The Elasmobranch Husbandry Manual:

Captive Care of Sharks, Rays and their Relatives

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Chapter 11

Elasmobranch Acclimatization and Introduction

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Abstract: The long-term success of an elasmobranch acquisition depends not only on how the animal is captured and transported, but also on its careful acclimatization and introduction. Acclimatization is undertaken when moving animals between different environments and involves a process of slowly changing parameters (especially water parameters) in which the animal is held, or transported, to meet the environmental parameters where it will ultimately be living. Acclimatization minimizes the physiological stress inherent in a rapid transition between different environmental parameters. Introduction refers to the process of moving an elasmobranch to its destination environment (e.g., exhibit, experimental tank, etc.), in some cases requiring capture and physical restraint of the animal, and its subsequent careful release. A program of post-introduction monitoring is essential to success, allowing workers to anticipate problems and intervene in the event of complications.

The acclimatization and introduction of an elasmobranch to its destination environment (e.g., exhibit, experimental tank, etc.) represents the final stage of an animal acquisition and must be carefully planned in conjunction with other aspects of a relocation strategy. While the science of elasmobranch husbandry continues to improve, acclimatization and introduction of fishes remains inexact and is often given cursory treatment for many elasmobranch species. It is clear, however, that an animal's expected survivability in captivity depends directly on how well the animal is captured, transported, acclimatized, and introduced.

For the purposes of this chapter, acclimatization refers to the gradual change of environmental parameters, predominantly water quality, to minimize physiological stress imposed on animals moved between different environments (e.g., from a transport vessel to an exhibit, etc.). During acclimatization, prophylactic treatments may be applied, and wounds and abrasions evaluated. Introduction refers to the process of moving an elasmobranch to its destination environment (e.g., exhibit, experimental tank, etc.), in some cases requiring the capture and physical restraint of the animal, and its subsequent careful release.

The basis for what we know about elasmobranch husbandry has been developed predominantly through educated guesses and trial and error. The collection, transportation, and maintenance of many different elasmobranch species was attempted, modified, and attempted again, before success was achieved. Clark (1963), and Gruber and Keyes (1981), published early work on elasmobranch transportation and acclimatization. Since then, many workers have added to the science (Cliff and Thurman, 1984; Hewitt, 1984; Murru, 1990; Smith, 1992; and Lowe, 1996).

In addition to the information reported in the literature, many successful strategies have been developed through accumulated practical experience. It is only through such experience that many of the more subtle indicators of elasmobranch health have been recognized. In many cases, these subtle signs will indicate an animal's status well before quantitative empirical data can confirm it. Changes in ventilation rate, body coloration, attitude in the water, swimming behavior, etc., will all speak to deeper changes at a biochemical and physiological level. Understanding these subtle changes, both within and between species, is crucial to the development of a suitable acclimatization and introduction regime. Responding quickly to negative trends can often be the difference between success or specimen mortality.

Biochemical and physiological changes incurred during capture and transportation, and their impact on survivability, are discussed in detail in Chapter 8 of this manual and repetition of that information will be minimized here. Similarly, quarantine procedures and medical treatments are covered in more detail in Chapters 10 and 29 of this manual, respectively.

ELASMOBRANCH ACCLIMATIZATION

Environmental changes (e.g., a change to water parameters) and the associated physiological stress, directly affect the health of sharks, rays, and their relatives. Elasmobranchs, like other fishes, need time to become accustomed to a change in water chemistry. Acclimatization should therefore be undertaken whenever an animal is moved from one environment, where it has been living for an extended period, to a new environment in which the water chemistry is different.

The importance of acclimatization

Rapid changes in water chemistry or temperature may cause physiological distress to fishes, contribute to disease susceptibility, and even cause death (Stoskopf, 1993). However, as Noga (1996) states: "…many fishes can tolerate stressful conditions if they are introduced to the environment slowly…". Therefore, an excellent axiom for the new aquarist is as follows: poor water quality is bad for fish health, but rapidly changing water quality is even worse.

The goal of acclimatization is to slowly change the water parameters in which an animal is held, or transported, to meet the parameters of the water where the animal will ultimately be living, with a minimum of imposed stress (Spotte, 1992). A complete knowledge of environmental parameters (e.g., temperature, pH, salinity, oxygen concentration, nutrient concentration, lighting regime, etc.), from both the source and destination environment, is therefore essential to best acclimatize a target animal.

In general, acclimatization provides an opportunity to undertake veterinary procedures (e.g., blood sampling, prophylactic treatments, physical inspections, etc.), as the target animal is confined within a small acclimatization vessel and easily accessible. The decision to extend the duration of acclimatization to allow these procedures should be weighed carefully, and only undertaken if the elasmobranch is stable. Over time, an animal will modify the water chemistry within a transport, acclimatization, and/or introduction tank. A balance should be struck between the time it takes to acclimatize and introduce a specimen, and the harmful effects that increasingly changed water chemistry will impose. An unnecessarily delayed introduction may compromise the chances of a successful operation.

