

Marine artificial structures as amplifiers of *Aurelia aurita* s.l. blooms: a case study of a newly installed floating pier

Ryosuke Makabe · Ryuji Furukawa ·
Mariko Takao · Shin-ichi Uye

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Abstract Increase of marine artificial structures, providing more substrate for jellyfish polyps, has been argued to increase jellyfish outbreaks, although no explicit evidence exists. We report a case study demonstrating a remarkable increase of *Aurelia aurita* s.l. ephyrae after the installation of a floating pier (48 × 6 m) in a fishing port on the Inland Sea of Japan. Monitoring of ephyrae from January 2010, prior to the installation of the floating pier in April 2010, to July 2011, revealed that their time-weighted average density increased 3.5 fold, from 1.1 to 3.9 ephyrae m⁻³, and the integrated number of ephyrae exported from the port increased 4.3 fold, from 5.7 × 10⁶ to 25 × 10⁶ ephyrae, after the installation. However, in a nearby port, a control site, the abundance of ephyrae decreased by ca. one third during the same period. Monitoring of polyps showed that they initially colonized the undersurface of the pier by August 2010, followed by a rapid population increase. They strobilated from December 2010 to May 2011. We computed the number of ephyrae released from the strobilae to be ca. 25 × 10⁶, very close to the net increase of ephyrae produced and exported from the port. This study corroborates that the installation of an artificial structure provides new a substrate for polyps, which allows them to produce more ephyrae to induce medusa blooms.

Keywords Artificial structures · Ephyrae · Polyps · Ports · Seeding grounds

1 Introduction

Jellyfish populations are likely to follow oscillations on a global basis (Condon et al. 2013), but they are increasing and/or showing more extreme and frequent outbreaks in some specific regions (Arai 2001; Brotz et al. 2012; Purcell et al. 2007). Major causes for the increase have been hypothesized to be a result of climate change (Attrill et al. 2007; Holst 2012; Kogovsek et al. 2010) and also may result from various human impacts on the ocean such as eutrophication, overfishing and modification of the coastal geomorphology (Purcell 2012; Richardson et al. 2009; Uye 2011). In elucidating mechanisms generating scyphomedusan population outbreaks, the benthic polyps of jellyfish have been given special attention, particularly since polyps increase in number by asexual reproduction. Further, by strobilation, usually seasonally restricted, polyps release more numerous planktonic ephyrae (Lucas et al. 2012; Purcell et al. 2009; Toyokawa et al. 2011). Since scyphozoan polyps tend to attach selectively to the overhanging surfaces of artificial structures (Hoover and Purcell 2009; Ishii and Katsukoshi 2010; Miyake et al. 2002), the relationships between medusa outbreaks and increases in marine constructions (i.e., favorable habitat for polyps) have been suggested by studies in various locations (e.g., Janben et al. 2013; Lo et al. 2008; Malej et al. 2012). Most recently, Duarte et al. (2013) have reviewed such reports and proposed that “the proliferation of artificial structures provides habitat for jellyfish polyps and may be an important driver of the global increase in jellyfish blooms.” To our knowledge, however, there is no direct evidence

R. Makabe (✉)
Research Center for Creative Partnerships, Ishinomaki Senshu
University, 1 Shinmito, Minamisakai, Ishinomaki 986-8580,
Japan
e-mail: makabe@isenshu-u.ac.jp

R. Furukawa · M. Takao · S. Uye
Graduate School of Biosphere Science, Hiroshima University,
4-4 Kagamiyama 1 Chome, Higashi-Hiroshima 739-8528, Japan

demonstrating the actual increase of ephyrae production resulting from installation of new marine artificial structures quantitatively.

The moon jellyfish *Aurelia aurita* s.l. (Linnaeus) is the most common scyphozoan in coastal waters around the world (Dawson 2003; Dawson and Martin 2001; Lucas 2001). It causes nuisance blooms in the Inland Sea of Japan, hampering not only fisheries but also coastal power plant operations (Uye et al. 2003; Uye and Ueta 2004). Uye and Ueta (2004) asked 1,152 local fishers with ≥ 20 -year careers about historical trends of *A. aurita* medusa populations and learned that the outbreaks became distinctly greater in the 1980s and have become even more intense since the 1990s. In the semi-enclosed Inland Sea of Japan, eutrophication was most serious during the late 1960s and early 1970s, but the enforcement of a law enacted in 1973 strictly regulated the influx of nutrients (P and N) and organic matter from the land (Okaichi and Yanagi 1997; Takeoka 2002). Since then, the overall environmental conditions, except for some continually eutrophic areas, have shifted toward oligotrophy (Yamamoto 2003). Thus, eutrophication may not be a direct cause of increases in population in the Inland Sea of Japan. The trends in other drivers, such as fish stock decline, water temperature elevation and coastline modifications with artificial structures, have continued up to the present. Through previous SCUBA diving studies (320 person-hours of diving in recent 10 years) along the coast of Hiroshima Bay, we noticed that some 20 floating piers were covered by *A. aurita* polyps (see web materials referenced in Duarte et al. 2013). The hypothesis that the addition of an artificial structure is responsible for the increase in *A. aurita* outbreaks in this region has not been disproved.

