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Pre-exploitation Abundances of Important Large Recreational and Commercial Fishes off Southern California

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Introduction

The goal of this Sea Grant project was to estimate pre-exploitation abundances for the white seabass (*Atractoscion nobilis*), the yellowtail (*Seriola lalandei*), and the giant sea bass (*Stereolepis gigas*). Baseline measures of abundance or biomass of fish and wildlife populations are valuable for assessment of human-induced changes in those populations. Such measures are, however, rare. Populations may be altered long before the need for baseline information is recognized.

Commercial fisheries for the white seabass, yellowtail, and giant sea bass were well established by the late 1910s and early 1920s, a period in which significant changes occurred in the populations of these three large predatory fishes (Figures 1–3). Fisheries data from this period to 1990 suggest that California populations of these fishes are in various states of depletion, but prefishery population levels have not been estimated.

A unique data set collected by the Avalon Tuna Club of Santa Catalina Island (Figure 4) contains information that predates large-scale commercial fishing off Southern California (Macrate, 1948). This data set contains records of the heaviest white seabass, yellowtail, and giant sea bass caught each year by a member of the club. To the extent that size composition reflects fishing pressure, these data provide a means of estimating pre-exploitation biomasses for white seabass and yellowtail populations by using a maximum likelihood approach. Estimates are made by combining a simple population model and a statistical model. Our original intent was to use the same modeling approach for the giant sea bass. However, inadequate data on the life history of this fish precluded use of this maximum likelihood approach; a lower limit of its pre-exploitation biomass was estimated by using catch data only.

The General Model

Maximum likelihood estimates of the pre-exploitation abundances for the white seabass and the yellowtail were generated by combining (1) a harvested population model generating the distribution of yearly weight frequencies, (2) a statistical model for the probability distribution of the heaviest fish in a sample from the model population, and (3) annual observations of the heaviest fish caught by a member of the Avalon Tuna Club. The statistical model links the records of the Avalon Tuna Club to the distribution of weight frequencies in the modeled population, providing a basis for estimating the likelihood that the Avalon Tuna Club data would have been observed, given the assumed population model.

The Population Model. The purpose of the population model is to provide distributions of annual weight frequency of an assumed resident, self-sustaining population in California waters. Components of the model include length-at-age and weight-at-length relationships, a stock-recruitment relationship (Figure 5), age of recruitment to the fishery, and the historical commercial and sport harvests. Fitted parameters from the population model are initial population size and instantaneous mortality rate.

By assuming a constant instantaneous natural mortality rate (M) and an initial population size (B_o), we constructed a stable age

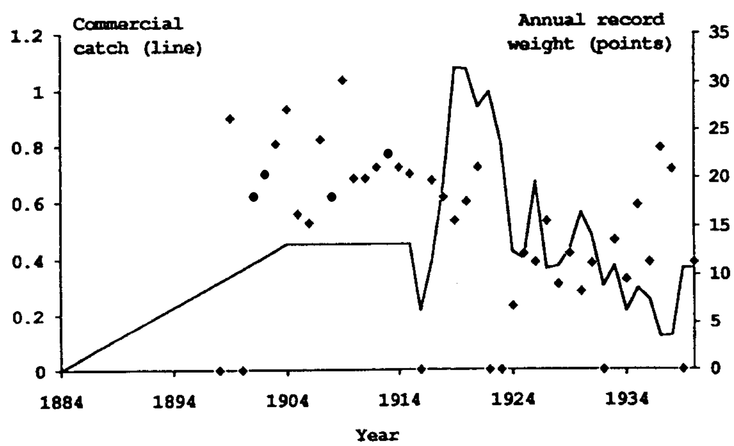

Figure 1. Commercial catch (1000 tons) and record weight (kg) of white seabass caught by a member of the Avalon Tuna Club, 1884–1940. Commercial catch for the period 1904 to 1915 set constant at 454 tons and linearly interpolated to that level beginning with zero catch in 1884 (Frey, 1971). See text for remaining data sources.

