Deep-Sea Research I 81 (2013) 49–61

Contents lists available at ScienceDirect

Deep-Sea Research I

journal homepage: www.elsevier.com/locate/dsri

Seasonal occurrence of mesopelagic fish larvae on the onshore side of the Kuroshio off southern Japan

Chiyuki Sassa [a,*], Yuichi Hirota [b]

[a] Seikai National Fisheries Research Institute, Fisheries Research Agency, 1551-8 Taira-machi, Nagasaki 851-2213, Japan
[b] National Research Institute of Fisheries Science, Fisheries Research Agency, 2-12-4 Fukuura, Kanazawa-ku, Yokohama, Kanagawa 236-8648, Japan

ARTICLE INFO

Article history:
Received 24 January 2013
Received in revised form
28 May 2013
Accepted 11 July 2013
Available online 20 July 2013

Keywords:
Kuroshio
Mesopelagic fish larvae
Myctophidae
Reproductive seasonality
Seasonal occurrence patterns

ABSTRACT

Information on the annual reproductive cycle of mesopelagic fishes has been limited in the western North Pacific, despite their ecological importance. The Kuroshio region is an important spawning ground for various mesopelagic fishes. To describe the reproductive seasonality, we examined the seasonal occurrence patterns of mesopelagic fish larvae at a fixed station (33°12′N, 133°48′E) on the continental slope in Tosa Bay which is strongly influenced by the Kuroshio, based on monthly samples collected from January 2001 to December 2004. In total, 2558 mesopelagic fish larvae were sampled, with a peak abundance during May to June. Larvae of the dominant families Myctophidae, Sternoptychidae, Gonostomatidae, Bathylagidae, and Phosichthyidae were represented by 26 species (or types) belonging to 18 genera. The 12 most abundant species accounted for 96.9% of the total catch. The seasonal occurrence patterns of these larvae were categorized into five groups in accordance with the physical properties of the water column: Winter (*Notoscopelus japonicus* and *Lipolagus ochotensis*); Spring (*Symbolophorus evermanni* and *Maurolicus japonicus*); Early summer (*Myctophum asperum* and *Diaphus* stubby type); Autumn (*Lampanyctus* sp. A, *Cyclothone* spp., and *Sigmops gracile*); and -round (*Vinciguerria nimbaria*, *Diaphus* slender type, and *Diogenichthys atlanticus*) groups. No significant difference was observed in the months of peak abundances of these larvae during the 4 years, suggesting that each species has a fixed seasonal pattern of reproduction. The various patterns of seasonal occurrence would result in seasonal habitat segregation of the larvae among species, potentially enabling the reduction of intraspecific competition for food resources in the oligotrophic waters of the Kuroshio.

1. Introduction

Mesopelagic fishes (1) occur in all of the world's oceans, (2) have a high species diversity, (3) numerically dominate oceanic fish assemblages, (4) have a high biomass–global estimate of 10^{10} t, and (5) act as an important link between secondary producers and upper trophic levels in ecosystems (Gjøsæter and Kawaguchi, 1980; Moser et al., 1993; Hulley, 1994; Brodeur and Yamamura, 2005; Kaartvedt et al., 2012). Thus, mesopelagic fishes are a key component of oceanic ecosystems. In order to understand the maintenance mechanism of the large biomass, high abundance, and high species diversity of mesopelagic fishes, it is necessary to accumulate information on their reproductive biology.

Generally, fishes inhabiting the temperate zone show various types of spawning periods, which are classified into spring, spring-to-summer, summer, autumn, winter-to-spring, and year-round spawning based on monthly changes in gonadal development of freshwater fishes and marine fishes inhabiting epipelagic and/or neritic habitats (e.g. Lam, 1983; Shimizu, 2006). However, information on reproductive seasonality of mesopelagic fish based on gonadal development has been limited in world's oceans (Kawaguchi and Marumo, 1967; Clarke, 1973; Kawaguchi and Mauchline, 1982; Gibbs and Krueger, 1987; Young et al., 1987; Dalpadado, 1988; Miya and Nemoto, 1991; Gartner, 1993; Moku, 2000) because of difficulties in seasonal sampling of a representative number of adult specimens in oceanic waters. Since larval fish abundance and species composition largely reflect the spawning seasons and locations of the adult fish populations, if the species identification has been established then larval sampling surveys are an effective method to obtain information on spawning compared to the analysis of the gonadal development of adult fish (Lasker, 1981; Koslow et al., 2011). Since most mesopelagic fishes spend their larval stages in the upper 200 m layer (Badcock and Merrett, 1976; Loeb, 1980; Sassa et al., 2002, 2004c) it is easier to sample them by routine plankton net tows (Moser and Ahlstrom, 1996). In addition, we can obtain multi-species information simultaneously by this method. Therefore, this approach has various advantages for studying the spawning seasons of mesopelagic fishes in offshore waters. The

* Corresponding author. Tel.: +81 95 860 1636; fax: +81 95 850 7767.
E-mail address: csassa@fra.affrc.go.jp (C. Sassa).

0967-0637/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.dsr.2013.07.008

spawning period of many species of mesopelagic fishes have been estimated from the monthly occurrence of larvae in the California Current region (Moser et al., 1993), the northwestern Mediterranean (Sabatés, 1990; Sabatés and Masó, 1990), the Benguela Current region (Sabatés and Olivar, 1989), the Agulhas Current region (Olivar and Beckley, 1994), and the transition region of the western North Pacific (Moku et al., 2003; Sassa et al., 2007a).

