forcing of A7 (Akkeshi line St 7 off Hokkaido, Japan). The model results show low growth rate in the third and fourth year cohort. The result strongly depends on water temperature.

Future work

This model is not perfect and needs improvements in several respects.

- The weight of the earliest stage is not reproduced well. We should re-parameterize values for this stage.
- More than half of the Pacific saury spawn in the first year and all of them spawn in the second year (Kurita and Sugisaki; in preparation). We should include the effect of spawning in this model.
- In this model only one ocean region is included. But the saury migrate from the subtropical to the subarctic region through the mixed water region, each with its own seasonal cycle of temperature and prey. We should include at least three ocean regions in the ecosystem-saury coupled model. We suggest Figure 4.8 as a prototype three ocean region model. This kind of model is very useful for the analysis of interannual variability of saury growth.

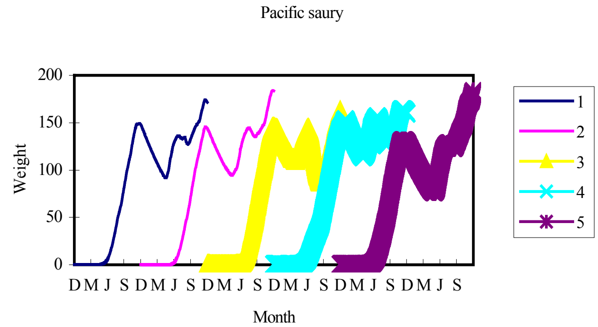

Fig. 4.7 Result of Pacific saury bioenergetics model with realistic forcing.

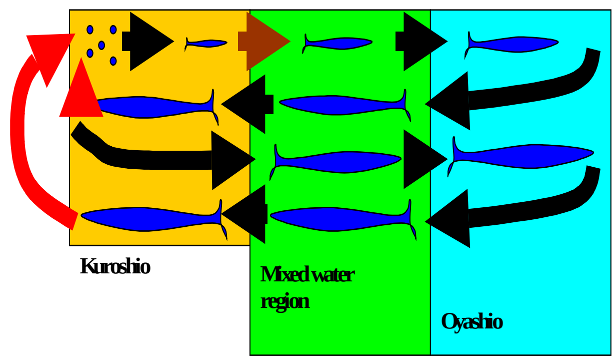

Fig. 4.8 Schematic picture of a three-ocean-box model. This model includes three ocean regions but only one saury bioenergetic model.

5.0 Model experiments and hypotheses

Several model experiments were discussed to test hypotheses regarding the effects of climate change. The details of the experiments and hypotheses are described below.

Space hypothesis

Geographic variation in fish growth: Differences in environmental conditions, and resulting differences in lower trophic conditions, can account for the differences in herring growth rates among selected sites in the North Pacific ecosystem. There exist long-term data sets on size-at-age of herring from many locations in the North Pacific. These data sets show that herring growth rates over the past decades have varied consistently among the different locations. Understanding the extent to which environmental conditions account for these temperature differences in herring growth is important for predicting climate change effects and for effective management of these fisheries in the future.

Key regions contributing to fish growth and biomass variations: Pacific saury are spawned in the subtropical and transition zone from autumn to spring, and migrate from the subtropical to the subarctic ocean through a transition zone. The environments of these three regions show different interannual variability, and it is very difficult to distinguish which location (or season) is most important to the interannual variability of fish growth and biomass. We will tune up the NPZ model coupled to the fish growth model with long-term climate and weather records by comparing the model results of fish growth with interannual variability in observed size composition. To understand which region contributes most to the interannual variability in fish growth and biomass, sensitivity tests of this model will be very useful. Understanding key regions in fish growth and biomass variation is also important for predicting climate change effects and for effective management of these fisheries in the future.

Time hypothesis

Understanding regime shifts: Synchronous changes in herring growth rates across locations may be accounted for by basin-wide decadal-scale changes in environmental conditions. Preliminary examination of herring growth rates at several locations showed sudden shifts in growth rates occurring in the same years across all locations. We will combine the long-term datasets on herring growth, where possible, with regional and local long-term climate and weather records, and use the NPZ model coupled to the fish growth model to examine possible environmental regime changes.

Understanding how regime shifts cascade up the food web may be our best chance for using past conditions to infer future effects of climate change.

Change of dominant species: Changes in the dominant small pelagic fish species seems to coincide with basin-wide decadal-scale changes in environmental conditions. For example, the dominant species changed from sardine to saury across the regime shift in 1987.

Comparing different fish bioenergetics models with the same NPZ model is very useful to understand the climate change effects on ocean ecosystems through bottom-up processes.

Climate change hypothesis

Global climate change effects on energy pathways and fish production: Climate change may result in energy being diverted from the pelagic pathway and shunted through the microbial pathway, resulting in less food for pelagic fish and consequently slower fish growth rates. We will use the coupled NPZ and fish models, the long-term datasets, and defined climate change scenarios to predict how climate change might affect energy cycling, shift the dominance among different phytoplankton and zooplankton groups, and affect fish growth and production in the North Pacific ecosystem. Model simulations will be performed under present-day (baseline) environmental conditions, and for a suite of realistic climate change scenarios. Comparing these linkages and pathways under baseline and climate change scenarios for a variety of locations that have different environmental conditions (*e.g.*, shallow coastal versus deep blue water) will aid in the interpretation and generalization of our results.

6.0 Recommendations

Results of the model work accomplished at the workshop resulted in several recommendations. They are listed here in priority. A description of workplan scheduling is indicated after each item in parentheses and in italics:

1. Develop site-specific applications (*to be scheduled*);
2. Perform herring comparison between the Sea of Okhotsk and Vancouver Island (*to be scheduled*);
3. Incorporate data observations into NEMURO (*to be programmed*);
   a. Obtain physical parameters (radiation, cloud cover, wind stress);
   b. Obtain realistic time series of SST and photosynthetically active light;
   c. Obtain physical observed time series;
   d. Obtain observed zooplankton time series;
4. Execute a dynamics linkage in NEMURO.FISH (*to be scheduled*);