

Interspecific Evaluation of Octopus Escape Behavior

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The well-known ability of octopuses to escape enclosures is a behavior that can be fatal and, therefore, is an animal welfare issue. This study obtained survey data from 38 participants—primarily scientists and public aquarists who work with octopuses—on 25 described species of octopus. The study demonstrates that the likeliness to escape is species specific ($p = .001$). The study gives husbandry techniques to keep captive octopuses contained. This first interspecific study of octopus escape behavior allows readers to make informed species-specific husbandry choices.

The only cephalopod to go out on to dry land is the octopus.
—Aristotle

Written records of octopuses leaving the water have existed for over 2,000 years to the time of Aristotle (Balme, 1991). *Octopus alpeus* is known to leave the water to crawl between tide pools (Norman, 2000). In the field, Wodinsky (1971) reported observing *Octopus vulgaris* leave the water and climb on exposed rocks to collect gastropods. The octopus then returned to the water to feed. We have observed wild *Octopus briareus* leave the water in the Caribbean and *Enteroctopus dofleini* and *Octopus rubescens* out of the water in the northeast Pacific. Leaving the water appears to be a normal behavior for some species.

Researchers and aquarists have reported octopuses escaping captivity despite elaborate precautions (Anderson, 1997; Wood, 1994). One of the first papers was

by Lee (1875), who reported that Brighton aquarists were puzzled by disappearing lumpfish, until one morning when the octopus was discovered in the lumpfish tank. More recently, Boyle (1991) wrote, "Octopuses are particularly prone to escape from aquarium tanks. Loose lids are of little value because the octopuses will easily lift them and push their way out of the tank" (p. 32). In contrast, other researchers have successfully kept octopuses without any escape precautions (Sinn, 2000; Wood, 2000), and some workers openly questioned the need for any safety measures against escaping.

Most behavioral work has focused on intraspecific differences (Mather & Anderson, 1993; Sinn, 2000; Sinn, Perrin, Mather, & Anderson, 2001). We investigate interspecific differences in escape behavior to allow workers to make informed husbandry decisions.

Keeping captive octopuses safely contained in their tanks is important for their welfare. Personal experience reveals that most octopuses, unlike the octopus at the Brighton Aquarium, often do not make it back to their aquarium once they escape. Like fish, they cannot breathe out of water (Wells, 1978) and will die in about 10 min (Anderson & Martin, 2002). Other hazards of escape include common floor-cleaning chemicals that can kill them and the danger of predation by animals in nearby aquaria.

In an ideal world, the question "Are there differences in escape behavior between different species of octopuses?" would be investigated with a controlled laboratory experiment. Logistics make such an experiment unlikely. There are substantial difficulties in obtaining large sample sizes for animal research (Gosling & Bonnenburg, 1998). This is especially true for obtaining a large number of a dozen species of octopuses. Octopuses do not ship well, as they can ink in transport; therefore, many ornamental distributors do not ship them. Another challenge is maintaining them in a large number of individual marine aquaria—necessary because many species are cannibalistic (Hanlon & Forsythe, 1985). More important, housing a large number of animals to investigate the likeliness of different species to behave in a way that might lead to their death is unethical.

Despite the logistical challenges and ethical research limitations, the husbandry questions remain. Are some species more prone to escape than others? Are there behavioral differences between species of octopus who live in shallow or intertidal habitats versus those who live deeper? What biological and environmental factors should be further investigated to determine their effect, if any, on octopus escape behavior?

To answer these questions, we followed methods used by Gosling and Bonnenburg (1998) and surveyed scientists, professional aquarists, and advanced home aquarists who were experienced keepers of octopuses. While collecting the results of the survey, we identified factors for future investigation that could be important in understanding the behavior of octopuses in both the wild and the laboratory.

MATERIALS AND METHOD

We circulated a questionnaire on Ceph-List and AquaticInfo, Internet list servers dedicated, respectively, to cephalopods and public aquaria. Colleagues who have worked with octopuses were contacted directly. The survey contained questions about species observed, the likeliness of their escaping, and the experience of the observer. We gathered qualitative data on biological and environmental factors that respondents believed influence the behavior of octopuses in captivity. In addition, we compiled a list of current methods used to keep octopuses in their enclosures.

