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Enrichment for Giant Pacific Octopuses: Happy as a Clam?

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What is environmental enrichment? During the last several decades, zoos and aquariums have come to realize (perhaps belatedly) that animals kept in captivity need environmental enrichment for their well-being (Seidensticher & Forthman, 1998). Early zoos and aquariums tried to show as many animals as possible; hence, their exhibits were frequently small and bare to permit easy viewing, cleaning, and sterilization. Now, all have come to realize that captive animals need environmental enrichment for their health and for the education and increased expectations of visitors to zoos and aquariums.

What is environmental enrichment? Shepherdson (1998) defined it as "an animal husbandry principle that seeks to enhance the quality of captive animal care by identifying and providing the environmental stimuli necessary for optimal psychological and physiological well-being" (p. 1). Mench (1998) pointed out the importance of exploratory behavior: "Housing systems should incorporate enrichment that allows animals to engage in their species-typical patterns of information gathering" (p. 41). Another form of enrichment, behavioral enrichment (or "behavioral engineering"), has been described in terms of modifying and enriching adaptive behaviors (Carlsted, 1998; Lindberg, 1998; Markowitz & Aday, 1998). For example, the use of interactive devices decreases abnormal behaviors in primates.

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WHY IS ENRICHMENT NEEDED?

Based on their behavior in captivity, captive animals need enrichment for three closely related reasons: (a) to maintain healthy activity levels, (b) to alleviate space confinement, and (c) to change a deviant behavior back to normal behavior. In other words, captive animals should be physically and mentally healthy. In the wild, animals spend significant amounts of time and energy acquiring resources such as food and mates while avoiding predators. In a captive environment, food and mates (if available) often are obtainable without much effort, and predation pressure usually is nonexistent. This can leave captive animals without the activities that normally take up their time.

We know that both intelligent and social animals get bored (Wemelsfelder, 1993). Boredom can be reflected in abnormal sleep or rest patterns. Captive animals, however, more usually exhibit boredom by destructive behavior, which can be directed against their surroundings, the contents of their enclosure, themselves, their cagemates, or their keepers.

Close confinement in barren surroundings classically has led to deviant behaviors (Hediger, 1955). Some common symptoms in an animal of close confinement are repetitive pacing, constant attempts to break confinement, resting or sleeping abnormally, or engaging in destructive or self-destructive behavior. The simple solution of enlarging an animal's enclosure often brings behavior back to normal.

Meeting the expectations of the public is a fourth reason for enrichment. The design of zoo and aquarium enclosures must be considered from the public's perspective. Although a sloth may be perfectly happy hanging from a projecting pipe all day, zoo visitors are more comfortable seeing the sloth hang from the branches of an artificial or natural tree. More and more zoos and aquariums are emphasizing enclosures that resemble natural habitats for the comfort and expectations of their customers as well as for the comfort of the animals (Baker, 1999).

Finally, preparing animals for reintroduction to the wild is a fifth reason for enrichment. Popular examples include Elsa the lion, Keiko the killer whale, whooping cranes, and California condors. In hope of re-establishing the population, many reintroductions are of endangered animals. Reintroduced animals need to cope with natural environmental conditions and hazards (Miller et al., 1998) such as daily or seasonal temperature changes, rain, snow, cold, variations in food supply, and parasites. They need to cope with competition among cohorts. They may need to migrate at certain times of the year and must be able to avoid predators. Hatchery-reared salmon are notorious for being unaware of predators and thus suffer higher than normal predation loss. Some salmon hatcheries have placed a predator in with the salmon to make them better at predator avoidance when they are released into the sea (Berejikian, 1995).

All wild animals live in complex and dynamic environments, and all have adaptations to those environments (Krebs & Davies, 1993). Because of our anthropocentricity, however, enrichment traditionally has focused on mammals (Shepherdson, 1998) but is beginning to be applied to reptiles, amphibians (Hayes, Jennings, & Mellon, 1998), and birds (King, 1993). The unspoken rule seems to apply enrichment only to animals thought of as social or intelligent. Until we know which animals benefit from enrichment, it also should apply to animals other than mammals and other vertebrates. We at least should consider enrichment for all species of captive animals, just as the ethics of animal experiments using invertebrates are now being considered (Mather, in pressTHIS ISSUE). Invertebrates (e.g., octopuses), who make up 95% of the animal kingdom, traditionally have been underrepresented in zoos, aquariums, and scientific research. With two exceptions, both on octopuses, almost nothing is written on enrichment for invertebrates (Rehling, 2000; Wood & Wood, 1999). Rehling has started an enrichment notebook on octopuses.