The Kuroshio is the western boundary warm current in the North Pacific originating from the North Equatorial Current (Fig. 1a) (Kawai, 1972; Kuroda et al., 2008). Mesopelagic fishes in the Kuroshio region show a high species diversity (Table 1) and are considered to be a key component of the food web (Gjøsæter and Kawaguchi, 1980; Watanabe and Kawaguchi, 2003a, 2003b; Brodeur and Yamamura, 2005). Recently, abundance, species composition, and spatial distribution of the mesopelagic fish larvae of the families Myctophidae, Gonostomatidae, Bathylagidae, Sternoptychidae, and Phosichthyidae were described in the Kuroshio region (Sassa et al., 2002, 2004a, 2004b, 2004c, 2007a; Watanabe et al., 2010), although these studies were based on data restricted to a particular season in various locations from 28° to 38°N. These papers show that species composition of mesopelagic fish larvae in the area of the Kuroshio axis and the onshore side of the axis is remarkably different from that of the offshore side of the axis, i.e. forming an indigenous mesopelagic fish assemblage in the Kuroshio region. In addition, these studies show that the Kuroshio region is an important spawning ground for not only commercially valuable epipelagic fishes such as Japanese sardine (*Sardinops melanostictus*), Japanese anchovy (*Engraulis japonicus*), chub mackerel (*Scomber japonicus*), and Pacific saury (*Cololabis saira*) (Sugisaki et al., 2010), but also various species of mesopelagic fishes including several subarctic and transition region species. However, information on the annual reproductive cycle of mesopelagic fishes has been limited in the Kuroshio region, which is essential to understanding their life histories.

The aim of the present study is to describe the reproductive seasonality of dominant mesopelagic fish species on the continental slope in Tosa Bay which is strongly influenced by the Kuroshio. In this study, we examined the seasonal occurrence patterns of the mesopelagic fish larvae, based on monthly sampling from January 2001 to December 2004 at a fixed station (33°12′N, 133°48′E).

2. Materials and methods

2.1. Study area

Tosa Bay has a wide mouth open to the Pacific Ocean, off Shikoku Island of southern Japan between Cape Ashizuri and Cape Muroto, with a narrow continental shelf (10–20 km) and steep

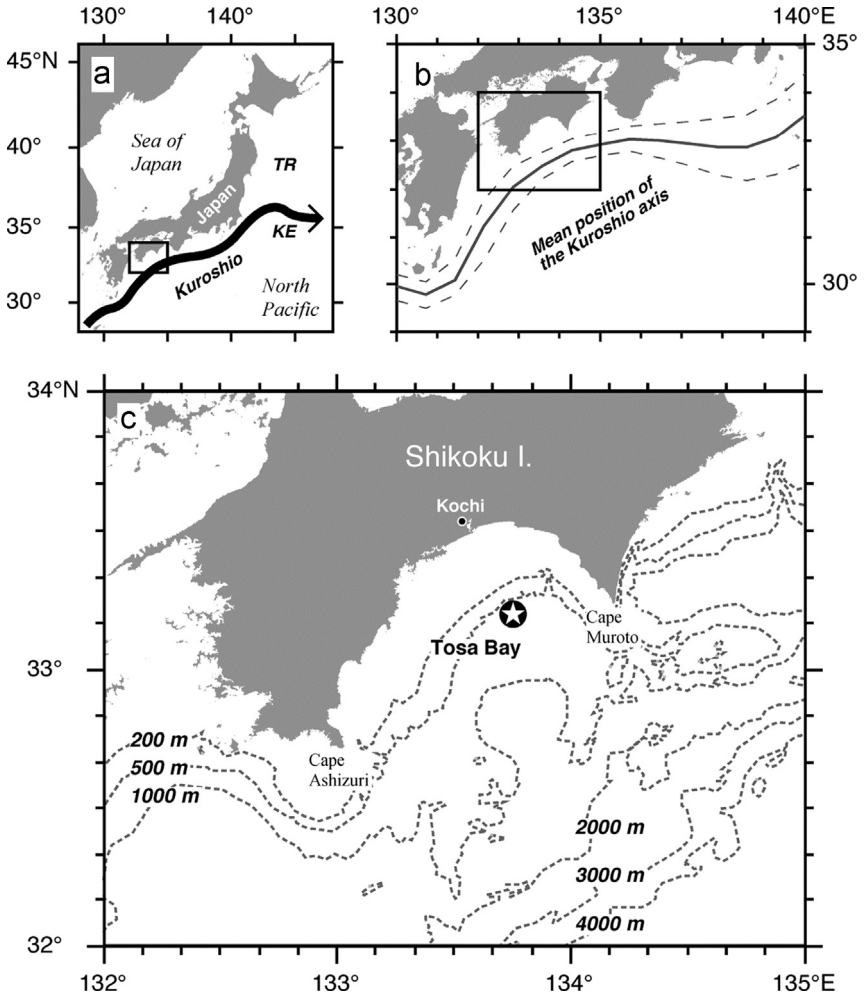

Fig. 1. Location of the sampling station (circled star, 33°12′N, 133°48′E) on the continental slope in Tosa Bay, southern Japan, from January 2001 to December 2004. (a) A typical path of the Kuroshio along the south side of the Japanese Archipelago. KE, Kuroshio Extension; TR, transition region. (b) Bold and broken lines represent mean and standard deviation of the Kuroshio axis position, respectively, based on data during 1985 to 2007 (Japan Meteorological Agency, available from: http://www.jma.go.jp/jma/indexe.html; accessed 23.12.12). (c) Isobaths are shown with dashed lines.