The Elasmobranch Husbandry Manual:

Captive Care of Sharks, Rays and their Relatives

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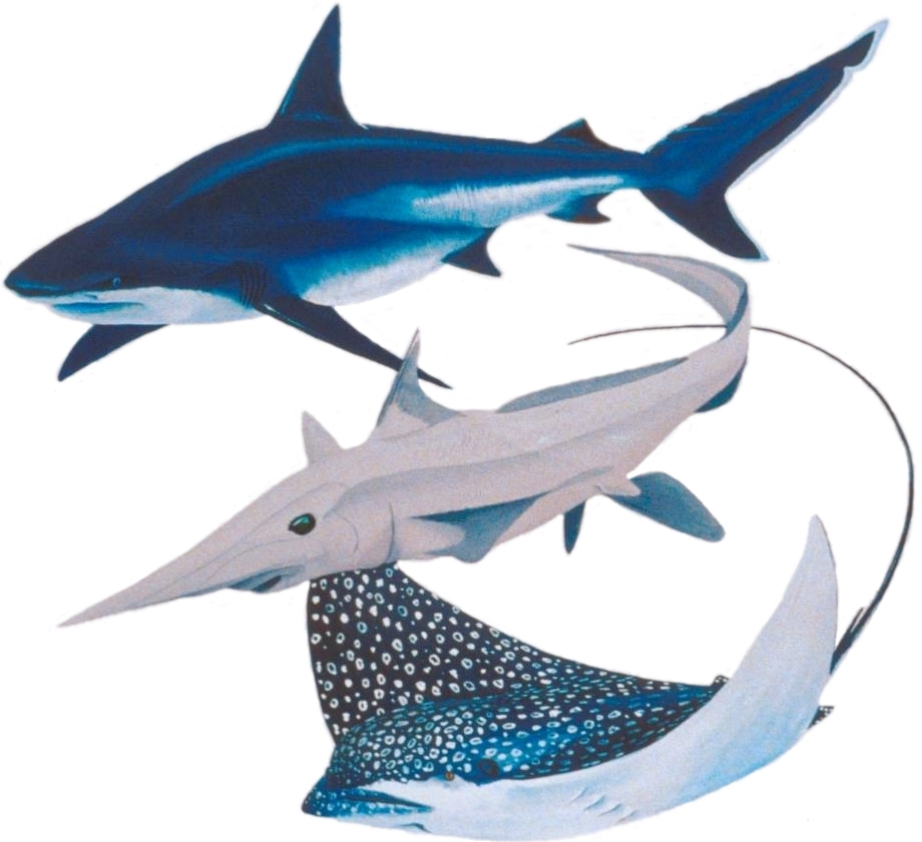

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Chapter 4
Quarantine and Isolation Facilities for Elasmobranchs: Design and Construction

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Abstract: When designing and constructing quarantine and isolation tanks for elasmobranchs, three key issues must be considered: the size of the tanks, the shape of the tanks, and the design of life support systems (LSS). Tanks must be sufficiently sized and shaped to cater for the swim-glide swimming pattern of the most sensitive or demanding species held. The design of LSSs should focus on maximizing biological carrying capacity, as stocking densities are frequently high in quarantine and isolation tanks. Effluent water treatment and disposal systems should be carefully considered during LSS design. Concrete is an excellent choice for constructing quarantine and isolation tanks, primarily because of its strength and relatively low cost for volume. Fiberglass reinforced plastic (FRP) offers an excellent alternative to concrete, having the advantage that no ferrous reinforcing is required. Buildings housing quarantine and isolation facilities should be constructed from non-ferrous materials. Quarantine and isolation facilities must be designed to allow unimpeded access for the staff (and husbandry equipment) to the tanks and the animals, and clear and easy access for trucks, trailers, and boats used to transport animals from collection sites. Quarantine and isolation facilities must incorporate husbandry support areas, including: (1) a food preparation area; (2) a water quality laboratory; (3) an office and record-keeping area; (4) a necropsy room; (5) a dive locker room; and (6) a storage area for husbandry equipment. Quarantine and isolation facilities should be air-conditioned and dehumidified, and provided with security systems to avoid fire, theft, vandalism, and power cuts.

