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Collection, Transport and Husbandry of the Coconut Octopus, *Amphioctopus marginatus* (Taki, 1964) from the Philippines

Bart Shepherd, Richard Ross, and Marisa Avila
Steinhart Aquarium, California Academy of Sciences
55 Music Concourse Drive, San Francisco CA 94118

The coconut octopus, *Amphioctopus marginatus* (Taki, 1964), is a small, charismatic, tropical, day-active species of octopus that is well suited for aquarium display. Despite this, they are never seen in the marine aquarium hobby and have never been displayed in public aquariums. As part of the California Academy of Sciences' long-term scientific collaboration in the Philippines, we collected 25 individuals of *A. marginatus* on two occasions (May 2011 and November 2012) and transported a total of 18 coconut octopuses to Steinhart Aquarium for research and display. We developed techniques that support 100% survival of specimens during 3 critical stages: (1) collection via SCUBA, (2) temporary staging in the field and (3) international air-cargo transport. At Steinhart Aquarium, we successfully displayed *A. marginatus* in two separate exhibits. In aquaria, coconut octopuses lived their presumed natural lifespans (longevity up to 375 days post-collection, average of 195 days), exhibited typical behaviors observed in the wild, such as constructing dens and hiding in containers, and proved to be exceptionally popular with museum guests. The coconut octopus is a small-egged species with tiny paralarvae, complicating the development of aquarium-based captive breeding programs. In addition, commercial collectors have proven to be an unreliable source for this species. Thus, for the time being, successful aquarium display programs will likely involve targeted collecting trips.

The coconut octopus, *Amphioctopus marginatus* (Taki, 1964), is an engaging, relatively small species of octopus, reaching a maximum mantle length (ML) of 80 mm and weight of 400 grams (Huffard and Hochberg 2005). *Amphioctopus marginatus* is also a benthic octopus occurring in the shallow tropical seas of the Indo-West Pacific, ranging from the tropical waters of Indian and Western Pacific oceans in continental coastal waters (Norman 2000). We have observed numerous individuals of coconut octopuses living in close proximity to each other in sandy habitats in the Philippines, especially at sites with large numbers of discarded bottles, cans, ceramic pots or coconut shells: all of which are readily used as octopus dens (Fig. 1). These sites include areas heavily impacted by human activities, such as piers and shallow water near municipal centers. The coconut octopus has been observed to be active both in the day and at night, "exploiting" bright dive lights for opportunistic feeding during night dives as well as actively exploring surroundings and socially interacting with conspecifics during the day.

These characteristics make it a fantastic candidate for display in public aquariums. Many other species of octopus traditionally displayed in public aquaria are either nocturnal, extremely cryptic, or both, making them difficult to observe and enjoy. It is not uncommon for octopus displays to fail to engage public aquarium guests, either because the animals are out of view, hiding under tank decor, in rocks or crevices, or simply because they are so perfectly camouflaged as to be invisible in plain sight. By comparison, the coconut octopus is almost always in view due to its affinity of using bottles, cans or coconut shells as dens. Within aquaria, coconut octopuses tend to pick a den and stay positioned in it in such a way that at least part of their bodies remain visible to guests.

In popular literature and on the web, the common name has been changed from the veined octopus to coconut octopus based on descriptions of this species using empty coconut shells as