To investigate the influence of a new floating pier on *A. aurita* populations, we monitored ephyrae in two fishing ports on the Inland Sea of Japan: one with the new pier and a nearby port without any structural changes as a control site. Our specific objectives were (1) to compare the abundance and production of ephyrae before and after the installation and (2) to monitor the polyp population under the new pier and to estimate the number of ephyrae released from the population.

2 Materials and methods

2.1 Study sites and installation of a new floating pier

Our survey was carried out in two rectangular, concrete-walled fishing ports: Kuba (area: $5.9 \times 10^4 \text{ m}^2$) and Ogata ($1.6 \times 10^4 \text{ m}^2$), along the northwest coast of Hiroshima Bay in the central part of the Inland Sea of Japan (Fig. 1). These ports open to Otake cove flanked by concave

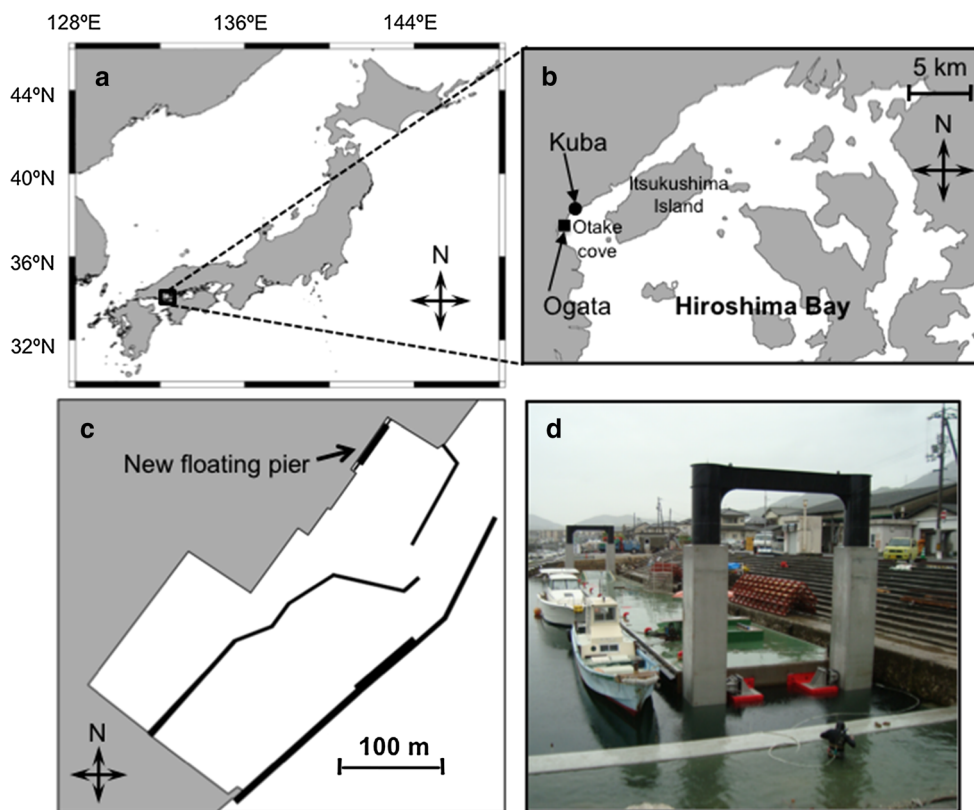
mainland to the north and west and Itsukushima Island to the east. Both ports are subject to the influence of the same offshore water mass by tidal mixing. Users of these ports are primarily local fishers, who install floating piers, barges, and buoys in the enclosures. The overhanging surfaces of these artificial structures enable *Aurelia aurita* polyps to attach, so that both ports may constitute a polyp habitat and seeding place for the local medusa population. A floating pier (length: 48 m, width: 6 m, thickness: 2.4 m, steel internal frame, pre-stressed concrete outer surfaces), which was built in January 2010, was towed to Kuba and moored to four pilings on 19 April 2010 (Fig. 1). Kuba port is separated into two parts by a concrete breakwater, and the pier was moored in the northernmost enclosure. The survey started in January 2010, when we learned that the Hiroshima Prefectural Port and Harbor Bureau were planning to install this new floating pier. The survey was conducted at weekly to monthly intervals in both ports for 19 months until July 2011. Ogata port was selected as a control site because of its proximity to Kuba port (2.5 km) and because no structural changes were planned there.

