2007 Gulf of Alaska Walleye Pollock Year-Class Prediction: Average Recruitment

26 September 2007

DATA

This forecast is based on five information sources: two physical properties and two biological data sets. The information sources are:

1. Observed 2007 Kodiak monthly precipitation. The Kodiak National Weather Service office (http://padq.arh.noaa.gov/) prepares monthly precipitation totals (inches) from hourly observations. Data for 2007 were obtained from the NOAA National Climate Data Center, Asheville, North Carolina.

2. Wind mixing energy at [57°N, 156°W] estimated from 2007 sea-level pressure analyses. Monthly estimates of wind mixing energy (W m^{-2}) were computed for a location near the southwestern end of Shelikof Strait. To make the estimates, twice-daily gradient winds were computed for that location using the METLIB utility (Macklin *et al.*, 1984). Gradient winds were converted to surface winds using an empirical formula based on Macklin *et al.* (1993). Estimates of wind mixing energy were computed using constant air density (1.293 kg m^{-3}) and the drag coefficient formulation of Large and Pond (1982).

3. Advection of ocean water near Shelikof Strait inferred from drogued drifters deployed during the spring of 2007.

4. Rough estimates of pollock larvae abundance from a survey conducted in late May–early June 2007.

5. Estimates of age-2 pollock abundance and spawner biomass from the 2007 assessment.

ANALYSIS

Kodiak Precipitation*:* Kodiak precipitation is a proxy for fresh-water runoff that contributes to the density contrast between coastal and Alaska Coastal Current water in Shelikof Strait. The greater the contrast, the more likely that eddies and other instabilities will form. Such secondary circulations have attributes that make them beneficial to survival of larval pollock.

Kodiak precipitation for the first half of 2007 showed extreme behavior compared to the 30-year average. The season began with a greater than seasonal drying trend from January through March (Table 1), with March being the fourth driest March since these records began in 1962. This diminished the potential for formation of baroclinic instabilities prior to and during spawning. April and May brought record rain, with April 2007 being the all-time wettest April and May 2007 the fourth wettest since 1962. June was near normal. The spring may have presented favorable habitat for late larval- and early juvenile-stage walleye pollock, although one might question the contribution of such extreme rain to favorable larval survival.

TABLE 1. Kodiak precipitation for 2007.

Month	% 30-yr average
Jan	121
Feb	67
Mar	25
Apr	298
May	213
June	72

Based on this information, the forecast element for Kodiak 2007 rainfall has a score of 2.58. This is "average to strong" recruitment on the 5-category continuum from 1 (weak) to 3 (strong), and “strong” using three categories.

Wind Mixing*:* Wind mixing at the southern end of Shelikof Strait was below the long-term average for the first two months of winter, near to above average for the end of winter and beginning of spring, and low for the final two months of spring 2007 (Table 2).

TABLE 2. Wind mixing at the exit of Shelikof Strait for 2007.

Month	% 30-yr average
Jan	77
Feb	39
Mar	103
Apr	135
May	44
June	36

Strong winds in winter help mix nutrients into the upper ocean layer to provide a basis for the spring phytoplankton bloom. Weak spring mixing is thought to better enable first-feeding pollock larvae to locate and capture food. Weak mixing in winter is not conducive to high survival rates, while weak mixing in spring favors recruitment. This year’s scenario produced a wind mixing score of 1.96, which is “average”.

Winds and Transport in the Alaska Coastal Current: The transport in the Alaska Coastal Current is strongly correlated with along shore winds. Winds in March 2007 were above average and rainfall during April and May was above average. The combination of these high winds and increased freshwater input contributed to conditions of above average advection. Strong flows would tend to advect the larvae downstream out of the preferred nursery grounds in the Shelikof Sea valley and into the basin.

Based on these observations, the 2007 pollock year-class prediction from transport information would indicate a below average year class. Based on transport in the Alaska Coastal Current, we give this element a score of 0..83, which equates to the middle of the range for the weak category.

***Relating the Larval Index to Recruitment**:* As in previous analyses, a nonlinear neural network model with one input neuron (larval abundance), three hidden neurons, and one output neuron (recruitment) was used to relate larval abundance (CPUA, average catch, m^{-2}) to age-2 recruitment abundance (billions). The model estimated eight weighting parameters.

The neural network model, which used the 21 observation pairs of Table 3 to fit the model, had a very low R^2 of 0.017. A plot of the observed recruitment (actual) and that predicted from larval abundance (predicted) is given in Fig. 1, where row number corresponds to the rows of the data matrix given in Table 3 and thus indicates year class.

TABLE 3. Data used in the neural network model.

