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Yearly fluctuations of stock-recruitment relationships of benthic fish popu1ations at the Tsushima strait and adjacent waters

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Abstract：The off-shore paired trawlers and danish seiners catch benthic fish at around Tsushima strait and adjacent waters. Majority of target stocks are yellow sea bream *Dentex tumifrons*, red sea bass *Doederleinia berycoides* and three species of flat fishes, spotted flounder *Eopsetta grigorjewi*, willowy flounder *Tanakius kitaharai* and long nose flounder *Hippoglossoides pinetorum*. They are warm water species exceptlong nose flounder. The long term fluctuation of stock – recruitment relationships of the stocks were analysed using virtual population analysis by back calculation with Pope's approximation equation. The RR, which is relative distance from Ricker type stock-recruitment model, was evaluated as the index of year-class strength. The RR of four warm water species showed positive correlation with sea water temperature,　but that of long nose flounder was negative.

Key words：Benthic fish population, sea water temperature, Ricker type stock-recruitment model, Virtual population analysis (VPA)

Introduction

The Sea of Japan has structure of two layer water masses. Very cold water mass of lower than 2℃ which is called as the Japan Sea cold original water is reserved in deeper than 200m depth[1]. The another water mass is warm waters of the Tsushima current system, which exists shallower layer than 100m depth[2]. The difference of sea water temperature is over 10℃ . So, the benthic fish fauna differs markedly between deep and shallow water fishing grounds.

The benthic fauna in deep cold original water area consists of cold water species of low diversity. The majorities of exploited species are pacific cod *Gadus macrocepharus*, walleye polluck *Theragura chalcogramma*, red halibut *Hippoglossoides dubius*, long nose flounder *H. pinetrum*, black fin founder *Glyptocephalus stelleri*, snow club *Cionoecetes opilio* and northern red shrimp *Pandalus eous*.

On the other hand, benthic fauna in Tsushima warm water system has high diversity consistsed by many warm water species. The major stocks are yellow sea bream *Dentex tumifrons*, red sea bass *Doederleinia berycoides*, spotted flounder *Eopsetta grigorjewi*, willowy flounder *Tanakius kitaharai*, yellow angler fish, *Lophius litulon*, conger eel *Conger myriaster* and so on.

Over one hundred of off-shore trawlers (more than 15t) have operated in the Sea of Japan. Majority of them operate in cold water area because shallow water area is narrow. However, twelve of paired trawlers (mainly 75t type) is based on Shimonoseki fishing port (seven pairs, Yamaguchi prefecture) and Hamada,　(five pairs, Shimane prefecture). The term "western trawlers" will be used later. The major fishing ground of them is in shallow warm water area, because the shallow water area becomes wide with going to south-west, and the water prevails total area around the Tsushima strait.

In this study, we describe on the results of stock analysis of target species of western trawlers by the virtual population analysis. The majority of target species are warm water ones, except the only cold water species of long nose flounder. The relationship between recruitment success and sea water temperature is also discussed.

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Data and Methods

The virtual population analysis (VPA) method was used to evaluate age-specific individual number of each stock. The VPA method requires the data of age specific catch number. We used landing data of both Shimonoseki (Yamaguchi) and Hamada (Shimane) fishing port. Paired trawlers land their catch packing to polystyrene or wooden containers classified to size (Fig.1).

Fig. 1. Photograph of landed yellow sea bream packed in polystyrene container.

Number of fish packing decrease with fish size. The size categories are named by number of fish packed in a containers. The power function is applied to size category and average fish size.

The period of data available was 1992 to 2014 at Shimonoseki and 1998 to 2014 at Hamada. The danish seines in Yamaguchi and Shimane also target similar stocks. The data were same type as off-shore trawlers in Yamaguchi, and were only catch weight in Shimane.

The age-size class key method[3] was used for evaluating age-specific number of catch. The method applies average age.

The virtual population analysis of back-calculation with Pope's approximation equation[5] was used. Age six and more were gathered as age 6+ on yellow sea bream, and 7+ on other four species. The natural mortality coefficient M was M=0.35 on yellow sea bream and M=0.3 was adopted for other four species.

