Final Report for the "Project to improve rebuilding plans for west coast fish stocks through inclusion of climate information"

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Introduction

Rebuilding plans are required by the U.S. Sustainable Fisheries Act (1996) for stocks that are designated to be overfished, including several stocks of groundfish on the U.S. West Coast. Despite evidence for climate effects on groundfish recruitment, the analyses that underlie rebuilding plans have typically ignored those effects. The goals of this project were to identify satellite-based measures of biological, chemical, and/or physical indicators of conditions in the California Current that have influenced recruitment of groundfish species over the past ~50 years and incorporate that information into rebuilding analyses. Three hypotheses about oceanographic effects on recruitment success were identified pertaining to (1) the timing of spring transition, (2) fine-scale spatial variability in ocean conditions, and (3) fine-scale temporal variability in ocean (upwelling) conditions. This report summarizes our findings from testing the first two hypotheses, and from applying the results of the first hypothesis to rebuilding analyses for overfished groundfish stocks. We include a description of the satellite data we found most useful for answering our research questions, and provide advice on what types of satellite data might be most valuable for addressing emerging questions in fisheries science and management. A list of workshops for this project are in Appendix A, including agendas and participants. Summary documents from those workshops are attached.

(1) Defining spring transition

While the physical and ecological importance of the spring transition has been embraced by many, there is no widely agreed upon metric for tracking the phenomenon (Kosro et al. 2006). Most indices of spring transition reflect physical and biological events common to the northern California Current; few pertain to southern regions. One common metric is the timing of the switch from downwelling-favorable winter winds to upwelling-favorable spring/summer winds (Schwing et al. 2006; Barth et al. 2007). Another is the timing of the persistent drop in coastal sea level from high levels characteristic of warm, winter, downwelled waters, to a lower level characteristic of cool, spring/summer, upwelled waters (Kosro et al. 2006; Strub et al. 1987; Bilbao 1999). Other metrics include the timing of a reversal in current direction off Vancouver Island (Thomson and Ware 1996), changes in the cross-shore pressure gradients indicating the development of a spring equatorward jet (Lynn et al. 2003), variations in the spatial structure of sea-surface temperatures (SST) off California from isotherms primarily perpendicular to the coast in winter, to isotherms parallel to the coast in summer (Lynn et al. 2003), increases in chlorophyll-a concentrations (Lynn et al. 2003), and shifts in zooplankton species composition from species found predominantly in southern regions (in winter) to those found in northern regions (in summer) (Peterson, http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/ec-biological-spring-trans.cfm).

The goals of this aspect of the project were to compare two commonly used methods for identifying spring transition in the California Current that use data on wind-driven upwelling and coastal sea levels to two newly developed methods that use those data as well as satellite-derived SSTs, and more specifically, to assess whether methods typically used in northern regions of the California Current can be applied to southern regions. In more detail, those methods were: (1) start of the upwelling season based on a shift in the prevailing direction of coastal winds (Schwing et al. 2006), (2) the method of

Logerwell (2003) (adapted from Bilbao (1999)) that combines information on coastal upwelling winds and sea levels (henceforth the Logerwell method), (3) a modified version of the Logerwell method that uses the rate of decline in low-pass filtered coastal sea levels, and (4) the date of steepest change in an index of spatial patterns in sea-surface temperatures (smoothed amplitudes of first EOF of SST fields) (see Figs. 1 and 2 for daily time series for an example year, 1999). In addition, we used spatial variability in magnitude and direction of winds (derived from QuickSCAT satellite data) to explain differences in coastal upwelling, sea levels, and SSTs among regions.

Our results suggest that using the Logerwell method, or the wind-derived indices alone (modified Logerwell method), provides an informative index of spring transition in the northern region. These metrics, however, may not be appropriate for the south because of diminished, intermittent, or absent winter downwelling in that region (e.g., Fig. 2a). For 8 of 38 years, either smoothed time-series of upwelling (Bakun winds) remained positive during the winter or smoothed time-series of sea levels remained below their long-term mean. Furthermore, for most years in that region, the timing of onset of upwelling favorable winds differed from the timing of declines in sea levels (e.g., Fig. 2b). In contrast, we were able to identify dates of spring transition in both northern and southern regions using our modified version of the Logerwell method (Figs. 1c and 2c). That method had two additional advantages. The choice of the date of steepest decline in low-pass filtered time series of sea levels was more objective than the date chosen using the Logerwell method in years when multiple dates of zero-crossing existed in the time series of Bakun upwelling and sea-level residuals. In those years, the choices of dates of spring transition for the Logerwell method were somewhat subjective. In addition, our method more accurately reflected the date of most rapid change in ocean conditions that defines the spring transition than previous methods that use point thresholds (e.g., declines below the long-term mean sea level).

Although SSTs have been used to characterize the seasonal changes in ocean conditions for specific locations (e.g., southern California, Lynn et al. 2003), those data have not been used to identify coast-wide time series of dates of spring transition. We developed a fourth method to identify those dates based on the dominant spatial patterns in SST fields extracted using Empirical Orthogonal Function (EOF) analysis (as in Armstrong 2000). We removed the spatial mean of SST fields prior to EOF analysis (i.e., examined residuals instead of raw values) because we were interested in spatial patterns independent of seasonal warming common across regions. The first EOF explained 64.1% and 34.0% of the total variation in SST fields in the northern and southern regions respectively, and represented a combination of latitudinal and cross-shore patterns. Higher order EOF axes explained a much smaller portion of the total variance (<20%) and their amplitudes did not vary seasonally, so were not considered further.

For both regions, the amplitude in those spatial patterns (as described by the first principal component, PC1) increased from winter to summer (e.g., Figs. 1d and 2d). The spatial patterns in PC1 (Fig. 3) suggest that nearshore and offshore areas exhibited opposite seasonal trends; nearshore areas were warmer than average during winter and cooler than average in summer (i.e., SSTs were negatively correlated with PC1 trends, reflecting the incursion of cold upwelled water in spring), whereas offshore areas (and nearshore areas around 46ºN and south of 34ºN) show the opposite trend (i.e., SSTs were positively correlated with PC1 trends).

In a subsequent analysis, we divided the southern region into two parts, north and south of Point Conception because of the large divergence in SST patterns between those areas (Figs. 3b and d). The first EOF explained 56.6% and 70.5% of the total variance in SSTs in the northern and southern sections of that region, respectively (i.e., higher proportions than when both areas were combined). Again, for both areas, the amplitude in the spatial patterns (as described by the first principal component, PC1) increased from winter to summer, but the spatial patterns in PC1 differed north and south of Point Conception (as expected from Fig. 3). In particular, SSTs south of Point Conception were cooler than average during winter and warmer than average in summer (i.e., SSTs were positively correlated with PC1 trends, except at the very near shore, Fig. 4). We used PC1 values from the region between Cape Mendocino and Point Conception to represent the southern region in subsequent analyses, since the region south of Point Conception exhibited trends that do not correspond to the wind-driven spring transition event that occurs over most of the U.S. West Coast. In addition, we found that interannual variability in the seasonal trends was greater for the southern regions than in the north (as shown in the Hovmoller plots in Fig. 5).