Year Class	Mean CPUA	Recruit
1982	71.14	0.212014
1985	80.42	0.563229
1987	329.74	0.381621
1988	260.21	1.63617
1989	537.29	1.02169
1990	335.00	0.408532
1991	54.22	0.243326
1992	562.79	0.147321
1993	185.34	0.223502
1994	126.58	0.865454
1995	610.33	0.41281
1996	477.69	0.176586
1997	568.42	0.160661
1998	72.20	0.219708
1999	96.14	0.862862
2000	492.04	0.774696
2001	171.30	0.120526
2002	175.64	0.11364
2003	135.36	0.130498
2004	21.22	0.731638
2005	76.22	0.482537

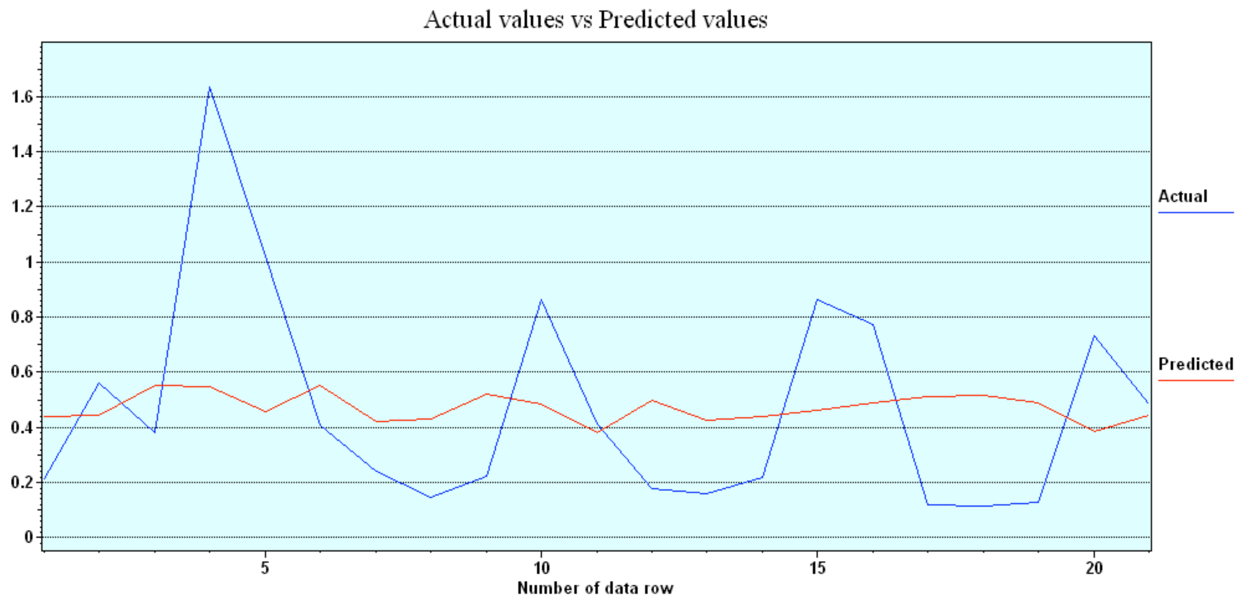

FIGURE 1. Observed and predicted recruitment values from the larval index-recruitment neural network model.

The trained network was then used to predict the recruitment for 2006 and 2007. The predictions are given in Table 4.

TABLE 4. Neural network model predictions for 2006 and 2007.

Year	Actual Recruitment	Predicted Recruitment
2006	n/a	0.531147
2007	n/a	0.445912

These values, using the 33% (0.3547) and 66% (0.7287) cutoff points given below, correspond to an average 2006 year class and an average 2007 year class or a score of 2.0.

Larval Index Counts: Plotting the larval abundance data by year and binning the data into catch/10 m^2 categories (given below) provides another view of the data. The pattern for 2007 (based on rough counts) show patterns different from last year in that the frequency distribution is skewed towards lower binning categories (Figure 2). These patterns indicate that the 2007 year class may be below average.