The successful maintenance of captive elasmobranchs begins by providing the correct environment, designed with a careful consideration of the ecological, physiological, and behavioral requirements of the species held. Maintaining captive elasmobranchs is not a new enterprise. However, it has been historically difficult to maintain larger, pelagic, obligate ram-ventilating species (Clark, 1963; Gruber and Keyes, 1981; Murru, 1990). Advances in technology and an increase in available financial resources (from an increased public popularity of aquariums) has provided the means to construct larger exhibits and resulted in the successful display of larger and more challenging species (for an excellent review of the history of elasmobranch exhibits refer to Chapters 1 and 5 of this manual). Advances in aquarium design are frequently the result of trial and error, and important advances are rarely published in the literature. This chapter therefore relies heavily on the collective experiences of public aquarium biologists, with limited references to published literature. This chapter will focus on sharks, which are typically more challenging than skates, rays, and chimeras from the standpoint of aquarium design.

Although there are many similarities, the design of a quarantine and isolation facility for elasmobranchs differs in many ways from the design of an elasmobranch aquarium exhibit. For the purposes of this chapter the main functions of an elasmobranch quarantine and isolation facility include: (1) the acclimatization and recovery of newly acquired sharks from the stress associated with capture, transport, handling, disease, or injury; (2) the quarantine of sharks prior to display; (3) the short-term isolation and treatment of sick or injured sharks; and (4) the long-term holding of sharks for some specific purpose (e.g., breeding, research, etc.).

With about 400 different described species, no shark can be considered as "typical" for the purposes of designing a quarantine and isolation facility. Each species has particular characteristics which impact husbandry requirements and facility design. Likewise, individual factors (e.g., size, age, behavior, susceptibility to stress, health status, etc.) vary and must be taken into consideration. Tanks should therefore be designed to accommodate the specific requirements, numbers, and maximum sizes of the most sensitive or demanding species to be held.

The construction of an adequate quarantine and isolation facility for elasmobranchs can be expensive, especially for larger, more sensitive species. Institutions or individuals with insufficient resources should not undertake the construction of such facilities or attempt to hold elasmobranchs.

TANK DESIGN

Tank size

The physical dimensions of quarantine and isolation tanks are of critical importance. The sheer size of adult sharks presents the first husbandry and, thus, design challenge. In general, large sharks require large tanks, and the larger the tank, the better it can accommodate a wide variety of elasmobranch species. Tank size requirements for large benthic sharks will be different from those required for large obligate ram-ventilating sharks (refer to Chapter 5 for a more detailed discussion). The key, once again, is to plan and design for the maximum sizes and numbers of the most sensitive or demanding species to be held.

Limited data exist on the spatial requirements for elasmobranchs in captivity. The only attempt to quantify the minimum dimensions of an elasmobranch enclosure was undertaken by Klay (1977) in an article examining shark dynamics and exhibit design. Klay claims to have studied the swimming behavior of 29 different species of sharks (although data for only seven species were reported in his article). Klay maintains that sharks over 1.8 m total length (TL), with the exception of bull (*Carcharhinus leucas*), lemon (*Negaprion brevirostris*), nurse (*Ginglymostoma cirratum*), and sand tiger (*Carcharias taurus*) sharks, require an introduction tank of dimensions 30.5 m long x 12 m wide in order to adopt normal swimming patterns and exhibit normal behavior (Klay, 1977).

Although not published, Klay is credited with developing a proprietary formula to determine the minimum tank dimensions for what he described as average sharks. Average sharks in this context referred to species he normally encountered as a commercial collector (i.e., bull, lemon, nurse, and sandbar (*Carcharhinus plumbeus*) sharks), while non-average sharks referred to more demanding species (i.e., tiger (*Galeocerdo cuvier*), hammerhead (*Sphyrna* spp.), and blacktip (*Carcharhinus limbatus*) sharks) (Hewitt, pers. com.). Klay's proprietary formula states that the tank dimensions for most average sharks should be as follows (where Z refers to the maximum expected TL of the largest species to be held):

