

# Husbandry of scalloped hammerhead sharks *Sphyrna lewini* (Griffith & Smith, 1834) at Reef HQ Aquarium, Townsville, Australia

## Zur Haltung des Bogenstirn-Hammerhais *Sphyrna lewini* (Griffith & Smith, 1834) im Reef HQ Aquarium, Townsville, Australia

**Short title:** Husbandry of scalloped hammerhead sharks

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### Abstract

Reef HQ Aquarium (Townsville, Australia) has successfully hosted two scalloped hammerhead sharks (*Sphyrna lewini*) in captivity in its 2.5 ML Coral Reef Exhibit since late 2011. Here we document this experience including collection and period of acclimation to captivity, transport, introduction into display, husbandry issues encountered, behavioural observations, health and growth observations, and management considerations.

**Keywords:** Scalloped hammerhead shark; *Sphyrna lewini*; Husbandry; Reef HQ Aquarium.

### Introduction

*Sphyrna lewini* is currently listed as endangered by the IUCN (International Union for Conservation of Nature). Its status specifically in Australia is not well known, though the IUCN red list of threatened species reports a large increase in the illegal, unregulated and unreported fishing trade in northern Australia in the last decade. Scalloped hammerhead sharks are known to feature as a by-product of net fisheries catches, and juveniles are extremely common on the East Coast of Northern Queensland (Australia) at certain times of the year (Lyle Squire pers. com.). According to the IUCN assessment done in 2007 they are suspected targets for their large valuable fins, although no specific data are available (Baum, Clarke, Domingo, Ducrocq, Lamónaca, Gaibor, Graham, Jorgensen, Kotas, Medina, Martinez-Ortiz, Monzini Taccone di Sitizano, Morales, Navarro, Pérez-Jiménez, Ruiz, Smith, Valenti, & Vooren, 2007). Their conservation is thus becoming a critical part of the more general efforts towards shark protection around the world, and educating the general public about threats to the shark population is a key part of Reef HQ Aquarium's activity.

### Scalloped hammerhead sharks in captivity

As the National Reef Education Centre for the Great Barrier Reef (GBR) Marine Park Authority, Reef HQ Aquarium (Townsville, Australia) aims at displaying species of the GBR environment. Here we describe the introduction and display of the scalloped hammerhead shark *Sphyrna lewini*. With between 10 and 15 aquaria displaying scalloped hammerhead sharks in total around the world in 2014 with most common captive conditions summarised in Table 1, it remains a “non-average shark” in captivity (Choromanski, 2004) and a rare species for the general public to observe. There is no record of any other successful public display of scalloped hammerhead shark in Australia to date.

**Table 1.** Most common conditions under which scalloped hammerhead sharks are held in captivity in aquaria (census done by authors in June 2014).

Tank depth	Tank volume in million liters	Number of <i>S. lewini</i> in tank	Duration in captivity	Size of <i>S. lewini</i>
2.5 to 10 m	Most around 3 Smallest 0.6 (for subadults) Largest 12	Most 1 to 3 Max 10	Most around 3 years Maximum 11.5 years	Most at 1.5 to 2 m Largest 2.5 m

### Decision to host scalloped hammerhead sharks at Reef HQ Aquarium

Reef HQ Aquarium had been contemplating hosting hammerhead sharks in its 2.5 million liters (ML) Coral Reef Exhibit (CRE) for many years but had not had access to healthy juvenile sharks. Prior to the introduction of the two hammerhead sharks, no other large fish or elasmobranch species had been hosted in the CRE, which is a tank aimed at displaying live corals and compatible reef fish, with only young turtles been hosted in that tank from time to time in the past. There was some concern that the extra nutrient loading the sharks would bring to the tank could be detrimental to the live corals but the potential benefits of displaying a very interesting and iconic shark species in terms of public experience were considered to outweigh this risk. It was deemed that the sharks would help to engage visitors and draw their attention to shark conservation issues. Besides, the capacity to increase water changes due to the operational setup of the aquarium [see Thomas & Anthony (2008) for details] provided a safety net for potentially increasing nutrient loads.

In 2011 Reef HQ Aquarium thus approached a local aquarium supplier who had developed enough knowledge and know-how to capture and transport two healthy individuals of *S. lewini*. Three hammerhead sharks species are present on the GBR that could potentially be targeted: the scalloped (*S. lewini*), the great (*Sphyrna mokarran*), and the winghead (*Eusphyrus blochii*) hammerhead shark.

When transported and held in captivity, *S. lewini* is reported by aquarium and fish trade professionals to be much more fragile as juveniles than *S. mokarran*, with death in captivity reported as being linked to transport and handling stress; predation by larger tank mates; external or internal injuries from collisions with exhibit features; fungal diseases possibly linked to low temperatures (below 23 °C); suspected meningitis; or irritation of the sensitive shark skin possibly due to high phosphate levels in some aquarium setting. Any stressor can lead to secondary bacterial infections, causing more health deterioration. Nevertheless, *S. lewini* was the species chosen for display at Reef HQ Aquarium because it does not grow as large as *S. mokarran* (ca. 3 m for *S. lewini* (Compagno, 1984) versus ca. 4.5 m for *S. Mokarran* (Stevens & Lyle, 1989)). The great hammerhead shark was also reported to be much more likely to prey on other tank inhabitants, which could have been a problem in a tank which displays several thousands of coral reef fish.

The winghead hammerhead shark is a similar but smaller animal to the scalloped type, reaching only 1.6 m long with anecdotal information from fisherman reporting pregnant females up to 2.4 m in length (*Batch pers. comm.*, 2012). It could have been an alternative choice; however it has never been transported or held successfully in a captive environment. The winghead hammerhead shark is elusive and would appear to be considerably rarer when compared with the relatively common scalloped hammerhead, and it has proven difficult to collect in the GBR area. Its bonnet is also proportionally larger than that of the scalloped hammerhead, which could possibly be problematic in captivity. Initial accidental captures have suggested that this species is far more delicate than any other species of hammerhead shark and less likely to be suited to captive situations in tight confines.

### Sourcing and transport of animals

On 17 November 2011, Reef HQ Aquarium received two scalloped hammerhead shark pups (*S. lewini*) from Cairns Marine, a marine fish wholesaler specialising in sustainably collected animals for public aquaria, based in Cairns (Far North Queensland, Australia). The shark pups had been collected on the GBR and held by the supplier before being transported from Cairns to Reef HQ Aquarium in Townsville.

Appropriate handling and collection techniques were developed by Cairns Marine over a 2 year period before they had the confidence to attempt long distance shipping of this species. Prior to the road transport of the two juveniles to Reef HQ Aquarium, the company had successfully shipped 20 small scalloped hammerhead sharks by air transport from Australia to

Europe using 2.2 m diameter tanks loaded on standard commercial aircraft. Typically most sharks are packed singly, but these were packed three to four animals per container.

