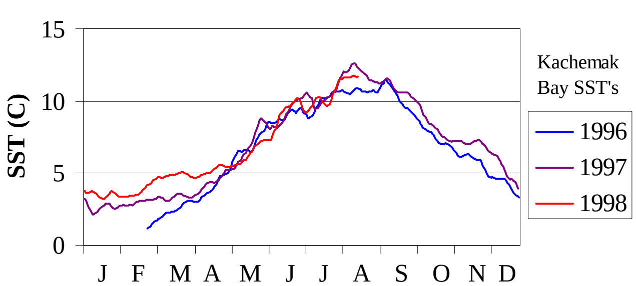


Figure 3. *Sea surface temperatures (5 m below low-low tide) in Kachemak Bay, Cook Inlet, Feb. 1996 to Aug. 1998. Mean daily temperatures smoothed with 7-day running average.*



waters are weakly stratified, warmer and less saline. Although they differ slightly in absolute temperature, SSTs from Kachemak Bay, Chisik (on the west side, Figure 2) and the Barren Islands (entrance to Cook Inlet) show similar seasonal and annual SST trends. As a consequence of this oceanographic regime, SSTs in Kachemak Bay (Figure 3) do not reflect SSTs in the outer GOA; instead they reflect temperature fluctuations of the entire GOA water column (Figure 1). SSTs in Kachemak Bay and the GOA during 1996 were about average most of the year. The large SST anomaly observed in the GOA during June–August of 1997 (Figure 1) was not observed in Kachemak Bay (Figure 3) or at Chisik and Barren islands. SSTs in Kachemak Bay began to increase in August 1997 and were 1–2°C higher than average throughout fall and winter; returning to average in May of 1998. As for GOA temperatures at 0–250 m depth, SSTs in Kachemak diverged most from average values during February and March of 1998 (Figure 3).

Biological Effects

Plankton

We began monitoring phytoplankton and zooplankton abundance in 1997. Phytoplankton concentrations were measured using a CTD with attached fluorometer. Zooplankton were collected seasonally at a single station in Kachemak Bay, and we measured settled volumes to estimate abundance (Figure 4). Primary and secondary production in Kachemak Bay varied among and between seasons, but with only two years of data we can only conclude that there was no indication of any dramatic ENSO effects (e.g., total production failure) in either year. However, maximum zooplankton volumes in 1998 were about a third of those observed in 1997.

Fish

Fish were sampled in both Kachemak Bay and around Chisik Island using a modified herring midwater trawl (July) and beach seines (June–Aug.), and in Kachemak Bay using a small bottom trawl (Aug.). The same gear and methods were used in all years of study. We targeted small forage fishes consumed by seabirds. More than 300,000 fish comprising over 60 species have been caught on these surveys. Dominant taxa include juvenile pollock, sand lance, osmerids, and herring. In general, fish

Figure 4. *Seasonal variation in zooplankton volume in Kachemak Bay during 1997 and 1998. Zooplankton were collected using a 1-m ring net with 505 micron mesh.*

catches are much higher in Kachemak Bay (Figure 5a) than around Chisik Island (Figure 5b) owing to regional differences in productivity. Catches of forage fish increased in Kachemak Bay, but decreased around Chisik Island, between 1997 and 1998. Catches in both areas in 1997/98 were higher or similar to those observed in 1996. However, trawl catches are highly variable and biased because we conduct trawls only where hydroacoustic signals indicate the presence of fish. Analyses of hydroacoustic data (in prep.) suggest that biomass of fish was reduced in most areas of Cook Inlet in 1998. Beach seines suggest that fish were delayed in arriving nearshore in 1998.

