Fish Sci
DOI 10.1007/s12562-014-0837-4

ORIGINAL ARTICLE

Fisheries

A new drifting underwater camera system for observing spawning Japanese eels in the epipelagic zone along the West Mariana Ridge

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Received: 17 July 2014 / Accepted: 25 November 2014

Abstract Spawning-condition Japanese eels *Anguilla japonica,* fertilized eggs, and newly-hatched preleptocephali have been captured, and studies for observing spawning eels with underwater camera systems have begun. This study describes a new, less invasive, free-drifting underwater camera observation system that was deployed from the research vessel (R/V) Natsushima in June 2013. Three drifting buoy camera systems (Una-Cam) with lights-on/lights-off programmed sequencing during daytime and nighttime hours were deployed over a period of seven days at 20 locations south of a salinity front along the southern West Mariana Ridge. Live artificially matured *A. japonica* eels held in transparent chambers were used as an attractant source through the release of reproductive pheromones and other odors. Each system was suspended from a buoy array at a depth of 174–200 m, with four cameras and three lights pointed downward at different angles towards the eel chamber. The Una-Cam systems were stable and were effective at recording images of fish, crustaceans, and gelatinous zooplankton. Olfactory cues may have attracted male and female *Derichthys serpentinus* eels, which showed what seemed to be reproductive behavior and attraction to the Japanese eels in the chamber. Una-Cam systems are capable of recording images of anguillid eels, if they approach, and may be useful for observing spawning eels in their offshore spawning areas.

Keywords Japanese eel · Spawning behavior · Underwater camera systems · West Mariana Ridge · Salinity front

Introduction

Spawning activity of the Japanese eel *Anguilla japonica* occurs in the western North Pacific within the westward-flowing North Equatorial Current (NEC), which transports its leptocephalus larvae towards its East Asian recruitment areas [1–3]. It has been hypothesized that *A. japonica* uses the seamount chain of the West Mariana Ridge as a

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spawning area landmark [4, 5], and fertilized eggs, preleptocephali, and spawning-condition adults of *A. japonica* and *A. marmorata* have been collected near the ridge [6–11]. Analyses of hatching dates and spawning times have indicated that *A. japonica* spawning events take place during a period of a few days just before the new moon [5, 7, 12]. Thus the amount and quality of information regarding the spawning ecology of the Japanese eel greatly exceeds that available for Atlantic eels [13–16].

Research aimed at identifying *A. japonica* spawning areas has been a long-term effort [5, 7, 17], during which various hypotheses have been established with regard to factors that may determine the exact spawning sites, such as the location of the West Mariana Ridge and the salinity front that forms in the NEC [1, 2, 8, 18]. How they detect these and how they find the spawning area during their long migration, however, remains undetermined [19]. If a distinct salinity front is present, spawning appears to occur just to its south, but can occur over a range of latitudes if the low-salinity surface water is more diffuse and widespread [1, 7, 8, 18]. Based on collection data and analyses, it appears that spawning occurs during new moon phases at likely depths of approximately 150–250 m, where adults have been captured [7, 10, 11], and below where eggs and preleptocephali accumulate at the top of the thermocline [7, 8, 11].

With this new information, it is now possible for the first time to make efforts to directly observe the behavior of spawning-condition Japanese eels [20]. Although various underwater observation systems have been developed for direct biological or geological observation in oceans or coastal areas at greater depths [21–25], there has been relatively little effort to observe mobile species in the upper layers of the open ocean. One problem is that various highly mobile species, including fish, react differently to these underwater observation systems [23, 26–30], and even the underwater sound of a research vessel at the surface can affect the behavior of some species [31]. Consequently, not all types of observation systems will work for certain species of marine animals.

In July 2012, the first effort to observe the spawning activity of anguillid eels along the West Mariana Ridge was made onboard the R/V Yokosuka (JAMSTEC), which deployed the Shinkai 6500 submersible and a deep-tow camera system to search for spawning aggregations of anguillid eels [20]. The survey provided a brief view of what may have been a male *A. japonica* or a marine eel, as well as various other organisms [20], and reported an interesting vertical body orientation of nemichthyid eels [32]. However, the use of large underwater vehicles and towed cameras—with bright lights that shine continuously, producing various types of noise or disturbance in the water—may not be the best way to observe the spawning behavior of eels in the darkness of their spawning sites. Therefore, we designed and developed a new camera observation platform that can freely drift at likely depths of eel spawning aggregations, with both lights-on and lights-off capability to reduce potential disturbances. Here, we describe this new system, termed Una-Cam, which was deployed and evaluated during a cruise of the R/V Natsushima (JAMSTEC) in May and June 2013, which also used the ROV Hyper-Dolphin to search for eels, and we report on the performance and observations made by the Una-Cam systems during the survey.

Materials and methods

The Una-Cam system

The Una-Cam system is intended to be deployed in areas of possible spawning activity and allowed to drift freely, without the presence of a ship nearby. The system is constructed from a rectangular aluminum frame, with underwater cameras and lights on the top of the frame and a transparent tubular chamber (eel chamber) on the bottom of the frame to hold artificially matured eels in order to provide an olfactory attractant for wild eels (Fig. 1). The eel chamber is 1 m in length, and has a 30 cm inner diameter, with 2 mm plastic mesh covers at both ends that are bolted shut after the eels are placed in the chamber just before deployment. Two high-definition (HD) video cameras (Goto Aquatics Co., Japan) and a high-intensity discharge (HID) light (Goto Aquatics Co.) are enclosed in pressure-tight housings mounted on the top of the frame. The other two cameras (HERO3 digital video recorders, GoPro Inc., USA) and two white LED arrays are enclosed in a pressure-tight glass sphere (Okamoto Glass Co., Ltd., Japan) with an inner diameter of 305 mm (Fig. 2a). For video recording, 128 GB SDXC cards and 64 GB microSDXC cards are used in the HD video cameras and HERO3 digital video recorders, respectively. Optimized orientation of a total of four cameras and three lights provides an almost panoramic view around the frame of the camera system. The Una-Cam systems were programmed to follow a specific on-and-off sequence of lights and cameras during their approximately 20-hour deployments, which included video recording with lights both on and off (see "Survey strategy" section). All cameras and lights are connected to and activated by a timer circuit. A standalone temperature and depth recorder (Model SP2T600, nke Instrumentation, France) is also mounted on the upper part of the frame at the level of the cameras to obtain environmental information during deployment.

