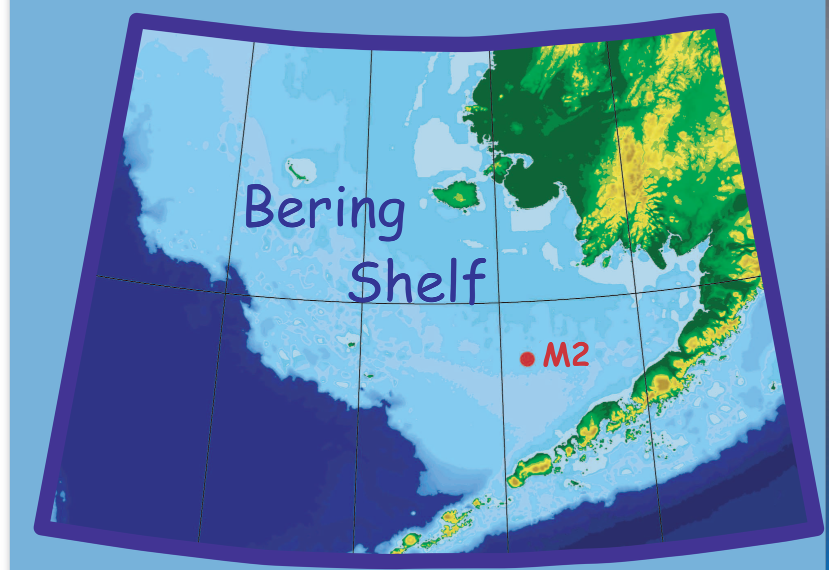

Stratification and mixing on the southeast Bering Sea Shelf

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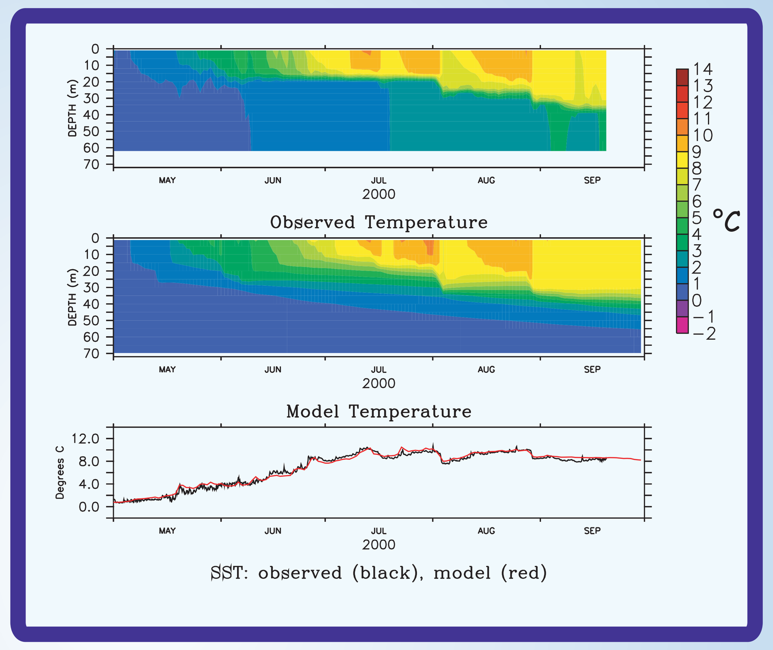
ABSTRACT:

