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Review

The crab genus *Hemigrapsus*: species native to Japan, their impact as invasive organisms and potential role in cephalopod aquaculture

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Introduction

Cephalopod aquaculture as a reliable commercial venture has proved difficult to put into practice. In species with a planktonic paralarval stage (such as those in the *Octopus vulgaris* group [1]), one of the major bottlenecks to success is the high mortality of the paralarvae [2]. Methods relying on the convenience of the anostracan branchiopod *Artemia* have failed so far [2-5] but research continues in the hope that suitable methods of supplementation can compensate for the apparent mismatch between the nutrient composition of *Artemia* as a prey item and the nutritive requirements of cephalopod paralarvae [6-8]. However, there is much potential for the use of crab zoeae [7-9]

In Japan, the common octopus species corresponding to the Mediterranean and Eastern Atlantic *O. vulgaris* Cuvier, 1797, is the East Asian common octopus, *Octopus sinensis* d'Orbigny, 1841 [10]. This was the first cephalopod species with a pelagic paralarva for which the life cycle was completed in experimental aquaculture: a study in which zoeae of the shrimp *Palaemon serrifer* (Stimpson, 1860) were used as feed during the paralarval stage [11]. Unfortunately, although half a century has elapsed since that landmark study, there is still no established commercial enterprise for culturing octopuses through a life cycle that includes a planktonic paralarval stage.

The present research project aims to successfully culture *O. sinensis*. The project members include a local aquaculture company, an octopus-based fast-food franchise group and three university research groups. As part of this effort, one avenue of exploration is to consider alternatives to *Artemia* [7-9].

A recent focus of attention is the larvae of small intertidal crabs commonly found along East Asian coasts. They are attractive because their small size and native rocky habitat render them of relatively little commercial value and in Japan normally they are used only as bait in recreational fishing for other organisms (pers. obs.). Some of these species have been identified recently as invasive species in other countries, which seems to suggest that they can reproduce successfully under a wide variety of environmental conditions. Reasons for their success are briefly reviewed here and observations are made on their hardiness and reproductive capacity. They are currently under consideration for mass production of their planktonic larvae as a suitable feed to culture octopuses successfully through their planktonic paralarval stage.

Species of *Hemigrapsus* native to Japan

Hemigrapsus is a genus of eubrachyuran grapsoid crabs (Family Varunidae) of which there are 15 to 16 species recognized world-wide [12]. In Japanese waters, there are three species: *H. penicillatus* (De Haan, 1835), *H. sanguineus* (De Haan, 1835) and *H. takanoi* Asakura & Watanabe, 2005 [13-15]. Table 1 summarizes some of their distinguishing characters. All three species have an adult carapace width of only 3-4 cm and are common endemic species along the shores of the Northwest Pacific [18]. Around Japan, *H. takanoi* enjoys a more extensive northern range than the others, comprising the only species of *Hemigrapsus* reported around most of the coastline of Hokkaido [14].

Table 1. Characters reported to distinguish among the three species of *Hemigrapsus* present in Japanese waters [14-16]

	H. penicill.	*H. sanguineus*	*H. takanoi*
DS: size	large	---	small
DS: abd	yes	---	no
Male claw	small SP	FV	large SP
Banding	no	Yes	no
Eye ridge	---	continuous	interrupted

Notes & abbreviations: abd., abdomen; banding, pattern of light bands across pereiopods (walking limbs); DS, dark spots; Eye ridge, suborbital stridulation ridge; FV, fleshy vesicle; *H. penicill.*, *Hemigrapsus penicillatus*; SP, setal patch (conspicuous patch of hair-like setae on male chelipeds, at joint of propodus and dactylus). N.B. These morphological distinctions are not 100% reliable [15-17].

Within the last three decades, *H. sanguineus* and *H. takanoi* have been reported as invasive species [19].

Hemigrapsus takanoi outside Japan was initially misidentified as *H. penicillatus* [20], highlighting the difficulties of distinguishing between these sibling species [15]. Indeed, it had been suggested that they comprise just a single species, *H. penicillatus* [21], although this has been refuted [22]. Confirmation that *H. takanoi* and *H. penicillatus* are indeed different, valid species was provided during comprehensive studies of the distribution of *H. takanoi* on European Atlantic coasts [15], but further research is needed to determine morphological characters better able to distinguish between *H. takanoi* and *H. penicillatus* than those in Table 1 [15,17].

The impact of invasive species of *Hemigrapsus*

Species in the genus *Hemigrapsus* have shown dramatically fast establishment in the Atlantic on both the European [15,20,23] and North American [19,24] coasts. They arrived in ballast water from ships originating in Japan [15], as confirmed by sampling and population analysis using microsatellite DNA [17], and there is speculation that *Hemigrapsus* may reach Pacific North America on floating wreckage following the massive Japanese tsunami of 2011. Most recently, in 2014, *H. takanoi* was detected for the first time both in the Baltic Sea [23] and at two river sites in SE England [15]. In the USA, *H. sanguineus* became common from Maine to S Carolina within 25 yr, reaching densities of >150 ind. m^{-2} [19]. In Europe, after first arriving in Germany in 1993, *H. takanoi* expanded its coastal distribution to more than 700 km within 3 yr [15]. This astounding success seems to be explained by a combination of several factors. (1) They are euryhaline [25,27] and broadly temperature tolerant [27]. (2) The females can spawn several times a year [27]. (3) They do not have highly specific cues for moulting [19]. (4) They can out-compete the young of larger endemic crab species [25,26]. So, a major threat is to local edible crab populations (e.g. *Carcinus maenas*): early in their life cycle, *Hemigrapsus* young take more prey animals, such as mussels, than those of endemic species. They also dominate prime shelter sites, under rocks, etc. [26].

Potential role of *Hemigrapsus* species in the aquaculture of *Octopus sinensis*

Experiments in our laboratories are still in progress, but experience with *Hemigrapsus sanguineus* and *H. takanoi* indicates that they are indeed much easier to handle and culture than other crab species [19]. Their reported spawning period [27] has already been extended by three months (artificial seawater, salinity 33±2 psu, 22±1°C; 12h light:12h dark), with individual females each spawning up to 3 times; and at first attempt the life cycle has been completed through to the second generation. The larvae are hardy and feed readily on a variety of natural and artificial feeds, such that supplementation for optimal feeding to cephalopod paralarvae should prove to be straightforward. In order to use them routinely for cephalopod culture, though, further research will be necessary to more closely control the timing of spawning to co-ordinate with the hatching of cephalopod culture species. In addition, it will be important to control the speed of development of different stages in the *Hemigrapsus* life cycle to enable their exploitation also at more advanced stages in the octopus life cycle.

Conclusions

Since the *Hemigrapsus* species under investigation are endemic to Japan, there are no issues about culturing them here. On the contrary, further research on species in this genus may provide information that might be useful in learning how to control their distribution in countries where they are aggressively invasive. This research therefore has the potential to kill two birds with one stone: helping to resolve one of the greatest barriers to commercial culturing of cephalopods; while also helping to understand how to deal with an alarmingly successful group of invaders.

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