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Catch fluctuations of the diamond squid *Thysanoteuthis rhombus* in the Sea of Japan and models to forecast CPUE based on analysis of environmental factors

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Abstract

This paper describes recent catch fluctuations of the diamond squid *Thysanoteuthis rhombus* in the Sea of Japan and the development of models used to forecast catch per unit effort (CPUE) off Hyogo Prefecture based on statistical analyses of environmental indices measured 600 km upstream in the Tsushima Current. Annual catches during 1989–2002 fluctuated widely, and prefectural annual catches were closely related to each other, especially among the western prefectures. Four indices in June were closely related with CPUE during the fishing season (September–November) off Hyogo: (1) water temperature in the Tsushima Strait, (2) salinity in the Tsushima Strait, (3) sea level at Izuhara (Tsushima Island) and (4) sea level difference between Izuhara and Hakata (Kyushu Island). Using these indices as independent variables, simple and multiple regression analyses were conducted, and CPUE was accurately estimated by both regression and extrapolation, indicating that the CPUE off Hyogo can be forecasted 2 months before the fishery starts using the described models. The strong correlation among catches in different prefectures suggests the indices discussed here affect the catches over a large area.

Keywords: *Thysanoteuthis rhombus*; Diamond squid; Forecasting; Sea of Japan; Tsushima Strait

1. Introduction

The diamond squid, *Thysanoteuthis rhombus*, is one of the most abundant and commercially important squids in the Sea of Japan, where a fishery began in the early 1960s (Nazumi, 1975a). Annual catches

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in the Sea of Japan ranged from 0 to 600 tons through the late 1980s, but have reached more than 2500 tons since the early 1990s (Bower and Miyahara, unpublished data). This recent increase in catches has been due in part to increased fishing effort, especially in the western Sea of Japan, and as a result of the increased catches, *T. rhombus* is now marketed throughout Japan (Omoto et al., 1998). As the fishery continues to grow, it will become increasingly important for managers of the fishery to accurately forecast catch levels.

T. rhombus is epipelagic and occurs throughout tropical and subtropical regions of the world's oceans, but reaches higher latitudes in some subtropical and temperate areas associated with warm currents (Roper et al., 1984; Nigmatullin and Arkhipkin, 1998). Around Japan, spawning occurs over a wide area in southern waters (Bower and Miyahara, unpublished data), including upstream areas of the Tsushima Current (Yamamoto and Okutani, 1975), which is thought to transport part of the population through the Tsushima Strait and into the Sea of Japan (Fig. 1) (Nishimura, 1966; Misaki and Okutani, 1976; Okiyama, 1993; Kitaura et al., 1998). Little is known about this migration, however Nazumi (1975a) suggested that *T. rhombus* enters the Sea of Japan from late May to June, and the occurrence of small (<20.5 cm mantle length) squid off Hyogo Prefecture (Fig. 1) in June and July (Nazumi, 1975b) also suggests the young stages pass through the strait in late spring or early summer.

Populations of short-lived species such as squids are unstable, and many species show a strong environment–recruitment relationship (Bakun and Csirke, 1998; Dawe et al., 2000; Rodhouse, 2001). As a result, environmental indices are increasingly being used to predict recruitment strength in squids (Pierce et al., 1998; Yokota et al., 1998; Robin and Denis, 1999; Ueta et al., 1999; Agnew et al., 2002; Denis et al., 2002; Hayashi, 2003). Tamaki (1987) suggested that fishing conditions for *T. rhombus* in the Sea of Japan can be forecasted based on the flow pattern and strength of the Tsushima Current, and water temperature on the fishing grounds, but he did not clearly quantify any of these relationships. Iizuka et al. (1986) also showed that there is an exponential relationship between the catch amount off Minato, Kyoto Prefecture, and water temperature around the Tsushima Strait. However, both of these studies examined data collected 20 years ago when the fishery was still small, and since fishery data are affected by changes that occur over time in fishing gear and practices that increase efficiency, an updated analysis of recent catches is needed.

The present study describes the catch fluctuations of *T. rhombus* that occurred in the Sea of Japan in 1989–2002 and identifies environmental indices that were closely related to fluctuations in the catch per unit effort (CPUE) off Hyogo Prefecture. We then develop forecasting methods based on regression analyses and discuss their goodness of fit, parsimony and importance.

2. Materials and methods

2.1. Annual catch

In the Sea of Japan, the *T. rhombus* fishery extends along the coast of Japan as far east as Toyama Prefecture (Takeda and Tanda, 1998). Here we used catch data collected in 1989–2002 from Shimane, Tottori, Hyogo, Kyoto, Fukui, Ishikawa and Toyama prefectures (Fig. 1). The Japanese national government does not publish official catch data for *T. rhombus*, and all catch data analyzed here were gathered from local governments or prefectural fishery research institutes. All prefectures except Hyogo started gathering catch data after 1989, and 9–14 years of data were available from each prefecture. Annual catch variation was measured as the coefficient of variation (CV). Catch fluctuations were compared among the prefectures using the correlation coefficient (r) to determine how synchronized the fluctuations were.

2.2. CPUE

CPUE was used as an index to examine the relationship between catch fluctuations and environmental indices. We examined daily catch data landed in 1989–2003 at Kasumi fishing port (Kasumi-cho Fisheries Cooperative Association, Fig. 1), which is where most of the catch in Hyogo Prefecture is landed. In this region, the main fishing season occurs during September–November (Takeda and Tanda, 1998), so the mean daily catch value per boat (kg/(day boat)) during these 3 months was used as the CPUE for the year.