It was found very early on during the research and development period that new juveniles (45-55 cm) are too delicate to transport over long distances but are an ideal size to collect by hook and line. The animals are also very fragile immediately after collection at this size, with particular concern about their eyes and contact abrasions with holding containers. However some collection sites within the Great Barrier Reef Marine Park are close to the Cairns Marine facility, allowing transport containers between 1.8 and 2.4 m diameter to be stationed on vehicles adjacent to the collection sites. This reduces the initial transport time and stress to the animals, and provides a significant advantage in the collection process.

Tiny juvenile sharks are never handled bare handed as the skin is very susceptible to damage; it is possible to almost burn the imprint of individual finger marks into the skin of the sharks if surgical gloves are not worn when handling and removing the hooks from the animals. Once placed into the holding containers, it is critical that the correct dissolved oxygen content be administered. Too little dissolved oxygen causes the animals to struggle in the limited confines of the container, whilst too much dissolved oxygen causes a narcotic effect with the sharks becoming disoriented, bumping into the container's walls, and sustaining inevitable eye damage.

Once animals are transported to the Cairns Marine facility, they are housed in a large above ground, oval shaped swimming pool 11.5 m long x 4.5 m wide. Initially the tank had a secondary vinyl liner around the walls at a 45° angle to the floor with the goal of preventing the animals from contacting the walls. The presence of small gaps between this liner and the floor enabled some individuals to become entrapped behind the liner, which was thus removed with no apparent increase in damage to the sharks as they were successfully negotiating the holding tank without contacting walls. Attempts to hold the juvenile sharks in smaller holding tanks immediately after capture (for example 4.5 m diameter round tank) was not as successful and there were higher incidences of contact injuries, particularly to the eyes. Once animals were habituated to captivity after only a month or two in the larger pool, it was possible to transfer them to smaller holding tanks with greater success.

Capture of scalloped hammerhead sharks close to shore on the GBR is more successful in summer than in winter, with two possible reasons for this. The first is that colder water causes the sharks' metabolism to slow down, and a less hungry shark is less likely to take a baited hook. The second is that during this time a prevailing south-east trade wind generates substantial coastal wave action, causing increased turbidity from resuspended sediment. Juvenile scalloped hammerhead sharks do not seem to like these conditions and move away from inshore regions, though it is unknown where they go. Wave action does not seem to deter them as a factor on its own, and in summer it is possible to catch juveniles in breaking waves on the shore although some limited fishing may still occur during substantial calm weather periods throughout winter.

Cairns Marine has established a minimum size of 65 to 75 cm that must be reached prior to successful shipping of scalloped hammerhead sharks. Once in the facility, the sharks are fed to satiation over short periods of time (15-20 minutes) three to four times a day on a variety of food types including squid, tuna, pilchards, prawns and mullet. This enables growth of *ca.* 5 cm per 1-2 month. Typically, a lead time of at least 3-4 months is allowed after collection to grow the sharks to appropriate length prior to shipment. In 2011-2012, Cairns Marine had two specimens grow from 55 cm to 1.3 m in one year, demonstrating that this species can have incredibly fast growth rates when provided with ideal conditions. The growth of the animals will slow through winter and the sharks are susceptible to fungal attack if the water is too cold for a prolonged period. The temperature range that Cairns Marine has observed as optimum is between 24 and 31 °C, however the sharks will continue to feed and survive at 23 °C. Sustained temperatures below this appear to reduce the immune capacity of animals long term and the delicate nature of their skin leads to development of fungal symptoms.

Cairns Marine has successfully treated juvenile scalloped hammerhead sharks with Prasiquantel in baths but more readily treated specimens as a group in the large tank with Trichlorfon based preparations such as Lepidex®. Atropine was on hand in case of adverse reactions. In 2011 at least 50% of the wild-caught pups arrived at the facility carrying a range of parasites. The primary problem was small aggregations of copepods around the tip of the upper lobe of the caudal fin and as larger specimens they would develop clusters of copepods around the base of the dorsal fin in similar positions to those found on bull sharks. The sharks were often treated with IM antibiotic injections of Baytril® if there were any signs of lesions from either holding or capture damage. Sharks were never treated with Lepidex® if they had a break in the surface of their skin.

After about 2 months of care at Cairns Marine facility, the two sharks destined for Reef HQ Aquarium had demonstrated typical growth rates of at least 5 cm per month, were in good physical condition and free of any visual parasites completing initial quarantine processes. The sharks were then transported to Reef HQ Aquarium by road on the back of a flatbed truck for approximately eight hours, allowing for checks along the way and maintenance of the correct dissolved oxygen content. The 2500 l round container with a footprint diameter of 2.2 m and a depth of ca. 70 cm was filled to capacity to prevent detrimental sloshing. The walls of the tank were striped with black paint to provide visual contrast in an attempt to prevent the animals from swimming into the walls. The tank was allowed to have filtered light so that the sharks could visually see the walls at all times. The water contained elevated levels of oxygen, ammonia blocker and did not have any mechanical pumps involved.

### Description of animals

The two scalloped hammerheads, a 58 cm male and a 60 cm female were collected around September 2011 and were estimated to be between 6 and 12 months old from reported pup length at birth (40-50 cm) and Australian pupping season. Stevens and Lyle (1989) report a pupping season from October to January; however umbilical spots have been observed on small animals under 50 cm as late as March (Lyle Squire pers. com.). Age upon collection is difficult to estimate due to a wide range of growth rates reported. Some aquarium professionals with a long experience in the Hawaii wild nursery areas for *S. lewini* have indicated that pups growth in the wild can be limited depending on conditions, with minimal growth for the first year or two. Bush and Holland (2002) also reported that young *S. lewini* in the wild may lose weight and that their food consumption may be below maintenance ration for much of the year, which could strongly bias the age estimated upon capture. In contrast Cairns Marine have experienced growth rates of about 5 cm every 1-2 months in the months following capture of juveniles in the 50-60 cm range, although like most elasmobranchs, they have been observed to go through distinctive growth spurts. Even in captivity animals seem to retain a high metabolism and lose weight and body condition very quickly when fasting. This needs to be accounted for prior to shipping to determine the correct amount of fasting for each shipping location.

### Facility description

The 2.5 ML CRE display seemed an optimal tank to host the hammerheads because: a) it provided a large, uninterrupted swimming area; b) it lacked potential predators, being stocked only with corals and small reef fish; c) it had minimal acrylic panels / tunnels area; and d) water quality was maintained to suit live corals which was expected to also be favourable to sharks.

