# Estimating Future Bering Sea Northern Rock Sole Productivity from IPCC Climate Models Using Empirical Downscaling


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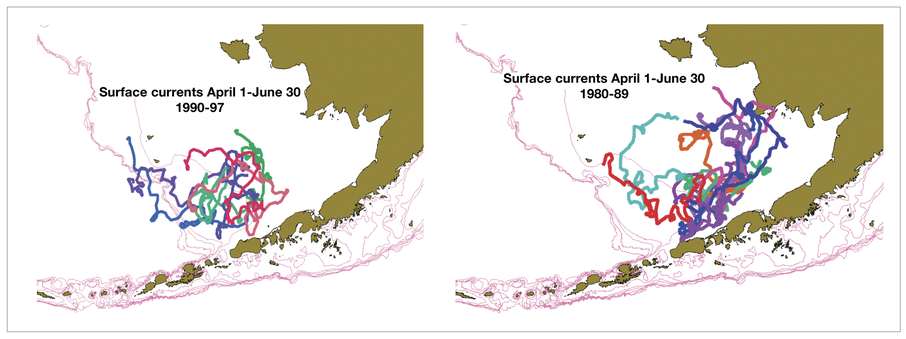
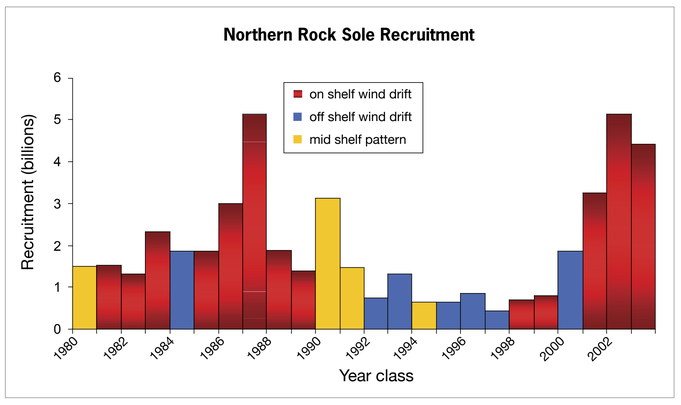
## INTRODUCTION

In order to forecast the implications of climate change on the production of marine fish a framework has been developed to conceptualize the linkages between the physical environment and their biology. The framework involves five steps: 1.) identification of mechanisms underlying the reproductive success, growth and distribution of major fish and shellfish populations; 2.) assessment of the feasibility of down-scaling implications of IPCC scenarios on regional ecosystems to select environmental indicators; 3.) evaluation of climate model scenarios and selection of IPCC models that appear to provide valid representations of forcing for the region of study; 4.) extraction of environmental indicators from climate scenarios to incorporate indicators into projection models for fish and shellfish; and 5.) evaluation of the mean, variance, and trend in fish and shellfish production under a changing ecosystem.

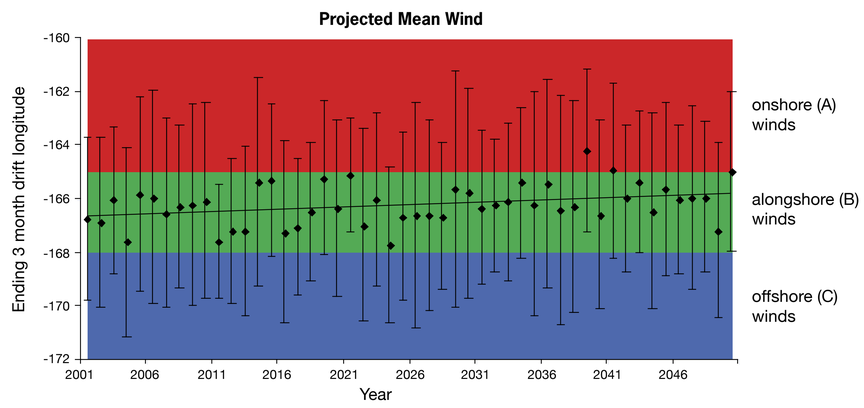
Northern rock sole *(Lepidopsetta polyzystra)* is a major flatfish species in the North Pacific Ocean and has a large biomass in the eastern Bering Sea. Temporal trends in northern rock sole production have been found to be consistent with the hypothesis that decadal scale (or shorter) climate variability influences marine survival during the early life history period (Wilderbuer *et al.,* 2002). After spawning in February-March, northern rock sole larvae are subject to advection from wind, currents, and tidal forcing during April-June. Using an ocean surface current model (OSCURS, Ingraham *et al.,* 1988), Wilderbuer *et al.,* (2002) found that wind-driven advection of larvae towards favorable nursery areas inside the 50m isobath coincided with recruitment. Ocean forcing resulting from onshelf (easterly) winds during the 1980s and again in 2001-2003 coincided with periods of above-average recruitment whereas offshelf (westerly) or midshelf (northerly) winds during the 1990s corresponded with periods of poor or average recruitment. This suggests that patterns of future recruitment for northern rock sole will depend on wind patterns that are influenced by future climate conditions. Thus, to predict future recruitment for northern rock sole, it is also necessary to predict future climate conditions.




## METHODS

Following the framework for projecting environmental indicators outlined above, spring wind and the associated transport on the Bering Sea shelf were estimated from a weighted ensemble of IPCC model simulations. The various IPCC models used were rated based on how well their hindcasts for the latter half of the 20th century matched observations. The two specific criteria for this rating were the IPCC model's ability to reproduce the overall mean April-June winds on the southeast Bering Sea shelf, and the interannual variance in the seasonal mean winds. The weighted models were each then used to form a projection (mean, variance) of the winds out to 2050, and converted to ending longitude of surface-drifting larvae. This projection indicates a slight tendency towards increased shoreward transports, with substantial variability on top of this weak trend.