2.2 Sampling of planktonic *Aurelia aurita*

Inside the breakwaters of both Kuba and Ogata ports, zooplankton sampling was conducted by towing a NOR-PAC net (45 cm diameter, 180 cm long, 315- μm mesh openings, with a flow meter) obliquely (approximate distance: 35 m) from ca. 1 m above the bottom at least three times on each sampling date along the northeastern shore at Kuba and along the pier at Ogata. The samples were immediately preserved with neutralized formalin (final concentration: 5 %). The weekly samplings were carried out from December to May of 2010–2011, when *A. aurita* ephyrae were expected to be released from strobilae (Thein et al. 2012; Uye and Shimauchi 2005). In other months, monthly samplings were done. On each sampling occasion, vertical profiles of water temperature, salinity, and in situ fluorescence were taken with a CTD (JFE Advantech Co., Ltd.). *Aurelia aurita* in the samples were counted, and their disc diameters (DD: distance between opposite sensory organs) were measured under a dissecting microscope and converted to live-specimen-equivalent DD, assuming 15 % fixation shrinkage (Möller 1980).

Based on numerical density of *A. aurita* ephyrae, which had been recently released but not yet exported outside the port by tidal exchange, the total numbers of ephyrae produced in the northern enclosure of the Kuba port could be estimated, assuming that exported ephyrae, which are diluted by a huge volume of water outside of the port, had no chance of returning to port. The water exchange rate (Q , $\text{m}^3 \text{ s}^{-1}$) during each tidal cycle was calculated by the following equation (Takeoka 1989):

Fig. 1 Maps showing the locations of Kuba and Ogata ports in Hiroshima Bay, Inland Sea of Japan (a, b). In the northern enclosure of Kuba ports (c), a floating pier (d) was installed in April 2010



$$Q = \frac{\beta \pi A^2 \eta^2}{2t_m HLW} \tag{1}$$

where A , H , L , and W are, respectively, the surface area of the northern port enclosure ($3.0 \times 10^4 \text{ m}^2$), mean water depth (4 m), length of the port enclosure (279 m) perpendicular to the mouth, and width of the mouth (30 m). β is a constant (0.1), and t_m is the principal lunar semidiurnal, or M_2 , tide (44,712 s). η is the tidal range in Hiroshima Bay reported by the Japan Coast Guard's 5th Regional Coast Guard Headquarters. The number of exported ephyrae from the port on a given day i (E_{ei} , ephyrae day $^{-1}$) was determined by:

$$E_{ei} = Ab_i \times Q_i \times 86,400 \tag{2}$$

where Ab_i and Q_i are the density of ephyrae (ephyrae m^{-3}) and the water exchange rate ($\text{m}^3 \text{ s}^{-1}$) on day i , respectively. We also assumed that ephyrae were evenly distributed in the northern port enclosure, because we observed no significant difference (t test, $T=0.142$, $df = 4$, $p = 0.89$) in their mean (\pm SD) density in the northeastern part, 9.1 ± 1.9 ephyrae m^{-3} , from that in the southwestern part, 8.9 ± 1.9 ephyrae m^{-3} , in the survey conducted in February 2011. Hence, the total numbers of ephyrae produced and exported from the Kuba port (TE_e) over the ephyra releasing season (n days), which is defined as the

period when ephyrae with ca. 2.0 mm in DD were caught, were calculated by:

$$TE_e = \sum_{i=1}^n E_{ei} \tag{3}$$

Similarly, TE_e was determined for the Ogata port, where the area, mean depth, enclosure length, and mouth width are $1.6 \times 10^4 \text{ m}^2$, 7, 106, and 51 m, respectively.