Once deployed, the Una-Cam system is suspended by ropes from buoys and floats at the surface (Fig. 2). To

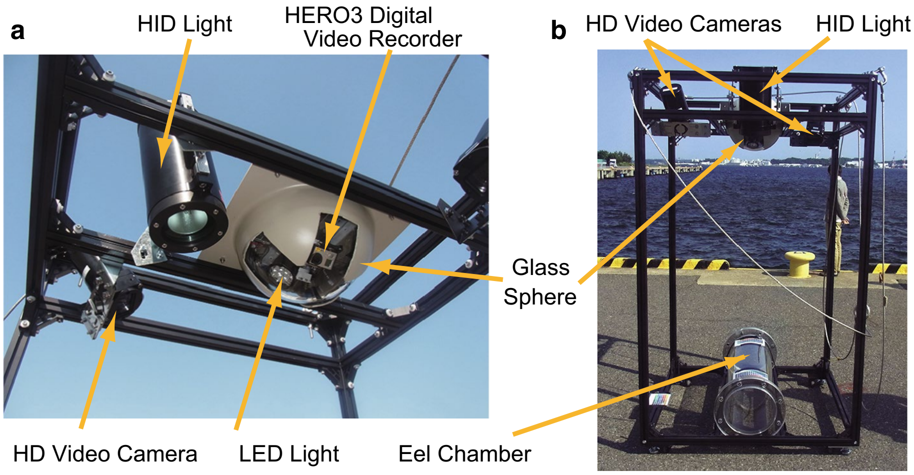

Fig. 1 Photographs of the components of the Una-Cam system, showing the camera and light array on the top of the frame, including two high-definition (HD) cameras and a high-intensity discharge (HID) lights, plus two HERO3 digital video recorders and two LED lights inside a glass sphere, most of which is covered with a hard plastic shell (**a**), and the whole system, including a transparent chamber with mesh ends for holding artificially matured Japanese eels (**b**)

minimize pitch motions caused by surface waves, eight plastic floats (19.7 kg buoyancy per float) are serially attached on a main line (nylon rope, 10 mm diameter). A separate large float is placed at the upper end of the buoy array for additional flotation and greater visibility from the ship. In addition, a radar reflector and flasher are attached to a small pole on a float attached to the buoy array. To locate the Una-Cam system during its drifting deployments, a floating ARGOS satellite transmitter (ABU-1003, Nomad Science Inc., Japan) is deployed with the buoy array, and transmits the position of the buoy every 30 s, and the position is transmitted back to the ship through the satellites approximately once every hour, depending on the satellite location. The ship is also equipped with a direction finder (ADF-1, Nomad Science Inc.) that can directly detect the 30-s ARGOS signals emitted from the transmitter. At the final stage, the ship's radar can be used to detect the radar reflector on the buoy. Also attached to the radar reflector pole is a GPS position recorder that records the buoy position every 10 s for later downloading. After each system is retrieved onboard, the eel chamber is removed and the eels returned to their holding tank. The camera systems are then removed, and the AVCHD (advanced video coding high definition) and MP4 (HERO3) video files are downloaded to a personal computer (PC). For detailed analysis of the recorded animal data, frame-capture images are created from the video files.

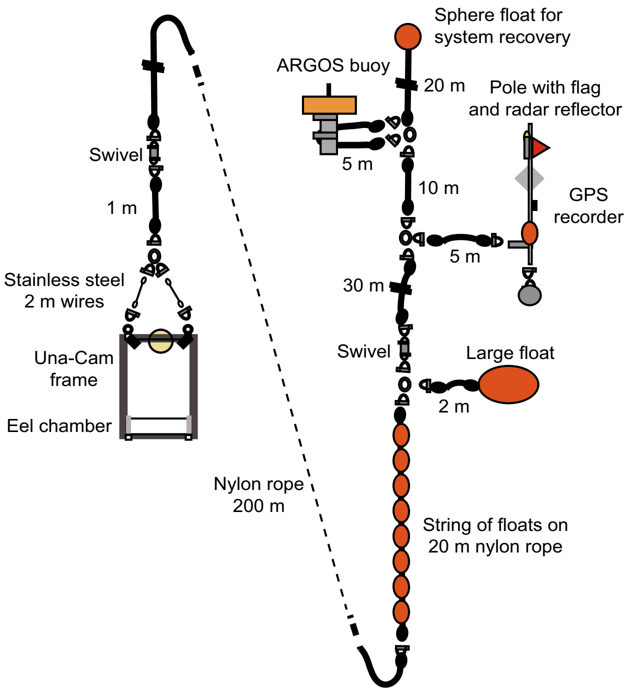

Fig. 2 A diagram of the Una-Cam system with a floating surface buoy array that supports devices such as a radar reflector with a flashing light and GPS recorder, and an ARGOS transmitter that sends GPS position data to a satellite, while the frame containing the cameras, lights, and the chamber containing artificially matured *Anguilla japonica* eels is suspended at the end of a rope 180–200 m in length. The various components are shown at different scales