Based on these results from the IPCC climate models, the future production of northern rock sole was projected for the period (2001 to 2050) as follows: A hierarchical bootstrap algorithm was applied to estimate annual variability in future springtime climate (i.e., wind direction and subsequent larval drift) as well as variability in recruitment under a given climate condition. First, three climate conditions were characterized according to the range of the ending longitude *(L)* expected for larval drift under each condition: A) onshelf drift ($L$<165° West), B) midshelf drift (165° West <$L$≤168° West), and C) offshelf drift (168° West ≤ $L$). Then, for each projected year, the corresponding predicted mean drift longitude and variance from the IPCC model results were used to draw a sample drift longitude from a normally-distributed population and the corresponding climate condition was identified. Finally, a value for recruitment was randomly selected (with replacement) from the set of "observed" recruitments corresponding to the given climate condition. This was repeated 20,000 times to generate bootstrap realizations for each projected year.

For each year, the probability of occurrence for each climate condition was computed, as well as the mean and distribution of recruitment.

A second projection method was also examined which included a Ricker stock recruitment curve with environmental factors to fit the Eastern Bering Sea northern rock sole stock, as follows:

$$R = \alpha S e^{(-\beta S + \varepsilon_1 V_1 + \varepsilon_2 V_2 + \varepsilon_3 V_3)}$$

where $R$ and $S$ are recruitment and stock in millions and kilotons, respectively, α is a density-independent parameter, β is a density-dependent parameter, and $V1$ through $V3$ are the following indicator variables:

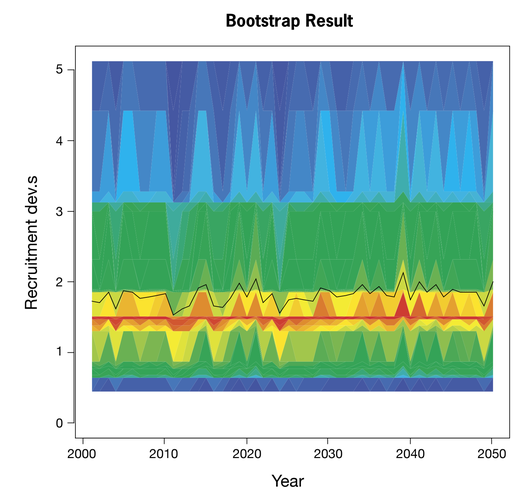
$V1$ = on-shelf wind
$V2$ = mid-shelf wind
$V3$ = off-shelf wind

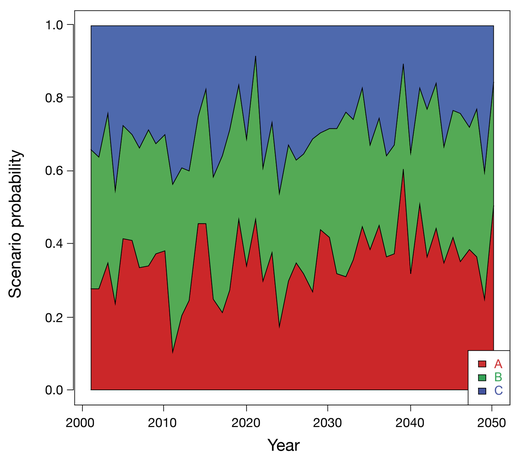
The projections begin with the vector of numbers at age, weight at age, fishery selectivity and maturity at age estimated in the most recent assessment. Fishing is set at the maximum allowable by the NPFMC and is limited by a harvest control rule. Future recruitment is drawn from the spawner-recruit curve depending on the IPCC predicted future springtime wind regime, with variability (lognormal with σ=0.6). One hundred stochastic recruitment scenarios are generated from each of 100 future climate scenarios.

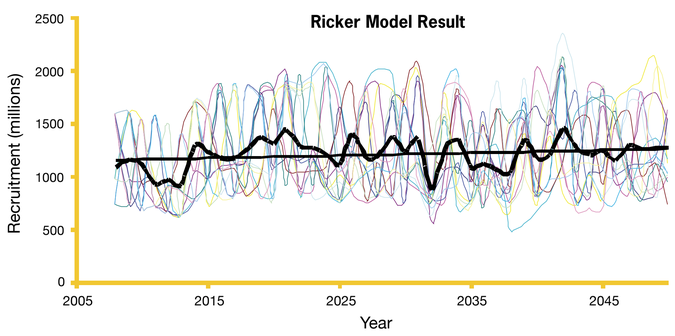
## RESULTS

Not surprisingly, the temporal trend in probability of occurrence of each climate scenario follows a pattern similar to that of the mean ending longitude of larval drift. These results suggest a moderate increase in expected recruitment with time because the trend indicates more frequent occurrence of the onshelf climate condition with time, which corresponds to the highest expected mean recruitment. However, this result does not incorporate the variation in recruitment. When the variation of recruitment within a climate condition is incorporated, any trend toward larger recruitments with time is much reduced. The mean of expected recruitment displays a comparatively smaller trend toward larger values with time while the median displays no trend whatsoever. The reduction in trend from mean to median occurs because of the asymmetrical nature of the distribution of recruitment under each of the three climate conditions.

For the second method, which models recruitment as a function of spawning biomass, a similar trend was observed.




## CONCLUSIONS

- The climate prediction models suggest that, to the best of our current knowledge, rock sole production will not be substantially impacted by future climate change - at least in regard to the effects of that change on patterns of springtime larval advection. The mean results indicate a modest trend towards improved recruitment through the end of the projection.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