FATAL ATTRACTION: SOLVING THE TUNA COLLISION PROBLEM AT THE MONTEREY BAY AQUARIUM

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INTRODUCTION

On March 2, 1996, the Monterey Bay Aquarium opened the Outer Bay, a $57 million, 93,000-square-foot new exhibit wing exhibiting life from the pelagic realm. The centerpiece of this new wing is the 1.2 million gallon Outer Bay Waters exhibit displaying epipelagic fishes such as yellowfin tuna (*Thunnus albacares*), Pacific bonito (*Sarda chiliensis*), and ocean sunfishes, (*Mola mola*). This exhibit was designed with many unique features to create the illusion of an endless open ocean for visitors (Hamilton and Choromanski, 1996). However, some of these design features may also be contributing to a different type of illusion on the fishes' side of the viewing panel that has caused a number of tuna impact mortalities over the past two years.

HISTORY

Although the Outer Bay did not open to the public until March 2, 1996, the Aquarium, as is now customary, planned a significant number of pre-opening events for members, donors, VIPs, and media, prior to the official public opening. Consequently, husbandry staff had to have all of the new exhibits ready by a January 26, 1996 deadline; five weeks prior to the public grand opening. Toward this end, in the construction master scheduling process, we incorporated a timeline specifying a substantial completion of the building from the contractor a year in advance, in January of 1995, that included operational access to the Outer Bay Waters exhibit tank and associated life support systems (LSS) in February of 1995. As is also seemingly customary, construction progress fell behind schedule many times during the course of construction, due primarily to an inability to locate and repair a fairly significant leak in this huge tank. For awhile, as each week passed, another month was added to the turnover date. Consequently, husbandry staff did not get operational access to the exhibit and LSS until August of 1995.

Filling the Outer Bay Waters exhibit with its first seawater fill (it was filled multiple times with freshwater for leak testing, LSS testing, Vandex® processing, etc.) took four full days at an accelerated rate (the Outer Bay Waters exhibit is regularly supplied with make-up filtered seawater from the original Aquarium building at 70 gpm; roughly a 13-day make-up turnover rate). Next came LSS testing, including fluorosseine dye flow pattern tests and biofiltration bacterial inoculation and feeding.

Finally, with the fall 1995 collecting season for additional tuna upon us, aquarium staff began the process of carefully transporting previously collected yellowfin tunas from the Tuna Research and Conservation Center (TRCC) located next door on the grounds of Stanford University's Hopkins Marine Station. The aquarium had done significant research and development work on the husbandry aspects of keeping tuna in a captive aquarium setting for many years prior to this point, and the husbandry and handling techniques, many of which were graciously shared by Japanese aquarium colleagues, were perfected and modified to suit our specific applications.

One of the husbandry staff's concerns during the design process was whether or not the tunas would swim into the acrylic viewing panel if the public viewing area was too brightly lit. This scenario (a lighter viewing area than the exhibit lighting) tends to make the viewing window disappear from an in-tank perspective and this has been shown to cause collision behavior with some sharks. The Japanese aquariums that display tunas cautioned us about this as well, and some of them have gone to great

lengths to keep their viewing areas dark, including adding black curtains at entrances and exits and curtaining off the windows at night. Consequently, our exhibit design included a purposefully darkened viewing area with many electrical failsafes that would prevent the occurrence of such an undesirable lighting scenario during normal operations. However, much of this was not operational during this still-under-construction phase, and the viewing area had to be lit brightly for various reasons during the times we needed to add fish to the exhibit. Consequently, we installed a large canvas curtain in front of the acrylic viewing panel on the public side not only to provide a darkened window for the fish, but also to protect the expensive window from the still lingering construction activities. Additionally, we decided to deploy a series of lead-filled nylon lines from the service area deck above the exhibit, inside the tank, covering the main viewing window and a smaller circular window. This was done to provide an additional visual barrier against the window for the tuna to see. An adjunct angled viewing panel on the unfinished first floor was masked with black plastic.

We use a similar technique, also learned from the Japanese, to transport and hold tunas off exhibit. Our tuna collecting ship's live well, our truck-mounted tuna transport tank, our field holding tank and our reserve animal holding tanks at the TRCC all have black painted vertical lines on all surfaces and are continuously illuminated. This provides a visual cue for these fish to orient by and to see the boundaries of their new environment.