To test for interspecific differences in likeliness to escape, the eight species that had three replies or more were analyzed using a single factor analysis of variance (ANOVA; Zar, 1999). The information from species with fewer than three replies also is presented.

RESULTS

Survey results from 38 respondents on 24 described species of octopuses were received. Respondents were research scientists (46%), public aquarists (33%), advanced hobbyists (10%), collectors (6%), or documentary filmmakers (5%). Respondents had experience with keeping a mean of 37 octopuses of each species they reported. The results from the survey are shown in Table 1.

There were significant differences in the likeliness to escape between different species of octopuses ($p < .001$). Of the eight species with three replies or more, *Octopus vulgaris* was the most likely to escape with an escape value of 8.5, followed by *Enteroctopus dofleini* with a value of 6.3 (see Figure 1). Although not included in the ANOVA because of low sample size, *Octopus briarrieus*, *Octopus fitchi*, and *Octopus micropyrsus* had escape values over 6.0. On the other end of the scale were the two sister species, *Octopus bimaculatus* with a value of 4 and *Octopus bimaculoides* with a value of 3.0. The octopus least likely to escape is the deadly blue ring octopus, *Hapalochlaena lunulata*, with a value of 1.7.

Respondents reported a number of biological and environmental factors that they believe influence the escape behavior of octopuses. One reply mentioned nutritional state as a factor that might affect the behavior of octopuses. Older octopuses, especially senescent males, were reported to be more likely to escape in captivity as well as to wander around in the open in the wild.

Differences in behavior were reported within species. This is not surprising, as intraspecific differences (temperament) have been described in several species of octopuses (Mather & Anderson, 1993; Sinn et al., 2001).

By far the most common comments received were on securing the physical environment so that the octopus could not escape. A typical response was, "The only

TABLE 1
 Mean Escape Factors Reported From Survey Respondents for Octopuses Kept in Captivity
 and Seen Leaving the Water in the Wild

<i>Species</i>	<i>M</i>	<i>SD</i>	<i>N</i>
<i>Enteroctopus dofleini</i>	6.3	2.2	12
<i>Octopus vulgaris</i>	8.5	1.2	10
<i>Octopus rubescens</i>	5.1	2.4	9
<i>Octopus bimaculoides</i>	3.0	1.3	6
<i>O. "joubini" (large egged)</i>	5.5	3.1	4
<i>Hapalochlaena lunulata</i>	1.7	0.6	3
<i>Octopus bimaculatus</i>	4.0	1.7	3
<i>Octopus digueti</i>	6.0	4.6	3
<i>Eledone moschata</i>	2.5		2
<i>Octopus californicus</i>	1.0		2
<i>Octopus cyanea</i>	5.5		2
<i>Bathypolypus arcticus</i>	3.0		1
<i>Eledone cirrhosa</i>	4.0		1
<i>Grimpoteuthis sp.</i>	1.0		1
<i>Japetella diaphana</i>	1.0		1
<i>Octopus areolatus</i>	3.0		1
<i>Octopus bocki</i>	4.0		1
<i>Octopus briarieus</i>	8.0		1
<i>Octopus fitchi</i>	7.0		1
<i>Octopus hongkongensis</i>	2.0		1
<i>Octopus macropus</i>	2.0		1
<i>Octopus micropyrsus</i>	7.0		1
<i>Octopus tetricus</i>	5.0		1
<i>Octopus wolfi</i>	6.0		1
<i>Opisthoteuthis californiana</i>	1.0		1

Note. Factors are given on a scale ranging from 1 (*low tendency to escape*) to 10 (*high tendency to escape*).



FIGURE 1 A 1.3-kg female *Octopus vulgaris* caught in the act of escaping during an experiment on camouflage (photo by James B. Wood).

way to keep them in is to completely seal the tank” (J. McKinnon, personal communication, April 2001).