Acclimatization and water parameters

Acclimatization can, and frequently should, commence the moment an animal is collected. Parameters can be adjusted gradually throughout transportation, taking into consideration the characteristics of the water at both the collection site and the final destination. Where possible, long transports should be broken into small stages, with corresponding water exchanges, reducing the acclimatization burden on arrival. An elasmobranch will modify the water chemistry of a transport or acclimatization container by consuming oxygen, and excreting nitrogenous wastes, CO_2, and other metabolic toxins. Acclimatization, through water exchanges, addresses each of these aspects of declining water quality, ultimately improving the immediate environment. Many stress-related chemicals are released during the period of initial capture and confinement, so a water exchange relatively early in the transport (e.g., 2-3 hours after confinement) will have immediate beneficial results.

Temperature, pH, and nutrients

In general, temperature, pH, and nutrients can be modified by the exchange of contaminated water with untainted water from the destination environment. Tolerable changes of temperature and pH, and suggested adjustment times, have been estimated from empirical data. Temperature differences of 1.0-2.0 ºC should be equalized in no less than 30 minutes, while pH should not change more than 0.2-0.4 over the same period (Stoskopf, 1993). Where pH levels are not life-threatening, pH should not change by more than 0.2-0.5 each day (Noga, 1996). More rapid parameter changes may cause distress, manifested as blanching, slow or exaggerated swimming and stalling, and difficulty maintaining equilibrium. In the wild, an elasmobranch may swim through temperature gradients greater than 1.0-2.0 ºC with no ill effect, but as a stressor during acclimatization such changes should be minimized. Ensure that pH never drops below 6.0, as this level approaches toxicity for many elasmobranchs.

Nitrite-induced methemoglobin formation reduces the oxygen carrying capacity of the blood (Stoskopf, 1993; Noga, 1996) and should be avoided by maintaining <0.10 mg l^{-1} nitrite ion at all times. Chronic ammonia toxicity, causing kidney damage, should not occur during short-term acclimatization and introduction; however, it may occur during transportation or long-term holding (Thurston and Russo, 1984). Never allow ammonia concentrations to exceed 1.0 mg l^{-1} and where possible, reduce ammonia concentrations to <0.10 mg l^{-1} before moving animals into a new system. In some cases, the use of ammonia sponges may be indicated (e.g., AmQuel®, Novalek Inc., USA), but these chemicals should always be used in conjunction with a pH buffer. Ammonia becomes increasingly toxic as pH increases (Post, 1987) so it is critical to adjust or dilute ammonia concentrations before modifying pH. It should be noted that ammonia toxicity is further affected by temperature and salinity and an understanding of these dynamics is advised (refer to Spotte, 1992).

Dissolved oxygen

Dissolved oxygen (DO) concentrations within an acclimatization and introduction container are vitally important. DO (as percentage saturation) should never fall below 85% and ideally should be maintained at 95-100%. During the acclimatization of highly active, ram-ventilating species DO levels can be as high as 150% without apparent harmful effects. In addition, empirical evidence suggests that hyper-oxygenation may have a mildly sedative effect on most elasmobranch species, a useful side-benefit during transport and acclimatization. The potentially harmful effects of hyper-oxygenation (e.g., respiratory depression and subsequent blood acidosis) must be understood and weighed against the benefits.

When DO needs to be stabilized or raised, it is a simple matter to enhance gas exchange across the water surface by adding air diffusers (Spotte 1973; Noga, 1996). The air bubbles rise to the surface, causing surrounding water to rise as well. Some gas dissolves from the air bubble directly into the water, but this quantity is small compared to the advantage of moving oxygen-poor water to the surface, where most gas exchange takes place. A more effective means of increasing DO is to add pure oxygen bubbles via the intake of a submersible pump (e.g., a 12 or 24 Volt bilge pump) or diffuser. It is important that oxygen is introduced as fine bubbles, promoting oxygen dissolution (Gruber and Keyes, 1981; Smith, 1992; Murru, 1990). Maintaining an oxygen-rich atmosphere immediately above the water surface can be achieved by using a well-fitted lid, which also prevents animals inadvertently exiting the acclimatization vessel.

Acclimatization and specimen origin

If elasmobranchs are acquired from different geographic regions, then water parameters, exhibit topography, and species combinations may be the result of a compromise between different environments. Such compromises required for a multi-species exhibit may affect the long-term health, welfare, and longevity of a given species, and importantly, how that species will be acclimatized and introduced.