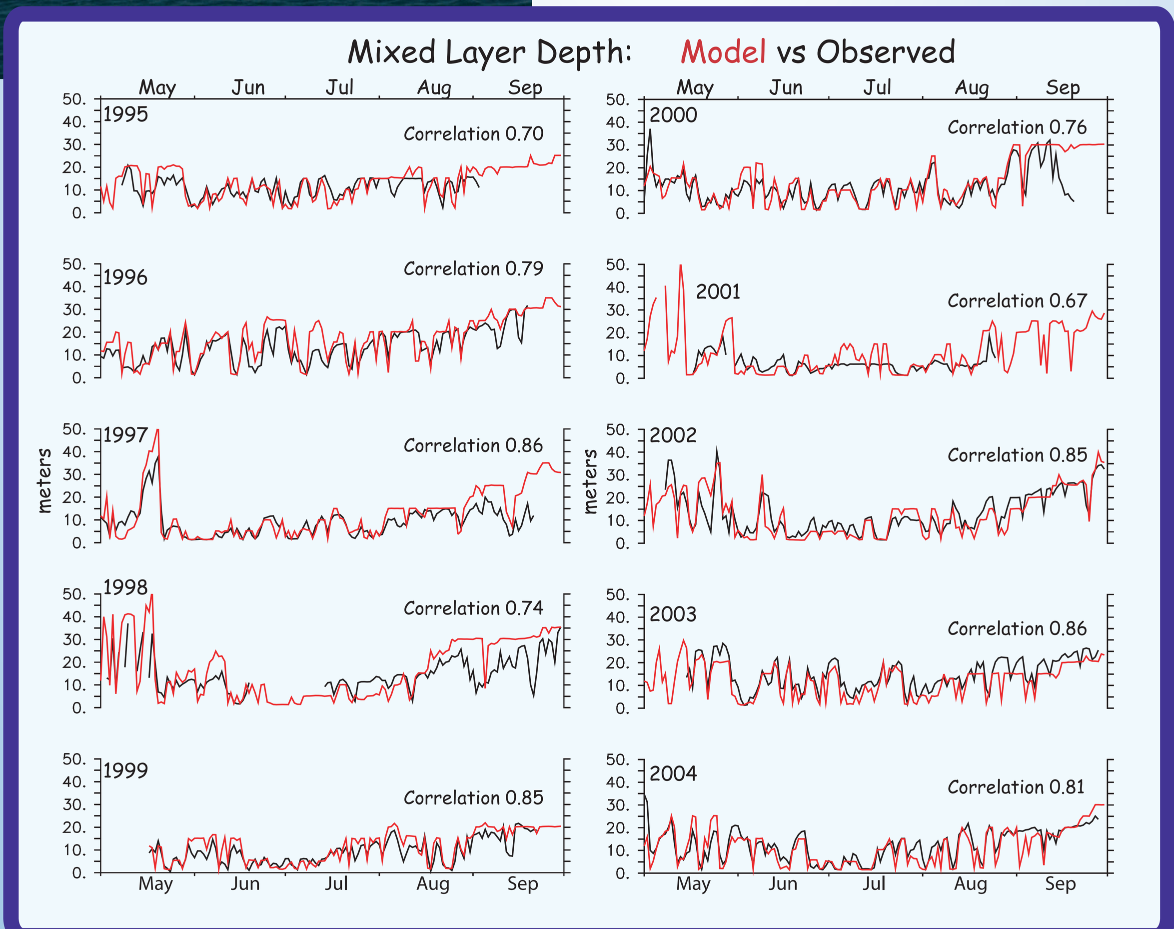
On the southeast Bering Sea shelf, initiation of the spring phytoplankton bloom is related to the onset of stratification. In summer, after the spring bloom has depleted the surface water of nutrients, vertical mixing entrains nutrients into the surface layer resulting in further production. Using the results from a series of one-dimensional mixed layer model runs, variability in spring/summer stratification and mixing was explored. The model runs were validated by comparison with data from a mooring on the southeast Bering Sea shelf deployed by the Fisheries Oceanography Coordinated Investigations (FOCI) (M2: 56.9°N, 164.1°W). The model reproduced the observed temperature, mixed layer depth, and timing of mixing events well, in comparison with the mooring data during the summers of 1995 – 2004. **Model runs from 1951 to 2004 provide time series of the timing of spring stratification, average mixed layer depths, average stratification and entrainment during the summer over the southeast Bering Sea.** The timing of initial spring stratification appears to influence walleye pollock survival. Spawner-to-recruit survival rates were significantly higher when spring stratification during the larval and juvenile stages occurred earlier. The model provides indices of stratification and entrainment that are not available from the instrumental record.

