

abundant production of zooplankton, specifically copepods, could explain both enhanced growth and year-class survival in herring and other species. There is a precedent for assuming that an abundant source of an alternate zooplankton prey species can reduce predation on herring. Ware and McFarlane (1995) showed that increased euphausiid production resulted in a decreased hake predation on adult herring off the west coast of

Vancouver Island. Similar mechanisms might operate at the juvenile stages, so factors promoting a strong year-class of herring might also support strong year-classes of other species, leading to synchrony between unrelated species such as blackcod and lingcod. Again, the answer is a tentative yes. Both of these species have early life stages (first several years of life) in nearshore waters.

## 2.4 Review for Pacific saury (*Cololabis saira*) study under the VENFISH project

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VENFISH (Comprehensive study of the Variation of the oceanic Environment and FISH populations in the northwestern Pacific) project was started in April 1997 and will end in March 2002. This project has been supported by Japan Agriculture Forest Fisheries Agency. The aim of this project is clarification of bottom-up control process for Pacific saury and walleye pollock in the Northwestern Pacific. More than 20 scientists from National Fisheries Research Centers at Hokkaido, Tohoku, Yokohama and Shimizu, and Hokkaido University and Tohoku University joined this project.

The VENFISH team is composed of 5 teams and there are primary production, zooplankton and fish teams. The fish team is composed of Pacific saury and walleye pollock groups. Between these three teams there is a plankton ecosystem model team and a fish population model team. In this report we will note our studies of saury, which is only one portion of this project.

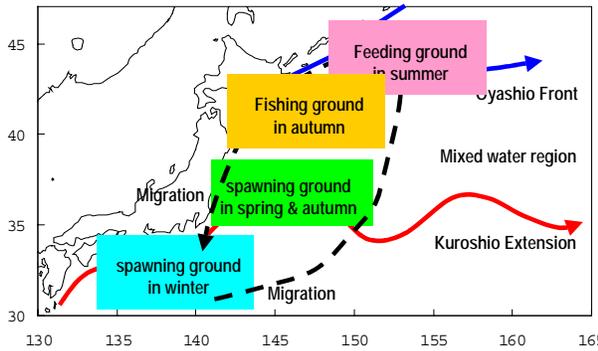
The main target area of the VENFISH project is east of 160°E in the northwestern Pacific, and in that region there is a warm Kuroshio current and a cold Oyashio current. Between these two western boundary currents, there is a mixed water region,

and in that area many eddies are detached from the Kuroshio and Oyashio and make very complicated environments. The saury spawning starts in the mixed water region in autumn, moves to the Kuroshio area in winter, and moves back to the mixed water region in spring (Fig. 2.4.1) (Odate 1977; Watanabe and Lo 1989; Watanabe *et al.* 1997). Juveniles are advected to the Kuroshio extension region, then grow and migrate to the Oyashio region through the mixed water region for feeding. After sufficient feeding they migrate back to the Kuroshio region for spawning. On the southward migration, they are fished in the Japanese coastal zone. We will briefly report the new findings for Pacific saury in the later sections.

### Feeding habitat

The feeding habitat of Pacific saury (*Cololabis saira*) changes according to the life stage and the location. Larvae smaller than 15 mm mainly feeds on *Oncea* and *Oitona* sp. (Nakata and Koyama 2002), whereas larvae and juvenile larger than 15 mm prefer *Calanus* sp. Young saury which migrate to the mixed water region mainly feed on *Euphausia pacifica*. In the Oyashio region they feed mainly on *Euphausia pacifica* and *Neocalanus cristatus* and the ration becomes the

maximum in this season. On the way of their backward migration, they feed *Euphausia pacifica* and *Sagitta elegans*, but the ration decreases to the minimum. In the spawning area they feed on calanoid copepods and the ration is higher than in autumn (Sugisaki and Kurita, in preparation; Kurita and Sugisaki, in preparation).



**Fig. 2.4.1** Schematic picture of Pacific saury (*Cololabis saira*) life history. Spawning starts in September and continues until June, shifting location from the mixed water region and Kuroshio region. The main spawning season is winter. Juveniles are advected to the Kuroshio extension region and migrate to the Oyashio region through the mixed region for feeding. After sufficient feeding they migrate back to the Kuroshio region for spawning. On the southward migration, they are fished in the Japanese coastal zone.