To identify dates of spring transition, the PC1 time series was smoothed using a low-pass filter (stop-frequency 1/(90 days)), and the initial dates of seasonally persistent upward slope (the dates of maximum rate of change or curvature) of PC1 values were selected. As expected, we found that the direction of the correlation between timing of SST changes and start of upwelling winds was the same in both northern and southern regions (recall, the area south of Point Conception was excluded from the southern region), but the magnitude of that correlation was stronger in the north than the south (top right and bottom left corners of Figs. 6 and 7). The timing of seasonal changes in SSTs were more strongly correlated with that of upwelling winds than with the timing of sea level declines (as reflected in dates derived by the modified Logerwell method) (far right and left columns of Figs. 6 and 7), suggesting that variability in SSTs, upwelling winds, and sea levels reflect independent features of the spring transition. South of Point Conception, the timing of upwelling winds was uncorrelated with timing of SST changes (Fig. 8). This lack of correlation between the timing of shifts in upwelling winds and the seasonal pattern of SST changes in the southern California Bight is due to the fact that winter-to-spring seasonal changes in windstress are very weak south of Pt Conception compared with those in the central and northern parts of our study region, both within the southern California Bight and offshore several hundred kilometers

In conclusion, we advise caution when identifying dates of spring transition. We found that different methods for choosing dates revealed different characteristics of that transition, especially South of Cape Mendocino, where dates derived from different types of data (upwelling, sea levels, or SSTs) often varied by one to two months. The choice of an appropriate method depends on the spatial extent of investigation (e.g., regionally-specific or spanning the entire California Current) and the oceanographic conditions relevant for the hypotheses being tested (e.g., related to currents, temperatures, and/or biological habitat).

Anticipated output:

- Carrie Holt and Nate Mantua to submit a paper titled, "Defining spring transition: regional indices for the California Current" to Fisheries and Oceanography (see Appendix B for a complete list of outputs from this project).

(2) Effects of timing of spring transition on groundfish recruitment: hypothesis test

To test the hypothesis that the timing of spring transition influences groundfish recruitment, we fit the following linear model to recruitment deviations and the date of spring transition:

$$(1) \qquad \log_e(R_t) = b_0 + b_1 \cdot x_t + \varepsilon_t \qquad\qquad \varepsilon \sim N(0, \sigma^2{}_\varepsilon),$$

where $\log_e(R_t)$ is the natural logarithm of the recruitment deviation in year t, x_t is the date of spring transition as defined by Logerwell (2003) for the northern region only, b_0 and b_1 are parameters, and ε is normally distributed random error. Although we did investigate the same relationship for the southern region using alternative definitions for date of spring transition, those results were not statistically significant and are not presented here.

For one group of species (northern species that spawn on the shelf or slope during winter and settle as juveniles nearshore), the relationships between recruitment and date of spring transition were consistently negative (Fig. 9, solid black lines), and for two of those species the relationships were statistically significant (Pacific ocean perch and sablefish, $p<0.05$). Despite large estimation errors in recruitment, accounting for those errors (i.e., using an errors-in-variables approach instead of the standard univariate maximum likelihood approach; Dichmont et al. 2003) did not alter our interpretation of the results. However, other sources of variability (e.g., observation errors and natural variability independent of spring transition) may swamp that environmental signal for some species.

Next, we explored two other methods for detecting effects of spring transition on recruitment that accounted for those uncertainties. The first explicitly separates variability in recruitment related to systematic (e.g., environmentally driven) time trends from random sources of variability independent of those trends (e.g., due to observation and estimation errors) using a Kalman filter formulation of a state-space model. The second method detects environmental signals that are common among species, independent of species-specific sources of variability (e.g., related to observation or measurement errors that vary between species) using a multi-species mixed-effects model. For both methods, we tested whether the linear model that included date of spring transition led to a significantly better fit to the data than a simpler model (i.e., a model that did not include spring transition) using likelihood-ratio tests.

The Kalman filter model consisted of two equations: a process equation that described variability in recruitment due to the timing of spring transition and an autoregressive (lag-1) process, and an observation equation that described random sources of variability independent of those trends:

$$(2a) \qquad R_t = \overline{R} + u_t + \nu_t, \;\; \nu_t \sim N\left(0, \phi \cdot \sigma^2{}_{\nu,t}\right) \qquad \text{(observation equation), and}$$

$$(2b) \qquad u_t = \rho \cdot u_{t-1} + b_3 \cdot x_t + \omega_t, \;\; \omega_t \sim N\left(0, \sigma^2{}_\omega\right) \qquad \text{(process equation),}$$

where $\overline{R}$ is the average recruitment deviation over all years (a correction factor), u_t is autocorrelated process error, ν_t is normally distributed observation error, $\sigma_{\nu,t}$ is the time series of the standard deviations in the estimates of the recruitment deviations from stock assessment outputs, ϕ is a multiplicative scalar, ρ is the AR(1) coefficient, b_3 is a parameter, x_t is time-varying spring transition, and ω_t is normally distributed random error with standard deviation σ_ω.

The model that included date of spring transition led to a significantly better fit to the data than the model without that parameter (b_3=0) for only 3 of the 15 cases: Pacific ocean perch (p <0.001), sablefish (p <0.001), and arrowtooth flounder (p=0.02) (Appendix C). Similar to the results for the maximum likelihood and errors-in-variables approaches, the direction of the relationship between date of spring transition and recruitment was consistently negative for all species in group 5 (Fig. 9, green dot-dashed lines, Appendix D).

If environmental trends are common among species, then it may be possible to increase the precision of parameter estimates by combining information in a multi-species mixed-effects model. That approach can also be used to generate informative priors for species with little or no data by borrowing strength from other species in the same ecological group. We therefore fit a mixed-effects model to species in group 5. For that model, the Y-intercept, $\beta_{0,i}$, and slope, $\beta_{1,i}$, (Eqn. 3a) for each species i, contain fixed (common among species) and random (species-specific) components:

$$\text{(3a)} \quad R_{i,t} = \beta_{0,i} + \beta_{1,i} \cdot x_t + \eta_{t,i}, \qquad \eta_{t,i} = \rho \cdot \eta_{t-1,i} + \varpi_{t,i},\ \varpi_{t,i} \sim N(0, \sigma^2_{\varpi,i})$$

$$\text{(3b)} \quad \beta_{0,i} = \delta_0 + b_{0,i}, \qquad b_{0,i} \sim N(0, \sigma_{b_0}{}^2)$$

$$\text{(3c)} \quad \beta_{1,i} = \delta_1 + b_{1,i}, \qquad b_{1,i} \sim N(0, \sigma_{b_1}{}^2),$$

$$\mathrm{Cov}(b_0, b_1)$$

where $\eta_{t,i}$ is autocorrelated deviations in recruitment; $\varpi_{t,i}$ is normally distributed random variation (with species-specific variances), $\sigma^2_{\varpi,i}$; δ_0 and δ_1 are fixed effects that are common among species; and $b_{0,i}$ and $b_{1,i}$ are species-specific random deviates from the fixed effects described by their variances, $\sigma^2_{b_0}$ and $\sigma^2_{b_1}$, and covariance, Cov(b_0,b_1). Equation 3 was fit using R software ("nlme" package).

The multi-species model that included date of spring transition led to a significantly better fit to the data than a simpler model with an intercept only (δ_1 = 0, $\sigma_{b1}{}^2$ =0) (ΔAIC = -8.24, likelihood-ratio test, p = 0.003). In addition, the direction of the relationship between the date of spring transition and deviations in recruitment was negative for all 6 species examined (Table 1, Fig. 9, red dotted lines). One limitation of this formulation of the multi-species model is that it does not include estimation errors in recruitment (i.e., those from stock assessment models). Although not possible with the "nlme" package in R, those errors may be included in mixed-effects models using other software package (e.g., AD Model Builder, random effects module).

Two additional questions emerged from the results of this analysis: (*i*) which of the four methods described above can detect environmental signals in recruitment time series most accurately? (*ii*) how should rebuilding plans for overfished groundfish be

updated to account for environmental effects? (described in more detail below). Our progress on answering those questions are described below (in Sections 3 and 4).