The Ricker type stock-recruitment models, $R_{est}=ape^{-bP}$ were evaluated using non-linear least regression method. Relative distance from the Ricker curve, $RR=(R-R_{est})/R_{est}$ was used as the index of recruitment success.

Results

Yellow sea bream

Yellow sea bream *Dentex tumifrons* is a small sparid species growing to 35cm in SL. Body is pink with yellow spots at nose and dorsal part. It inhabits waters of 80 to 160m depth. Spawning period is twice a year at March to June and September to October. Sex change from female to male[5].

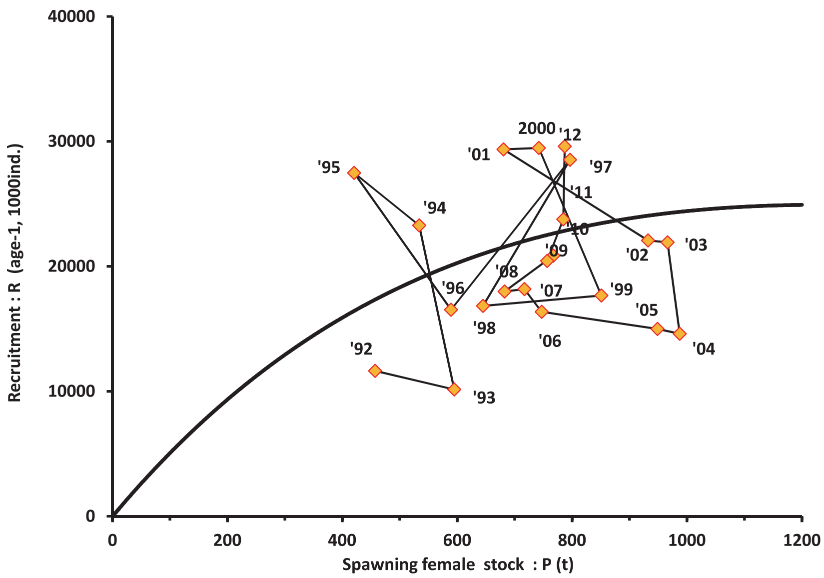

Fig. 2. The stock-recruitment relationship of yellow sea bream *Dentex tumifrons*.

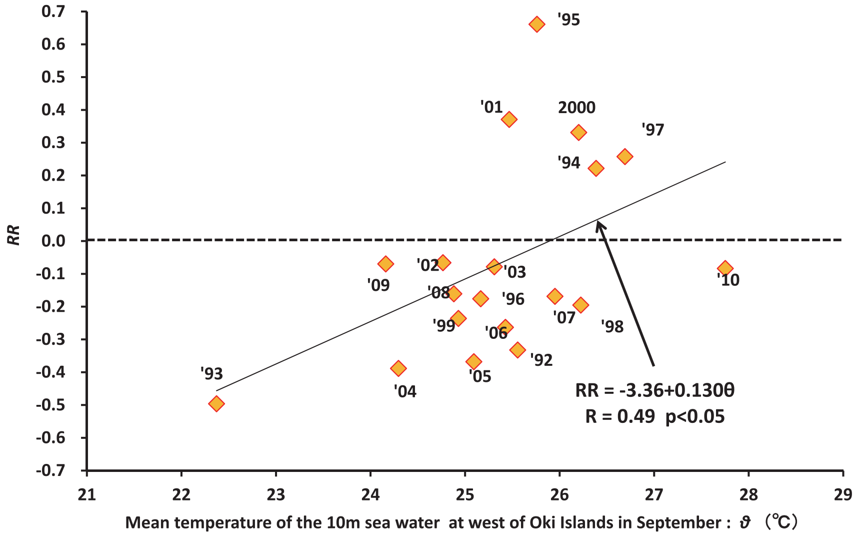

Fig. 3. The relationship between mean sea water temperature and the index of recruitment success of yellow sea bream *Dentex tumifrons*.