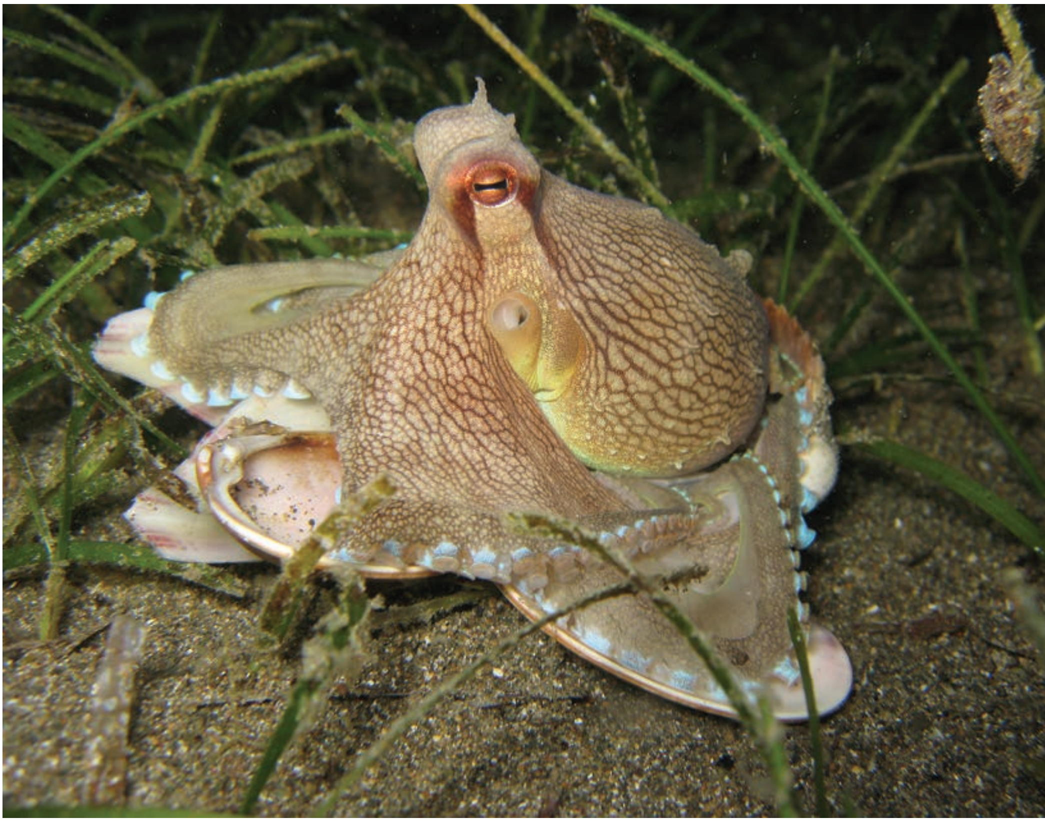

FIGURE 1. The coconut octopus, *Amphioctopus marginatus* (Taki, 1964), in its natural habitat in the Philippines. Note the "veined" appearance and the opalescence along the suction cups (defining characters used to identify appropriate specimens for collecting), as well as this individual's use of multiple (empty) bivalve shells as a portable den. Photo by Bart Shepherd.

tools as a portable defense mechanism (Finn et al. 2009). *Amphioctopus marginatus* have been observed carrying coconut shells under their bodies, 'stilt-walking' on the tips of their arms, and bringing two halves of a coconut shell together while hiding inside and rolling the shells across the sediment. Because it is presumed that the shell is being carried by the octopus for future (rather than immediate) use, and due to the complexity involved with correctly manipulating two different coconut shells into a single functioning "tool", these unique behaviors may satisfy the definition of tool use. However, it may be the case that the use of coconut shells by these octopuses is indeed for immediate use as protection from substrate dwelling predators. *Amphioctopus marginatus* is also one of several species of octopuses known to exhibit bipedal locomotion (Huffard et al. 2005).

There have been very few *in situ* research studies on this species. Huffard and Godfrey-Smith (2010) documented the details of *Amphioctopus marginatus* mating behavior. The male and female were observed to be in close proximity during mating, with periods of crawling along the open sand by both sexes. During mating, the male was observed 'reaching' his hectocotylus, a modified tentacle used to pass spermatophores into the female mantle cavity, and holding it horizontally above the substratum. It is unknown whether the 'reaching' behavior is necessary for mating, or how many spermatophores were passed to the female during mating.

Ex situ research has also been scant. *Amphioctopus marginatus* are 'small-egged' octopuses; they produce copious amounts of very tiny eggs. Sreeja and Bijukumar (2013) observed a female that laid approximately 20,000 eggs. Their specimen ate the day she laid the eggs, but did not eat again after laying, and died on the eighth day following laying. *Amphioctopus marginatus* eggs are less than 6 mm in diameter, and laid in festoons of 33–45 eggs per centimeter of festoon. They were cemented to the inside of a coconut shell den, and the female tended the eggs for around 16 days, until they hatched as planktonic paralarvae (Sreeja and Bijukumar 2013). The paralarvae of *A. marginatus*, like in other paralarval octopuses, are very tiny (ML approximately 2 mm). It has proven difficult to find first-foods to sustain them through the early life stages. Although there has been some reported success feeding primarily crab zoea, the survival and settlement rates remain low (Carrasco, Arronte and Rodríguez, 2006).