### Spawning density

Kurita and Sugisaki (in preparation) surveyed the seasonal change of the saury distribution and the ratio of mature stage in the three regions. In early autumn, half of the saury occur in the Oyashio region and they are immature. In winter almost all of the saury are in the Kuroshio and they are mature. In spring, half of the saury exist in the Kuroshio and most of them are mature. But the other half occurs in the mixed water region and only about 70% of them are mature. These results show that the most important area is the Kuroshio region and the most important season is winter for the saury spawning.

Kurita and Sugisaki (in preparation) estimated the spawning interval and batch fecundity. Using

these values and ratio of mature saury to the total, they estimated the spawning density for each season. Their result showed that the most important season for spawning is winter.

### Larvae and juvenile

Many studies have been done about larval and juvenile saury (Watanabe *et al.* 1997; Oozeki and Watanabe 2000; Oozeki and Watanabe, in preparation). Using widely sampled field data, Watanabe *et al.* (1997) and Oozeki and Watanabe (2000) estimated the production of hatched larvae in each season since 1990 to 1997. The average value for 8 years showed the highest value in autumn and the lowest value in spring. They also estimated the growth rate and mortality of larvae and production of juveniles. Growth rate showed a maximum in autumn and a minimum in spring. Mortality was highest in autumn and lowest in spring. As a result, the production of surviving juveniles showed a maximum in spring and a minimum in autumn. But the fluctuation of juvenile production in spring is very high and stable in winter. Watanabe *et al.* (1997) suggested that the stable winter juvenile might contribute to stable recruitment and middle size saury landings in autumn. Also Watanabe and Lo (1989) pointed out that winter was the most active spawning season using larval catch data during 1973-1986.

Oozeki and Watanabe (2000) conducted laboratory incubation experiments on saury eggs. They reared same age larvae at three different temperatures and observed growth rate. This was done for three different age larvae (9, 20, 30 days) and the dependency of growth rate on age was also tested. The result showed that the growth rate increased linearly with temperature and also increased with age. Analysis of the otolith increment and the knob length of the larvae showed the possibility of the estimation of growth rate of saury juveniles from the otolith field data. Then, they estimated the instantaneous growth rate from otolith field data and analyzed the relationship between the recent growth rate and oceanic environments (Oozeki and Watanabe: in preparation). Their result showed that the SST and food density affected larval growth during the early stages, and SST and chlorophyll become more important in the later stage.

### **Growth rate of adults**

Suyama *et al.* (in preparation) analyzed the presence of a hyaline zone in the otoliths of Pacific saury. Usually the size decomposition is done by knob length, but sometimes it is difficult to divide them only from body length information. On the other hand, the otoliths of large size saury have the hyaline zone whereas the small and middle sizes do not. They analyzed the existence of the hyaline zone and found out that the large and middle size cohort can be decomposed by the boundary of 50% existence ratio of hyaline zone. Using this definition they decomposed the large and middle cohort and analyzed the inter-annual variability in the growth of each cohort. The middle size fluctuated between 264 and 286 mm, and the large size fluctuated between 303 and 314 mm, and the fluctuation was larger in the middle size.

For example, the growth increment of the large and middle cohort from July to November 1999, was 11.3 and 19.3 mm respectively. On the other hand, they increased to 12.5 and 31.3 mm respectively in 2000. This result suggests that the growth rate of the large size cohort is more stably estimated compared to the middle size cohort.

### **Growth rate between juvenile and large size**

Using the hyaline zone information from the otolith it is possible to estimate the growth rate of young and adult saury, but the growth rate between juvenile and young saury is very difficult to estimate because of the existence of the hyaline zone. We cannot count the increment of the otolith because the increment is unclear in the hyaline zone. So, we cannot determine the age of adult saury.

For this problem, Kurita (personal communication) developed a new method to estimate the hatch date from the age at which the otolith increment width reached a second maximum. It became possible to estimate the age of saury using this method even if there is a hyaline zone. He estimated the hatch date of the large size saury and developed a new scenario of the life history of Pacific saury combined with the information of the growth of the saury with no

hyaline zone. According to his scenario, saury which are born in the earlier season spawn in the first winter and also in the second winter. But the later spawned saury do not spawn in the first year and spawn in the second year.

