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Aquarium design for the Portuguese man-of-war *Physalia physalis*

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Maintaining the Portuguese man-of-war *Physalia physalis* in captivity, either for display or study, has not been successful to date. A new aquarium was designed and constructed in an attempt to simulate natural conditions so more could be learned about the husbandry requirements of this species. The prototype aquarium increased longevity, up to four to seven times that of previous attempts, and promoted natural behaviours. Inside the aquarium six acrylic containment cylinders, each containing one Portuguese man-of-war, held the animals away from the sides and the force of water being drawn down through the cylinders retained the centred position of the specimens. Detailed information is given on the design of the aquarium in relation to the natural behaviour of the Portuguese man-of-war.

Key-words: aquarium design, display, exhibit, jellyfish, Portuguese man-of-war

The Portuguese man-of-war *Physalia physalis* (Hydrozoa: Siphonophora) is found in tropical and subtropical areas of the Pacific, Atlantic and Indian oceans. Each 'individual' is in fact a colony of four different polyp types: dactylozooids (tentacles), gastrozooids, gonozooids and a single pneumatophore, specializing in prey capture, digestion, gamete production and floatation/sailing, respectively. The pneumatophore is a single polyp that forms a gas-filled float that extends out of the water and functions as a sail, catching wind currents to propel the colony through the water. While the gonozooids and gastrozooids hang just a few cm below the float, the dactylozooids can extend many meters into the water. This curtain of tentacles is dragged through the water to capture prey, consisting mostly of larval fish (Purcell, 1984).

The Portuguese man-of-war generates much interest, both in the scientific community and in the general public; however, little is known about its biology. Almost all investigative work to date has been carried out on either preserved specimens or those dissected immediately after capture because keeping the species alive in captivity for an appreciable amount of time has not been possible (Lane, 1960). This means that the biology of the species has not been studied comprehensively and public aquariums do not tend to display Portuguese man-of-war for educational purposes. Longevity has been documented as an average 7 days ($n = 33$), < 6 days (average 3 days) or the animals began to show signs of stress by the day 2 in captivity, losing volume after a few hours and deteriorating quickly (Wilson, 1947; Mackie 1960; Kennedy, 1972), although a number of specimens had been kept alive for a week or more (Bigelow, 1891). The Portuguese man-of-war is a difficult animal to maintain but if the technical difficulties could be overcome, thorough investigation would be possible (Mackie, 1960).

In this article a detailed description is given of an aquarium that allows biologists to maintain, study and, for the first time, display to the public live Portuguese man-of-war. Recommendations are also provided for improvements to the prototype aquarium described here. Although not a complete success, longevity in the prototype aquarium was an average 5·5 weeks ($n = 8$), with one individual surviving 7·5 weeks. It is proposed that this method of maintenance provides an environment that facilitates natural behaviour and is a crucial step towards being able to maintain these animals in captivity for long-term display and study.

The Portuguese man-of-war poses a particularly unique problem because the float rests above the surface of the water. If the animal comes into contact with either the sides of an aquarium or another Portuguese man-of-war a meniscus can form, caused by the effects of the surface tension of the water and the protective mucous layer covering the float. If this happens the Portuguese man-of-war will not be able to somersault, a behaviour that it is believed to keep the float moist, and this may result in desiccation (Wilson, 1947; Mackie, 1960). The rolling movement of the Portuguese man-of-war is usually from side-to-side but occasional end-over-end rolling has also been observed (Mackie, 1960; pers. obs) (Plate 1). When this happens the float may reach up higher than when it is in its fully erect state. In the past various techniques, such as wetting the sides of the tank with a spray-bar to prevent sticking (R. Steele, pers. comm.), using air-blowers to create a circular wind pattern, creating circular water currents and producing a sea-spray effect using heavy aeration (Kennedy, 1972), have all been used to keep the animals away from the sides of the aquarium but these techniques were unsuccessful and, in the case of circular water currents, debilitated the specimens. Fishing line has been used to make a barricade but the animals got stuck on it and this prevented somersaulting behaviour (R. Toth, pers. comm.; pers. obs). Portuguese man-of-war have even been kept in a plastic cage anchored in a bay but the wave action battered the animals and damaged their tentacles (Mackie, 1960).