The California Academy of Sciences has a long-term research program focused in the Philippines. Two of our primary goals are to (1) study and document the tremendous marine biodiversity present in the more than 7,000 islands that define the Philippines, and (2) to use this knowledge to help inform and enhance conservation through education, social and scientific outreach — in the Philippines, online and in our facility in Golden Gate Park. Over the past twenty years, a particular focus for marine invertebrate biodiversity surveys is the area known as the Verde Island Passage (Fig. 2). This region has been called the "center of the center" of marine biodiversity due to the presence of more species of reef fishes than anywhere else on Earth (Carpenter and Springer 2005). In addition, more species of nudibranchs exist in this area than anywhere else on Earth (Gosliner, pers. comm.) and there is exceptionally high biodiversity in octocorals, with a single site, Devil's Rock, hosting more species of soft corals than the entire Caribbean basin (Williams, pers. comm.). Scientists from the Academy have visited this area since the early 1990s, documenting species diversity and collaborating with in-country partners such as the Bureau of Fisheries and Aquatic Resources (BFAR), the National Fisheries Research and Development Institute (NFRDI), and the University of the Philippines (UP).

In the mid 2000s, the Academy signed a memorandum of understanding (MOU) with BFAR and NFRDI to foster international collaboration on documenting marine biodiversity, to create a framework for the continued training of Filipino students and scientists, and for the development of novel animal husbandry techniques. The latter component supports one of Steinhart Aquarium's core strategic goals: to both increase the sustainability of the marine aquarium trade in the Philippines and to foster the development of new economic incentives to protect and steward Philippine coral reefs (e.g., through jobs created by the aquaculture of marine aquarium species). Our work with the coconut octopus directly supports this aspect of the MOU through the development and dissemination of new techniques for the collection, transport, husbandry and captive management of a charismatic species that is not currently traded within the international marine aquarium industry.

Materials and Methods

Collecting.— Coconut octopuses were collected on two occasions in the Verde Island Passage area of the Philippines, Batangas Province, Luzon Island, near the municipality of Mabini (Fig. 2). On both occasions, gratuitous collecting permits were secured through our MOU with BFAR and NFRDI. In addition, we obtained Mayor's permits granting us permission from the local government to collect on reefs located within the municipal waters of Mabini and Tingloy. All animals were collected in shallow water (2–8 meters depth), at night, using SCUBA, at the dive site "Anilao Pier" (13°45.62′N, 120°55.56′E). Dives were conducted from local boats, called "bankas", based at the dive resort Club Ocellaris (13°46′N, 120°58′E), with local SCUBA dive guides assist-

FIGURE 2. The Verde Island Passage area traditionally known as "Anilao". This region features numerous dive sites of varying composition: reefs, "muck diving", sea grass beds and rubble habitats. The Coconut Octopus, *Amphioctopus marginatus*, was collected at Anilao Pier, just north of our field station, Club Ocellaris, Mabini, Batangas, Philippines. Map by Gary Williams.

ing in the identification of appropriate sites and individual specimens. In this area, *A. marginatus* is relatively easy to identify underwater, even at night, due to the conspicuous opalescence along the suction-cups, as well as their typical behavior of hiding within bivalve shells, small cans, bottles or broken coconut shells (Fig. 1).

Our first attempts at collecting coconut octopuses occurred during the shallow-water component on the Academy's Philippine Biodiversity Expedition in late May 2011, funded by William Randolph and Margaret Hearst. Smaller sizes were preferentially chosen for ease of transport and longevity, as small specimens were presumed to be the youngest specimens. All animals were collected in clear plastic bags or rigid plastic jars with mesh lids. Whenever possible, each octopus was collected with its den in order to reduce stress and give the specimens cover and structure during the transport. In these cases, octopus dens consisted of small bivalve shells, cans or bottles. Following collection, specimens were returned to our field station by banka (approximately 30 minute transit time) and immediately staged in holding containers placed in shallow water just offshore of our field station. The next morning the animals were removed from the ocean and transported to Manila (approximately 120 minutes by car) where they were prepared and exported to the Steinhart Aquarium.

