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〈Original Article〉

Growth and mortality of the juvenile common octopus (*Octopus vulgaris*) in pipe- and tire-type shelters placed in flow-through seawater tanks

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The common octopus, which has a high growth rate and high market price, is a prime candidate for commercial marine aquaculture operations. We evaluated the effectiveness of two types of shelters (pipe and tire types) for juvenile common octopus growing out in flow-through seawater tanks. Growth rates were evaluated in two experiments. The first experiment (Experiment 1) ran for 72 days, and the second (Experiment 2; replicated) ran for 46 days. Each trial included 40 octopuses fed a diet of frozen sardine (*Sardinops melanostictus*) and swimming crab (*Portunustri tuberculatus*) at 3–8% of body weight once every 3 days. In the two experiments, the respective specific growth rates were 0.3 and 0.04%/day in pipe-type shelters and 0.00 and 0.88%/day in tire-type shelters, while the respective percentage survivals were 80 and 80% in pipe-type shelters and 70 and 90% in tire-type shelters. Shelter type had little influence on the growth rate ($P < 0.05$).

Keywords: Octopus, Pipe shelter, Tire shelter, Rearing system, Flow-through seawater tank

Introduction

As the global demand for aquatic food increases, aquaculture techniques are developing and expanding worldwide, with many finfish and shellfish currently under aquaculture. Moreover, although they are valuable potential candidates for marine aquaculture operations, benthic cephalopods have received relatively little study. In particular, the rapid growth rate and high market price of the common octopus (*Octopus vulgaris*) makes it a highly valuable animal (Semmens et al., 2004; Vaz-Pires et al., 2004; Estefanell et al., 2012a).

The common octopus occurs worldwide in benthic environments extending from coastlines to depths of 200 m at the outer edges of continental shelves. Globally, octopus capture peaked at 110,000 MT in 1975, with recent octopus yields decreasing from 50,000 MT in 2004 to 42,000 MT in 2010 (FAO, 2012). In a commercial South Korean fishery, the harvest decreased from 15,000 MT in 2009 to 10,000 MT in 2012 (KOSIS, 2013).

The juvenile common octopus can be cultured in floating cages with internal shelters (Rodriguez et al., 2006). Pascual et al. (2006), García García et al. (2009), and Chapela et al. (2006) described grow-out techniques for the common octopus, with the animals growing in shelters suspended from mussel rafts. Estefanell et al. (2012a) showed that mortality was higher when octopuses were reared in groups without individual shelters. Such mortality was associated with cannibalism, and adverse hierarchical and reproductive behaviors (García García et al., 2009; Estefanell et al., 2012a; Estefanell et al., 2012b).

The influence of initial stocking density on growth has

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been studied (Rodriguez et al., 2006). Initial stocking densities of 24.5 and 10.7 kg/m^3 were associated with specific growth rates (SGRs) of 0.5% and 1.5%, and mortalities of 41% and 17%, respectively. In another study, survival rates in tanks were higher at a stocking density of 8.0 kg/m^3 compared to those at 15 kg/m^3 (Domingues et al., 2010). The effects of water temperature were investigated in flow-through seawater tanks in Spain (Delgado et al., 2011), with high mortalities (47–88%) evident in summer (when the water temperature was >28°C) and winter (when the water temperature was <10°C).

Several studies have sought to reduce cannibalism by varying rearing conditions, food levels (Hanlon and Messenger, 1996), size disparities (Hanlon and Messenger, 1996; Chapela et al., 2006), and shelters (Katsanevakis and Verriopoulos, 2003; Chapela et al., 2006). In particular, shelters were thought to decrease cannibalism (Chapela et al., 2006).

Optimized grow-out shelters that reduce cannibalism are clearly required if benthic cephalopod aquaculture is to expand. Seclusion and protection are the major criteria used by an octopus when choosing a shelter. In addition to natural caves and holes beneath rock formations, individuals are often found in anthropogenic debris, including barrels, jugs, cans, tires, and bottles on the ocean floor (High, 1976).