Ambient habitat temperature was identified as a factor that affects the activity levels of some octopuses: “In my experience, the cold water species tend to be more sluggish and less likely to escape, while warm water species like *O. vulgaris* are veritable hyperactive Houdinis!” (I. Gleadall, personal communication, April 2001).

Tank size and comments relating to time were also reported. Animals kept in tanks too small for them were observed to be more likely to escape. Several temporal factors were reported to have an effect on octopus escapes. Respondents indicated increased chances of escapes at night and increased activity near feeding time. Octopuses that had been collected recently or moved into a new aquarium were thought to be more likely to escape.

Several workers reported that providing a good lair made of rock, PVC, a glass bottle, or other aquarium-safe objects reduced escape attempts. Public aquarists also have presented octopuses with puzzle boxes (Rehling, 2000) as a form of enrichment to keep octopuses busy and active. The use of this form of enrichment is thought to increase octopuses’ activity levels to something more like what they would be in the wild (Rehling, 2000). On the other hand, one respondent noted that because of increased activity and curiosity levels, active octopuses enriched in this manner were more likely to escape.

DISCUSSION

In the wild, most near-shore octopuses live in lairs or dens (Hanlon & Messenger, 1996). Their life style has been described as a “refuging predator” (Curio, 1976). *O. vulgaris* in Bermuda leave their lairs to forage in home ranges of 120 to 200 m² and always return directly to their lairs when done. After a few weeks, they move on to a new lair (Mather, 1991). Wild octopuses hunt over an area much larger than typical captive environments provide and do not live in just one lair, as is common in captivity. Leaving the confined area and single lair of an aquarium might be normal behavior for many species of octopus.

Species such as *Octopus vulgaris* and *Enteroctopus dofleini* are perceived to be very likely to escape, whereas *Octopus bimaculoides*, *Octopus bimaculatus*, and *Hapalochlaena lunulata* are much less likely to leave the water. As a group, the deep-sea species such as *Bathypolypus arcticus*, *Eledone cirrhosa*, *Grimpoteuthis sp.*, *Japetella diaphana*, and *Opisthoteuthis californiana* were also some of the least likely octopuses to escape in captivity.

However, depth of occurrence in the wild does not fully explain the results. Both *Octopus briareus* and *Octopus bimaculatus* are found in shallow subtidal habitats (Ambrose, 1984; Aronson, 1986). *O. briareus* has been observed to leave the water readily; *Octopus bimaculatus* is much less likely to do so.

Although the blue ring octopus, *Hapalochlaena lunulata*, was one of the octopuses reported least likely to escape, this octopus is one of the most deadly marine animals in the world. A blue ring octopus weighing just 25 g possesses enough venom (tetrodotoxin) to paralyze 10 humans fatally (Caldwell, 2000). In spite of these octopuses' tendency not to escape, we strongly urge that the public not keep them. If professional aquarists display them, these octopuses should be kept in secure enclosures, and a contingency plan in case of a bite should be instituted.

For logistical and ethical reasons, it is unlikely that proper scientific experiments will be conducted to examine the effect of various treatments on the potentially fatal escape behavior of captive octopuses. Respondents have suggested the following factors as potentially influencing the escape behavior of captive octopuses. Until we have empirical data, these should be considered potential factors that experienced colleagues have identified as possibly influencing the behavior of captive octopuses.

A number of biological factors were mentioned by respondents. These were age, sex, individual temperaments, and state of hunger. There also were a number of environmental factors mentioned that might affect escape behavior. These were escape-proofed enclosure, tank size, water temperature, water quality, time of day, and environmental enrichment.

Age

The age of octopuses might affect their escape behavior. Some species are planktonic after hatching and behave very differently from older benthic members of their species (Young & Harman, 1988). In older octopuses, the behavior of reproductive and postreproductive animals depends on their sex.

Sex

Mature female octopuses lay and brood eggs (Boletzky, 1994; Mangold, 1987) and are unlikely to leave their lair because, typically, they do not leave their eggs. Hence, they are extremely unlikely to leave the water and escape.

