



Occurrence and potential prediction of the giant jellyfish *Nemopilema nomurai* off Hyogo Prefecture, southwestern Sea of Japan, during 2006–2015



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HIGHLIGHTS

- We monitored the occurrences of giant jellyfish *Nemopilema nomurai* in southwestern Sea of Japan.
- Annual by-catch number of medusae exceeding ten thousand was observed in 2006, 2007 and 2009.
- The first detection time of medusa occurred around the timing when the salinity reached the minimum value.
- Prediction of the occurrence timing of medusae may become possible by monitoring salinity data.
- Predicting the amount of medusae will be improved by using the catch data from offshore trawl surveys.

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ABSTRACT

We monitored the occurrences of giant jellyfish *Nemopilema nomurai* off Hyogo Prefecture, southwestern Sea of Japan, from 2006 to 2015. Occurrence data were collected from daily by-catch number of medusae at three large-scale set-nets operated in Hyogo Prefecture. In addition, we examined parameters to base predictions of outbreaks of *N. nomurai* using environmental factors measured at Amarube set-net and by-catch data of a preliminary offshore trawl survey. Annual by-catch number of *N. nomurai* medusae exceeding ten thousand in the three set-nets was observed in 2006, 2007 and 2009. On the other hand, no medusa was observed in 2014 and 2015, and the annual values were 2–147 in the other five years (2008 and 2010–2013). Salinity measured at the Amarube set-net decreased from June to August or September, and then increased in every year. The first detection time of *N. nomurai* medusa occurred within one week from the day when the salinity reached a minimum value for the year. It is thought that prediction of the occurrence timing of *N. nomurai* may become possible in the future by monitoring salinity data. The present study revealed that in the years when large amounts of medusae were caught in the offshore trawl survey, many medusae were also collected in the set-nets. For predicting the amount of *N. nomurai* medusae impacting coastal areas of Hyogo Prefecture, the use of catch data from offshore trawl surveys will enable early assessment of potential damage to fisheries.

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1. Introduction

Nemopilema nomurai is one of the largest jellyfish, attaining ca. 2 m in bell diameter and ca. 200 kg in wet body weight (Yasuda, 2004; Uye, 2008). The original distribution of this species is in the large bay area consisting of the Bohai, Yellow and East China seas, an area bordered by the Korean Peninsula and the mainland of

China (Fig. 1), and this species is transported from the main habitat to the Sea of Japan by the Tsushima Warm Current (Shimomura, 1959; Omori and Kitamura, 2004; Uye, 2008; Yoon et al., 2008). Before 2000, mass occurrences of *N. nomurai* in the Sea of Japan were observed only in 1920, 1958 and 1995, and the frequency was considered to be about once per ca. 40 years (Shimomura, 1959; Yasuda, 2004). Since the 2000s, however, large numbers of *N. nomurai* medusae have been recurrently observed in this area (Yasuda, 2004; Iizumi, 2005; Kawahara et al., 2006; Kitajima et al., 2015). It was thought that the frequent mass occurrences of *N.*

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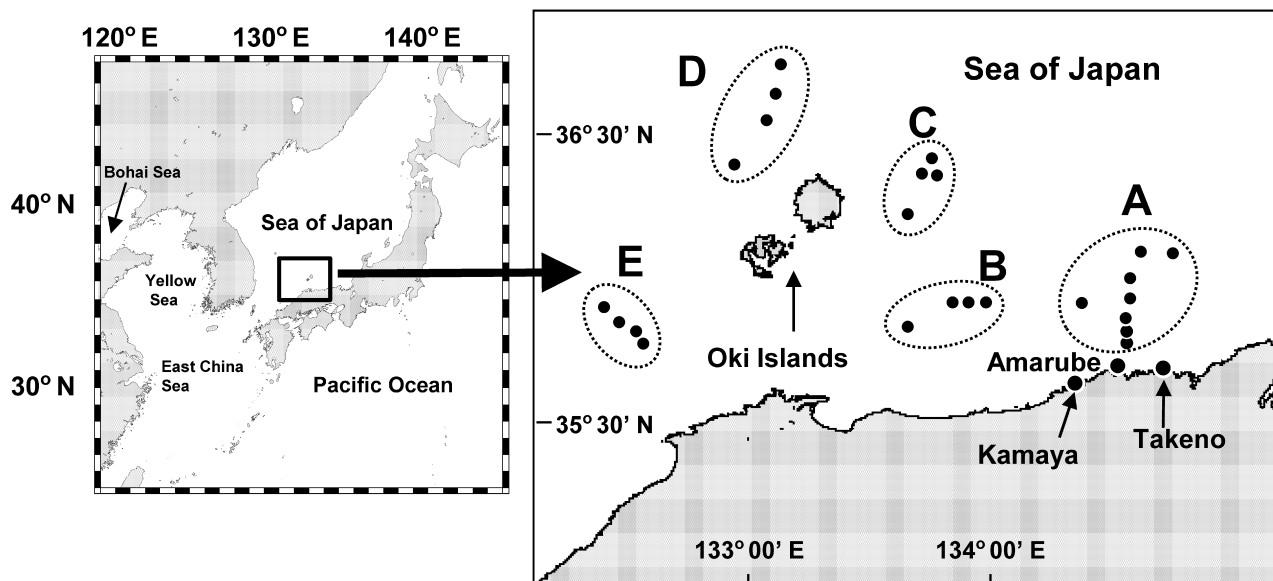