(3) Evaluating methods for detecting environmental effects

One challenge to identifying environmental effects on population dynamics is separating environmental signals from other sources of variability, such as those related to observation errors and natural variability. Future work (beyond this project) will evaluate the performance of the four statistical methods for detecting environmental signals that we identified: a standard maximum likelihood approach, a modified version of the maximum likelihood approach that accounts for estimation uncertainty in recruitment (i.e., an errors-in-variables approach), a method that explicitly separates variation related to systematic (e.g., environmentally driven) time trends from random sources of variability independent of those trends (e.g., observation and estimation errors) using a Kalman filter, and a method that detects signals that are common across species, independent of species-specific sources of variability using a mixed-effects model. In other words, analyses could assess which method (or combination of methods) can detect environmental signals most accurately under different scenarios about the quality and quantity of data available.

Specifically, those analyses will evaluate the effects of accounting for four types of variability in recruitment: (1) lag-one year autocorrelation (due to, e.g., the influence of autocorrelated environmental factors), (2) estimation errors from stock assessment models, (3) process errors (related to, for example, systematic changes in environmental conditions), and (4) mixed-effects errors (i.e., a combination of fixed-effects that are common among species and random effects that are species-specific) (columns in Table 3). The performance of models that either include or ignore each type of variability could be compared (rows in Table 3). Although it may not be practical to test all possible permutations, an experimental design such as the one described in Table 3 could be used to assess the most important dimensions.

Performance will be evaluated in a simulation modeling framework using "fake" data on recruitment that include an environmental signal common among species and species-specific variability (incorporating natural "process" variability, observation errors, and estimation errors from stock assessment models). By simulating fake data, it is possible to compare the estimates of environmental effects with known “true” values. So far, we have developed a preliminary modelling framework for several groundfish species of the U.S. West Coast, and propose applying that framework to SST effects on Pacific salmon stocks in British Columbia in the future (Mueter et al. 2002; Mueter et al. 2005).

(4) Incorporating climate information into rebuilding analyses for overfished groundfish stocks

Introduction and Methods

Despite evidence for climate effects such as timing of spring transition on groundfish recruitment, the analyses that underlie rebuilding plans have typically ignored those effects. We extended the conventional approach used to conduct rebuilding analyses to evaluate the sensitivity of outputs from those analyses to two hypotheses

about climate effects on recruitment (temporal auto-correlation due to unknown factors, and reduction in expected recruitment due to a delay in the date of spring transition) for an overfished stock, Pacific ocean perch (*Sebastes alutus*).

Specifically, we considered three scenarios about how future (age-3) recruitments were generated when conducting rebuilding analyses to capture our three hypotheses about environmental effects:

1. Each future years' recruitment is selected at random from the historical age-3 recruitments for 1970 through 2005 (the current way rebuilding analyses are conducted for Pacific ocean perch assuming no environmental effects (Hamel, 2007, scenario A). We developed one variant of this scenario where we sampled recruitment from a distribution parameterized from historical data (scenario A-alt).
2. The annual recruitments are treated as an auto-correlated time-series (scenario B).
3. The expected annual recruitments are projected based on the relationship between recruitment and the date of spring transition, including a one-month delay in that date over the next 100 years associated with IPCC projections of a doubling in CO2 (and several variants on that delay, scenarios C1-C4, Fig. 10) (Snyder et al. 2003).

Managers are tasked with making decisions about rebuilding without knowing the "true" state of nature. We therefore reran the rebuilding analyses in two parts to examine the implications of setting catch limits based on one assumption about recruitment when another scenario is the actual state of nature. For each year in the projection, "true" recruitments were selected from one scenario (A, B, or C), and the catch limits were chosen based on a different scenario.

Results and Discussion

Catch limits, probabilities of rebuilding to target levels (biomass levels at maximum sustainable yield), and times for rebuilding were sensitive to assumptions about recruitment, and those assumptions may have an important influence on management decisions. For example, recovery probabilities were higher for the scenario that included autocorrelation in recruitment than for the base scenario (A) at the start of the projection period, but lower after target year for recovery, T_{TARGET} (Fig. 11a). In contrast, recovery probabilities for scenarios A-alt and C1 were lower than for the base scenario (A) before T_{TARGET} and higher after T_{TARGET}, although the differences were small. The probability of exceeding the target spawning biomass increased at a slower rate (or leveled off) after T_{TARGET} compared with the base scenario when recruitment was related to delays in spring transition (scenarios C2-C4) (Fig. 11b).

When we varied the assumptions about recruitment used to represent the "true" state of nature and applied catch limits according to each alternative hypothesis (reflecting managers uncertainty about which hypothesis is true), we found that the probability of recovery differed from the required level (0.5) when an incorrect assumption was made, and that the direction of that difference depended on both the catch limits and "true" state of nature. For example, when catch limits were based on scenario A, probabilities of recovery by the putative T_{TARGET}s were higher than 0.5 when

recruitment was actually autocorrelated, and lower than 0.5 when recruitment was related to delays in spring transition (top row, Table 4a and b).

Catch limits, probability of recovery, and to a lesser extent, the time for rebuilding, are sensitive to assumptions about recruitment, and those assumptions may therefore influence decisions about rebuilding. For example, to account for potential declines in recruitment due to delayed spring transition, decision-makers may wish to decrease catch limits to achieve rebuilding by a specified T_{TARGET}; or to avoid further restrictions to the fisheries yield, they may delay rebuilding (i.e., increase T_{TARGET}) instead.

Although accounting for environmentally-driven autocorrelation in recruitment may seem like a suitable proxy for including the specific environmental mechanisms in the stock-recruitment relationship, the results suggest that those two approaches can result in opposite recommendations for decision-makers. Specifically, accounting for autocorrelation implied larger catch limits than the base scenario, whereas accounting for one specific mechanism, delay in spring transition, implied lower catch limits owing to projected long-term declines in recruitment. Long-term trends in recruitment will therefore need to be considered separately from environmentally driven autocorrelation in rebuilding analyses.

A trade-off between time for rebuilding and catch limits is currently made by the Pacific Fisheries Management Council using outputs of rebuilding analyses combined with social and economic considerations, but in the future, account could also be taken of information on climate effects on recruitment.

Output:

- Holt, C.A., and Punt, A.E. Incorporating climate information into rebuilding plans for overfished groundfish species of the U.S. West Coast. Fisheries Research (submitted June 13, 2008). (see attached)

(5) Effects of variability in ocean conditions at fine spatial scales on groundfish recruitment

Previous studies suggest upwelling conditions are an important driver of recruitment success, although most of those studies have focused on spatial scales much larger than oceanographic features relevant to home ranges of individual fish (e.g., those related to fronts and eddies, Shanks and Eckert 2005, Larson et al. 1994). Variability in conditions at those fine spatial scales may be important for habitat complexity and prey availability. We hypothesized that recruitment success increases with enhanced variability in ocean conditions at fine spatial scales (0.25º latitude or 28km, a scale that captures spatial patterns due to fronts and eddies) during larval life stages in late winter and spring. Probabilities of frontal occurrence were calculated using satellite data on SSTs (blended Reynolds-AVHRR SSTs) (1985-present, at 28-km and 4-km resolutions) to test this hypothesis. These data have the advantage over other satellite products of being interpolated over missing points. Frontal locations were then derived from SSTs using a Sobel filter (a discrete differentiation operator) and an algorithm described by Breaker et al. (2005) and Castelao et al. (2006). Probability of frontal occurrence was calculated as the proportion of dates in a 10-day period that each SST-gradient value was classified as a front from the algorithm (as described by Breaker et al. 2005). We then

averaged the probability of frontal occurrence over days within years and over species geographic ranges to generate annual time series for each species.