Seabird Productivity

Here we consider two species (Common Murres and Black-legged Kittiwakes) from colonies at Chisik Island and Gull Island. Murres maintained relatively high productivity among all years of study at Gull Island in Kachemak Bay (Figure 6). Diets were similar among years, and analyses of time budgets (foraging trip duration, "loafing time") suggest that murres had no difficulty finding food in 1997 or 1998. At Chisik Island, however, murres experienced a complete breeding failure in 1998 (Figure 6). They started breeding later than usual (Figure 7), displayed erratic attendance, and had significantly higher levels of stress hormones in their blood plasma in 1998 than in 1997 (Figure 8). Complete breeding failure is rare in murres because they can compensate for wide fluctuations in food supply by

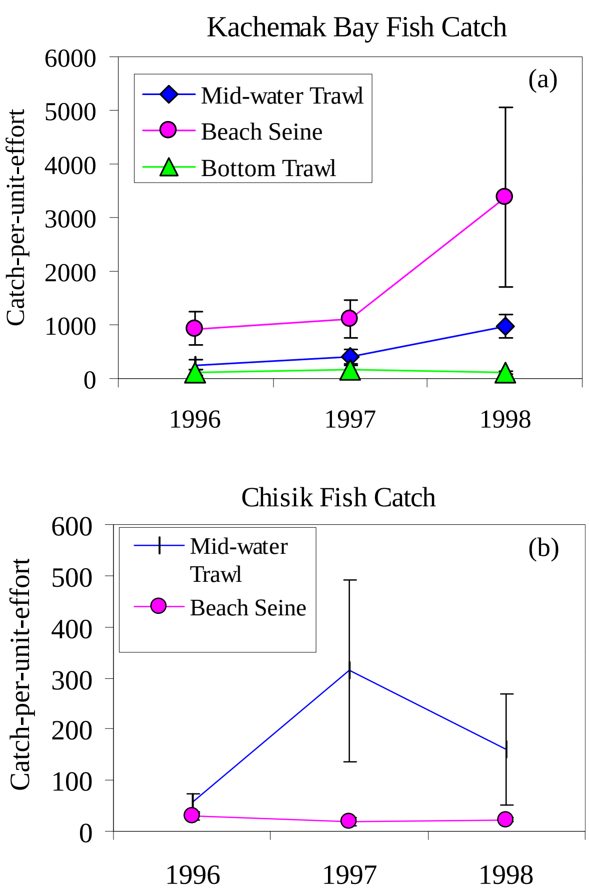


Figure 5. *Catches of fish in mid-water trawls, beach seines and bottom trawls: (a) in Kachemak Bay and (b) around Chisik Island, 1996–1998.*

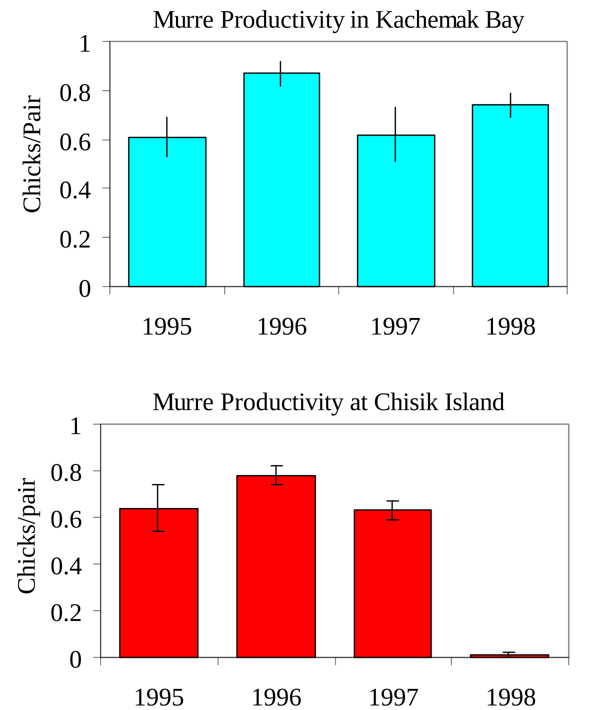


Figure 6. *Breeding success of Common Murres in 1995–1998.*

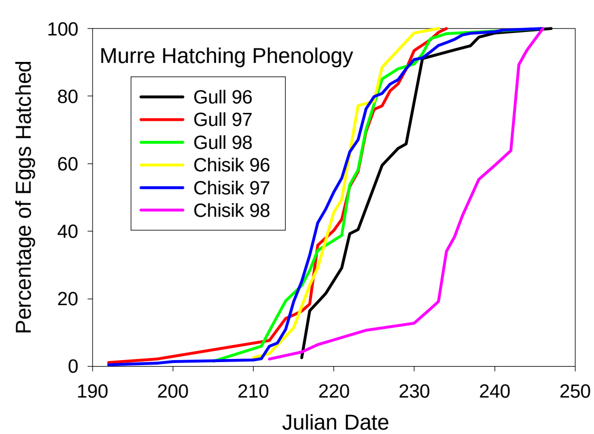


Figure 7. *Phenology of egg hatching in murres at Gull and Chisik islands, 1996–1998.*

