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Cephalopod Stocks: Review, Analysis, Assessment, and Sustainable Management

Stock assessment method and management procedure used for the *Todarodes pacificus* fishery in Japan

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1. Introduction

In this paper, we describe the methods used in Japan to assess the stock size of *Todarodes pacificus* and to manage its fishery. Since 1998, this stock has been managed based on a total allowable catch (TAC). This catch level is set by the government based on socioeconomic factors and an allowable biological catch (ABC), which is determined based on the recommendations of researchers. The ABC aims to achieve and sustain the level of stock status at a proper level (e.g. B_{MSY}), and is calculated based on biological reference points (e.g., F_{MSY}) and the forecasted stock abundance for the following year. Since changing environmental conditions affect the stock abundance of *T. pacificus*, they must be considered when estimating the ABC and recommending management procedures.

2. Unit of stock assessment

The *T. pacificus* stock around Japan comprises 3-4 seasonal spawning groups, of which the autumn and winter spawning groups have the largest biomass. Therefore, the *T. pacificus* stock is assessed as two stocks (autumn stock and winter stock), and an ABC is determined for each. The autumn stock spawns mainly from October to December, and is distributed and landed chiefly in the Sea of Japan (Fig.1). The winter stock spawns mainly from January to March and performs a counterclockwise migration around the Japanese Islands (Fig.1). Monthly landing data are separated for each stock, and landing data from the South Korean fishery are also used.

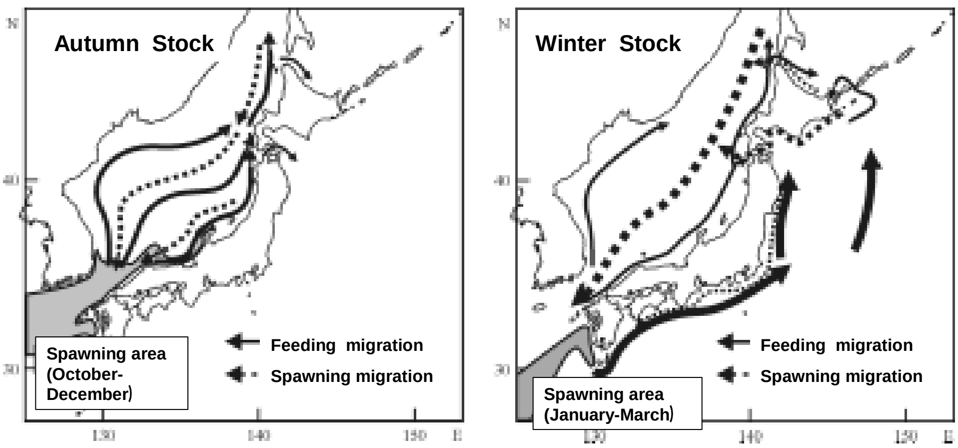

Fig. 1. Distribution and migratory routes of the autumn stock and the winter stock of *T. pacificus*

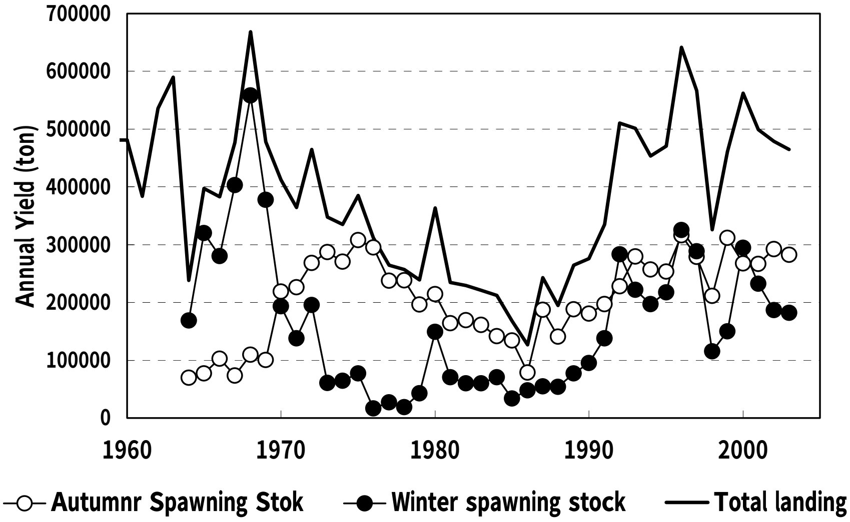

Fig.2. Annual landings of the autumn stock and the winter stock.