Survey strategy

The scientific cruise (NT13-11) of the R/V Natsushima was conducted along the West Mariana Ridge from 26 May to 11 June 2013 (Fig. 1), with the purpose of observing spawning eels, using the newly developed Una-Cam systems and the ROV Hyper-Dolphin. The objective in the initial stage of the survey was to define a candidate area, depending on the location of the salinity front, where *A. japonica* spawning activity might occur during the period just before the new moon. To locate the salinity front, which is formed as a result of tropical rainfall over the NEC [1, 7, 18, 33], a series of XCTD probes (XCTD-1, Tsurumi Seiki Co., Ltd., Japan) were deployed from the R/V Natsushima along the seamount chain of the West Mariana Ridge, with data recorded to a depth of 1,100 m along the east side of the ridge. Both CTD and XCTD stations (to a depth of 1,000 m) were established by the R/V Kaiyo Maru

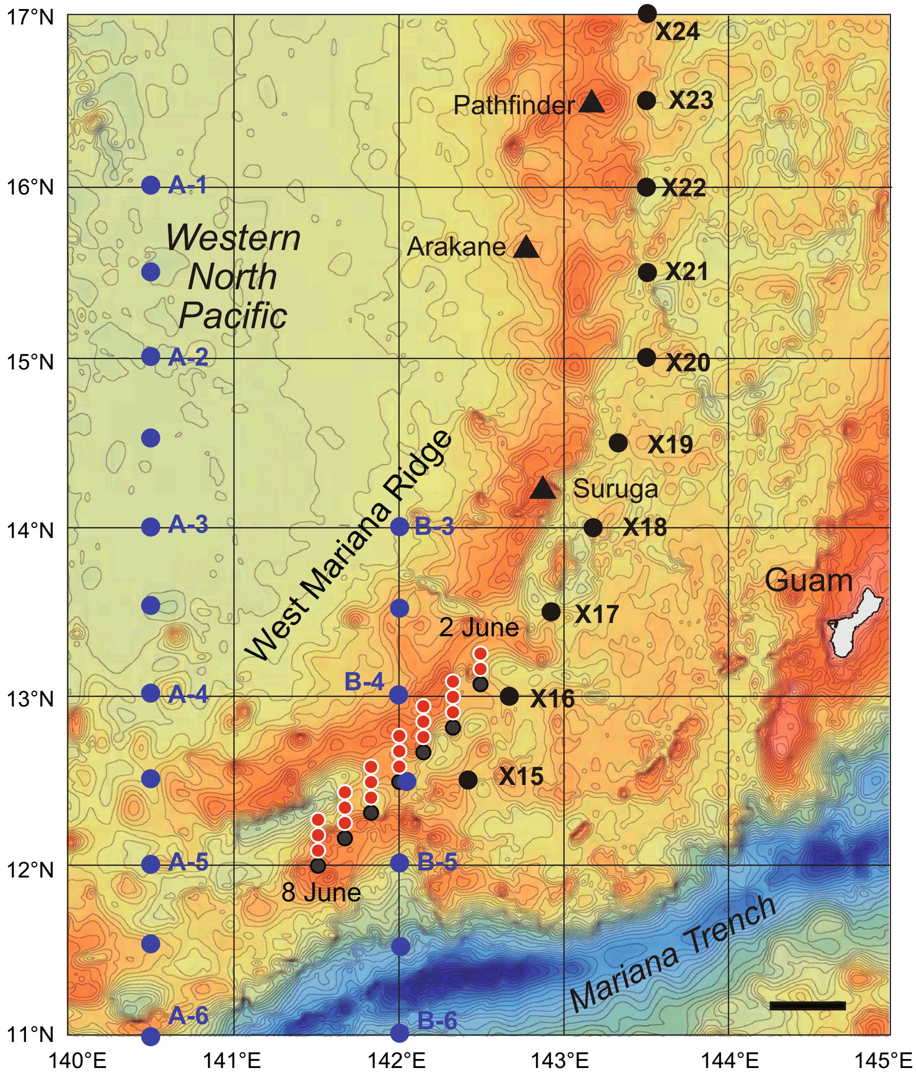

Fig. 3 Map of the study area that was surveyed during the NT13-11 cruise of the R/V Natsushima in May and June 2013. The locations of XCTD stations (X15–X24) established by the Natsushima (*black circles*) along the east side of the West Mariana Ridge (numbered according to proposed stations, with a western transect not conducted). Hydrographic stations on the west side of the ridge established by the R/V Kaiyo Maru are shown with *blue circles* (numbered stations A1–A6 and B1–B6 used a CTD, and the other stations used XCTD probes). The deployment locations of individual Una-Cam systems are indicated with *red circles with white borders*, and the starting points of locations that were surveyed using the ROV Hyper-Dolphin are marked with *dark circles*. Three shallow seamounts within the West Mariana Ridge (Pathfinder, Arakane, and Suruga) are shown with *black triangles*. The *scale bar* represents 10 km

(Japan Fisheries Agency), which was conducting a joint investigation of *A. japonica* spawning ecology at the same time (cruise KY1302) [34] on the west side, over the southern part of the ridge (Fig. 3).

Once a location of likely spawning activity was chosen based on the salinity structure, the Una-Cam systems were scheduled to be deployed in the afternoon and recovered by the ship the next day. At night, from 1800 to 0000 hours, the ROV Hyper-Dolphin was to be deployed and to travel horizontally to search for eels at depths of about 180–300 m, after initially descending to greater depths of 500–800 m. Although various fishes and invertebrates were observed, the present study does not include the results of ROV observations (see JAMSTEC Cruise Report: http://www.godac.jamstec.go.jp/catalog/data/doc_catalog/media/NT13-11_all.pdf, accessed 5 Sept, 2014; and a paper that describes observations of the squid *Sthenoteuthis oualaniensis* hiding in its ink trails made by the ROV [35]).