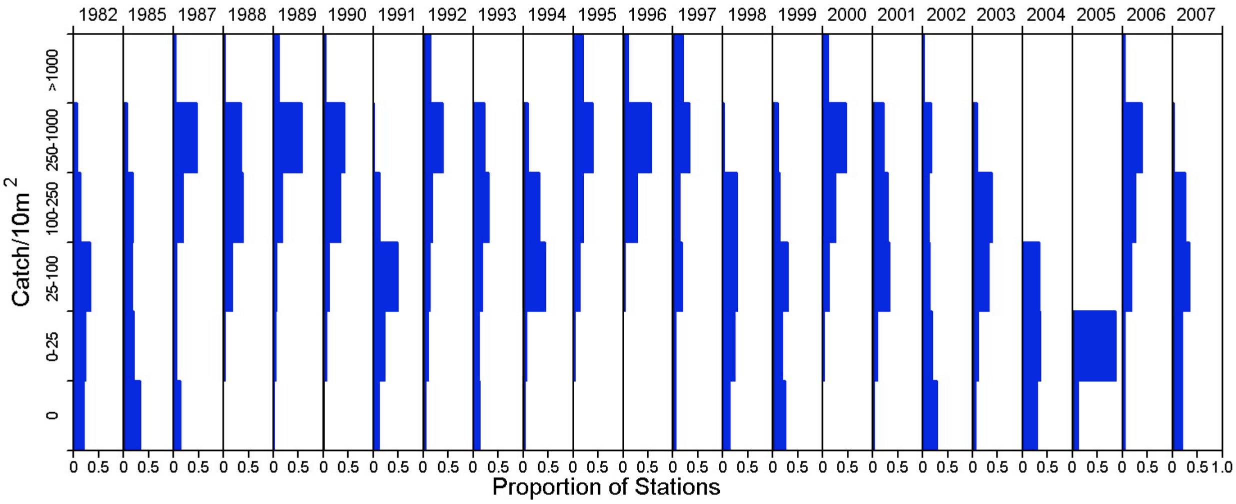

FIGURE 2. A series of histograms for larval walleye pollock densities in late May from 1982 to 2007. Data were binned into catch/10 m^2 categories. The data from 2000-2005 are actual verified larval counts, 2006 are unverified counts from the Polish Plankton Sorting Institute, and 2007 data are rough counts from the 5MF07 FRV *Miller Freeman* survey cruise that was completed in late May.

The data for Figures 3, 4, 5 and 6 are taken from a reference area that is routinely sampled and that usually contains the majority of the larvae. This year's distribution of pollock (Fig. 6) appears to be centered in the typical reference area, and the larval abundance figures in the middle of the reference area seem to be average. Comparing the catch rates (Fig. 2) shows that the 2007 rough counts seem to be distributed to lower values compared to 2006, and the distribution of larvae in 2007 (Fig. 6) compared to last year (Fig. 5) was spatially similar. Given these two pieces of information, the score for larval index is set to the low end of average or 1.67.

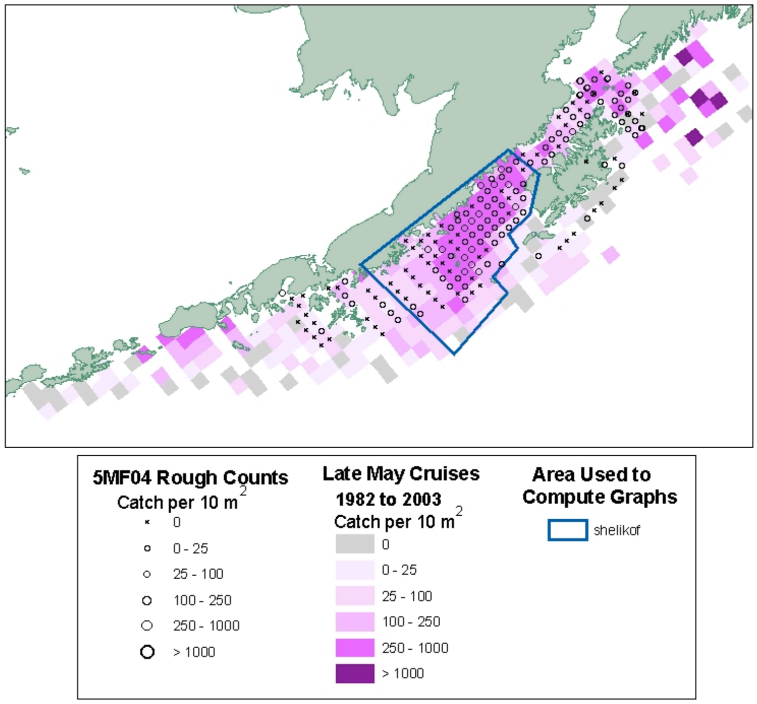

FIGURE 3. Mean catch per 10 m^2 for late May cruises during 1982-2003, with observed rough counts overlayed for 2004.