ENRICHMENT FOR GIANT PACIFIC OCTOPUSES

The giant Pacific octopus (*Enteroctopus dofleini*) is the cephalopod most exhibited by zoos and aquariums (Carlson & Delbeek, 1999), probably because, growing to more than 100 lbs., it is the largest octopus species in the world (High, 1976). The genus of the giant Pacific octopus (GPO) recently has been changed from *Octopus* to *Enteroctopus* (Hochberg, 1998). Octopuses in general are popular with the public because of their intelligence, their alien appearance, ability to change color and texture (Anderson, 1997), and the impression that “they watch you” (Wells, 1978, p. 8). Octopuses have been known for their large brains and intelligence since at least 330 BCE, when Aristotle wrote his *Historia Animalium*.

In recent years, much more has been learned about their intelligence. They can open jars to get food, distinguish between targets of different shapes, textures, and shades (Hanlon & Messenger, 1996), navigate simple mazes, navigate in the wild using landmarks, and use tools. They have temperaments akin to personalities and exhibit possible play behavior (Mather & Anderson, 2000). All these accomplishments are indicators of intelligence. Cephalopods collect large amounts of information about their environment with their well-developed sense organs (Hanlon & Messenger, 1996). Their brain-to-body weight ratio is higher than that of most fish and reptiles (Packard, 1972) and is the largest of the invertebrates. Hence, captive octopuses are prime animals for enrichment.

HOW CAN WE KNOW IF GPOS NEED ENRICHMENT?

Simply put, we cannot. Let us consider the five needs we have given for enrichment and apply them to GPOs. How can we tell if an octopus is bored? We cannot. An octopus is a refuging predator (Curio, 1976). In the wild, unless inspired by hunger, sex, irritation, or predators, most octopuses probably are just going to sit in their dens. Field observations have indicated that *O. cyanea* in Hawaii spend 72% of their time during daylight hours in their dens (Forsythe & Hanlon, 1997). *O. vulgaris* in Bermuda spend 88% of their daylight hours in dens (Mather & O'Dor, 1991). Mather and O'Dor suggested that wild octopuses minimize risk of predation by minimizing foraging time.

Predators have a large influence on the population structure of octopuses. In areas without teleost predators, wild *O. briareus* were 100 times more abundant (Aronson, 1991). Evolution and current behavior of octopuses are thought to be largely a response to predation pressure from vertebrates (Aronson, 1991; Packard, 1972). Captive environments typically lack predation pressure; therefore, one might expect captive octopuses to be at least as active as wild ones. However, at the Seattle Aquarium, we have seen many examples of well-fed octopuses in captivity who sit all day and night with little activity other than breathing. With a diet of easy-to-capture and easy-to-eat frozen food and no enrichment, captive octopuses appear to have little reason for activity.

How about destructive behavior exhibited by GPOs or attempts to escape from their tanks? We have examples of both. At the Seattle Aquarium, a particularly destructive female octopus was named Lucretia MacEvil (after the song by Blood, Sweat, and Tears) for her destructive behaviors. One morning, Roland C. Anderson arrived to find that the octopus had excavated the bottom undergravel filter by removing the gravel and rocks on top. The filter had been broken, the cable ties holding a fine-mesh screen on top were cut (presumably with the octopus's beak), and the screen was torn or cut into pieces and left floating on the surface. Was this destructive or abnormal behavior, or was it curiosity? Was it exploratory play behavior (Hutt, 1966), or was it an attempt by a female to find a place to lay her eggs? This may have been destructive behavior indicating that enrichment was needed. As yet, we have no way of knowing.

THE GPO AS ESCAPE ARTIST

Escape attempts are another matter. Octopuses are well known as the grand masters of escape in the animal world (Lane, 1957), and GPOs are no exception (Anderson, 1997). Do octopuses try to escape from their tanks because of boredom and lack of enrichment, poor water quality, or lack of food quantity or quality—or are escapes normal foraging behavior? There are indications that some octopus species are more prone to escape from captivity than others; the California two-spot octopus (*O. bimaculoides*), for example, rarely tries to escape (Wood, 1994).

GPOs are well-known escape artists, and they are strong. One 40-lb. GPO kept at the Seattle Aquarium slid a plywood cover off a tank with 66 lbs. of rocks on top and thus escaped. Others escaped from one tank to crawl to adjacent tanks to get food, then returned to their home tank (Lane, 1957). This sort of escape seems to be a foraging expedition. The activity pattern of wild octopuses is to stay in a single lair for days or weeks. They leave it to forage and return to eat (Mather & O'Dor, 1991). Hence, attempts to escape from tanks simply may be the octopuses' efforts to go get something to eat.