The second collecting trip occurred at the end of a Steinhart Aquarium led expedition focused on developing our coral conservation efforts in the Philippines. We were joined on this trip by biologists from the SECORE Foundation (Bremen, Germany), The Florida Aquarium (Tampa, Florida, USA) and Moody Gardens (Galveston, Texas, USA). Florida Aquarium and Moody Gardens staff assisted in the collecting, transport and documentation of these efforts and we are very grateful for their contributions. Our methods closely resembled the initial collecting trip, except for two major differences. First, as an attempt to eliminate death by "rigor" during collection (see results and discussion), we decided to use only rigid plastic jars rather than clear plastic bags (Fig. 3). Second, to increase longevity and reduce the size of our transport container, we focused our collecting efforts on extremely small specimens (< 2 cm ML).

FIGURE 3. Clear, food-safe plastic jars with tight fitting screw top lids were used for collecting, staging and both short and long-distance transports with a high degree of success (100% survival). Photo by Eric Hovland.

Square-sided plastic jugs constructed of FDA-approved PVC were purchased from TAP Plastics (Easy Grip Plastic Jugs, *www.tapplastics.com*, USA). The uniform size and cube-like shape of these containers facilitated packing in Styrofoam aquarium shipping boxes, while the plastic protected the octopuses during the collecting dive (40–60 minute bottom time), transport back to the field station (30 minute boat ride) and transport to the shipping facility (2–3 hour car ride).

Two sizes of containers were selected: 1 liter (32 oz) (n = 8) and 2 liter (64 oz) (n = 2). Both sizes have tight-fitting screw-on lids that are easy to manipulate under water. To prepare the jars for our purposes, a 5.08 cm (2 inch) hole was drilled into each lid, and 1 mm fiberglass window screen was glued over the opening with cyanoacrylate glue. These containers were used to both collect and ship the coconut octopuses collected on the second expedition. Following collection, specimens were returned to our field station by banka (approximately 30 minute transit time) and immediately staged in holding containers placed in shallow water just offshore of our field station. The 11 specimens were held overnight in the plastic collecting containers,locked between two heavy plastic milk crates, and secured on the bottom using large round stones (Fig. 4). The next morning the animals were removed from the ocean and transported to Manila where they were prepared and exported to the Steinhart Aquarium.

FIGURE 4. Plastic collecting containers and storage crates were used for temporarily staging the coconut octopus. The collecting containers were secured between the two crates, weighted down with large stones and placed in shallow water off of our field station in between collecting and shipping. Photo by Eric Hovland.

SHIPPING.— The coconut octopuses we collected in May 2011 were professionally packed at an aquarium export facility (Aquascapes Philippines, Manila) with oversight by Steinhart Aquarium biologists. Animals collected in metal dens (cans) were removed from their dens prior to shipping to avoid the risk of the corroding metal contaminating the transport water. All specimens were shipped in clear plastic deli cups with 1mm mesh window screen tops to protect them from being trapped in the corners of the shipping bag, while still allowing access to well-oxygenated water. The deli cups created a den-like, contained space for the animals, and prevented them from biting through the shipping bag. Each individual deli cup was placed in a large, clear, plastic shipping bag filled with a total volume of approximately 2 liters, consisting of 50% seawater and 50% oxygen. The salinity of the shipping water was adjusted to match the salinity of the water with which the octopus were collected. Shipping bags were placed inside a second bag (double-bagged) with a newspaper liner in between the two layers, and then packed tightly inside Styrofoam coolers with cardboard outer liners. Small pieces of ice were used to keep the temperature inside the shipping boxes cool for the time between packing and when they were loaded on to the aircraft. All eight specimens of coconut octopus were shipped on a direct flight from Manila to SFO (total transit time of 14 hours). Export permits were arranged with BFAR and coordinated with Aquascapes Philippines and our stateside customs broker (Service Express, San Francisco, California, USA).