Between late September and early October 1995, 80 yellowfin tuna were added to the exhibit. These fish were from three different collecting seasons (1993, 1994 and 1995) and year classes, and ranged in weight from 3 to 50 kg.

MORTALITIES

Despite our concerns stemming from the experiences of our Japanese aquarium colleagues, we did not experience a single tuna mortality during these transports and initial acclimations. In fact, we did not have any tuna mortalities until late October 1995, and this mortality was caused by the animal jumping out of the tank. Initially, we lost a dozen or so bonito from the same cause, and aquarium staff quickly addressed this problem by modifying the existing safety stanchions into cushioned and elastic jump-guards.

The first tuna impact mortality was discovered on November 27, 1995 when a yellowfin tuna was found dead on the tank bottom during morning rounds. Post-mortem examination revealed broken facial/nasal bones indicative of an impact. A second impact mortality occurred on January 18, 1996, and this tuna was also discovered dead on the tank bottom during morning rounds. Necropsy of this animal revealed a far more significant impact as evidenced by broken, dislodged and offset spinal column, separated between the second and third vertebra.

After this, a series of four impact mortalities occurred in January in close order, this time all during the day, and some were actually witnessed by aquarium staff or construction workers in the building. At this same time, significant above-tank electrical work to install a new lighting array via a large raft was taking place. Aquarium staff had earlier decided that the original, downward-pointing, Hi-Bay style exhibit lighting was inappropriate for the exhibit, causing the blue-tiled lower walls and bottom to reflect brightly which made the tiles visible, and created a brighter bottom than top—the opposite of the desired effect. Consequently, a lighting consultant was brought in and recommended a new, theatrical-style lighting system that would provide angled, filtered and color-gelled light that better accomplished the desired effect of a boundless open ocean. It was presumed at this time that these four mortalities were caused by the new lighting effect, the associated construction activity, or both. After the fourth mortality of this series in January 1996, the electrical work was stopped and the exhibit returned as close as possible to its original lighting scheme by using the remaining original Hi-Bay lighting still in place.

After this, we continued to have sporadic mortalities for the next few months (Fig. 1) caused by impact with something hard, but we could not determine a cause. We seemingly had addressed all potential construction-related causes, and yet these mortalities continued after our public opening. Also, at this time, we were still not exactly sure what these animals were colliding with. The overwhelming

majority of these impact mortalities occurred at night, and the dead animals were found on the tank bottom the next morning.

TIME-LAPSE VIDEO RECORDING/MONITORING

To try and determine the exact nature of these unexplained and unobserved, albeit obviously impact-caused mortalities, a custom underwater camera and time-lapse video system was purchased and installed. This video recording system was operational on July 4, 1996 and we experienced another impact mortality the very next day. This first underwater time-lapse video recording from the exhibit documented exactly what we had suspected all along, but had only occasionally witnessed—that these mortalities were caused by high speed impact with the acrylic viewing window.

Subsequent impact mortalities were all captured on videotape (with a few exceptions caused by minor technical glitches or human error). Analysis of these tapes revealed that 100% of all of the impact mortalities were with the main vertical acrylic viewing window. Interestingly, during mock-up lighting tests using both the old and the new styles of lighting, observations made while diving in the exhibit revealed that there was indeed a reflection of the exhibit's curved blue-tiled walls onto the inside (water side) of the viewing panel. This reflection created an illusion from the human perspective, and possibly from tuna perspective, that the exhibit tank boundaries extended through the acrylic viewing panel into the public space.

THE BUBBLE CURTAIN

Additional animals had been added to the exhibit from the TRCC reserve in June of 1996 to replace the attrition from mortalities, and Aquarium management requested a per tuna cost estimate to help put this dilemma into perspective. Rough calculations revealed that the overall cost per tuna from hook to tank, based on the 1995 collecting season was about $5,000 per animal. Needless to say, staff began to study this problem in earnest.

