

Chapter 8

Elasmobranch Transport Techniques and Equipment

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Abstract: Elasmobranchs are delicate animals and appropriate care should be observed during their transport or permanent damage and even death can result. Key considerations include risk of physical injury, elevated energy expenditure, impaired gas exchange, compromised systemic circulation, hypoglycemia, blood acidosis, hyperkalemia, accumulation of metabolic toxins, and declining water quality. Carefully planned logistics, appropriate staging facilities, minimal handling, suitable equipment, an appropriate transport regime, adequate oxygenation, comprehensive water treatment, and careful monitoring will all greatly increase the chances of a successful transport. In special cases the use of anesthesia and corrective therapy may be merited.

Despite common perception to the contrary, sharks and rays are delicate animals. This delicate nature is nowhere more evident than during the difficult process of capturing and transporting these animals from their natural habitat to a place of study or display. If sufficient care is not used, it is not uncommon for

elasmobranchs to perish during transport or shortly thereafter (Essapian, 1962; Clark, 1963; Gohar and Mazhar, 1964; Gruber, 1980).

Any elasmobranch transport regime should take into account a number of considerations related to species biology and transport logistics. A list of

these considerations has been outlined in Table 8.1 and each will be covered in this chapter or elsewhere in this volume.

Table 8.1. Important issues to consider when formulating an elasmobranch transport.

1. Elasmobranch biology
2. Species selection (refer chapter 2)
3. Legislation and permitting (refer chapter 3)
4. Logistics and equipment preparation
5. Specimen acquisition (refer chapter 7)
6. Handling and physical activity
7. Staging
8. Oxygenation, ventilation and circulation
9. Transport regime
10. Water treatment
11. Anesthesia (see also chapter 21)
12. Corrective therapy
13. Monitoring
14. Acclimation and recovery
15. Quarantine (refer chapter 10)
16. Specimen introduction (refer chapter 11)

ELASMOBRANCH BIOLOGY

Before discussing elasmobranch transport techniques it is important to understand the basics of elasmobranch biology as they pertain to capture, restraint, and handling.

Cartilaginous skeleton

Unlike teleosts (i.e., bony fishes), sharks and rays have a skeleton made of cartilage and lack ribs. This characteristic means that the internal organs and musculature of elasmobranchs are poorly protected and susceptible to damage without horizontal support (Clark, 1963; Gruber and Keyes, 1981; Murru, 1990).

Integument

Like other fishes elasmobranch skin is delicate and susceptible to abrasions especially on the snout and distal section of the fins (Howe, 1988).

Lateral line

Elasmobranchs detect low-frequency vibrations and pressure changes using a sensory organ called the lateral line (Boord and Campbell, 1977).

Ampullae of Lorenzini

Elasmobranchs detect weak electromagnetic fields using a specialized sensory organ called the Ampullae of Lorenzini, allowing them to detect electrical signatures produced by potential prey. They are sensitive to electrochemical cells induced by metals immersed in seawater and intolerant of dissolved heavy metallic ions (especially copper) (Gruber, 1980).

Optimal swimming velocity

An elasmobranch has achieved optimal swimming velocity when its energy expenditure per unit distance traveled, or total cost of transport (TCT), is minimized (Parsons, 1990; Carlson et al., 1999). If the elasmobranch swims slower or faster than this speed it will consume more energy. Carlson et al. (1999) observed that the optimal swimming velocity for blacknose sharks (*Carcharhinus acronotus*) was at speeds of 36-39 cm s⁻¹ where TCT was 0.9-1.0 cal g⁻¹ km⁻¹. If the sharks slowed down to 25 cm s⁻¹, then energy expenditure increased to 1.7 cal g⁻¹ km⁻¹.

Negative buoyancy

Elasmobranchs have no swim bladder and are negatively buoyant (Bigelow and Schroeder, 1948). Sharks maintain or increase their vertical position within the water column by using their caudal fin to provide thrust and their rigid pectoral fins and snout to generate lift.

One technique negatively buoyant fishes use to conserve energy is to powerlessly glide at an oblique angle, gradually increasing depth, then return to the original depth by actively swimming upward. An energy saving in excess of 50% has been calculated for animals that adopt this strategy referred to as the swim-glide hypothesis (Weihs, 1973; Klay, 1977). An uninterrupted horizontal distance is required for the completion of the glide phase of this swimming strategy. If this minimum horizontal distance is not available the fish will consume excess energy through the muscular contractions required to turn. In the case of extreme interruptions the fish may stall and consume valuable energy reserves as it attempts to regain its position within the water column and re-attain a near-optimal swimming velocity. If this situation persists, the animal can become exhausted and ultimately die (Klay, 1977; Gruber and Keyes, 1981; Stoskopf, 1993).

Anaerobic metabolism

Many sedentary elasmobranchs have a low aerobic capacity relying heavily on the anaerobic metabolism of white muscle to support activity (Bennett, 1978). This strategy provides a great opportunity for sudden bursts of activity but implies long periods of immobility during recovery. Conversely, pelagic elasmobranchs have an increased commitment to the aerobic red muscle more suitable for their constantly cruising lifestyle. If oxygen (O_2) demand increases to a point where an insufficient supply feeds the working tissue aerobic red muscle will also start to metabolize anaerobically.

The velocity beyond which a swimming elasmobranch starts to metabolize anaerobically is referred to as U_{crit} or the maximum aerobically sustainable swimming speed (Lowe, 1996). The U_{crit} for leopard sharks (*Triakis semifasciata*) has been measured at 1.6 L s^{-1} for 30-50 cm TL specimens (where L = a distance equivalent to one body length and TL = total length of the specimen). U_{crit} was found to vary inversely with body size; 120 cm TL sharks exhibit a U_{crit} of 0.6 L s^{-1} (Graham et al., 1990). It is believed that less-active sharks have a lower U_{crit} than species adapted to a cruising pelagic lifestyle (Lowe, 1996).

Once an elasmobranch starts to metabolize anaerobically, be it benthic or pelagic, it produces lactic acid as a byproduct (Bennett, 1978).

Ventilation

Elasmobranchs have a small gill surface and their blood has a low oxygen-carrying capacity (Gruber and Keyes, 1981). Most demersal and benthic species ventilate gas-exchange surfaces using movements of the mouth to actively pump water across their gills. Pelagic species often use ram ventilation (i.e., forward motion and induced head pressure to force water into their mouth and out across their gill surfaces) to improve their ability to extract oxygen from the water. Species that are obliged to swim forward for effective gas exchange are referred to as obligate ram ventilators (Hughs and Umezawa, 1968; Clark and Kabasawa, 1977; Gruber and Keyes, 1981; Hewitt, 1984; Graham et al., 1990; Lowe, 1996; Carlson et al., 1999). An increased dependence on ram ventilation by pelagic species is possibly related to their increased reliance on oxygenated red swimming muscle.

Muscular pumping and systemic circulation

Elasmobranchs have limited cardiac capacity, low blood pressure, and low vascular flow rates. They rely on vascular valves and muscular contractions to aid systemic circulation. Optimal oxygenation of musculature and removal of toxic metabolites therefore occurs while swimming rather than at rest (Gruber and Keyes, 1981; Murru, 1984; Baldwin and Wells, 1990; Lowe, 1996). Muscular-assisted circulation is particularly important for pelagic and some demersal elasmobranchs because their aerobic swimming muscle requires constant oxygenation (Hewitt, pers. com.; Powell, pers. com.).

Hypoglycemia

During hyperactivity blood-glucose concentrations tend to rise as liver glycogen stores are mobilized (Mazeaud et al., 1977; Cliff and Thurman, 1984; Jones and Andrews, 1990). Cliff and Thurman (1984) observed an increase in the blood-glucose concentration of dusky sharks (*Carcharhinus obscurus*) from 5 to 10 mmol l^{-1} following 70 minutes of hyperactivity. Blood-glucose concentrations remained at 10 mmol l^{-1} for three hours and then continued to rise to a level in excess of 15 mmol l^{-1} over the next 24 hours. Glucose enters muscle cells where it supplies energy and raw material to restore glycogen reserves. If hyperactivity is prolonged blood-glucose elevation can be followed by a decline as liver glycogen reserves become exhausted (Cliff and Thurman, 1984; Hewitt, 1984; Jones and Andrews, 1990; Wood, 1991; Wells et al., 1986). Cliff and Thurman (1984) observed a decrease in blood-glucose concentrations to 2.9 mmol l^{-1} and 5.7 mmol l^{-1} in two dusky sharks that had struggled to the point of death.

Acidosis

Blood acid becomes elevated (i.e., pH declines) during hyperactivity. Acidosis is the result of two processes: increased plasma carbon dioxide (CO_2) concentration, and anaerobic metabolism and lactic acid production (Piiper and Baumgarten, 1969; Høleton and Heisler, 1978; Cliff and Thurman, 1984).

When CO_2 production in the muscles exceeds excretion via the gills, blood pH declines (Murdaugh and Robin, 1967; Albers, 1970). This pH decline happens because CO_2 reacts with H_2O according to Equation 8.1. This process is fast, happening within minutes of hyperactivity (Piiper

and Baumgarten, 1969; Cliff and Thurman, 1984; Lai et al., 1990; Wood, 1991). Cliff and Thurman (1984) observed a sharp blood-pH decline in a dusky shark from 7.29 to 7.12 within 10 minutes of hyperactivity. This decline is equivalent to an effective 57% increase in hydrogen ions (H^+).

Lactic acid produced during anaerobic metabolism dissociates into lactate and H^+ further lowering blood pH (Piiper and Baumgarten, 1969; Albers, 1970; Piiper et al., 1972; Bennett, 1978; Martini, 1978; Holeyton and Heisler, 1978; Wardle, 1981; Holeyton and Heisler, 1983; Cliff and Thurman, 1984; Wood, 1991). Cliff and Thurman (1984) observed that blood pH continued to decline during hyperactivity in a dusky shark from 7.12 at 10 minutes to 6.96 by the 70th minute. This slow decline, following an initial CO_2 -induced decline, was attributed to the formation of lactic acid, and thus, H^+ .

It has been suggested that only 20% of H^+ produced during anaerobic metabolism is released from the cells. Therefore, extracellular acidosis may be indicative of a more profound intracellular acidosis (Wood et al., 1983).

Hyperkalemia

Hyperactivity and blood acidosis can result in elevated serum electrolytes—in particular potassium ion (K^+) concentration—through the effusion of cellular electrolytes into the blood serum (Wood et al., 1983; Cliff and Thurman, 1984; Wells et al., 1986; Jones and Andrews, 1990; Wood, 1991). Cliff and Thurman (1984) observed an increase in plasma K^+ concentration from 3.3 $mmol\ l^{-1}$ to 5.3 $mmol\ l^{-1}$ in a dusky shark during hyperactivity.

Increased plasma K^+ concentration can disrupt cardiac function and promote muscular tetanus, augmenting anaerobic metabolism and promoting acidosis (Cliff and Thurman, 1984; Wells et al., 1986).

Excretion of metabolites

Elasmobranchs excrete many biochemical metabolites into the surrounding environment via their gills. Amongst others CO_2 , H^+ , and ammonia ion (NH_4^+) are excreted during normal metabolism

(Robin et al., 1965; Murdaugh and Robin, 1967; Albers, 1970). Unless they are diluted or removed environmental accumulation of these metabolites will become toxic. As elasmobranchs are hyperosmotic to their environment an elevated NH_4^+ concentration may induce or further promote acidosis (Murru, 1990).

Transport mortality

Although mortality during and after elasmobranch transport is not fully understood it appears to be due, at least in part, to: depletion of blood-glucose concentrations and starvation of muscle tissue; blood acidosis, circulatory disruption, and central nervous system damage; elevated plasma K^+ concentration and cardiac dysfunction; accumulation of toxic metabolites within the immediate environment; or a combination of all these factors (Mazeaud et al., 1977; Bennett, 1978; Gruber and Keyes, 1981; Wood et al., 1983; Cliff and Thurman, 1984; Hewitt, 1984; Murru, 1984; Wells et al., 1986; Dunn and Koester, 1990; Stoskopf, 1993). The effect of these processes may not always be immediately obvious and their contribution to post-transport mortality may be overlooked or underestimated (Gruber and Keyes, 1981).