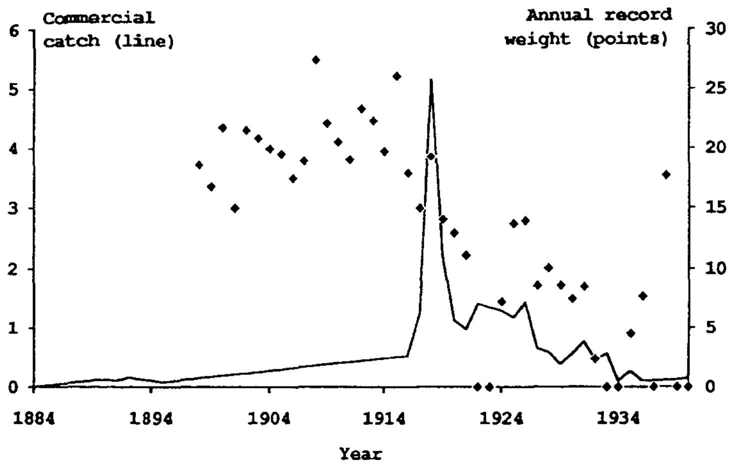

Figure 2. Commercial catch (1000 tons) and record weight (kg) of yellowtail caught by a member of the Avalon Tuna Club, 1884–1940.

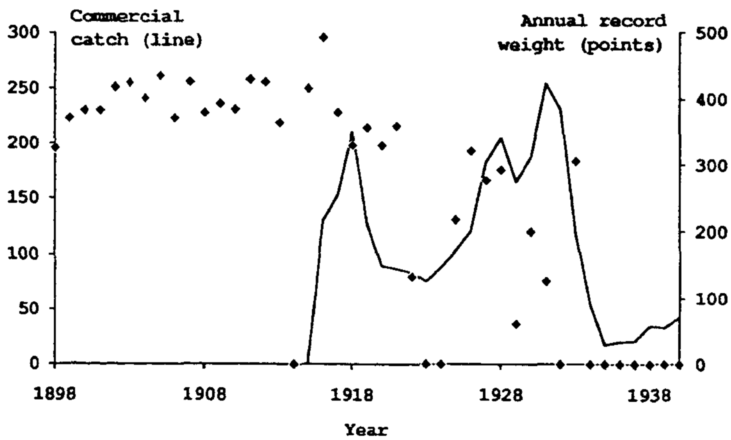

Figure 3. Commercial catch (1000 tons) and record weight (kg) of giant sea bass caught by a member of the Avalon Tuna Club, 1898–1940.

frequency distribution. Age-length (with variability) and length-weight relationships from the literature were used to convert the age frequency distribution to a weight frequency distribution, with fish summed over discrete weight categories of unit width. Constant recruitment to the model population in the absence of other extraneous perturbation leads to a constant population abundance and weight frequency distribution over time.

Such constancy ceases under conditions of harvesting, and the weight distribution subsequently varies with the removal of portions of the model population according to historical commercial and sport catch records.

The population model runs from 1884 to 1940. Avalon Tuna Club records begin in 1898. The period from 1884 to 1897 is included to incorporate the effects of earlier years of commercial fishing for which records are available.

The Statistical Model. Based on a year-specific weight frequency distribution from the population model, the statistical model provides a method of determining a year-specific probability distribution for the heaviest fish in a sample from the population. This extreme-value probability distribution is taken from Hogg and Craig (1965):

$$f(W_{\max} \mid S) = S\,[F(W)]^{S-1} f(W), \qquad (1)$$

where S, $f(W)$, and $F(W)$ are the sample size, weight frequency distribution, and cumulative weight frequency distribution, respectively, for the model population. Because the year-specific weight frequency and cumulative weight frequency distributions ($f(W)$ and $F(W)$, respectively) are functions of the population model and its estimated parameters, the resulting year-specific probability distribution for the heaviest fish taken in a sample from the population is also a function of those parameters. Although the Avalon Tuna Club records do not include sample size, and hence true sample size is unknown, the mean sample size can be assumed to be approximately proportional to the year-specific abundance in numbers of fish (N) given by the population model. The constant of proportionality (q, where $S_{mean}=qN$) is a parameter to be estimated. Because actual S varies about S_{mean}, and is a relatively small number, S is assumed to have a Poisson distribution. The density function used in the likelihood equation is the weighted mean of the $f(W_{\max} \mid S)$ values from equation (1), with weighting from the Poisson frequency distribution $p(s)$. Thus, if a maximum weight observation exists for a particular year,

$$f(W_{\max} \mid S_{mean}) = \qquad (2a)$$

$$\sum_{n=1}^{\infty} [f(W_{\max} \mid s)p(s \mid S_{mean})],$$

and if there is no observation,

$$f\,(no\ obs) = p(s = 0\,|\,S_{mean}). \qquad (2b)$$

Note that lack of a recorded maximum-sized fish for a particular year (which occurs in these time series) is likely to indicate that recreational catch rates, and hence available biomass, were low. The stochastic treatment allows this inference to be incorporated explicitly in the likelihood function.