For a variety of reasons, trying to eliminate the reflection by affecting additional lighting changes was not an option. We knew that our earlier attempts at creating a visual barrier against the window and inside of the exhibit by hanging lead-filled nylon lines vertically along its length was not 100% effective. A number of the pre-opening mortalities in January and February 1996 had occurred even with these deployed, and in several instances evidence of a window impact could be seen between these hanging lines. Observations during dives showed that the reflection of the tiled wall and the illusion this created could be seen through these deployed lines. Additionally, even if these lines would work as a barrier, they would represent a significant daily operational challenge as well an aesthetic detraction from this exhibit. Consequently, our thinking shifted toward developing a barrier that was less static and more dynamic and visually disruptive to this reflection.

The idea to install a bubble curtain in the Outer Bay Waters exhibit as a window barrier was actually conceived of before animals were ever added, however, early prototypes using suspended (but heavily weighted) PVC pipe and using both conventionally compressed air and the building LSS air supply proved inadequate to create a true curtain of air, primarily due to the length and bottom depth of the large acrylic viewing panel. After the tuna mortality pattern was discerned, we re-opened the idea of designing a bubble curtain that could be turned on after public hours. At that time, the vast majority (83%) of the win-dow impact mortalities were occurring at night (Table 1). Our hope was to eliminate, or at least greatly reduce, these tuna mortalities with an underwater bubble curtain to provide the tunas with a moving visual barrier in front of the viewing panel.

Since our prototypes using conventional air supplies proved ineffective, we contacted an aeration specialty company to recommend appropriate equipment. The result was fairly simple; a 2HP rotary air pump ultimately connected to sixty feet of 11/2" diameter PVC pipe with 3/64" diameters holes drilled at 5.22" intervals on the bottom of the pipe which was installed below the viewing panel at about 25' tank depth. Husbandry staff installed the PVC pipe manifold underwater using FRP unistrut and clamps, and

Kopper's Z-spar A-788 Splash Zone Compound. This air pump was also connected to the building systems operation computer via a programmable logic controller (PLC) which allowed us to precisely control the on and off times in relation to regular operating hours and night events.

RESULTS

The results to date have been dramatic. Since the bubble curtain installation in October 1996, we have not had a single impact mortality with the acrylic viewing panel during the hours of bubble curtain operation (see "Window Collisions —Non-public Hours" in Fig. 3 and Table 1). The exact times of public vs. non-public hours varies throughout the year depending upon season (*i.e.*, open at 0930 hours during Summer and 1000 hours in the off-season) and whether or not there is a night event in the building (the Outer Bay Wing can remain open until 2200 hours; normal public closing is 1800 hours year-round) thus, the data were segmented into public vs. non-public based upon these operating hours.

DISCUSSION

Although the bubble curtain has been successful in doing what it was designed to do—eliminate acrylic window impact mortalities during non-public hours, we still are experiencing some window impact mortalities during public hours. A few of these have been human-induced and have been segmented as such. Of the remaining 19 window impact mortalities that have occurred to date during public hours, we feel that eight of these (four in January 1996 and four in February 1997) can be attributed to aberrant swimming behavior somehow caused by using the newer, theatrical-style lighting system. During these brief lighting test periods, tuna have been observed and videotaped swimming purposefully into the window. During the February 1997 testing, there were multiple non-fatal window impacts recorded in addition to the four mortalities. Exactly what aspect of the new lighting system was causing this behavior is unknown, but may be related to the reflection/illusion issue being more predominant under the newer lighting system. Clearly, yellowfin tuna are very visually-oriented animals and much work still needs to be done to understand their visually-induced collision behavior. Perhaps we may be able to address this problem in the future with additional lighting changes that reduce the amount of wall reflection and/or experiment with wavelength perception.

ACKNOWLEDGMENTS

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REFERENCE

Hamilton, R.M. and J.M. Choromanski. 1996. The New Outer Bay Wing of the Monterey Bay Aquarium. *Proceedings of the 1996 Annual Conference of the American Zoo and Aquarium Association*, Honolulu, Hawaii, September 12-17, 1996, pp.127-131.

EQUIPMENT LIST

Underwater Time-Lapse Video Recording System:
Recorder: Panasonic Model AG-6740-P(Professional) (S-VHS).

Bubble Curtain:

- "Modern Air" Oil-less Rotary Air Pump, Model # MA510-14, Aquaculture Research/Environmental Associates (AREA), Inc., P.O. Box 901303, Homestead, FL 33090-1303 (305) 248-4205.