In conclusion the following challenges need to be considered during the transport of elasmobranchs: (1) risk of injury to internal organs, delicate skin, and sensitive sensory organs; (2) increased turning frequency and elevated energy expenditure; (3) impaired ventilation and compromised systemic oxygenation; (4) decreased muscular pumping resulting in reduced vascular circulation, reduced muscular oxygenation, and reduced metabolite elimination; (5) hypoglycemia; (6) blood acidosis; (7) hyperkalemia; and (8) the excretion and environmental accumulation of CO_2 , H^+ and NH_4^+ . An overview of these challenges and possible solutions has been outlined in Table 8.2.

LOGISTICS AND EQUIPMENT PREPARATION

A fundamental aspect of any elasmobranch transport, determining ultimate success or failure, is logistical planning and equipment preparation. Equipment malfunction, vehicular breakdowns,

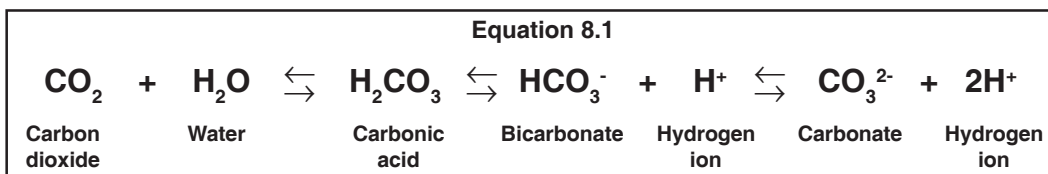


Table 8.2. Biological characteristics of elasmobranchs and possible strategies to mitigate negative effects during transport.

Biological characteristics	Solutions
Cartilaginous skeleton	1.1 While handling, ensure horizontal support using water-filled plastic bags for small specimens or stretchers for large specimens.
Integument	1.2 Always transport in a water-filled vessel. 2.1 Use plastic bags or soft knot-less nets when catching specimens, and flexible plastic stretchers when restraining them. 2.2 Minimize handling and use sterilized plastic gloves if handling is absolutely necessary. 2.3 Minimize obstructions to natural swimming patterns within transport tank. 2.4 Construct transport tank from non-abrasive material. 2.5 In extreme cases, consider the use of sedation to minimize handling time and reduce physical injury.
Lateral line	3.1 Minimize external physical impacts to the transport tank.
Ampullae of Lorenzini	4.1 Avoid using metallic objects, especially within transport tank. 4.2 Avoid using copper as a chemico-therapeutic. 4.3 Where possible minimize electric currents in and around the transport vessel.
Optimal swimming velocity and negative buoyancy	5.1 Generate gentle current in transport tank to facilitate hydrodynamic lift, maintain specimen buoyancy, and simulate swimming behavior. 5.2 Minimize turning frequency by transporting small specimens and reducing obstructions within transport tank (e.g., LSS equipment, conspecifics, etc.).
Anaerobic metabolism	6.1 Minimize hyperactivity by catching and restraining specimens quickly and calmly. 6.2 Minimize transport duration. 6.3 In extreme cases, consider the use of anesthesia to slow metabolic rate and to reduce O ₂ consumption and metabolic waste production. 6.4 Maximize dissolved O ₂ concentration (as per 12.2 and 12.3) 6.5 Maximize ventilation and systemic circulation (as per 7 and 8)
Ventilation	7.1 Where possible, transport specimens in 'free-swimming' mode to allow natural ventilation. 7.2 When transporting in 'restrained' mode simulate natural ventilation by directing a current of oxygenated water into the mouth of the specimen.
Muscular pumping and systemic circulation	8.1 Where possible, transport specimens in 'free-swimming' mode to allow natural muscular pumping. 8.2 When transporting in 'restrained' mode periodically flex the trunk of the specimen to stimulate muscular pumping.
Hypoglycemia	9.1 Minimize hyperactivity (as per 6.1 - 6.3). 9.2 Consider use of IV- or IP-administered glucose supplementation.
Acidosis	10.1 Minimize hyperactivity (as per 6.1 - 6.3). 10.2 Maximize O ₂ and CO ₂ exchange by facilitating ventilation (as per 7.1 and 7.2), degassing transport water (as per 15.2), and oxygenating transport water (as per 12.2 and 12.3). 10.3 Minimize blood [CO ₂] and [H ⁺] increase by facilitating systemic circulation (as per 8.1 and 8.2). 10.4 Consider use of IV- or IP-administered bicarbonate or acetate to buffer the blood.
Hyperkalemia	11.1 Minimize hyperactivity (as per 6.1 - 6.3). 11.2 Minimize blood acidosis (as per 10.1 - 10.4).
Oxygen (O₂) depletion	12.1 Minimize hyperactivity (as per 6.1 - 6.3). 12.2 Maximize dissolved oxygen concentration within transport vessel by supplementing with pure O ₂ at ~120-200% saturation. 12.3 Maximize dissolved oxygen concentration within transport vessel by degassing transport water and liberating excess CO ₂ .
Temperature fluctuation	13.1 Mitigate temperature fluctuations by insulating transport vessel. 13.2 Ensure vessel is transported and staged in temperature-controlled environments. 13.3 Modify temperature as required using bagged ice, immersion heaters, etc.
Excreted particulates and 'organics'	14.1 Minimize hyperactivity (as per 6.1 - 6.3). 14.2 Minimize waste accumulation by applying water exchanges, mechanical filtration, adsorption or chemical filtration, and foam fractionation to transport water.
Carbon dioxide (CO₂) buildup and pH decline	15.1 Minimize hyperactivity (as per 6.1 - 6.3). 15.2 Minimize pH decline by degassing transport water and liberating excess CO ₂ . 15.3 Minimize pH decline by buffering transport water with bicarbonate, carbonate, or Tris-amino®.
Nutrient buildup	16.1 Minimize hyperactivity (as per 6.1 - 6.3). 16.2 Minimize [NH ₃ / NH ₄ ⁺] accumulation by performing periodic water exchanges, using ammonia sponges (e.g., AmQuel), and applying adsorption or chemical filtration (as per 14.2).

Table 8.3. Basic logistics and equipment preparation required for a typical intercontinental elasmobranch transport. This basic model may be adapted and used as a checklist for any transport.

Research	<p>1.1 Information is power! Research as much as possible about the chosen species - appropriateness for display, special requirements, reliable sources (e.g., collection sites / professional collectors / other aquaria), transportability, etc.</p> <p>1.2 Obtain references for professional collectors. Inspect collector's facilities. Finalize species list and fix agreement with professional collector (i.e., fees, dates, responsibilities, etc.). Ensure that both you and the collector have appropriate permits.</p> <p>1.3 Determine shipment routes, dates, and times. Obtain references for haulers, carriers, airports, etc. Ensure shipment route is as direct as possible, secure, and requires minimal cargo handling. Have a freight agent negotiate with carriers to determine the best routes, minimize costs, and handle paperwork. Strive for non-peak times and working days when customs / quarantine staff are readily available.</p> <p>1.4 Clarify available transport conditions: Is climate control available throughout? Can staff easily enter cargo areas? Can animals be accompanied and checked in-flight? What are the plane loading and unloading restrictions (e.g., door dimensions, lifting equipment, etc.) at both the origin and destination?</p>
Plan	<p>2.1 Think your way through the entire transport process considering all equipment, transport, and infrastructure requirements (e.g., forklifts, pallet jacks, power supplies, water exchanges, etc.). Ensure that transport tanks and ancillary equipment will fit on trucks, airplanes, forklifts, and through all doors and corridors. Consider urban restrictions between staging facility, airports, and destination aquarium. Verify your plan with an individual experienced in the type of transport you are undertaking. Formulate final plan and review with all parties.</p> <p>2.2 Make a manifest of all required equipment and transport tanks (refer Table 8.4). Ensure that all equipment conforms to regulation (e.g., HazMat of the International Civil Aviation Organization (ICAO) and the International Air Transport Association (IATA)) and understand any possible restrictions. Calculate required amount of consumables (e.g. oxygen, batteries, water conditioners, etc.).</p> <p>2.3 Make a comprehensive list of all required permits and other documentation for exportation and importation (e.g., conservation certification (federal, state, etc.), health certification, HazMat documentation, way-bills, customs declarations, insurance policies, passports, visas, etc.).</p> <p>2.4 Make a comprehensive list of all tasks with completion dates / times and individuals responsible. Establish teams of people for every task (e.g., catching specimens, handling specimens, transporting specimens, receiving and acclimatization, post-transport monitoring, etc.). Ensure that the plan is clearly understood by everyone. Build in critical 'mileposts' for 'go' / 'no-go' decisions (e.g., carrier confirmed landed = commence loading animals into transport tanks, etc.). Be reasonable with timing estimates for each step and build in extra time.</p>
Contingency	<p>3.1 Ensure suitable infrastructure is available at all points throughout the transport route (e.g., lifting equipment, power supplies, climate control, water for exchanges, security, police escorts, etc.). Identify areas of risk and ensure suitable contingencies are in place.</p> <p>3.2 Adapt! You have a clear plan but be prepared to change the plan if it is simply not workable. Ensure any changes to the plan are communicated to everyone.</p>
Communicate	<p>4.1 Establish clear channels of communication with all parties and make a comprehensive contact list. Circulate plan, equipment manifest, required documentation, task list, and contact sheet to appropriate parties. These will include, but may not be limited to: husbandry staff, local security, public relations staff, local constabulary, freight agent, hauler, hazmat specialist, airport cargo handlers, carrier administration, carrier cargo handlers, customs officials, US Fish and Wildlife Service (or equivalent), Department of Agriculture (or equivalent), Department of Transport (or equivalent) and Immigration. Appoint the freight agent, or other appropriate party, to be the primary liaison with transport personnel. Using one spokesperson will minimize omissions and conflicting information.</p>
Educate	<p>5.1 Be prepared to be a teacher! Educate all personnel along the route of the transport (as per list detailed in 4.1 above). Airport officials are always interested in a transport and will cooperate if they are correctly and politely apprised of the situation. Ensure that all are aware of the need for expeditious processing of any documents and loading of cargo, etc. Likewise, local constabulary, security guards, and company PR personnel will be more sympathetic if everything is explained clearly and politely.</p>
Prepare	<p>6.1 Acquire all equipment on manifest (as per 2.2 above) and ensure it functions correctly.</p> <p>6.2 Acquire required permits (as per 2.3 above). Carry originals and copies throughout transport.</p> <p>6.3 Collect specimens and allow to recuperate in staging facility.</p> <p>6.4 Fast specimens (48 - 72 hours) if appropriate and verify that they are healthy and ready for transport.</p> <p>6.5 Prepare equipment, double-checking the manifest (as per 2.2 above) to ensure you have everything - remember permits! Include backups. Include tools for every pump, filter, battery, oxygen bottle, bolt, nut, screw, fastener, etc. Wash filtration media and pack filters. Test all batteries and pumps. Check oxygen supplies. Ensure transport tanks are robust, leak-proof, and have no pipes protruding where they could be sheared off. Calculate required quantities of water conditioners (e.g., AmQuel[®], etc.) and prepare in advance. Ensure all loose equipment is stored in robust waterproof boxes.</p> <p>6.6 Pack tanks and ancillary equipment on trucks so they form discrete self-contained units for ease of movement with forklifts, pallet jacks, etc. Orientate and securely strap down tanks to minimize surge and allow ease of access to all equipment.</p> <p>6.7 Allocate specimens to specific tanks and make a check-list for final loading.</p> <p>6.8 Final check! On the day before the transport ensure EVERYTHING is prepared! Ensure all contingencies are in place. Review tasks and timing with team members adjusting where necessary. Get some rest!</p>

Table 8.3 (continued). Basic logistics and equipment preparation required for a typical intercontinental elasmobranch transport. This basic model may be adapted and used as a checklist for any transport.