The CRE is a 36 m long, 17 m wide tank approximately 4.5 m deep with a total water flow of ca. 500 m<sup>3</sup> h<sup>-1</sup>. The tank is uncovered and fully exposed to natural conditions, including rain and sunlight, with occasional shading by shade cloths in summer for some midday hours.

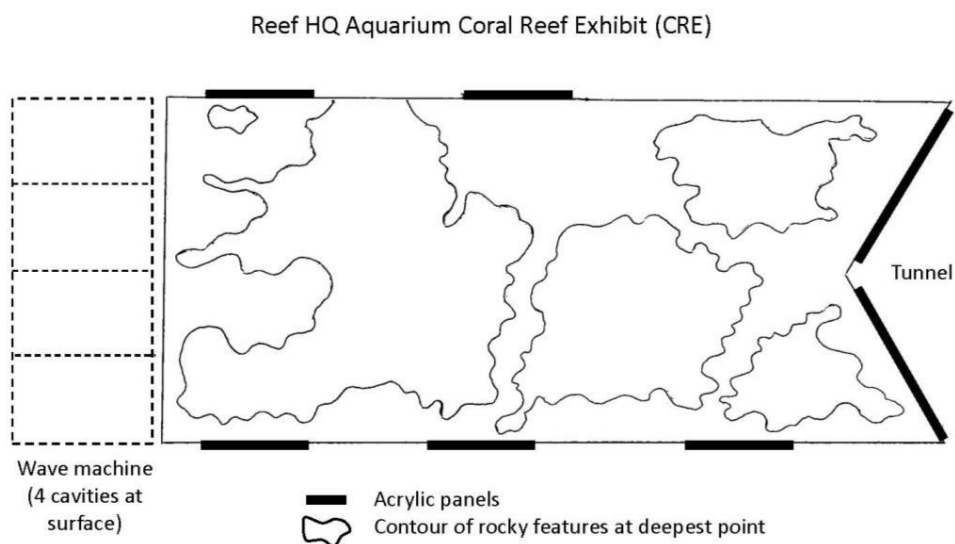


Fig. 1. Shape and rock structure of CRE.

Life support systems, filtration characteristics, water supply and water quality of the CRE as they were in 2008 were described in details by Thomas and Anthony (2008). Two protein skimmers have been added since 2008, with a total in 2014 of four

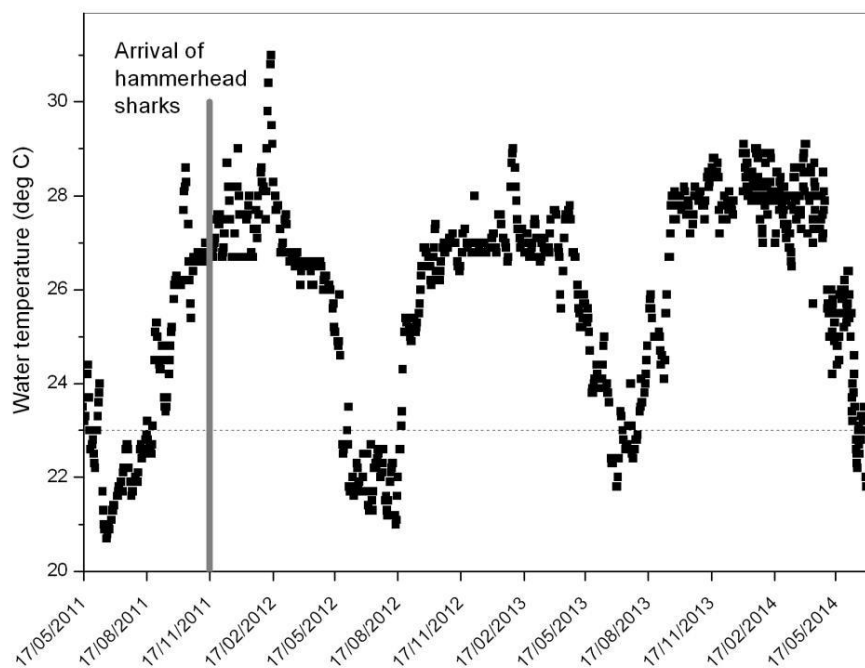
skimmers for a total flow of  $180 \text{ m}^3 \text{ h}^{-1}$  (turn around rate of 14 hours) and a total ozone rate applied dropping from 20 to  $10 \text{ g h}^{-1}$  for approximately the last year. Three sand filters have also been brought back on line since 2008, with a total flow of  $250 \text{ m}^3 \text{ h}^{-1}$  (turn around rate of 10 hours).

The CRE has a V-shaped section of transparent tunnel along its width with two sections approximately 8 m in length each, and five flat double acrylic viewing windows 4 m wide by 3.5 m high, each divided vertically by a concrete mullion in the middle. This represents a total acrylic surface of ca. 25% of the tank walls and an overall surface area of acrylic proportionally small for the exhibit compared with many other public aquaria.

The rock structures and associated corals are totally natural (Figure 1) and are placed such that they allow an uninterrupted swimming pattern of ~100 m around its circumference with the longest straight line for swimming being 36 m. Several passages within the rock structure also allow a variety of longer and diverse uninterrupted swimming courses.

Seawater is sourced from a tidal inlet in front of the aquarium via a semi-open setup. Since arrival of the hammerhead sharks in the tank, water temperature has fluctuated seasonally between  $21^\circ\text{C}$  and  $29^\circ\text{C}$  (except for short term extremes above and below, see Figure 2Error! Reference source not found.) whilst salinity varied around 33-35 PSU, with extremes at 29 and 38 PSU respectively.

Simultaneously to the hammerhead sharks' arrival, low voltage underwater pumps have been deployed to maintain high circulation in replacement to high voltage pumps. Another potential source of electric field inside the CRE is a cable connecting a remotely controlled camera that the public can direct and that is laid over the tank substrate over ca. 5 m and up the tank wall.



**Fig. 1.** Temperature in CRE since arrival of scalloped hammerhead sharks.

### Live population in tank

Around the time when the hammerhead pups arrived, two leopard sharks (*Stegostoma fasciatum*) were also introduced into the CRE. Two shovelnose rays (*Glaucostegus typus*) were added to the exhibit approximately six months after the arrival of the hammerhead sharks, totalling six elasmobranch individuals in the CRE. No adverse interaction was observed between those three species. The CRE hosts several thousands of tropical fish representing dozens of species (butterfly fish, angelfish, surgeonfish, rabbit fish, damselfish, wrasses, triggerfish, etc), many of which could be preyed upon by the hammerhead sharks; and several hundreds of live coral colonies, mainly soft coral species at the time of introduction of the hammerhead sharks.