Stock-recruitment relationship of yellow sea bream is shown in Fig.2. Spawning females biomass increased from 450t in 1995 to 1050t in 2004. It decreased to 810t in 2006, and it was stable from 700 to 800t in later years. Recruitment was in a range of 10 to 34million. Strong year-class of over 27million recruitment was observed in 1995, 1997, 2001, 2011 and 2012. Relationship between sea water temperature and index of recruitment success RR of yellow sea bream is shown in Fig. 3. Significant plus correlation was observed.

Red sea bass

Red sea bass *Doederleinia berycoides* belongs acropomatidae. Body color is red, which is the origin of Japanese standard name "akamutsu". Throat is black, so the fish is frequently called as "nodoguro" means black throat in Japanese. It tastes very good, because fish flesh contains much lipids of high quolity. Red sea bass is one of the most high price fish among target species of western trawllers.

Stock-recruitment relationship of red sea bass is shown in Fig.4. Strong year classes was observed in 1998. Later years, strong year-classes recruited about three years interval. Significant plus correlation was observed between 100m rayer sea water temperature in June.

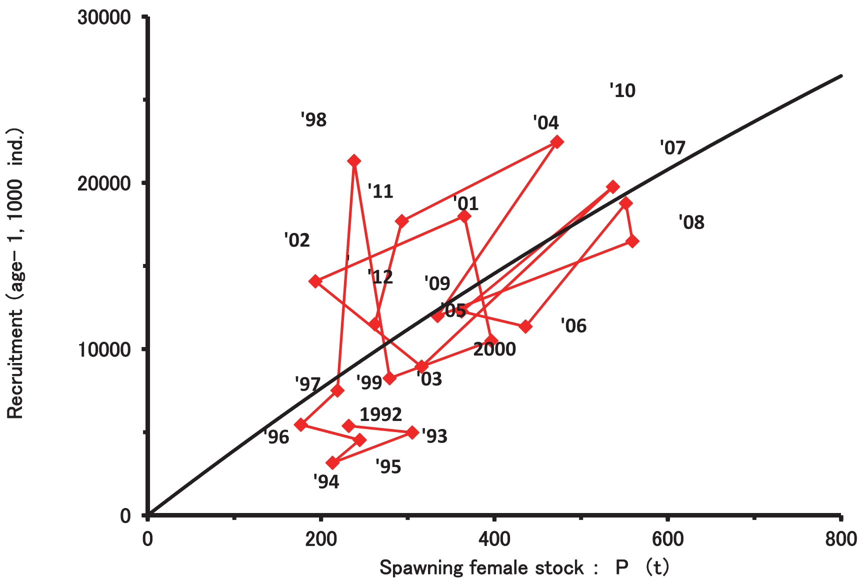

Fig. 4. The stock-recruitment relationship of red sea bass Doederleinia berycoides.

Flat fishes

Flat fish stocks being mainly targeted by western trawllers are three. They are spotted flounder *Eopsetta grigorjewi*, willowy flounder *Tanakius kitaharai*, and long nose flounder *Hippoglossoides pinetrum*. The three species have similar ecological features. Spawning season is January to March. Body sizes are small or middle, and longevities are same as about eight years.

Spotted flounder is a flat fish of middle size, growing to about 45cmTL. Six marked circuler spots on right (eye) side are the origin of Japanese name "mushigarei" and English name. Spotted flounder inhabits widely around Japan, and the density is high in waters around Tsushima Islands. Annual catch of spotted flounder was over 5000t before 1970's, but it decreased to 1000-2000t level later.

The stock-recruitment relationship of spotted flounder is shown in Fig.5. Spawning female stock was 820-1050t from 1992 to 1998. It increased to 1530t in 2003. It decreased thereafter, and it is low level of about 600t in recent three years. Recruitment was high in 1998-2000, and it was in medium or low level after 2005.