Execute	
	7.1 Verify that all team members and infrastructures are ready.
	7.2 Start and verify that all LSSs (life support systems) are functioning (i.e., oxygen supplies, pumps, mechanical filtration, directed water currents, etc.).
	7.3 Capture and transfer specimens to transport tanks quickly and calmly. Have extra personnel available to lift and carry.
	7.4 When all specimens and equipment is loaded re-check LSSs. If all is OK transport specimens to airport for processing.
	7.5 At the airport ensure tanks are secure throughout processing and be prepared to perform water exchanges and equipment repairs before loading. Pack tanks in aircraft securely (as per 6.6). Pack tanks on the final pallet spaces so they are the first off the aircraft on arrival.
	7.6 Monitor specimens, LSSs, and water quality throughout transport and make appropriate adjustments (e.g., adjust oxygen regulators, add water conditioners, etc.).
	7.7 On landing re-check LSSs and water quality. Perform water exchanges if necessary. Expedite customs and airport processing.
	7.8 Load tanks on truck(s) (as per 6.6) and transfer to destination aquaria.
	7.9 On arrival off-load tanks and commence specimen acclimation. Apply prophylactic measures as appropriate. Transfer specimens to quarantine tanks.

belligerent officials, and replacement resources (e.g., water, filtration media, spares, etc.) should be taken into account and contingencies previewed (Young, pers. com.). Use a competent freight agent to handle negotiations, transport bureaucracy, hazardous material documentation, and logistics communication (McHugh, pers. com.). Logistical planning and equipment preparation for a typical elasmobranch transport can be divided into seven basic steps. These steps have been outlined in Table 8.3 and a corresponding equipment manifest detailed in Table 8.4.

HANDLING AND PHYSICAL ACTIVITY

When initially restraining a specimen it is often necessary to use a net made of soft knot-less nylon to prevent abrasions (Powell, pers. com.). Some sharks, in particular the sand tiger shark (*Carcharias taurus*), are prone to catching their teeth in nets. Care should be taken to minimize tooth entanglement as permanent damage to the upper jaw may result (Mohan, pers. com.).

Another consideration for the sand tiger shark is its unique ability to swallow air and store it in its stomach to assist buoyancy (Hussain, 1989). If a portion of the air is not removed before transport the sand tiger shark may float upside-down in the transport tank. It is preferable to induce the sand tiger to expel some of the air before transport commences.

At no stage should the body of an elasmobranch be allowed to hang loosely from the head or tail. Sharks and rays should always be maintained in a horizontal position (Clark, 1963; Gruber and Keyes, 1981; Andrews and Jones, 1990; Stoskopf, 1993). When lifting and moving large specimens

a stretcher has been employed (Clark, 1963; Davies et al., 1963; Murru, 1984; Smith, 1992; Visser, 1996). A stretcher consists of a flexible reinforced vinyl or canvas sheet stretched between two parallel poles. The shark is lifted out of the water while lying in a horizontal position within the bag formed by the sheet (Figure 8.1).

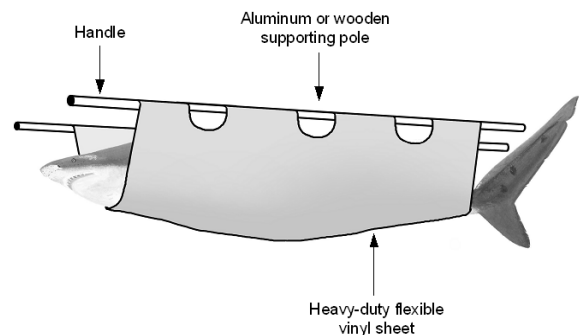


Figure 8.1. Flexible vinyl stretcher used to maintain sharks in a horizontal position while handling.

For small sharks horizontal support can be achieved by using a strong, rip-resistant, plastic

bag. The water provides support while the flexible and smooth walls of the bag allow the specimen to move without damaging itself. The elasmobranch remains submerged and can continue to respire (Marshall, 1999; Ross and Ross, 1999). Double bagging provides security against breakage. Rays require support for their pectoral fins. Support can be achieved by using a vinyl or canvas sheet stretched within a rigid, circular, exterior hoop (Figure 8.2).

When handling elasmobranchs the use of sterile plastic gloves is recommended (Gruber, 1980;

Table 8.4. Comprehensive list of equipment considered necessary for the preparation and execution of a large-scale, long-duration elasmobranch transport. Short-term transports may be less demanding of resources and only require some of the equipment listed.

Transportation equipment	Tool kit	Medical equipment + Water analyses
Air pumps (battery operated)	Battery charger	Acidosis therapy (e.g. Bicarbonate)
Bags (plastic)	Block and tackle	Ammonia sponge (e.g., Amquel)
Bottles (plastic)	Cable ties	Anesthetic - IM (e.g., Ketamine, Xylazine, Yohimbine)
Buckets (plastic)	Double adapters / Power packs	Anesthetic - Immersion (e.g. MS-222)
Diving equipment (mask, snorkel, fins, etc.)	Drill - bits	Anesthetic - Local (e.g. Lignocaine)
Dry boxes	Drill - holesaw fittings	Anti-bleed therapy - IM (Vitamin K)
Electrical - batteries (12V) (sealed)	Drill - screwdriver fittings	Antiseptic - Topical (e.g., Betadine, Mercurochrome)
Electrical - cables + connectors + fusible links	Drill (electrical and battery operated)	Anti-shock therapy (e.g., Dexamethasone)
Electrical - inverter (DC 12V to AC?)	Electrical extension flex	Cardiac stimulant - (e.g., Adrenaline)
Electrical - transformer (AC? To DC 12V)	Fasteners, nails, screws & glues (assorted)	Catheters (14, 16, 18, 21G)
Filter (cartridge) - mechanical / chemical	Flashlights (+ batteries)	Dissection kit
Filter (cartridge) - media - activated carbon	Gloves	Hypoglycemia therapy (e.g., Glucose IV infusion)
Filter (cartridge) - media - pleated paper	Hammer	IV administration lines
First aid kit	Jigsaw (electrical)	Magnifying glass
Foam rubber	Knives	Measuring vials
Hose (flexible w/ reinforcing to avoid kinks)	Marker pens (permanent)	Needles (14, 18, 21, 22 and 24G)
Hose clamps	Multi-meter	Respiratory stimulant (e.g., Doxapram)
Ice box + ice packs	Pliers	Sample jars
Manifest	PVC pipes (+ fittings, glue and rags)	Scalpel blades
Money + credit cards	Ropes (assorted)	Scalpel handles
Net (cargo)	Saw (hack) (+ blades)	Sedative - IM (e.g. Valium)
Net (hand)	Saw (wood)	Stainless clamps (e.g., hemostat)
Net (shark restraining)	Screwdrivers	Staple gun + staples
Oxygen - airline + assorted connectors / manifolds	Silicone (+ gun)	Sterile swabs
Oxygen - cylinder + key + regulator + manifolds	Sponges	Sutures (nylon, stainless)
Oxygen - diffusers + weight	Stainless nuts + bolts + washers	Suturing needles
Oxygen - spare cylinder(s)	Tape (electrical, thread, duct)	Syringes (1, 2, 5, 10, 50 ml)
Pallet jack	Tie down straps	Tweezers
Pallets (allow access by forklift / pallet jack)	Tie Wire	Water pH buffer (e.g., Tris-Amino, Bicarbonate)
Slings (lifting)	Tool box	Lab wash bottles (for anesthetic administration)
Stretchers (shark + ray)	Towels	Ammonia test kit
Submersible pump (12V) - circulation	Vice grips	Oxygen meter
Submersible pump (12V) - water exchanges	Wire cutters	pH test kit
Transport tanks(s) + life support system	Wrench (adjustable)	Refractometer
	Wrenches (assorted)	Thermometer (+ spares)

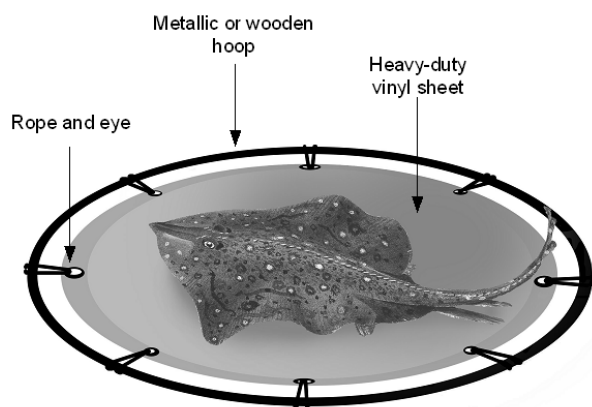


Figure 8.2. Rigid vinyl stretcher used to maintain rays in a horizontal position while handling.

Young et al., 2002). Sterile gloves will help prevent the development of post-handling infections of the skin. To minimize struggling during restraint it is possible to induce a trance-like state in many shark species by holding them in an upside-down position for a few minutes. This phenomenon is referred to as tonic immobility (Watsky and Gruber, 1990; Henningsen, 1994).

Throughout specimen restraint and transport physical activity must be minimized to reduce adverse biochemical reactions and the risk of specimens abrading their delicate snout and fin tips (Murru, 1990; Smith, 1992). A transport tank with smooth walls and a dark interior will reduce physical injury. Physical injury will be further reduced by the minimization of external stimuli and a reduction of surge by thoughtful design and positioning of the transport tank (i.e., placement of a rectangular tank transversely across the transport vehicle) (Smith, 1992; Arai, 1997).

STAGING

Staging refers to the process of temporarily maintaining a specimen in a large secure recovery enclosure close to the collection site. This process is important, as the biochemical changes induced during elasmobranch capture are often profound. Staging a specimen for at least 24 hours before transport commences will dramatically increase the chances of success (Cliff and Thurman, 1984; Murru, 1984; Wisner, 1987; Andrews and Jones, 1990; Arai, 1997; Young et al., 2002). It is critical that the staging facility has sufficient dimensions and water parameters to adequately maintain the specimen(s). If not, you will simply compound the already damaging biochemical changes.

A typical temporary staging facility comprises a plastic-lined pool supplied with raw seawater via an offshore intake and pumping system. A secure fence, for security from onlookers, and roofing to cut down radiant energy is beneficial (Visser, 1996). Water parameters, especially oxygen, temperature, pH, and nitrogenous wastes become a critical issue if water is not being constantly replenished. A re-circulating water treatment system capable of maintaining optimal water parameters is then required.

OXYGENATION, VENTILATION AND CIRCULATION

Oxygenation

The importance of oxygenation cannot be over-emphasized. Fishes consume up to three times their normal oxygen requirement under transport conditions. Exhausted fishes may consume as much as 5-10 times their normal requirement (Wardle, 1981; Froese, 1988). The greater a commitment to aerobic respiration, the more important an unimpeded oxygen supply (Wardle, 1981). This increasing demand for oxygen is illustrated by adjusted oxygen consumption rates for increasingly pelagic elasmobranchs (i.e., 296, 395 and 849 mg of O₂ kg⁻¹ h⁻¹ for *Sphyrna tiburo*, *Carcharhinus acronotus*, and *Isurus oxyrinchus*, respectively) (Parsons, 1990; Graham et al., 1990; Carlson et al., 1999).

The ability of elasmobranch blood to carry oxygen to the tissues, as demonstrated in the white shark (*Carcharodon carcharias*), is determined by: (1) the amount of oxygen transferred across the gills; (2) the oxygen-carrying capacity of the blood; and (3) the ability of the circulatory system to deliver oxygen to the tissues (Emery, 1985). These restrictions emphasize the importance of a steady supply of dissolved oxygen, adequate gill ventilation, and unimpaired systemic circulation to achieve normal metabolic respiration (Butler and Taylor, 1975; Wardle, 1981; Cliff and Thurman 1984; Lai et al., 1990; Smith, 1992).