Octopuses also attempt to escape from tanks that have poor water quality such as not enough water flow, not enough oxygen, improper salinity, improper chemical balance, or presence of metals. In addition, GPOs try to escape from tanks where other conditions are not "right." Hence, if conditions were made right through enhancement, there would be fewer escape attempts. These escape attempts are GPOs literally jumping out of the frying pan into the fire, as they may be discovered dead on the floor the next morning. At the Seattle Aquarium, there have been fewer escape attempts from tanks with front viewing windows than from those without, indicating that these octopuses like a "room with a view." Perhaps the movement of aquarium visitors is an effective enrichment.

We cannot say whether enrichment can help captive-reared GPOs survive better if released into the wild, because we do not know how many of their behaviors are learned and how many are innate. There is some evidence of innateness in GPOs (Anderson, 2000), but octopuses as a whole are difficult to rear and difficult to follow in the wild. There have been very few cases of captive-reared octopuses being released and observed. Because octopuses can learn, however, the more experiences they encounter while growing, the more likely they are to succeed in later life. Hence, an octopus reared for possible release should lead an enriched life.

ENRICHMENT FOR GPOS

Good reviews of enrichment ideas for smaller octopuses can be found in Wood and Wood (1999) and Rehling (2000). In summary, they suggested octopuses can be enriched by use of suitable space; inclusion of a complex environment, including "toys," "complex" food or feeding strategies, and proper den or lair space. Because of GPOs' large size and strength, their enrichments may be different from those used for small octopus species.

Food and feeding strategies can be an important source of enrichment for GPOs. An easy and effective enrichment is simply varying the food given. This also is good nutritional practice. At the Seattle Aquarium, GPOs have been reared on a varied diet to 97 lbs. GPOs in captivity can live, grow, and reproduce when fed a diet of thawed frozen–uncooked seafood such as herring, smelt, capelin, fish fillets, clam meat, or squid.

A simple form of enrichment is to feed a GPO live food, such as crabs, fish, lobsters, clams, or even freshwater crayfish. A recent feeding of a large, live Dungeness crab to a GPO at the Seattle Aquarium provides a good example. Once the crab was added to the tank, the octopus had to stalk the crab, pounce on it, and subdue it in its arms and web. Then, the octopus drilled a hole in the crab's shell, using a radula (rasping tongue) in combination with a salivary papilla that exudes a dissolving agent. When the tiny hole was drilled, the octopus injected a venomous saliva that first paralyzed the crab and then killed it within minutes. The injected saliva also began the digestive process by loosening the muscle attachments. There is preliminary evidence that the octopus's saliva affects the crab flesh, making it easier to extract from their thin legs (Boyle, 1990). All of the crab flesh was eaten. The carapace was removed from the body, and all the legs were dismembered and broken at the joints, presumably with the octopus's hard, horny beak, or pulled apart after loosening the ligaments holding them together by the injected saliva. Cleaned shell parts were then dropped or blown out of the den to form a midden. This process took more than 2 hr.

Live clams also are drilled before opening and eating, which can engage an octopus in species-appropriate behavior for hours. By comparison, one of the puzzle boxes presented by Rehling (2000) was solved in 16 sec the first time it was introduced, and several commercially produced puzzle boxes were solved in 6 sec. Feeding live food is simple and can keep the octopus busy with natural behaviors for a long time.

Public aquariums have been creative in supplying live food for their captive GPOs. Such food stuff has included Maine lobsters and Chesapeake Bay blue crabs (Bronikowski, 1984). These are not prey items that a GPO normally would encounter or know how to catch and eat. Therefore, they must learn how to catch and eat the item in addition to doing the actual feeding. Freshwater crayfish have proven to be a valuable and practical live food for GPOs and other species of octopus large enough to eat them (DeRusha, Forsythe, & Dimarco, 1989).

Other live foods can be fish or shrimp. Octopuses use a speculative pounce technique called a "webover" (Mather, 1998) to catch small, hidden prey by spreading the web between their arms and "throwing" it up, forward, and down over rocks that may house potential prey items (Forsythe & Hanlon, 1997; Hanlon & Messenger, 1996). In other words, they use their bodies like a living cast net. Octopuses then squeeze the water from this "balloon" and feel inside with their arm tips to catch small swimming prey. This method of capture is used extensively by *O. cyanea* (Forsythe & Hanlon, 1997), *O. briareus* (Hanlon & Messenger, 1996), *O. vulgaris* (Mather, 1991), and GPOs (Johnson, 1942).