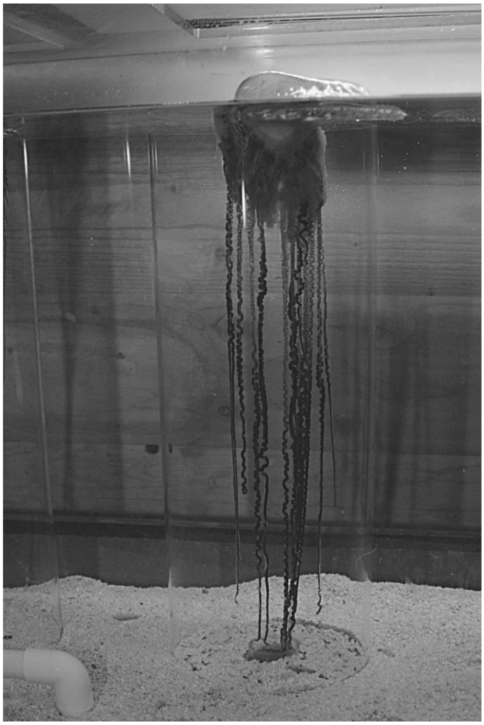

Plate 1. A Portuguese man-of-war *Physalia physalis* **exhibiting rolling behaviour in the prototype aquarium. The float is laying on one side and some tentacles can be seen extending down into the manifold system.** *Justin Pierce.*

AQUARIUM DESIGN

A prototype aquarium for Portuguese man-of-war was designed and constructed at Mote Aquarium, Sarasota, FL. Large 15 cm-diameter acrylic cylinders were glued vertically to the inside bottom of an aquarium measuring 244 cm × 43 cm × 76·5 cm high (Plate 2). The top rim of each cylinder was slightly lower than the water-surface level. Holes were drilled in the base of the aquarium, at the centre point of each cylinder, and 5 cm-diameter bulkhead fittings were plumbed together (using 5 cm-diameter pipes) into a 10 cm-diameter manifold positioned underneath the whole system. The water from the aquarium was drawn through the manifold by a 7600 litre/hour pump (‘manifold pump’) that returned water back into the aquarium (Plate 3). As water was drawn down through the cylinders and into the manifold it was replaced by the water in

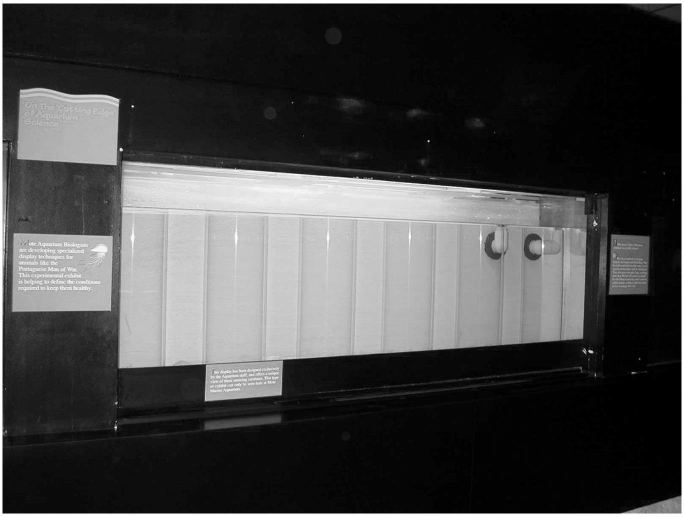

Plate 2. Front view of the aquarium designed to house Portuguese man-of-war. Six acrylic containment cylinders are visible. Two overflow pipes can be seen in the top right-hand side of the aquarium. *Justin Pierce.*

the aquarium flowing over the top rims of the cylinders at the water surface (Fig. 1).