Fig. 1. Location of the survey area in the southwestern part of the Sea of Japan. Black circles in the right panel indicate the locations of three large-scale set-nets operated in Hyogo Prefecture and survey stations of offshore trawl examinations surrounded by dotted line circle labeled A through E. Area A (off Tajima); B (off Daisen); C (Oki-east); D (Oki-north); E (off Hinomisaki).

nomurai in recent years might be attributable to the environmental changes in Chinese coastal waters, such as over-fishing, global warming, eutrophication and increasing marine construction (Uye, 2008). Xu et al. (2013) indicated that high water temperature during late spring and early summer and eutrophication in the Yellow Sea and East China Sea enhanced *N. nomurai* outbreaks.

Mass occurrences of *N. nomurai* cause serious damage to fisheries as follows: reduced catch, fish value depreciation, fishing gear damage, delays of operation activities as well as health issues such as skin trouble (Iizumi, 2005). In Hyogo Prefecture, the problems have occurred mainly in set-net and offshore trawl fisheries. There are no effective countermeasures against mass occurrence of *N. nomurai*. Therefore, it is important to monitor the occurrence of *N. nomurai* and to announce the information to fishers as a first step of the giant jellyfish precautionary measures. In the present study, we investigated the occurrences of *N. nomurai* in relation to temperature and salinity in the set-nets off Hyogo Prefecture, southwestern Sea of Japan and assessed potential factor for occurrence prediction of *N. nomurai* using monitoring data of *N. nomurai* medusae, environmental factors and the offshore trawl survey results, to enhance counter-actions for reducing the damage from *N. nomurai*.

2. Materials and methods

N. nomurai was monitored in the southwestern part of the Sea of Japan from August 2006 to February 2016. In Hyogo Prefecture, three large-scale set-nets (Kamaya, Amarube and Takeno) are operated (Fig. 1). The fishers usually haul the set-nets six days a week except Saturday through the year. We collected data on the occurrence of *N. nomurai* from the daily by-catch number of the medusae reported by the fishers of the three set-nets during the period from August to the following February in each year, but no data were available from the Kamaya set-net in 2015 and 2016 since the fishers did not haul the set-net. In the present study, mass occurrence of *N. nomurai* was defined as a by-catch in the set-net in a day exceeding 100 medusae.

Since 2007, to clarify the environmental conditions of the occurrence period of *N. nomurai*, water temperature and salinity were measured at ca. 3 m depth of Amarube set-net per hour from June to November or December using a T-S sensor (ACTW-CMP,

JFE Advantech). Measurements of water temperature and salinity were carried out from 25 June to 10 November in all the years, except for 2010 and 2013, when measurements from 13 August to 15 September 2010 were missing due to the damage of the set-net caused by a typhoon. In addition, no data for salinity were retrieved after September in 2013 due to the settlement of sessile organisms on sensor.

To examine the relationship presence and absence of *N. nomurai* in the set-nets with their appearance in the offshore, the medusa collections by a trawl were made as a part of a preliminary survey of fisheries resources using the R/V Tajima of the Tajima Fisheries Technology Institute, Hyogo Prefecture in August of 2009–2015. The collections were conducted in five survey areas in the southwestern part of the Sea of Japan: off Tajima (area A), off Daisen (B), Oki-east (C), Oki-north (D) and off Hinomisaki (E) (Fig. 1). The bottom trawl net comprised a mouth opening of 58.8 m² and an 8 setsu (ca. 43 mm) mesh-sized cod-end. Every tow of the trawl usually took 30 min at 8 stations of area A and 4 stations in areas B–E each year. In 2015, however, we could not carry out the offshore trawl survey at area E. We calculated the average weight of medusae per net caught in each area and compared the data with the by-catch in the three set-nets in each year.

3. Results

Higher numbers of medusae were observed in 2006, 2007 and 2009 than other years, and the total number caught by the three set-nets was 32,973, 40,914 and 87,735 medusae, respectively (Fig. 2). In contrast, no medusae were caught in 2014 and 2015, and the annual total by-catch number ranged 2–147 medusae in the other five years (2008 and 2010–2013). In 2006 and 2009, the first catch occurred on 12 and 5 August, and the by-catch continued until late January and mid December. The mass occurrences were observed from late and mid August to late and mid December. In 2007, the first catch was on 2 August and the by-catch continued until early January. The amount remained relatively low until mid September, then more than 100 medusae day⁻¹ were observed between late October and mid December. In 2012 and 2013, when the annual total by-catch were 78 and 147 medusae, *N. nomurai* were observed from late and mid August to late and early October. The medusae were observed in early November and from mid

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