By comparing the observed annual records of the Avalon Tuna Club with the corresponding probability distribution for the heaviest fish, a year-specific probability can be determined for each year of the interval 1898 to 1940 in the model simulation. The sum of the natural logarithms of those year-specific probabilities over the period 1898 to 1940 is the log-likelihood function for the population model and its specific input.

The simplex algorithm (Nelder and Mead, 1965) is combined with a single- and double-parameter searching method to locate the combination of parameters that leads to the maximum likelihood. Those parameters include the pre-exploitation abundance and the instantaneous mortality rate from the population model and the constant of proportionality for sample size from the statistical model.

Two methods of testing precision of the results were used. The first estimated minimum-variance bounds for the parameters by using second and mixed partial derivatives (Norden, 1972, 1973). The second method varied the assumptions of the population model, including the stock-recruitment function, the age of recruitment to the fishery, the biomass of seasonal migrants to the population and commercial fishery, the period of extensive sport fishing, the variability and density dependence of length-age functions, and the stability of the starting age distribution.

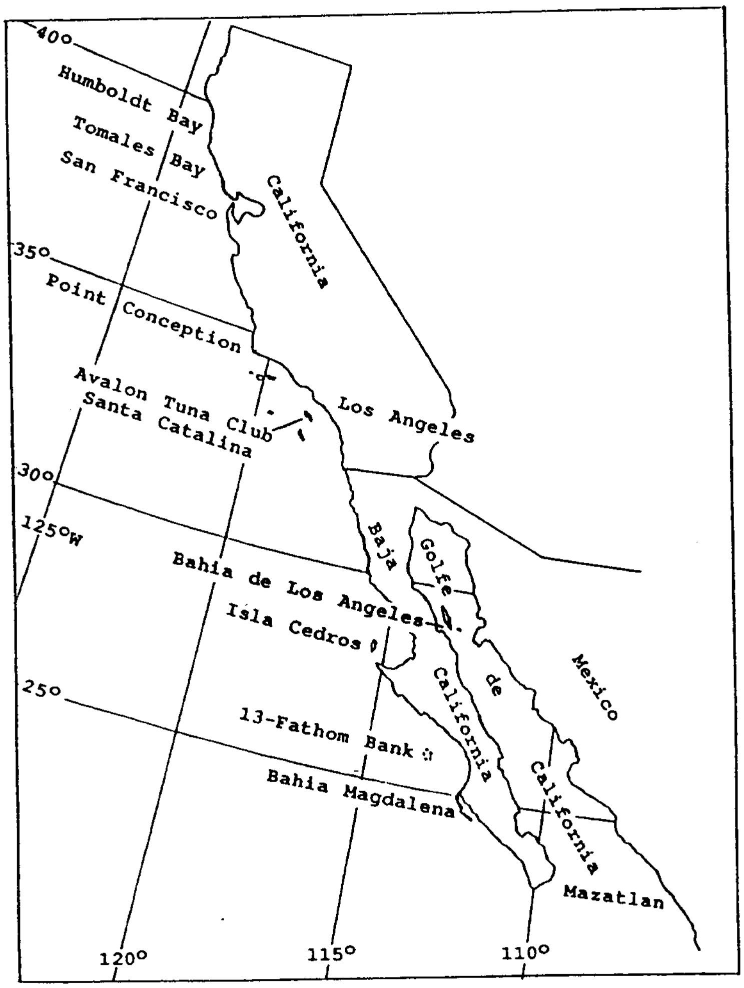

Figure 4. Oceanic area pertinent to study.

Results

White Seabass. Model simulations suggested that the pre-exploitation biomass of white seabass was near or slightly greater than 20,000 tons, with coefficients of variation on the order of 0.25 to 0.4. Corresponding population abundances ranged from approximately 2 million to 2.5 million fish. Results also suggested an instantaneous natural mortality rate on the order of 0.08 yr^{-1} (coefficient of variation ~ 0.15), somewhat lower than previous estimates of 0.33 yr^{-1} (Thomas, 1968) and 0.12 yr^{-1} (MacCall, et al., 1976). Figure 6 shows the correspondence of model biomass to annual record weight of white seabass taken by the Avalon Tuna Club. Similarly, the correspondence of model biomass to annual commercial catch is shown in Figure 7.