A single Portuguese man-of-war was placed into each acrylic cylinder. The velocity of water flowing into a cylinder was greatest near the edge and least in the centre. If the Portuguese man-of-war started to drift towards the edge, the force created by the higher velocity would push it back towards the centre. The centering effect of the converging water being pulled across the lip of the cylinder held the Por-

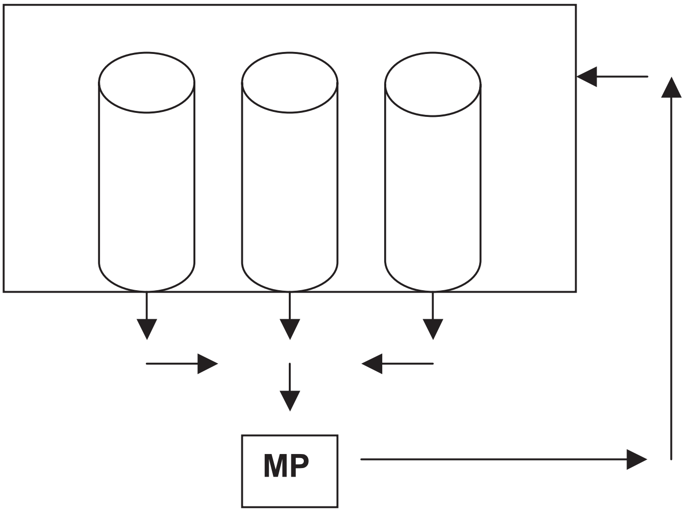

Fig. 1. Schematic diagram showing the direction of water flow in the prototype aquarium designed to house Portuguese man-of-war ***Physalia physalis.*** **The water flows down through all the acrylic cylinders, into the manifold system, through the manifold pump (MP) and returns to the aquarium, flowing back into the acrylic cylinders over the top rims. The diffuser is positioned inside the aquarium but is not shown in this diagram.**

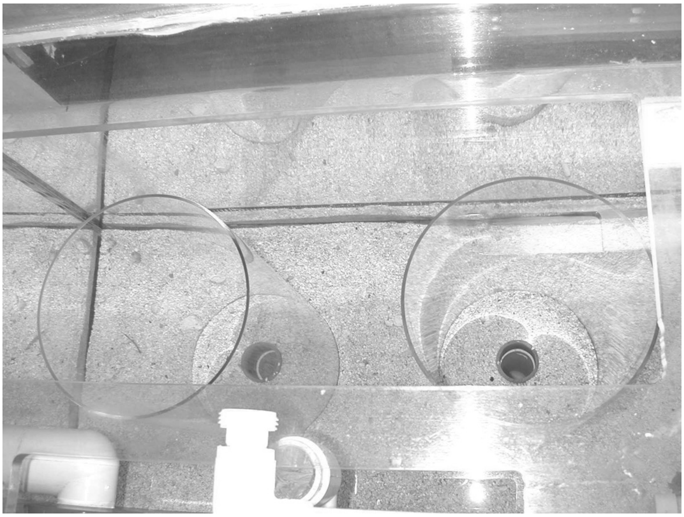

Plate 3. Top view of acrylic containment cylinders in the aquarium designed for Portuguese man-of-war. Water is drawn down through the 5 cm-diameter bulkhead fittings in the centre bottom of each cylinder and into the manifold system underneath. Then water from the aquarium flows into the cylinders over their top rims. *Justin Pierce.*

tuguese man-of-war stable, while still allowing the freedom for natural somersaulting behaviour to occur.

The top ends of the cylinders were polished smooth to prevent tissue damage to the animals should they make contact with the rim. The cylinders were spaced so that the floats of two adjacent Portuguese man-of-war could not touch each another. Space constraints in the prototype only allowed 14 cm between cylinders and 14 cm between the sides of the cylinders and the front and back of the aquarium.

The relationship between the water-surface level and the top rim of the acrylic cylinders was controlled using an adjustable overflow. In the prototype aquarium, 5 cm-diameter PVC elbows, which could be rotated to control the water-surface level, were used as overflow pipes. The actual depth of the water above the top rim of the acrylic cylinder will depend on both the water-flow rate down through the cylinder and its diameter. The overflow needs to be far enough away from the cylinders to prevent water-movement interference around the perimeter or the float of the Portuguese man-of-war. In the prototype aquarium the overflow pipe was at least 10 cm away from the cylinders. The lip of the overflow pipe must *never* be lower than the top lip of the acrylic cylinder because, if the filtration pump fails, the manifold pump would continue to draw water through the cylinders and return it to the main aquarium. The overflow pipe would allow the water to flow down into the sump instead of flowing over the rims into the acrylic cylinders and both water and the Portuguese man-of-war would drain away.