Dissolved oxygen concentrations of 120-160% saturation have been reported as appropriate for the transport of elasmobranchs (Thoney, pers. com.). Other workers recommend concentrations as high as 200% saturation (i.e., 15 mg l⁻¹ at 20°C) (Stoskopf, 1993). It has been suggested that higher concentrations may cause neurological damage or may be responsible for burning or

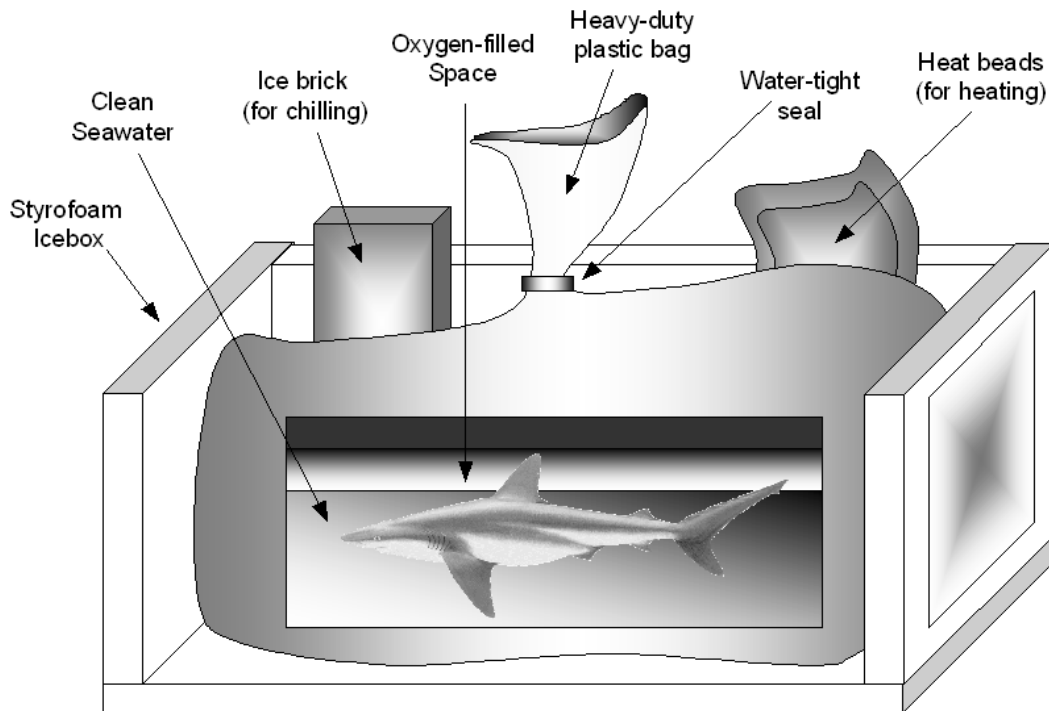


Figure 8.3. Sealed bag and insulated box transport regime.

oxidizing the gills (Stoskopf, 1993). However other workers have supersaturated transport water to 30 mg l^{-1} and observed no apparent adverse reactions (Hewitt, pers. com.; Powell, pers. com.). Regardless, caution should be exercised as hyperoxygenation may depress respiration and reduce offloading of CO_2 at the gill surface. This process will induce acidosis, one of the biochemical changes that oxygenation is intended to reduce.

Ventilation

Water flow across the gills is normally quite high in the shark. In the dogfish (*Squalus acanthias*) water flow across the gills can equal half the body weight of the animal every minute (Murdaugh and Robin, 1967). Water movement within the transport tank enhances ventilation and helps reduce anaerobic respiration by allowing the specimen to take advantage of the oxygen-rich environment. By directing currents so they flush across the gills of a stationary shark, it is possible to approximate ram ventilation (Ballard, 1989; Smith, 1992).

Circulation

When an elasmobranch is prevented from normal locomotion, muscular pumping of blood and lymphatic vessels can be impaired. If restraint is

prolonged, lack of systemic circulation may result in both anaerobic metabolism and a buildup of toxic metabolites. Increased concentrations of metabolites can be associated with an increased rigidity progressing forward from the caudal region along the length of an animal. Another sign of this condition may be a reddening of the skin on the ventral surface (Powell, pers. com.). In extreme cases the animal can become completely immobile and die (Gruber and Keyes, 1981; Cliff and Thurman, 1984; Stoskopf, 1993).

When transporting non-sedentary elasmobranchs, in a restrained manner, consideration should be given to gently massaging the musculature by flexing the caudal peduncle and stroking the dorsal surface (Gruber and Keyes, 1981; Dunn and Koester, 1990; Powell, pers. com.; Young, pers. com.). Care should be exercised during this operation to repeat the process regularly. Delays may allow the accumulation of toxic metabolites that could be inadvertently introduced into systemic circulation in a single bolus dose (Smith, 1992; Stoskopf, 1993).

TRANSPORT REGIME

Transport regimes may be grouped into three basic types: (1) sealed bag and insulated box; (2) free-swimming; and (3) restrained.

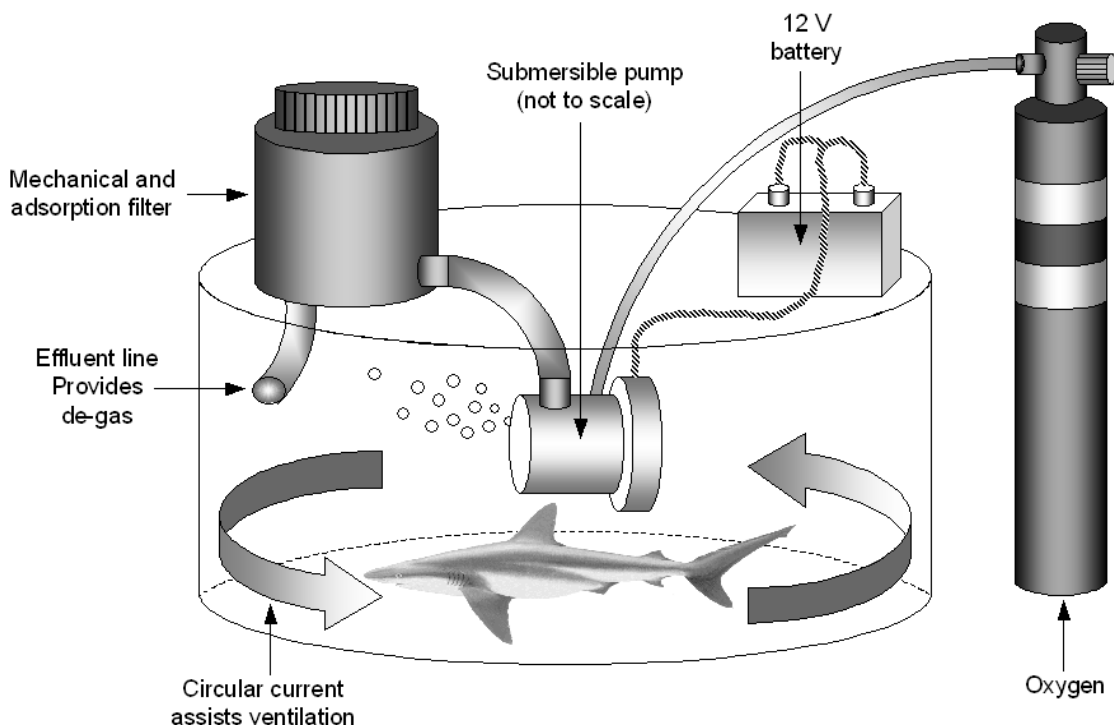


Figure 8.4. Free-swimming transport regime.

Sealed bag and insulated box

One of the simplest means to transport elasmobranchs is using the sealed bag and insulated box technique (Figure 8.3) (Gruber and Keyes, 1981; Wisner, 1987; Froese, 1988; Stoskopf, 1993; Ross and Ross, 1999). This option is appropriate for small benthic and some small demersal species (i.e., < 1 m TL).

The specimen is placed in a large, tough, plastic bag (e.g., 0.25 mm polyethylene) half filled with seawater. The dimensions of the bag should prevent the specimen from turning and getting wedged in an awkward position, or alternatively, be sufficiently large that it may swim gently (Gruber and Keyes, 1981). Double or triple bagging is preferred as it will help prevent leaks due to tearing. The upper half of the bag is filled with pure oxygen and sealed. The specimen remains in the bottom-half of the bag, covered with water, while the void above is filled with oxygen. Oxygen slowly diffuses into the water throughout the transport. The bagged shark or ray is placed into an insulated box (e.g., Styrofoam icebox) providing thermal isolation and protection against physical and visual stimuli. It is possible to include a basic water treatment system in the form of an ammonia scrubber (e.g., Poly-Filter®, Poly-Bio-Marine®, USA) and microwave heat beads or ice packs to maintain an appropriate temperature (Wisner, 1987).

Prepared in this manner a small elasmobranch can travel for 24-48 hours. An advantage of this technique is that specimens can be moved unattended, allowing a greater range of transport options and reduced expense.

Free-swimming

The second transport option, used principally for smaller pelagic elasmobranchs, is the free-swimming technique (Figure 8.4) (Hiruda et al., 1997; Marshall, 1999; Young et al., 2002). This technique consists of a circular, smooth-walled, plastic or fiber-reinforced polyester tank (e.g., 2.5 m diameter x 1 m deep) within which the elasmobranchs are free to move. The animals are often encouraged to swim against a gentle current generated by a 12 Volt submersible pump. In general, the pump should be capable of moving water equivalent to the volume of the tank every hour. In the example detailed above this requirement would necessitate a pump capable of moving $5 \text{ m}^3 \text{ hour}^{-1}$ (e.g., Model 02, Rule ITT Industries, USA). Pumped water is sent to a water treatment system and returned to the transport tank via a directed line. The transport vehicle may supply energy for the pump, however, it is wise to have an independent and portable supply of energy (e.g., 12 Volt deep-cycle battery, Model 800-S, Optima, USA). This alternative supply

provides an energy source during transfers between vehicles and can be used as a backup in emergencies.

The submersible pump is usually suspended from the underside of the transport tank lid, keeping it off the floor where it could disrupt the swimming pattern of the specimens. It is possible to have a pump mounted externally, with the intake line draining from the side of the tank. If such is the case, care must be exercised to ensure the intake line is flush with the interior wall of the tank and covered with a large, smooth, protective mesh manifold. This manifold prevents animals from becoming trapped by the suction of the intake line. Care must be taken to ensure that external pipes and fittings cannot be sheared off in transit.

The water treatment system typically consists of a canister filter filled with mechanical and adsorption media (see below). Once the water is filtered, it is returned above the surface to facilitate gas exchange (i.e., O₂ dissolution and CO₂ liberation) and drive the gentle current. During long transports it may be necessary to use additional diffusers (i.e., air-stones) to eliminate accumulated CO₂. Monitoring pH will give an indication of changes in dissolved CO₂ concentration (Thoney, pers. com.). Dissolved oxygen is increased using bottled O₂, a reliable regulator, and a diffuser situated in the center of the tank (Smith, 1992). Oxygen may be introduced directly into the suction line of the submersible pump for better dissolution (Powell, pers. com.).

The transport tank should be leak-proof but allow ventilation for the elimination of excess CO₂. Ventilation can be achieved with both breather holes and a centrally located access hatch. The hatch may be opened periodically to flush out CO₂ and to manipulate equipment or animals as required. A robust side-mounted inspection window is useful. The entire top of the tank should be strong enough to withstand the weight of a person and provide a good seal against leaks. The top of the tank should be easy to remove for effective handling of specimens on arrival at the final destination.

The free-swimming technique is preferred for those species that are reliant on aerobic respiration, ram ventilation, and muscular-assisted vascular return. When formulating a free-swimming transport regime it is important to consider: (1) swimming behavior; (2) specimen size; (3) specimen number; (4) tank shape; (5) tank size; and (6) the number of obstructions within the tank (Young et al., 2002). These factors

will determine the number of interactions with obstructions or conspecifics, turning frequency, and therefore energy expenditure. The less encumbered an environment, the lower the consumption of vital energy reserves, the lower the production of toxins, and the lower the risk of metabolic shock. An example of a transport regime with a good safety margin would be three 0.5 m TL scalloped hammerheads (*Sphyrna lewini*), transported for 48 hours, in a tank of dimensions 2.5 m diameter x 0.65 m deep (Young et al., 2002).