As with the first collection, the animals from our second collection were professionally packed at an aquarium exporter (Aquascapes Philippines, Manila) and the salinity of the shipping water was adjusted to match the water in which the octopuses were collected. This time, however, all specimens were shipped inside the plastic collecting jars. The jars were placed inside a large plastic shipping bag with a ratio of approximately 50% seawater and 50% oxygen (Fig. 5). In contrast

FIGURE 5. Successful shipping was accomplished by packing the coconut octopus in individual hard plastic containers within plastic bags. Double-bagged specimens were tightly packed in styrofoam coolers with outer cardboard shells. Photo by Eric Hovland.

to a typical international aquarium fish shipment, where water volumes are minimized to reduce shipping costs, we shipped these containers "heavy"; each specimen was shipped with approximately 2–3 liters of seawater. Again, this approach allowed animals access to an abundance of high-quality, well-oxygenated water, increased the stability of the temperature during the long duration of the air transport, protected the octopuses from being trapped in the 'corners' of a flexible shipping bag, gave them a secure den-like space during shipping and eliminated the possibility of them puncturing the shipping bag with their beaks. As with our first collection, the animals were double-bagged with newspaper liners in Styrofoam coolers with cardboard outer liners, and ice packs were used. The boxes were then shipped air cargo on a direct flight from Manila to SFO, with a total transit time of 14 hours. Export permits were arranged with BFAR and coordinated with Aquascapes Philippines and our stateside customs broker (Service Express, San Francisco, CA, USA).

TABLE 1. Water parameter ranges for two displays of coconut octopus, *Amphioctopus marginatus*, at Steinhart Aquarium.

Water Quality Parameter	Range of Values
Ammonia	0 mg/L
Nitrite	0 mg/L
Nitrate	< 15 mg/L
pH	8.1 - 8.4
Temperature	24–25°Celsius
Salinity	34–35 ppt
Alkalinity	3.2 - 3.8 meq/L
Calcium	380–420 mg/L
Magnesium	1250–1350 mg/L
Phosphate	0.05– 0.15 mg/L

AQUARIUM DISPLAY.— We displayed single individuals of coconut octopus in two separate aquaria over a period of 2.5 years. The first (*Animal Attraction* gallery, May 2011–March 2013) was a 350–liter acrylic aquarium (122 cm x 60 cm x 46 cm), the second (*Water Planet* gallery, March 2013–present) is a 240–liter acrylic aquarium (60 cm cube). These exhibits have very tight fitting lids made from twin-wall polycarbonate greenhouse material held in place by plastic coated lead weights. The exhibits were set up as 'natural systems' where biological filtration is provided by live rock. Mechanical filtration, oxygenation and off gassing of carbon dioxide is provided via foam fractionation (ASM protein skimmer, model G4). Lighting consists of a combination of blue and white, 3 x 1 watt MR-16 LED lamps (EcoGreen Solutions, Laguna Niguel, CA, USA). Water parameters are maintained at standard levels for delicate marine invertebrates (Table 1).

Tank decor consists of a few coral rubble rocks, small bivalve shells, coconut shells, glass bottles and jars. The tank substratum was initially "Mineral Mud" (CaribSea, Florida, USA), which closely mimics the muck substrata in which these octopuses are found. This was later replaced with silica sand for maintenance reasons and the animals showed no behavioral changes when substratum was switched. Chocolate Chip Starfish, *Protoreaster nodosus* (Linnaeus, 1758) were sporadically used as a scavenger to keep uneaten food from degrading water quality. Live algae, *Caulerpa prolifera* (Lamouroux, 1809), was grown in the exhibit to assist with maintaining high water quality and guest visual interest.

Feeding.— At Steinhart Aquarium, *Amphioctopus* are fed live freshwater ghost shrimp enriched with CYCLOP-EEZE (Argent Chemical Laboratories, Redmond, WA, USA), live *Crangon* shrimp, frozen *Crangon* shrimp, locally collected crabs (*Hemigrapsus* spp.), and live Manila clams (*Venerupis philippinarum*). *Crangon* shrimp are commonly used as bait for recreational fishing, and are purchased from a fishing supply store. Manila clams are purchased from a restaurant seafood industry supplier. In the rare instances that live shrimp were not available, frozen prawn was accepted and eaten by the octopus. Food was often given in jars (see below) and inside wiffle balls as part of a formal behavioral enrichment program.

Attempts to Acquire Specimens Through Commercial Sources.— As the animals from our May 2011 collecting trip began to get old and undergo senescence, we made several attempts to obtain replacement octopuses through the normal public aquarium channels of commercial collectors and suppliers. None of these attempts were successful. Instead of receiving *Amphioctopus*, we received several shipments of *Abdophus* or *Macropus*. The second author has experienced this trend for the last 10 years. We postulate that because octopus are rarely collected for the marine aquarium trade, it is very difficult to find collectors that can tell the difference between the various octopus species. Also, *Amphioctopus* occur in areas that are not often visited by commercial collectors, and most are unwilling to do special trips to selected areas for only one kind of animal as such trips are not cost effective. It is unknown whether *Amphioctopus* are targeted or opportunistically caught in traps used by traditional fishers, or whether this method could be used to collect specimens without requiring SCUBA.