We estimated parameters of the linear relationship between average probability of frontal occurrence and recruitment deviations using maximum likelihood estimation (as in methods 1 and 2 described above) and tested if that model provided a better fit to the data than a simpler model without probability of frontal occurrence. As for Hypothesis 1, we found no convincing relationship between average probability of frontal occurrence and recruitment deviations (i.e., the linear relationship did not lead to a significantly better fit to the data than the simpler model for any of the 17 cases). However, the directions of the relationships tended to be positive for those species that spawn and settle nearshore (Fig. 12) (i.e., in years when the probability of frontal occurrence was higher than average, recruitment was also high). For those species, fronts may be associated with enhanced habitat complexity and prey availability, resulting in increased recruitment. Note, the one exception, English sole, is unique for that group of species, in that adults are found in relatively deep water prior to spawning (up to 500m). However, when we used 4-km resolution SST data, only 6 of the 8 species in that group had a positive relationship (Fig. 13). In addition, when we changed the threshold for detecting fronts from 0.07ºC to 0.05ºC (i.e., made a more lenient assumption), we did not find any significant relationships.

Output:

- Armstrong, E., Holt, C.A., Punt, A.E., Methot, R., Haltuch, M., and Mantua, N. 2008. Satellite-derived sea surface temperature frontal analysis for fisheries management. Ocean Sciences Meeting. Feb. 2008 (oral presentation). Orlando, Florida.
- Time series of frontal probabilities published online as an experimental product.

(6) Effects of variability in ocean conditions at fine temporal scales on groundfish recruitment

We also hypothesized that recruitment success of west coast groundfish may increase with enhanced variability (amplitude and/or frequency of cycles) in upwelling conditions at fine time scales (3-10 days) during larval life stages. Due to time constraints, we were unable to test that hypothesis. However, the following steps may be used to guide future analyses.

(1) Extract daily time series of upwelling indices for six locations along U.S. West Coast for years 1967 to present (Environmental Research Division of the PFEL).
(2) Identify the scale of spatial coherence in upwelling across locations (possibly from previous analyses on those data), and calculate aggregate measures of upwelling corresponding to the spatial scale of rockfish assessments (either coastwide or region-specific, depending on the species).
(3) Identify dominant time scales of variability in upwelling indices (~3 to 10 days) using wavelet analysis, and compute indices for variance in upwelling winds at those scales.

(4) Model the relationship between temporal variability in upwelling and recruitment success (as for the relationship between dates of spring transition and recruitment).

(7) Satellite data: present and future use for addressing fisheries questions

We identified dates of spring transition in the California Current using daily Reynolds-AVHRR SST data, extracted from the NOAA National Operational Model Archive & Distribution System. The SST data were a blend between coarse-scale in situ (Reynolds) and fine-scale satellite (AVHRR) observations and were interpolated over points missing in the satellite record (Reynolds et al. 2007). Those data were from 1985 through 2007 at a spatial resolution of 0.25º. To test hypotheses about climate effects on recruitment, time series of at least that length (20+ years) are required.

For the examining the fine scale oceanographic spatial variability on groundfish recruitment hypothesis, a frontal sea surface temperature (SST) probability index was developed using satellite observations. The product itself was a measure of the probability of encountering a SST front of specific magnitude within a 10 day window. The methodology leveraged the methodology of Breaker (2005) and Castelao (2006) who used GOES SST imagery to calculate SST spatial gradients and the probabilities of encountering a specific gradient magnitude in a time series of imagery on a pixel-by-pixel basis.

In our case, we used AVHRR-based SST data since we required the longest time series possible going back to at least the mid-1980s. The first data set used to create the frontal probability products was the daily 0.25 degree (28 km) GHRSST AVHRR_OI Level 4 product (Reynolds 2007). This is the successor to the popular weekly 1 degree Reynolds SST product now produced as part of the GHRSST project (Donlon, 2007). Like the weekly product, it is based on blending AVHRR SST and *in situ* SST from ship and buoys through optimal interpolation and is gap free (no missing pixels). However, instead of using the operational global NOAA AVHRR SST data as the satellite source, it uses the climate quality NOAA/NASA Pathfinder SST (Kilpatrick, 2001) products that are produced twice daily since 1985. The significantly higher spatial and temporal resolution (as compared to the weekly product) allows it to modestly detect strong fronts due to upwelling and mesoscale eddy variability. It has previously been used to detect frontal activity in the Gulf Stream (Reynolds, 2007). In the application of the frontal detection, a Sobel edge detection filter was applied to each daily product and a gradient magnitude was characterized as a front if the magnitude for that pixel was at least 2.5 °C/ 100 km. Within a 10 day window, a probability of encountering a front was then calculated by simply summing the number of times a particular pixel exceeded this threshold divided by the number of days (ten in this case).

The second data set used in this frontal probability approach, was the NOAA/NASA Pathfinder SST time series produced at a twice daily (daytime/nighttime) 4 km resolution. This product is not a blended product but simply the native AVHRR satellite data at its highest global resolution. The same frontal probability methodology was applied with the only difference being a higher gradient threshold of 7 °C/ 100 km employed. This is nearly identical to the gradient threshold as used by Breaker (2005) when developing the frontal probability for 6 km GOES SST imagery. The gradient threshold can be expected to increase with increasing spatial resolution as more fine scale

features over smaller distances are detectable. A gradient threshold set too small for a particular spatial resolution, however, results in a large contribution of gradient "noise." In the case of this product, it is not gap free, but suffers from cloud contamination. Where a pixel is cloudy for the entire 10 day period a front probability cannot be calculated.

Fig. 14 depicts the two frontal probability products for the same time 10 day period in 1991. Similarities and differences are readily apparent. Despite the cloud contamination in the higher resolution Pathfinder based product, many more fine scale features are apparent due to well known upwelling fronts and mesoscale eddies in the California Current System. However, the cloud free nature of the GHRSST AVHRR_OI derived product is a significant advantage for determining the frontal characteristics everywhere even while lacking the fine scale detail.

Satellite-derived surface windstress fields provide additional valuable information in fishery oceanography applications. Many studies have already made great use of the Bakun upwelling indices that are derived from weather forecast models, but these indices are typically only used to estimate coastal upwelling at a resolution of 3 degrees of latitude. We have begun to analyze 0.25 degree resolution QuickSCAT winds to identify patterns of coastal and open ocean (windstress curl-driven) upwelling to better understanding the relative role of these two important processes in the climatology and seasonal-to-interannual variability in wind forcing of the California Current System. At 0.25 degree resolution it is possible to identify important spatial features such as coastal jets in the lee of major headlands and strong gradients between positive and negative windstress curl in the offshore direction. While the temporal coverage of satellite wind data is limited to the period since 1985, we are pursuing a method for statistically mapping sea level pressure fields at a 2.5 degree resolution onto the 0.25 km satellite winds. If successful, we will be able to economically downscale sea level pressure fields for both the historic period of the 20th century and for future climate change scenarios for the 21st century, and in doing so provide data sets that can be used in a wide variety of fishery oceanography applications.

In the future we hope to utilize satellite remote-sensing products like ocean color and altimeter data to develop additional high-resolution measures for aspects of marine habitat that are important for marine ecosystems. For example, currently altimeters are limited by resolution and synoptic scale but future altimeters will employ a wide swath high resolution capability, such as the proposed Decadal Survey mission called Surface Water Ocean Topography (SWOT), scheduled for launch in 2015. This mission will measure water elevation to the kilometer scale with a swath of over 100 km and thus have the resolution and accuracy necessary to resolve the energy and velocities of ocean circulation at the mesoscale level. We are also particularly interested in the possibility of combining different data products in ways that yield ecologically-relevant measures for ocean properties that can be used to better understand such fundamental fisheries issues as recruitment variability, animal migration patterns, and by-catch of protected species in ocean fisheries.