12(Z) long x 5(Z) wide x 2.5(Z) deep

For example, if the largest shark is, or will be, 1.5 m TL, then the tank should be 18 m long x 7.5 m wide x 3.75 m deep (Hewitt, pers. com.). Klay (1977) further believed that obligate ram-ventilating species (e.g., mako (*Isurus oxyrinchus*), great white (*Carcharodon carcharias*), tiger, and blue (*Prionace glauca*) sharks) had more demanding biological requirements and therefore required much larger enclosures. Although Klay's studies are relatively unscientific, and the conclusions generalized, they do represent a potential starting point for the designer of tanks for elasmobranchs. In addition, Klay's article was one of the first to present the swim-glide hypothesis (see below), a behavioral characteristic of elasmobranchs that has implications for tank design and was thus reflected in Klay's formula.

Klay's formula appears to be overgenerous for some elasmobranch species, exaggerates depth requirements (i.e., depth does not need to increase in a linear relationship to increasing horizontal dimension), fails to address differences in tank geometry (e.g., rectangular vs. circular, etc.), and does not account for a disruption of the swim-glide swimming pattern by other animals or obstructions within the tank. As a general rule, horizontal tank dimensions are more important than vertical depth, if a normal swimming pattern is to be maintained (Murru, 1990). In addition, it is possible to maintain hardier species in smaller tanks than Klay's formula would suggest. For example, Ripley's Aquarium of the Smokies, Gatlinburg, Tennessee, USA, successfully maintained eight adult sand tiger sharks, two adult sandbar sharks, two medium-sized freshwater sawfish (*Pristis microdon*), and two adult roughtail stingrays (*Dasyatis centroura*), for almost two years, in a tank measuring 12.2 m in diameter x 1.7 m depth. The tank contained ~195.7 m^3 of water and the life support system included an oversized biological filter.

Indirect evidence suggests that for the long-term, larger tanks are more suitable for holding elasmobranchs. For example, Gruber and Keyes (1981) reported a significant decrease in food consumption by lemon sharks when the animals were moved to a larger pool, indicating a decreased metabolic demand.

Tank shape

Consideration of size alone does not guarantee a successful tank design for elasmobranchs; the shape of a tank can be of equal importance. In general, the swimming pattern of sharks comprises a number of discrete stages: (1) a forward power component, either cruising or bursts of high speed; (2) a rest/glide phase; and (3) a recovery phase (Klay, 1977). This generalized swimming pattern, referred to as the swim-glide hypothesis, enables sharks to conserve valuable energy reserves. As sharks lack a swim bladder for buoyancy control, most species use forward motion, in combination with their rigid pectoral fins, to generate lift. If a tank has restrictive horizontal dimensions, sharks will struggle to maintain their position within the water column, will be unable to complete the swim-glide sequence, and will consume excess energy reserves. If this situation persists, exhaustion and ultimately death can result.

Historically, many different tank shapes have been used for elasmobranchs. Rectangular tanks are common and inexpensive to build, but they can present problems. The right-angle corners of rectangular tanks represent wasted space for most shark species and can exacerbate the acclimatization of new sharks as they expend excessive energy attempting to navigate out of, or recover from entrapment within, corners (Murru, 1990). Rectangular tanks can be improved by chamfering the corners or rounding the corners to large-radius bends.

Cylindrical tanks have been used successfully with many species; however, problems can arise if the tank is not large enough to allow animals to complete species-specific, and/or swim-glide, swimming sequences. If a shark is subjected to these unsuitable conditions it will initially hit the walls, and then swim close to the tank perimeter hugging the wall surface. This behavior disrupts the shark's normal swimming pattern, causes the animal to make constant small turning adjustments, increases metabolic demand, and consumes excess energy reserves. It has been further suggested that wall-hugging may create inefficiencies in oxygen transfer across the gills (Klay, 1977). Hugging the walls can result in external abrasions to the shark's skin, with an associated risk of infection.

