Mass strandings of the common paper nautilus *Argonauta argo* along the coast of Yoichi Bay, Hokkaido, in the autumn of 2012

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Abstract

Shells of the common paper nautilus, *Argonauta argo*, that had washed up along the coast of Yoichi Bay in Hokkaido were collected from October to November in 2012. Specimens were collected along the foreshore during ebb tide, where they were found together with flotsam that had been washed ashore by storms associated with the northwestern monsoon on the Japan Sea-side of Hokkaido. Shell length measurements of 276 shells revealed that shell length ranged from 20 to 199 mm. Of the shells that were collected, 270 had shell heights that were less than 200 mm. In addition, a bimodal peak was observed at the size-frequency distributions of 60-79 mm and 140-159 mm and strong correlation was observed between shell height and shell length（R^2=0.98）. The mass strandings of *A. argo* along the Yoichi coast are considered to have occurred in response to an anomalous increase in sea surface temperatures（SST）in the northern Japan Sea in the autumn of 2012, which was similar to an increase in SST in 2010.

Key words: *Argonauta argo*, Hokkaido, Japan Sea, mass stranding, Tsushima Warm Current

Introduction

The common paper nautilus, *Argonauta argo* Linnaeus 1758, is distributed throughout the tropical and subtropical oceans of the world（Kubodera 2000; Norman 2003）, including the waters around Japan（Okutani 1987; Kubodera 2000）. Although rarely recorded on the Pacific-side of the Japanese Islands（Kubota and Miyashita 1973; Kosuge 1982）, *A. argo* is relatively common in the Japan Sea between Jeju Island in the south and Hokkaido in the north（e.g., Nishimura 1968; Okutani and Kawaguchi 1983; Suzuki 2006; Sakurai and Kawano 2010）. Of particular interest to malacologists and marine biologists are the mass strandings of *A. argo* that periodically occur along the coast of the Japan Sea of Japan（Nishimura 1968; Ueno et al. 1996; Shiga 2007; Suzuki 2011）.

In October to November 2012, mass strandings of *A. argo* occurred along the coast of Yoichi Bay. This study examined the phenomenon of mass strandings of *A. argo* and performed biometric analysis on the shells of this species. In addition, the relationship between mass strandings and the environmental change in the marine environment were also clarified, and the results of a case study conducted in the autumn of 2010 are also discussed.

Materials and Methods

The study area was located along the coast of Yoichi Bay in central Hokkaido（Fig. 1）. The north-facing sandy beaches extend for 6 km and are composed of light-grayish, medium-grained sands. The area was divided into four sections, A to D, primarily according to coastal morphology（Fig. 1）. The sections are also bisected by rivers that originate in the hills around Yoichi Bay.

Argonauta argo shells were collected along the beach at weekly intervals from September to November in 2012. In addition, we also collected flotsam that had washed up together with the *A. argo* shells, and identified any stranded marine animals. Undamaged *A. argo* shells were subjected to morphometric analysis according to Okutani and Kawaguchi（1983）. Measurements were performed using digital calipers（Mitutoyo CD67-S20PS, Mitutoyo Corporation）.

Results

1. Modes of occurrence of stranded shells

During the study period, *A. argo* shells are considered to have started washing up on the beach of Yoichi Bay in October 2012, with mass strandings occurring for

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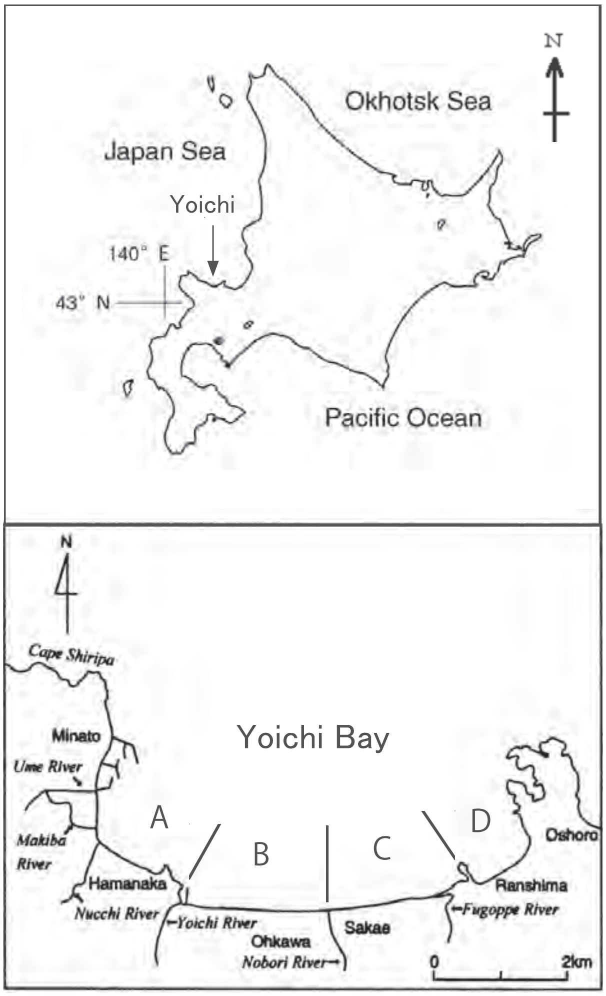