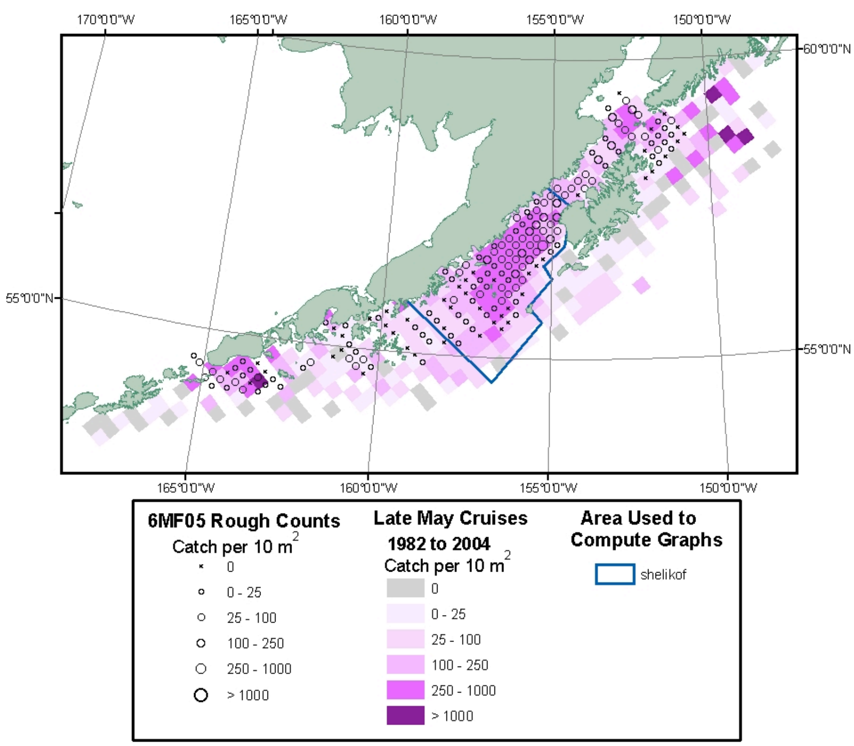

FIGURE 4. Mean catch per 10 m^2 for late May cruises during 1982-2004, with observed rough counts overlayed for 2005.

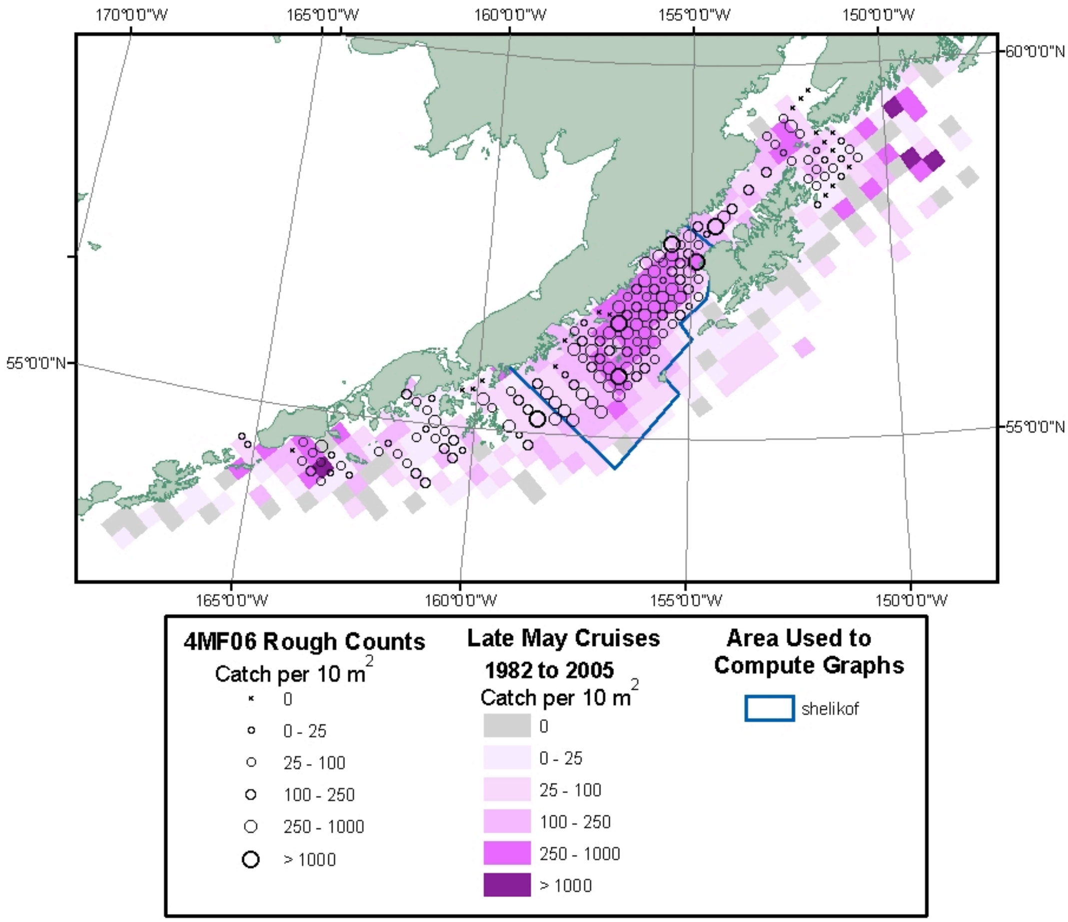

FIGURE 5. Mean catch per 10 m^2 for late May cruises during 1982-2005, with observed rough counts overlayed for 2006.

