

low. In the 1990s the numbers have increased moderately. The size-at-age for 25 years (mid 1960s- late 1980s) has been increased gradually. To the early 1990s the size of herring has been similar to that for the 1940s. Thus, the most favorable conditions for growth of Korf-Karaginsky herring usually have been created at a moderate abundance of mature fish in the population. Under the extreme conditions (too high or too low stock abundance) individual growth has been slow.

The most important factor determining individual growth is food supply. In the 1950s - 1980s average zooplankton biomass in Olyutorsky Bay

and average dimension (length and mass) of 4-10 years-old fish demonstrate synchronic variations (Fig. 23 and 24). In the periods when the biomass of zooplankton was increasing, the length and the mass of mature herring increased as well, and *vice versa*. A reliable direct correlation has been found between these patterns. The character of the correlation indicates that a zooplankton biomass increase of 100 mg/m³ corresponds to a length increase of 2.5 mm and to the mass increase of 10 g in average in all age groups. Thus, the size-at-age variations of Korf-Karaginsky herring demonstrate cyclic dynamics. The stock abundance and forage base conditions influence the growth of fish considerably.

Effects of climate on Pacific herring, *Clupea pallasii*, in the northern Gulf of Alaska and Prince William Sound, Alaska

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Introduction

Links between trends of North Pacific fish populations and climatic variations are well documented. One well-known example is the exceptional salmon production in the North Pacific that occurred during a period associated with an intensified Aleutian Low: high levels of salmon production are strongly correlated with the Pacific Decadal Oscillation (PDO) (Mantua *et al.* 1997), with Alaskan stocks responding positively to the positive phases of the PDO.

Pacific herring (*Clupea pallasii*) also appear to respond to climate. A negative correlation exists between southern British Columbia (BC) herring year-class strength and warm conditions; warm conditions appear to increase piscivory on herring and reduce zooplankton food resources (Ware 1992). The same negative correlation was later reported by Hollowed and Wooster (1995) with higher average recruitment for Vancouver Island herring during cool years associated with a weakened winter Aleutian Low (AL). However, the opposite effect occurred in northern BC and the Gulf of Alaska (GOA), with increased herring

production during warm years associated with an intensified winter AL (Hollowed and Wooster 1995). Recruitment of Pacific herring in Southeast Alaska is positively associated with warm, wet climate conditions (Zebdi and Collie 1995). This indicates a north-south bifurcation in climate response by Pacific herring populations similar to that observed in Pacific salmon.

This study shows that the trend in abundance of northern GOA Pacific herring appears to be in phase with decadal-scale climate indices. Population parameters such as growth and spawn timing also appear to be related to climatic signals and may be in opposition to responses by Pacific herring from more southern locations.

Results

An index of GOA herring abundance was developed by combining historic fisheries catches with recent biomass estimate (Fig. 25). Herring abundances were compared to several climate indices and good, positive correlations were found for the Atmospheric Forcing Index (AFI) and Aleutian Low Pressure Index (ALPI) (Beamish

and Bouillon 1993), the Pacific Inter-Decadal Oscillation (PIDO) (Enfield and Mestas-Nunez 1999) and the winter time Pacific Decadal Oscillation (PDO) (Mantua et al. 1997). The abundance of herring in Prince William Sound over the period 1973-present was well-correlated with these indices (Fig. 26), as was the composite herring time series (from 1900-present) (Fig. 27). The common result was high population levels during the positive phases of the three indices. The positive phases correspond in general to intensification of the Aleutian Low, higher sea surface temperatures, and increased storms and wind stress in the GOA. A strong Aleutian Low causes above-average water column stability in the sub-arctic Pacific, creating conditions that optimize primary and secondary production and thus may be the mechanism involved in the positive response of zooplankton and Pacific herring, as previously hypothesized for salmon.

Herring size-at-age trends exhibited oscillatory behavior with a maximum spectral density at a period of 13 years for all ages (Fig. 28). There was no evidence of density-dependence as plots of size and biomass levels were flat for each age examined. The spectral peak was strongest in ages 3-5. The raw and smoothed (using the Hamming filter) size-at-age data was significantly correlated to peak zooplankton density lagged one year ($p < 0.05$; $r \geq 0.50$; Fig. 28). Peak and average zooplankton biomass was significantly correlated to the winter PDO lagged 3 yrs ($r = 0.52$ and 0.65

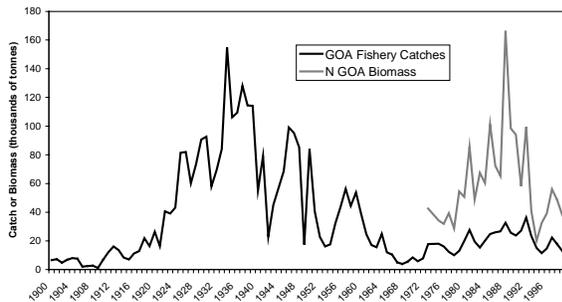


Fig. 25 The two types of fishery data used in this analysis. The solid black line is total annual Gulf of Alaska (GOA) fishery catches. The grey line represents the annual biomass estimates for Prince William Sound (see Brown and Funk for details).