2.3 Monitoring of *Aurelia aurita* polyps on the pier

After the installation of the pier, we started monitoring *A. aurita* polyps on its undersurface on 28 June 2010 and then conducted surveys at bi-weekly to monthly intervals from 18 August 2010 to 21 July 2011. Photographs were taken in a 10 cm \times 10 cm quadrat by SCUBA divers with a Ricoh CX2 camera. The quadrat was placed and photographed at the fixed 12 locations on each sampling date (i.e., 3 locations ca. 2 m apart on 4 transects ca. 8 m apart along the pier length) from the outset until 16 December 2010. Thereafter, the monitoring was conducted with an underwater video camera (Sony HDR-SR12) attached to a specially designed L-shaped frame that sequentially positioned the camera at the same 12 locations. Archived digital photographic images were analyzed using image-analysis software (Image J, National Institute of Health, USA) to

count the numbers of polyps with calyx diameters \geq ca. 550 μm , a size set by an image-analysis detection limit. The dimensions of objects in the images were calibrated from an image of a ruler placed in the photographed area. Strobilae were identified based on segmentation of their stalks into multiple discs and their red body coloration (similar to and older than the “mid and advanced” strobilae defined by Purcell et al. 2009) and counted. Further, the number of discs was counted for those polyps whose images were clear enough.

The numbers of ephyrae released from strobilae attached to the floating pier were estimated using the method of Ishii and Katsukoshi (2010): the number of ephyrae released on a given day i (E_{pi} , ephyrae $\text{cm}^{-2} \text{day}^{-1}$) was estimated from

$$E_{pi} = \frac{S_i \times C_i}{D_i} \quad (4)$$

where S_i is the mean density of strobilae on the floating pier (strobilae cm^{-2}), C_i is the mean disc number per strobila (ephyrae strobila $^{-1}$), and D_i is the retention duration of discs by red-colored strobilae (days). We determined the relationship between the red-colored strobilae duration (D , days) and temperature (T , $^{\circ}\text{C}$) in laboratory experiments (see below) as:

$$D = 109 \times e^{-0.221 \times T} \quad (5)$$

The mean ambient water temperature between two consecutive sampling dates was interpolated to substitute in Eq. (5), and the number of ephyrae liberated during the period between dates was estimated. By summing over the entire season of ephyra production (n days), the total numbers of ephyrae released from the pier (TE_p , ephyrae per pier), the area of which is $2.88 \times 10^6 \text{ cm}^2$, were estimated as:

$$TE_p = \sum_{i=1}^n (2.88 \times 10^6 \times E_{pi}) \quad (6)$$

2.4 Relationship between red-colored strobila duration and temperature

The culture stock of *A. aurita* polyps originated from matured medusae collected in the Inland Sea of Japan in July 2010. Nine groups, each consisting of 58–69 polyps, raised by feeding them *Artemia* sp. nauplii at 18 $^{\circ}\text{C}$ for 3–4 weeks, were placed in plastic containers containing 600 ml of filtered seawater. Three groups were transferred to each of three lower temperatures (9, 11, and 13 $^{\circ}\text{C}$) to induce strobilation (Han and Uye 2010; Kakinuma 1962). The range of calyx diameters of the polyps was 0.9–2.2 mm, closely similar to that observed on the pier. They were kept starved in the dark, and the seawater was

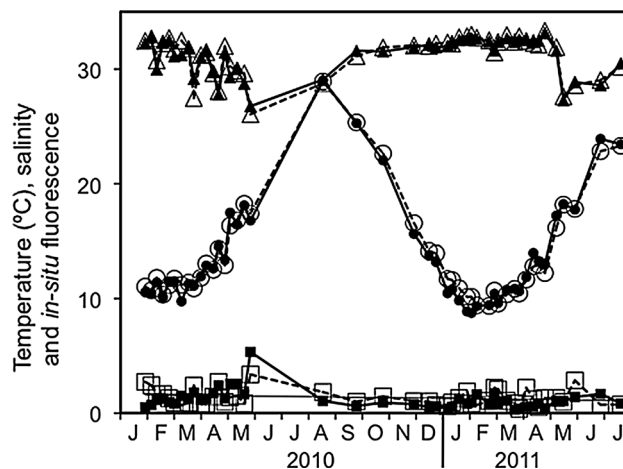


Fig. 2 Seasonal variations in temperature (circles), salinity (triangles), and relative intensity of in situ fluorescence (squares) at 1 m depth in Kuba (filled symbols) and Ogata (open symbols) ports

replaced weekly. Individual strobilating polyps were inspected daily under a dissecting microscope to determine the interval from their bodies first turning reddish until the liberation of ephyrae was complete. The mean duration at each temperature was calculated after exclusion of outlier data by the Smirnov-Grubbs rejection test. A one-way analysis of variance (ANOVA) and Tukey’s pairwise comparisons were applied to confirm the differences among the temperature treatments.