Males, on the other hand, become senescent after mating (Anderson, Wood, & Byrne, 2003). Respondents reported that older male octopuses often are seen engaged in undirected activity, even during the day, in the wild and in captivity. In captivity, this behavior may continue for some time; in the wild, it probably results in the octopus quickly becoming part of the food chain (Anderson et al., 2003).

Individual Temperaments

Mather and Anderson (1993) and Sinn et al. (2001) investigated the temperaments ("personalities") of individual octopuses and found differences between

individuals of a species. It is clear that octopus behavior has both inter- and intraspecific differences.

State of Hunger

Wells (1962, 1978) found that starved octopuses were less likely to be active and less responsive. Yet Boyle (1983) found that adding an aqueous crab extract activated octopuses. The daily activity patterns of octopuses are determined largely by their foraging habits (Mather, 1991). Some respondents believed that a hungry captive octopus, in an attempt to forage, is more likely to attempt to escape than one who is satiated.

Environmental Factors Affecting Escapes

Escape-proofing the tank. There are records of some species of octopuses who have been kept in tanks without lids. They are *B. arcticus* (Wood, 2000), *O. bimaculatus* (Sinn, 2000), and *O. rubescens* (Dorsey, 1976). We found low escape values for the first two species and a medium one for the second. However, we are aware of at least one example of an escape for each of these three species. We therefore recommend that precautions should be taken for all species of octopus kept in captivity. Keeping any species of octopus in an open tank risks the animal's welfare, although there are large differences between species. When in doubt, secure the tank well (see Appendix).

Tank size. Although Boyle (1991) stated that octopuses can be kept in small tanks as long as there is sufficient water exchange to maintain quality, several workers reported having problems with animals escaping or attempting to escape when kept in tanks that were too small. Just as we would not accept a gorilla kept in a small cage, we should not accept putting another intelligent animal like an octopus into a small enclosure. Aside from the ethical considerations, many respondents felt this increases the risk of escapes.

Water temperature. Octopuses are ectothermic and thus the rate of their metabolism is a result of water temperature. Temperature affects the rate of embryonic development (Boletzky, 1994), the rate of growth (Forsythe, 1993), and the time to maturity (Forsythe, 1993; Wood & O'Dor, 2000). Species living in very cold water, such as deep-sea species, have reduced activity levels and will be much less likely to try to escape. In addition, species stressed by being kept at a temperature inappropriate for them also might be more likely to leave the water—especially if the water is too warm.

Water quality. Deteriorating water quality can be a prime factor in causing octopus escapes, a factor referred to numerous times by the survey respondents. In

the field, fishers use chemicals—copper sulfate (Van Heukelem, 1976), cyanide, and other noxious chemicals, as well as ammonia, salt, and fresh water—to flush octopuses from their lairs in the wild. Therefore, it is not surprising that deteriorating water quality could be a strong incentive for an octopus to leave the tank. Low oxygen, improper pH, elevated ammonia levels, presence of heavy metals, and improper salinity all have been implicated in octopus escapes.

Time of day. Most octopuses are more active at night (Hanlon & Messenger, 1996) and several respondents reported escape attempts to be more frequent then. It is not surprising that most escapes mentioned occurred when the octopuses are normally more active.

At feeding times, octopuses frequently are more active and, at least partially, often get out of the water. Laboratory experiments have demonstrated that octopuses can learn very quickly and have flexible and adaptive behavior (Hanlon & Messenger, 1996).

Environmental enrichment. As mollusks without protective shells, octopuses avoid predators by staying in a protective lair. In the wild, *Octopus vulgaris* was observed spending 82.5% of the time in a lair (Mather & O'Dor, 1991). Wood (1994) and Anderson and Wood (2001) commented on the importance of providing an enriched environment for octopuses that contains potential lairs for use by the inhabitants.

Enrichment has been shown to have many benefits for captive animals (Shepherdson, 1998), but investigations on the benefits of enrichment for octopuses can be considered to be only in a preliminary state (Anderson & Wood, 2001). Octopuses are advanced invertebrates. Although rigorous experiments demonstrating the benefits of enrichment to octopuses have not been performed, we feel strongly that some form of enrichment should be provided. In a study on cuttlefish, Dickel, Boal, and Budelmann (2000) provided the first and—so far—only empirical evidence that enrichment matters for cephalopods.