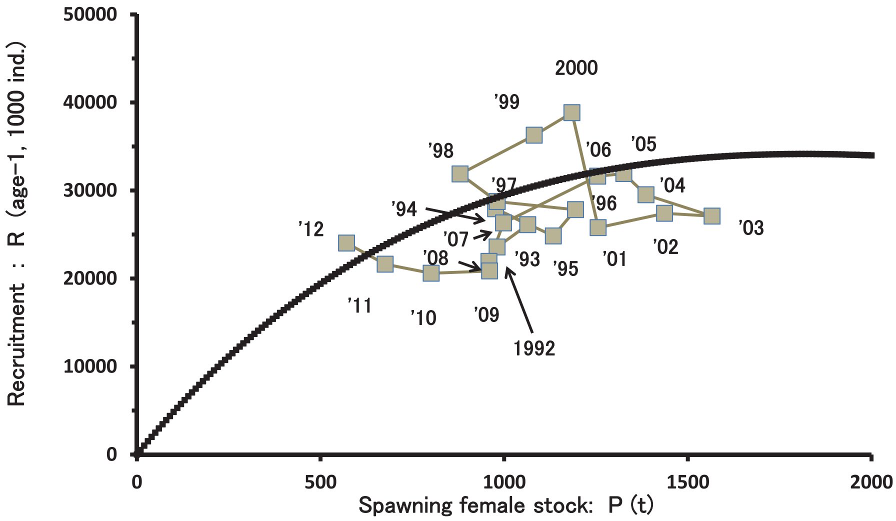

Fig. 5. The stock-recruitment relationship of spotted flounder *Eopsetta grigorjewi*

Willowy flounder is a little smaller than spotted flounder. Maximum TL is about 35cm. The catch of the species was low before 1998. Annual catch increased markedly later. Therefore, data of after 1998 were only available.

Stock-recruitment relationship of willowy flounder is shown in Fig.6. Spawning female stock increased from 410t in 1998 to 1110t in 2007. The stock change to decreasing trend after 2008, and 2013 stock was minimum of 610t. Recruitment was high level of over 20milion from 2001 to 2004, but decreased later. Recruitment in 2012 was minimum of 13million.

Long nose flounder is also a flat fish of middle size growing to 50 ㎝ in TL. The major habitat of the species is northern half of Japanese Islands. It is only cold water species caught large amount by western trawlers. The stock-recruitment relationship of long nose flounder is shown in Fig.7. The spawning female biomass was minimum of 950t in 1992. It increased to a peak of 2400t in 1999, and decreased to a bottom of 1400t in 2004. It again increased to the maximum of 2910t in 2008, and decreased slowly to 2040t in 2013. Recruitment was high level of over 47milion from 1995 to 1997. It was moderate level of about 35million from 1998 to 2000. Recruitments in 2000 and 2002 were very weak about 2000 million. On the other hand, 2004 and 2005 year-class were very strong, and contributed to rehabilitate the stock. The relationship between sea water temperature of 50m layer in May off Shimane and RR of long nose flounder is shown in Fig.8. Significant ($p<0.01$)minus correlation was taken.

Discussion

The stock recruitment relationship of five stocks exploited by western trawlers were analyzed. Four of five stocks are warm water species, and longnose flounder is only one cold water

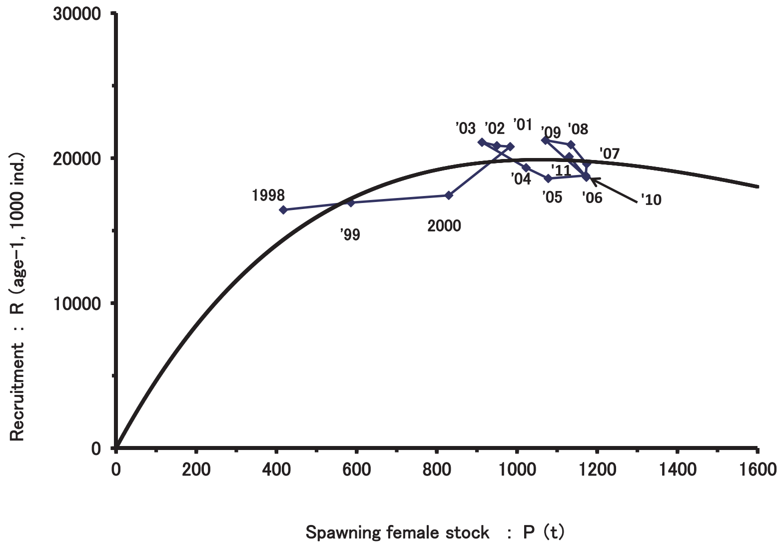

Fig. 6. The stock-recruitment relationship of willowy flounder *Tanakius kitaharai*