Fig.1 Map showing the study area along the coastline of Yoichi Bay, which was divided into four sections (A-D).

approximately one month from October 15 (Fig. 2-1, 2-2). The *A. argo* shells were typically associated with marine litter and natural flotsam, such as drift wood, walnuts, mollusks and sea urchins (Fig. 2-3, 2-4). On rare occasions, whole *A. argo* specimens also washed ashore (i.e., the body was still attached to the shell) (Fig. 2-5, 2-6). In addition, large shells were occasionally found at the low-tide line during late October.

Although *A. argo* shells were collected on all four beach sections in Yoichi Bay (Fig. 1), most were found in Section A (Hamanaka Beach), followed by Sections C (Sakae Beach), B (Ohkawa Beach), and D (Ranshima Beach). The number of *A. argo* shells in the flotsam was related to the morphology of the coast and the presence of a rocky cape (Fig. 3).

Detailed frequency characteristics of shells on Hamanaka Beach are shown in Fig. 4. Mass stranding of shells started in mid-October 2012 and continued until mid-November, peaking in late October. This peak also corresponded to a period of *A. argo* mass strandings along the coast of Ishikari Bay in the same year.

2. Morphometry of shells

Shell length was measured in the longitudinal axis by placing the shell on a plane with the aperture facing downward. Shell height was also measured as the vertical distance to the shell length (Okutani and Kawaguchi 1983).

The shell length of the 276 *A. argo* specimens collected in the study area ranged from 20 to 199 mm (Fig. 5). The shell length of 270 of these specimens (ca. 98 %) measured less than 150 mm, and exhibited a bimodal size-frequency distribution with peaks at 60-79 mm and 140-159 mm. Only six shells had lengths that exceeded 180 mm. A strong linear relationship, described by the equation $y=0.64x-4.50$, was observed between the shell length and shell height (Fig. 6). Similarly, shell length was also proportional to shell width and could be described by the equation $y=0.22x+12.42$ (Fig. 7).

Discussion

Figure 8 shows the oceanographic conditions for the autumn of 2012 in the northern Japan Sea (Japan Meteorological Agency 2012). The sea surface temperature (SST) of the Tsushima Warm Current north of 42ºN ranged within normal limits (17-18ºC; Japan Meteorological Agency 2012) until mid-October, where it increased abruptly by 2.0 to 2.5ºC above the mean for the period 1950-2000 until early November (Suzuki 2013).

The marine biota along the Yoichi coast is typical of the cool-template realm from a viewpoint of biogeography, and is represented by both cold- and warm-water species. However, records of subtropical and tropical species along the coast are becoming increasingly frequent. It is thus possible that the mass strandings of *A. argo* and associated species that were washed up along the Yoichi coast could be explained by an increase in the temperature of the Tsushima Warm Current that flows northwards.

Comparing the mass strandings along the Yoichi coast in 2012 with those in 2010 revealed the following. In the 2010 event, SST increased 1.0 to 2.0ºC above the mean SST for the period 1950-2000, while in the event