In the present study, two shelter types for octopus grow-out were evaluated. One shelter type used in previous studies (Chapela et al., 2006; Rodriguez et al., 2006; García García et al., 2009; Estefanell et al., 2012a; Estefanell et al., 2012b) was made from inexpensive polyvinyl chloride (PVC) pipe, while the second shelter type consisted of scrap tires, often used in breakwaters and retaining walls of harbors and estuaries. Tires, which have found many applications in marine construction, serve as artificial reefs when seeking to enhance fishery yields (Collins et al., 2002). Notably, in Alaska, scrap tires are used to catch the giant Pacific octopus (*Enteroctopus dofleini*) (Conners et al., 2012). Pots made of scrap tires were found to be better than plastic pots as the tires were easier to handle, cheaper, and more quickly assembled. In many regions, waste tires are readily available at little cost; they are durable and contain large empty spaces (Collins et al., 2002). In addition, many octopus species prefer dark environments (Okamoto et al., 2001; Conners et al., 2012). Therefore, in addition to PVC pipe, we tested tire-type shelters, considering the biological features of the octopus and the economic viability of such shelters.

Thus, we explored whether PVC and tire-type shelters reduced cannibalism in the common octopus bearing in mind shelter quality, durability, and habitat. Two sets of experiments were performed to quantify juvenile grow-out in four, controlled, flow-through seawater tanks.

Materials and Methods

Experimental shelters

We evaluated pipe- and tire-type shelters (Fig. 1a, b). The PVC pipe-type shelter was described by Oh and Kim (2014). The outer frames were made of polypropylene pipe (diameter 3.2 cm) covered with net (Nylon Td 210 × 12, mesh size: 0.5 cm). The nominal dimensions of the pipe-shelter frame were 1 m × 0.5 m × 0.5 m. Internal to the frame, additional PVC pipe sections served as hiding places (12 pieces each 0.31 m in length; total volume 0.25 m^3).

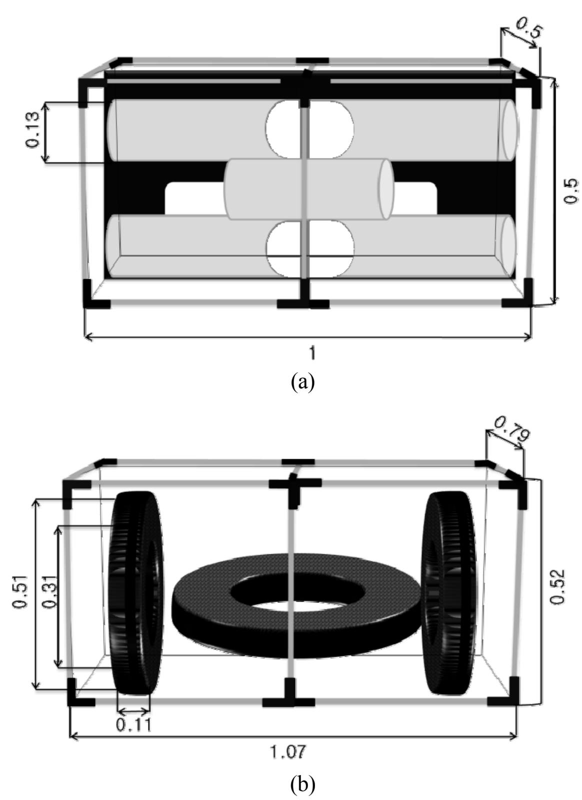


Fig. 1. (a) A pipe-type shelter and (b) a tire-type shelter (unit: m).

The nominal dimensions of the tire-shelter frame were 1.07 m × 0.52 m × 0.79 m (total volume 0.41 m^3), and three scrap tires (0.51 m outer and 0.31 m inner diameter) were placed internally. For comparative growth rate studies, the shelters were placed in separate, flow-through seawater tanks; flow, dissolved oxygen level, and animal growth were all evaluated under controlled conditions.

Source of animals and acclimatization

Study area

All studies were performed in four flow-through seawater tanks located at the Aquaculture Research Center (ARC) of Chonnam National University in Gamak Bay, Korea. Gamak Bay lies in the Jeollanamdo region of the south coast of Korea. The bay is oval in shape and has a surface area of approximately 112 km^2.

We used 40 juvenile common octopuses caught by local fishermen in octopus traps. Each specimen was acclimatized in a separate shelter for 7 days to minimize biological interaction prior to the experiment. At the commencement of experiments, the respective average weights were 452 ± 119 and 430 ± 100 g in the pipe-shelter tanks and replicate tanks, and 546 ± 104 and 285 ± 90 g in the tire-shelter tanks and replicate tanks.

Males and females were reared together (Rodriguez et al., 2006; García García et al., 2009).

