Life history of the sesarmid crab, *Clistocoeloma villosum*, on the southern coast of the Izu Peninsula, central Japan

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Abstract: We investigated the life history traits of a population of the sesarmid crab, *Clistocoeloma villosum* on the southern coast of Izu Peninsula, the known eastern range limit of the species distribution. Traits investigated included new recruitment, reproduction, and overwintering ability, to determine whether the species had become established at the edge of its distribution range. During the study period, 902 individual *C. villosum* were obtained, including 479 males, 386 non-ovigerous females, 2 ovigerous females, and 35 sex-undetermined juveniles. Because population numbers and changes in the size structure were consistent over the study period, it is highly likely that *C. villosum* had overwintered successfully in the study site. Additionally, intermittent new recruitment of juvenile crabs was apparent over the year. However, only two ovigerous females were recorded in August, so the reproductive period was very short compared with most sesarmid crabs in East Asia. Such weak reproductive activity together with the likelihood of planktonic larval recruitment via the warm Kuroshio Current most likely indicates that the southern Izu Peninsula population of *C. villosum* represents a sink population.

Key words: distributional limit, life history traits, near-threatened species, sesarmid crab

Introduction

The sesarmid crab *Clistocoeloma villosum* (A. Milne-Edwards, 1869) is widely distributed in the Indo-Pacific oceans, including Madagascar, Sumatra, New Guinea, Australia, the Caroline and Samoan Islands, Japan, and Jeju Island in Korea (Tesch 1917; Crosnier 1965; Komai et al. 2004; Lee et al. 2010). In Japan, the crab has been recorded on the central and southern Ryukyu Islands, Kyushu, Shikoku, the Kii and Izu Peninsulas and Shimane Prefecture in Honshu mainland (Kishino et al. 2001; Shokita et al. 2002; Komai et al. 2004; Kawakubo et al. 2005; Ministry of the Environment 2005; Karasawa et al. 2006; Miura & Jitsumasa 2010; Wada 2013; Maenosono & Saeki 2016; Osawa et al. 2017; Yuhara et al. 2017). *Clistocoeloma villosum* is generally regarded as uncommon in Japan, except for the southern Ryukyu Islands where the species is treated as near-threatened (Japanese Association of Benthology 2012; Ministry of the Environment 2017). In 2014, it was recorded on the southern Izu Peninsula, an approxi-

mately 350 km eastward extension of its previously-known distribution range of the tidal flat of Waka River Estuary in the Kii Peninsula (Karasawa et al. 2006; Yuhara et al. 2017).

In recent years, several reports have documented the northeasterly distribution expansion of intertidal crabs, including the pilumnid crab *Pilumnopus marginatus* (Shimetsugu 2015a), the hymenosomatid crab *Neorhynchoplax okinawaensis* (Shimetsugu 2015b), the varunid crab *Ptychognathus capillidigitatus* (Yokooka et al. 2015), the macrophthalmid crab *Macrophthalmus banzai* (Yokooka & Nomoto 2013; Itoh & Shimazu 2018), the ocypodid crabs *Ocypode sinensis*, *O. ceratophthalma* (Watanabe & Ito 2001; Yodo et al. 2006), and *Tubuca arcuata* (Yuhara & Aizawa 2016); all planktonic larvae are considered to be transported by the warm Kuroshio Current along the Pacific coast of the Honshu mainland. The studies of *Ocypode* crabs suggest that the populations were unstable due to an inability to overcome low temperatures during winter, with their persistence depending exclusively on an influx of individuals from their main distribution areas, such as southern Kyushu and Ryukyu Islands, aided by the Kuro-

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shio Current (Yodo et al. 2006; Mano et al. 2008).

The coastline of the southern Izu Peninsula, central Honshu Island, Japan, is strongly influenced by the Kuroshio Current, which conveys warm tropical waters in a northeasterly direction (Yamano et al. 2011). This suggests that planktonic larvae of *C. villosum* can be transported northeastward along the Pacific coast of Japan by the current, subsequently settling on the southern Izu Peninsula (Yuhara et al. 2017). To determine whether or not the crab species had become established on the distribution range limit, the population size and demographic characteristics need be evaluated, as indicated by Gaston (2009). Therefore, we investigated the life history of *C. villosum* including the demographic aspects of new recruitment, reproduction, and overwintering ability.

Materials and Methods

One *C. villosum* population was monitored along the Aono River (34°38'06" N, 138°53'11" E) in Minami-Izu, Shizuoka Prefecture, Izu Peninsula, central Japan (Fig. 1). The intertidal zone habitat at the river mouth was characterized by mud flats, gravel, cobble stones, oyster beds, and salt marshes. In the study site, plants included the common reed *Phragmites australis*, semi-mangrove plant *Hibiscus hamabo* (cf. Nakanishi 2001) and the mangrove plant *Kandelia obovate*, an introduced species from Iriomote Island, Japan in 1958 (Iijima & Hayashi 1999; Masuda 1999). The site has been designated as a protected area by the Shizuoka Prefectural Government. Although "Gabion"—cylindrical steel nets inside containing stones—had been set on the revetment in 1995 to protect against soil erosion caused by flooding (Iijima & Hayashi 1999), they were destroyed in October 2014 as a consequence of typhoon-fed flooding of the Aono River. The reconstruction to repair the nets of the revetment was conducted on the

site in February and March 2015 (Fig. 2).