ACKNOWLEDGEMENTS

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REFERENCES

Armstrong, E. 2000. Satellite derived sea surface temperature variability off California during the upwelling season. Remote Sensing and the Environment 73:1-17.

Barth, J.A., Menge, B.A., Lubchenco, J., Chan, F., Bane, F., Bane, J.M., Kirincich, A.R., McManus, M.A., Nielsen, K.J., Pierce, S.D., and Washburn, L. 2007. Delayed upwelling alters nearshore coastal ocean ecosystems in the northern California current. Proceedings of the National Academy of Sciences 104:3719-3724.

Bilbao, P.A. Interannual and interdecadal variability in the timing and strength of the spring transitions along the United States west coast. 1999. M.Sc. thesis. Department of Oceanography, Oregon State University, Corvallis, Oregon. Pp 115.

Breaker, L.C., Mavor, T.P., and Broenkow, W.W. 2005. Mapping and monitoring large-scale ocean fronts off the California coast using imagery from the GOES-10 geostationary satellite. California Sea Grant College Program, Paper Coastal 05-02.

Castelao, R., Mavor, T., Barth, J.A., and Breaker, L.C. 2006. Sea surface temperature fronts in the California Current system from geostationary satellite observations. Journal of Geophysical Research 111, C09026, doi: 10.1029/2006JC003541.

Donlon, C., I. Robinson, K.S. Casey, J. Vazquez-Cuervo, E. Armstrong. 2007. The Global Ocean Data Assimilation Experiment High Resolution Sea Surface Temperature Pilot Project (GHRSST-PP). Bulletin of the American Meteorological Society 88 (8),1197–1213, 2007

Dichmont, C.M., Punt, A.E., Deng, A., Dell, Q., and Venables, W. 2003. Application of a weekly delay-difference model to commercial catch and effort data for tiger prawns in Australia's Northern Prawn Fishery. Fisheries Research 65:335-350.

Hamel, O., 2007. Rebuilding update for Pacific Ocean Perch. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 200, Portland OR 97220, USA.

Kilpatrick, K., G. Podesta, R. Evans. 2001. Overview of the NOA/NASA AVHRR Pathfinder sea surface temperature algorithm and matchup database. Journal of Geophysical Research, 106: 9179-9197

Kosro, P. M., Peterson, W. T., Hickey, B. M., Shearman, R. K., and Price, S. D. 2006. Physical versus biological spring transition: 2005, Geophysical Research Letters 33, L22S03, doi:10.1029/2006GL027072.

Larson, R.J., Lenarz, W.H., and Ralston, S. 1994. The distribution of pelagic juvenile rockfish of the genus *Sebastes* in the upwelling region off central California. California Cooperative Oceanic Fisheries Investigations Reports 35: 175-221.

Logerwell, E.A., Mantua, N., Lawson, P.W., Francis, R.C., Agostini, V.N., 2003. Tracking environmental processes in the coastal zone for understanding and predicting Oregon coho (*Oncorhynchus kisutch*) marine survival. Fish. Ocean. 12, 554-568.

Lynn R. J., Bograd, S.J., Chereskin, T.K., and Huyer, A. 2003. Seasonal renewal of the California Current: the spring transition off California. Journal of Geophysical Research. 108, NO. C8, 3279, doi:10.1029/2003JC001787.

Mueter, F.J., Peterman, R.M., Pyper, B.J., 2002. Opposite effects of ocean temperature on survival rates of 120 stocks of Pacific salmon (*Oncorhynchus* spp.) in northern and southern areas. Can. J. Fish. Aquat. Sci. 59, 456-463.

Mueter, F.J., Pyper, B.J., Peterman, R.M., 2005. Relationships between coastal ocean conditions and survival rates of northeast Pacific salmon at multiple lags. Transactions of the American Fisheries Society 134, 105-109.

Reynolds, R.W., T. M. Smith, C. Liu, D. B. Chelton, K. S. Casey, and M. G. Schlax, 2007: Daily high-resolution blended analyses for sea surface temperature. J. Climate 20, 5473–5496.

Schwing, F.B., Bond, N.A., Bograd, S.J., Mitchell, T., Alexander, M.A., and Mantua, N. 2006. Delayed coastal upwelling along the U.S. west coast in 2005: a historical perspective. Geophysical Research Letters 33, L22S01, doi:10.1029/2006GL026911.

Shanks, A.L. and Eckert, G.L. 2005. Population persistence of California Current fishes and benthic crustaceans: a marine drift paradox. Ecological Monographs 74: 505-524.

Snyder, M.A., Sloan, L.C., Diffenbaugh, N.S., Bell, J.L., 2003. Future climate change and upwelling in the California Current. Geophys. Res. Lett. 30, 1823.

Strub, P.T., Allen, J.S., Huyer, A., and Smith, R.L. 1987. Large-scale structure of the spring transition in the coastal ocean off western North America. Journal of Geophysical Research 92:1527-1544.

Thomson R.E., and Ware, D.M. 1996. A current velocity index of ocean variability. Journal of Geophysical Research 101(No. C6): 14,297–14,310.

Table 1. (a) Parameter estimates for mixed-effects models (Eqn. 3) for 6 northern groundfish species that spawn on the slope or shelf during winter and settle as juveniles nearshore (group 5). δ_0 and δ_1 are fixed-effects for the *Y*-intercept and slope, respectively; σ_{b0} and σ_{b1} are the variances for the species-specific random effects, ρ is an autoregressive coefficient; ΔAIC is the change in AIC from the simpler model with random effects for the *Y*-intercept only (i.e., $\delta_1 = 0$ and $\sigma_{b1} = 0$); *P*-value is the statistical significance of the likelihood-ratio test of the mixed-effects model described by Eqn. 3 compared with the simpler model. (b) The species-specific coefficients (β_0 and β_1, for the Y-intercept and slope, respectively) (Eqn. 3), which combine fixed and random effects, and the residual variances, σ^2_{ϖ}.

(a)

	Fixed effects		Random effects			AR(1) coefficient		
	δ_0	δ_1	σ_{b0}	σ_{b1}	$Cov(\sigma_{b0}, \sigma_{b1})$	ρ	ΔAIC	*P*-value
Parameter values	0.941	-0.010	0.540	0.00602	-0.996	0.178	-8.24	0.003

(b)

	Species-specific coefficients		Residual variance
Species	β_0	β_1	σ^2_{ϖ}
Canary rockfish	0.310	-0.0031	0.44
Pacific ocean perch	1.283	-0.0138	0.47
Sablefish	1.339	-0.0149	0.63
Widow rockfish	0.687	-0.0074	0.57
Yelloweye rockfish	1.183	-0.0128	0.98
Chilipepper rockfish	0.842	-0.0091	1.05

Table 2. Estimates of the autoregressive (AR(1)) coefficient, ρ, from the Kalman filter model without date of spring transition (Eqn. 2, b_3=0). $\overline{R}$ is mean recruitment (a correction factor); ϕ is a scalar multiplier on the estimation error variance, σ^2_v; ΔAIC is the change in AIC from the simpler model that does not include the autoregressive AR(1) coefficient (ρ=0); and *P*-value is the statistical significance for the corresponding likelihood-ratio test.