A 5 cm-wide ball valve was fitted onto each 5 cm-diameter pipe coming from the acrylic cylinders to control the flow of water (Plate 4). Water is drawn at an unequal rate from each acrylic cylinder by the manifold pump. Different flow rates were required in each cylinder depending on the size of the Portuguese man-of-war contained within them: larger animals need a higher flow rate than smaller ones to maintain their centred position. There-

Plate 4. The 5 cm-diameter pipe from the bottom of each acrylic containment cylinder joins into the *c.* 10 cm-wide manifold. A ball valve regulates flow of water through each cylinder. A digital thermostat along with the UV sterilizer can also be seen. *Justin Pierce.*

fore, water flow must be regulated independently in each cylinder.

The prototype aquarium was relatively shallow, with a water depth of 63·5 cm and a 13 cm gap between the water surface and the top of the aquarium. A short stem of clear extruded PVC was placed in each bulkhead, so that only the aperture could be seen. The bottom of the aquarium was visible to the public so coarse calcium-carbonate substrate (*c.* 2–5 mm diameter) was poured into and around the acrylic cylinders, covering the bulkhead and spread evenly. Coarse substrate was less likely to be drawn down into manifold and it lessened the visual impact of the acrylic cylinders when spread across the bottom of the aquarium in this way (Plate 5).

The pump running the manifold returned water through a pipe in the bottom of the aquarium, via a diffuser made of 2·5 cm-diameter pipe with holes drilled into it (Plate 5). This is similar to a spray bar except the holes are drilled randomly to prevent the occurrence of water movement compounded by unidirectional flow. This return diffuser was positioned near the bottom of the tank so the effect on water-surface motion was minimal, as even a small influence could counteract the centering force in the acrylic cylinders.

A drain valve was installed from the water-return pipe for the manifold system to maintain an equal water height in the cylinders and the aquarium while the tank was being drained. This prevented the Portuguese man-of-war from spilling over the edge of a full acrylic cylinder while the water level in the rest of the aquarium was lowered during draining. During this process the float came into contact with the inner wall of the acrylic cylinder for *c.* 15 minutes but this did not appear to affect the Portuguese man-of-war.

Various components were added to the prototype aquarium for life support, although the usefulness of some of the equipment (both included and excluded) may be debated (Plate 6). Future studies will reveal which components are most beneficial but for the preliminary trials reported here the following were included: a degassing tower, foam fractionator, ultraviolet (UV) sterilizer, chiller, fluidized

Plate 5. Calcium-carbonate gravel substrate (*c.* 2–5 mm diameter) is spread both inside and outside the acrylic containment cylinder along the bottom of the aquarium, hiding the short stem of clear extruded PVC leading into manifold. The substrate is used for aesthetic reasons to hide the bottom of the aquarium from the viewing public. The diffuser for the return of water from the manifold can be seen behind the cylinder. *Justin Pierce.*

bed sand filter, fibre pad for mechanical filtration and a pump to run the life-support system (the 'filtration pump': separate from the manifold pump) (Fig. 2).

Some of the water returning from the life-support system was diverted to the top of the aquarium where spray bars, or perhaps more accurately 'drip bars', replicated sea spray (Woodcock, 1971) (Plate 7). This system was utilized because of its reliability and effectiveness.

DISCUSSION

The diameter of the acrylic cylinders used should be based on the size of the specimens to be maintained in them. A *c.* 15 cm-diameter PVC cylinder with a small submersible pump was tested and these successfully controlled the position of a Portuguese man-of-war with a 4 cm-long float. However, it is recommended that this is the smallest diameter of cylinder used because the effect of the vortex created by water being drawn through a pipe by a centrifugal pump is more apparent in smaller-diameter pipes. If the vortex is too forceful, the Portuguese man-of-war will spin causing the tentacles to become entwined and the natural function and movement will be impeded.