Some workers have found that circular tanks work well for short-duration, free-swimming transports where specimens potentially impacting the walls is of primary concern (Wisner, 1987; Marshall, 1999). However for long-term transports, where biochemical changes become increasingly important, the continuous turning required to negotiate a circular tank may be too energetically challenging (Powell, pers. com.). It has been equated to the energetic inefficiency of a constantly turning aircraft (Klay, 1977; Gruber and Keyes, 1981). It has been suggested that a larger rectangular tank, allowing animals to swim normally for short distances and then opt for discrete turns, will be less energetically challenging during long-term transports.

Restrained

Some elasmobranchs are simply too large to transport free-swimming. In such cases it may be possible to transport them in a restrained manner (Gruber, 1980; Gruber and Keyes, 1981; Hewitt, 1984; Ballard, 1989; Andrews and Jones, 1990; Murru, 1990; Smith, 1992). This technique consists of a smooth-walled rectangular plastic or fiber-reinforced polyester transport tank, only slightly larger than the specimen to be transported (Figure 8.5). A typical tank size would be 2.5 m x 0.5 m x 0.5 m. The dimensions should be such that the animal cannot turn easily and lies in the same position throughout the transport. The interior, especially the wall in front of the specimen's snout, may be padded with a soft flexible material (e.g., neoprene). Degassing and water treatment are performed in a similar manner to that described for the free-swimming technique. A pump is often employed to drive oxygenated water from the rear to the front of the tank, where it is gently jetted into the mouth of the specimen. This water circulation system is referred to as a raceway and is designed to approximate ram ventilation. In some cases a custom-designed harness has been employed to maintain the position of the shark relative to both the tank and

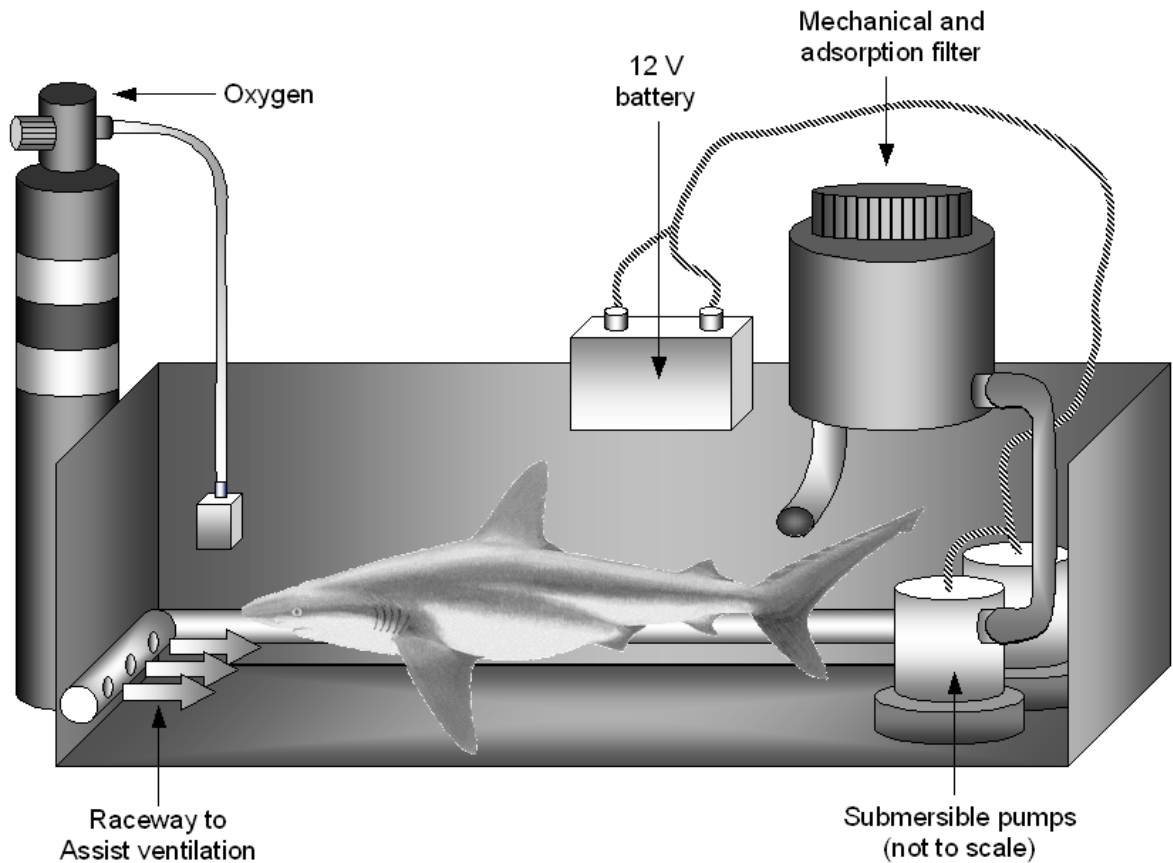


Figure 8.5. Restrained transport regime.

water flow (Hewitt, 1984; Andrews and Jones, 1990; Jones and Andrews, 1990; Murru, 1990).

Table 8.5 details a list of elasmobranch species that have been transported successfully using the three techniques described. Quoted durations are not a guarantee of survival. Capture technique, specimen size, handling technique, and water quality will all impact the success of the transport. Minimizing transport times should be the ultimate goal of any transport regime.

It is important to note that many workers reported limited success transporting the following species: thresher sharks (*Alopias spp.*), white sharks, mako sharks, porbeagle sharks (*Lamna nasus*), and blue sharks. Transport of these species should only be attempted by very experienced personnel.

WATER TREATMENT

Elasmobranchs continually excrete waste products that contaminate water in a transport tank. Decreasing water quality may be responsible for more losses during transport than any other

factor (Murru, 1990). For a successful transport, water quality must be monitored closely and adjusted where necessary.

Before starting, transport tanks should be scrubbed thoroughly with seawater. Ensure that all traces of possible contaminants are removed. Transport water should be clean and preferably from the same source as the specimens to be transported. When transporting animals from a staging facility it is preferable to fast them for 48-72 hours beforehand. Referred to as conditioning, this process reduces water contamination via regurgitation and defecation in transit (Stoskopf, 1993; Sabalones, 1995; Ross and Ross, 1999). Once specimens are loaded and settled into the transport tank, a comprehensive water exchange (i.e., >75%) is recommended before transport commences. The water exchange will dilute stress-related metabolites and other contaminants, and greatly extend the period of time before water quality starts to decline (James, pers. com.). If transporting by boat there may be access to a continuous supply of fresh seawater; precluding the need to treat the water further. Land and air transports, on the other hand, may require a water

Table 8.5. Successfully transported elasmobranchs, showing technique and duration of transport; (j) refers to juvenile and (t) refers to a towed sea-cage. If more than one reference is available, durations are given as a range showing minimums and maximums. All references were personal communications unless otherwise indicated by a date of publication.

Species name	Common name	Technique	Duration (h)	Reference
<i>Aetobatus narinari</i>	Spotted eagle ray	Sealed bag and box Free-swimming Restrained	12 - 30 (j) 21 - 56 7	Thomas; Violetta; Young Henningsen; Thomas; Violetta; Young; Marshall Henningsen
<i>Aetomyaerus niehofii</i>	Banded eagle ray	Free-swimming Restrained	24 - 48 26	McEwan Hiruda et al., 1997
<i>Apychotrema bougainvillii</i>	Short-snouted shovelnose ray	Restrained	2	Kinnunen
<i>Apychotrema rostrata</i>	Eastern shovelnose ray	Sealed bag and box	6	Kinnunen
<i>Asymbolus analis</i>	Australian spotted catshark	Free-swimming	3	Thomas
<i>Bathyraja aleutica</i>	Whitecheek skate	Free-swimming	3	Thomas
<i>Bathyraja interrupta</i>	Sandpaper skate	Sealed bag and box	1	Kinnunen
<i>Brachaelurus waddi</i>	Blind shark	Free-swimming	1	Kinnunen
<i>Carcharhinus acronotus</i>	Blacknose shark	Sealed bag and box Free-swimming	24 (j) 10 - 54	Young Henningsen; Violetta; Young; Young et al., 2001
<i>Carcharhinus altimus</i>	Bignose shark	Restrained	1	Christie
<i>Carcharhinus brachyurus</i>	Copper shark	Free-swimming	12	Powell
<i>Carcharhinus brevipinna</i>	Spinner shark	Free-swimming	2.5	Kinnunen
<i>Carcharhinus dussumieri</i>	Whitecheek shark	Free-swimming	1	Kinnunen
<i>Carcharhinus falciformis</i>	Silky shark	Free-swimming Restrained	24 - 48 26 - 30 2	McEwan Young; Young et al., 2001 Christie
<i>Carcharhinus leucas</i>	Bull shark	Restrained	4 - 36	Gruber and Keyes, 1981; Ballard, 1989; Smith, 1992; Thomas; Violetta
<i>Carcharhinus limbatus</i>	Blacktip shark	Free-swimming Restrained	8 - 56 1	Thomas; Young et al., 2001; Christie; Violetta Christie
<i>Carcharhinus longimanus</i>	Oceanic whitetip shark	Free-swimming	64	Ezurra
<i>Carcharhinus melanopterus</i>	Blacktip reef shark	Sealed bag and box Free-swimming	14 - 35 (j) 5 - 56	Wisner, 1987; James; McEwan; Romero; Violetta Barthelemy; Henningsen; Janse; Marshall
<i>Carcharhinus obscurus</i>	Dusky shark	Free-swimming Restrained	2 6 - 8	Kinnunen Cliff and Thurman, 1984; Ballard, 1990; Steslow
<i>Carcharhinus perezi</i>	Caribbean reef shark	Restrained	1 - 2	Sabalones, 1995; Christie
<i>Carcharhinus plumbeus</i>	Sandbar shark	Sealed bag and box Free-swimming	16 - 30 (j) 3 - 47	Henningsen; James; Young Barthelemy; Choromanski; Henningsen; James; Thomas; Violetta; Young
<i>Carcharias taurus</i>	Sand tiger shark	Restrained	4 - 40	Gruber and Keyes, 1981; Andrews and Jones, 1990; Choromanski; Thomas; Violetta;
<i>Carcharodon carcharias</i>	Great white shark	Sealed bag and box Free-swimming	5 - 15 3 - 48	Marrel Bourbon Hiruda et al., 1997; Choromanski; Farquar; Henningsen; Kinnunen; Thomas; Violetta
<i>Cephaloscyllium laticeps</i>	Australian swellshark	Restrained	2 - 84	Smith, 1992; Choromanski; Henningsen; Romero; Thomas; Violetta; Marshall
<i>Cephaloscyllium ventriosum</i>	Swellshark	Free-swimming Restrained	2 16 - 24	Kinnunen Gruber and Keyes, 1981; Hewitt, 1985
<i>Chiloscyllium plagiosum</i>	Whitespotted bambooshark	Restrained	7	Kinnunen
<i>Chiloscyllium punctatum</i>	Brownbanded bambooshark	Free-swimming	12 - 36	Howard; Thomas; Marshall
<i>Dasyatis americana</i>	Southern stingray	Sealed bag and box Free-swimming	40 20 - 24	Thomas Christie; Violetta
<i>Dasyatis brevicaudata</i>	Short-tail stingray	Sealed bag and box Free-swimming Restrained	24 12 - 36 10 - 70 54 2 (t) 26	Christie Henningsen; Thomas; Violetta; Young Henningsen; Thomas; Violetta; Young Marshall Kinnunen Hiruda et al., 1997

Table 8.5 (continued). Successfully transported elasmobranchs, showing technique and duration of transport; (j) refers to juvenile and (t) refers to a towed sea-cage. If more than one reference is available, durations are given as a range showing minimums and maximums. All references were personal communications unless otherwise indicated by a date of publication.