3 Results

3.1 Seasonal environmental variations

The seasonal variations in temperature, salinity, and in situ fluorescence at 1 m depth, a depth similar to the undersurface of the newly deployed floating pier, were similar in Kuba and Ogata, with annual ranges of 9–29 $^{\circ}\text{C}$, 26–33, and 0.3–5.3, respectively (Fig. 2). There was no significant difference in these environmental parameters over the study period between two ports (paired t -test, $DF = 41$); further, there was a significant positive correlation in all parameters during the study period between two ports ($p < 0.01$). There were no marked vertical variations in those parameters, except for low salinity in the top 2–3 m of the water column immediately after heavy rain, indicating that the water in both ports was generally well mixed.

3.2 Seasonal occurrence of planktonic *Aurelia aurita*

Ephyrae accounted for 99.8 % of total *Aurelia aurita* specimens (2,318 individuals) caught in both ports, and

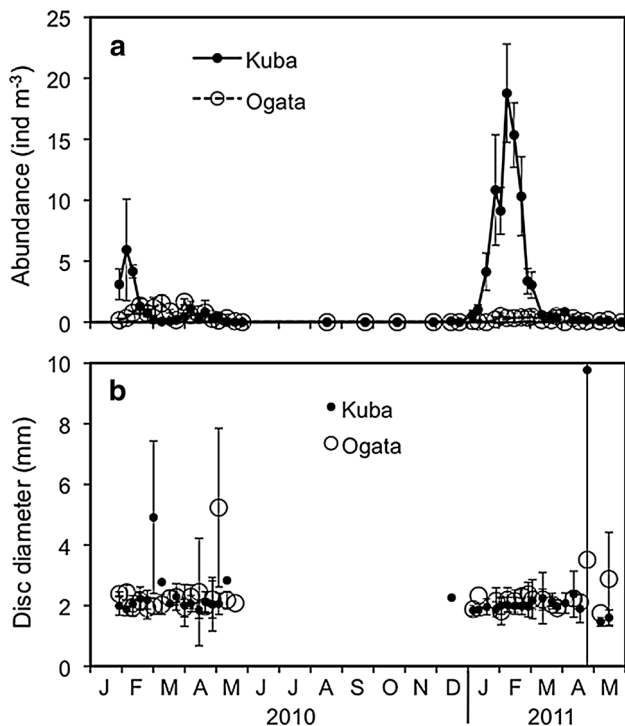


Fig. 3 Seasonal variations in mean density (a) and disc diameter (b) of planktonic *Aurelia aurita* in Kuba (filled circles) and Ogata (open circles) ports. Error bars: SD

their occurrence was confined to the winter-spring when water temperature was \leq ca. 15 °C. There was a significant increase in their density after installation of the new pier in Kuba (Fig. 3a).

In Kuba, *A. aurita* ephyrae were already present at 3.1 ± 1.3 (mean \pm SD) ephyrae m^{-3} on 29 January 2010, followed by a prominent peak at 5.9 ± 4.2 ephyrae m^{-3} on 5 February. Then, ephyra abundance decreased until a small second peak of 1.1 ± 0.6 ephyrae m^{-3} on 8 April; thereafter, they remained at low densities until 13 May. In the next season after the installation, ephyrae first occurred on 16 December 2010, increased steeply to a prominent peak of 18.8 ± 4.0 ephyrae m^{-3} on 8 February 2011, followed by a rapid decline to low levels sustained until 17 May (Fig. 3a). There was a significant difference in mean density between the first season (i.e., before the installation: from 29 January–13 May 2010) and comparable periods (28 January–17 May 2011) of the second one (i.e., after the installation: 16 December 2010–17 May 2011) (paired *t*-test, DF = 15, $p < 0.01$). The time-weighted average densities in the first and comparable periods of the second seasons were 1.1 and 3.9 ephyrae m^{-3} , respectively, a 3.5-fold increase after deployment of the pier.