Experimental design

Replicate tests were conducted in octagonal, flow-through, concrete seawater tanks (each 47.33 m^3 in volume; Fig. 2); the tanks were sufficiently large to ensure relatively uniform flow patterns and each tank was covered with a sun-protective net. The first test (Experiment 1) ran for 72 days (from 2 April to 13 June 2013) and the second test (Experiment 2, replicated) ran for 46 days (from 29 April 2013 to 13 June 2013). Growth and survival were compared. Ten individuals were placed in each tank. The pipe shelter had smaller hiding places than the tire shelter. Accordingly, the respective initial stocking densities were 11.46 and 17.64 kg/m^3 in the pipe-shelter tests and 8 and 10.85 kg/m^3 in the tire-shelter tests. The octopuses were fed frozen sardine (*Sardinops melanostictus*) and swimming crab (*Portunustri tuberculatus*) at 3–8% body weight once every 3 days (Rodriguez et al., 2006). Uneaten food was removed at the end of each 3-day period.

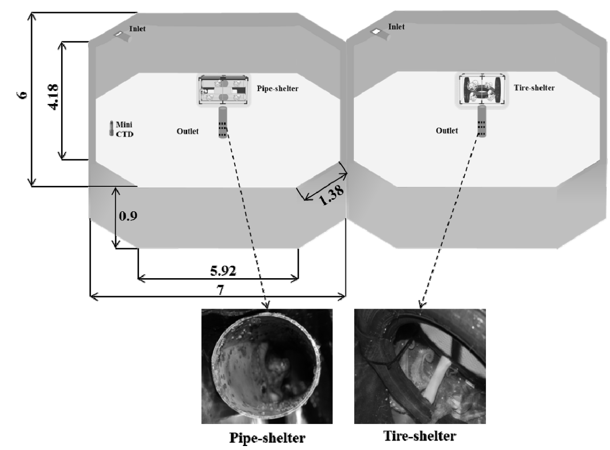


Fig. 2. Experimental setup in flow-through seawater tanks (unit: m).

Rearing conditions

Each structure was placed in a 36-tonne, octagon-shaped flow-through tank receiving sand-filtered seawater that was turned over twice daily. The water inlet lay tangential to the wall, with the water outlet at the center of the floor (Fig. 2). The diameter of the water inlet pipe was 0.06 m, and the tank water outlet was a vertically slotted 0.2 m length of PVC pipe. Water leaving the tank was discharged by gravity into the sea. The water depth in each tank was maintained at approximately 0.82 m. Seawater temperature and salinity were continuously measured using a logger-type CTD-Diver (Eijkelkamp, Giesbeek, The Netherlands), and dissolved oxygen and pH levels were measured once every 3 days using a handheld multi-probe instrument (YSI 556 MPS-20M; YSI Instrumental, Yellow Springs, OH, USA). During the experiments, the inlet seawater temperature ranged from 10.88 to 19.71°C, and the salinity ranged from 32.26 to 34.34 psu (Fig. 3).

The dissolved oxygen level was maintained above 7 mg L^{-1}, and the pH was held between 7.87 and 8.0. Water quality parameters were similar in all test tanks; the water sources were identical. Water velocities were measured using an Aquadopp Acoustic Doppler Velocimeter (Nortek AS, Rud, Norway). The instrument was configured to measure velocities in the X and Y directions at every 1 m of depth on a diametric axis. Measurements were obtained at the mid-water depth of each point at 23 Hz for 2 min (n = 2760). The average water velocity ranged from 0.01 to 0.1 m/s.

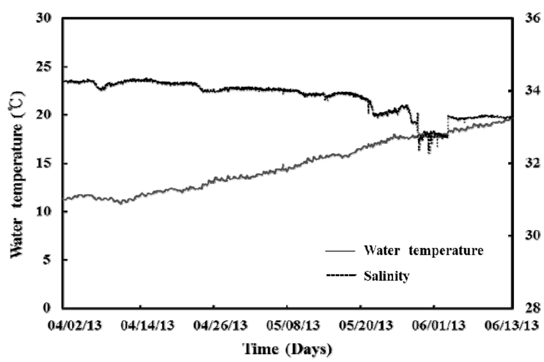


Fig. 3. Water temperature and salinity over time in the experimental tanks.