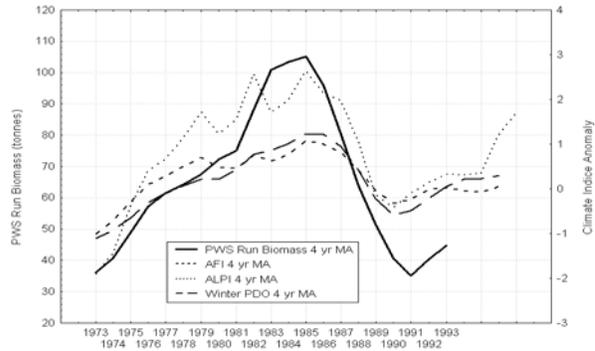


Fig. 26 A 4 year moving average (ma) transformation of the Prince William Sound (PWS) biomass index compared to the AFI, the ALPI and the winter PDO for the period of 1973 to 1993.

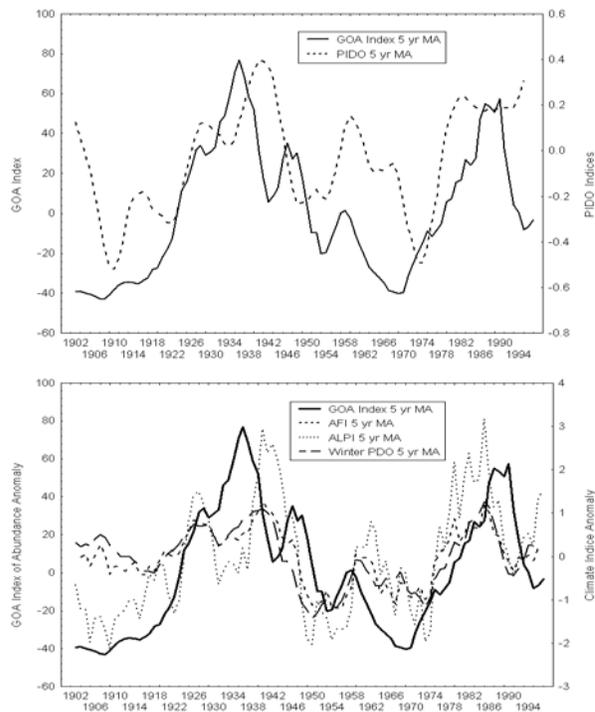


Fig. 27 A 5 year moving average (ma) transformation of the Gulf of Alaska (GOA) Index, created by combining catch and biomass, compared (upper panel) to a 5 year ma of the Pacific Inter-Decadal Oscillation and (lower panel), 5 year mas of the AFI, ALPI and winter PDO plotted for the period of 1902 to 1995.

respectively). Size-at-age for ages 7 and 8 were also significantly correlated to both the PDO lagged 3 years ($r = 0.55$) and the PIDO lagged 2 years ($r = 0.61$).