It is possible that healthy enriched octopuses with increases in activity are more likely to escape. It is left to their keepers to take measures for all aspects of their welfare, including providing a secure environment.

CONCLUSIONS

Survey results from workers who have considerable experience working with octopuses show interspecific differences in octopus escape behavior. Some species like *Octopus vulgaris* and *Enteroctopus dofleini* are more likely to escape than *Octopus bimaculoides*, *Octopus bimaculatus*, and *Hapalochlaena lunulata*.

Although traditionally most comparative behavioral work has been done within a species, cross-species comparisons provide an opportunity to investigate envi-

ronmental, biological, and genetic effects on behavior (Gosling, 2001). Respondents identified a number of factors affecting escape behaviors that warrant further investigation:

1. Biological (age, sex, personality, hunger).
2. Environmental (tank security, tank size, water temperature, water quality, time of day, and enrichment).

We hope this preliminary study on interspecific differences in octopuses will promote additional work in this area.

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APPENDIX

How to Keep a Captive Octopus Contained

Octopuses are nature's ultimate Houdini; they are able to squeeze through holes that are a fraction of their body size. *Octopus rubescens* is often found living in beer bottles. They can easily squeeze through the 17-mm opening (Anderson, Hughes, Mather, & Steele, 1999). Octopuses are strong, have incredibly flexible bodies, some degree of intelligence, and the natural habit of hunting over an area much larger than that provided in captivity. Some species are known to leave the water in nature, and most species can—and will—crawl out of an aquarium.

The physics is simple—to escape, an octopus must be able to hold onto a surface and find a hole or space large enough to squeeze through. Octopuses use strong suckers to grab and hold on. Once attached, an octopus can easily pull many times its body weight vertically. A single sucker with a 6-mm diameter can hold 147.4 g (Parker, 1921).

One method of keeping octopuses in tanks is to make sure that nothing that the octopus can hold onto is within reach at the top of the tank. Any substance should work that is impossible for a suction cup to stick to, that is secured well, and that is aquarium safe. Traditionally, AstroTurf® and open cell foam have been used (Boyle, 1991). They both have air spaces that prevent an octopus from grabbing on with its suckers. It is critical to have enough vertical surface covered so that the octopus cannot reach across the “no suck” barrier and grab onto something on the other side. For this reason, this solution is more popular with public aquariums as they can hide a tall, vertical barrier behind the scenes.

It is important to make sure that the “no suck” barrier actually works. Astro turf has enough air spaces to thwart the large suckers of adult giant Pacific octopuses, but smaller species might be able to use it as a ladder. *O. maorum* use Astro turf as a “red carpet” invitation to escape (J. McKinnon, personal communication, April 2001).

The second method is used more commonly to keep octopuses in their tanks: Seal the aquarium shut by using tight-fitting lids and securing all intake and return hoses (Boyle, 1991). Many researchers have gone so far as to fabricate acrylic lids with locking devices (Anderson, 1987). Lids should be attached securely and should have no openings that an octopus can work an arm through or pry open. Weights and clamps can be used to secure the lid.

Octopuses can escape through almost any pipe, fitting, or filter in the tank. Octopuses are born with the ability to get into and out of things, and even hatchling octopuses can get into places where they do not belong. Wood and Wood (1998) reported a hatchling octopus crawling up inside the 1/8-in. airline tubing that was used to siphon water into the octopus-rearing chamber. Octopuses also have died after pulling the drain plug in their tanks, so these must be secured tightly. Octopuses like secure, dark, narrow places for their lairs—under undergravel filter beds or behind fiberglass backdrops are ideal. Undergravel filters should not be used in the octopus tank (Wood, 1994). In addition, all backdrops, pipes, drain holes, and plumbing to and from the filter should be secured, sealed, or covered with “no suck” material.

Careful planning, attention to octopuses’ preferences, and enrichment can be used to create a lair where the octopus will stay and where it also can be viewed (Anderson & Wood, 2001).