On our November 2012 collecting trip, we invited a commercial collector working for Aquascapes Philippines to join us on the expedition to learn how to identify the species, where to find it, and to learn appropriate collecting techniques. This was an attempt to create a reliable source for future acquisitions of *Amphioctopus marginatus*. The fisherman joined us on the boat, saw the collecting sites and snorkeled with us while we collected the specimens. Challenges here revolved around a language barrier (all communication was through a translator) and limited access to equipment (everything from SCUBA equipment and underwater flashlights to the plastic collecting jars). It remains to be seen whether or not this will be an effective strategy for future acquisitions of coconut octopus.

Results and Discussion

Collecting and Shipping.— On May 24, 2011, as part of the Hearst expedition, Steinhart Aquarium biologists collected a total of 14 specimens exhibiting a range of sizes from 0.75 cm to 5.0 cm ML. During collection, three larger octopuses died of what we now call "rigor": a stiffening of arms and mantles. These three individuals were all larger animals. Two died almost immediately (before the collection dive was over). The third specimen was inactive but still alive when we returned to our holding area; this individual died during the night.

The cause of this sudden mortality is unknown, but we postulate that this may be a "fear" reflex, and is perhaps a result of collecting larger animals without dens and placing them in clear plastic bags. An alternate explanation is that the larger specimens experienced a sudden decrease in water quality while enclosed in the plastic bags for the duration of the collecting dive. This rapid decrease in water quality could be caused by increased physiological activity resulting from the stress associated with collecting, or perhaps due to the animal inking in the bag. A drop in dissolved oxygen or an accumulation of carbon dioxide or ammonia could cause sudden mortality in the minimal water volume in a sealed collecting bag. No water quality tests were conducted in the field, so we have no data to substantiate this hypothesis.

During the night, three specimens secured in individual small containers inside of a 20 liter opaque plastic bucket went missing. We assume that local fishers, who are regularly seen out on the reef at night, took the bucket. Our other temporary holding containers, "Kritter Keepers" (Lee's Aquarium and Pet Products, San Marcos, California, USA) were not taken, presumably because the clear boxes were less visible or because the "Kritter Keepers" are less desirable than the opaque plastic buckets. This was the first and only time we used plastic buckets as an offshore holding container.

We were only able to ship eight specimens out of the 14 that we collected on our first expedition, as three were lost, and three died of rigor. Initial mortality resulting from collecting on our first expedition was 21%. This is significantly higher than expected, and higher than we have experienced when collecting other species for aquarium research and display. During shipping, an additional specimen died in transit, bringing the total mortality rate for our first collecting and shipping trial to 29%. In total, only seven of the 14 specimens collected on this first trip made it to Steinhart Aquarium for display, representing a 50% success rate from field collection to exhibit. If we exclude the three specimens that went missing with their bucket, this success rate climbs to 64%.

A total of 11 octopuses were collected on our second expedition (November 19, 2012). Despite the presence of fishers, heavy currents and surge in the area, all 11 specimens were alive the following morning when they were removed from the ocean for packing and transport to Manila to be exported back to Steinhart Aquarium. Because our export permit only allowed us to ship 10 specimens to Steinhart Aquarium, a single specimen was released the morning following collecting. No animals died during transit. The 0% mortality rate on our second collecting and shipping trial was likely the result of our collecting only small individuals, collecting the animals with their dens, and using the rigid plastic containers for all stages of the operation: collection, temporary staging and shipping. The screened tops of these containers allow for continuous water exchange and thus prevent rapid degradation of water quality due to physiological processes or inking. This is a model that we will use for any future collections of small octopuses.

Seasonality, Sympatry, and Lifespan.— *Amphioctopus marginatus* were readily available during the months of May and November when these collecting expeditions occurred. During both of these times, a wide range of sizes was visible, and small specimens were targeted for collecting. This suggests that eggs of this species may hatch during the spring or early summer. The presence of many individuals of several sizes is likely a result of the individuals' success rate with capturing food, as animals that feed more frequently will grow more rapidly (Wells and Wells 1977).

