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Unusual aggregations of the scyphomedusa *Aurelia aurita* in coastal waters along western Shikoku, Japan

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Abstract: The scyphomedusa *Aurelia aurita* formed dense aggregations in the coastal waters of the Uwakai Sea, western Shikoku, Japan, in the summer of 2000. Composite airphotographs from a Cessna combined with a ground-truthed net survey revealed that these aggregations, which looked cloud-like, covered a total area of 2.34 km^2, and contained at least 5.83×10^8 individuals or 9.36×10^4 metric tons wet weight of medusae along approximately 100 km of coastline. The aggregation was most intense in the inner part of inlets, suggesting that the physical transport of medusae by a swift intrusion current from offshore to inshore (called "kyucho") was primarily responsible. Within the aggregation, predation on mesozooplankton was nearly 100%. Although the occurrence of *A. aurita* aggregations is more or less common in this area, such large aggregations have never before been recorded, indicating that the population increase in 2000 was unusual. A combined method employing aerial surveys and in situ net sampling can be a useful and time-saving technique to quantify *A. aurita* populations over a relatively extended sea area, such as the Uwakai Sea.

Key words: scyphomedusa, *Aurelia aurita*, aggregation, aerial survey, ecological impact

Introduction

The ecological importance of large gelatinous zooplankton such as cnidarians and ctenophores has been increasingly recognized in marine ecosystems (reviewed by Arai 1988, 2001; Purcell 1997; Schneider & Behrends 1998), and there is concern that they are becoming more prevalent in a variety of regions around the world (Brodeur et al. 1999; Shiganova & Bulgakova 2000; Graham 2001). Many species of scyphomedusae aggregate (Alldredge 1984; Hamner & Schneider 1986; Graham et al. 2001). In particular, seasonal aggregations of *Aurelia aurita* are probably the most widely reported in the coastal areas of the world (Yasuda 1969; Schneider 1989; Hay et al. 1990; Hamner et al. 1994). These aggregations have strong impacts on local ichthyoplankton and mesozooplankton populations, which are themselves important prey for planktivorous fish (Möller 1980; Purcell & Arai 2001). In addition to their potential predatory and competitive impacts on fish populations, scyphomedusae hamper fishing activities by clogging and bursting trawl nets, and cause problems to coastal power plants by blocking intakes for cooling water (Rajagopal et al. 1989).

In order to assess the ecological impacts by scyphomedusae, it is necessary to determine their spatial distribution and to estimate their biomass. However, conventional net samplings at predetermined stations are inappropriate for organisms like scyphomedusae with extremely patchy distributions (Omori & Hamner 1982). One of the tools to determine the spatial (mainly vertical) distribution of scyphomedusan density is a multi-frequency echo sounder (Inagaki & Toyokawa 1991; Brierley et al. 2001). Aerial surveys are also useful to record the location and spatial (only horizontal) distribution of aggregations over a larger sea area. Aerial surveys, however, are limited to aggregations that can be seen either in reasonably clear seawater or aggregations immediately at the surface. Few studies have attempted to measure aggregations of scyphomedusae by means of aerial surveys (Purcell et al. 2000; Graham et al. in press).

Upon a report by fishermen of the occurrence of *Aurelia aurita* aggregations, we surveyed the geographical distribution of jellyfish from the air. Subsequently, we ground-truthed medusa aggregations in coastal waters of the Uwakai Sea, western Shikoku, Japan, in summer of 2000. Here, we describe the distribution, abundance and biomass

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of aggregations, and discuss their accumulation mechanisms and their impact on the local marine ecosystem.

Methods

We used a single-engine Cessna, which has an overhead wing and hence allows us make observations directly below the plane, from a nearby airport in Matusyama, Ehime Prefecture, along the coast of the Uwakai Sea (the sea area in the eastern half of the Bungo Channel) south to Yura Peninsula for an hour (local time: 13.45 to 14.45) on August 24, 2000 (Fig. 1). Photoslides were taken using a 35 mm still camera (Nikon FA with a zoom lens Nikkor 35–200 mm and a polarizing filter) from ca. 300 m altitude. Jellyfish aggregations, detected as cloud-like features (Fig. 2), were found on 40 out of the 150 slide total. They were projected on magnified maps. Distance calibration was made by adjusting the position of known measurable objects (e.g. islands, coastline, breakwaters, fish pens, etc.) on the map. The area of aggregations was traced on the map and cut out with scissors; the paper weights were converted to the actual aggregation area by also cutting out known area and weighing the paper contents.