	Parameter values					
Species	ρ	$\overline{R}$	ϕ	σ^2_ε	ΔAIC	*P*-value
Black rockfish	0.173	-0.01	1.56E-07	0.279	-9.08	0.00063
Lingcod (N)	0.719	0.225	2.42	0.445	2.1	0.436
English sole	0.763	0.0846	0.563	0.286	-1.09	0.0556
Starry flounder (N)	0.571	-0.66	1.19E-10	0.817	-2.75	0.0125
Kelp greenling	0.882	-0.0265	4.47	1.88E-05	-3.6	0.0104
Cabezon (N)	0.224	0.0951	4.33E-07	0.804	-2.81	0.0145
Cabezon (S)	-0.254	0.852	3.77	0.511	-3.57	0.0131
Lingcod (S)	0.844	0.159	1.93	2.11E-05	-1.6	0.0303
Starry flounder (S)	0.729	0.042	2.95	0.58	-0.67	0.0621
California scorpionfish	0.855	1.12	5.92	4.71E-05	-3.12	0.0168
Gopher rockfish	0.293	0.401	5.37E-07	0.465	-2.05	0.0253
Canary rockfish	0.399	-0.00676	1.61E-07	0.423	-0.72	0.0703
Pacific ocean perch	0.256	-0.31	6.58E-08	0.69	-13.77	<0.0001
Sablefish	0.417	0.00735	3.08	0.481	-7.58	0.00145
Widow rockfish	0.308	-0.0813	2.05E-06	0.542	-7.99	0.00115
Yelloweye rockfish	-0.246	0.136	5.50E-07	0.863	-12.54	<0.0001
Chilipepper rockfish	-0.289	0.0115	2.50E-07	0.936	-19.46	<0.0001
Pacific hake	-0.0249	-0.115	2.77E-05	1.12	-23.68	<0.0001
Arrowtooth flounder	-0.463	0.612	6.04	0.33	-4.61	0.0074
Darkblotched rockfish	0.262	-0.0516	1.01E-05	0.818	-8.45	0.00082
Petrale sole (N)	0.684	-0.105	1.65E-10	0.269	-2.8	0.0202
Petrale sole (S)	0.6	0.0371	9.97E-08	0.374	-0.89	0.0617

Table 3. Models used to identify environmental signals in recruitment data, which include four types of errors: autocorrelation in recruitment, and estimation (i.e., errors introduced with stock assessment model), process, and mixed-effects errors.

Model number	Model	Type of error included in model			
		(1) Temporal autocorrelation	(2) Estimation errors	(3) Process error	(4) Mixed-effects errors
1	Linear model without autocorrelation	No	No	No	No
2	Linear model with autocorrelation	Yes	No	No	No
3	Linear model with autocorrelation and estimation errors (with a multivariate normal likelihood)	Yes	Yes	No	No
4	Kalman filter model with autocorrelation	Yes*	Yes	Yes	No
5	Multi-species, mixed-effects model with autocorrelation	Yes	Yes*	No	Yes

*further work required to develop model to include those sources of errors

Table. 4. Decision table examining the implications, in terms of the probability of recovery by 2025 (T_{TARGET}) of setting catch limits using one of the scenarios when another scenarios is considered to be "true".

		State of nature					
		A	B	C1	C2	C3	C4
Scenario	A	0.484	0.526	0.404	0.391	0.379	0.354
on which	B	0.446	0.502	0.370	0.359	0.343	0.323
catch	C1	0.616	0.592	0.500	0.490	0.478	0.456
limits are	C2	0.632	0.601	0.508	0.500	0.489	0.466
based	C3	0.636	0.607	0.520	0.509	0.499	0.478
	C4	0.654	0.623	0.549	0.535	0.524	0.501

Appendix A

Progress on this project benefited tremendously from four workshops held between June 2007 and September 2008. In brief, at the first workshop, hypotheses about environmental effects were developed and sources of satellite, model-derived, and fisheries data were presented. At the second, results from testing the first hypothesis (regarding the effects of timing of spring transition on recruitment) were presented using simple linear models, and species were divided into groups of similar ecological characteristics to test the first hypothesis. At the third, results from several different models of testing the first hypothesis were presented, as well as results from tests of the second hypothesis on fine-scale (~25km) spatial variability in ocean conditions. At the final workshop, progress on those research avenues were presented, as well as results on incorporating climate information into rebuilding analyses for one overfished groundfish stock, Pacific Ocean perch. Below are the agendas and participant lists for each workshop (also listed on the Wiki site: http://buck.atmos.washington.edu/pmwiki/pmwiki.php).

Agenda for workshop

Improving Rebuilding Plans for Overfished West Coast Fish Stocks through Inclusion of Climate Information

As a component of the NASA-NOAA Program for Integrating Satellite Data into Ecosystem-Based Management of Living Marine Resources

June 14-15, 2007
Room 113, Fisheries Science Building
1122 NE Boat Street, Seattle
(http://www.washington.edu/home/maps/southwest.html?FSH)

Thursday June 14		
9:00-9:15	Welcome and introductions Goals for workshop Overview of project	Carrie Holt
9:15-9:45	Tutorial on rebuilding analyses • Methodology and assumptions	Andre Punt
9:45-10:15	Background on oceanographic effects on rockfish	Liz Clarke
10:15-11:00	Hypotheses • General description of initial hypotheses • How can we test the hypotheses? • Potential biological and oceanographic metrics	Carrie Holt followed by discussion
11:00-11:15	Break	
11:15-12:15	Biological data • Data sources: stock assessment, surveys, and other sources • For which rockfish species? • Spatial resolution and extent of biological data • Temporal resolution and extent of biological data	Melissa Haltuch/ Rick Methot followed by discussion
12:15-1:15	Lunch	
1:15-1:45	Oceanographic data • Overview of data sources from observations: COADS, NOAA World Ocean Database, satellite products, ARGO, NCAR/NCEP reanalysis, PFEL upwelling indices, etc. • Requirements for spatial and temporal scales of oceanographic data	Nate Mantua followed by discussion
1:45-2:30	Satellite products: presentation • Challenges and limitations • Possible forward projections	Ed Armstrong/ Yi Chao/ Ben Holt followed by discussion

2:30-3:15	Model outputs: Regional Ocean Modeling System (ROMS), Carbon, $Si(OH)_4$, Nitrogen Ecosystem model (CoSINE): presentation • Challenges and limitations • Forward projections	Yi Chao followed by discussion
3:15-3:30	Coffee break	
3:30-5:00	Statistical methods for analysis: • Integrating oceanographic information from several sources • Meta-analyses for modeling oceanographic effects on multiple stocks or species	Discussion
6:00	Dinner at local restaurant	

Friday, June 15

9:00-9:15	Summary of discussion from Day 1 Follow-up of any points left from earlier discussions	Carrie Holt
9:15-10:00	Decision Support Tool: Including oceanographic effects in rebuilding analyses	Andre Punt followed by discussion
10:00-11:00	Possible extensions of the project: • Other biological parameters affected by oceanographic conditions (e.g., growth, distribution, migration patterns) • Other extensions?	Discussion
11:00-11:15	Summary and concluding remarks	Carrie Holt and Andre Punt
11:15-11:30	Next steps: • Outline steps for compiling data: *who* will get *what* data *when*? • Summary of the workshop to be written and distributed to the group • Set date and agenda for a future workshop	Discussion

Participants

Name	Organization	Email
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Agenda for Second Workshop on the
"Project to improve rebuilding plans for west coast fish stocks through inclusion of climate information"
September 7, 2007

Friday September 7, 2007
San Francisco Marriott Hotel
55 Fourth Street
Pacific Conference Suite C (fifth floor)
8:00 AM- 4:00 PM