Una-Cam system deployment

After a test deployment of an Una-Cam (No. 1) with no live eels in the eel chamber, single Una-Cam systems were deployed in the morning at three different stations per day on each observation line, to be recovered the next day starting at 1300 hours, after drifting all night (there were only two systems in the northernmost line) (Fig. 3). Prior to deployment, two to seven artificially matured eels (maximum three females, four males) were placed into each eel chamber. Just before the eels were placed in the chambers, they were given a final injection of human chorionic hormone and 17α-hydroxyprogesterone to stimulate reproductive maturation, after having received two months of injections during the cruise and earlier while they were still being held at the IRAGO Institute in Japan [36]. Thirty males and 26 females were prepared for the cruise and were carefully kept alive onboard in ambient surface seawater in a 1,000-l container until their use. Frozen ovaries of artificially matured pre-spawning *A. japonica* were used as an attractant for the initial single Una-Cam test deployment on 1 June, and live eels were used for the remaining deployments from 2 June though 8 June.

During the cruise, Una-Cam systems were deployed with three slightly different lengths of mainline rope in order to achieve the targeted depths of 180–200 m for drifting and video recording. The same schedule for video recording and lighting was employed for all three systems. HD video camera footage was recorded every 30 min for 6 min, with the HID lights turning on 2 min after the cameras turned on and staying on for 3 min. Each hour, the HERO3 digital video recorders in the glass sphere were deployed to record for 6 min, with the LED lights coming on after 2 min and staying on for 2 min, but the HID light staying on for 1 min longer. The LED lights helped to illuminate the area during the approximately 30 s until the HID light reached full brightness. All lights were then off for the remaining 1 min of video recording during both the 30 min and 1 h scheduled periods. HERO3 digital video recorders and LED lights were activated only once every 60 min due to limited battery capacity.

Results

Salinity front localization

The hydrographic sections indicated that the salinity structure along the ridge was similar to its usual pattern, with lower surface salinity in the southern region and a subsurface tongue of higher-salinity water above the deeper lower-salinity water (Fig. 4). The section to the east of the ridge showed a diffuse salinity front located between approximately 11.5°N and 12.0°N, with a thin layer of low-salinity water ($\leq$34.5) extending up to 14.0°N (Fig. 4a). To the west of the ridge, there was a more distinct salinity front just south of 13.5°N (Fig. 4b). Slightly higher-salinity water was present at the surface and at greater depths to the north of 14.0°N in both sections. The location of the salinity front as it crossed the ridge indicated the area in which to focus the survey to observe the spawning activity of eels, which was conducted from 12.0° to 13.3°N across the region or to the south of the salinity front.

Una-Cam deployments

The Una-Cam systems with live eels (Nos. 2–21) were deployed on seven consecutive days, resulting in 20 deployments after the initial test deployment (No. 1, 1 June). Even after the maximum approximately 20 hours of deployment, the eels in the chambers were still active upon recovery of the systems. The deployments were at 20 different stations located at intervals along observation lines to the north of the ROV deployment points (Fig. 3), and occurred from one to seven days before the new moon (new moon: 0057 hours, 9 June 2013). All of the Una-Cam systems functioned properly. Video files were obtained from the four cameras of each system, and approximately 60 % of the files were then viewed onboard during the cruise, and all files were examined later in the laboratory.

The drift tracks of the Una-Cam systems from their GPS recorder data showed various trajectories on different days, all including a westward component, although drift tracks observed on each individual day were similar among the three systems (Fig. 5a). The individual Una-Cam systems drifted 4.6–23.8 km per deployment in along-track distance and 1.6–22.4 km in straight-line start-to-finish distance. The flow of the NEC appeared to be stronger in the southern part of the study area, as the systems in the south drifted more than twice as far in both along-track (Fig. 5b) and start-to-finish distances (Fig. 5c) as those in the north. It is possible that the sudden changes in direction observed in some system deployments (e.g., Nos. 8, 15, and 18) were related to differences between the transport direction of the buoy array (caused by surface winds or currents) and the direction of deeper currents at the depths where the Una-Cam systems were located. For example, if surface winds weakened after sunset, the drift direction of the systems might suddenly change to follow the deeper currents more directly. Water was often observed moving horizontally past the Una-Cam frames in the video recordings, suggesting differences between the flow of current at the surface and at Una-Cam depths, and changes in the degree of difference may have caused minor variations in system drifting depth during some deployments. The recorded videos indicated that the effects of any vertical movement of the buoy array at the surface due to wave actions were successfully counterbalanced by the string of buoy floats, as no up-and-down movements of the Una-Cam frame were visible in the recordings. The depth-recorder data from each deployment revealed that the depth of the systems generally remained quite constant, although changes of less than a few meters were occasionally observed (Fig. 6). Although most Una-Cam frames were at depths between 176 m and 198 m, No. 9 reached depths as shallow as 173 m, while No. 13 was at approximately 200 m. The degree of difference in flow (direction or velocity) between surface and deployment depths is likely the cause of the minor variations in system depth, since large differences in flow would increase the angle of the rope from the buoys to the Una-Cam frame, reducing their depth. Some deployments, such as Nos. 9, 12, and 16, showed one or two periods when the depth was reduced by as much as 2.5 m, but other deployments remained at fairly constant depths (No. 15) or gradually increased in depth, possibly as a result of reduced surface wind speeds or stretching of the rope.