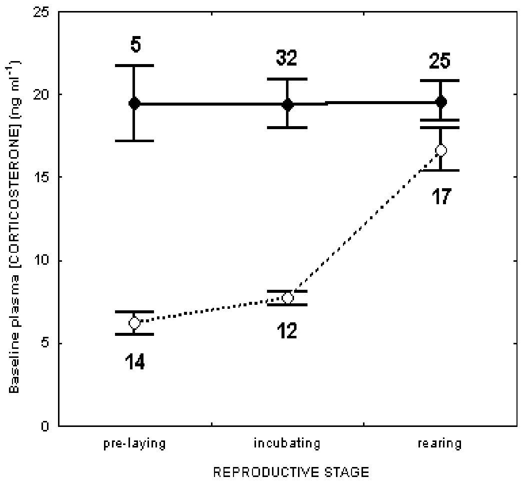


Figure 8. *Stress hormone levels in murres at Chisik during a 'normal' year (1997, open circles) with seasonal increase in food stress, and ENSO year (1998, closed circles) with high stress load at beginning of the breeding season.*

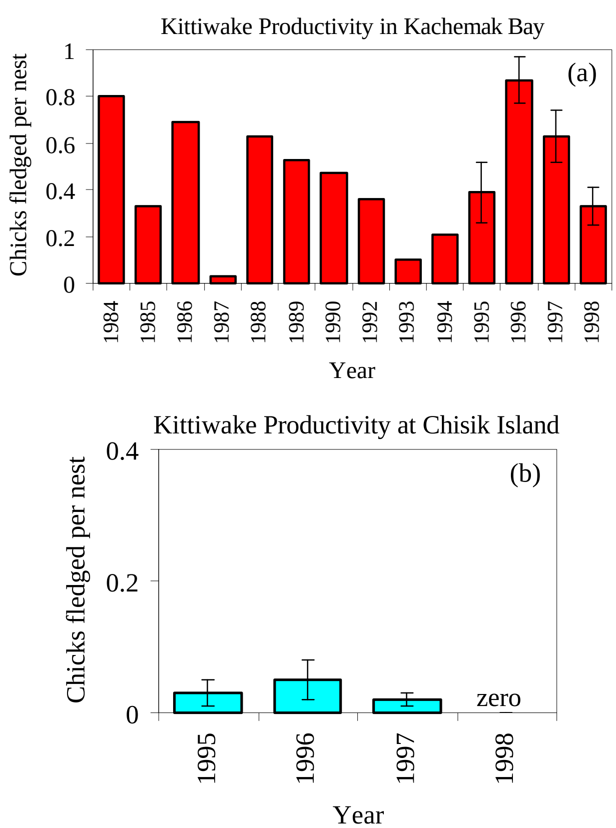


Figure 9. *Breeding success of Black-legged Kittiwakes at (a) Gull Island, Kachemak Bay and (b) Chisik Island.*

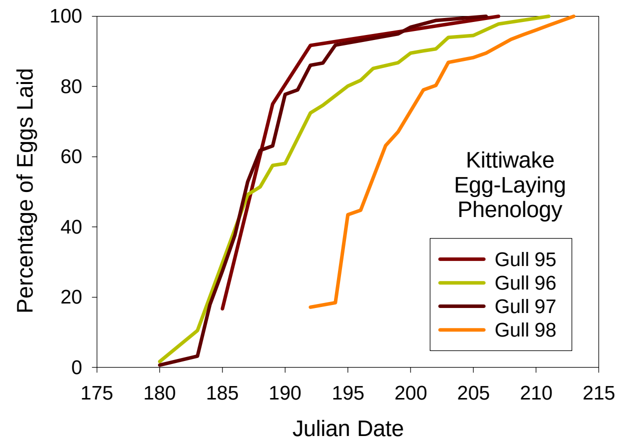


Figure 10. *Phenology of kittiwake egg-laying on Gull Is., 1995–1998.*

adjusting their time budgets – which is why they usually manage to produce chicks at Chisik despite poor food supplies. We therefore view the delayed phenology and subsequent breeding failure of murres at Chisik in 1998 as particularly significant.