## Husbandry details

### Initial introduction into display tank

Upon arrival at Reef HQ Aquarium, the hammerhead sharks were assessed to be in excellent physical condition as a) they were swimming strongly around the transportation tub; b) they had consistent, dark grey dorsal colouration with the white underside showing no red blotches or inconsistencies; and c) they each accepted about three pieces of food (whole prawn and squid heads) thrown into the transportation tub (Figure 3).

The sharks remained in the transportation tub for ca. 2 hours before being transferred to the CRE. This waiting period was due to a pH difference between the transportation tub and the tank, which was gradually adjusted. The sharks were not quarantined for the following reasons: a) Reef HQ Aquarium's long term experience with the supplier shows an exemplary track record in terms of fish health upon delivery; b) no other tank of an adequate size was available to hold the sharks; and c) access to a large swimming area and good quality water was prioritised over trying to develop feeding behaviour in a smaller holding facility.



**Fig. 2.** Hammerhead shark pups in transportation tub upon arrival at Reef HQ Aquarium. Photo: Reef HQ Aquarium.

Thus two hours after arrival, the sharks were gently placed into a rubber net and transferred into smaller tubs (0.9 m length x 0.6 m width x 0.6 m depth) lined with protective rubber matting (Figure 4) to minimise any potential abrasions and injuries. The tubs were wheeled to the exhibit and the sharks were lifted into the CRE with the rubber lining (Figure 5) within five minutes after being transferred to the smaller tubs. They were placed in the tank above the viewing tunnel at the northern end of the exhibit, and they both swam off the rubber lining as soon as submerged in the CRE.





**Fig. 3.** Transfer tub and net were used to transfer scalloped hammerhead sharks from transport tub to display (both in rubber to avoid skin damage). Photo: Reef HQ Aquarium



**Fig. 4.** Scalloped hammerhead shark being lifted from the transfer tub to the display tank (CRE). Photo: Reef HQ Aquarium

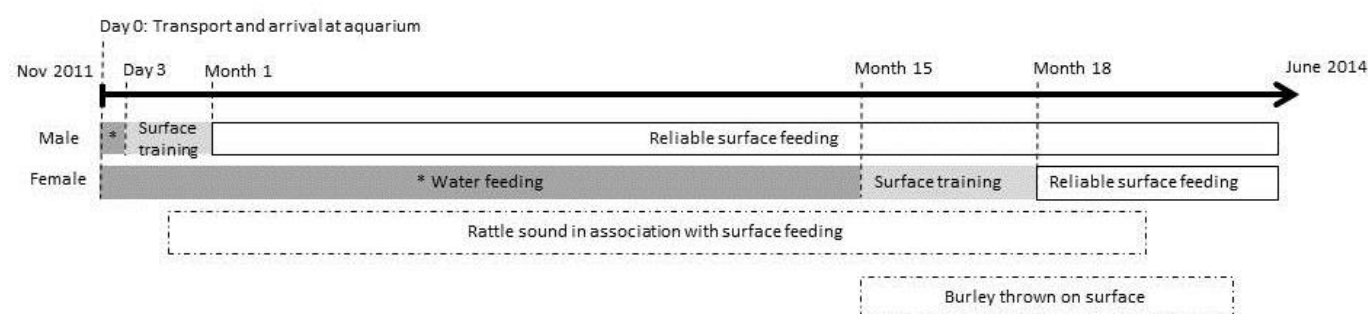
Within an hour of introduction into the CRE both sharks entered the wave machine cavities at the southern end of the exhibit (each cavity is about 4 m wide x 4 m long with an inclined floor going from the surface to the tank maximum depth of 4 m). Within the following 30 minutes they exited this chamber and swam alongside the eastern wall (18 metre width, no acrylic panels present on that wall), appearing reluctant to explore the tank further. Over the next few days the sharks traversed the entire tank but showed a preference for staying in the wave machine chambers, especially the female, and it was hypothesised that the dark atmosphere and minimal fish activity was attractive to them. The supplier hypothesised that it may be somewhat reminiscent of the shoreline habitat that they were accustomed to feeding in prior to capture.

The female shark bumped into the rockwork, windows and a sea urchin on the first day but soon became accustomed to the tank and its relief without further collision.

## Feeding

### ‘Water’ feeding

Since the sharks remained in the wave machine cavity for the first few days, feeding was first trialled in this confined area. To this end staff would dive (mostly free diving but also scuba diving on rare occasions) into the cavity. It was found that air bubbles were scaring so free diving was preferred, with a SCUBA diver in visual contact outside the chamber for safety reasons. The hammerhead sharks were offered food pieces using feeding tongs and readily took the dead food placed in front of them this way from the beginning. This technique was used only for the four days with the male shark but for ca. 15 months with the female (Figure 6Error! Reference source not found.).



**Fig. 5.** Summary of steps to train scalloped hammerhead sharks to feed from the surface.

### Surface feeding

Feeding with staff in the water as described above was used to ensure that both sharks were getting fed consistently at the beginning. However it presented disadvantages, being time-consuming, potentially creating an association between divers and food, and also causing some stress to the sharks from the divers’ presence.

Thus a surface technique was trialled in the first week by bringing the food to the bottom of the tank without entering the water, as it was assumed that the sharks would normally feed close to the substrate. A 5 m long x 150 mm diameter PVC pipe was placed from the water surface to the bottom of the exhibit, with a ‘flap’ valve on the end. Food was placed into the pipe, and water was hosed down the pipe from the surface. When the food reached the end of the pipe, the flap was opened using a pulley system, therewith releasing food into the tank. This technique was rapidly discarded because the food released near the bottom of the pipe attracted many the other fish, deterring the hammerhead sharks from coming close to the pipe area.

A few days later, both sharks were offered food from the surface twice a day with a pole around 8:30 am and 3 pm. The male shark thus commenced feeding from the surface on the wave machine side of the exhibit from day four after arrival at the aquarium. The male shark continued to feed consistently in this manner thereafter.

The surface feeding location of the male was then slowly moved to a more convenient location of the exhibit which also enabled the public to observe the feeding sessions. This was done by moving the feeding location in small increment over several days; until the desired area above the tunnel was reached (four intermediate stations were used). It was easily accomplished as the male shark was very proactive in seeking out food.

The female on the contrary was difficult to train and it accepted to feed exclusively within the wave machine cavity for the first 15 months. Attempts were made by divers or snorkelers to feed her within the general exhibit, but she was adverse to staff approaching her and would flee in an erratic and stressed fashion. Since the feeding by a snorkeler from a stick inside the wave machine cavity had initially been successful, a routine was devised to corral the female hammerhead shark into the cavity by divers; then a snorkeler would enter the cavity and feed her with chopped up food taken in a container for this purpose and presented to her with feeding tongs.