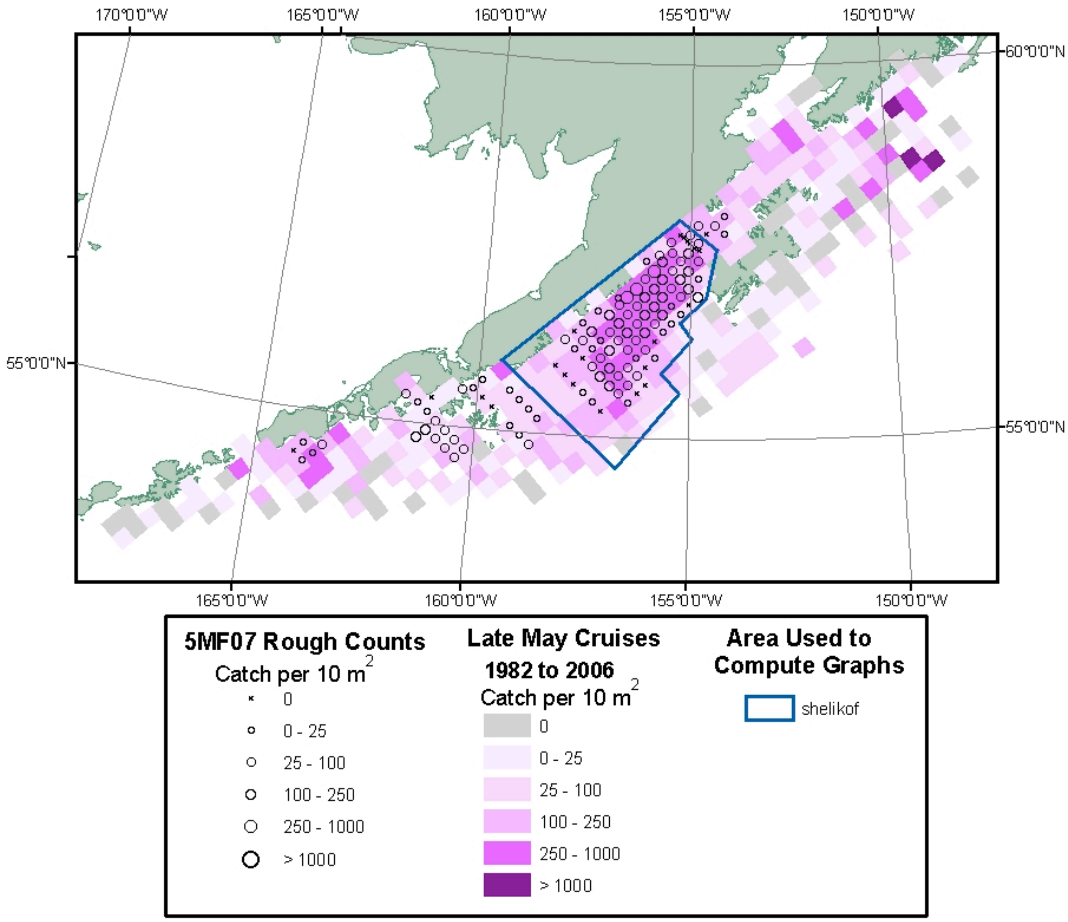

FIGURE 6. Mean catch per 10 m^2 for late May cruises during 1982-2006, with observed rough counts overlayed for 2007.

Recruitment Time Series: The time series of recruitment from this year's assessment was analyzed in the context of a probabilistic transition in time. The data set consisted of age-2 pollock abundance estimates from 1961-2007, representing the 1959-2005 year classes. There were a total of 47 recruitment data points. The 33% (0.354736 billion) and 66% (0.728742 billion) percentile cutoff points were calculated from the full time series and used to define the three recruitment states of weak, average and strong. The lower third of the data points were called weak, the middle third average and the upper third strong. Using these definitions, nine transition probabilities were then calculated:

1. Probability of a weak year class following a weak
2. Probability of a weak year class following an average
3. Probability of a weak year class following a strong
4. Probability of an average year class following a weak
5. Probability of an average year class following an average
6. Probability of an average year class following a strong
7. Probability of a strong year class following a weak

8. Probability of a strong year class following an average
9. Probability of a strong year class following a strong

The probabilities were calculated with a time lag of two years so that the 2007 year class could be predicted from the size of the 2005 year class. The 2005 year class was estimated to be 0.482537 billion and was classified as average. The probabilities of other recruitment states following an average year class for a lag of 2 years (n=47) are given below:

TABLE 5. Probability of the 2007 year class being weak, average and strong following an average 2005 year class.

2007 Year Class		2005 Year Class	Probability	N
Weak	Follows	Average	0.13333	6
Average	follows	Average	0.08889	8
Strong	follows	Average	0.08889	8

The probability was highest for a weak year class following an average year class and almost twice the other two probabilities. We classified this data element to be in the weak category but toward the higher end of the range, giving it a score of 1.66.