Bulkhead fittings and pipes should be the largest diameter feasible to avoid this vortex effect. The goal is to achieve the most laminar flow of water and this is best accomplished with large-diameter pipes. If a submersible pump is used and it has a small *c.* 2 cm-diameter inlet connected to the acrylic containment cylinder, the vortex effect is created quickly. The larger the Portuguese man-of-war the stronger the centering force has to be to keep it in position and this requires a greater water flow. Although a more powerful submersible pump could be used, water-flow rate is limited because the small-diameter pipes increase the vortex effect, which is also affected by the proximity of the pump.

If a manifold apparatus is used, as in the prototype aquarium, then large-diameter pipes can be used and the pump inlet can be located further away from the acrylic containment cylinders. These factors allow a much higher water-flow rate before the vortex effect becomes evident

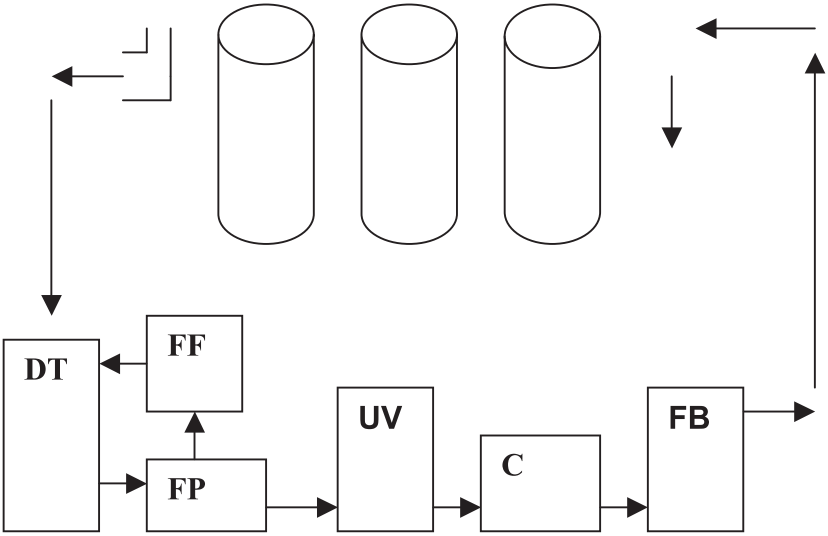

Fig. 2. Schematic diagram showing the filtration system in the prototype aquarium designed to house Portuguese man-of-war. Water flows out through the adjustable overflow pipe (5 cm-diameter PVC elbow) and down through a degassing tower (DT) to remove bubbles, into the filtration pump (FP), though foam fractionator (FF), the ultraviolet sterilizer (UV), the chiller (C) and the fluidized bed sand filter (FB), and then returns to the aquarium and is directed downwards. This diagram does not exactly match the actual placement of the filtration components shown in Plate 6.

in the cylinders, which means that the movement of larger Portuguese man-of-war can be controlled.

A distance of at least 46 cm between cylinders is recommended to accommodate larger specimens. The distance between the acrylic cylinders and the front and back of the aquarium must be taken into consideration to prevent floats coming into contact with the surfaces or other floats. Although only 14 cm was possible in the prototype aquarium, the recommended distance between the cylinders and the back or front of the aquarium is 23 cm.

Supporting braces positioned across the top of the aquarium, such as those over acrylic tanks, are not recommended. If they have to be used, then at least 23 cm should be allowed between the water surface and the brace. This distance should ensure that the float does not come into contact with the brace during somersaulting. Salt creep, formed as water evaporates or splashes onto surfaces leaving salt deposits on aquarium components, may accumulate on the central brace and this is extremely caustic to cnidarian tissue. Because the float of Portuguese man-of-war rests above the water-surface level, it is particularly vulnerable to crystals that may flake off from an overhead structure. Centred braces also restrict movement for researchers working around the aquarium.