Data processing

Every 15 days, the wet body weights of all octopuses were measured to the nearest 0.01 kg using an electronic balance. During sampling, fouling organisms and dead octopuses were removed from the shelters. Juvenile SGRs were calculated as

$$SGR(\%) = \left[1n(W_f) - 1n(W_i)\right]\left(\frac{100}{t}\right) \tag{1}$$

where W_f is the final mean weight, W_i is the initial mean weight, and t is the time in days. Survival (S) was determined by censusing numbers from each replicate and was expressed as

$$S = (100)\frac{N_f}{N_i} \tag{2}$$

where N_f is the final and N_i is the initial number of octopuses. The effects of shelter type on growth and survival were analyzed using the Mann-Whitney *U*-test (Ruxton, 2006) of the statistical package SPSS version 21 (SPSS Inc., Chicago, IL, USA). A P value <0.05 was considered significant.

Results

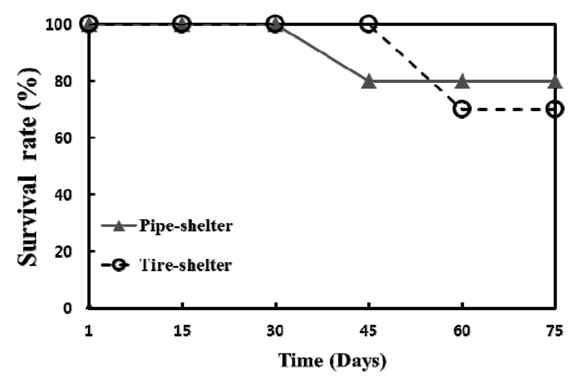
Growth and survival

SGRs and survival levels were calculated using Equations (1) and (2), respectively. The respective initial average body weights were 452 ± 119 and 430 ± 100 g in the pipe-shelter tests, and 546 ± 104 and 285 ± 90 g in the tire-shelter tests. At the end of the experiments, body weights increased to 562 ± 149 and 438 ± 80 g, and 548 ± 75 and 427 ± 90 g, in the pipe- and tire-shelter tests, respectively. The SGRs (%) and weight data are shown in Table 1.

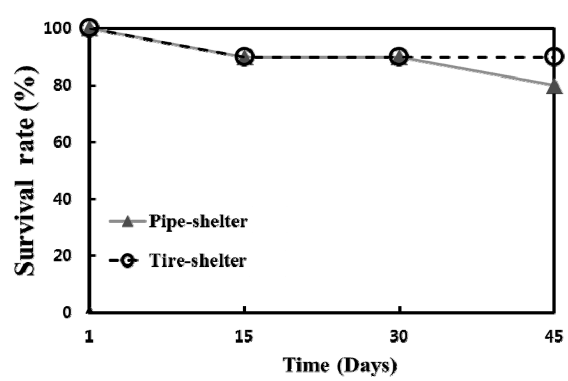
Table 1. Growth rates of the common octopus in pipe and tire shelters of flow-through seawater tanks

Shelter	Initial body weight (g)	Intermediate body weight[3](g)	Final body weight (g)	SGR (%/day)
Pipe[1]	452 ± 119	621 ± 144	562 ± 149	0.30
Tire[1]	546 ± 104	593 ± 163	548 ± 75	0.00
Pipe[2]	430 ± 100	488 ± 90	438 ± 80	0.04
Tire[2]	285 ± 90	432 ± 90	427 ± 90	0.88

[1]: Experiment 1: 72 days (2 April to 13 June 2013).
[2]: Experiment 2: 46 days (29 April to 13 June 2013).
[3]: Intermediate body weight (body weight in mid-May).



(a)



(b)

Fig. 4. Survival rates (%) of the common octopus in the pipe-and tire-shelter tests. (a) Experiment 1 and (b) Experiment 2.

The SGR was 0.3–0.04%/day in the pipe-shelter tests and 0.00–0.88%/day in the tire-shelter tests. The average survival percentages in both pipe-shelter tests were 80%, while they were 70 and 90% in the type-shelter tests (Fig. 4).

Statistical analysis

The outcomes of Mann–Whitney *U*-test analyses of the survival and growth data sets are shown in Table 2 for each shelter type. No significant between-shelter difference in survival was noted ($P > 0.05$). The SGRs of Experiment 1 differed significantly between the two groups ($P < 0.05$).

Table 2. Mann–Whitney *U*-test[a] comparisons of survival rates and SGRs of the common octopus growing in pipe and tire shelters in flow-through seawater tanks ($P < 0.05$)

	Survival[1]	Survival[2]	SGR[1]	SGR[2]
Mann–Whitney *U*	28.00	15.50	3.50	2.50
Wilcoxon *W*	64.00	36.50	24.50	8.50
Z	–0.49	–0.53	–2.36	–0.89
Asymptotic Sig. (two-tailed)	0.63	0.60	0.02	0.38
Exact Sig. [2*(one-tailed)]	0.72[b]	0.70[b]	0.02[b]	0.40[b]

[a]: Grouped data, [b]: Not corrected for ties.
[1]: Experiment 1, [2]: Experiment 2.