Yellowtail. Estimates of pre-exploitation biomass and abundance for the yellowtail were similar to the estimates for the white seabass, that is, just greater than 20,000 tons and 2 million fish, respectively. However, the coefficients of variation for the yellowtail were on the order of 0.05 to 0.12, and therefore were much smaller than is the case for the white seabass. Instantaneous natural mortality for the yellowtail was estimated to be about 0.09 yr^{-1}, slightly greater than that of the white seabass. The correspondence of model biomass to annual record weight of yellowtail taken by the Avalon Tuna Club is shown in Figure 8; Figure 9 shows the correspondence of model biomass to annual commercial catch.

Giant Sea Bass. As noted before, insufficient information on the life history of the giant sea bass, particularly age-length-weight relationships, precluded the estimation of pre-exploitation biomass for this fish with the model used here. However, Frey (1971) concluded that the combination of commercial fishing, slow recruitment, and continued sportfishing has inhibited the recovery of the giant sea bass. If this is the case, then the lower limit for that biomass can be approximated by summing the total commercial catch of giant sea bass during the period from 1916 (when records begin for the commercial fishery) to 1940. The sum of those landings is approximately 1300 tons. Certainly, this estimate could be improved if information on growth and mortality of the giant sea bass and estimates of the sportcatch during this period were available. Still, the sportcatch before 1940 probably was negligible relative to the commercial catch, and regardless of growth and mortality, recruitment is sufficiently low to prevent rapid turnover of the population.

Discussion

The essence of the maximum likelihood approach used here is the search of a multivariate response surface for its peak. In this model, the likelihood surface was a function of three parameters that were subject to at least one major constraint: The initial abundance and mortality rate must allow an initial population sufficiently large to withstand the removal of the biomass taken in the commercial catch. On the response surface, this constraint manifests itself in the form of a boundary beyond which any solution is infeasible. Figure 10 illustrates likelihood response surfaces for the white seabass and the yellowtail when only mortality and initial abundance are varied. For both the white seabass and the yellowtail, the peak of the surface is located close to this boundary of feasible solutions, suggesting that these populations were fished to low levels during the early part of this century. The close correspondence between the parameter estimates for the white seabass and the yellowtail suggests these two fishes were similar in population size and have similar life histories.

In general, results for the white seabass and the yellowtail were robust to the multiple assumptions required by this modeling approach. Furthermore, these results are the only available estimates of pre-

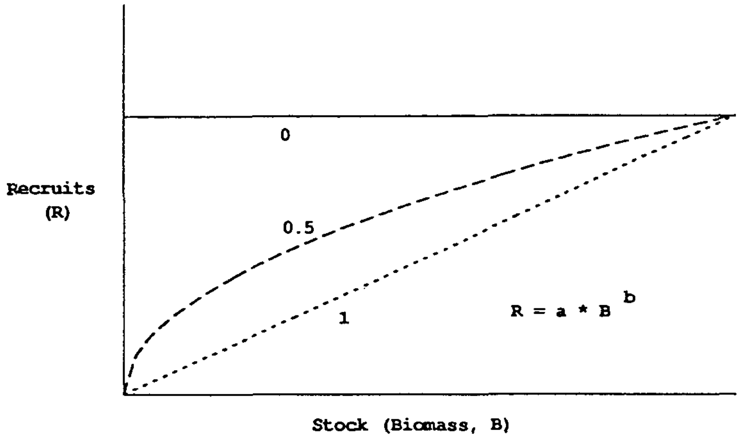

Figure 5. Stock-recruitment relationships used in the model. The three lines correspond to the indicated values of b.

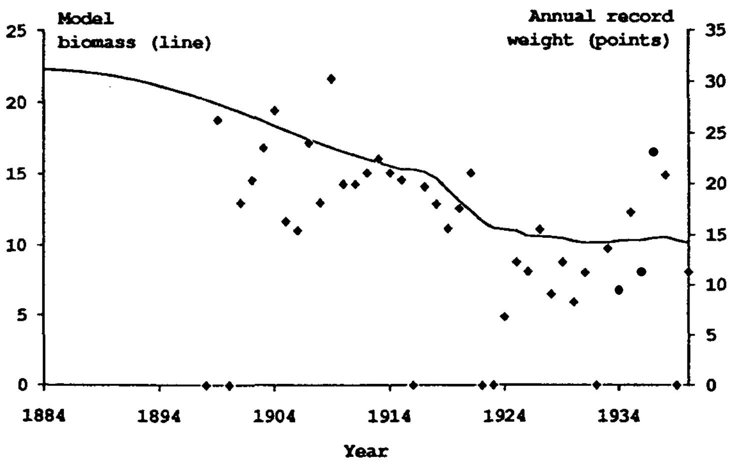

Figure 6. Model biomass (1000 tons) and annual record catch (kg) of white seabass by an Avalon Tuna Club member, 1884–1940.