A correctly placed adjustable overflow pipe is a critical component because it removes surfactant compounds that form an organic slick at the air–water interface. This slick may have an adverse effect on the functioning of the exposed float. The float contains *c.* 2% carbon monoxide ($n = 50$), *c.* 16% oxygen ($n = 50$) and non-absorbable gases (Wittenberg, 1960). The carbon monoxide is produced *in vivo* in the gas gland and is used to fill the float. Thereafter, gas exchange through the exposed surface of the float replaces the carbon monoxide (Wittenberg, 1960). Sur-

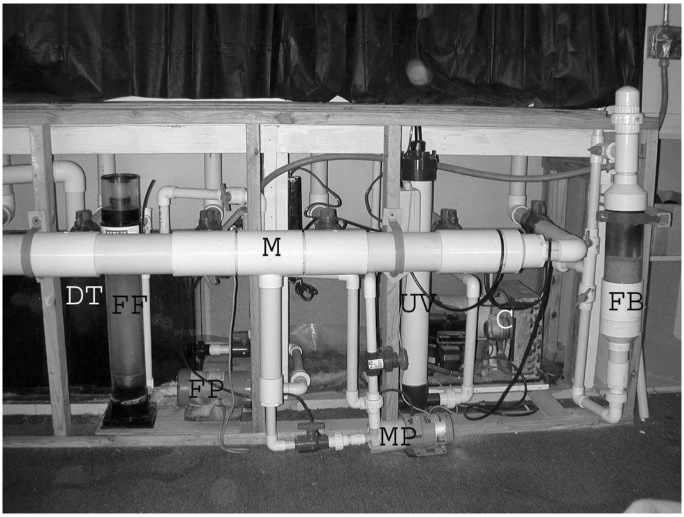

Plate 6. Components of life-support system in the aquarium for Portuguese man-of-war. The 10 cm-wide manifold system runs horizontally in the foreground: M. manifold; MP. manifold pump; DT. degassing tower; FP. filtration pump; FF. filtration fractionator; UV. UV sterilizer; C. chiller; FB. fluidized bed sand filter. *Justin Pierce.*

factant compounds may potentially inhibit this exchange.

Gate valves may be used to give finer adjustment capabilities but ball valves worked well in the prototype aquarium. If a ball or gate valve is partially closed it will be the smallest cross-sectional diameter in the system and, therefore, the greatest restriction to flow, so these valves should be installed at least 30 cm away from the bulkhead to reduce the vortex effect in the cylinder. The tentacles are less likely to become entwined the greater the distance between the valves and the aquarium.

Tentacles of the Portuguese man-of-war sometimes extended down into the manifold system then retracted seconds later (Plate 1). This behaviour is reported in the literature (Bigelow, 1891; Parker, 1932; Wilson, 1947; Mackie, 1960), with extremes (tentacles coiled to 10·3 mm and then darting out to a length of 3·7–5·5 m) recorded in Bennett (1837). Coiling and relaxing of the tentacles can be observed almost continuously in an aquarium. There is a rhythmicity to the contractions that is particularly evident in Portuguese man-of-war recently brought into captivity, suggesting that healthy specimens exhibit this behaviour more dependably (Mackie, 1960).

The notoriously long tentacles of the Portuguese man-of-war will eventually touch the bottom of even the deepest tanks. It has been reported that deeper tanks simply result in longer tentacles (Wilson, 1947). Tentacles tend to autotomize if they come into contact with the substrate. Although this does not appear to have any adverse effects, it may be prudent to trim the tentacles manually, making a more aseptic wound and reducing the possibility of infection. Ideally, if the aquarium is deep enough, the bottom can be obscured from sight, eliminating the need for substrate.

Every effort should be made to reduce the water-movement effect from water returning from filtration. This could be accomplished using another diffuser, in which case the pipe returning the water would feed two 2·5 cm-diameter pipes into the aquarium: one near the water surface and one near the bottom of the aquarium. The top feed should be directed down-

Plate 7. Top view of the Portuguese man-of-war aquarium. Drip bars are used to maintain hydration of the float. *Justin Pierce.*

wards, while the bottom feed should be directed along the back of the aquarium. This configuration also seems to work, although the random-holed diffuser described in the prototype aquarium may be preferable. The size of the filtration pump may dictate the appropriate configuration of water return in an aquarium of the sort described in this paper.