Time		Presenter
8:00	Welcome and logistics	
	Review of hypotheses identified at the June workshop and overview of progress to date	Carrie Holt
	Results: species classification	Carrie Holt
	Discussion	
	Results: identifying dates of spring transition	Carrie Holt
	Discussion	
10:00-10:15	Break	
	Results: modeling relationship between dates of spring transition and recruitment deviations	Carrie Holt
	Discussion	
12:30-1:30	Lunch at local eatery	
	Future steps on Hypothesis 3 (relationship between fine-scale spatial variability in ocean conditions and recruitment)*	Carrie Holt
	Possible metrics of spatial variability in ocean conditions	Ed Armstrong
	Discussion	
	Future steps on Hypothesis 1 (relationship between spring transition and recruitment)	Carrie Holt
	Discussion	
	Future steps on Hypothesis 2 (relationship between fine-scale temporal variability in upwelling conditions and recruitment)	Carrie Holt
	Discussion	
	Future steps: case studies and incorporating climate information into rebuilding analyses	
	Discussion	
4:00	Conclusions and summary	

* Note the reversal in order of hypotheses for our discussion

Participants

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Agenda for Third Workshop on the
"Project to improve rebuilding plans for west coast fish stocks through inclusion of climate information"

Thursday March 20, 2008
School of Aquatic and Fishery Sciences
Fishery Sciences Building, room 314
1122 NE Boat Street
University of Washington
Seattle
9:00 AM- 4:00 PM

Time		Presenter
9:00	Welcome and logistics	
	Review of hypotheses identified at previous workshops and overview of progress to date	Carrie Holt
	Results: identifying dates of spring transition	Carrie Holt
	Results: progress on modeling relationship between dates of spring transition and recruitment deviations	Carrie Holt
	Discussion	
10:30-10:45	Coffee break	
	Results: identifying probabilities of frontal occurrence (and report from the Ocean Sciences Meeting in Orlando, Florida)	Ed Armstrong
	Results: progress on modeling relationship between probability of frontal occurrence and recruitment deviations	Carrie Holt
	Discussion	
12:00-1:00	Lunch provided	
	Preliminary results: Evaluating performance of methods to detect environmental signals on simulated recruitment data	Carrie Holt
	Discussion	
	Future steps: Incorporating climate information into rebuilding analyses	Carrie Holt/André Punt
	Discussion	
	Other future steps for the project; prioritize	
	Discussion	
4:00	Conclusions and summary	

* Afternoon break at the discretion of the group

Invitees

Name	Organization	Email
Teresa A'mar	University of Washington	zta@u.washington.edu
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Ian Stewart	NOAA	ian.stewart@noaa.gov

Agenda for Final Workshop on the
"Project to improve rebuilding plans for west coast fish stocks through inclusion of climate information"

Friday, Sept. 5, 2008
South Coast Office, Seminar Room
3225 Stephenson Point Road
Fisheries and Oceans Canada
Nanaimo, British Columbia
9:00 AM- 4:00 PM
Carrie Holt's cell phone: (250) 618-4208

Time		Presenter
9:00	Welcome and logistics	
	Review of hypotheses identified at previous workshops and overview of progress to date	Carrie Holt
	Results: regional variability in dates of spring transition	Carrie Holt
	Results: regional variability in satellite-derived wind data	Nate Mantua
	Discussion	
10:30-10:45	Coffee break	
	Results: identifying probabilities of frontal occurrence update (using 4-km resolution SST data)	Ed Armstrong
	Results: progress on modeling relationship between probability of frontal occurrence and recruitment deviations	Carrie Holt
	Discussion	
	Results: incorporating climate information into rebuilding plans for overfished fish stocks	Carrie Holt
	Discussion	
12:00-1:00	Lunch at the Pacific Biological Station; brief tour of the facilities	
	Methodology: evaluating performance of methods to detect environmental signals on simulated recruitment data	Carrie Holt
	Discussion	
	Summary of project outputs to date	Carrie Holt
	Discussion: future work on this project and requirements for the Final Report	
	Discussion: proposal ideas for future projects	
4:00	Wrap up	

* Afternoon break at the discretion of the group

Participants

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Appendix B. List of project outputs

Outputs to date

- Holt, C.A., and Punt, A.E. Incorporating climate information into rebuilding plans for overfished groundfish species of the U.S. West Coast. Fisheries Research (submitted June 13, 2008). (see attached)
- Armstrong, E., Holt, C.A., Punt, A.E., Methot, R., Haltuch, M., and Mantua, N. 2008. Satellite-derived sea surface temperature frontal analysis for fisheries management. Ocean Sciences Meeting. Feb. 2008 (oral presentation). Orlando, Florida (see abstract below).
- Holt., C.A., Punt, A.E, and Mantua, N.M. 2007. Incorporating climate information into rebuilding analyses for overfished groundfish stocks. Annual Meeting the North Pacific Marine Science Organization (PICES). October 26-November 5, 2007. Victoria, British Columbia, Canada (poster presentation; see abstract below).

Anticipated outputs

- Paper submitted to Fisheries Oceanography titled, "Defining spring transition: regional indices for the California Current".
- Simulation model evaluating methods to detect environmental effects
- Paper describing that model with applications to Pacific salmon, submitted to a high quality journal (yet to be chosen).

Abstracts

Satellite-derived sea surface temperature frontal analysis for fisheries management
Ed Armstrong, C. Holt, A. Punt, R. Methot, M. Haltuch, N.Mantua

It is well known that along the west coast of North America. strong seasonal sea surface temperature (SST) fronts and gradients develop in the coastal regime of the California Current in response to coastal upwelling during the Spring-Fall period. These frontal zones often extend 150 km or more offshore and represent convergence zones rich in nutrients and biological productivity. In this study, a systematic analysis of the probability of encountering a SST front of a certain gradient magnitude was undertaken using a 21 year data set of SST observations from a blend of AVHRR/AMSRE/in situ SST observations (i.e., the GHRSST NCDC Level 4 products). The seasonality and interannual variability of these SST frontal probabilities was established using an EOF analysis of the 21 year time series.

A key purpose of this investigation was to identify physical and other indicators of conditions in the California Current that potentially influence the recruitment of groundfish species over the last several decades and incorporate that information into rebuilding analyses for overfished stocks. In this respect, the frontal probability maps were used as one physical (and indirectly biological) factor and examined through statistical approaches to determine their effect on the spatial and temporal variability of recruitment success for 21 rockfish species. These results have significant implications

for using other climate quality satellite products (e.g., from altimetery, ocean color) in similar approaches to fisheries management.

Incorporating climate information into rebuilding analyses for overfished groundfish stocks

Carrie Holt, André Punt, and Nathan Mantua

Population abundances of several groundfish species on the U.S. west coast have declined dramatically over the last several decades, largely due to overfishing. The Magnuson-Stevens Fishery Conservation and Management Act requires rebuilding plans for stocks that have been overfished (stocks with spawning outputs that have dropped below minimum stock size thresholds). Previous studies suggest that climate variability may influence rockfish populations, yet rebuilding plans for overfished stocks have so far ignored those effects. Our goal is to identify biological and physical indicators of conditions in the California Current that have influenced recruitment of groundfish species over the past ~50 years and incorporate this information into rebuilding analyses for overfished stocks. One challenge to testing hypotheses about oceanographic effects on recruitment has been the limited availability of *in situ* oceanographic data at fine time and spatial scales. We will combine coarse-scale *in situ* observations with satellite-derived measures of ocean condition to test hypotheses at finer space and time scales than previously possible (25km spatial and 3-10 day temporal resolution). Another challenge is degradation in power due to multiple tests of a large number of environmental indices. Using a hierarchical modeling approach, we will increase power by combining information from various species and assessment regions. Specifically, we will test two hypotheses that relate recruitment success to: variability in upwelling habitat at fine time and spatial scales, and the timing of the spring transition from coastal downwelling to upwelling conditions, which is associated with changes in larval groundfish habitat and feeding.