To clarify the life history of *C. villosum*, field observations were conducted monthly around each spring tide from September 2014 to July 2015, and twice in August 2015. Crabs were collected by hand during a 2-hour period (one person) or 1-hour period (two people) from a survey site of 1000 m². The maximum carapace width (CW) of each crab was measured to the nearest 0.1 mm using hand calipers. The crabs were sexed on the basis of their abdominal structure and ovigerous females noted. The sex of crabs less than 5.0 mm CW could not be determined. After field observations and measurements were finished, the crabs were released at their original place of capture.

Results and Discussion

During the study period, 902 *Clistocoeloma villosum* individuals were obtained, including 479 males (53.1%), 386 non-ovigerous females (42.8%), 2 ovigerous females (0.2%) and 35 crabs of undetermined sex (3.9%). Seasonal changes in the number of crabs were characterized by two features during the study period (Fig. 3). In general, low numbers of crabs were collected; totals of early August 2015, middle August 2015, September 2014, November 2014, December 2014, and January 2015 being 25, 32, 34, 18, 10, and 2 individuals, respectively (Fig. 3). This was in keeping with the previous reports by Kitami & Honma (1981) and Kyomo (1986) indicating that sesamid crabs may migrate deeper into cobble stone crevices and burrow to avoid high temperatures. The crabs remain in their burrows during the daytime in summer, being active mainly in the late evening and early morning when temperatures are lower (Kitami & Honma 1981; Kyomo 1986). Additionally, semi-terrestrial crabs are known to remain in their burrows during the winter in temperate regions (Hashiguchi & Miyake 1967; Luppi et al. 2013). Nevertheless,

Fig. 1. Map of the sampling location and the Kuroshio Current off southeastern Japan and the Izu Peninsula.

Fig. 2. A: Revetment reconstruction to repair flood-damaged steel nets on 7 February 2015. B, C: Excavation of deeper zone cobble stones for revetment construction enabled the collection of many crabs. White arrows represent *Clistocoeloma villosum*. D: Overview of the study site photographed on 8 March 2015 [Aono River on left; mangrove trees (*Kandelia obovate*) on right].

in the present study, a significant number of crabs was observed in February and March, (198 and 225 individuals, respectively) (Fig. 3). This research contradicts the accepted belief that semi-terrestrial crabs generally remain in their burrows during winter (Fig. 2). Instead, the revetment reconstruction program demonstrated that this *C. villosum* population largely overwintered under deeper zone cobble stones. Since the crab population numbers were maintained over subsequent spring and early summer monthly sampling, it is highly likely that the *C. villosum* population has successfully overwintered in this area.

The size frequency distribution was polymodal, including at least two size categories (modes) for each sex throughout the study period (9–10 mm and 6–7 mm CW for males; 10–12 mm and ca. 7 mm CW for females), and ca. 4 mm CW for unsexed juveniles crabs (Fig. 3). The two modes for each sex appeared in the 2014 autumn season (September–October), while the larger CW modes subsequently disappeared during the 2014/15 winter season (November–January). However, modes of the larger 9–10 mm CW (males) and 10–11 mm CW (females) appeared again in February 2015, suggesting that the crabs had overwin-

tered. Thereafter, two modes for each sex and a very small mode of 4 mm CW (unsexed juveniles) continued to be in evidence over spring and summer 2015. Both the maintenance of the population number over the winter period and the monthly changes in size structure reinforced the likelihood of the existing population overwintering at this eastern distribution limit.

During the present study, only two ovigerous *C. villosum* females were recorded in August 2015 (Fig. 3). It is well established that most sesarmid crabs inhabiting temperate East Asian tidal flats have their reproductive periods during early summer and autumn (Hashiguchi & Miyake 1967; Suzuki 1981; Kyomo 1986; Yau 1992; Kwok 1995; Chu et al. 2013; Yuhara & Furota 2014). However, when compared to previous studies, the reproductive activity of the *C. villosum* population in the southern Izu Peninsula appeared to be weak with a very limited ovigerous period that is inadequate for successful reproduction. This is consistent with one of the most common demographic explanations for species' distribution range limits (cf. Gaston 2009).

Unsexed juveniles of *C. villosum* (<5 mm CW) were

Fig. 3. Size-frequency distributions of *Clistocoeloma villosum* from September 2014 to mid-August 2015. White histograms, males; gray histograms, non-ovigerous females; black histograms, ovigerous females; oblique-lined histograms, unsexed juveniles.

observed year-round, occurring in October, December, March, May, and June (Fig. 3). The size frequency distribution showed that unsexed juveniles of 3–4 mm CW occurred in October and December 2014, with juveniles of 2–3 mm CW occurring intermittently from March to August 2015. This indicates that in the study area there were at least two recruitment periods of settled juveniles (autumn and spring) as individuals of 3–4 mm CW in autumn would be expected to have grown or died by the subsequent spring. The present result suggests that the *C. villosum* population in the southern Izu Peninsula may function as a sink population, being dependent on recruitment of planktonic larvae from more southern Pacific coastal areas via the warm Kuroshio Current, rather than self-reproducing. This inference may be further investigated by

examination of gene flow data for *C. villosum* by comparing mitochondrial DNA haplotypes between the southern Izu Peninsula population and others from more southern Japanese localities.

In conclusion, the *C. villosum* population in the southern Izu Peninsula at the extreme limit of the distribution range was characterized by population variability through the year, overwintering and the intermittent recruitment of juveniles but with very weak reproductive activity. These patterns are key characteristics of a sink population (cf. Gaston 2009). If this is the case, and the upper intertidal area of the Aono River mouth on the southern Izu Peninsula provides a sink habitat for the northeastern-most population of *C. villosum*, this site must be conserved for habitation by this rare crab.

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