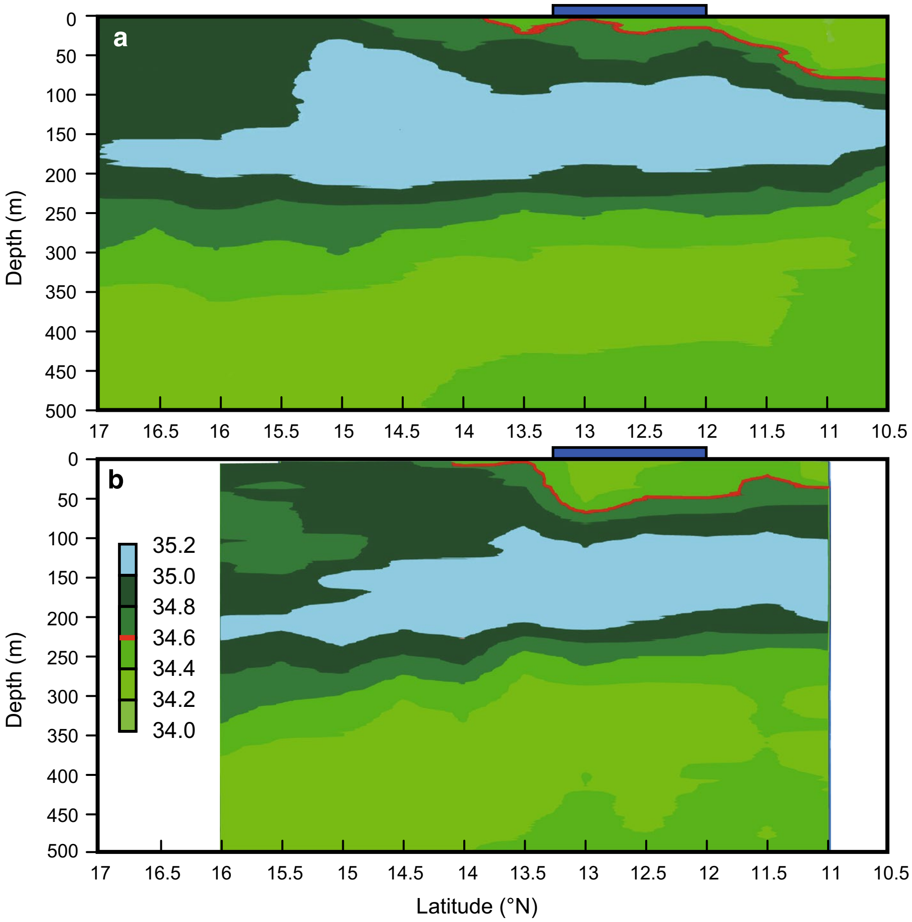

Fig. 4 Salinity sections across the North Equatorial Current in the western North Pacific on the east side of the West Mariana Ridge (142.0°–143.5°E) (**a**) and further to the west of the ridge along 140.5°E (**b**). The *red line* shows the bottom of the low-salinity water (≤34.5) associated with the salinity front, and the latitudes of deployment of the Una-Cam systems are shown by the *thick lines* above the plots

In contrast to the relatively constant system depths, temperatures fluctuated more frequently. The water temperatures experienced in the Una-Cam frames at their deployment depths were usually between 20 °C and 25 °C, but several degrees of change occurred during most deployments, even when the depths of the Una-Cam frames remained constant. For example, No. 9 reached the shallowest depths and recorded the warmest temperature, 27 °C, but also recorded temperatures of less than 25 °C. No. 12 showed an increase in temperature caused by a reduction in depth, but also showed later temperature fluctuations not associated with depth changes. This observation indicates that there were fine-scale differences in temperature structure at these depths, which were within the thermocline [7, 8].

Biological observations

Observations from the video files of the Una-Cam systems showed that the four-camera system was effective for viewing the areas around the eel chamber. The eels in the chamber could be clearly observed in the HD camera images, and when fish or invertebrates came into view, they were observable in the video recordings, even though they were often moving too fast to be clearly identified. Small zooplankton and marine snow could be seen continuously moving past the field of view. Several types of small fish were observed individually or in small schools, including the freckled driftfish *Psenes cyanophrys* (Fig. 7a), and other shallow-distribution mesopelagic fishes such as myctophids. A few apparent leptocephali with anguilliform body shapes were briefly observed, but could not be identified to taxon. Many siphonophores and other gelatinous zooplankton as well as crustaceans could be observed moving with the currents, and occasionally a squid would discharge its ink near the Una-Cam frame. During lights-off periods, bioluminescent organisms were visible when they were stimulated through contact with parts of the Una-Cam systems. Another interesting observation was that eels inside the chamber released eggs and sperm, although this phenomenon was not unexpected, as they had been prepared to reach the final stage of maturation according to the IRAGO Institute protocols.

The ability to observe eels attracted to the reproductive pheromones or other odors released by the maturing eels in the chambers was confirmed in an observation of