***Spawner/Recruit Time Series**:* The data from the previous analysis only looked at the time sequence of the recruitment data points. This section looks at both the recruitment (R) and the spawning biomass (SB) in the context of transition probabilities after Rothschild and Mullin (1985). The benefit is that it is non-parametric, and it provides a way to predict recruitment without applying a presumed functional spawner-recruit relationship. It involves partitioning the spawning stock into N-tiles and the recruitment into N-tiles, classifying the stock into NxN states. We used the 50% percentile of the data to calculate the median spawning biomass (0.2377 million tons) and recruitment (0.4475 billion). These values were used to partition the spawner-recruit space into 4 states. State 1:low SB-low R, state 2:low SB-high R, state 3:high SB-low R, and state 4:high SB-high R. These areas correspond to the lower left, upper left, lower right, and upper right quadrants of the lower panel in Figure 7. The classification then makes it possible to study the probability of any state and the transitions between the states.

The time series of recruitment data and the 2x2 spawning biomass-recruitment plot are shown in Figure 7.

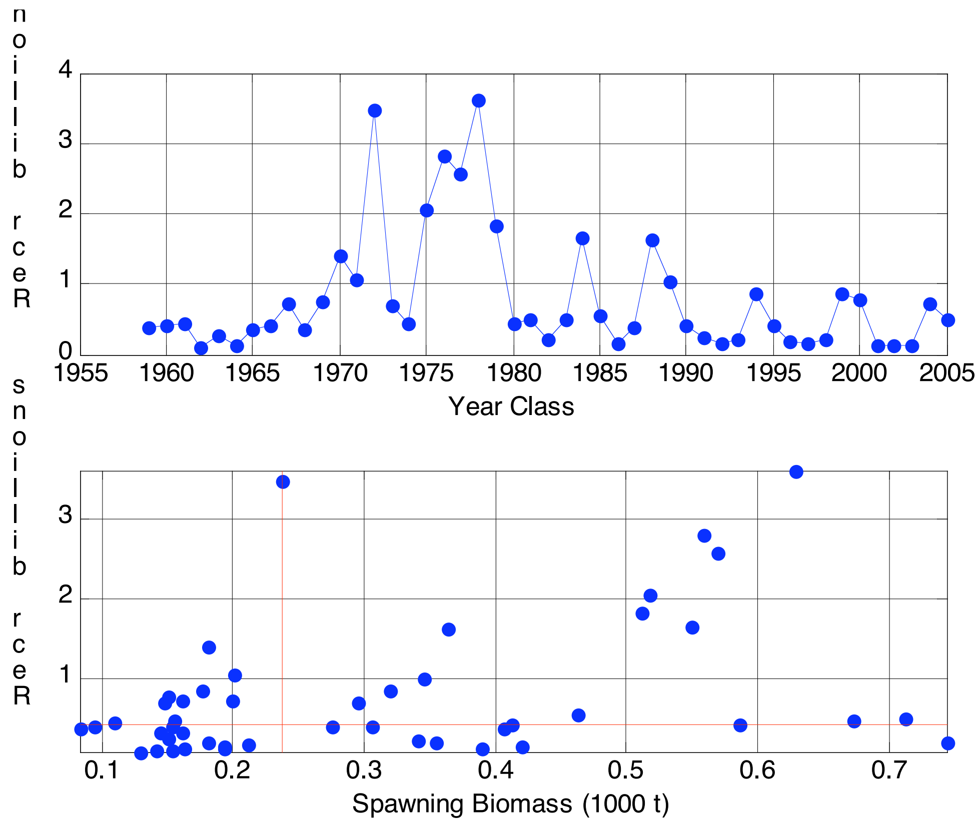

FIGURE 7. Time series of recruitment and the 2x2 classification of the 2007 spawning biomass and recruitment data.

TABLE 6. Transition matrix calculated from data in Figure 7.

Transition Probability Matrix	To state 1	To state 2	To state 3	To state 4
From state 1	0.6429	0.3571	0.0000	0.0000
From state 2	0.3750	0.5000	0.0000	0.1250
From state 3	0.1111	0.0000	0.4444	0.4444
From state 4	0.0000	0.0000	0.3333	0.6667

To calculate the score from Figure 7 takes two steps. First, we determine which state is the current state by taking the estimate of spawning biomass in 2007 (0.15527 million tons) and note that it falls below the median value of 0.2377. We can see that in 2007 we are in either state 1 or state 2 (low spawning biomass). The probabilities of transitioning from state 1 or state 2 to other states are given in the first two rows of Table 6.