It is quite common for facilities to import elasmobranchs from international sources and this may necessitate specimens undergoing a rapid seasonal reversal. Temperature is the most obvious change to water quality and this should be carefully considered when developing transport schedules. It should be recognized that many species will be forced to undergo relatively rapid metabolic changes which will then affect appetite and other aspects of their behavior. Maintaining a homogeneous transport temperature is preferable; however, if a significant temperature differential is anticipated at the final destination, then a gradual variation can be applied during the transport to reduce acclimatization periods on arrival.

Another consideration, when moving animals between different seasons, is the change in photoperiod. Wherever possible, destination environments should try to match photoperiods encountered at the source.

Acclimatization by elasmobranch type

Elasmobranchs may be categorized into four basic types (essentially the same as those described in Chapter 5 and Table 5.1 of this manual), requiring different acclimatization times and techniques. Factors determining elasmobranch type include species size, ecology, spatial requirements, mode of ventilation, and response to stressors. Table 11.1 presents a review of the four basic elasmobranch types, showing representative species.

Benthic

During acclimatization, source water should be diluted by replacing half the volume over a period of no less than 30 minutes. Use a small diameter siphon hose (i.e., <12 mm diameter) to ensure that the water change is slow. For larger transport containers use a larger diameter hose, but do not complete the dilution in less than 30 minutes. Water from the destination aquarium should be used wherever possible. Since this group generally responds well to confinement, it is preferable to adjust parameters as slowly as possible. Ensure that oxygen concentration remains above 85% and below 100% saturation.

To minimize stress lighting should be dimmed when first opening a transport box, particularly if the lid has been closed throughout transportation. Gradually increase lighting to the lowest level that allows specimen behavior and condition to be monitored. Shortly before specimen introduction (e.g., ~15 minutes), lighting illumination should be slowly raised to levels approximating conditions within the destination environment.

If animals regurgitate, defecate, or produce excessive mucus, remove solid particles immediately and mechanically filter the water if at all possible. Some rays produce copious amounts of mucus that can interfere with oxygen uptake. Ensure that any excess wastes are removed. Transport water should always be sent to waste and not introduced into the destination exhibit. This practice will reduce the chances of introducing disease.

Semi-pelagic

Unless otherwise indicated, follow the guidelines for benthic species. Acclimatization containers should be sized (i.e., ~2.0-4.0 m^3) to allow specimens to swim freely for brief periods. Square or rectangular containers are generally preferred as circular containers may cause the animal to swim along the perimeter, turn constantly, and consequently generate a higher oxygen debt. Although rays and skates typically tolerate longer transport and acclimatization times, they too require room to swim as this facilitates blood circulation and the excretion of metabolic toxins.

Dilute source water by replacing half the volume over 60 minutes. For large volumes, it may be necessary to remove old water from the container before adding new water. If specimens are coping well, an additional dilution (~50%) should be performed to dilute the original transport water by ~75%. This additional dilution should bring water quality parameters within acceptable limits. Dissolved oxygen should be maintained between 85% and 100% saturation, as per benthic animals. However, consider the application of slightly higher oxygen levels when animals are hyperactive (e.g., 90%-105% saturation). In this case, pure oxygen, rather than a supply of air, should be used.

Pelagic (non-obligate ram ventilator)

Non-obligate ram ventilators frequently will be transported in confined containers, due primarily to the space and weight constraints of transport vehicles. Transport containers are usually accompanied by water treatment and oxygenation systems, to provide elevated DO levels. These elasmobranchs should be acclimatized as per semi-pelagic animals, although acclimatization times should not exceed 60 minutes. These animals must be watched closely during acclimatization, as they can easily become distressed. If distress is evident, slowly adjusting water parameters becomes of secondary importance and specimens should be moved into a larger tank or the destination exhibit immediately, allowing them to swim freely.

Table 11.1 Four generalized categories of elasmobranch type, showing issues to consider during specimen acclimatization and introduction.