In Ogata, ephyrae were much fewer, and their peaks were less prominent; the annual maximum densities were 1.7 ± 0.2 ephyrae m^{-3} on 2 April 2010 and 0.5 ± 0.2

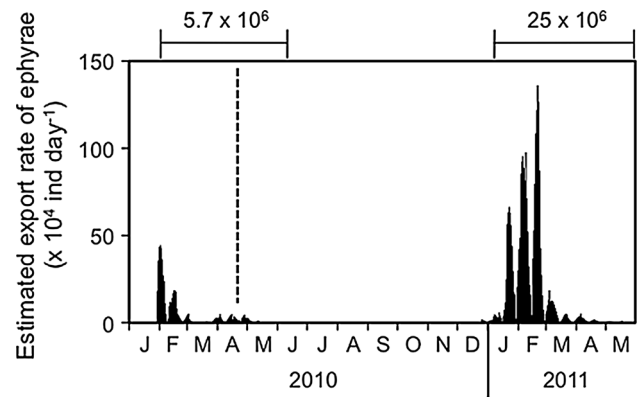


Fig. 4 Daily variations in estimated export rates of *Aurelia aurita* ephyrae from Kuba port. Numerals above horizontal bars show the integrated numbers of ephyrae exported during the periods indicated by the bars. A dashed line shows the date of installation of the pier

ephyrae m^{-3} on 2 February 2011 (Fig. 3a). The time-weighted average density decreased one-third from 0.7 ephyrae m^{-3} in the first season to 0.2 ephyrae m^{-3} in the comparable periods of the second season.

The mean DD of planktonic *A. aurita* was relatively constant, 2.1 ± 0.3 mm in Kuba and 2.2 ± 0.3 mm in Ogata throughout the surveys, except for occasions when post-ephyra stages were present and mean DD increased to 4.9–9.8 mm (Fig. 3b).

3.3 Numbers of ephyrae exported from the ports

The numbers of ephyrae exported daily, E_{ei} , from both ports clearly changed with the neap-spring variation of the tidal cycle (Fig. 4, for Kuba only). The integrated numbers of ephyrae exported from the port at Ogata were 1.0×10^6 in the first season and 0.3×10^6 in the second season. However, the total numbers of ephyrae leaving the Kuba increased 4.3 fold from 5.7×10^6 in the first season to 25×10^6 in the second season.

3.4 Seasonal *Aurelia aurita* polyp population dynamics on the pier

On 28 June 2010, ca. 2 months after the mooring of the pier, no *A. aurita* polyps were found (Fig. 5), whereas a few bryozoans, polychaete tubes, and small (body length: \leq ca. 1 cm) tunicates (*Ciona* sp.) were already attached. On 18 August, polyps were found for the first time, not only on exposed concrete but also on tunicates (*Styela plicata*), dead bryozoan colonies, and polychaete tubes, with overall mean density on the pier of 2.6 ± 1.0 polyps cm^{-2} (Fig. 5). Their density peaked at 4.5 ± 2.3 polyps cm^{-2} on 24 September and thereafter decreased in irregular patterns

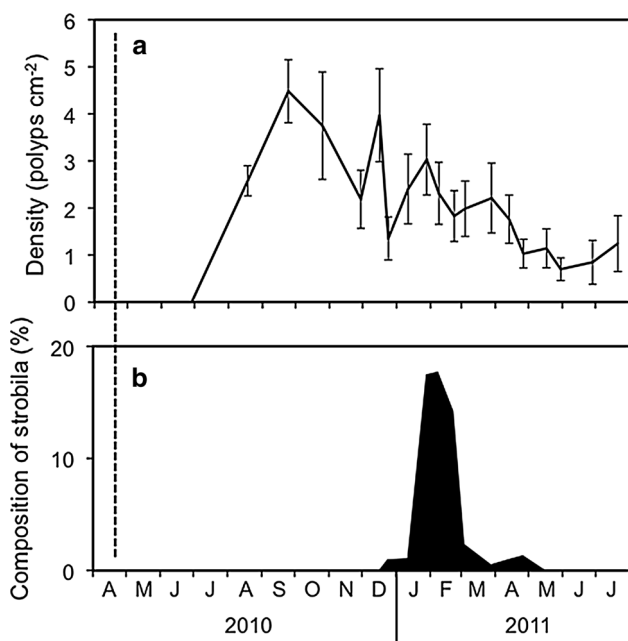


Fig. 5 Seasonal variations in mean density of *Aurelia aurita* polyps (a) and proportion of red-colored strobilae (b) on the undersurface of the floating pier in Kuba port. Error bars: SD. A vertical dashed line shows the date of installation of the pier