Variations on the cylindrical tank include roundabouts, racetracks, or doughnuts, whereby the center of the tank is filled with a structure designed to prescribe a circular path for the animals. The center structure can be exhibit décor (hiding LSS components, holding areas, etc.) or even serve as a visitor's viewing area. The roundabout tank theoretically provides an endless column of water for swimming sharks. However, despite much experimentation, these tanks rarely perform as desired, resulting in the sharks failing to constantly swim in the direction intended. Experience demonstrates that sharks will swim until they encounter an object, whereupon they will turn and swim until they encounter another object (i.e., their swimming patterns are modified by obstacles, as and when they are encountered, rather than by pre-planned routes). This turn-and-go behavior means that prescribed circular paths are less than optimal.

Modern tank designs frequently include figure-eight or dumbbell shapes, allowing for swim-glide swimming patterns. First developed by SeaWorld, San Diego, USA (Keyes, 1979), this design has been used successfully by many other aquariums (e.g., the Pacific shark exhibit at the John G. Shedd Aquarium, Chicago, USA). Other modern tank designs include free-form shapes, most of which are acceptable as long as they have sufficiently large horizontal dimensions and corners greater than right-angles.

Stocking density and life support systems

The design of a life support system (LSS) for elasmobranch quarantine and isolation tanks should focus on maximizing biological carrying capacity (i.e., the capacity of the system to remove biological waste products, ammonia and nitrite) rather than spending valuable resources on optimizing water clarity. Although water clarity is a necessary and important consideration for quarantine and isolation facilities, the LSS does not need to provide the +30 m visibility required for most large elasmobranch exhibits. In order to maximize the functionality of holding and quarantine tanks, LSS designers should focus resources on enhancing or increasing biological filtration and oxygenation rather than fine-particle mechanical filtration. After tank size and tank shape, biological carrying capacity is the most important design consideration for quarantine and isolation tanks. In combination, these three factors determine the overall holding capacity of the quarantine and isolation facility. The biological carrying capacity of an LSS is measured by its maximum allowable bio-load or stocking density (measured in kilograms of animal per cubic meter of water). A typical public display may be bio-loaded at a stocking density of ~1.0 kg m^{3-1} (Garibaldi, 1982). Intensive aquaculture systems may be stocked at 50 kg m^{3-1} or even higher. As quarantine and isolation facilities are expensive to build, and provide a vital support to public exhibits, they should be prepared for the highest practicable bio-loading, well in excess of the typical elasmobranch exhibit. In general, it is usually less expensive to add surface area to the biological filters, than to add more volume to the tank itself. LSS design considerations for maximizing allowable bio-load can be found in aquaculture literature (e.g., Wheaton, 1977; Huguenin and Colt, 1989).

The higher bio-loading of quarantine and holding systems (and systems with high-metabolism elasmobranchs) necessitates an enhanced mass-transfer removal of carbon dioxide (CO_2). If not effectively addressed, excess CO_2 accumulation will cause a decline in the pH of the water with negative physiological ramifications for the animals (refer to Chapter 8 of this manual). Excess CO_2 can be removed via counter-current exchange in foam fractionators, de-gassing towers, and wet-dry biological filters. Designers of LSSs should therefore consider the inclusion of additional foam fractionators, air supplies to de-gassing towers and biological filters, and a back-up aeration/oxygenation system to promote gas exchange and maintain dissolved oxygen levels.

Seawater sourcing (i.e., acquisition or manufacture), pre-treatment (i.e., mechanical filtration, sterilization, etc.), and storage represents another important aspect of LSS design for quarantine and isolation tanks. The relative advantages and disadvantages of natural seawater (NSW) and artificial seawater (ASW) are discussed elsewhere (refer to Chapter 6 of this manual). Considerable cost savings can be achieved if the same raw water pre-treatment and storage systems are employed for both quarantine and holding, and exhibit LSSs. Water storage tanks can be located aboveground, but it is often desirable and more practical to place them underground if they can be installed during building construction. Storage tanks can be made from concrete or fiberglass-reinforced plastic (FRP). The addition of an aeration system will assist the mixing of salts (in the case of ASW) and keep the water well oxygenated for immediate use. A re-circulation pump should be attached to storage tanks, allowing easy transfer of raw water to destination tanks. If freshwater is used (i.e., for manufacturing ASW or for use in exhibits containing freshwater species—e.g., *Potamotrygon* spp.) it should be carefully analyzed for heavy metals and other contaminants, and pre-filtered with activated carbon.