THE GPO AS EXPLORER

Octopuses often explore their environment and even may indulge in exploratory play behavior (Mather & Anderson, 1999). Fagen (1982) stated that although a complex environment and presence of conspecifics are important, the opportunity for certain kinds of direct interaction (play, exploration, and manipulation) are most important. Hence, two additional food enrichments are hiding the food so the octopus has to search for it or putting food in a puzzle box. One idea is to release a number of smaller live prey that will hide themselves all over the tank and let the octopus find them (Wood & Wood, 1999). Even giving a larger crab time to bury or hide increases its lifespan and hence, the predation time. Wood and Wood also hid food in a play ship—the octopus had to “sink” the ship to get the proffered food. Such a demonstration with a large octopus and an appropriately larger toy ship probably would interest the paying customers of a public aquarium by invoking a “sea monster” image.

A simpler version of hiding the food is to put it in a container the octopus has to open. Various species of octopuses have been trained to open puzzle boxes to get at a crab or other food (Rehling, 2000; Wood & Wood, 1999). Although octopuses frequently can get at the food very quickly, interaction with the puzzle boxes can last much longer as some octopuses hold onto the puzzle box or parts of it for hours (Rehling, 2000; Wood & Wood, 1999). At the Seattle Aquarium, we put a small, dead herring inside a plastic cigar container and timed how long it took a female GPO to open it and get the food. Although the octopus never showed signs of habituation to the container because she never let go, she also did not show outward signs of learning to open it, as the mean time to opening hovered around 1 hr. The point here is not whether the octopus really learned to open the container but that she remained active during the process.

One way to maintain the octopuses’ interest is to smear the outside of a container with food, such as herring fluids. Octopuses taste with their suckers; thus, the octopus associates the container with food or realizes that somewhere there is food. At the Seattle Aquarium, we also have used this propensity of tasting with their suckers to facilitate getting large (and strong) octopuses out of their tanks with a minimal amount of stress. We smear herring fluids on the lip and outer surface of the tank, and the octopuses pursue the “phantom” herring and crawl out by themselves (Anderson, 1998). Obviously, this method would work to train the octopus to do other tasks.

TRAINING THE GPO

There are a number of ways to train a GPO, depending on the task to be learned. Food is a good positive reinforcement for having performed the desired task, but the environmental preferences and habits of the octopus also can be used in training or learning. We have seen how food can be a stimulus for learning to open containers.

To be effective, we must take into account both octopus behaviors in the wild and normal behaviors seen in captivity. At the Seattle Aquarium, we recently built a new GPO exhibit with a 3,000-gallon triangular tank that had one side against a wall. We wanted the octopus to rest or sit in the front corner, the corner most visible to the public. Knowing that GPOs like dark dens (Cosgrove, 1993), we purposely increased the lighting in the back corners and decreased it in the front corner. Knowing from previous experience that GPOs prefer to sit in front of water currents, we directed both the new water and recirculated water inlets toward the front corner. All four GPOs who have lived in that tank (separately, of course) to date have chosen to sit in the front corner. When octopuses have chosen to sit in a back corner, we increased the light intensity there and—making it uncomfortable—prodded them out with a bristly brush, and they moved to the front corner.

Individual octopuses have different temperaments that may be akin to our own personalities (Mather & Anderson, 1993; Sinn, 2000), and octopuses with some of these temperaments make poor display animals. Such differences frequently have led to their being creatively named, like Leisure Suit Larry, whose “pawing” of volunteers would have led to a sexual harassment suit had he been human. One reclusive female at the Seattle Aquarium was Emily Dickinson, named after the notoriously shy poet. This octopus persisted in squeezing behind a fiberglass backdrop at the rear of a rectangular 300-gallon tank. Although it was interesting for staff and volunteers to view an almost two-dimensional, 30-lb. octopus (only 2 in. thick), she was not visible to the public. The octopus had to be persuaded to come out, as the backdrop was not easily removed. Use of a bristly brush did not do the trick, and the placing of a sunflower star, known to be repulsive to octopuses, did not work, either (Hendrickson, 1984). Finally, we used stronger negative reinforcement—a mild electric shock administered by a long wire connected to an AA battery. The octopus learned not to go behind the backdrop, and the space eventually was sealed. This octopus also was ultimately released, being deemed not suitable for public display.