Category description	Representative species	Typical size	Transportability	Oxygenation	Water circulation	Acclimation duration
1. Benthic						
Sedentary species with low metabolism. Able to actively ventilate. Spend majority of time on bottom without accumulating an oxygen debt. May be attacked by established exhibit residents.	Bamboo sharks (Hemiscylliidae) Cat sharks (Scyliorhinidae) Wobbegong sharks (Orectolobidae) Horned sharks (Heterodontidae) Stingrays (Dasyatidae) Round rays (Urolophidae)	< 1.0 m TL	High	Normal	Preferred	Extended: 0.5-2.0 hours
2. Semi-pelagic						
Free-swimming species. Periodically rests on bottom. Able to actively ventilate. Able to swim in confined areas and negotiate obstacles. May be attacked by established exhibit residents.	Smooth-hound (*Mustelus mustelus*) Spiny dogfish (*Squalus acanthias*) Whitetip reef shark (*Triaenodon obesus*) Leopard shark (*Triakis semifasciata*) Cownose ray (*Rhinoptera bonasus*)	1.0-1.5 m TL	Medium to High	Normal to High	Preferred	Extended: 1.0-2.0 hours
3. Pelagic (non-obligate ram ventilator)						
Large, pelagic species. Some species rest on bottom for limited periods, but normally need to swim to aid respiration and circulate body fluids. Can negotiate obstacles. May be attacked by, or attack, established exhibit residents.	Sand tiger shark (*Carcharias taurus*) Lemon shark (*Negaprion brevirostris*) Spotted eagle ray (*Aetobatus narinari*)	1.5-2.0 m TL	Medium	Normal to Very High	Necessary	Limited: 0.5-1.0 hours
4. Pelagic (obligate ram ventilator)						
Large, pelagic species. Relatively fast metabolism and high oxygen demand. Swim constantly to create hydrodynamic lift, aid respiration, and circulate body fluids. Unable to negotiate tight corners and requires large horizontal distances to allow uninterrupted swimming patterns. Low tolerance to confinement. Should be introduced into a sufficiently large aquarium as quickly as possible for any chance of long-term success. May attack resident animals.	Blacktip shark (*Carcharhinus limbatus*) Caribbean reef shark (*Carcharhinus perezi*) Great white shark (*Carcharodon carcharias*) Sevengill shark (*Notorynchus cepedianus*) Blue shark (*Prionace glauca*) Whale shark (*Rhincodon typus*) Scalloped hammerhead shark (*Sphyrna lewini*) Giant manta (*Manta birostris*) Pelagic stingray (*Pteroplatytrygon violacea*)	1.0-3.0 m TL	Low	Very High	Mandatory	Minimal

Dissolved oxygen should be applied as per semi-pelagic animals. However, if abnormally high ventilation rates are observed, elevated oxygen levels should be applied (i.e., 95%-110% saturation). In this case pure oxygen, introduced via a bilge pump (to maximize dissolution), is recommended.

Pelagic (obligate ram ventilator)

Obligate ram ventilators typically have high oxygen requirements and need to swim constantly. If an obligate ram ventilator has been in transit for >3.0 hours, it may not tolerate further confinement for acclimatization purposes. On arrival, a quick assessment of the animal's condition should be made to determine if normal acclimatization protocols should be bypassed. If it has been deemed appropriate to acclimatize an obligate ram ventilator then transport water should be rapidly diluted by 75% over a period of 20-30 minutes. If the animal becomes distressed it should be moved into its destination exhibit immediately. Dissolved oxygen should be applied at elevated levels (i.e., 95%-150% saturation).

SPECIMEN ASSESSMENT

It is important to carefully assess the condition of an elasmobranch throughout acclimatization to detect possible deterioration. Any potential negative trends should be counteracted immediately, as delay can result in specimen mortality. A detailed report of capture techniques, transport times and conditions, and water quality parameters will be invaluable in assessing an animal's condition and formulating an effective acclimatization regime.

The clinical assessment of an animal during acclimatization is often quite subjective given that the animal's history may be largely unknown. Where possible, blood should be drawn and biochemistry analysed. This information is invaluable when formulating long-term medical treatments, future transports, and acclimatization regimes. Blood-gas monitors give immediate results and provide an opportunity to apply informed corrective therapies as and when they are required.

Acclimatization provides an ideal opportunity to inspect specimens, since they are accessible and usually docile. If no further isolation is anticipated prior to specimen release, then acclimatization represents the final opportunity to check for abrasions, lacerations, external parasites, and other unusual or life-threatening conditions. During this time, short-term clinical procedures may be undertaken and can include:

1. Application of topical medications;
2. Application of injectable antibiotics or other therapies;
3. Acquisition of blood samples;
4. Removal of capture tags or fishing hooks;
5. Measurement of baseline husbandry data (e.g., length, weight, etc.);
6. Removal of external parasites (manually, or through the use of medicated baths);
7. Confirmation of sex and reproductive status (possibly influencing the method and timing of specimen introduction); and,
8. Application of sutures.

Many profound internal problems, that may threaten the life of an elasmobranch (e.g., hypoxia, acidosis, hyperkalemia, etc.), present few or no external signs but may be suspected if there is a significant deviation from the normal aspect and behavior of healthy conspecifics. Familiarity with a species will allow recognition of unusual behaviors or changes in appearance that may indicate a problem during acclimatization and introduction. Key areas to consider include, but are not limited to, the following:

1. Changes to ventilation rate (both elevated or depressed);
2. Changes to body coloration (blanching can indicate shock, but may also be normal—e.g., many rays mimic container coloration, in this case a positive sign);
3. Swimming behavior (e.g., hyperactivity can indicate distress and exaggerated swimming can indicate increasing exhaustion);
4. Body attitude and orientation, especially while swimming; and
5. Responses to stimuli.