Species name	Common name	Technique	Duration (h)	Reference
<i>Dasyatis brevis</i>	Whiptail stingray	Free-swimming	3	Thomas
<i>Dasyatis centroura</i>	Roughtail stingray	Sealed bag and box	30	Young
		Restrained	28	Steslow
<i>Dasyatis chrysonota</i>	Marbled stingray	Restrained	84	Unpub. Results
<i>Dasyatis marmorata</i>		Sealed bag and box	20 - 30	Farquar; Sabalones
		Free-swimming	84	Marshall
<i>Dasyatis pastinaca</i>	Common stingray	Free-swimming	5 - 21	James; Janse
<i>Dasyatis violacea</i> (= <i>Pteroplatytrygon</i>)	Pelagic stingray	Free-swimming	9	Thomas
<i>Dipturus batris</i>	Skate	Restrained	8	Marshall
<i>Echinorhinus cookei</i>	Prickly shark	Free-swimming	14	James
<i>Galeocerdo cuvier</i>	Tiger shark	Restrained	2	O'Sullivan
		Free-swimming	1 - 3	Kinnunen; Marin-Osorno
<i>Galeorhinus galeus</i>	Tope shark	Restrained	2 - 24	Gruber and Keyes, 1981; Ballard, 1989; Christie; Marin-Osorno; Thomas
		Free-swimming	6 - 26	James; Thomas
<i>Ginglymostoma cirratum</i>	Nurse shark	Restrained	2 - 6	Engelbrecht; Howard; Thomas
		Sealed bag and box	24 - 48 (j)	Carrier; Violetta; Young
		Free-swimming	12 - 50	James; Thomas; Violetta; Young
<i>Gymnura altavela</i>	Spiny butterfly ray	Restrained	1 - 36	Clark, 1963; Christie; Marin-Osorno; Thomas; Violetta
		Free-swimming	3	Henningsen
<i>Gymnura micrura</i>	Smooth butterfly ray	Restrained	5	Marshall
		Free-swimming	24	Young
<i>Haploblepharus edwardsii</i>	Puffadder shyshark	Free-swimming	7 - 9	Henningsen
		Sealed bag and box	20 - 30	Farquar; Sabalones
<i>Haploblepharus fuscus</i>	Brown shyshark	Free-swimming	42	Marshall
		Sealed bag and box	30	Sabalones
<i>Haploblepharus pictus</i>	Dark shyshark	Free-swimming	42	Marshall
		Sealed bag and box	20 - 30	Farquar; Sabalones
<i>Hemiscyllium ocellatum</i>	Epaulette shark	Free-swimming	42	Marshall
<i>Heterodontus francisci</i>	Horn shark	Sealed bag and box	14 - 20	McEwan; Violetta
		Free-swimming	14 - 36	James; Thomas; Violetta; Marshall
<i>Heterodontus galeatus</i>	Crested bullhead shark	Free-swimming	48	Thomas
<i>Heterodontus japonicus</i>	Japanese bullhead shark	Restrained	2 - 26	Hiruda et al., 1997; Kimmunen
<i>Heterodontus portusjacksoni</i>	Port Jackson shark	Free-swimming	56	Marshall
		Sealed bag and box	14 - 38	James; McEwan; Romero
		Free-swimming	10	Marshall
		Restrained	26	Hiruda et al., 1997
<i>Hexanchus griseus</i>	Bluntnose sixgill shark	Free-swimming	3	Thomas
		Restrained	3	Engelbrecht; Thomas
<i>Himantura bleekeri</i>	Bleeker's whiptail	Free-swimming	24 - 48	McEwan
<i>Himantura fai</i>	Pink whiptail	Restrained	56	Marshall
<i>Himantura gerrardi</i>	Sharptnose stingray	Free-swimming	24 - 48	McEwan
<i>Himantura imbricata</i>	Scaly whiptail	Free-swimming	24 - 48	McEwan
<i>Himantura schmarda</i>	Chupate stingray	Free-swimming	2	Christie
<i>Himantura uarnak</i>	Honeycomb stingray	Free-swimming	24 - 48	McEwan
		Restrained	10 - 56	Marshall
<i>Himantura undulata</i>	Leopard whiptail	Restrained	56	Marshall
<i>Hydrolagus collii</i>	Spotted ratfish	Sealed bag and box	12	Marshall
		Free-swimming	44	Correia, J. 2001

Table 8.5 (continued). Successfully transported elasmobranchs, showing technique and duration of transport; (j) refers to juvenile and (t) refers to a towed sea-cage. If more than one reference is available, durations are given as a range showing minimums and maximums. All references were personal communications unless otherwise indicated by a date of publication.

Species name	Common name	Technique	Duration (h)	Reference
<i>Isurus oxyrinchus</i>	Shortfin mako	Free-swimming	2 - 7 (j)	Kinnunen; Steslow; Thomas
<i>Manta birostris</i>	Giant manta	Restrained	1.5	Powell
<i>Mobula munkiana</i>	Munk's devil ray	Free-swimming	1 - 3	Christie; Marin-Osorno
<i>Mustelus antarcticus</i>	Gummy shark	Free-swimming	12	O'Sullivan
<i>Mustelus asterias</i>	Starry smooth-hound	Free-swimming	8	Kinnunen
<i>Mustelus californicus</i>	Grey smooth-hound	Free-swimming	10	Janse
		Sealed bag and box	36	Thomas
		Free-swimming	36	Thomas
<i>Mustelus henlei</i>	Brown smooth-hound	Restrained	6	Engelbrecht
		Sealed bag and box	36	Thomas
<i>Mustelus mustelus</i>	Smooth-hound	Free-swimming	1 - 36	Howard; Thomas
		Sealed bag and box	12	James
<i>Myliobatis aquila</i>	Common eagle ray	Free-swimming	10 - 50	Janse; Romero
		Free-swimming	20	Farquar
		Restrained	84	Marshall
<i>Myliobatis australis</i>	Australian bull ray	Free-swimming	8	Kinnunen
<i>Myliobatis californica</i>	Bat eagle ray	Sealed bag and box	30 (j)	Thomas
		Free-swimming	1 - 36	Howard; Thomas
<i>Myliobatis freminvillii</i>	Bullnose eagle ray	Restrained	3	Engelbrecht
		Free-swimming	3	Henningsen
<i>Narcine brasiliensis</i>	Brazilian electric ray	Restrained	84	Marshall
<i>Nebrius ferrugineus</i>	Tawny nurse shark	Sealed bag and box	24	Young
		Sealed bag and box	14	McEwan
		Restrained	56	Marshall
<i>Negaprion acutidens</i>	Sicklefin lemon shark	Restrained	32	Engelbrecht
<i>Negaprion brevirostris</i>	Lemon shark	Sealed bag and box	14 - 48	Henningsen; Young
		Free-swimming	30 - 36	Thomas; Violetta
		Restrained	23 - 36	Gruber and Keyes, 1981; Henningsen; Thomas; Young
<i>Notorynchus cepedianus</i>	Broadnose sevengill shark	Free-swimming	3 - 5	Kinnunen; Thomas
		Restrained	1 - 6	Engelbrecht; Howard
<i>Orectolobus maculatus</i>	Spotted wobbegong	Sealed bag and box	24 - 30	Christie; Romero
		Free-swimming	8 - 10	Kinnunen; Marshall
<i>Orectolobus ornatus</i>	Ornate wobbegong	Restrained	4 - 26	Hiruda et al., 1997; Marshall
<i>Paragaleus randalli</i>	Slender weasel shark	Sealed bag and box	18 - 24	Christie; Violetta
<i>Pastinachus sephen</i>	Cowtail stingray	Restrained	3 - 26	Hiruda et al., 1997; Kinnunen
<i>Platyrhinoidis triseriata</i>	Thornback guitarfish	Free-swimming	24 - 48	McEwan
<i>Poroderma africanum</i>	Striped catshark	Free-swimming	24 - 56	McEwan; Marshall
		Sealed bag and box	4	Thomas
<i>Poroderma pantherinum</i>	Leopard catshark	Free-swimming	20 - 30	Farquar; Sabalones
		Sealed bag and box	56	Marshall
<i>Potamotrygon motoro</i>	Ocellate river stingray	Free-swimming	20 - 30	Farquar; Sabalones
<i>Prionace glauca</i>	Blue shark	Free-swimming	56	Marshall
		Free-swimming	4	Janse
<i>Pristis pectinata</i>	Smalltooth sawfish	Restrained	1.5 - 4 (j, t)	Kinnunen; Thomas
		Sealed bag and box	3 - 8	Howard; Powell; Steslow; Thomas
		Restrained	12	Christie; Henningsen
		Restrained	12 - 24	Christie; Engelbrecht; Henningsen; Violetta

Table 8.5 (continued). Successfully transported elasmobranchs, showing technique and duration of transport; (j) refers to juvenile and (t) refers to a towed sea-cage. If more than one reference is available, durations are given as a range showing minimums and maximums. All references were personal communications unless otherwise indicated by a date of publication.

Species name	Common name	Technique	Duration (h)	Reference
<i>Pristis pristis</i>	Common sawfish	Restrained	32	Romero
<i>Raja binoculata</i>	Big skate	Sealed bag and box Free-swimming	12 (j) 1 - 5	Howard Howard; Thomas
		Restrained	6	Engelbrecht
<i>Raja clavata</i>	Thornback ray	Sealed bag and box	24	Marshall
		Free-swimming	10	Janse
<i>Raja eglanteria</i>	Clearnose skate	Sealed bag and box	30	Young
<i>Raja rhina</i>	Longnose skate	Free-swimming	3 - 16	Howard; Thomas
<i>Raja stellulata</i>	Starry skate	Free-swimming	3 - 15	Howard; Thomas
<i>Raja undulata</i>	Undulate ray	Free-swimming	8	Marshall
<i>Rhina ancylostoma</i>	Bowmouth guitarfish	Restrained	5	Smith, 1992
<i>Rhinocodon typus</i>	Whale shark	Restrained	2	Kinnunen
<i>Rhinobatos annulatus</i>	Lesser sandshark	Sealed bag and box	20 - 30	Farquar; Sabalones
		Free-swimming	42	Marshall
<i>Rhinobatos granulatus</i>	Sharpnose guitarfish	Free-swimming	24 - 48	McEwan
<i>Rhinobatos lentiginosus</i>	Atlantic guitarfish	Sealed bag and box	6 - 30	Christie; Young
<i>Rhinobatos productus</i>	Shovelnose guitarfish	Free-swimming	36	Thomas
<i>Rhinobatos typus</i>	Giant shovelnose ray	Restrained	56	Marshall
<i>Rhinoptera bonasus</i>	Cownose ray	Sealed bag and box	6 - 60	Christie; Violetta; Young
		Free-swimming	12 - 76	Henningsen; Young
		Sealed bag and box	10	Henningsen
		Free-swimming	3 - 30 (j)	Christie; Henningsen; Violetta
<i>Rhizoprionodon terraenovae</i>	Atlantic sharpnose shark	Restrained	6 - 8	Steslow
		Sealed bag and box	2 - 42	Kinnunen; Unpub. Results
<i>Rhynchobatus djiddensis</i>	Giant guitarfish	Sealed bag and box	3 - 25 (j)	James; Janse; Marshall
<i>Scyliorhinus canicula</i>	Smallspotted catshark	Free-swimming	26	James
<i>Scyliorhinus retifer</i>	Chain catshark	Sealed bag and box	18	Marshall
<i>Scyliorhinus stellaris</i>	Nursehound	Sealed bag and box	10 - 24	James; Marshall
		Free-swimming	3 - 26	James; Janse
<i>Somniosus pacificus</i>	Pacific sleeper shark	Free-swimming	5	Thomas
<i>Sphyrna lewini</i>	Scalloped hammerhead	Free-swimming	6 - 60 (j)	Arai, 1997; Young, 2002; Thomas; Violetta
<i>Sphyrna mokarran</i>	Great hammerhead	Free-swimming	12 - 21	Christie; Young
<i>Sphyrna tiburo</i>	Bonnethead	Sealed bag and box	8 - 48 (j)	Christie; James; Thomas; Violetta; Young
		Free-swimming	8 - 76	Christie; James; Henningsen; Thomas; Violetta; Young
<i>Sphyrna zygaena</i>	Smooth hammerhead	Free-swimming	8 (t)	Kinnunen
<i>Squalus acanthias</i>	Spiry dogfish	Free-swimming	1 - 36	Howard; James; Thomas
		Restrained	1 - 6	Engelbrecht; Howard
<i>Squatina australis</i>	Australian angelshark	Restrained	3.5	Kinnunen
<i>Squatina californica</i>	Pacific angelshark	Free-swimming	4	Howard
		Restrained	6	Engelbrecht
<i>Squatina dumeril</i>	Sand devil	Restrained	0.5 - 1	Marin-Osorno
<i>Squatina squatina</i>	Angelshark	Sealed bag and box	17	Romero
<i>Stegostoma fasciatum</i>	Zebra shark	Sealed bag and box	14 - 24	Christie; McEwan; Violetta
		Free-swimming	8 - 20	Kinnunen; Romero; Violetta
		Restrained	6 - 56	Smith, 1992; Hiruda et al., 1997; Marshall
<i>Taeniura lymna</i>	Bluespotted ribbontail ray	Sealed bag and box	14 - 24	McEwan; Marshall
		Restrained	56	Marshall

Table 8.5 (continued). Successfully transported elasmobranchs, showing technique and duration of transport; (j) refers to juvenile and (t) refers to a towed sea-cage. If more than one reference is available, durations are given as a range showing minimums and maximums. All references were personal communications unless otherwise indicated by a date of publication.