MIXED LAYER MODEL:

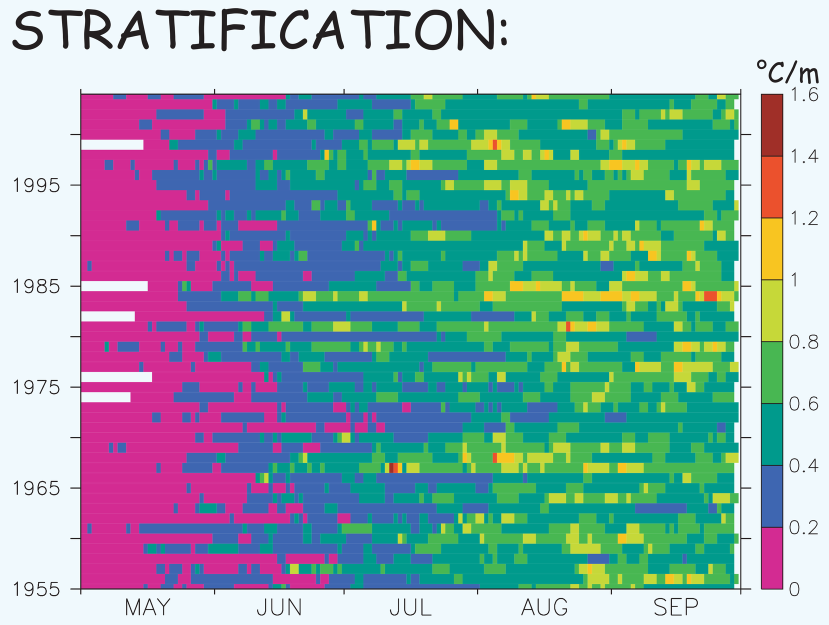
While one-dimensional models are often not realistic in the ocean, the weak advection of the middle shelf region of the Bering Sea during the summer suggests that a one-dimensional model may have some applicability here. We use the Price-Weller-Pinkel (Price et al., 1986) one-dimensional mixed layer model to hindcast the initiation of stratification and subsequent mixing on the southeast Bering Sea shelf during the summer. Except in the case where ice was present after May 1, the model was run from May 1 to September 30 of each year (1951 – 2004). Runs were initialized with May 1 temperature from the National Centers for Environmental Prediction (NCEP) Reanalysis (Kalnay et al., 1996) and forced with NCEP reanalysis windstress and heat fluxes.

MODEL/DATA COMPARISONS:





STRATIFICATION:

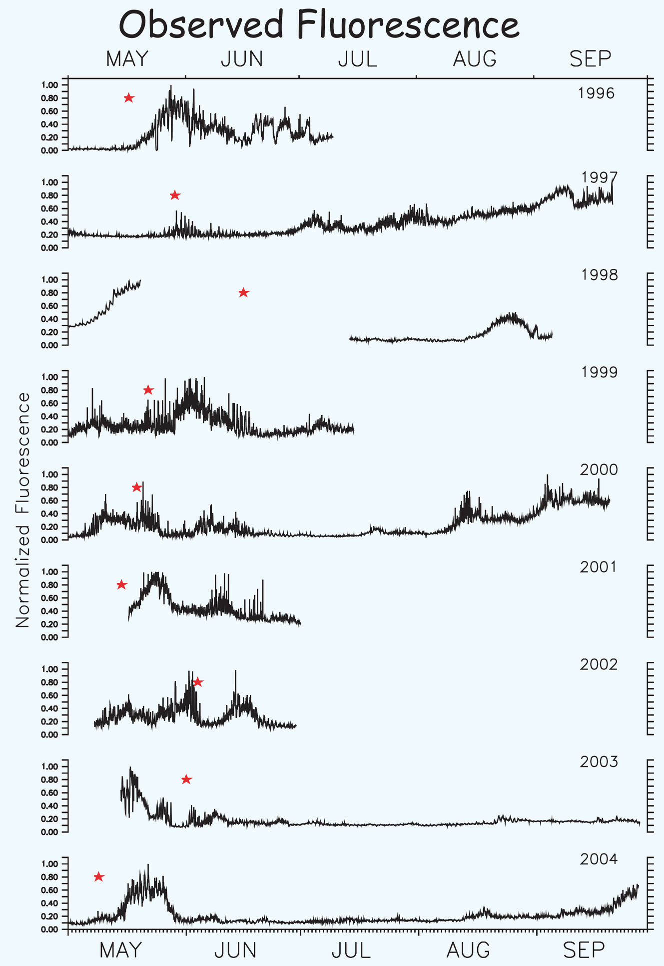


Water column stratification has varying effects on the ecosystem depending on the season. Prior to the spring bloom, nutrients are plentiful in the surface waters. During this light-limited regime, the onset of stratification allows phytoplankton to remain in the surface layer reducing light-limitation. Thus, stratification is necessary for the onset of the spring bloom. After the spring bloom depletes the surface layer of nutrients, the nutrient-limited regime of summer occurs in a stratified 2-layer system. Under this regime, mixing reduces stratification and allows nutrients to be entrained into the surface layer from below generating primary production. Thus, during the nutrient-limited regime, reduction of stratification is necessary for production.

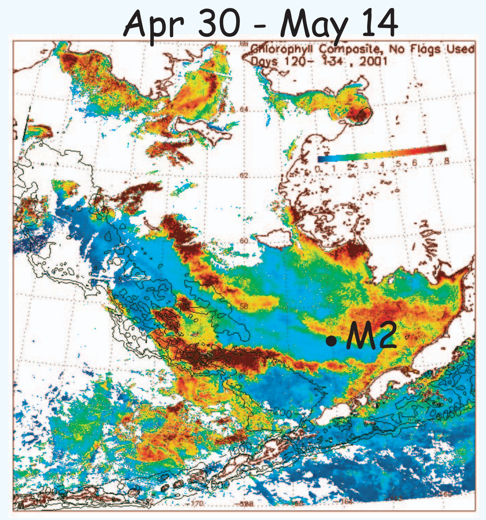
Stratification has been estimated from the model output as the maximum in the vertical derivative of temperature. Stratification is typically very low throughout May and into June. High interannual variability is apparent in both the timing of the onset of stratification and in the strength of summer stratification. **The early 1970s stand out as years with very late stratification onset and weak stratification throughout the summer.** That would imply a late spring bloom and potentially increased summer production. Recent years show early stratification onset.

STRATIFICATION (BLOOM) DATE

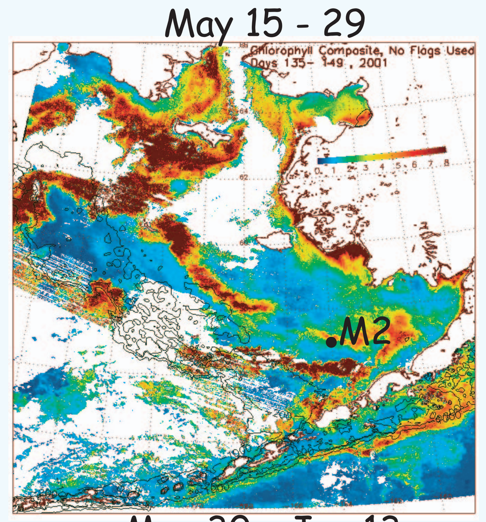
Stratification Date (Model) vs Observed Fluorescence