We obtained the density of medusae at 3 locations (depth: ca. 7 m) within an aggregation in Nishiuchi Inlet (see Fig. 1 for sampling site) on September 4. Our sampling activities were videotaped by a local NHK television station from a helicopter, and the VTR revealed that the sampling locations were approximately in the middle of the aggregation of ca. 150 m width along the shore. From a boat, medusae were caught by towing a conical net (0.5 m diameter, 1 mm mesh opening) from 5 m to the surface, since the lower limit of the aggregation was shallower than 3–4 m. The number of captured medusae were counted and their bell diameters were measured with a ruler while laying each specimen flat on a plastic tray. At each station mesozooplankton were collected by a vertical tow of a plankton net (0.225 m diameter, 100 μm mesh opening, fitted with a flowmeter). For the sampling, a coarse net (1.5 cm mesh opening) of conical shape was laid over the net mouth to avoid capturing the medusae. A mesozooplankton sampling was also made outside the aggregation (ca. 200 m away from the edge of the aggregation). The zooplankton samples were preserved in 5% formalin-seawater solution and later they were identified and enumerated using split sub-samples.

Results and Discussion

It was a clear and calm day when we photographed aggregations of *Aurelia aurita* along the coast of the Uwakai Sea. Large aggregations were observed in the inner part of inlets, particularly Uwajima, Higashiuchi, Nishiuchi, Yusu and Nezunaki Inlets (Fig. 1). Small aggregations with diameters (or length) less than ca. 20 m were dispersed throughout the area, but they were too small to process and were not included in the calculation to determine the aggregation area. Aggregations were largest (area: 0.96 km^2) in Higashiuchi Inlet, while only several small patches were seen in Shitaba and Kitanada Inlets.

An in situ survey in Nishiuchi Inlet, where the water temperature varied from 27.2°C at the surface to 24.9°C at 5 m, demonstrated that the aggregation contained, on average, 250 (SD: 6.8) *Aurelia aurita* per m^2 with mean bell diameter of 14.6 (SD: 3.1) cm (N=63). Most individuals were sexually mature and the sex ratio was nearly 1 : 1. According to our unpublished (Shimauchi & Uye) regression to describe the relationship between the bell diameter and wet weight: $WW=0.0748BL^{2.86}$, where WW and BL are wet weight (g) and bell diameter (cm), respectively, the mean individual wet weight of a medusa was 159 g. Therefore, the aggregation contained 40 kg wet weight of *A. aurita* per m^2. The aggregation thickness was ca. 3.5 m (i.e. from ca. 0.5 to 4 m deep); the density per unit water volume (m^3) was 71 medusae or 11.4 kg wet weight. Assuming the same density for the entire aggregation area, there was a total of 5.83×10^8 individuals or 9.36×10^4 metric tons wet weight of *A. aurita* in the survey area. Higashiuchi Inlet held the highest biomass (2.93×10^8 individuals or 3.80×10^4 metric tons wet weight), while Kitanada Inlet had the lowest (1.71×10^6 individuals or 2.73×10^2 metric tons wet weight) (Fig. 3). These estimates, however, are conservative, since small patches and deep aggregations, both of which yielded poor photo images, were not included.

The exact mechanisms responsible for the aggregations of *Aurelia aurita* being most intense in the inner part of inlets could not be determined because of the absence of time-sequence observations leading up to aggregation formation. We suspect that they aggregated mainly due to physical forces rather than biological factors, as the former factors have been reported to be much more important for large scale aggregations such as those observed in the present study (Graham et al. 2001). In the Uwakai Sea, a sudden, swift current (locally called "kyucho") is an important hydrodynamic feature during summer (Takeoka & Yoshimura 1988). The kyucho is caused by intrusion of an offshore warm water mass along the eastern Bungo Channel, resulting in a rapid increase in water temperature and transparency in the coastal Uwakai Sea. There were two such increases in water temperature (>4°C), evidence of a strong kyucho, first between August 5 and 8 and the second between August 17 and 20 (data from the Ehime Prefectural Fisheries Experimental Station in Shitaba Inlet), before our aerial survey. We speculate that *A. aurita* populations had been distributed more sparsely both in inshore and offshore waters of the Uwakai Sea before being transported shoreward and accumulated there by ocean physics. This speculation was supported by anecdotal evidence from local fishermen (in Uwajima and Yusu), who told us that the aggregations were more conspicuous after the kyucho. The reasons why there were large differences in *A. aurita* biomass among the different inlets (Figs. 1 & 3) were not