The second collecting trip (November 2012) yielded two to three different species of *Amphioctopus*. These animals were impossible to distinguish from each other while collecting, but differences in coloration and behavior that were observed in aquaria suggest that we were dealing with at least two species among the ten specimens exported successfully to the Academy. Further research at the collection site will be useful in determining whether different species of *Amphioctopus* are sympatric all year round, for only part of the year, or if our experience was an outlier event.

Like most small tropical octopuses, *A. marginatus* is estimated to have a short lifespan. We tracked the lifespan, post-collection, for five of seven specimens from the May 2011 collecting trip and all 10 specimens from the November 2012 trip. Longevity of *A. marginatus* held at Steinhart Aquarium varied between 33 days and 375 days (Fig. 6). The average longevity post collection was 195.4 days (± 116.2 days standard deviation). Longevity varied between the collections, with the animals from the first collection (May 2011) living an average of 173.6 days (± standard deviation of 126.9 days), while the animals from our second collection lived an average of 206.3 days (± standard deviation of 116.0 days). A t-test was performed on the data set, and there was no statistical difference between the longevity from the two collecting trips (independent samples, unequal variance, $p = 0.642$). The longest lifespan that we witnessed at Steinhart Aquarium was 375 days following collection (specimen 1.5, collected May 24, 2011, death on June 2, 2012).

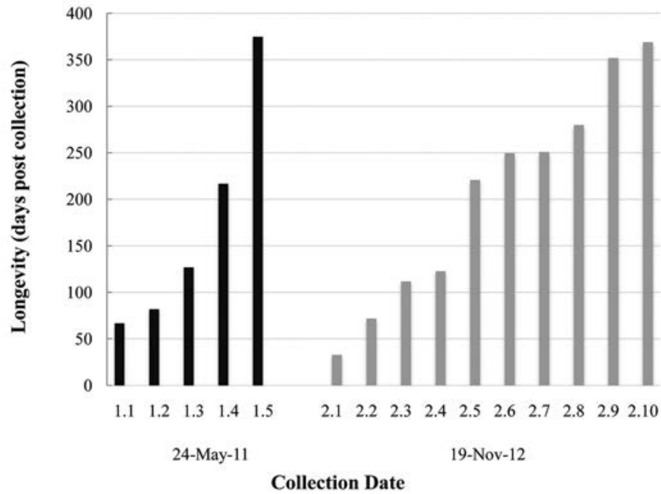

FIGURE 6: Longevity data from both groups of *Amphioctopus marginatus* collected in the Philippines. Black bars are 24 May 2011; grey bars are 19 November 2012. Longevity was highly variable, but the second collection lived longer on average (206.3 + 116.0 days, as compared to 173.6 + 126.9 days). So far, our longest-lived specimen (1.5) was 375 days post collection.

Senescence was observed in both large and small animals and followed the general pattern seen in other octopuses: lethargy, unwillingness to leave a den, spiraling arm tips, dulling of skin color, refusal to feed. Like other species of small, warm-water octopuses, it is likely that in the wild, *A. marginatus* grows very rapidly, is semelparous (breeds a single time), and then dies within 1 to 2 years (Wells and Wells 1977).

DISPLAY TECHNIQUES.— Steinhart Aquarium at the California Academy of Sciences has been successful in displaying *Amphioctopus* judged on the basis that (1) the animals are living to their presumed natural lifespan (> 1 year post collection), and (2) we are achieving positive educational engagement with aquarium visitors. Guests are often crowded around the exhibit to observe the octopus. Our displays are simple and are based on the environments where we collected *Amphioctopus*. They accurately represent the animals native habitat: soft, sandy substrate with a small amount of rock and stemmed algae, and included various items to be utilized as dens. Periodically we have added “toys”, such as legos, and plastic squid or octopus figures, but none of the animals showed much interest in these items.

Initially, the octopuses were given pvc fittings, flowerpots, and coconut shells to use as dens. The display of *Amphioctopus* was further enhanced by giving the animals clear glass bottles to use, so that they are visible even when they retreat into their dens. Steinhart Aquarium Senior Biologist Richard Ross created several hand-blown glass dens of different sizes and shapes. We have found that a den slightly larger than the octopus, with an inner fold (a lip of glass that projects inside the den) seems to be preferred by these animals (Fig. 7). These hand blown glass dens have also been used with other species of octopus (larger Pacific striped octopus, an undescribed species) with great success for both the animals and the viewing public. We are planning further research to determine what makes one type of artificial den more preferable to another.