### **Energy for migration and spawning**

Kurita (personal communication) analyzed seasonal variation of lipid and protein content in 30 cm knob length saury. The protein content did not vary much but lipid variation showed very large variability. The average lipid content is about 40 g in summer. In winter, which is the active spawning season, mature saury contained little neutral lipid. Moreover, protein seemed to be utilized as energy sources because the sum of protein and water content was constant. From this result he concluded that saury need to feed in order to spawn eggs in the Kuroshio region.

Thus, the environment may be very important for the saury reproduction in the Kuroshio region. From the energy balance between the food nutrient and egg production, he estimated that about 35.6% of total assimilated energy was used for winter egg production in the Kuroshio.

### **Population dynamics model for Pacific saury**

Tian *et al.* (2002b) analyzed the interannual variability of the saury stock using a population dynamics model. In his model there are two cohorts. One is a cohort spawned during autumn - winter and the other is spawned during winter - spring. The life span of the saury was assumed to be two years, and as a result the large size saury included both cohorts. The governing equations were growth rate, population, fishing effort and reproduction equations. In the population dynamics the mortality included environmental effects. As environment factors they adapted SST in the Kuroshio Extension zone (KE SST) and SOI (Southern Oscillation Index) according to the result of Tian *et al.* (2000a).

The results showed that the effect of KE SST was important to the longer-period variability, and the SOI effect was important to both the longer-period and inter-annual variability.

## Conclusion

Under the VENFISH project, much has been learned about Pacific saury and a new life history of the saury was proposed. But information about the time between the juvenile and small saury stages are still limited. In the future more study is needed on these stages.

A population dynamics model was constructed under VENFISH and the effect of KE SST and SOI was tested. But in that model the environment influenced only mortality. In the future we should include the environmental influence on production and clarify the bottom-up control mechanism of Pacific saury.

## 2.5 Formalization of interactions between chemical and biological compartments in the mathematical model describing the transformation of nitrogen, phosphorus, silicon and carbon compounds

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In the significant part of the ecological models used for studying the joint dynamics of the microorganism biomasses and biogenic substance concentrations in the natural waters, several most important biological functions are formalized.

They are connected with the consumption of biogenic substances (UP) by microorganisms, excretion of the metabolic products (L) by them, the microorganism mortality (S) and grazing (G) by microorganisms of higher trophic levels. The change of the microorganism biomass in the course of time (dB/dt) in the ecological models, as a rule, is represented by the following structural equation:

$$(2.5.1) \quad dB / dt = (UP - L - S) * B - G * B^*$$

here B\* is the biomass of microorganisms from the higher trophic level, and due to grazing they have an influence on the development and activity of the considered microorganism group B; UP, L, S, and G are specific rates of the biogenic substance consumption, the metabolic product excretion, the mortality of microorganisms B and their grazing by B\*, respectively (day<sup>-1</sup>).

Biomasses B and B\* are calculated in the units of biogenic elements (N, P, C or Si).

### The simulation of processes of the substrate consumption by microorganisms

For the simulation of processes of the substrate consumption by microorganisms (bacterio-, phyto- and zooplankton), the equation of Michaelis-Menten-Monod is traditionally used:

$$(2.5.2) \quad UP = K(T, L) * C_i / (K_m + C_i)$$

where UP is the growth rate of the microorganism biomass (or the substrate uptake), day<sup>-1</sup>; C<sub>i</sub> is the concentration of concrete substratum, mg/l; K<sub>m</sub> is the Michaelis constant, mg/l; K(T, L) is the maximum growth rate of the microorganism biomass (or the substrate uptake) corrected to the temperature (T) and radiation (L) conditions in the water environment, mg/(l day). Thus, for description of the process of the substrate uptake by one group of microorganism (by bacterio-, phyto- or zooplankton) it is necessary to estimate the values of two coefficients - K(T, L) and K<sub>m</sub>. Using this equation form for the description of the consumption of several substrata by microorganisms, means that the process of the substrate uptake is described independently of each other for any substrate, and in this case, the values of the rate constants for the consumption of each substrata should be evaluated. If the number of such substrata reaches five (ammonia, nitrites,