It is essential to assess specimens quickly, on arrival, and at regular intervals, to guide the most appropriate acclimatization and introduction strategy. If negative trends are observed, steps must be taken to mitigate trends and, in some extreme cases, discontinue acclimatization or treatments and release specimens into destination environments immediately.

ELASMOBRANCH INTRODUCTION

Ideally, all new animals should be quarantined, to control disease and allow for observation of behavior (e.g., feeding, swimming, etc.), before introduction into their final environment. Unfortunately, this requirement is often impractical for larger specimens. In this case, it is important to carefully observe new specimens, following introduction, to ensure both a healthy status and normal feeding behavior.

Wherever possible, it is preferable to maintain some level of control over the animal until it is clearly healthy and apparently able to survive in its new environment. If at all possible, exhibit design should include a large, smooth-walled isolation pool, directly linked to the main filtration system and exhibit.

Careful thought should be given to the introduction of multiple specimens and, if possible, plan arrivals to minimize compatibility problems. It is better to habituate potential prey species to a system before predators are introduced. Many species will benefit from being introduced as a group (e.g., Myliobatids), and it may be better to hold small numbers of specimens until a larger group can be released simultaneously.

Lighting should be at lowered levels when animals are first introduced and it is usually best to maintain some light throughout the first few nights, minimizing predation and assisting in orientation. Full-strength lighting may increase stress levels and should be avoided. The ideal intensity and diurnal variation of lighting is species-dependent and therefore it is often best to have a variety of “night light” intensities in different parts of the aquarium. This accomodation allows animals to choose an intensity under which they are most comfortable.

Elasmobranchs may be introduced into a new exhibit using four basic methods:

1. Lifted into the exhibit by stretcher and immediately released;
2. Lifted into the exhibit by stretcher, restrained near the surface within a well-oxygenated current for a short period, and then released;
3. Lowered into the exhibit within a restraining vessel (e.g., the vessel used to transport the animal) and gently released; and
4. Maintained in an adjoining holding pool, or a floating cage within the exhibit, for an extended period (e.g., a week) and then subsequently released.

A basic summarized checklist of equipment and logistics required for an elasmobranch acclimatization and introduction has been provided in Table 11.2.

Handling and restraint of elasmobranchs

Personnel handling elasmobranchs should always wear protective clothing/wetsuits and sterile latex gloves to protect the skin of the specimen. When handling or restraining elasmobranchs, avoid using unprotected nets as they may abrade the skin and lead to secondary infection. Heavy plastic bags, or stretchers made of canvas or plastic tarpaulin, are typically used to restrain or move elasmobranchs. It is best to have a selection of stretcher sizes and designs to allow the greatest flexibility of use. A large, 1.0 mm thick, plastic bag has been used successfully to capture and restrain a 4.0 m TL tiger shark (*Galeocerdo cuvier*). The bag was submerged inside the shark’s holding pool and the animal encouraged to swim inside. Once the shark was caught, staff were able to safely enter the water and maneuver the shark onto a stretcher. To remove the shark from the plastic bag, staff cut along a predetermined sacrificial seam. Minimal abrasions were incurred to both shark and personnel (Long, pers. com.). Self-draining stretchers with poles have the advantage of allowing more people to assist with lifting and restraint. Usually the most difficult specimens to lift out of the water are rays, because they are slippery and relatively heavy for their size. A self-draining, circular, or “dish-shaped”, stretcher is often better suited to moving rays.

When handling sharks, consideration should be given to covering the mouth of the animal, and it is best if the system used is inherent in the design of the carrying device. Preventing significant lateral movement of the head and body is advantageous. Once released, if an animal does not immediately swim out of its restraining bag or stretcher, gently tracing a hand along the lateral line can often stimulate the animal to start swimming (Gruber and Keyes, 1981).

Holding pools and floating cages

Where possible, holding pools linked to the main system, or floating cages, should be used to habituate elasmobranchs to their new environment, allowing them to normalize their swimming and feeding behavior. This strategy reduces the chances of new specimens becoming prey when they are finally released into an exhibit, as the behavior of newly-arrived and stressed animals will frequently stimulate resident animals to attack (Lai, pers. com.). Floating cages can be made from heavy and perforated clear plastic

Table 11.2. Summarized checklist of equipment and logistics required for elasmobranch acclimatization and introduction.