This method was used for over a year and kept her healthy, but it presented some risks of injury and exhaustion for divers when corralling the shark into the cavity, and the stress factor to the shark itself was also considered high. In addition, the male hammerhead shark became very persistent in its attempt to reach the food carried by the divers.

At this point the female shark was pressured to surface feed by promoting hunger. Food was offered to her exclusively on a pole close to the wave machine cavity, i.e. where the sharks had deemed to be 'safe', and after approximately a week she finally accepted a pilchard off the stick from the surface. This continued to happen on an inconsistent basis for a further week. Once this feeding station had been established, again it was gradually moved along the tank length until it coincided with that of the male near the tunnel windows. However this process was slower than with the male and required six intermediate stations. It took another three weeks for the female to pole-feed from the surface at the same feeding station as the male and in satisfactory amounts.

The male initially fed very enthusiastically, which seemed to intimidate the female at first. As time went on, the female seemed to be excited by the male's rapid feeding movement and it appeared to enhance her feeding own response but in general, she has not been as food motivated as the male has. She has consumed less food on a more inconsistent basis than the male, which remains true after 2.5 years of captivity. However, although she is now significantly smaller than the male, she is no longer shy to feed.

### **Type of food and amounts**

Food items offered include pilchard, whiting, small mullet, squid and slimy mackerel. Cairns Marine has established that the food needs to be correctly sized to one mouthful for juveniles rather than requiring cutting or biting by the pups themselves as the thrashing behaviour to cut the food to small enough sizes to swallow could cause the animals to hit a tank structure or another tank mate. Hence food was 'cubed' for the first 3 months of captivity at Reef HQ, after which both sharks were consuming whole fish and squid. Both sharks have shown a preference for oily fish such as pilchard and slimy mackerel.

In June 2014, 2.5 years since their arrival, the sharks are fed once a day at ca. 3 pm, five days a week – Monday through Friday. They have been continuously fed at the established feeding station near the tunnel, within public viewing, after the initial training period described above. They consume on average 5 kg of fish per week or about 12 whole fish for the male and 8 for the female per feeding session.

### **Seasonal and daily patterns for feeding**

In general Cairns Marine has observed that juvenile scalloped hammerhead sharks would not stay interested in food if presented to them for longer periods than 15-20 minutes at a time. This may be because scalloped hammerhead sharks seem to eat only to satiation and then stop. Indeed they do not go obese in captivity even when food is offered ad libitum and even though they are always offered ca. 25% of their body weight per week at Cairns Marine, they may not eat as much depending on season (Lyle Squire pers. com.).

Upon arrival at Reef HQ food was thus offered at various times of the day initially, with advice from Cairns Marine to reduce it to twice a day for animals above the 85 cm range. In general the afternoon prompted the strongest feed response at Reef HQ Aquarium, and the scalloped hammerhead sharks are now pole fed around 3 pm (for about 15 minutes) for this reason and because it also coincides with the feeding show program for visitors. Both hammerhead sharks have appeared more active and food motivated in summer so far with water temperature ranging between 25 and 29 °C, than in winter when water temperature is below 24 °C. Both sharks have continued to feed in winter, though with less enthusiasm. Finally, both hammerhead sharks appear to be more bold and forthcoming to food on overcast days.

## **Discussion**

### **Behavioural observations**

#### **Interaction with divers**

Divers have been swimming with the scalloped hammerhead sharks since their introduction in the CRE, with a minimum of two staff diving in the CRE daily for routine tank maintenance. At first, the sharks first showed an aversion to the scuba exhaust

bubbles, and would not allow the divers to approach closer than approximately 3 m. No sign of curiosity or aggression was ever displayed but in general, both sharks exhibited a fairly nervous, 'flighty' disposition. When disturbed by other tank inhabitants they became agitated and often collided slightly with walls and objects in their efforts to 'escape'. After several weeks they adopted a slower and calmer swimming pattern including around divers. Whilst carrying out routine tank maintenance, divers often reported that the hammerhead sharks swam behind, under and over them, although they remained approximately 2 m away from them at all times. The sharks remain to this day easily startled if adversely interacted with by fish, but no longer during surface feeding.

After approximately several months of uneventful interactions, the male began associating divers with food. This was due to the fact that divers were routinely taking food into the tank in a plastic bag to feed the smaller female and the shovelnose rays. By then the male had developed a very enthusiastic feed response when pole fed from the surface, and attempted to take food from divers. It often followed closely behind divers carrying food, and approached fins, arms and legs of divers, often with mouth agape. On one occasion the male snatched a bag from a diver with a fresh dead *Polyancanthus acanthachromis* in it. It was thus decided to stop feeding the female in the water and insist on pole feeding her, as well as the shovelnose rays, to avoid any food being taken into the tank by divers.

The demeanour of scalloped hammerhead sharks in captivity is largely unknown, mainly due to the lack of documented history for this species. Within Australian waters, the scalloped hammerhead species is not regarded as a dangerous shark and most attacks associated with the hammerhead group are attributed to the great hammerhead (*S. mokarran*), and are usually provoked by spearfishing activities. It was anticipated that the scalloped hammerhead would be a timid, retiring shark in captivity, which has been the case so far at Reef HQ Aquarium – except when divers have taken food into the tank. Behaviour as the animals grow and continue to establish themselves remains mostly unknown though the authors are not aware of report of aggressive behaviour in aquaria to date.

#### **Interactions with other tank animals**

The scalloped hammerhead sharks have been overall indifferent to the other fish ever since their introduction in the CRE, which hosts several thousands of tropical fish. Occasionally the hammerhead sharks would 'track' onto a fish, mainly palate surgeon fish and red toothed trigger fish, and pursue them for a short time, before apparently losing interest.

On rare occasions, dead fish were found in the morning with moon crescent bite marks and the sharks have been seen catching spiny chromis damselfish (*P. acanthochromis*). After over two years of captivity and at about three years old (~1.0 m and ~1.4 m total length), it seems that if the hammerhead sharks do indeed consume tank inhabitants, this does not significantly impact the density of fish in the exhibit. This situation may change as they increase in size.

With regards to other elasmobranch hosted in the tank, the male hammerhead shark was frequently observed to bite both juvenile and adult leopard sharks whilst being pole fed, and it keeps doing it to this day. This occurs during feeding sessions when the leopard sharks converge to the hammerheads feeding station, despite them being fed at an earlier hour and at a different location. As the leopard sharks clumsily swim close to the pole, their long, moving caudal lobe seems to be perceived as potential food by the hammerhead sharks. The subsequent bites appear to be brief and exploratory, and more opportunistic than from aggression. The leopard sharks show no damage from these bites, possibly thanks to their very abrasive and thick skin, and they continue to frequent the area during the hammerhead sharks feeding sessions.