Species name	Common name	Technique	Duration (h)	Reference
<i>Taeniura meyeri</i>	Blotched fantail ray	Restrained	56	Marshall
<i>Torpedo californica</i>	Pacific electric ray	Free-swimming	2 - 6	Howard
<i>Torpedo marmorata</i>	Marbled electric ray	Free-swimming	8	Marshall
<i>Torpedo nobiliana</i>	Electric ray	Free-swimming	18	Janse
<i>Torpedo panthera</i>	Panther electric ray	Free-swimming	24 - 48	McEwan
<i>Triaenodon obesus</i>	Whitetip reef shark	Sealed bag and box	10 - 18 (j)	Henningsen; McEwan; Violetta
		Free-swimming	7 - 34	Barthelemy; Marshall
<i>Triakis megalopterus</i>	Sharptooth houndshark	Restrained	26 - 56	Hiruda et al., 1997; Marshall
<i>Triakis semifasciata</i>	Leopard shark	Restrained	20 - 30	Farquar; Sabalones
		Restrained	84	Marshall
		Sealed bag and box	24 - 36 (j)	Carrier; Thomas; Marshall
		Free-swimming	1 - 48	Howard; James; Thomas
<i>Trygonorrhina fasciata</i>	Southern fiddler	Restrained	6	Engelbrecht
		Sealed bag and box	3 - 10	Kinnunen; Marshall
		Free-swimming	10	Marshall
<i>Urolophus halleri</i>	Haller's round ray	Restrained	26	Hiruda et al., 1997
		Sealed bag and box	24 - 36	Thomas; Young
<i>Urobatis jamaicensis</i>	Yellow stingray	Free-swimming	36	Thomas
<i>Urolophus sufflavus</i>	Yellowback stingaree	Sealed bag and box	24 - 48	Thomas; Violetta; Young; Marshall
		Free-swimming	1 - 36	Christie; Thomas
		Restrained	26	Hiruda et al., 1997

treatment system. Throughout any transport critical water parameters to monitor and control include: (1) oxygen (described above); (2) temperature; (3) particulates and organics; (4) pH; and (5) nitrogenous wastes.

Temperature

When elasmobranchs go from a warmer to cooler environment they suffer a short-term thermal shock that can result in respiratory depression. Conversely, an increased temperature can promote and exacerbate hyperactivity (Stoskopf, 1993, Ross and Ross, 1999). Reducing temperature differentials at the source, in transit, and at the final destination, will increase the chances of a successful transport (Andrews and Jones, 1990; Stoskopf, 1993). Transport tanks should be well-insulated, and as much as possible, temperature-controlled environments should be used (e.g., air conditioned vehicles, covered airport hangars, etc.). In extreme cases water exchanges, bagged ice, bagged hot water, and heat beads may be used to minimize temperature changes depending on prevailing trends.

Particulates and organics

Particulate and dissolved organo-carbon compounds, or organics, are excreted by elasmobranchs during transport. In particular skates and rays produce copious amounts of a proteinaceous slimes when subjected to stress. Particulates, or suspended solids, will irritate the gills, reduce water clarity, and cause distress to specimens being transported (Ross and Ross, 1999). Dissolved organics will tend to reduce pH, increase ammonia (NH_3) concentration, and consume O_2 . The concentration of both particulates and organics should therefore be minimized during transport. Dilution of particulates and organics can be achieved by water exchanges, mechanical filtration, adsorption or chemical filtration, and foam fractionation (Gruber and Keyes, 1981; Stoskopf, 1993; Dehart, pers. com.).

Mechanical filtration usually takes the form of a canister filter containing appropriate media (e.g., pleated paper, filter wool, etc.). Filtration may be enhanced by the addition of an adsorption or chemical filtration medium such as activated carbon (e.g., Professional Grade Activated Carbon, Aquarium Pharmaceuticals Inc, USA) or other chemical filter (e.g., Eco-lyte™, Mesco Aquatic Products, USA) (Marshall, 1999). Eco-lyte™ is particularly effective (i.e., ~100 times as

effective as activated carbon) at removing dissolved organics (Gruber and Keyes, 1981). As Eco-lyte™ is an adsorption medium it will be more effective if preceded by a mechanical filter. When using Eco-lyte™ it should be borne in mind that it will remove medications from the water (e.g., anti-stress agents, anesthetics, etc.). Always pre-wash a medium before packing a filter. For long transports it is beneficial to completely replace the medium, in transit, once it has become heavily contaminated.

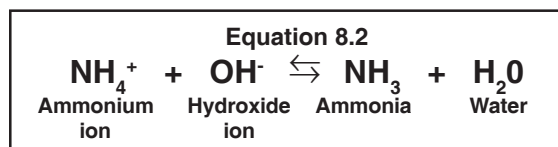
pH

Continued excretion of dissolved CO_2 and H^+ will drive pH in a transport tank down (i.e., the water will become more acidic). Efforts should be made to resist this trend and pH should be maintained at a level of 7.8-8.2 (Murru, 1990). One important way to counter pH decline is the continuous removal of CO_2 from transport water by degassing. Degassing is achieved by spraying recirculated water into the tank and agitating the surface, or alternatively, bubbling the water surface with a diffuser. Air ventilation is critical during this process as it will carry away liberated CO_2 gas (Young et al., 2002).

Both sodium bicarbonate (NaHCO_3) and sodium carbonate (Na_2CO_3) have been added to transport water to successfully resist decreasing pH (Cliff and Thurman, 1984; Murru, 1990; Smith, 1992). A more efficient buffer is tris-hydroxymethyl aminomethane (e.g., Tris-amino®, Angus Chemical, USA). This compound is more effective within the expected pH range (i.e. 7.5-8.5) and is able to increase the acid-absorbing capacity of seawater by up to 50 times (McFarlane and Norris, 1958; Murru, 1990). It is important to remember that increased pH results in an increased proportion of the toxic form of ammonia according to the reaction given in Equation 8.2. Any corrective therapy applied to the pH of the water must therefore be coupled with the removal of excess ammonia (Ross and Ross, 1999).

Nitrogenous wastes (NH_3 / NH_4^+)

Ammonia constitutes approximately 70% of the nitrogenous wastes excreted by aquatic organisms (Ross and Ross, 1999). Some delicate



elasmobranchs are particularly nutrient-sensitive and ammonia concentrations should never be allowed to exceed 1.0 mg l⁻¹. The removal of ammonia from a transport tank should therefore be one of the principal objectives of any water treatment system. Ammonia can be removed successfully using periodic 50% water exchanges and the application of adsorption media (see above). Pre-matured biological filters may be employed if ammonia production levels during transport can be calculated and simulated beforehand (e.g., with ammonium chloride) (Dehart, pers. com.). Another option is to use an ammonia sponge such as sodium hydroxy-methanesulfonate (e.g., AmQuel[®], Novalek Inc., USA) (Visser, 1996; Young et al., 2002). AmQuel[®] inactivates ammonia according to the reaction given in Equation 8.3. The substance formed is stable and non-toxic, and will not release ammonia back into the water. It should be noted that this reaction will lower pH so the addition of AmQuel[®] should be accompanied by the careful application of a buffer as discussed above. Following the application of AmQuel[®], only salicylate-based ammonia tests will yield accurate results.

Zeolite (e.g., Ammo-Rocks[®], Aquarium Pharmaceuticals Ltd., USA), an ion-exchange resin used for the removal of nitrogenous wastes in freshwater systems, does not work well in seawater because the ammonia molecule is similar in size to the sodium ion. At a salinity of 36 ppt there is a 95% reduction in zeolite's ability to remove ammonia from the water—although its ability to remove organic dyes remains unchanged (Noga, 1996).

ANESTHESIA

The mechanics of anesthesia, appropriate sedatives for elasmobranchs, and corresponding dosage rates will be covered in Chapter 21 of this manual. We will therefore focus only on specific examples as they relate to elasmobranch transport.

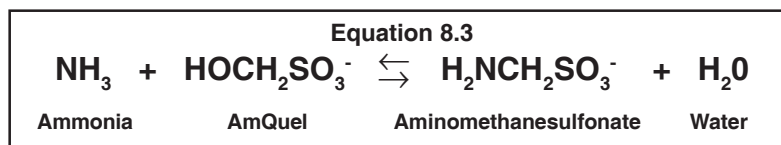
Anesthesia may be valuable during specific transports as it can minimize handling times, reduce physical injury, slow metabolic rate and O₂ consumption, and reduce the production of

metabolic wastes (Ross and Ross, 1999). If anesthesia is used, respiratory and cardiovascular depression becomes a risk and must be avoided (Tyler and Hawkins 1981; Dunn and Koester, 1990; Smith, 1992). Reduction of a specimen's metabolism by chemical immobilization will constitute a poor trade-off if circulation becomes so weakened that O₂ uptake and metabolite effusion at the gill surface are impaired (Smith, 1992). Additionally, the wide inter-specific diversity of elasmobranchs can make it difficult to predict dosage rates and possible sensitivity reactions to immobilizing agents (Vogelnest et al., 1994). Consequently anesthesia may be warranted in specific cases but is not advocated for general use during elasmobranch transports.

If anesthesia is used it will be more valuable if transport does not begin until the drug has taken its full effect and specimen stability has been assured (Smith, 1992). If defense reactions are not fully moderated the animal could respond to external stimuli and physically injure itself or personnel. Aggressive emergence reactions should be avoided for the same reasons so visual, auditory, and pressure stimuli should be minimized during recovery (Smith, 1992). Some means to adequately monitor depth of anesthesia must be employed throughout the transport so that corrective measures can be undertaken should system deterioration be observed (Dunn and Koester, 1990).

Inhalation anesthesia

A popular method of inducing anesthesia in small sharks is by immersing them in water containing an anesthetic agent. The thin gill membranes act as the site of adsorption and the anesthetic passes directly into arterial blood (Oswald, 1977; Stoskopf, 1986). It is possible to control the depth of anesthesia by adjusting the concentration of drug in the water. Immersion, or inhalation, anesthesia is often impractical for large sharks so a modification of the technique, irrigation anesthesia, may be used as an alternative. Irrigation anesthesia is achieved by spraying a concentrated solution of the anesthetic over the gills using a plastic laboratory wash bottle or pressurized mister. This system yields a rapid



induction but there is a risk of overdose and it can result in delayed recovery (Tyler and Hawkins, 1981).

Some filtration media (e.g., ion-exchange resins and activated carbon) may remove drugs used for inhalation anesthesia. Inhalation anesthesia cannot be employed in aquariums where contamination of the water is a consideration (Stoskopf, 1986).