Although not included in the prototype aquarium, it may be beneficial to have a mechanical filter positioned before the intake of the pump running the manifold. The Portuguese man-of-war releases partially digested fish (Parker, 1928; J. Pierce, pers. obs), and gonozooids and dactylozooids (reproductive and stinging polyps, respectively) when maintained in captivity (Bigelow, 1891; Wilson, 1947; Parks, 2000/2001; J. Pierce, pers. obs). These releases make it necessary to pre-filter the manifold water to trap debris that would otherwise end up being pulled through the bottom of the cylinders and into the intake of the pump. Any solid debris macerated by the pump would be returned to the aquarium as slurry. The pre-filter should be a large-micron size (e.g. $\geqslant 100\ \mu m$ so as not to restrict the pump intake.

In the prototype aquarium, water was partially drained to allow new water to enter the system. Future designs should incorporate a system that allows water to be exchanged without having to lower the water level in the aquarium, thus avoiding the float contacting the inner wall of the containment tubes. Although there were no immediately obvious ill effects from this practice, eliminating this event would still be worthwhile. This could be accomplished by using flow meters to match the rate of new water entering the aquarium with that of the water being pumped out. Alternatively, an overflow pipe could be installed in a sump/degassing tower that could drain away displaced water as new water was supplied to the aquarium.

In early literature it was suggested that the Portuguese man-of-war is able to deflate the float rapidly and sink (Haeckel, 1888). If this is true it would be cause for concern with the aquarium system described here because a deflated Portuguese man-of-war may sink down into the manifold and along to the pump intake.

However, this behaviour has not been reported elsewhere. In fact it is even difficult to squeeze a few bubbles out the apical pore and the species has not been observed liberating gas spontaneously (Mackie, 1960). The Portuguese man-of-war was never seen submerged during *c.* 6 months observations (J. Pierce, pers. obs).

Degassing towers are used in aquariums for Scyphomedusa and Hydromedusa because fine bubbles get trapped in these jellyfish and damage them. However, the Portuguese man-of-war is a siphonophore and the configuration of the gastrozooids means it is able to tolerate exposure to bubbles. In the prototype aquarium a degassing tower was used for purely aesthetic reasons to stop bubbles adhering to the inside walls of the aquarium.

The foam fractionator and UV sterilizer were installed in the prototype aquarium because the Portuguese man-of-war is an open-ocean species and it needs optimum water quality. Although in the study reported here a standard Venturi driven model fractionator was used, it can be assumed that a more efficient downdraft style would be ideal. The UV sterilizer was used to destroy and reduce water-borne bacteria and organics.

A 7600 litre/hour pump was used to run the filtration system but this was oversized and much of the effluent was bypassed back into a sump instead of returning to the aquarium. A 5000 litre/hour pump should be adequate.

Although the contribution that sea spray makes to float hydration is not known, the Portuguese man-of-war only rolls onto one side (Bigelow, 1891) and it is unclear how the other side of the float stays wet. It has been suggested that either sea spray keeps the float moist or the wet side of the mucous membrane uses contractions to deliver moisture to the other side of the float (Parks, 2000/2001). The difference in osmotic pressure resulting from the higher evaporation rate on the windward side of the float may be the stimulus that initiates the rolling action (Woodcock, 1971). Experiments involving dripping water of different salinities onto the float elicited different reactions. Seawater, which has a salinity of 36 g/kg, did not elicit any response. However, water with a higher salinity (e.g. 100 g/kg) caused the float to roll. This suggests that open-ocean salinity (36 g/kg) is ideal for moistening the float of the Portuguese man-of-war. In earlier hydration systems there was a much higher rate of water delivery to the float (Kennedy, 1972) than was used in the prototype aquarium described here (a light drip). Although in the past degradation of the float has been attributed to dehydration of study animals, recent observations suggest that the float always appears wet, even when less water is applied (J. Pierce, pers. obs). Further study is required to assess what factors cause the float to degrade.