Consideration	Critical Information and Equipment	Strategies and Tips
Transport regime	Specimen condition. Journey duration. Water quality.	Undertake water exchanges at strategic locations. Brief all personnel in advance. Minimize delays at customs in advance. Ensure that all transport vehicles are reliable. Healthy animals respond better to acclimatization and introduction.
Cargo handling	Container dimensions. Container volume. Container weight.	Remove portion of water to make handling easier. Forklifts represent a good alternate unloading strategy.
Access	Doorway dimensions. System to access upper floors.	Move specimen to acclimatization site in the transport container. Ensure tank at acclimatization site is suitably sized for extended holding. Design specimen holding spaces with plenty of access space. Design specimen holding spaces with lifting systems.
Water circulation	Hoses for siphons. System for waste water disposal. Power outlets (for pumps).	Siphons are failsafe and avoid the need for electricity. Hose size will determine water flow rate. Ensure suitable head pressure to drive siphons. If pumps are required, use 12-Volt batteries and bilge pumps. Introducing water with buckets is not recommended for large specimens.
Lighting	Power outlets (for lights). Reliable and adjustable lights.	Use low lighting to minimize specimen stress. Lighting should be variable to allow specimen inspection and safe handling. Underwater torches are useful.
Oxygenation	Oxygen bottles. Oxygen regulators. Oxygen airstones/diffusors. Weights for airstones/diffusors.	An excess of oxygen bottles is better than running out at a critical moment. If oxygen is unavailable, air is essential. Dive cylinders can be used as an air supply in an emergency.
Test equipment	Testing equipment for water parameters.	Testing equipment for oxygen, temperature, pH, salinity, and ammonia. Testing equipment for blood-gas, lactate, etc., if required. Equipment should be waterproof, easy to use, reliable, and give rapid results. Assign someone to record all data and give updates.
Other equipment	Stretcher. Scales and weighing slings. Flexible tape measures. Hand tools (for hook or tag removal).	

sheeting, heavy plastic mesh, or rigid plastic bars (e.g., PVC pipes). Floating cages should always incorporate perforations or mesh to allow a free exchange of water with the destination exhibit, as water quality can deteriorate quickly in the relatively small volume of a cage.

Water quality in destination environments

Any enclosure designed for a new elasmobranch must have a fully functioning water treatment system, mature biological filters, and optimal water parameters. Adding elasmobranchs to an exhibit implies an increased biological load and nutrient concentrations (e.g., ammonia, nitrite, and nitrate) must be closely monitored to ensure that they are stable and do not reach toxic levels. Poor water quality will almost certainly reduce the chances of a specimen adapting to its new environment, exacerbate post-transport trauma, promote the proliferation of disease, and eventually may result in mortality. Despite this cautionary approach, it may not always be practical to introduce new specimens into an optimal environment, and exposure to immature filtration systems and compromised water quality may result. The purpose of acclimatization must remain the process of gradually adjusting specimens to destination water quality, despite the less-than-ideal environment. Most elasmobranchs can tolerate a wide range of water quality parameters as long as they are given sufficient time to adapt. As a new system matures the water quality should improve gradually and the animals will correspondingly adapt to this gradual change.

In some circumstances, it may be necessary to manipulate water quality within a new system to reduce the impact of a specific water parameter (e.g., lowering pH to reduce the toxicity of ammonia). Many facilities using synthetic seawater maintain a salinity lower than seawater to control disease or save on costs associated with sea salt acquisition. With appropriate acclimation many elasmobranchs can tolerate salinity levels slightly lower than normal seawater. It should be emphasized, however, that some species will not tolerate low salinity when other environmental stressors have lowered overall tolerance to water quality challenges.

Obstructions in destination environments

When an elasmobranch is released, it should be prevented from hitting the walls or other obstructions within the pool. The most likely time for an animal to hit the walls is when it is darting away as it is first released. It is therefore important to release the animal so that it is unlikely to immediately encounter an obstruction (e.g., orientated in the direction of the largest horizontal dimension of the exhibit, or possibly parallel to a long wall). In some cases it may be necessary to station personnel around the edge of an exhibit to ward animals away from the walls. If an animal approaches a wall, personnel wave a conspicuous PVC pole (e.g., wrapped candy-cane style with colored tape) in front of the animal to ward it away. If pelagic animals are expected to hit walls repeatedly within an exhibit, it is possible to line the pool with a curtain of heavy plastic or tarpaulin mounted 30-50 cm away from the walls. This barrier provides a cushion to animals that swim toward the walls and will often ward them away before they strike the solid surface of the wall itself. A barrier of this type should be installed before new animals are introduced, and staff should be aware that animals could conceivably get caught between the curtain and the walls.

Introduction by elasmobranch type

Benthic

Benthic elasmobranchs can usually be released directly into an exhibit as they are unlikely to crash into a wall by rapidly swimming away. Resident animals should be fed 3-4 hours beforehand and a regular feeding schedule maintained while introduced animals adjust to their new environment. If the predation of newcomers by existing inhabitants is a concern, the exhibit should remain illuminated for at least 24 hours as this will discourage aggression and facilitate monitoring.