Apr 30 - May 14

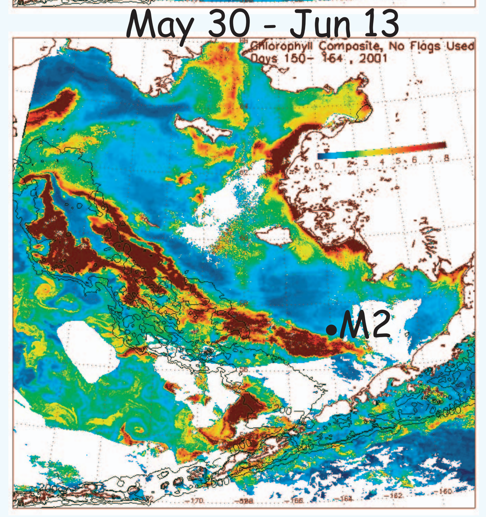


May 15 - 29



2001 SeaWiFS chlorophyll (model stratification date: 15 May 2001)

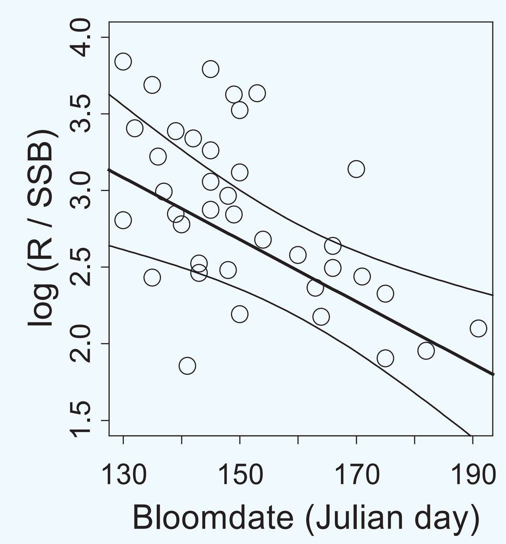
May 30 - Jun 13



The high degree of spatial and temporal variability in chlorophyll concentrations suggests that the model stratification date may be a better representation of mean conditions on the middle shelf than fluorescence data at M2.

Using the model output, we defined a stratification date as the first date when the depth of maximum stratification shoaled to less than 25 m and the temperature difference across the thermocline remained stronger than 0.2 °C m^{-1} for more than one day. These values were based on Sambrotto et al. (1986), who found that, in the ice-free years of 1979-1981, bloom conditions were always preceded by shoaling of the mixed layer above the bottom of the 0.1% light level euphotic zone. The model derived stratification date corresponds to periods of increasing fluorescence (blooming conditions) in most years.

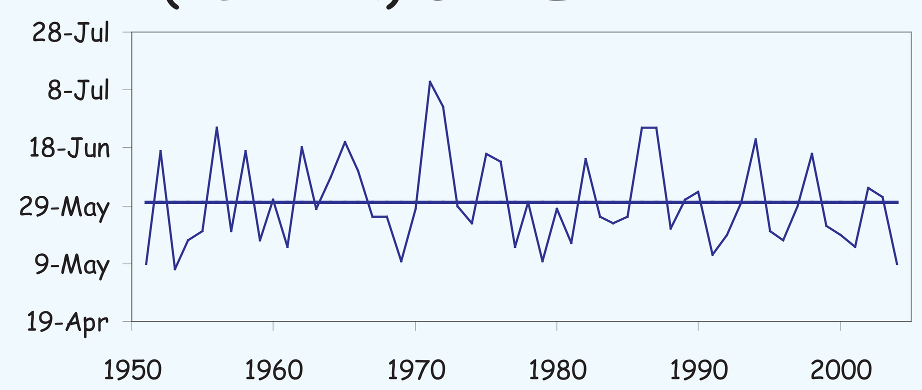
The timing of the open-water spring bloom appears critical to pollock (both first-feeding larvae and juveniles emerging from their first winter). **Mueter et al. (2005) found that when the estimated stratification date was delayed past the beginning of June (approximate Julian day 160) survival during the early juvenile stage was generally below average.**