The location and design of tank drainage lines (i.e., surface skimmers and bottom drains) and seawater supply lines (i.e., inlets returning water to the tank) should be carefully considered. Drains and surface skimmers should be carefully screened or protected to prevent animal entrapment. Seawater supply lines should be designed and located to create a slight current for obligate ram-ventilating species.

Effluent water treatment and disposal systems should be carefully considered during LSS design. Effluent water from water exchanges, filter backwashes, foam fractionator overflows, and chemical treatments should all be considered. Local regulations should be carefully reviewed as many municipalities—particularly those that recycle sewerage—do not allow the discharge of seawater into municipal sewer systems. Likewise, the discharge of chemical treatments may be subject to regulation. LSS designers must understand local restrictions on the quality of discharged water and consider the addition of pressurized ozone reactors and/or other similar effluent water treatment systems as required. Effluent treatment is critically important for flow-through systems that discharge water directly to the natural environment (Garibaldi, 1982).

One way to conserve costs (both capital and operational) during LSS design is to divide each

LSS component into smaller additive pieces and only operate those pieces required (i.e., as a function of stocking density). For example, the LSS could be operated with a number of smaller pumps rather than a single large pump, each of the smaller pumps engaged as required. This modular approach to LSS design has the added benefit of built-in equipment redundancy. LSS design considerations are addressed in more detail in Chapter 6 of this manual.

TANK CONSTRUCTION

Quarantine and holding tanks must be built with suitable materials to provide strength (e.g., resistance to head pressure, water surges, impacts from animal collisions), long-term durability (and thus investment protection), water-tightness, non-toxicity (to the animals), and resistance to corrosion.

Recommended construction materials

Concrete

Concrete is an excellent choice for large aquarium tanks, primarily because of its strength (dependent upon mix recipe and steel reinforcing or rebar) and relatively low cost for volume. Concrete relies on internal steel reinforcing, or rebar, to resist tensile stress. Rebar can create problems if not installed correctly (see Hawkins and Lloyd (1981) and Chapter 5 of this manual for a more detailed review of concrete tank construction).

The construction of concrete seawater aquariums is not in the domain of ordinary structural design. Not only should strength be designed into concrete tanks, but a careful selection of reinforcing materials and concrete ingredients should be considered. Particular attention should be paid to joints, intersecting structural elements, reinforcing patterns, secondary stresses, flow of stress within the reinforcing patterns, and penetration details. Above all, tank designers must educate the contractor, since the quality of finished products depends a great deal on construction techniques.

Polyvinyl pipe (PVC) penetrations through cast concrete tank walls can cause leakages at the interface between the different materials, so some form of mechanical water-stop should be incorporated into pipe stubs prior to pouring the concrete. Although holes can be drilled through the concrete after it has cured, and pipe penetrations sealed with mechanical seals (e.g., Link-Seal, PSI-ThunderLine Link-Seal, USA), this should be avoided where possible as it can expose steel rebar to tank water and thus corrosion. Concrete tanks are often limited by cost and logistics to relatively simple shapes (e.g., rectangular), as they must be formed and cast in place.

Fiberglass reinforced plastic (FRP)

Fiberglass reinforced plastic (FRP) is an excellent choice for tank construction, having several advantages over concrete. FRP is inherently strong when molded into the shape of a tank, especially when the tank is cylindrical and/or incorporates a flange at the top, and usually requires no other reinforcing other than the incorporated woven fiberglass mesh or chopped matting. Odd-shaped, tall, or long tanks may require additional structural support, provided by a steel skeleton wrapped within the FRP or, alternatively, structurally robust pultruded FRP shapes may be employed.

PVC pipe penetrations through FRP tank walls are facilitated by FRP pipe fittings, and present little risk of leakage. Depending on size, FRP tanks are usually less expensive than concrete tanks. FRP tanks can be partially buried to improve structural strength and provide easier staff access to the interior of the tank.