Semi-pelagic

When possible, semi-pelagic elasmobranchs should be introduced via a holding pool or floating cage, following a 4-7 day staging period. This duration may be reduced for more active sharks if it is felt they won't tolerate the confined space for an extended period. If an animal exhibits signs of stress, the causes should be investigated and immediately rectified. In some cases this may necessitate the release of the animal into the exhibit. Resident animals should be fed 3-4 hours before new animals are released and illumination should be maintained for at least 24 hours thereafter to reduce the risk of predation.

Pelagic (non-obligate ram ventilator)

Ideally, non-obligate ram ventilators should be maintained in a sufficiently large holding pool or floating cage, for a 1-2 day staging period, before final release into their new environment. This requirement may overstretch the resources of most institutions. If this is the case, non-obligate ram ventilators can be gently lifted into an exhibit using a stretcher and released directly into the water. Resident animals should be fed 3-4 hours before new animals are released and illumination should be maintained for 48-72 hours, to reduce the risk of predation. A 24-hour watch should be maintained for at least one day to monitor the status of new animals.

Sand tiger sharks (*Carcharias taurus*) maintain a small amount of air in their gut to achieve neutral buoyancy. This air may be lost during handling or transport. Some commercial collectors intentionally remove air from sharks to encourage negative buoyancy within the transport container, effectively immobilizing the specimen. Once introduced into its new environment, it is not unusual to observe a sand tiger shark swimming rapidly to surface and swallowing or “gulping” air. This behavior is quite normal, and indeed is desired. If a sand tiger shark does not achieve optimum buoyancy within the first few days of release, it may be necessary to intervene and artificially introduce air into the gut using a flexible tube.

Pelagic (obligate ram ventilator)

The needs of pelagic obligate ram ventilators are not well understood and are still under investigation. However, anecdotal information from various aquariums, about specific species, can lead us to some general conclusions.

Bonnethead sharks (*Sphyrna tiburo*) have become relatively common in public aquariums over the past 20 years, with many reproducing in captivity. In general, this species should be transported and acclimatized as per semi-pelagic elasmobranchs. Transport and acclimatization tanks should have rounded corners and lids. This species has been known to jump out of small tanks. Transport times for sharks >1 year of age (i.e., >85 cm TL) should be kept to a minimum, and dissolved oxygen levels should be maintained at >95% at all times. Acclimatization times will depend on animal size and overall post-transport condition. Larger specimens (>1.5 m TL) are easily stressed during transport and may not respond well to acclimatization in a small container. If signs of distress are evident, specimens should be moved immediately to the final exhibit or a large holding pool. Where possible, bonnethead sharks should be introduced via a holding pool or a floating cage. Bonnethead sharks are readily preyed on by large elasmobranchs and teleosts, so take great care choosing your initial species list and carefully monitor new specimens during introduction.

Scalloped hammerhead sharks (*Sphyrna lewini*), close relatives of the bonnethead shark, are less common in public aquariums but have been successfully displayed in Asia, Europe, and the USA. Young, small (<1.0 m TL) sharks are the best candidates for transportation, and high dissolved oxygen levels (~85-120% saturation) are critical throughout (Young et al., 2002). If sharks are able to swim freely within the transport container, a 30-minute acclimatization period is possible on arrival. The skin of scalloped hammerheads is easily bruised and the location of their eyes, at the extremities of the “hammer” (i.e., cephalofoil), make them vulnerable to damage. Thus, no nets can be used and handlers must wear sterile latex gloves. In some cases, a soft wet protective cloth may be placed over the eyes during handling. Hammerheads should be moved using a rigid stretcher (e.g., a net stretched tightly over a PVC frame and covered with soft plastic). Introduction via a floating cage for specimens <1 meter TL is recommended. Animals should only remain in the floating cage for a sufficient period to allow their swimming patterns to normalize, before final release.

Oceanic whitetip sharks (*Carcharhinus longimanus*) have been maintained successfully in aquariums for up to two years (Hamilton, pers. com.; Uchida, pers. com.). Acclimatization for this species is secondary to the demands of its physiology and the requirement to swim unimpeded. The key factor for success with oceanic whitetip sharks is to minimize transport times and introduce specimens into their final exhibit immediately on arrival.

The great white shark (*Carcharodon carcharias*) is yet to survive in captivity for more than 17 days. Great care and minimal handling during capture and transport are critical to success. The shortest possible transport times are recommended, and once again, acclimatization is secondary to the animal’s requirement to swim freely. It has been observed that this species does not respond well to physical obstructions within an exhibit, so personnel will be required to ward a new specimen away from the walls during the first few days. It is recommended that displaying great white sharks should not be attempted without adequate research, resources, and experience. The same general recommendation can be made for mako (*Isurus* spp.) and thresher (*Alopias* spp.) sharks. Although there have been some recent positive attempts at maintaining these species, no long-term successes have been recorded.