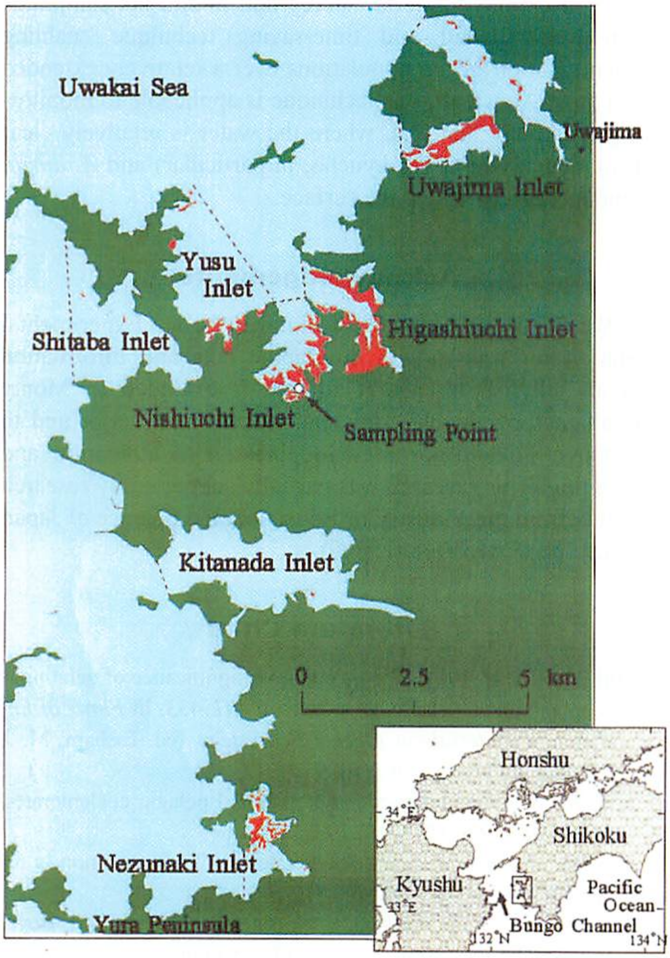

Fig. 1. Map of the Uwakai Sea along the coast of western Shikoku, where our aerial survey on the aggregations of *Aurelia aurita* (denoted by red areas) was made on August 24, 2000.

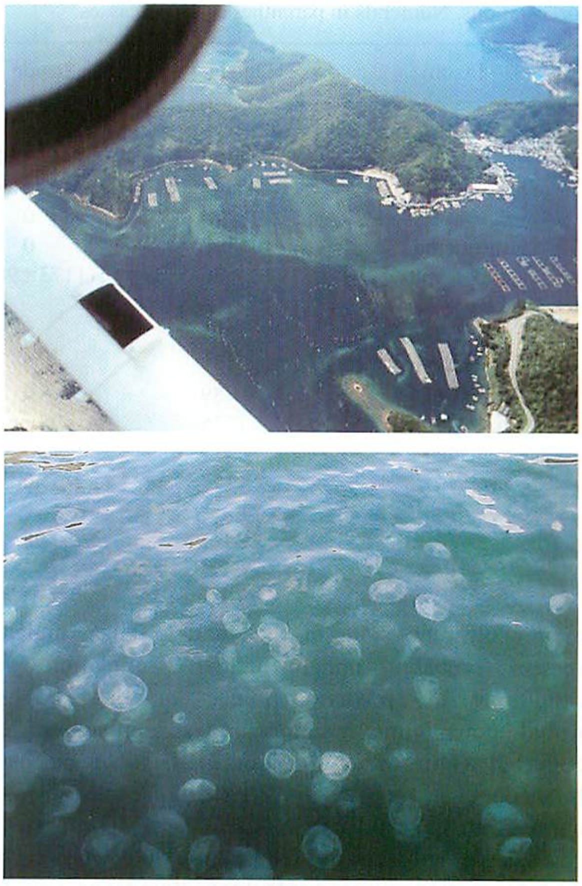

Fig. 2. Photograph of *Aurelia aurita* aggregations from the air (top) and from a boat (bottom, mean bell diameter: 14.6 cm).