Appendix C: Parameter values for Kalman filter model

Parameter estimates for the Kalman filter version of the linear model between dates of spring transition and $\log_e$(recruitment deviations) for northern species (Eqn. 2). $\overline{R}$ is the mean $\log_e$(recruitment deviation), b_3 is the coefficient for date of spring transition, ϕ is a scalar multiplier on the estimation error variance, $\sigma^2_{\nu,t}$, ρ is an autoregressive lag-1 coefficient, σ^2_{ϖ} is the variance of the residual process error, ΔAIC is the change in AIC from the simpler model that does not include date of spring transition (b_3 =0), and *P*-value is the statistical significance of the corresponding likelihood-ratio test.

		Parameter values						
Species	Group	$\overline{R}$	b_3	ϕ	ρ	σ^2_{ω}	ΔAIC	*P*-value
Black rockfish	1	-0.343	0.00278	6.55E-05	0.207	0.272	1.06	0.189
Lingcod (N)	1	-2.78	0.0039	3.83	0.889	0.238	1.2	0.187
English sole	1	-1.01	0.00218	0.852	0.811	0.257	2.18	0.443
Starry flounder (N)	1	0.422	-0.00472	0.000393	0.57	0.807	3.74	0.538
Kelp greenling	2	1.1	-0.00133	4.34	0.885	0.000573	1.98	0.251
Canary rockfish	5	0.16	-0.00103	0.00543	0.396	0.422	2.63	0.742
Pacific ocean perch	5	1.42	-0.0167	5.51E-05	0.0777	0.588	-8.12	<0.001
Sablefish	5	1.68	-0.0163	0.000587	0.0632	0.444	-13.7	<0.001
Widow rockfish	5	0.468	-0.00409	0.00294	0.287	0.534	1.76	0.318
Yelloweye rockfish	5	2.16	-0.0272	2.09	-0.69	0.00373	3.35	0.316
Chilipepper rockfish	5	0.795	-0.0108	0.00131	-0.345	0.902	-0.08	0.0977
Pacific hake	5	0.26	-0.00398	0.0722	-0.0503	1.12	2.46	0.64
Arrowtooth flounder	7	1.4	-0.0128	4.02	-0.371	0.39	-2.91	0.0175
Darkblotched rockfish	7	0.885	-0.00733	0.00613	0.257	0.798	1.61	0.241
Petrale sole (N)	7	0.069	-0.00058	5.08E-05	0.684	0.268	2.72	0.777

Appendix D

Groundfish species of the U.S. west coast possess a diverse array of life history strategies and habitat preferences and may respond to environmental forcing in a variety of ways. Classifying species into groups with similar ecological characteristics and geographic distributions prior to testing hypotheses may improve our ability to detect significant effects. We therefore classified species according to: location of juvenile life stages (nearshore or shelf/slope), location of adults during spawning (nearshore or shelf/slope), geographic range (north or south of Cape Mendocino), seasonal timing of spawning (spawning period that includes winter and does not include winter), and duration of pelagic life stages (less than 6 months or greater than one year) (Fig. D1, next page). Note, not all dimensions are important for each subset of species (e.g., duration of pelagic life stages did not vary substantially for nearshore species). Although other characteristics may be more important in determining environmental effects on recruitment (e.g., changes in habitat and food preferences from parturition to juvenile settlement), for most groundfish species few details are known about early life stages. See the attached supplementary document, "Holt_TableSpeciesGroups.xls" for summaries of ecological characteristics of each species and previously published classification schemes.

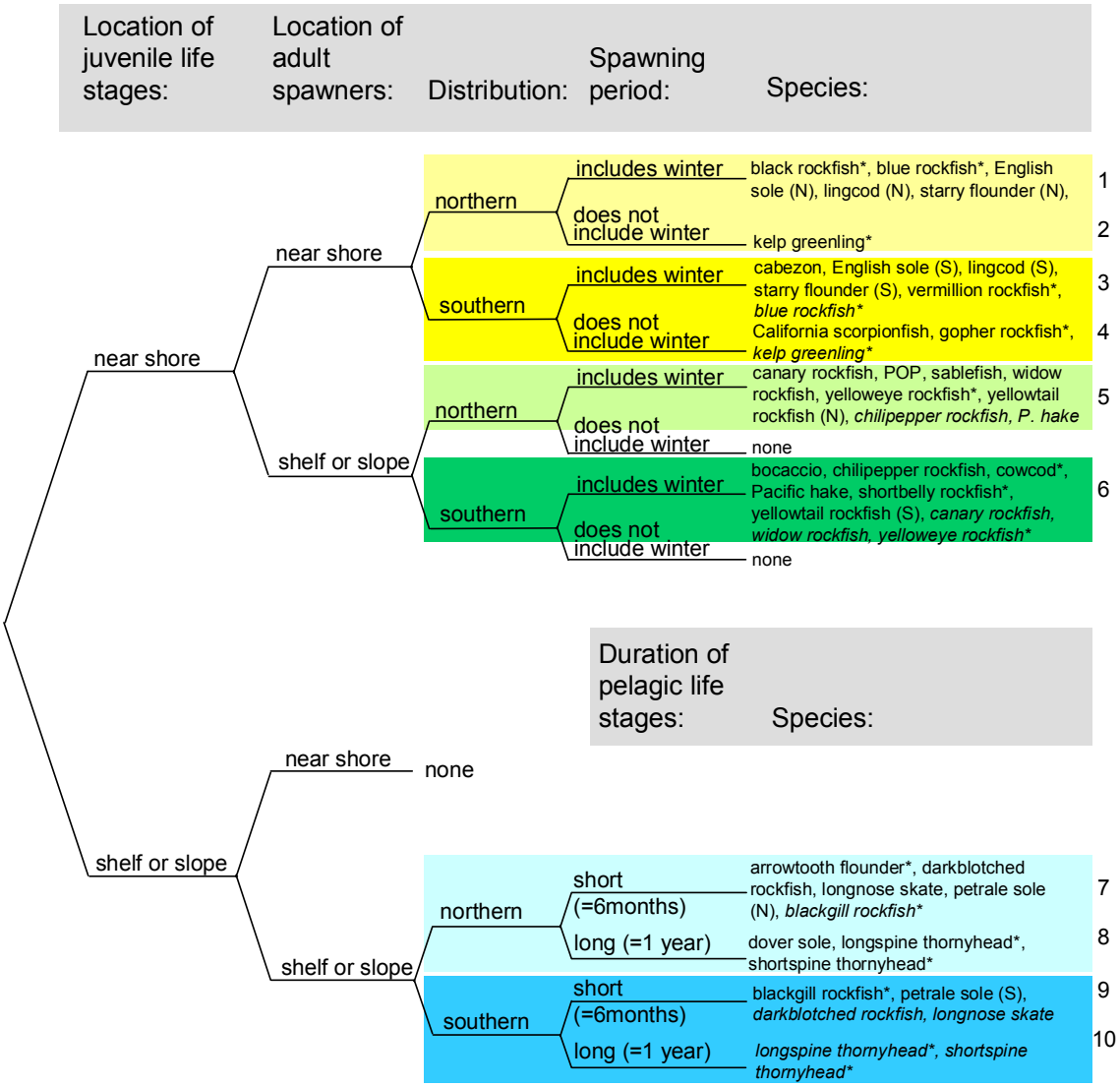

Fig. D1. Species classification scheme for U.S. west coast groundfish based on early life history characteristics and geographic distribution. Asterisks denote species that are data poor and italics denote species that are classified in a region (north or south) that does not contain their center of distribution. Species groups are labeled by the numbers on the right side of the tree.