Annual landings of the winter stock were about 300-500 thousand tons through the 1960s, but declined to 50 thousand tons during the 1970s and 1980s. After the 1990s, catches began to increase again and have risen to about 200-300 thousand tons in recent years (Fig.2). Annual landings of the autumn stock were about 200-300 thousand tons in the 1970s, but declined to less than 100 thousand tons in 1986. After the 1990s, catches again increased and have also risen to about 200-300 thousand tons in recent years (Fig.2). Combing the data from these two stocks shows that total landings of *T. pacificus* were 400-600 thousand tons before the early 1970s, but declined to 100-200 thousand tons during the 1980s. After the 1990s, they began to increase and have risen to about 400-600 thousand tons in recent years.

3. Method of stock assessment

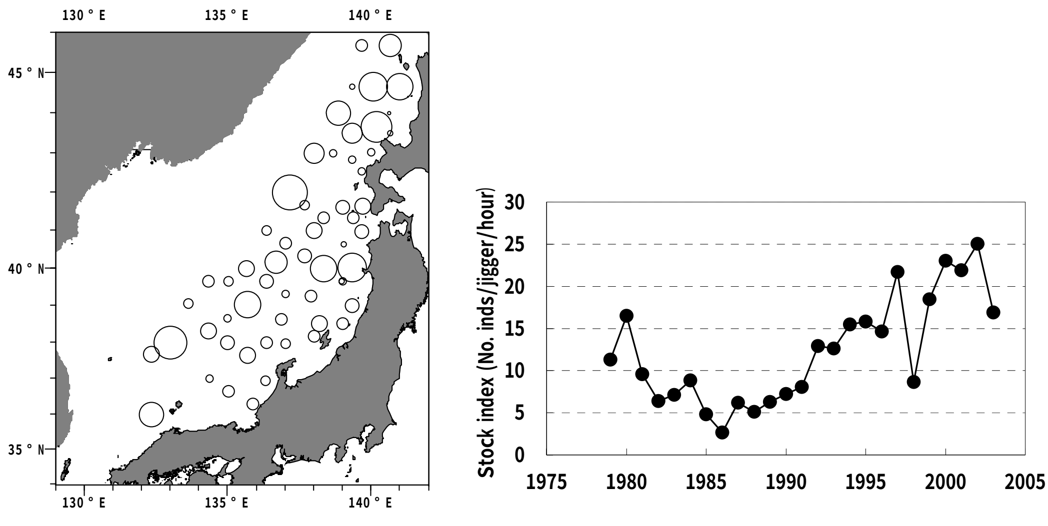

Fig.3. Horizontal distribution of CPUE investigated by research cruise in 2003, and trend in annual stock index

In this section, we describe the method used to assess the stock size of the autumn stock. The abundance of this stock is investigated by conducting research cruises at the beginning of the fishing season (Fig.3). Ten research vessels equipped with squid-jigging machines sample about 60 stations throughout the Sea of Japan. The density of *T. pacificus* at each station estimated based on the CPUE (the number of squid caught/squid-jigging machine/hour), and the average CPUE of all the stations is used as an annual stock index (U). Stock abundance is quantified using this stock index as follows:

$$N_t = p \cdot U_t$$

where N_t is the stock number of squid in year t, U_t is the stock index in year t, and p is a factor determined based on the relation between the stock index and stock abundance in former years. Using this equation, the abundance of the autumn stock was estimated to be about 500 thousand tons in the 1980s and 100-150 thousand tons in the 1990s.

Escapement in the stock (S_t: Spawning Stock) is calculated as follows :

$$S_t = N_t \cdot e^{-M_t - F_t}$$

F_t is the fishing mortality in year t, which is calculated from the stock size and catch number. M is natural mortality and is set at 0.6.

In October and November (the spawning season), we investigate the distribution and abundance of paralarvae on the spawning grounds using plankton nets. Paralarval density is used as an index of the spawning stock size.

4. Stock assessment and calculation of the ABC

Estimated stock abundances and annual landings have shown similar trends over time; both decreased during the late 1970s and early 1980s, but began to increase in the late 1980s and have reached high levels in recent years. Estimated spawning stock abundance and paralarval densities have also shown similar trends with estimated stock abundance. These data suggest the abundance of the autumn stock was low in the 1980s, began to increase in the 1990s, and has sustained a high level in recent years.