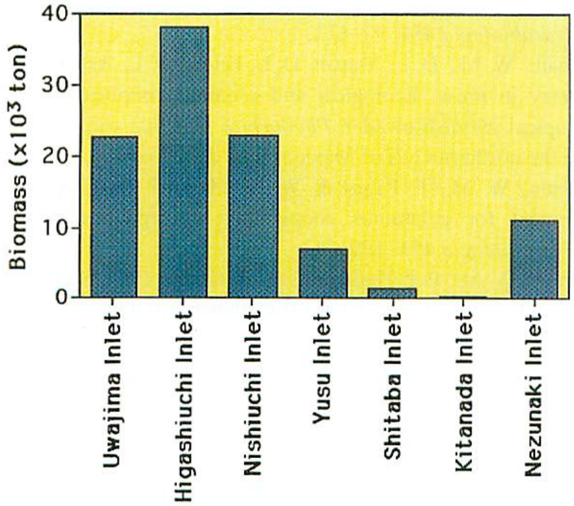

Fig. 3. Estimated wet weight biomass of *Aurelia aurita* in each inlet of the Uwakai Sea.

certain.

We do not deny any effects of the biology and behavior of *Aurelia aurita* on the aggregations, but these are considered more important on the local scale (Hamner et al. 1994; Graham et al. 2001). Large numbers of planulae ($>1\times10^5\,m^{-3}$) were contained in the plankton samples, demonstrating that aggregated *A. aurita* were actively spawning. Aggregations in inshore shallow waters provide potential advantages for both increased fertilization success and retention of local spawning populations near local recruitment sites. Again it is unlikely, however, that aggregation formation in the inner inlet waters resulted without physical factors. These aggregations gradually decreased in numbers, due to transport offshore and/or mortality until disappearance in November.

If *Aurelia aurita* distribution had been homogenous in the southern Uwakai Sea (area: 68 km^2) before accumulation by the kyucho, the approximate density would have been ca. 1 medusa m^{-2}. Our unpublished data (Shimauchi & Uye) show that the prey clearance rate of an *A. aurita* of 159 g wet weight is 0.58 m^3 $medusa^{-1}\,d^{-1}$; this would yield

Table 1. Comparison of mesozooplankton abundance (individuals m^{-3}) inside and outside *Aurelia aurita* aggregations in Nishiuchi Inlet. The abundance inside the aggregations is mean±SD for 3 stations. Numerals in parentheses are carcasses.

Taxon	Outside	Inside
Copepod adults and copepodites		
Acartia spp.	1183	(782±176)
Oithona spp.	39840	(9485±834)
Paracalanus spp.	197	0
Harpacticoids	197	0
Copepod nauplii	23670	(1173±98)
Cladocerans		
Penilia avirostris	394	0
Cirriped nauplii	179	0
Rotifers	789	0
Polychaete larvae	1775	98±56
Chaetognaths		
Sagitta crassa	197	0
Total	68421	98

a prey clearance rate of $0.58\,m^3\,d^{-1}$. Thus, under such sparse (probably underestimated) population density conditions, the predation impact on mesozooplankton would be negligible. In contrast, mesozooplankton samples collected within the aggregation of *A. aurita* in Nishiuchi Inlet contained very few polychaete larvae and considerable numbers of copepod carcasses (Table 1). The latter were perhaps egested from the food pouch of *A. aurita*. Outside the aggregation, mesozooplankton abundance was 6.84×10^4 indiv m^{-3}, 95% of which were attributed to copepods (Table 1). Hence, predation on mesozooplankton may have been nearly 100% within the aggregation. The impact of *A. aurita* on fish populations in the Uwakai Sea is not completely known, but impairments by clogging of the nets of pens and cages for finfish aquaculture (e.g. red sea bream, yellow tail, puffer fish, etc.) have been reported (Ehime Prefectural Fisheries Experimental Station and fishermen of Yusu).

According to local fishermen and staff of the Ehime Prefectural Fisheries Experimental Station, although the occurrence of *Aurelia aurita* aggregations is a common annual event along the coast of the Uwakai Sea, such intense blooms had never before been observed, or documented at least, although the kyucho phenomenon is more or less a permanent fixture of the summer season. This suggests that the increase in *A. aurita* populations was sudden in 2000. A similar survey (aerial survey plus in situ net sampling) was made in summer of 2001, and revealed that the aggregations were much smaller with an estimated biomass of 6.47×10^3 metric tons wet weight (unpublished), 1/16 of the biomass of the previous year. With regard to concerns about global increases in scyphomedusan populations, it is important to annually monitor their biomass to see if this pattern continues in the future. A combined method employing aerial survey and in situ net samplings can be a useful and time-saving technique enabling quantification of the populations over a relatively extended sea area. Above all, this technique is applicable to monitoring in the Uwakai Sea, where the water is relatively clear (immediately after the kyucho, in particular) and *A. aurita* tend to aggregate near the surface.

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