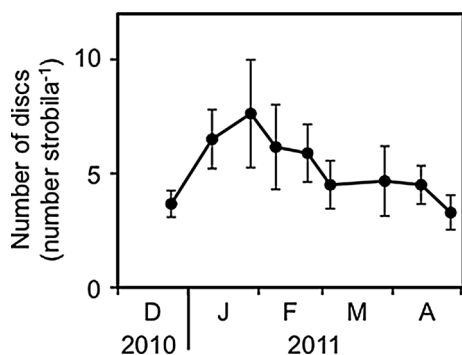


Fig. 6 Seasonal variation in mean number of discs per strobila on the undersurface of the floating pier in Kuba port. Error bars: SD

to a minimum of 0.7 ± 0.8 polyps cm^{-2} on 30 May 2011. Conversely, the coverage of tunicates, the dominant sessile taxon, increased from < ca. 20 % of the surface area before 24 September 2010 to nearly 80 % of the area toward 30 May 2011. A significantly negative correlation was found between the tunicate coverage and the polyp density ($r = -0.40$, $p < 0.01$). In addition, mean polyp density (1.5 ± 0.8 polyps cm^{-2}) on tunicates was significantly lower (Welch's t -test, $F = 2.9$, $df = 28$, $p < 0.01$) than that (2.6 ± 1.4 polyps cm^{-2}) on exposed concrete substrate.

Strobilation took place during the decline in polyp density, and red-colored strobilae were detected from 24

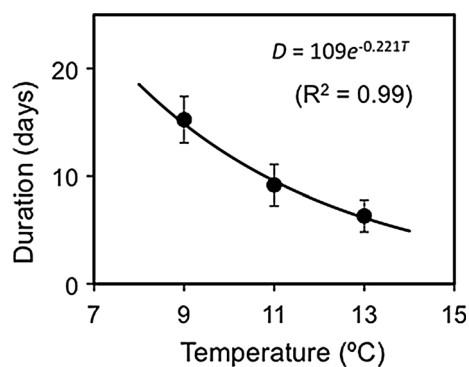


Fig. 7 Relationship between mean red-colored strobilae duration of *Aurelia aurita* and temperature. Error bars: SD

December 2010 to 26 April 2011 (Fig. 5). The fraction of strobilating polyps was highest (i.e., 17.8 %) on 8 February 2011, when their density was 0.4 ± 0.4 strobilae cm^{-2} . The time-weighted average density was 0.1 strobilae cm^{-2} , 5.9 % of the total polyps. The mean disc numbers per strobila ranged from 3.3 to 7.6, tending to be higher in January and February (Fig. 6).

3.5 Estimated numbers of ephyrae liberated from the pier

In the laboratory experiments, 64, 58 and 50 % of polyps strobilated at 9, 11 and 13 °C, respectively. The mean disc numbers at those temperatures were 4.9 ± 1.6 , 5.5 ± 1.9 and 6.0 ± 2.0 . The mean red-colored strobilae durations were 15.2 ± 2.1 ($n = 114$), 9.2 ± 1.9 ($n = 115$) and 6.3 ± 1.5 ($n = 91$) days at 9, 11 and 13 °C, respectively (Fig. 7). Significant differences were found among temperatures (ANOVA: $F = 609$, $df = 2$, $p < 0.01$; by Tukey's pairwise comparisons, $p < 0.01$). The ephyra retention time versus temperature relationship (Fig. 7, see Eq. 5) and the mean disc number of wild strobilae (Fig. 6) were used to estimate ephyra liberation rates.

The daily liberation rates were high in January and February 2011, primarily because of the numerous strobilae, and were maximal at 0.27 ephyrae $\text{cm}^{-2} \text{day}^{-1}$ during late January-early February (Fig. 8). The liberation rate on a given sampling date was strongly correlated with ephyra density in the plankton on that date ($r = 0.94$, $p < 0.01$). From the polyp population established on the newly installed floating pier, a total of 25×10^6 ephyrae were released from December 2010 to May 2011 (Fig. 8).

4 Discussion

The installation plan of a new floating pier in Kuba port enabled us to investigate the temporal changes in polyp