If we are in state 1, then recruitment can either be below (a recruitment score of 1) or above (a recruitment score of 3) the median (a recruitment score of 2). Note the probability for transitioning from state 1 to state 3 or 4 is 0.0. If we start in state 1, then the combined recruitment score would be the weighted average of the recruitment scores for each possible transition, where the weighting factors are the transition probabilities. So, the calculations for the second step proceed as described below.

The weighted recruitment score (given we start in state 1) is the recruitment score for staying in state 1 (recruitment below the median, score=1) times the weight (the probability of transitioning from state 1 back to state 1) plus the recruitment score for transitioning from state 1 to state 2 (recruitment above the median, score=3) times the weight (the probability of transitioning from state 1 to state 2), all divided by the sum of the weights.

$$= \frac{(1 * 0.6429) + (3 * 0.3571)}{(0.6429 + 0.3571)} = 1.714$$

Similarly, the weighted recruitment score (given we start in state 2) is the recruitment score for staying in state 2 (recruitment above the median, score=3) times the weight (the probability of transitioning from state 2 back to state 2) plus the recruitment score for transitioning from state 2 to state 1 (recruitment below the median, score=1) times the weight (the probability of transitioning from state 2 to state 1), plus the recruitment score for transitioning from state 2 to state 4 (recruitment above the median, score=3) times the weight (the probability of transitioning from state 2 to state 4), all divided by the sum of the weights.

$$= \frac{(3 * 0.5) + (1 * 0.375) + (3 * 0.125)}{(0.5 + 0.375 + 0.125)} = 2.25$$

We average over these two weighted scores because starting from either state 1 or state 2 is equally likely if the starting spawning biomass in 2007 is below the median, giving a final score of 1.98, or average.

One final calculation possible from these data is the expected first passage time or the number of years on average that a stock and recruitment system in a particular state will take to return to a particular state. These data are given in Table 7. For example, it would take 8.0 years for Gulf of Alaska pollock in State 2 to return to State 1.

TABLE 7. Expected First Passage Time.

State	1	2	3	4
1	3.8571	2.8000	22.2000	19.2000
2	8.0000	5.4000	19.4000	16.4000
3	21.0000	23.8000	4.8000	5.6400
4	24.0000	26.8000	3.0000	2.8800

CONCLUSION

The larval index data element was weighted low (0.1) because the recruitment variability explained by larval abundance was very low. All the remaining elements were weighted equally.

Based on these seven elements and the weights assigned in Table 8, below, the FOCI forecast of the 2007 year class is average.

TABLE 8. Final 2007 pollock recruitment forecast.

Element	Weights	Score	Total
Rain	0.15	2.58	0.3870
Wind Mixing	0.15	1.96	0.2940
Advection	0.15	1.33	0.1995
Larval Index-abundance	0.10	2.00	0.2000
Larval Rough Counts and Distribution	0.15	1.67	0.2505
Time Sequence of R	0.15	1.66	0.2490
Spawner-Recruit Time Series	0.15	1.98	0.2970
Total	**1.00**		**1.877= Average**

ADDENDUM

The information provided below is not used in the forecast but is presented for additional perspective. Figure 8 shows the latest and preliminary data on pollock from the 2007 late larval survey put into a historical context. Total larval numbers track the spawning biomass in the western and central GOA (Fig. 9) (taken from the 2006 SAFE report) fairly well. These trends follow estimates of spawning biomass from acoustic surveys (Fig. 10). We note that the 2007 numbers continue to trend in low numbers. It seems that since about 2002 we have been in a phase of very low larval numbers. Strong recruitment can arise from such low numbers for a number of reasons, for example, 1) a strong year class may be hidden in the total numbers but is better reflected by the size structure of the larval population, 2) lack of overlap in predators and prey may relax predation on juveniles to generate a strong cohort, especially in the current regime when predation seems very strong, or the 3) recruits are coming from or going to someplace else.

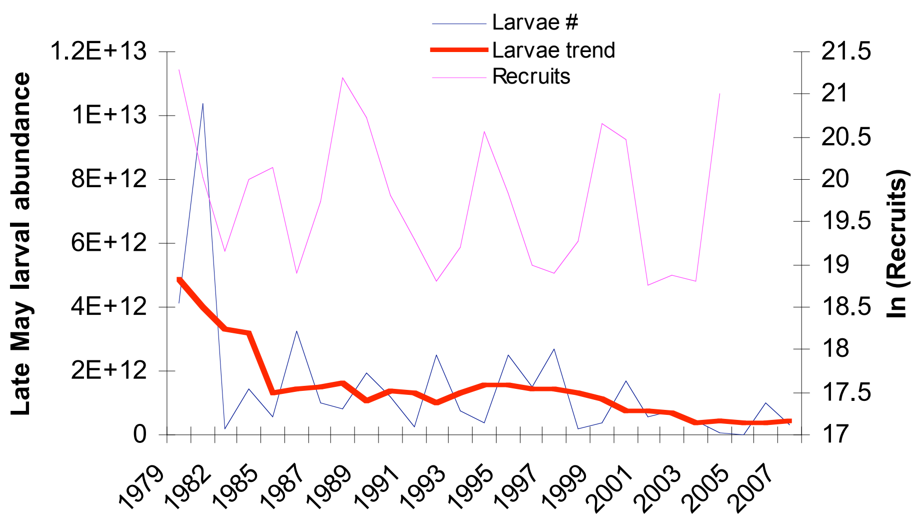

FIGURE 8. Late May larval abundance and running mean trend (red) in the Shelikof to Semidi region compared against the number of recruits.