#### **Interactions with exhibit (walls, rocks, acrylic windows)**

Both hammerhead sharks negotiated the exhibit walls well immediately after initial introduction and even at times of panic later on, the sharks would not collide with the exhibit walls or rocks. Only few collisions due to high stress during initial feedings have been observed.

Days after their introduction into the CRE, both sharks showed difficulty sensing some of the large flat acrylic windows, regularly and consistently trying to swim "through" them. They then make large 'sweeping' movements across the acrylic with the bonnet, causing abrasions and fine scratches on the full length of the acrylic panels (3.5 m high) as the sharks start at the top and drop to the bottom losing momentum whilst still attempting to swim forwards. The resulting damage to at least three of the five panels will require extensive buffing to repair. This behaviour continues after over two years in captivity and they are still

sometimes observed to bump into some of the flat acrylic panels (not in the curved tunnel ones), although no consequent damage has been observed on the hammerhead sharks.

A similar behaviour has been observed by Hamish Tristram during past attempts to establish smooth hammerhead shark (*Sphyrna zygaena*) in other public aquaria, with great difficulty in avoiding acrylic panels (either as viewing tunnels, backdrops or observation windows) but no difficulty with rockwork, whether genuine or artificial. The smooth hammerhead shark is structurally and behaviourally very similar to the scalloped hammerhead shark kept at Reef HQ Aquarium, with the only significant differences being adult size and geographical distribution. It seems like other shark species do not display the same difficulty in avoiding acrylic panels.

These observations suggest that the scalloped hammerhead sharks may not negotiate large flat acrylic panels very well in general, but that the relative low acrylic surface in the CRE tank has minimised this problem at Reef HQ Aquarium with only about 25% of the wall surface made of acrylic.

No reaction by the hammerhead sharks was recorded to public viewing, flashed photography, or other potential stimuli through the acrylic windows.

It is also noteworthy that the sharks use the full range of water depth in the CRE, from the tank reef flat which is about 50 cm deep in places to the deeper and narrow channels.

#### **Influence of water clarity on behaviour**

Visibility in the CRE is typically 20 to 30 m but when reduced (due to maintenance work for instance), the hammerhead sharks have been observed to behave more boldly than under normal conditions. They also become unperturbed by divers, swimming closer to them than usually, searching for prey very close to the sandy substrate and often 'shuffling' around in tight circles. This may be due to

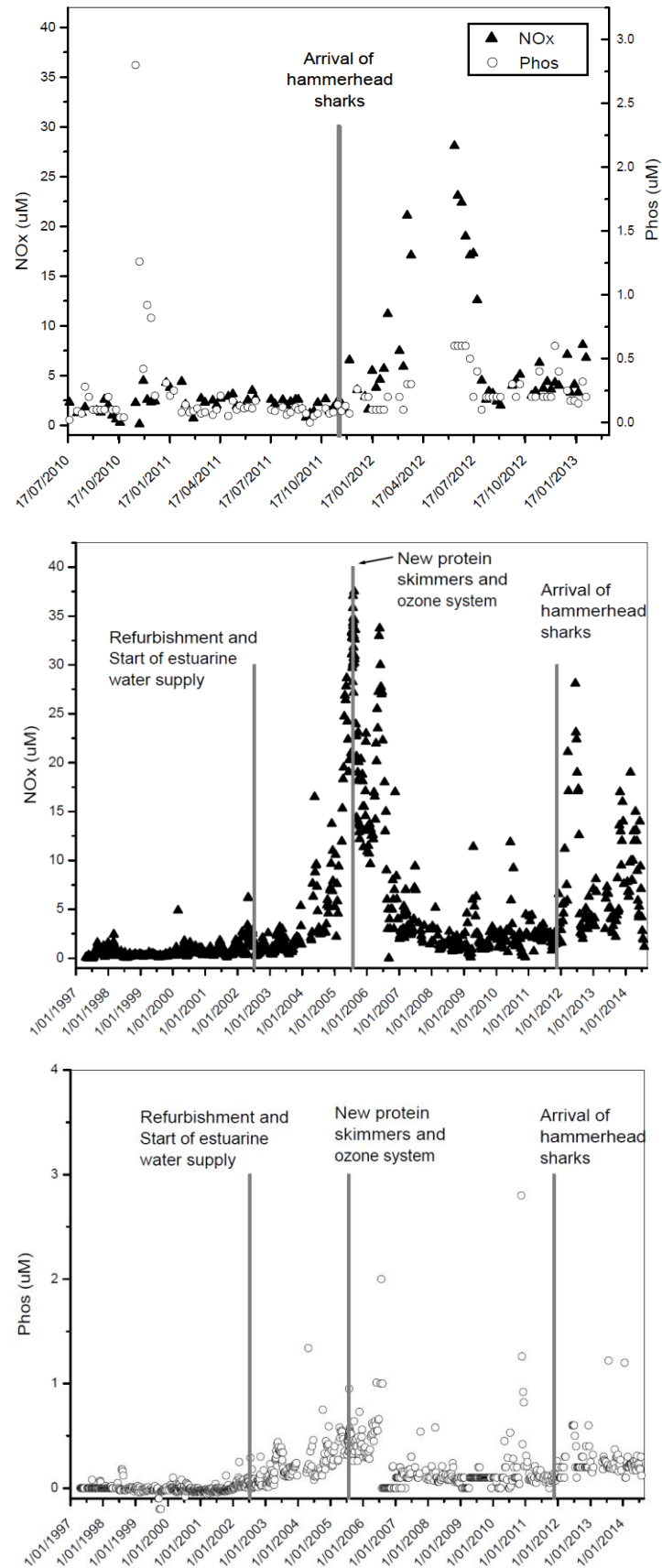
- a) various crustaceans and invertebrates being dislodged by rock movement by the divers and being perceived as potential prey by the hammerhead sharks;
- b) better "hunting" conditions in low visibility;
- c) murky water reproducing a more natural environment for the pups, since wild scalloped hammerhead pups usually congregate in 'nursery' grounds often located at the mouths of estuaries or within harbours. These nursery grounds appear to have a high density of appropriate prey items (cephalopods, teleost fish) but also offer the safety of reduced visibility to hide from potential predators.

#### **Water quality changes**

The CRE was designed as a live coral exhibit and no large fish was held in this display for the first two decades. Six elasmobranchs were then introduced into the CRE tank: 2 hammerhead sharks late 2011, 2 leopard sharks in 2012, and 2 shovel nose rays around the same period.