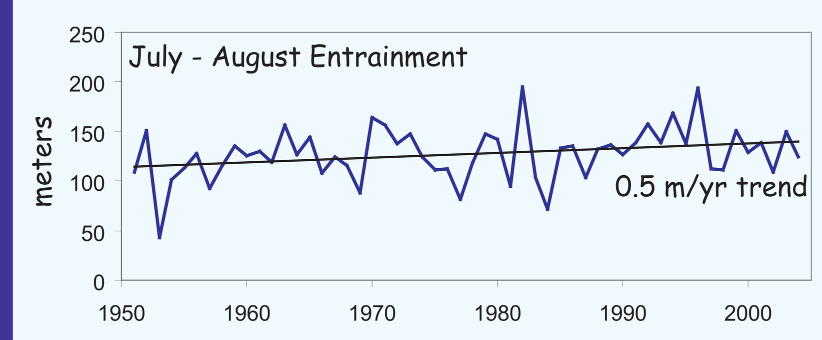
Estimated relationship between log-survival (log(R/SSB)) and bloom date, where R is recruitment and SSB is female spawning stock biomass . Relationship was adjusted for effects of SSB and wind mixing on log-survival based on multiple regression of log-survival on SSB, bloom date, and May-Sep wind mixing. From Mueter et al. (2005).

STRATIFICATION (BLOOM) DATE

The time series of the date of the onset of stratification shows high interannual variability. Over the 54 years of model runs, the average bloom date is 30 May. **The early 1970s stand out as a period of late blooms, consistent with the cold temperatures observed during that time. The recent warm years have resulted in earlier bloom dates.**



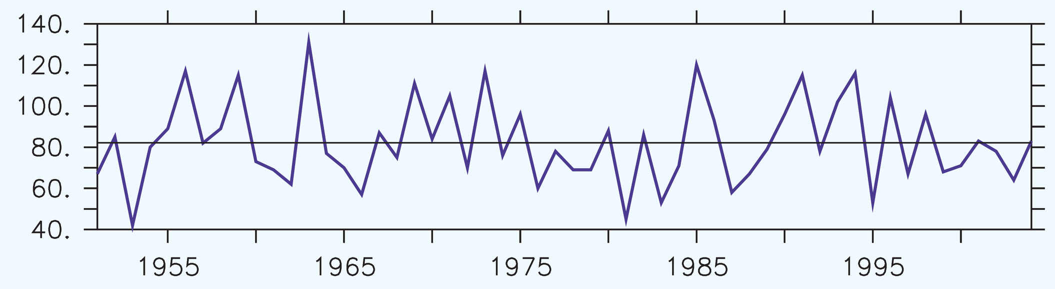
SUMMER ENTRAINMENT



Bond and Overland (2005) suggest that strong summer wind mixing may positively influence Pollock year class strength due to enhanced production resulting from the flux of nutrients into the mixed layer. As an estimate of the cumulative amount of mixing (which we will call entrainment) over the summer, we calculate the daily change in mixed layer depth, and then sum the amount of mixed layer deepening for each deepening event over July – August. This calculation integrates the effects of wind mixing and ocean stratification.

Linear regression suggests a marginally significant increase in entrainment over time (0.5 m/yr). This is surprising as summer winds have not been increasing. However, entrainment is a complicated process dependent on the depth of the mixed layer and the strength of stratification as well as the strength of wind mixing.

SEPTEMBER ENTRAINMENT



September entrainment

September entrainment is essentially a measure of the timing of the autumn transition. In recent years, **September entrainment has been decreasing implying that the fall transition is occurring later. A fall bloom usually occurs at the fall transition due to the increased wind mixing. If the fall transition occurs later, the decreasing amount of daylight may limit the magnitude of the fall bloom.**

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