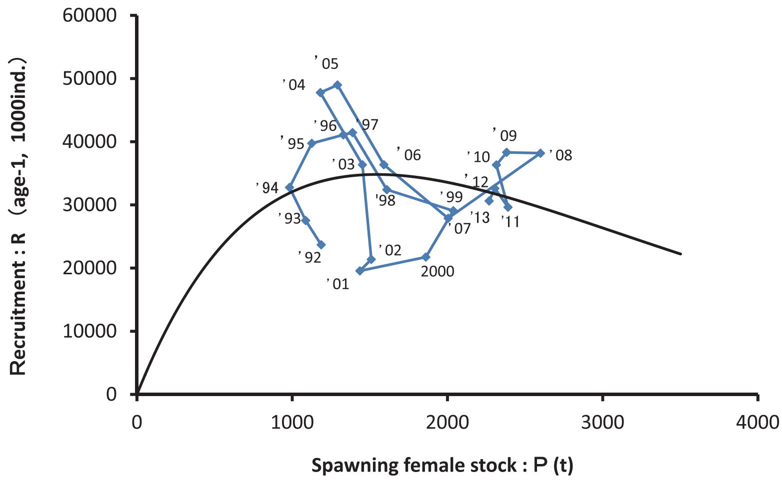

Fig. 7. The stock-recruitment relationship of long nose flounder *Hippoglossoides pinetorum*

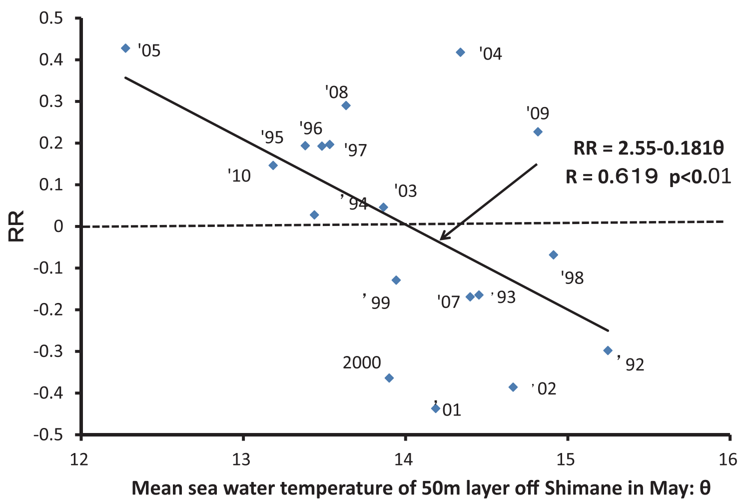

Fig. 8. The relationship between mean sea water temperature and the index of recruitment success of long nose flounder *Hippoglossoides pinetorum*

species. Recruitment success of four warm water species showed plus correlations versus sea water temperature. On the other hand, the coefficient of correlation between recruitment success of long nose flounder and sea water temperature was minus. The growth rate of larval sardine and anchovy show dome-shaped curves versus sea water temperature[8]. Temperature at growth rate peak (optimum temperature)of anchovy was higher than that of sardine. Furthermore, Takasuka et al[9] proposed the growth-selective predation hypothesis that larger larvae have higher ability to escape from predators like skipjack tunas. The two hypotheses persist that survival rates of larval sardine and anchovy will become maximum when environmental temperature is the same as optimum temperature. If optimum temperature of four warm water species are higher than average environmental temperature, and is lower that of long nose flounder, plus correlations of the recruitment success of the former versus environmental temperature and minus of the latter are reasonable.

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