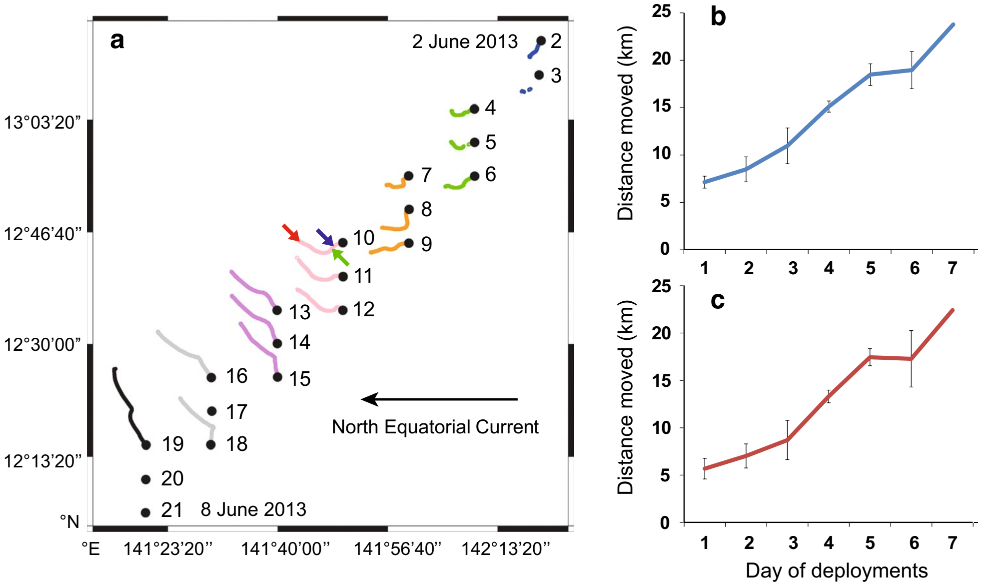

Fig. 5 Plots of the surface positions of the Una-Cam surface buoy arrays (Nos. 2–21) based on their GPS recorder data, showing the drift trajectories of each deployment along the West Mariana Ridge during the NT13-11 cruise (**a**). Three Una-Cam systems were deployed each day from 2 June through 8 June (a single system was tested on 1 June), but the GPS recorders malfunctioned during three deployments on the last two days, as well as for part of the first day. Positions of eel and fish appearances shown in Figs. 7 and 8 are indicated by *arrows* on the plot for No. 10 (*red*: eels, *blue*: fish 1, and *green*: fish 2). Mean along-track and straight-line start-to-finish distances for the deployments each day are plotted in (**b**) and (**c**), respectively

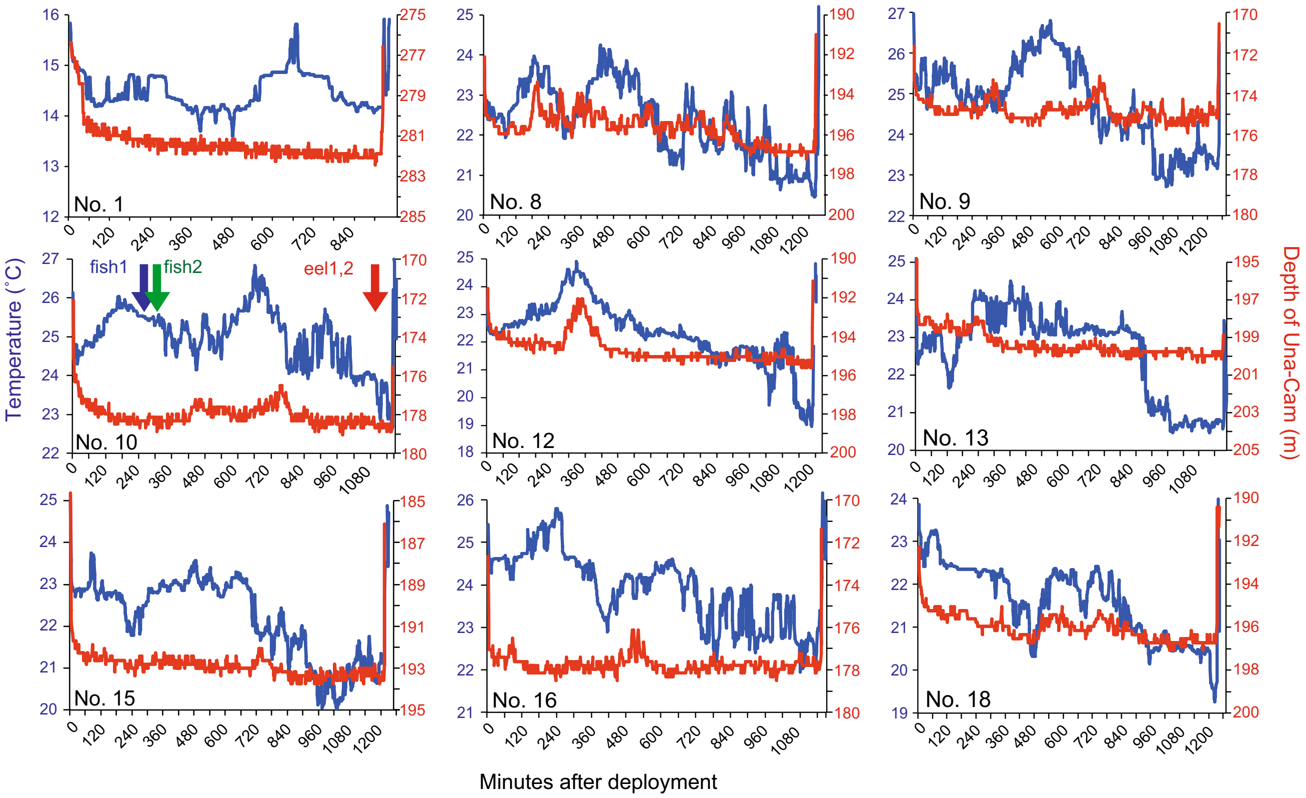

Fig. 6 Depths of Una-Cam systems (*red lines*) and water temperatures at those depths (*blue lines*) during nine representative deployments