exploitation abundance for the white seabass and yellowtail. As such, they provide the only indication of the severity of historical exploitation and the extent of recovery that would be necessary to return these populations to their natural state. Clearly, however, these estimates apply to the natural state in the late 1800s. To suggest that in the absence of exploitation these fish populations would be at similar levels today requires the assumption that the overall influence of the pertinent demographic and environmental conditions has not changed. In the absence of information on such changes, the estimates generated here provide our best indication of the natural state of these fishes.

As such, this information should be useful as a guide for programs such as California's Ocean Resources Enhancement and Hatchery Program (OREHP). One of the projects funded by OREHP has been development of a cost-benefit assessment model of hatchery performance and stock rehabilitation, with particular emphasis on the white seabass. As the population dynamics of the white seabass have heretofore not been well known, the OREHP investigation has necessarily relied on many assumptions about vital rates and related population properties. Although the white seabass is thought to be depleted, data have been insufficient to obtain clear results by using standard fishery assessment models (MacCall et al., 1976).

To the present, assessment and management of the white seabass, the yellowtail, and the giant sea bass have been based on the assumption that California's catches are taken from the seasonal northward migrants, which has largely been the case over most of the last half century. Managers have understandably hesitated to impose restrictions on harvests from a resource over which they would seem to have little real control. Management based on conservation of a strictly resident stock would require much greater restrictions on fishing effort. In addition, our results indicate natural mortality is low, which also suggests fishing mortality must be kept low if a resident stock is to be sustained. Presumably a population composed of both resident and migrant fish would allow intermediate levels of fishing. Until now, lack of sufficient information on the early resources and fisheries has prevented quantitative consideration of resident Southern California stocks of these species. The estimates provided by this study give managers a new view of the potential productivity of these stocks in Southern California. For example, the results allow application of the Gulland potential yield rule-of-thumb, $Y_{pot} = MB_o/2$, where Y_{pot} is potential yield. These cases indicate a Y_{pot} on the order of 500 to 900 metric tons. Indeed, the recent interest in artificial propagation of white seabass would seem to be more consistent with a management of a resident rather than a migrant resource. If artificial

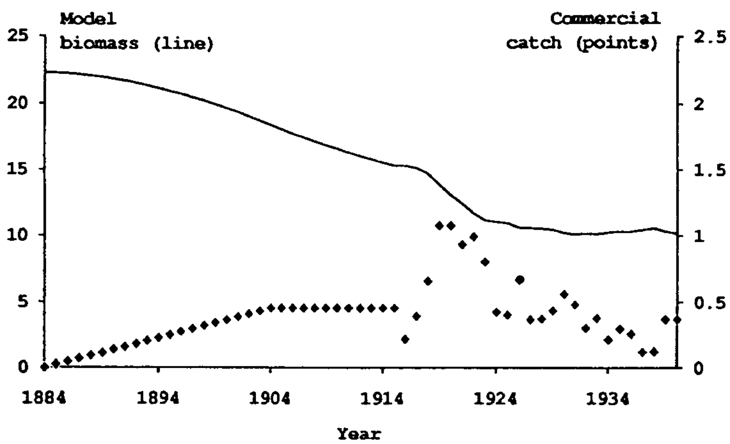

Figure 7. Model biomass and commercial catch of white seabass, 1884–1940. Both vertical axes are in units of 1000 tons.