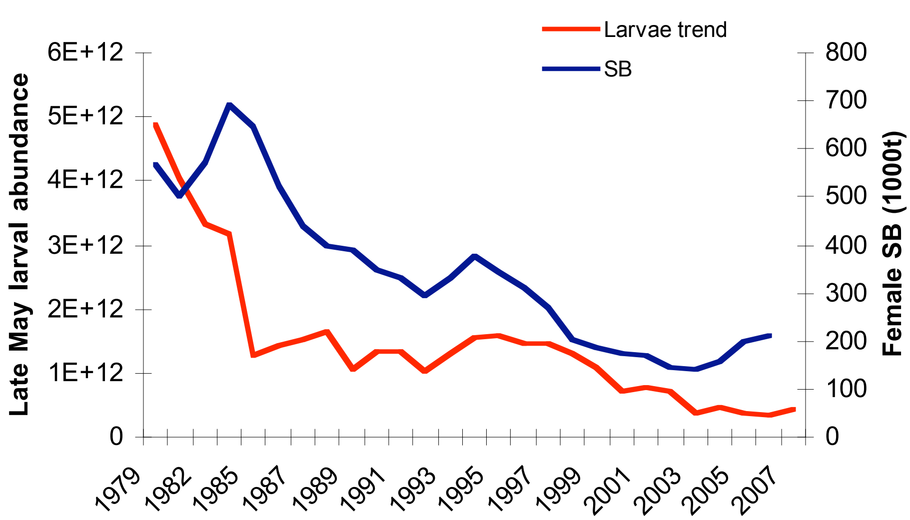

Figure 9. Late May larval abundance trend in the Shelikof to Semidi region (red) compared against the spawning biomass in the Gulf of Alaska (blue).

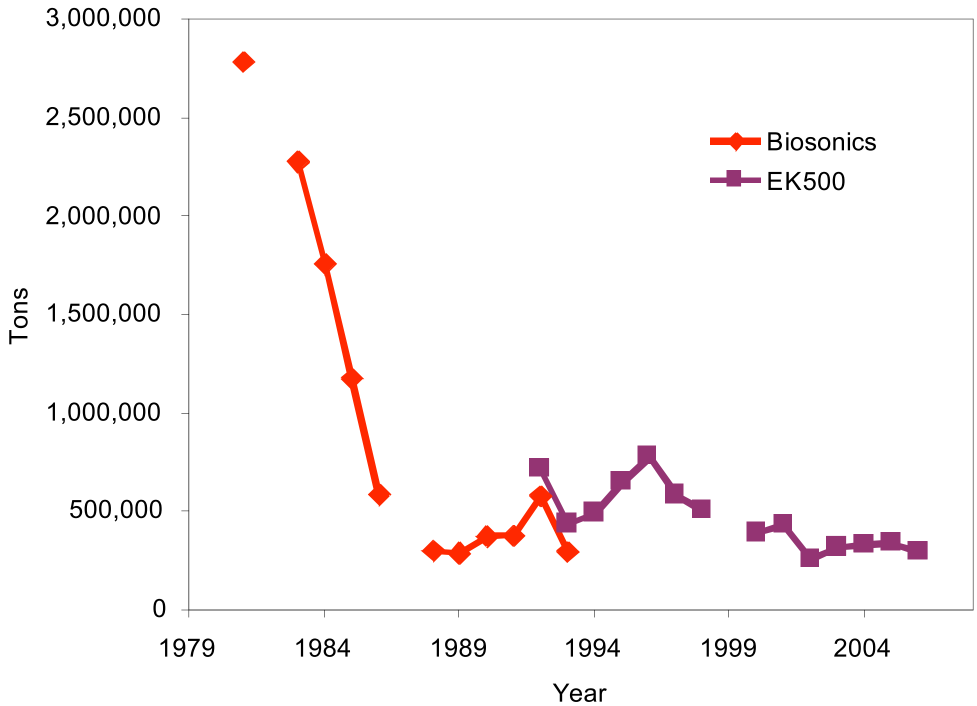

Figure 10. Comparison of estimates of GOA spawning biomass (tons) from AFSC hydroacoustic surveys using two different sets of instruments.

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