Was this animal suffering from lack of enrichment? Was she bored or engaging in abnormal behavior? Was she just shy? Was she looking for a secluded spot to lay her eggs? We think it is very likely the latter explanation, which leads to another aspect of habitat enrichment: Do we need to provide a proper den for females to lay eggs? The answer probably is yes—with qualifications. One of the goals of environmental enrichment is to bring behaviors of captive animals back to those seen in the wild. The problem is that brooding females hide in dens not much larger than themselves (Cosgrove, 1993). Females protect themselves and their eggs even further by piling up rocks to block the entrance to the den. This situation would seem to make impossible the displaying of such animals in public aquariums, but this is not the case if displays are creatively designed with the aforementioned considerations in mind.

PLANNING THE DISPLAY DEN

Because GPOs frequently grow to 60 to 80 lbs. in captivity, the display den should be only a little larger than the volume needed for an octopus that size.

The opening should face down-slope; thus, the den should be elevated a bit and facing down. Octopuses like to look out from their dens and down-slope. If there is a likelihood of a female's being kept, there should be a hard ceiling to the den so she can attach her eggs to it. Adult female octopuses are very reclusive (Cosgrove, 1993). To show the inside of an octopus's den, creative exhibitry can include a dark nook in the public area with either one-way or tinted glass to view the back of the den. Exhibit designers must remember that the den must be dark for the octopus's comfort; to see into the den, that part of the public area also must be dark. Note that octopuses are colorblind (Messenger, 1977) and that use of red light will not be beneficial.

Current policy at the Seattle Aquarium is to release females before they lay eggs so they can reproduce successfully in the wild. The display of a brooding female, however, can be used to educate the public about alternative life-history strategies such as semelparity (dying after reproduction, like Pacific salmon). There is no point in attempting any behavioral or environmental enrichment once the octopuses have arrived at this life stage; all of their behaviors are directed at keeping their eggs alive.

A parallel situation is found in males. Mature male GPOs, even if they have not had a chance to mate, end up at a life stage called "senescence." Isolated captive males frequently will pass out spermatophores, 2- to 3-foot-long transparent structures that superficially resemble round worms, and keepers of older male GPOs may find these lying on the bottom of an octopus tank. Even in the wild, senescent male GPOs do not behave normally. They do not eat, they rarely sit in dens, and they crawl or swim about aimlessly. In Puget Sound, they frequently are found on shore or in river outlets. Until they die, however, they are wonderfully active aquarium display animals.

Another opportunity for designers of GPO tanks is to provide enrichment by adding cohabitants to the tank. Many temperate invertebrates and some fishes can be added. Species of *Urticina* (formerly *Tealia*) sea anemones, sea cucumbers, sea stars (other than sunflower stars), plumose sea anemones, chitons, and sea urchins all can be used. In addition, some fish such as rockfish, sea perch, sculpins, and flounders can be added. These are all animals that a GPO might encounter in the wild. No valuable animals should be added, because GPOs may catch and eat them (Anderson, 1991). At best, there is an uneasy truce between a well-fed octopus and some species of fish.

TESTING THE EFFECT OF ENRICHMENT FOR OCTOPUSES

We feel that enrichment probably will benefit cephalopods such as GPOs, but no scientific evidence supports this. Rehling (2000) found that enriched octopuses were more active. Although this may be a positive effect of enrichment, increased activity also can be a sign of stress in animals (Baer, 1998). A scientific experiment—with a proper control group and a large enough sample size—is needed to demonstrate if enrichment is beneficial to Cephalopods. Such experiments could determine the effect of enrichment on growth rates, survival rates, and stress (as measured by inking, respiratory rates, incidents of jetting into the side of the tank, or levels of stress hormones).

GPOs' large space requirements make them a poor choice for such experiments in most universities, but public aquariums may take on the task. Hatchling GPOs are planktonic (Cosgrove, 1987), and such planktonic octopuses are very difficult to rear (Wood, 1994). Smaller species, however, are easier to rear, and if enrichment proves to benefit these octopuses, the case for enrichment for all octopuses, including GPOs, will be much stronger. Lacking concrete evidence of benefits to the animals, we suggest that enrichment should be considered for all species.

SUMMARY

In other animals, enrichment can be used to increase activity, reduce destructive behaviors, reinforce behaviors seen in the wild, prepare animals for release into the wild, and enlighten the paying public. As yet, we have no evidence that enrichment is beneficial for captive GPOs. We have no indication that captive octopuses need enrichment. This certainly is an area for further research. GPOs are intelligent animals and—on this basis alone—should be candidates for enrichment until we learn more about the behavior of octopuses.

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