Although using the prototype aquarium did not sustain the Portuguese man-of-war for $>7{\cdot}5$ weeks, this revolutionary aquarium design offers the potential to extend the longevity of the species in captivity. The system is described in great detail, however, the way in which it functions is straightforward. This aquarium design offers a feasible and effective means of duplicating the natural habitat of these floating siphonophores. It must be made clear that the aquarium design itself is not the only obstacle to being able to maintain these animals successfully in captivity. Rather, this is the first step and solves only one of the many challenges involved. Detailed husbandry aspects of the Portuguese man-of-war have not been described here. Being able to maintain these animals in captivity for extended periods will be extremely useful for research and education, and it is hoped that this prototype aquarium design will be used as a foundation on which to build knowledge and develop optimal husbandry techniques for the species in captivity.

CAVEATS

One important consideration for anyone wishing to work with this species is the degree of danger posed by it. The venom of the Portuguese man-of-war is 75% as toxic as cobra *Naja* spp venom (Lane, 1960), therefore proper protection must be worn at all times. The stings from the nematocysts are powerful enough to penetrate 'tough surgical gloves', although thick rubber gloves are usually adequate for protection (Lane, 1960; J. Pierce, pers. obs). However, the danger is not only from coming into direct contact with the tentacles. Nematocysts have been put through rigorous procedures to isolate and store them but even after these procedures were complete, including air-drying, the nematocysts retained the ability to discharge (Lane, 1960). Surfaces in the laboratory, such as water taps, bench tops and aprons, could all be contaminated with undischarged nematocysts. Painful stings and mild allergic reactions may afflict researchers that are allergic to insect venom and they should avoid contact with any equipment that may have had contact with the Portuguese man-of-war (J. Pierce, pers. obs). Anyone who is allergic to venom of any kind should stay far away from the aquarium or associated equipment to avoid being stung inadvertently (J. Pierce, pers. obs).

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PRODUCT MENTIONED IN THE TEXT

Iwaki 40: pump, manufactured by Iwaki Walchem, Corp., Holliston, MA 01746, USA. www.Iwakiwalchem.com

REFERENCES

Bennett, G. (1837): Some observations on the *Physalia. Proceedings of the Zoological Society of London* **5:** 43.

Bigelow, R. P. (1891): Notes on the physiology of Caravella maxima, Haeckel *(Physalia caravella,* Eschscholtz). *Johns Hopkins University Circular* **X**(88): 90–93.

Haeckel, E. (1888): Report on the siphonophorae collected by H.M.S. Challenger during the years 1873–1896. *Report on the Scientific Results of the Voyage of the H.M.S. Challenger, Zoology* **28:** 1–380.

Kennedy Jr, F. S. (1972): Distribution and abundance of *Physalia* in Florida waters. *Florida Department of Natural Resources Marine Research Laboratory. Professional Papers Series* No. 18: 1–38.

Lane, C. E. (1960): The Portuguese man-of-war. *Scientific American* **202**(3): 158–168.

Mackie, G. O. (1960): Studies on *Physalia physalis* (L.). Part 2. Behaviour and Histology. *Discovery Report* **30:** 371–407.

Parker, G. H. (1928): The shepherd fish and its strange pasture lands. *Natural History* **28:** 53–57.

Parker, G. H. (1932): Neuromuscular activities of the fishing filaments of *Physalia. Journal of Cellular and Comparative Physiology* **1:** 53–63.

Parks, P. (2000/2001): The Blues Brothers. *Ocean Realm* **Winter:** 76–89.

Purcell, J. E. (1984): Predation on fish larvae by *Physalia physalis,* the Portuguese man of war. *Marine Ecology Progress Series* **19:** 189–191.

Wilson, D. P. (1947): The Portuguese man-of-war, *Physalia physalis* L., in British and adjacent seas. *Journal of the Marine Biological Association of the United Kingdom* **27:** 139–172.

Wittenberg, J. B. (1960): The source of carbon monoxide in the float of the Portuguese man-of-war, *Physalia physalis* L. *Journal of Experimental Biology* **37:** 698–705.

Woodcock, A. H. (1971): Note concerning *Physalia* behavior at sea. *Limnology and Oceanography* **16:** 551–552.

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