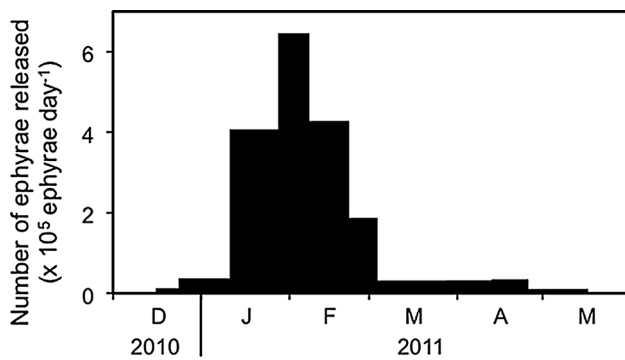


Fig. 8 Seasonal variation in the estimated number of *Aurelia aurita* ephyrae released from strobilae on the floating pier in Kuba port

population on this pier as well as in the ephyra population in the enclosure before and after the installation. Nearby Ogata port functioned as a control site as it had no structural changes but similar environmental conditions to Kuba port. These facts implied a similar intensity in both asexual reproduction of polyps and production of ephyrae, if both ports harbored comparable polyp population sizes. However, cryptic existence of polyps precluded the direct assessment of their population size in the whole port area, the relative size of which could be estimated only by knowing the total number of ephyrae exported from the port area. The planktonic *A. aurita* we collected in both ports consisted almost entirely of the ephyra stage, and water exchange rates of both ports were relatively high (up to 93 % day $^{-1}$ and 20 % day $^{-1}$ at Kuba and Ogata, respectively). These results indicate that newly released *A. aurita* ephyrae in port enclosures are at the mercy of tidal mixing, and consequently they are rapidly dispersed offshore.

As total numbers of ephyrae produced and exported from Kuba and Ogata ports were 5.7×10^6 and 1.0×10^6 , respectively, in the first season, the natural polyp population size prior to installation of the floating pier might have been ca. six times greater in Kuba port. The ephyrae produced in the Ogata port decreased by one third in the second season. On the other hand, those in Kuba increased by nearly four fold after installation of the floating pier. Assuming a similar reduction of ephyrae produced from previously present polyps occurred in Kuba port in the second season as it did in Ogata port, the total numbers of ephyrae produced would have been 2.4×10^6 , unless the pier had been installed. In fact, ca. 25×10^6 ephyrae were produced in Kuba port. These indicated that the large difference (ca. 22×10^6 ephyrae) was primarily attributable to the polyp population that promptly established on the new floating pier. Our monitoring of the polyp population on the pier revealed that they produced ca. 25×10^6 ephyrae, close to our estimate based on net tows.

Although we rarely sighted mature medusae in the port enclosures during the survey, free-swimming planulae did attach to the undersurface of the newly moored pier to start colonization sometime between 28 June and 18 August (Fig. 5). The initial increase in polyp density by 24 September 2010 was remarkable because of the high asexual reproductive rates supported by high temperature and food supply (Han and Uye 2010; Kamiyama 2011). In addition, there was little competition with other sessile organisms, which only covered <ca. 20 % of the surface area. Thereafter, the polyp density decreased rather irregularly, and at the same time tunicates proliferated, covering ca. 80 % of the area toward the end of the survey. Hence, we speculate that the increased competition with sessile animals for space inhibited the polyp population from further increase (Ishii and Katsukoshi 2010; Miyake et al. 2002; Willcox et al. 2008). We found no polyp predators, such as nudibranchs, on the pier (Hernroth and Gröndahl 1985; Hoover et al. 2012; Takao et al. 2014). Newly installed artificial structures provide a virgin substrate for settlement of planktonic larvae of various sessile animals, among which *A. aurita* planulae may be pioneer settlers that then metamorphose to the polyp phase.

Our study confirms that the addition of a small floating pier (48 \times 6 m) resulted in the birth of more than 20 million ephyrae, which were transported offshore to magnify the medusa population in Hiroshima Bay. As there are 93 ports of various sizes and purposes along the coast of Hiroshima Bay, these ports may function as seeding grounds for the bay's *A. aurita* medusa population. Hiroshima Bay is one of the areas most heavily affected by *A. aurita* blooms in the Inland Sea of Japan (Shoji et al. 2010; Uye and Shimauchi 2005; Uye and Ueta 2004). Although no information is available about long-term increases in numbers of ports and associated artificial structures along the coasts of the Inland Sea of Japan, the proportion of the shoreline covered with ferroconcrete structures increased from 43.6 to 48.9 % during 1978–1996 (http://www.env.go.jp/water/heisa/heisa_net/setouchiNet/seto/), and that trend continues up to the present. There has been a continuous, long-term increase of varied artificial structures, most of which provide shaded undersurfaces being associated with the above constructions. We conclude that the addition of marine artificial structures is one of the major drivers for the increase of *A. aurita* blooms in the Inland Sea of Japan. The expansion of similar artifacts in coastal areas worldwide is likely contributing to the global increase of jellyfish outbursts (Duarte et al. 2013).

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