In contrast, kittiwake breeding success is typically more variable and sensitive to fluctuations in food supply. In Kachemak Bay, kittiwake breeding success was much reduced in 1998 compared to 1996/1997 – but fell within range of variability observed in previous years of study (Figure 9a). However, notable low production events in the past also correspond to years with moderate ENSO warming of winter water temperatures in Alaska (1987, 1993, 1994). Low production in 1998 was largely due to low laying and hatching success, which was about 3 weeks later than usual (Figure 10). Once hatched, chick survival was high. At Chisik Island, kittiwakes have always done poorly in recent years (Figure 9b). Evidence suggests this is because of generally poor food supplies around Chisik and because, in contrast to murres, kittiwakes cannot adjust their time budgets to deal with fluctuations in food supply, nor can they range as far to find food. The 1998 breeding season at Chisik was notable because birds failed much earlier than usual (during incubation), phenology of egg laying was about 2–3 weeks later than usual, and adults produced absolutely zero chicks.

Seabird die-offs

A large and extensive seabird die-off was observed in Alaska during summer 1997; largely confined to the southern Bering Sea and Aleutians. Surface-feeding species such as shearwaters (and much lesser numbers of kittiwakes) died *en masse* from apparent starvation. Some hundreds of thousands of birds were probably affected, and peak mortality occurred in August when SST anomalies were highest. Smaller die-offs of murres were also reported from the northern Bering Sea, mostly in May and June. Although SST anomalies were also high in the GOA during the summer of 1997, no die-offs were reported there. In 1998, however, a moderate die-off of Common Murres was observed in the northern GOA. Dead murres were reported over a wide area (Figure 11) from about March through May, with peak mortality occurring in mid-April. This followed a long period of anomalously warm water temperatures in the GOA (Figure 1). Most murres were apparently subadult (non-breeders) and died of starvation. A preliminary tally indicates that at least 1300 dead murres were observed on beaches in the GOA. Previous studies indicate this would be a small fraction of the total mortality, which probably numbered in the tens of thousands. The most recent large seabird die-off observed in the GOA occurred during late winter of 1993 following a prolonged period of anomalously warm SSTs associated with the 1992/93 ENSO. In that die-off, about 120,000 murres died from starvation in the northern GOA.

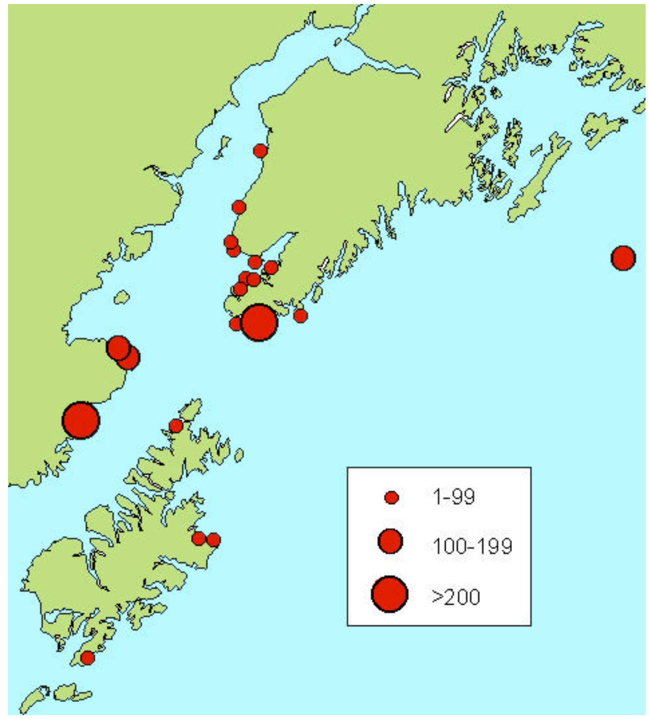


Figure 11. *Distribution of dead murres recovered from beaches in the northern Gulf of Alaska during March–May, 1998.*