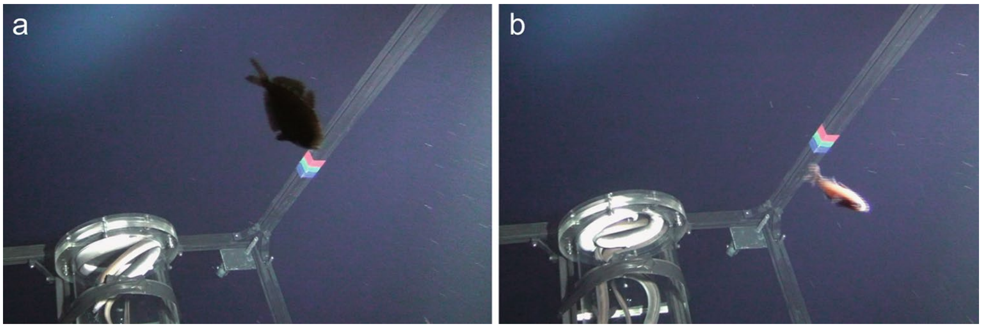

Fig. 7 Examples of frame-capture images of fish from the HD video cameras of the Una-Cam systems deployed during the NT13-11 cruise, showing a freckled driftfish, *Psenes cyanophrys* (**a** fish 1), a species that was frequently observed (probably because they have a tendency to hide under floating structures in the ocean), and a more shallow-bodied unidentified fish (**b** fish 2)

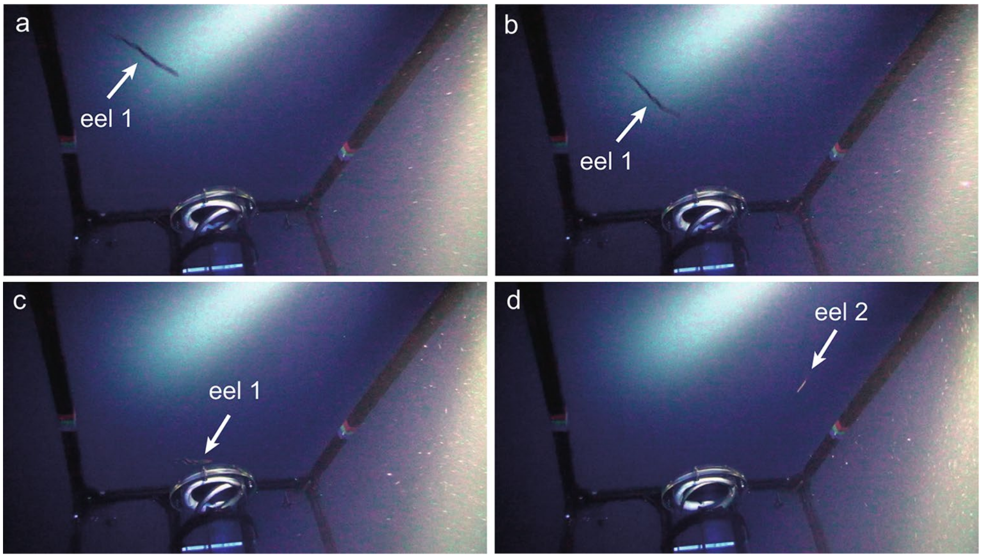

Fig. 8 Frame captures of two eels that appeared to be attracted to one of the Una-Cam systems. A larger eel entered the field of view first (**a**, **b**, eel 1), and then moved directly to the opening of the eel tube (**c**), before moving to the bottom left out of view. A second eel (**d**, eel 2) then suddenly appeared, and then moved back out of view. This may have been a female *Derichthys serpentinus* that was displaying a form of mate-attraction or reproduction-related behavior in order to attract the male *Derichthys* eel

two small eels that approached one of the Una-Cam systems (No. 10, at 0804 hours on 6 June). A larger eel (eel 1 in Fig. 8) entered into view, and directly approached the front opening of the eel chamber. Its body was rapidly undulating in a manner apparently unrelated to locomotion, but this movement may have been a mechanism for producing a vibrational signal. The undulations were anguilliform in structure, but with very high frequency and low amplitude. The eel then moved across the top and down the side of the front of the eel chamber before moving out of the field of view. Immediately after the first eel disappeared, a second, smaller eel, possibly male (eel 2 in Fig. 8d), appeared to the upper right, outside the Una-Cam frame. It moved around nearby and then disappeared from view.

Discussion

The Una-Cam systems that were deployed in the present study with four sets of cameras and three lights, allowed the observation of a variety of organisms present at the deployed depths of 173–200 m. A wide variety of marine animals could be observed, including fishes, small eels, leptocephali, gelatinous zooplankton, and crustaceans; therefore, if anguillid eels had moved near the Una-Cam frames, they would have been clearly observed in the video recordings. Some types of organisms observed in the recordings were different from those observed using the Shinkai 6500 submersible and deep-tow camera system that was deployed in the previous year along the West Mariana Ridge [20]. For example, species such as the small tuna, soldierfish, and squid that had appeared to be attracted to the bright lights of the deep-tow camera deployed at overlapping depths were not observed in this study. The only fish that lingered near the frame of the Una-Cam system were those that were likely to be attracted to drifting objects, such as the frequently freckled driftfish [37] that were frequently seen.

One advantage of the Una-Cam system compared to other observation platforms is that they are quiet while they are freely drifting, and their lights are not on continuously throughout their deployment. Consequently, wild eels could approach the eels in the chambers during periods when the lights were turned off, and may have detected relatively few abnormal sensory stimuli. If the current differential between the surface and Una-Cam system is sufficiently high, the water moving past the frame of the Una-Cam will produce mechanical noise, but noise production will be minimal at times of less flow across the frame. The two derichthyid eels showed no reluctance to approach the Una-Cam even with the lights on, and thus there is a chance that anguillid eels could approach the system during a no-lights period, and could then be recorded when the lights are turned on.

Deployment location and depth

The deployment locations of the Una-Cam systems over the southeastern region of the West Mariana Ridge overlapped areas where adult eels and preleptocephali had previously been caught [7, 10, 11], but were either considerably (2009) or slightly (2011) to the east of where eggs were collected in the area [7, 8]. The locations of spawning events seem to shift throughout years, or even months [7, 8, 18], and so if eels were spawning even slightly outside the area of Una-Cam deployment, they would not have been lured close enough to be filmed.