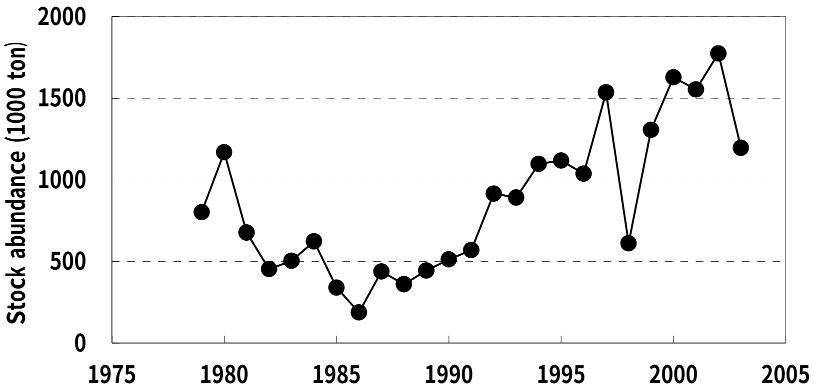

Fig.4. Estimated stock abundance. Stock abundance is quantified using stock index

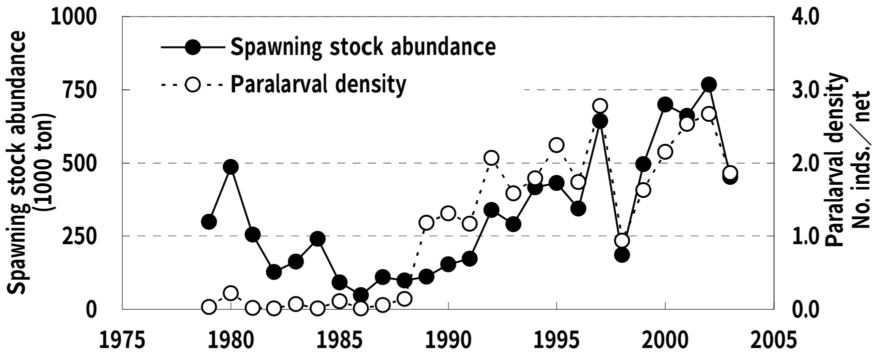

Fig.5. Estimated spawning stock abundance, and paralarval density

ABC is calculated based on biological reference points (BRP) and the forecasted stock abundance, which are both estimated from the spawner-recruit relationship (Fig. 6) using the Beverton-Holt model:

$$N_t = \frac{aS_{t-1}}{1+bS_{t-1}}$$

where, *a* and *b* are parameters.

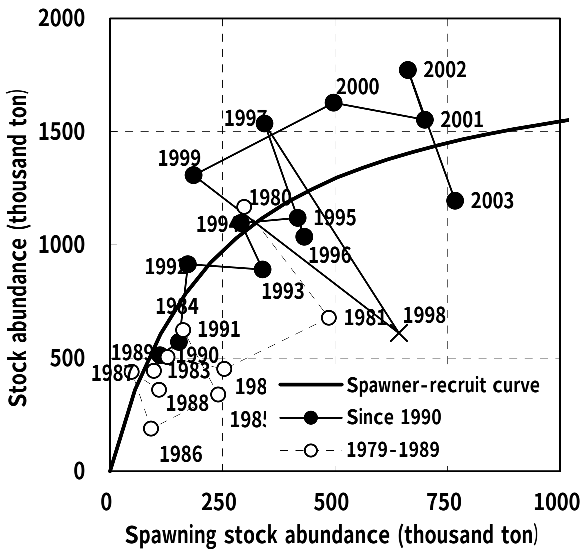

Fig.5. Spawner-recruit relationship. Spawner-recruit curve is fitted in Beverton-Holt model

The sustainable yield is estimated as follows:

$$Y = \frac{F}{F+M} \cdot (1-e^{-M-F}) \cdot \frac{ae^{-M-F}-1}{be^{-M-F}} \cdot w$$

and the fishing mortality that achieves the maximum sustainable yield (F_{MSY}) is used as the BRP. Stock abundance in the following year is forecasted by substituting the present stock number and fishing mortality into the spawner-recruit equation.

5. Influence of changing environmental conditions

Generally, sea surface temperatures (SST) in the northwest Pacific showed negative anomalies during 1976-1988 and have shown positive anomalies since 1989, suggesting a “regime shift” occurred around 1975-1976 and 1988-89. This shift from cool to warm SST coincided with an increase in the stock size of *T. pacificus*, suggesting changing environmental conditions influence the stock size.

Changing environmental conditions will presumably cause changes in the spawner-recruit relationship. The parameters used in our spawner-recruit curve are estimated from data collected since 1990 following this apparent “regime shift”, but when the current regime changes, these parameters should be revised accordingly.

It is unclear how changing environmental conditions influence the stock abundance of *T. pacificus*, and is difficult to predict when “regime shifts” might occur. On the other hand, the results of investigations conducted over many years show that the spawning grounds, spawning migration routes, and body size all show changes that coincide with changing stock size. These changes are assumed to be closely connected with changing environmental conditions and/or stock abundance. We need to better understand these changes in ecological characteristics based on the results of investigations, which will allow us to forecast future trends in stock abundance.