Discussion

Juvenile common octopuses exhibited similar biological performance when growing in pipe and tire shelters in flow-through seawater tanks. Compared to other studies, our observed growth rates were low, but the survival rates were relatively high (Table 3).

Compared to the data of other indoor tank experiments, our survival rates were higher than those of Delgado et al. (2011), possibly because our water temperatures were warmer. However, the survival rates of the present study were lower than those of Domingues et al. (2010), probably because our stocking densities were higher. Table 3 shows the results of sea cage experiments described in Estefanell et al. (2012b); survival was only 72% under group conditions, being compromised by weight dispersion, cannibalism, and abnormal reproductive behavior.

In general, the growth rates noted in the present study were lower than those of the other studies summarized in Table 3. Several factors, including initial stocking density (Garcia Garcia et al., 2009), influence octopus growth rate. In the present study, initial culture densities in the pipe-shelter tests were higher (11.46 and 17.64 kg/m^3) than the previously reported optimal density of 10 kg/m^3 (Garcia Garcia et al., 2009). Therefore, the survival rates of the tire-shelter tests (with culture densities of 8 and 10.85 kg/m^3) were slightly higher than those of the pipe-shelter tests. Water temperature significantly affects growth and food intake of the common octopus (Mangold, 1983; Delgado et al., 2011).

Table 3. Survival rates and SGRs of the common octopus in the field and indoors

Culture methd	Shelter type (Culture type)	Period (days)	Survival rate (%)	Initial body weight (g)	Final body weight (g)	SGR (%/day)	Initial density (kg/m^3)	Source
Indoor tank	Den (Grouped)	70	90	1174	2660	1.17	4	Domingues et al. (2010)
Indoor tank	Scrap tire (Grouped)	72	80	445	476	0.00	10.85	This study[1]
Indoor tank	PVC pipe (Grouped)	72	70	441	500	0.30	17.64	This study[1]
Indoor tank	Den (Grouped)	84	22	731	2200	1.31	4.9	Delgado et al. (2011)[2]
Suspended sea cage	Tube (Individual)	60	100	1502	3350	1.3	10	Estefanell et al. (2012a)
Subsurface sea cage	No shelter (Grouped)	60	72	873	2615	1.8	10	Estefanell et al. (2012a)
Suspended from rafts	Den (Grouped)	1–75	98.10	2440	2440	0.93 (Female)	13.1	Chapela et al. (2006)[3]
		>75	98	2440	2210	–0.66 (Female)	13.1	
Suspended sea cage	Den (Grouped)	91	81.3	996	3982	1.54	10.7	Rodríguez et al. (2006)[4]
		86	58.9	1090	1694	0.5	24.5	Rodríguez et al. (2006)[4]

[1]: Experiment 1, [2]: Trial 1, [3]: Trial 2, [4]: Experiment 4.

A temperature of about 16°C was associated with good octopus growth rates in suspended mussel rafts (Chapela et al., 2006). Iglesias et al. (2000) reported SGRs of 0.77–0.95%/day at water temperatures from 13 to 16°C. The optimum water temperature for octopus growth has been described as being 18.5°C (García García et al., 2009). In the present study, juvenile octopuses were only mildly affected by water temperatures of 10.88–19.71°C. Higher rates of early growth (from the initial to the intermediate stage) (pipe shelter: 0.63 and 0.54%/day; tire shelter: 0.54 and 1.8%/day) were observed as the water temperature increased. Holding the water temperature at 16°C appeared to positively influence octopus growth (Chapela et al., 2006). Our average intermediate-stage water temperature was 16.6°C (at about mid-May). When the water temperature was above 18°C (at about the end of May), some weight loss was evident (pipe shelter: −0.50 and −0.53; tire shelter: −0.40 and −0.02%/day) from the intermediate to the final stage of growth. However, the common octopuses we used were smaller and younger than those of other studies (Chapela et al., 2006; Estefanell et al., 2010; Delgado et al., 2011; Estefanell et al., 2012a), and most weight loss occurred after mid-May. Smaller individuals are more sensitive to both water temperature *per se* (Aguado Giménez and García García, 2002) and increases in water temperature (Miliou et al., 2005).