Figure 7 (top) shows a clear increase in phosphate and nitrate concentrations (approximately equal to nitrogen oxides [NO<sub>x</sub>] levels) for 6 months after introduction of the scalloped hammerheads sharks up to about 10 times the starting levels, before dropping back close to pre-introduction levels around one year on. Although chronologically correlated with the arrival of the hammerhead sharks, this increase in nutrients is neither unique nor the largest event when compared to the last 15 years (Figure 7 middle and bottom).

Beside the introduction of the elasmobranchs in 2011-2012, other changes have taken place over the broader period 2008-2014, making it difficult to untangle the potential effect of the sharks on water quality in the CRE. These include: re-introduction of the use of sand filters, which were not used for several years in a row; reduction of the routine vacuuming; and variations in feeding amounts to the tank.



**Fig. 6.** Top: Nutrient levels in CRE a year before and after introduction of scalloped hammerhead sharks. NOx = nitrate  $\text{NO}_3\text{-N}$  + nitrite  $\text{NO}_2\text{-N}$  concentration. Phos = phosphate. Unit is  $\mu\text{mol l}^{-1} = \text{uM}$ . Middle: NOx levels and Bottom: phosphate levels between 1997 and 2014 in the CRE.

### Health and growth observations

Over 2.5 years in captivity and at an estimated age of ca. three years, the hammerhead sharks have grown from about ~60 cm total length for both sharks in November 2011, to ca. 1.4 m for the male and ca. 1.0 m for the female as estimated in April 2014 (i.e. average of 0.36 m and 0.17 m per year for the male and female respectively). In both cases the width of the 'hammer' is about 25% of the total body length at about three years old (34 cm and 23 cm respectively for the male and female in April 2014). These measurements were done by taking photographs when the sharks were swimming on the surface along a marked pole (Figure 8).



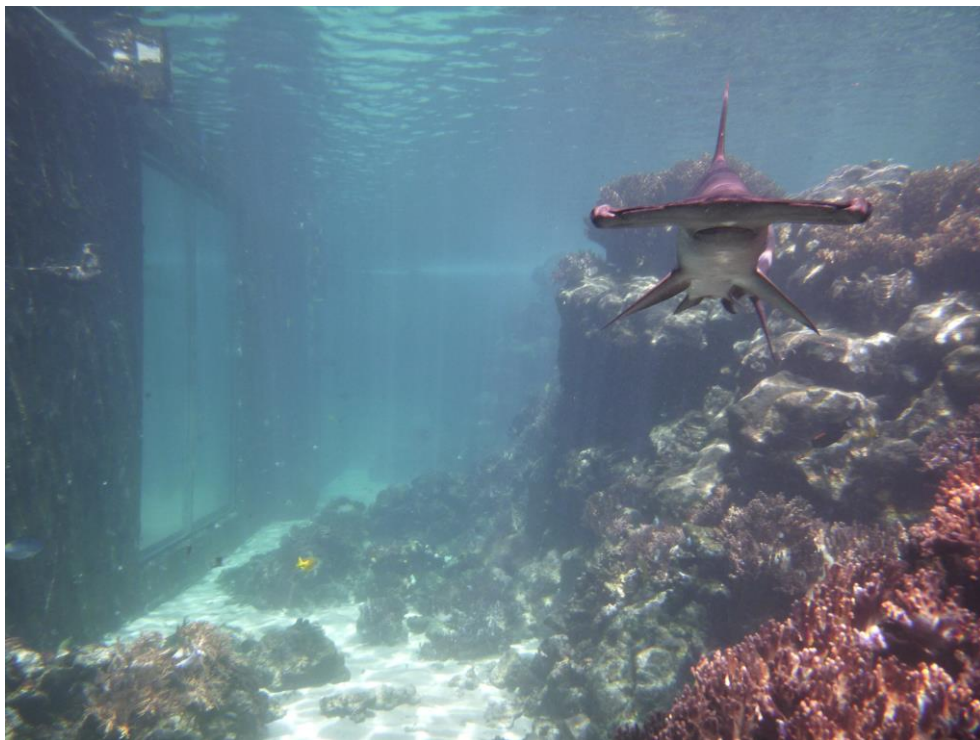
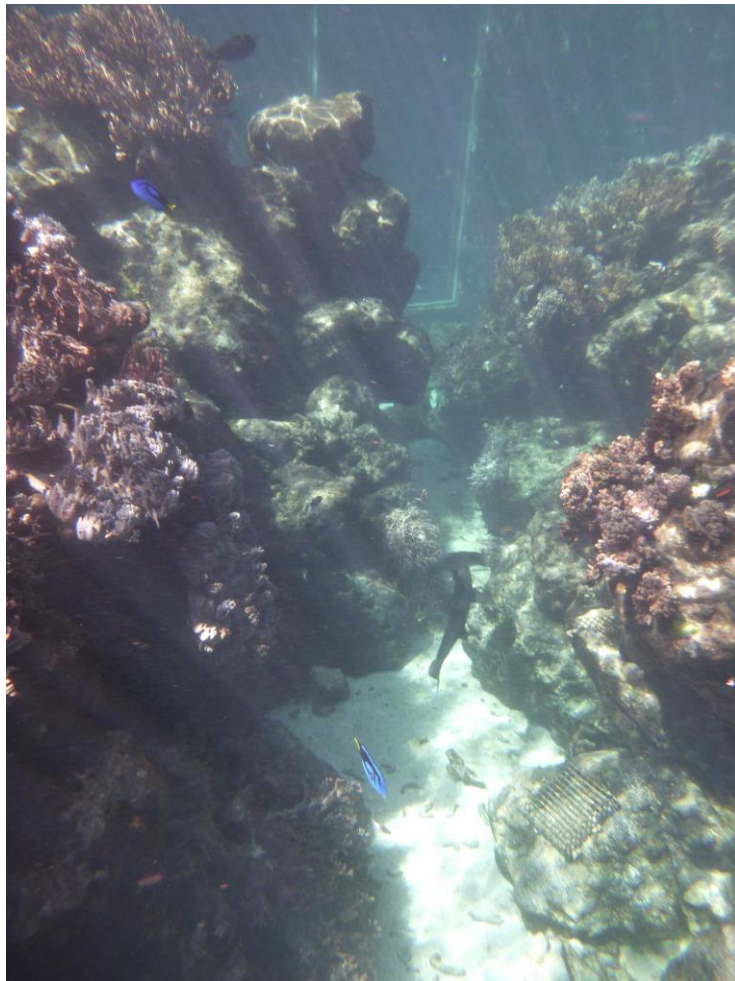
**Fig. 7.** Both hammerhead sharks from above tank at feeding station in April 2014. Black marks on white pole along wall mark every 30 cm. Photo: Reef HQ Aquarium

The growth rate of the female compares well with wild conditions, with an expected total length of ca. 1 m at three years old, as opposed to captive individuals that have been recorded to grow much faster, reaching this size soon after one year old (Mohan, Clark, & Schmid, 2004). The male on the contrary, has grown significantly faster than wild animals, reaching over 1.4 m at about three years old when wild animals are expected to reach this size at about five years old (Mohan et al., 2004). Although the data analysed by Mohan et al. (2004) does not cover that size in captivity, it is in agreement with the extrapolation of the curve.