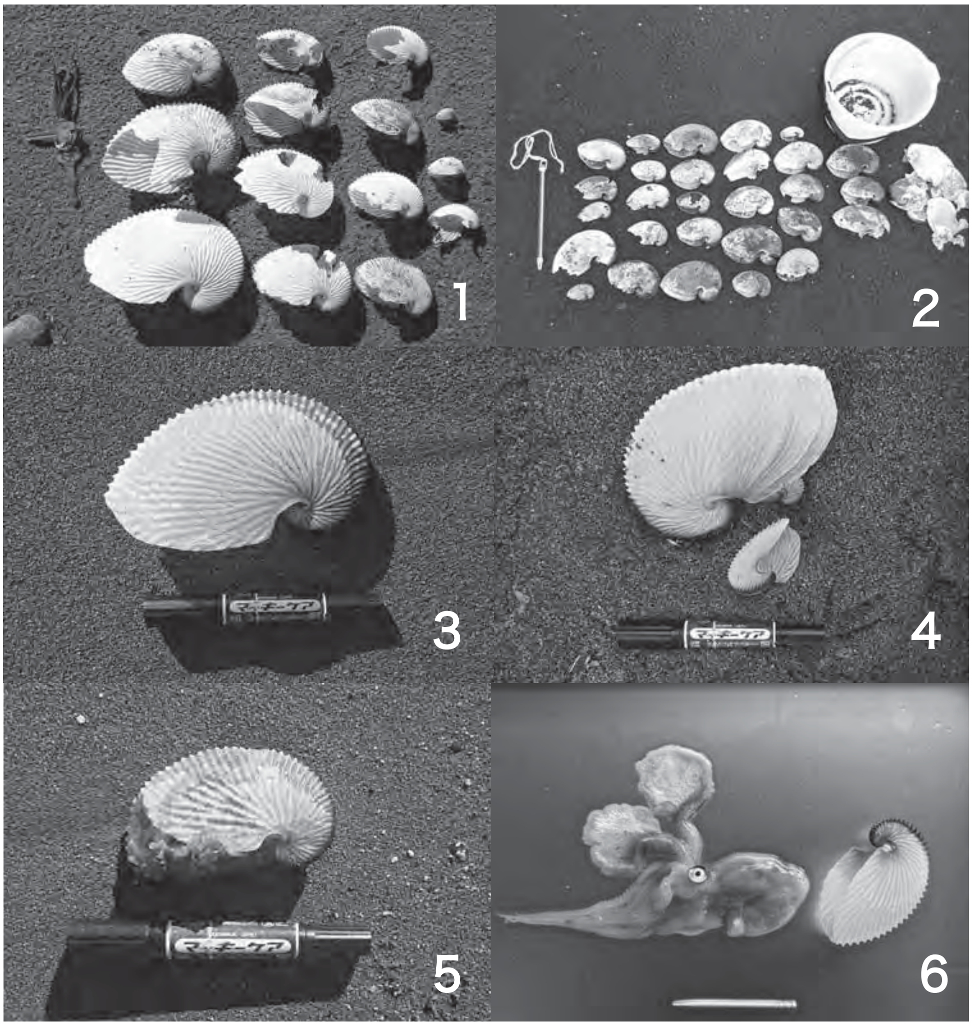

Fig.2 Shells of *Argonauta argo* that had washed up on the sea shore.
1. Shells on Hamanaka Beach in late October 2012.
2. Shells on Hamanaka Beach in early November 2012.
3. Large *A. argo* on Ohkawa Beach (black marker pen: 14 cm).
4. Shells along the low-tide line on Sakae Beach (black marker pen: 14 cm).
5. *A. argo* on Hamanaka Beach with animal body (black marker pen: 14 cm).
6. Animal body and a shell of *A. argo* (toothpick: 5 cm).

of 2012, SSTs increased 2.0 to 2.5ºC above the mean SST for the period 1950-2000. This SST anomaly was also associated with the influx of other warm-water organisms along the Ishikari coast, including the winged argonaut *Argonauta hians*, the blue button *Porpita porpita* and the sea nettle *Chrysaora pacifica*.

This tendency of warm-water species to migrate northward in the Pacific Ocean has also been reported in the Atlantic Ocean, where increased SSTs are considered to be responsible for the appearance of *A. argo* (Guerra et al. 2002). As a result, stranding records for *A. argo* now extend to approximately 44ºN in the northeastern Atlantic Ocean.

The shell length of the 276 *A. argo* specimens measured ranged from 20 to 199 mm (Fig. 5). The shell length of 270 specimens remained less than 150 mm, and exhibited a bimodal size-frequency distribution with peaks at 60-79 mm and 140-159 mm. Only six shells had lengths that exceeded 180 mm. The bimodal distribution was likely due to the existence of two separate cohorts in the population that were collected on different dates in 2012. A linear significant relationship was obtained between the shell height and shell length (Fig. 6). There was also no significant difference in mean shell length between the incubating and non-incubating females.

It is proposed that the mass strandings of the common paper nautilus, *A. argo*, which occurred along the