FRP tanks can be cast in one piece from a mold or assembled from pre-fabricated panels. If they are pre-fabricated off-site, consider access into the quarantine and holding facility for their final installation. Pre-fabricated panels require bolting and then sealing with either fiberglass resin or silicone. Some pre-fabricated panel tanks are effectively expandable (i.e., by adding straight wall sections between rounded end sections to form a large oval, or by adding additional sections to the top of the walls). Pre-fabricated panel tanks can be pulled apart relatively easily and relocated and assembled for use elsewhere.

Waterproofing and tank coatings

Concrete tanks can be designed and constructed to be completely watertight, although it is recommended that an additional waterproofing material (e.g., Vandex, Vandex International, Ltd., Switzerland) or a post-cure internal tank coating (e.g., Polibrid, Polibrid Coatings, Inc., Brownsville, Texas, USA) be applied. The effectiveness of waterproofing treatments relies on a high-quality design and construction of concrete substrates.

Because FRP is a dense plastic, it is inherently inert, non-toxic, and watertight upon curing. In addition, FRP can be readily painted with epoxy paints or molded with a colored gel-coat. In some cases it may be desirable to coat the interior walls of the tank to produce a smoother, longer-lasting, and non-toxic interior finish, or to color the walls to assist with animal acclimatization. An all-white tank can be disorienting for newly-acquired elasmobranchs, so blue colors which better mimic the oceanic environment, or vertical lines of contrasting colors, which denote the walls, might be preferred for quarantine and holding tanks. If internal coatings are used, they should be completely non-toxic upon curing and compatible with the tank construction materials. In the past, epoxy-based paints (e.g., Sta-Crete, Epmar Corporation, Santa Fe Springs, California, USA) have worked well for this purpose, as have some newer polymer coatings (e.g., Polibrid, Polibrid Coatings, Inc., Brownsville, Texas, USA). The addition of a soft vinyl boundary wall (or a curtain of air bubbles), suspended inside the tank wall, may also be used to denote the outer wall for disorientated animals (Farwell, 2001; Choromanski and Hamilton, 1997). The use of substrate on tank bottoms may be warranted for some batoids, but is generally not recommended in quarantine or holding tanks.

Less-desirable construction materials

Prior to the availability of FRP (or other similar polymer materials) many tanks were constructed from ferrous metals, including galvanized iron, etc. Some of these tanks survive to this day, usually in facilities with flow-through seawater supplies that continuously dilute the toxic metals (e.g., zinc, chromium, etc.) leached from the tank walls. With the availability of modern, non-toxic construction materials, metals of any kind should not be used when constructing quarantine and holding tanks.

The construction of tanks using fiberglass wrapped around a wooden skeleton and wooden sheeting is not recommended. Although inexpensive, the wood has a tendency to rot and the tank to fail structurally. Rigid PVC foam (e.g., Divinycell, American Foam Group, Chambers-burg, Pennsylvania, USA) is a good alternative to wood, providing shape, insulation, and impermeability.

Pond liners, laid on top of open-earth excavations, have been used successfully for open-air elasmobranch exhibits (e.g., Discovery Cove, Orlando, Florida, USA). However, this construction technique is not recommended for quarantine and isolation facilities.

BUILDING CONSTRUCTION

In addition to the tanks themselves, the choice of construction materials has a tremendous bearing on the building that houses the quarantine and isolation facilities. Construction costs increase with the use of non-corrosive materials, but as the saying goes, you get what you pay for. Although there are many brands of pre-engineered, metal building systems available (e.g., Butler Manufacturing Company, Kansas City, Missouri, USA), offering both inexpensive and easily-constructed enclosures, they require additional insulation materials for climate control and special coatings to prevent corrosion in the salty environment. A superior method of construction uses pre-cast concrete or cinder block walls and wooden trusses for the roofing system. This technique reduces the concerns of insulation and corrosion, although such custom designs are generally more expensive. Temporary fabric buildings (e.g., canvas attached to a strong, rigid frame, etc.) have been used for animal holding facilities, but these have poor climate control and an associated high energy cost to operate.