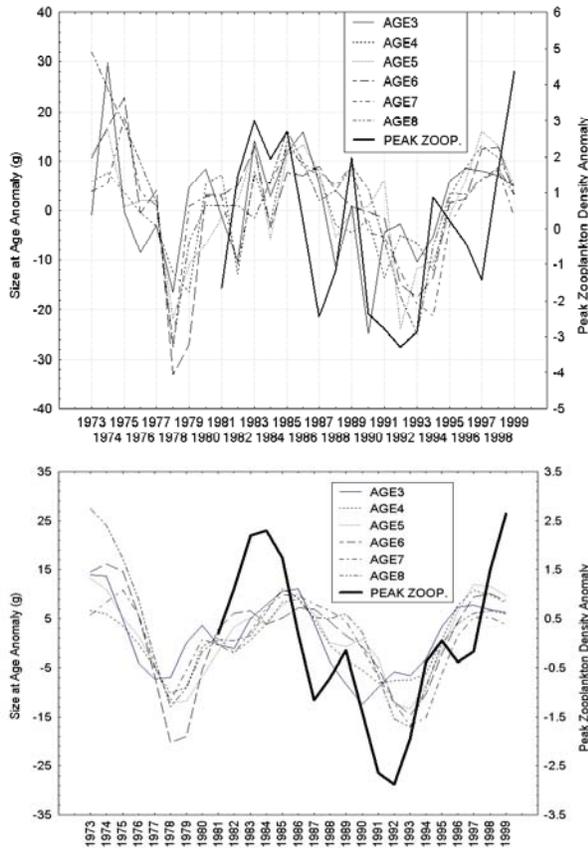


Fig. 28 Size-at-age by weight (g) of age 3-8 Pacific herring from PWS plotted with peak zooplankton density anomalies (from southwestern PWS) for the period of 1973 to 1999. The top figure are the raw values. The bottom figure shows a spectral transformation (type Hamming) of the size-at-age data plotted with a 4 year moving average transformation of the peak zooplankton anomalies.

There is an overall downward trend in spawn timing from 1973 to 1999 with mean spawn dates approximately 7 days earlier in the late 1990s than in the early 1970s (Fig. 29). Although not significantly correlated, there is a corresponding downward trend in PWS surface salinity during September and October, lagged 6 months from spawning, over the same period. There was no apparent relationship between spawn timing and either population size or climate trends. Spawn

timing is affected by maturity rate that is in turn directly affected by ocean conditions, especially 6-9 months prior to spawning.

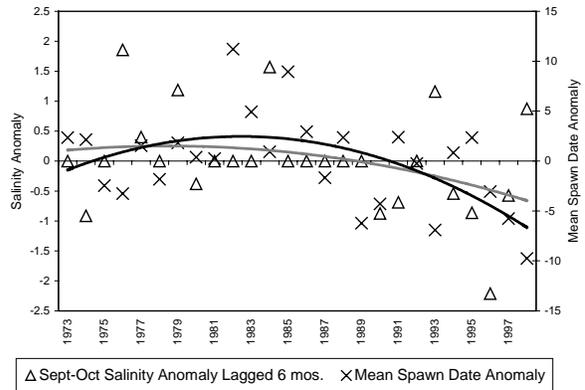


Fig. 29 Surface salinity (at 20 m) anomalies with a 6 month lag, for the combined months of September and October are plotted with the mean date of spawning anomaly for PWS for the period of 1973 to 1999. The solid lines represent 2nd order polynomial transformations of the mean spawn date (black) and salinity (grey). Note that black line is polynomial (2nd order) trend line for mean spawn date anomaly and the gray line is polynomial (2nd order) trend line for PWS Sept.-Oct. SSS anomaly

Spawning areas have also shifted over the same time period accompanied by a trend in reduced recruit per spawner rates. The implications of these observations are discussed more fully in Brown and Funk (unpublished manuscript).

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Herring size-at-age variation in the North Pacific

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Introduction

Herring have been one of the more important components of the marine fisheries on the west coast of North America over the past century. Dramatic population fluctuations are common in all stocks of herring but virtually all populations from Alaska to California declined dramatically and synchronously in the late 1960s and all have subsequently recovered. Despite the impacts of a significant harvest in most of these stocks, large scale environmental forcing appears to have been a significant factor in the observed population fluctuations. However, it is unclear what mechanisms were involved in affecting survival over such a broad geographical scale. Long time series of stock abundance estimates are not available for most of these populations. Instead, we investigated the available data on fish size and growth, reviewing trends in weight-at-age, condition factor, and growth increments of Pacific herring from Alaska to California in relation to environmental conditions or food supply to assess whether these factors may have affected herring survival in the North Pacific.

Methods

Pacific herring weight-at-age data were collated for a number of stocks in the North Pacific (Fig. 30) ranging from the Bering Sea [Togiak] through the Gulf of Alaska (Kodiak], Prince William Sound [PWS]), SE Alaska [Sitka], British Columbia (Queen Charlotte Islands [QCI], Prince Rupert [PRD], Central Coast [CC], Strait of Georgia [GS], west coast of Vancouver Island [WCVI]), and California (San Francisco Bay [SFB], Tomales Bay [TB]). Unfortunately, the available data is sparse in many cases and generally available for only limited time periods restricting the type and extent of statistical analyses possible. The time period investigated for this study ranges from 1940-2000. For some populations both length and weight at age data are available and for those we examined changes in condition factor. For all populations trends in weight at age 4 were examined as well as trends in the annual growth increment at age over time.

The condition factor was also calculated annually for each age-class in each stock following Tesch (1988), as:

$$CF_t = \frac{Weight_{at}}{Length_{at}^3}$$