It would appear that the Una-Cam systems were deployed at appropriate depths, based on several types of information. Studies using pop-up satellite-transmitting tags attached to other species of temperate anguillid eels have shown that these eels have a very distinct pattern of diurnal vertical migration, from great depths during the day to depths shallower than 200 m during nighttime [38–40], and this is also true for *A. japonica* [41] and *A. marmorata* [42]. Although only one large female *A. marmorata* may have reached its spawning area [42], these observations suggest that spawning eels would also be at similar depths at night. In addition, the capture depths for *A. japonica* and *A. marmorata* within their spawning area near the West Mariana Ridge are thought to be less than 250 m [7, 10, 11]. The presence of eggs [8] and preleptocephali [7, 11] in narrow layers at the top of the thermocline, just below 150 m, also suggests that spawning occurs not far below those depths. The temperature ranges experienced by the Una-Cam systems (20–25 °C) also overlap with optimal temperature ranges observed in studies on induced natural spawning in the laboratory [43], and egg incubation and larval rearing [44]. This overlap suggests that while Una-Cam deployment depths may have been appropriate for attracting spawning eels, if the eels formed aggregations at slightly greater depths, they would not have been able to detect the odor of the eels in the chambers without adequate vertical mixing of water to transport the odor to deeper levels.

Artificially matured eels as an attractant

The artificially matured eels functioned well during the survey as a potential attractant for wild eels. They were observed to behave normally at the deployment depths, and some actually released eggs and sperm while they were being video-recorded in the chambers. The mature eels seemed to provide strong olfactory signals, based on the observation of what appeared to be a female *Derichthys serpentinus* moving directly toward the end of the eel chamber, while seeming to perform a mate-attraction or courtship display of rapid body vibrations, which has not been observed previously. It is possible that the extreme high-frequency undulations could emit a mechanical signal detected by the male eel. The pheromone stimulus from the mature anguillid eels may have attracted these *D. serpentinus* eels and triggered their behavior, even though they are of different anguilliform species. *D. serpentinus* are mesopelagic eels that are known only from collections of adults and larvae [45–47], as there are no reports of observations of juveniles and adults from underwater vehicles. These phenomena suggest that if the Una-Cam systems are deployed in an area where *A. japonica* eels or spawning aggregations are present, there is a chance that some eels will be attracted to the odors of the highly mature spawning-conditioned eels in the chambers.

Towards future observations of eel spawning activity

This type of observational challenge is relatively new in oceanography, as underwater vehicles or stationary camera systems are typically used to observe biological activity or other features on the ocean floor or in deeper ocean depths [21–30]. These systems are also used to observe or survey the abundance of fishes in coastal waters [23], including spawning aggregations [48]. Less attention has been given to the upper pelagic zone, with the exception of the use of these systems to record data such as zooplankton or fish larvae abundance or marine snow concentrations [49–51]. Attempts to perform similar studies have been made, however, such as attracting large squid to suspended food as bait [52, 53]. Baited camera video systems have also been used to study the assemblages of midwater fishes in nearshore areas [54, 55]. These types of systems have been more extensively used in shallow coastal water or estuarine habitats, where the fish species observed can be affected by the type of bait used or the current patterns that transport the odor trail [56–58]. Various baited ocean floor lander-type camera systems have been used successfully to attract and photograph fish and invertebrate species at great depths, but even these types of structures can affect the outcome of the observations [59]. Submersible and ROV observations in the pelagic environment are also likely to be biased with respect to the kinds of marine animals observed, due to factors associated with avoidance of, or attraction to, the lights or other aspects of the underwater vehicles [23, 28] or towed camera systems [20]. For example, more deep-sea fishes were observed with an ROV when red light was used than when white light was used [60], suggesting avoidance of bright lights. As mentioned previously, some animals have been attracted to the deep-tow camera system [20]. In consideration of these factors, the less invasive nature of the Una-Cam system provides a useful new methodology for viewing spawning eels. These systems are also less expensive and require less specialized logistical support than submersibles and ROV-type observation platforms.

With various factors being known about when and where *A. japonica* spawning activity occurs along the West Mariana Ridge, the Una-Cam systems can provide opportunities for future observation of eels or other pelagic organisms that can be attracted to this type of camera platform, such as that described in the present study. In the case of *A. japonica*, the observation that spawning occurs only just before the new moon and that the latitude at which spawning takes place appears to be influenced by surface salinity structure makes it possible to narrow the target area for the deployment of observation systems [20] or net sampling efforts [7, 8]. As such, it appears that future deployments of Una-Cam systems at different depths or locations for the purpose of observing spawning eels may have a greater chance of success. Such systems might also be able to include other technologies, such as size measurement software to evaluate the body sizes of observed animals, or environmental sensors to record salinity or other parameters. Alternatively, they could be used simultaneously to deploy other small measurement devices for unrelated studies, if these would not be detected by eels, and could be adapted to attract or survey other types of marine animals at various depths. Thus, through the use of these relatively inexpensive technologies, there is a chance to observe phenomenon never seen before, such as anguillid eels within their mysterious spawning areas in the deep ocean.

Acknowledgments We sincerely thank the ROV Hyper-Dolphin operation team and the captain and crew of the R/V Natsushima for their excellent effort and support during the intensive activities to deploy and retrieve the Una-Cam systems. We also especially thank the IRAGO Institute for providing the artificially matured Japanese eels for this study, and the R/V Kaiyo Maru for providing their oceanographic data during the survey. In addition, we greatly appreciate the support of the JAMSTEC cruise administration team who helped make this cruise possible.

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