The floor of the quarantine and holding building should be designed and engineered to accommodate the weight of the tanks, water, and associated LSS equipment. Despite all efforts to the contrary, water will leak and spill onto the floor, so careful consideration should be given to an extensive drainage system throughout the building. Drains should be provided for both LSS equipment (e.g., foam fractionator effluent, etc.) and general work spaces, to contain spilled water. Trench drains, although expensive, are ideal for effectively draining large spaces. Drains and piping should be constructed from PVC, acrylo-nitrile butadiene styrene (ABS), or some other saltwater-resistant material, and drains should be fitted with screens to trap debris. Concrete floors should be sloped toward floor drains and coated with a saltwater-resistant non-skid coating (e.g., Terralite, Marbelite International Corp, Sarasota, Florida, USA; or Silikal, Specialty Resin Systems, Waterbury, Connecticut, USA).

Construction specifications should be carefully developed by designers so that inert, non-toxic materials are always selected. Non-toxicity is important not only for materials that will come into direct contact with aquarium water (e.g., PVC pipes, titanium plate heat exchangers, etc.), but also materials that will be located anywhere near the quarantine and holding tanks. There are too many examples of tanks and LSSs built using appropriate materials that are surrounded by buildings and infrastructure made of potentially toxic materials (e.g., PVC piping suspended over a tank using FRP hangers, adjacent to an anti-fire sprinkler system constructed of iron or copper pipe and suspended over the tank using ferrous hangers). The corrosion of inappropriate toxic construction materials and their potential introduction into system water should always be avoided. Many excellent inert construction materials are available, including PVC electrical conduit (e.g., Carlon-Lamson and Sessions Company, Cleveland, Ohio, USA) and FRP pipe hangers and structural members (e.g., Aickinstrut-Tyco International, Portsmouth, New Hampshire, USA). For additional information about aquarium construction materials refer to Garibaldi (1982), and Hawkins and Lloyd (1981).

ACCESS

A quarantine and isolation facility must have unimpeded access for the staff (and husbandry equipment) to the tanks and the animals. It must be possible for animals to be moved easily to any part of the facility (e.g., from a community tank to an isolation tank, etc.). Although it is tempting to fill available space with additional tanks, ample access must be provided for observation, husbandry, cleaning, feeding, LSSs, etc. (Garibaldi, 1982).

The quarantine and isolation facility should be designed to provide clear and easy access for the trucks, trailers, and boats (i.e., an adjacent berth) used to transport animals from collection sites. Loading bays should be adjacent to the quarantine and holding tanks. Vehicle access can be in the form of an internal driveway with doors on either end of the building (especially useful in extreme climates) and access for forklifts or an overhead crane rail should be incorporated into the building design. This equipment is especially useful when handling large animals and heavy transport tanks. Ample space should be available between tanks for the movement of transport and lifting equipment.

All tanks must have windows enabling a clear view of the animals. Windows need to be sufficiently large and strategically located so that all parts of the quarantine and isolation tanks can be seen. It is imperative that sick or injured animals do not go unnoticed. Acrylic is the most desirable material for tank windows because it is optically and structurally superior to glass, it can be polished if scratched, and it can be readily made into any shape, including curves for cylindrical tanks.

Raised catwalks, around the perimeter of quarantine and holding tanks, will provide access for cleaning the tanks and feeding the animals. The floor of the catwalk should be located 0.9 m below the top of the tank and guard rails should be fitted to the outside of the catwalk if it is higher than 0.76 m above the base of the floor. Water levels should be maintained at 0.15-0.30 m below the top of the tank (species-dependent) to prevent animals from escaping, but not so low that it causes access problems for staff. Removable anti-jump guards (e.g., plastic mesh stretched over a PVC pipe frame) can be added to the tank perimeter for additional security.

