Environmentally-explicit population models for coastal pelagic species (Pacific mackerel and Pacific sardine)

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Some of the best known examples for application of environmental data to stock assessments are available from the coastal pelagic species ('CPS', *e.g.*, anchovy, sardine, mackerel, and herring). Assessments for 6 of 18 major CPS stocks worldwide now incorporate some type of environmental data to improve current estimates or forecasts of recruitment. Two of these examples include CPS stocks from the U.S. West Coast: northern anchovy, and Pacific sardine. The earliest research in this area was published by Parrish and MacCall (1978), who explored various stock-recruitment (S-R) models for Pacific mackerel based on 40 years (1929-69) of biomass and recruitment data and long time series of environmental data, including sea level, sea-surface temperature (SST), wind speed, upwelling, and offshore divergence. An examination of the updated time series (1929-02) has revealed recent divergence of a previously significant relationship between recruitment success (recruits per spawning stock biomass; R/SSB) and SST off southern California; however, the positive correlation between estimates of R/SSB and upwelling off central Baja California continues to hold 'true' today. One possible explanation is that SST off southern California is important as an environmental threshold for opening prime nursery habitat to large-scale recruitment booms such as the one that occurred in the late 1970s, but that productivity off Baja California, the center of mackerel spawning activity, serves as a driving mechanism for spawning stock productivity over the long term.

Pacific sardine has become the 'poster fish' for application of environmental data in both stock assessment and management processes. It has long been acknowledged that sardine productivity, and hence maximum sustainable yield (MSY), varies on a decadal scale under prevailing ocean climate regimes, with productivity being lower under 'cold regimes' and higher under warm conditions. The groundwork for implementation of this concept was laid by Jacobson and MacCall (1995), who developed a S-R model for sardine that included a three-year running average of SST at Scripps Pier, La Jolla, CA. Their S-R relationship is used in the current stock assessment model to estimate and constrain recruitment in the most recent years. The S-R model was ultimately used in simulations to estimate changes in deterministic MSY reference points due to changes in environmental conditions. Based on this work, the harvest control rule adopted by the Pacific Fishery Management Council under the CPS Fishery Management Plan includes an environmentally-based exploitation fraction, F_{MSY}, which is used as an MSY proxy to set annual harvest guidelines for the forthcoming year (time t+1).

$$HARVEST\ GUIDELINE_{t+1} = (B_t - CUTOFF) \times F_{MSY} \times U.S.\ DISTRIBUTION$$

B_t is the biomass of age-1+ sardines at time t. The *CUTOFF* is 150,000 mt (below which no fishing is permitted). F_{MSY} ranges from 5-15%, and $F_{MSY} = 0.249 \cdot SST^2 - 8.190 \cdot SST + 67.456$. *U.S. DISTRIBUTION* is the assumed portion of the stock in U.S. waters (87%).

Future application of environmental data may include the use of temperature (COADS or other SST) to parameterize sardine movement rates or availabilities-at-age in a spatially-explicit assessment model.

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