In general, feeding and lighting regimes during the introduction of obligate ram ventilators should be same as for non-obligate ram ventilators. These elasmobranchs require high concentrations of dissolved oxygen all the time. Constant monitoring and adjustment of oxygen concentrations should remain a priority throughout transport, acclimatization, and introduction.

“Walking” distressed elasmobranchs

If pelagic sharks have been excessively hyperactive or traumatized during transport, acclimatization, or introduction, they may rest on the bottom of the tank when released into the final enclosure. This is generally considered to be a warning sign that the animal is distressed and may be at risk of permanent or even fatal physiological changes. In particular, obligate ram ventilating animals cannot remain in this condition for any extended period, as they need to remain swimming to facilitate gas exchange and systemic circulation. If a pelagic animal is observed “resting” on the bottom, following introduction, it should be gently encouraged to swim as per its natural behavior. If the shark continues to stall and fall to the bottom, two courses of action are available. The first course of action is to “walk” the shark. This procedure requires a diver to walk or swim beside the shark, while supporting it under the belly, and move it forward into the prevailing current. This process aids gas exchange, helps void metabolic toxins, and ultimately encourages the shark to start swimming by itself. There is some concern that the metabolic activity induced by "walking" elasmobranchs may compound post-transport trauma, in particular lactic acid accumulation (Stoskopf, 1993). However, the authors have found that "walking" an animal for 5-10 minutes, immediately after it has been removed from the confines of a transport container, can have a beneficial influence. In one case, a distressed lemon shark (*Negaprion brevirostris*), having blanched skin and an immobile trunk, was walked for over an hour with positive results. Should "walking" an animal yield no immediate reaction, it may be deemed appropriate to place the animal in front of an oxygen-rich (i.e., ~100-120% oxygen) stream of water and not disturb the animal further. This procedure will partially simulate ram ventilation and aid the animal in overcoming incurred acidosis.

It is quite common for sand tiger sharks to "rest" on the bottom after an arduous transport and this should not cause immediate concern, especially if color is normal (i.e., dark and homogeneous) and respiration is regular. This species is quite capable of buccal respiration and seems to benefit from a brief period of post-transport inactivity. In addition, if a sand tiger shark lies on the bottom it does not necessarily indicate buoyancy problems, unless a prolonged period of labored, non-horizontal swimming (i.e., with the tail down) has been observed.

Post-introduction monitoring

Once an elasmobranch has been introduced into a new exhibit, it should be carefully monitored for at least 24 hours. Signs of physiological complication (e.g., abnormal ventilation rates, unusual swimming behavior, etc.) should be assessed and corrective measures undertaken where deemed appropriate. It may be necessary to augment dissolved oxygen concentrations within the new environment for the first few days.

Close attention should be paid to resident animals to allow intervention should aggression or risk of predation become evident. In multi-species tanks this may be difficult or may even occur before preventative action can be implemented. In some cases it may be necessary to move other animals to a separate holding tank, allowing time for new animals to adjust to the exhibit without the complication of aggressive residents. An alternative option can be to divide an exhibit in half using a net or perforated plastic sheeting, which should be taut to prevent animals becoming entangled. Of course, it is preferable to avoid obvious compatibility problems during exhibit planning and by introducing animals in an appropriate sequence.

Personnel and SCUBA equipment should be prepared for direct intervention before new animals are introduced. Consideration should be given to the availability of alternative holding systems, should a compromised animal need to be removed. It is usually much easier to introduce an animal to a large exhibit than to subsequently remove it, so plan ahead in anticipation of having to safely remove a specimen where necessary.

In addition to medical considerations, newly acquired animals may need to acclimatize to new foods. Where possible, animals should be given the same foods they were eating before transportation began, and these foods should then gradually shift to match their long-term diet. A healthy appetite is a good indicator of a successful introduction. Animals conditioned to take food from aquarists are less likely to prey on other inhabitants, although this is no guarantee, and controlled feeding provides the opportunity for administering oral medications.

CONCLUSIONS

An aquarist intending to keep sharks, skates, or rays must be familiar with an elasmobranch's physiology and natural history. Only in this way can they accurately assess how well an animal is responding to its new environment. Observation and recognition of problems is critical. It is, of course, preferable to use this knowledge during exhibit design to facilitate species selection, habitat design, and formulate suitable transport, acclimatization, and introduction regimes. In a typical multi-species aquarium there will be many compromises, but a fundamental understanding of acclimatization and introduction strategies, will mitigate many of these negative effects. Acclimatization and introduction strategies however, should never be viewed as a solution to inadequate planning or inappropriate species selection.

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