Similar to large elasmobranch exhibits, large quarantine tanks should have an attached acclimatization and isolation pool for husbandry procedures. This pool should be able to accommodate the largest anticipated species (as per the criteria discussed above) and husbandry staff should be able to enter and exit the pool easily when burdened with husbandry equipment (e.g., SCUBA, shark stretchers, etc.). The acclimatization pool should be shallow (i.e., ~0.9 m) to allow the performance of husbandry procedures. It is particularly useful to have a false floor, capable of withstanding the weight of both sharks and husbandry personnel, which can be raised clear of the water (as per marine mammal husbandry and weighing apparati). It should be possible to completely isolate the acclimatization and isolation pool (using water-tight doors and independent LSSs) from the adjacent quarantine tank. This precaution will enable the true isolation of animals for disease treatment and control, or for the application of specialized environmental parameters (e.g., alternative temperatures, salinities, etc.). Sharks should be able to access the isolation pool with ease (i.e., the pool should have wide entrances, etc.) and the doors should be strong and easy to operate rapidly. If a separate acclimatization and isolation pool is not available, staff may need to capture target animals using surface-deployed nets (e.g., the moveable gantry and net system employed by SeaWorld's Shark Encounter, Orlando, USA), or by draining the tank to workable water levels. In the latter case, it may be desirable to have a system for saving and re-using drained water, such as pre-installed underground tanks, portable pillow-style storage tanks (e.g., Interstate Products, Sarasota, USA), pumping systems, etc.

OTHER CONSIDERATIONS

Husbandry support areas

The design of an elasmobranch quarantine and isolation facility would not be complete without the provision of a husbandry support area. This area should include: (1) a fully-equipped food preparation area with a walk-in freezer, high-capacity refrigerator, and stainless steel sinks and tables that meet National Sanitation Foundation certification (or equivalent) for food safety (www1); (2) a fully-equipped water quality laboratory; (3) an office for animal record-keeping and fire-protected file storage; (4) a necropsy room; (5) a dive locker room with showers and equipment storage; and (6) storage rooms for husbandry equipment and seasonal collecting equipment. Provision should be made for enclosed truck, trailer, and boat storage areas, especially in colder climates. If the quarantine and isolation facility is adjacent to the exhibit building, some or all of these areas may be shared.

Lighting

Natural lighting is ideal as it provides a natural photoperiod and seasonal cues. Skylights can be designed into most buildings and should be considered, especially over tanks. Skylights are a potential site for heating or cooling losses. However, they can save on electrical consumption for artificial lighting. Skylights should be controllable, via louvers or shade cloth. Additional work lighting will always be required.

An advantage of artificial lighting over natural lighting is that it can be finely adjusted, controlled, and manipulated for husbandry purposes (e.g., altering photoperiods to stimulate captive breeding, etc.). Artificial light fixtures should be designed to allow easy and safe access for lamp replacement (e.g., movable lighting systems on tracks, etc.). Artificial lighting should be designed to simulate sunrise and sunset (so that animals are not startled), by slowly ramping illumination up and down, and should be adjustable to replicate season-dependent photoperiods.

There is no published literature on the spectral lighting requirements of elasmobranchs and, with the exception of some deeper-water species, they seem to tolerate a broad range of lighting wavelengths and intensities. Fluorescent, incandescent, and metal vapor-arc lamps have all been used successfully. Combinations of lamp types can be used to address the slow warm-up times of some lamps (e.g., the use of incandescent or fluorescent lights, in lieu of metal halide high-intensity discharge lamps). High-intensity lighting is unnecessary, can lead to excessive algae growth, and create maintenance issues. For additional information on lighting see Hawkins and Anthony (1981) and Spotte (1979).

Heating, ventilation, and air conditioning

Because water temperatures are normally controlled independently by the heat exchanger systems of the LSS, budget-driven designers might be tempted to eliminate the air conditioning of building air spaces. However, in most climates, air conditioning (i.e., heating, cooling, and importantly, dehumidification) will be required. This precaution is especially valuable if tanks are maintained at temperatures below ambient. Not only will husbandry staff be safer, comfortable, and more productive, it will save tremendous wear-and-tear on the building and equipment from condensation. In addition, dry areas must be provided for record-keeping, necropsy, and laboratory areas.

Security

Security systems should be implemented to avoid fire, theft, vandalism, etc. A perimeter fence around the entire quarantine and isolation facility is highly recommended. Electronic surveillance systems are readily available and can be modified to include simple LSS alarms (e.g., water flow switches, water level switches, electrical power status, etc.), as well as fire and burglar alarms. Camera systems can be installed and monitored remotely via the Internet. An emergency electricity generator, with an automatic power transfer switch and adequate fuel supply, is highly recommended, especially in areas where power is frequently interrupted by severe weather.

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