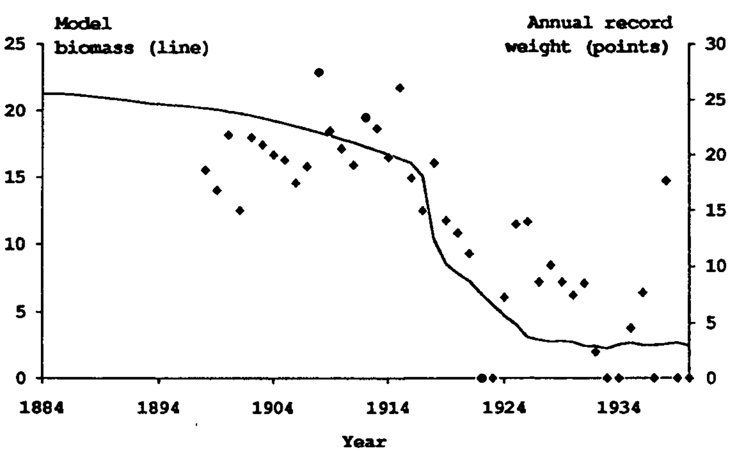

Figure 8. Model biomass (1000 tons) and annual record catch (kg) of yellowtail by an Avalon Tuna Club member, 1884–1940.

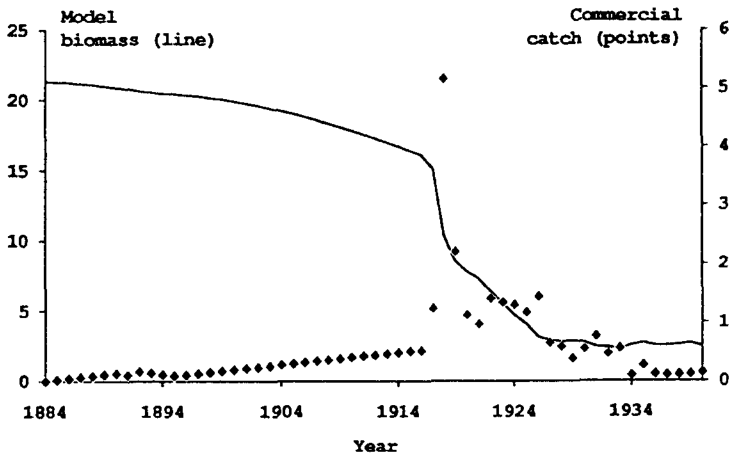

Figure 9. Model biomass and commercial catch of yellowtail, 1884–1940. Both vertical axes are in units of 1000 tons.

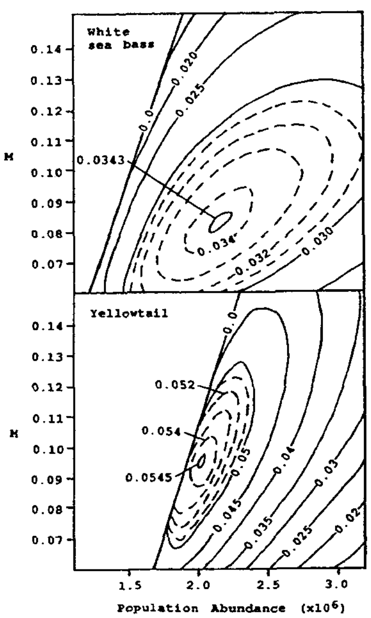

Figure 10. Contour plots of model response surfaces for the white seabass and the yellowtail. Isobars are of geometric mean probabilities, determined as antilog (log-likelihood/43 years).

propagation is to be attempted seriously, it is desirable and perhaps essential that management of these populations in Southern California be made consistent with conservation of a resident population. This study provides information which will help fishery scientists evaluate and managers decide whether the benefits of resident-based population management are worth the restrictions that would have to be imposed on fisheries.

Cooperating Organizations

Avalon Tuna Club, Avalon, California
California Department of Fish and Game, Long Beach, California
National Marine Fisheries Service, Southwest Fisheries Center, La Jolla, California
University of California, San Diego Supercomputer Center

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Publications

Ragen, T. J. 1990. Pre-exploitation abundances for the white seabass (*Atractoscion nobilis*), yellowtail (*Seriola lalandei*), and giant sea bass (*Stereolepis gigas*) off Southern California. In The estimation of theoretical population levels for natural populations. Doctoral dissertation, University of California, San Diego.

Lectures

MacCall, A. D. Historical changes in the California Current ecosystem. Seminar presentation. NOAA/NMFS Tiburon Laboratories, Tiburon, California, March 1990.
MacCall, A. D. Historical changes in the California Current ecosystem. Seminar presentation. University of California Bodega Marine Laboratories, Bodega Bay, California, March 1990.
MacCall, A. D. Historical changes in the California Current ecosystem. Seminar presentation. California State University, Hayward, California, May 1990.