At Steinhart Aquarium, *Amphioctopus* were only displayed singly. Given the natural population density of these animals, research on displaying multiple animals in larger exhibits (750 liters or more) might yield interesting results, including successful mating or observations of other social behaviors.

CAPTIVE BEHAVIOR.— *Amphioctopus* is a very visible display animal, usually nestled in some

FIGURE 7: *Amphioctopus marginatus* on display at the California Academy of Sciences, peering out of a hand-blown clear glass den. This approach to display fosters a successful and engaging cephalopod-guest interaction. Photo by Richard Ross.

type of decor right in the center of the exhibit. Individuals will use all available materials to partially enclose themselves into their den. These octopuses are very active and regularly venture around their exhibit when they have been fed. We have witnessed display specimens swimming across the entire length of the exhibit to chase down prey. Sometimes an octopus would elongate its body and have just the tips of the arms in contact with its den in a type of "lookout" position (Fig. 8). It is also common to see them sitting in their dens with their arms folded in tightly to the mantle so their suckers and mouth area exposed (Fig. 7).

These octopuses are also very curious and tactile; when they spot an aquarist taking the lid off of their enclosure they will usually swim up, reach out their arms and try to make contact with that person, perhaps rushing to get food. Unlike many octopus species that shy away from people and remain hidden, *Amphioctopus* are often out in the open, staying aware of their surroundings and looking for a new interaction. This tendency to remain active makes *Amphioctopus* a very engaging animal to care for and for guests to see on display.

On display *Amphioctopus* were taught to open clear glass screw top jars to access prey inside the jars. The behavior was trained by starting with a prey item in an open jar. When we first began to add the lid, it was left very loose. As the training progressed, the lid was tightened more and more on subsequent feedings. Within two weeks, animals learned to open jar lids that were fully closed and hand tight. *Amphioctopus* were also offered prey items inside of plastic wiffle balls as an enrichment activity, as it takes time for the octopus to figure out there is food in the ball and how to remove it.

On exhibit, we have not seen the 'stilting' or 'rolling' behaviors with coconut shells that have been observed in the wild, nor have we observed the bipedal locomotion that has also been documented for *Amphioctopus* (Finn et al. 2009). We have observed *Amphioctopus* defending food from its tank mate, the chocolate chip starfish, *Protoreaster nodosus*. After a coconut octopus had been fed a Manila clam, the starfish was attracted to the open clam and attempted to take it. The coconut octopus responded by using one of its arms to push the starfish away while using the remaining seven arms to stabilize itself on the bottom, secure itself in its den (small glass bottle) and hold on to the open clam shell. Ultimately the starfish was repelled and the octopus was able to feed in peace.

FIGURE 8: *Amphioctopus marginatus* on display in the "lookout" pose. Note the use of a clay flowerpot as a den, and a coral skeleton as an operable "door" to the den. Photo by Richard Ross.

Observations of mating behavior and captive breeding were limited, as we were almost exclusively displaying single specimens in our exhibits. On one instance, we did attempt to put two animals together for mating. The larger specimen quickly engulfed the smaller in its arm webbing. These two individuals were allowed to stay in this position until we observed inking, at which point they were separated. On display and in holding, three *Amphioctopus marginatus* each laid a single clutch of eggs; two of these three were fertile. Unfortunately, hatchings were not observed, so we did not have an opportunity to attempt to raise the paralarvae.

Amphioctopus marginatus is an ideal candidate for public aquarium display. It is an engaging species with minimal space needs, and most facilities will be able to meet the minimum requirements for successfully caring for the animal for the duration of its natural lifespan. It is popular with guests due to its interesting behaviors and it has a tendency to be active during daylight hours. The major challenges with this species surround acquisition. It will likely remain difficult to acquire specimens through regular commercial collectors and exporters. We have developed collecting techniques that minimize stress and eliminate mortality. Future research is needed to develop captive-breeding and larval-rearing protocols, and to examine whether populations within the Philippines are robust enough to support repeated collections of aquariums specimens in a sustainable manner.

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