It is noteworthy that the male, which was slightly smaller than the female upon arrival, has outgrown her after the first month in the tank. This may be due to the male feeding more readily than the female, or to some social adjustment since the male is the more dominant of the two. In June 2014, the pair of scalloped hammerhead sharks at Reef HQ Aquarium is healthy and well adjusted. Both animals are in good body condition, and feed regularly.

Few health issues have arisen with the hammerhead sharks since their arrival. A 1-2 cm diameter circle of discolouration was observed on the bonnet of one shark. A large abrasion mark was also seen on the female after one month in the display with no treatment or negative consequences. In June 2012, a large red groove with white edges appeared on the ventral side of one of the sharks and in June 2013, the female showed some damage to her right eye. In all these cases the sharks recovered with no intervention, a sign of good adjustment to captive conditions and overall good health. Figure 9 shows them fully adapted to the CRE environment they have been growing in for over two and a half years.





**Fig. 9.** Top and bottom: scalloped hammerhead sharks in their Coral Reef Exhibit environment at Reef HQ Aquarium in April 2014, about 2.5 years after their arrival. Photo: Reef HQ Aquarium

Generally speaking, most husbandry issues experienced by Cairns Marine occurred in winter time, with scrapes and marks appearing if temperature dropped below 23 °C for several weeks. This does not apply for the two specimens held at Reef HQ Aquarium so far. However it is noteworthy that the animals arrived at the onset of the Southern hemisphere summer (November 2011), providing them with the longest possible duration of warmer water to acclimatise to their new environment before temperature dropped sharply in May 2012 (Figure 2), which may have contributed to the success of their adaptation.

## Management issues

### Favourable captive conditions at Reef HQ Aquarium

Several favourable conditions allowed Reef HQ Aquarium to attempt to house hammerheads sharks. These are:

- absence of potential predators in the display;
- many fish had the potential to be considered food, reproducing a stimulating environment;
- the rock structures in the centre of the tank allows an uninterrupted swimming pattern around its circumference (ca. 100 m long).
- the overall surface area of the acrylic windows in the tank is small (25%).

### Size and behaviour considerations for hosting adult hammerheads

The scalloped hammerhead sharks have the potential to reach ca. 3 m in length when fully grown. It is not known so far if they will reach this size and if so, if the CRE will remain of sufficient size. There is some concern that they may require a larger tank than the CRE. Behaviour towards divers or tank inhabitants could also become more challenging at a larger size.

When using Klay's formula to estimate the minimum tank size to host sharks, a 3 m scalloped hammerhead shark would require a tank of 36 m long x 15 m wide x 7 m deep (Choromanski, 2004), which is approximately the CRE size except for depth (maximum 4.5 m). Choromanski also specifies that horizontal tank dimensions are more important than vertical ones, and Klay (1977) indicates that tank size requirements will decrease as animals acclimatise to captivity. The minimum distances required for various species of sharks as estimated by Klay (1977) are all below 28 m. Although no data is available specifically for scalloped hammerhead sharks, the 36 m length of the CRE is about a third greater than this. In this light, it seems very likely that the two scalloped hammerhead sharks at Reef HQ Aquarium will be able to maintain sufficient rest/glide and recovery periods as their size increases, and that the CRE will remain of an appropriate size for them.

The number of animals is not considered the primary concern for sharks well-being in a tank compared to other factors such as uninterrupted swim-glide distance for instance (Klay 1977), and with only six elasmobranch in 2.5 ML the stocking of the CRE is very low. This is also considered a favourable condition for long term hosting.

The hammerhead sharks were initially taken by Reef HQ Aquarium based on the understanding with the supplier that the latter would take the sharks back when they reached ~1.2 m. This threshold was considered by the supplier to be the maximum size for safe transport. The sharks would then be forwarded to another facility with larger tanks. At the time of writing this article, discussions are underway with Australian aquaria that may be able to accommodate the hammerhead sharks at an adult size. Under current Australian legislation they may not be released back into the wild. It is thus an important consideration to secure long term housing when acquiring these animals for display, as successful acclimation means that they will need accommodation at a fully grown size.

### Maturity considerations

Surveys from wild caught *S. lewini* males have recorded a maturity size of 1.61 m precaudal length (minimum 1.55 m and maximum 1.9 m) (De Bruyn, P., Dudley, S. F. J., Cliff, G., & Smale, M. J., 2005) based on claspers calcification. Branstetter (1987) reported that 50% of a female population had their first reproduction at a total length of 2.35 m and at an age of 15 years old. These indicate that the two individuals at Reef HQ Aquarium are still far away from mature age.

To the author's knowledge, there is no report of captive breeding of scalloped hammerhead sharks to date.

## Public feedback / conservation value

The public has embraced and enjoyed the hammerhead shark display at Reef HQ Aquarium. An important charter of the Great Barrier Reef Marine Park Authority is to promote the conservation of the GBR and all the plant and animal species it encompasses. Thus staff make a point of highlighting the presence of the hammerhead sharks to the public and incorporate discussion of them in public talks and tours, and ensure that accurate and detailed facts are portrayed in relation to their physiology and wild counterparts. These sharks are unique in appearance and evoke wonderment and amazement from the public. They capture attention and provide a platform for further educational opportunities. Since being established at Reef HQ Aquarium, the hammerhead sharks have been the subject of numerous media events.

These sharks have also provided an opportunity for curatorial staff to develop and refine husbandry knowledge specific to this species. The resulting observations and experience have increased the captive prospects of future animals (within Reef HQ Aquarium and other public aquaria).

## Conclusion

Hosting two scalloped hammerhead sharks at Reef HQ Aquarium has been very valuable in terms of husbandry experience, including acclimation period, feeding, interactions with divers and other animals, and growth observations. The captive hammerhead sharks have also provided a very effective opportunity to communicate with the general public on sharks' conditions in the wild, their role in the environment as an apex predator, and the concerns on their declining numbers. At this point they have been displayed successfully for two and a half years and are the only specimens held in captivity in Australia's aquaria. Their adaptation to the CRE display will remain an on-going process as they grow fully over the next decade.

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