Mating and spawning, which occur throughout the year in many octopus species, may also affect growth. Octopuses of the Gran Canarian waters of Spain exhibit peak reproductive activity in April off the western coast of Africa (Hernández-García et al., 2002). On the southern coast of Korea, the spawning periods occur from May to June, and again in September (Kang et al., 2009). Female octopuses with attached egg masses exhibited low growth rates (Kang et al., 2009). Chapela et al. (2006) reported that the growth rate of female octopuses decreased from 0.93% to 0.66% in summer, probably caused by spawning. In the present study, reproductive behavior was evident after mid-May; the SGRs fell from 0.63 and 0.54%/day in pipe shelters and 0.54 and 1.8%/day in tire shelters to −0.50 and −0.53%/day in pipe shelters and −0.40 and −0.02%/day in tire shelters (Fig. 5). These low values may reflect the fact that energy was expended on reproductive processes.

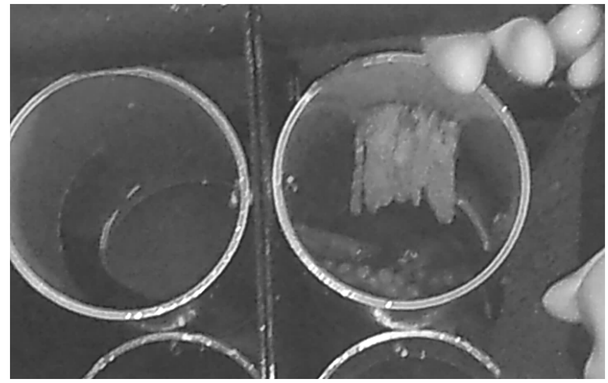


Fig. 5. Reproduction of the common octopus in pipe-type shelters.

Cannibalism is practiced principally by large (>1 kg) octopuses (Salia et al., 1980; Chapela et al., 2006) and was not a significant problem in the present study.

Finally, octopuses are highly mobile, sensory animals and are likely to select shelters carefully (Anderson, 1997). Although the common octopus continues to grow at relatively high densities in captivity, the species is inherently territorial and requires a minimum amount of space for development and growth (Rodriguez et al., 2006). In the natural environment, introduction of artificial dens may allow an octopus population to increase in numbers (Katsanevakis and Verriopoulos, 2003), and shelter is therefore extremely important. Estefanell et al. (2012a) showed that mortality was higher when octopuses were reared as a group, without shelters, rather than individually, with shelters. Octopuses were reared as a group in a floating cage (5 m^3) containing 90 PVC T-shaped pipes as shelters (Estefanell et al., 2012a). Four types of artificial dens were investigated via SCUBA diving surveys: these included wells (vertical holes in the sediment), rocks/stones, empty shells, and structures of human origin (bottles, tires, and pipes) (Katsanevakis and Verriopoulos, 2003). In total, 38.7% of all octopuses were found to be sheltered in structures of human origin.

Thus, the lower growth rates in each shelter type studied here were attributable not only to initial culture densities but also to water temperature, reproductive requirements, and differences in growth habitat, as described above.

Even if waste tires seem suitable for use as octopus shelters, heavy metal levels in cultured octopuses must be monitored. The principal heavy metal leached from tires is zinc (Collins et al., 1994), which was found to be accumulated by hydroids growing on tire surfaces (Collins et al., 2002). Heavy metals are accumulated by caged animals (Collins et al., 2002) and the levels peak in the highest predators of the food chain (Kim et al., 2008). Therefore, the heavy metal levels of octopuses grown in tire-type shelters must be monitored.

In conclusion, we conducted two replicate experiments to evaluate the survival and growth rates of the common octopus in tanks fitted with two types of shelter made of PVC pipe and waste tires. The survival rates were 80% (Experiment 1) and 80% (Experiment 2) in pipe shelters and 70% (Experiment 1) and 90% (Experiment 2) in tire shelters. The SGRs were 0.3 (Experiment 1) and 0.04%/day (Experiment 2) in pipe shelters and 0.00 (Experiment 1) and 0.88%/day (Experiment 2) in tire shelters. No significant between-shelter difference in growth or survival was evident. The observed low growth rates may be attributable to effects of water temperature and reproductive demands. Tire shelters are cost-effective, but tires are often viewed as examples of environmental pollution. *In situ* follow-up work is needed to explore whether pipe and tire shelters can be effectively incorporated into existing octopus aquaculture operations.

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