A popular inhalation anesthetic for elasmobranchs is tricaine methanesulfonate or MS-222 (Finquel[®], Argent Laboratories, USA) (Gilbert and Wood, 1957; Clark, 1963; Gilbert and Douglas, 1963; Gruber, 1980; Gruber and Keyes, 1981; Tyler and Hawkins, 1981; Stoskopf, 1986; Dunn and Koester, 1990). Unfortunately dosage rates for transport purposes are not well documented. Stoskopf (1993) has suggested an immersion induction dose of 100 mg l⁻¹ MS-222 for the long-term anesthesia of small sharks; with an expected induction time of 15 minutes. For the transport of fishes in general, Ross and Ross (1999) advocate a lower immersion induction dose of 50 mg l⁻¹ followed by a maintenance dosage of 10 mg l⁻¹. Brittsan (pers. com.) successfully restrained and transported two blacktip reef sharks (*Carcharhinus melanopterus*) for 24 hours using an induction dose of 48 mg l⁻¹ MS-222. Initial induction time was approximately two minutes and both animals were transferred to the transport tanks within eight minutes. A maintenance dose was considered unnecessary and was not applied.

Injection anesthesia

Injection anesthesia may be administered intravenously (IV), intraperitoneally (IP), and intramuscularly (IM). IV injections result in a quick onset of anesthesia but can only be administered to restrained animals, allowing accurate location of appropriate blood vessels. IP administered sedatives must pass through the intestinal wall or associated membranes so induction time is often delayed. IM injections can be administered to slow-swimming sharks without previous restraint and induction time is usually quite fast. It is possible to administer IM injections to active elasmobranchs with pole syringes or similar remote-injection devices. A convenient site for IM injection is an area of musculature surrounding the first dorsal fin, referred to as the dorsal saddle (Stoskopf, 1993).

The tough nature of shark skin and denticles requires the use of a heavy-gauge needle to

penetrate through to a blood vessel, body cavity or musculature (Stoskopf, 1986). The use of heavy-gauge needles may present problems as shark skin is not very elastic and drugs may leak from the injection site. If possible, gently massaging the injection site can reduce leakage. When using any form of injection anesthetic it may be difficult to control depth of anesthesia because once the drug has been introduced into systemic circulation it is not easily reversed. In addition, recovery from a heavy dose of an injected anesthetic may be prolonged if the drug is slowly released from non-nervous tissue.

Sedation is defined as a preliminary level of anesthesia where response to stimulation is reduced and some analgesia is evident (Ross and Ross, 1999). Sedation may be useful if a specimen is likely to struggle excessively during the initial stages of capture and preparation for transport. The sooner a specimen becomes quiescent the better the chances of its long-term survival (Dunn and Koester, 1990). One of the authors (Smith) has used Diazepam (Valium[®], F. Hoffmann-La Roche Ltd, Switzerland) successfully at 0.1 mg kg⁻¹ IM to mitigate hyperactivity in sand tiger sharks for short periods. Visser (1996) applied 5.0 mg of Diazepam to a 1.8 m sand tiger shark prior to transferring the animal from the site of capture to a staging facility. Within minutes of application the shark was sedated and could be handled safely for a period of approximately one hour.

A combination of ketamine hydrochloride (Ketalar[®], Parke-Davis, USA) and xylazine hydrochloride (Rompun[®], Bayer AG, Germany) has been used successfully to deeply anesthetize large elasmobranchs, for long periods, when administered IM (Oswald, 1977; Stoskopf, 1986; Andrews and Jones, 1990; Jones and Andrews, 1990; Smith, 1992). Stoskopf (1993) suggests the use of 12.0 mg kg⁻¹ ketamine hydrochloride and 6.0 mg kg⁻¹ xylazine hydrochloride for anesthetizing large sharks. Stoskopf (1986) further recommends using higher doses for more active sharks, such as the sandbar shark (*Carcharhinus plumbeus*) (i.e., 16.5 mg kg⁻¹ and 7.5 mg kg⁻¹, respectively), and lower dosage rates for less active sharks like the sand tiger (i.e., 8.25 mg kg⁻¹ and 4.1 mg kg⁻¹, respectively). The expected induction time at these dosage rates is ~8-10 minutes. Andrews and Jones (1990) successfully used 16.5 mg kg⁻¹ ketamine hydrochloride and 7.5 mg kg⁻¹ xylazine hydrochloride IM to anesthetize sandbar sharks for transport purposes. Similarly the sand tiger shark, bull shark, zebra shark (*Stegostoma*

fasciatum), and bowmouth guitarfish (*Rhina ancylostoma*) have been anesthetized and transported using a combination of 15.0 mg kg⁻¹ ketamine hydrochloride and 6.0 mg kg⁻¹ xylazine hydrochloride IM, in conjunction with 0.125 mg kg⁻¹ IM of the antagonist yohimbine hydrochloride (Antagonil®, Wildlife Pharmaceuticals Inc, USA) at the conclusion of the operation (Smith, 1992). Visser (1996) has anesthetized two 1.8 m sand tiger sharks, for transport purposes, using 900 mg ketamine hydrochloride and 360 mg xylazine hydrochloride IM.

CORRECTIVE THERAPY

If a transport is extensive in duration, or preceded by specimen hyperactivity, an elasmobranch will consume a lot of its stored energy reserves. By administering glucose directly into the bloodstream it is possible to compensate for a drop in blood-glucose concentrations and decrease the need to mobilize valuable glycogen stores from the liver. Reduced mobilization of glycogen is particularly important if hyperactivity has proceeded to such an extent that glucocorticoids are depleted or blood-glucose reserves are nearing exhaustion (Smith, 1992).

Although elasmobranchs have a limited ability to buffer their blood, it has been observed that they are able to absorb bicarbonate (HCO₃⁻) directly from the surrounding environment to help counteract acidosis (Murdaugh and Robin, 1967; Holeyton and Heisler, 1978). This ability suggests an avenue for therapy directed at alleviating acid-base disruption in an acidotic elasmobranch: specifically, direct administration of HCO₃⁻ into the bloodstream (Cliff and Thurman, 1984). Acetate has been suggested as an effective alternative to bicarbonate (Hewitt, 1984), although there is some concern that acetate degradation may be more noxious than bicarbonate dissociation (Young, pers. com.). Nevertheless, an acetate-bicarbonate combination has been used successfully to revive a prostrated blacktip reef shark by injecting the mix directly into the bloodstream (Hewitt, pers. com.).

In practice, a corrective therapy for hypoglycemia and acidosis can be prepared by adding HCO₃⁻ or CO₃²⁻ (carbonate) to an IV drip-bag of glucose or dextrose (e.g., 100 ml of 8.4% NaHCO₃ mixed in a 1.0 l IV drip-bag of 5% glucose in saline). The resulting mixture is introduced into the specimen via an IV drip line and heavy-gauge catheter. The preferred site for therapy

administration is the large dorsal blood sinus just under the skin and posterior to the first dorsal fin. This site allows the position of the catheter to be monitored closely (Murru 1990). If this blood vessel resists penetration, it is possible to use a caudal blood vessel just posterior to the anal fin or even to introduce the catheter IP. IV will be more effective than IP in the case of bradycardia (cardiac depression). Approximately 500 ml of the corrective therapy should be administered to a 100 kg shark every hour (i.e., 5 ml kg⁻¹ h⁻¹). This dosage may be increased if the decline in blood pH is known to be profound (Smith, 1992).

Many workers have produced variations on this therapeutic recipe to make it less physiologically challenging to target elasmobranchs (Table 8.6). In some cases, urea has been added to equilibrate the osmotic pressure of the mixture with that of shark plasma (Murru, 1990; Andrews and Jones, 1990). This area of corrective therapy would benefit greatly from some structured research.

MONITORING

When transporting delicate species, or using an elaborate transport regime, it is important to frequently check specimen and equipment status (Cliff and Thurman, 1984; Smith, 1992; Ross and Ross, 1999). Many important factors should be verified and have been summarized in Table 8.7. If a problem is observed, corrective measures should be undertaken immediately. Tanks should be packed so that windows, access hatches, and critical equipment (e.g., valves, gauges, tools, etc.) are all easily accessible. Testing equipment to measure critical water parameters should be carried and used.

It is important to monitor ventilation rate. Ventilation and cardiac rates are functionally linked in many fishes and may be neurologically synchronized (Ross and Ross, 1999). Gilbert and Wood (1957) observed that heartbeat was synchronous with ventilation rate in anesthetized lemon sharks. Skin color should be monitored as it may be used to loosely assess biochemical impact on a specimen; increasing loss of skin color equating to an increased biochemical change (Cliff and Thurman, 1984; Smith, 1992). Stoskopf (1993) observed that hypo-oxygenation could cause sharks to turn blotchy and increase their respiration rate, while hyper-oxygenation caused them to become pale and occasionally cease ventilation altogether (Stoskopf, 1993).

Table 8.6. Corrective therapies applied to hypoglycemic and acidotic elasmobranchs during transportation showing formulations, dosage rates for adult specimens, mode of administration, and species treated.

	Hewitt, 1984	Ballard, 1989	Murru, 1990	Andrews and Jones, 1990	Smith, 1992	Visser, 1996
Dextrose	25.0 g l ⁻¹ (2.5%)	Dextrose ? ^a	Dextrose 20.0 g l ⁻¹ (2.0%)	Glucose 1.00 g l ⁻¹	Glucose 50.0 g l ⁻¹ (5.0%)	Glucose 50.0 g l ⁻¹ (5.0%)
NaHCO ₃	? ^a	NaHCO ₃ 0.42 g l ⁻¹	NaCO ₃ ? ^b	NaHCO ₃ 0.35 g l ⁻¹	NaHCO ₃ 0.84 g l ⁻¹ d	NaHCO ₃ 0.84 - 3.36 g l ⁻¹ e
Amino acids	? ^a		Urea 300 mEq l ⁻¹	Urea ^c 21.02 g l ⁻¹		
Electrolytes	? ^a		Na ⁺ 280 mEq l ⁻¹	NaCl 16.00 g l ⁻¹		
B-vitamins	? ^a		Cl ⁻ 230 mEq l ⁻¹	KCl 0.40 g l ⁻¹		
			K ⁺ 4.4 mEq l ⁻¹	CaCl ₂ 0.14 g l ⁻¹		
				MgCl ₂ 0.10 g l ⁻¹		
				KH ₂ PO ₄ 0.06 g l ⁻¹		
				MgSO ₄ 0.10 g l ⁻¹		
				NaHPO ₄ 0.90 g l ⁻¹		
? ^a	250 - 500 ml h ⁻¹		40 - 100 ml h ⁻¹	120 ml h ⁻¹	500 ml h ⁻¹	600 - 700 ml h ⁻¹
IV	IP	IP (or IV)	IP (or IV)	IP	IP (or IV)	IP
<i>Carcharodon carcharias</i>	<i>Carcharhinus leucas</i>	<i>Carcharhinus leucas</i>	<i>Carcharhinus leucas</i>	<i>Carcharhinus plumbeus</i>	<i>Carcharhinus leucas</i>	<i>Carcharias taurus</i>
	<i>Carcharhinus obscurus</i>	<i>Carcharhinus obscurus</i>	<i>Carcharhinus obscurus</i>		<i>Carcharias taurus</i>	
		<i>Carcharhinus plumbeus</i>				

a: value unknown.

b: value unknown; sodium carbonate added to formulation until pH value of 8.4 attained.

c: urea added to formulation until osmotic pressure equilibrated with shark plasma.

d: quoted as 8.4 g 100ml⁻¹ HCO₃⁻ added to 900 ml of 5% glucose in saline.e: quoted as 8.4 g 100ml⁻¹ HCO₃⁻ added to 900 ml of 5% glucose in saline and 16.8 g 200ml⁻¹ HCO₃⁻ added to 800 ml of 5% glucose in saline.

Table 8.7. Important factors to monitor throughout an elasmobranch transport. Should any of these factors represent a progressive problem corrective measures should be undertaken immediately.

Specimens	1.1 Ataxia (uncoordinated movements) or disorientation.
	1.2 Partial or total loss of equilibrium.
	1.3 Tachy-ventilation or brady-ventilation (i.e. increased or decreased gill ventilation rates).
	1.4 Changes in muscle tone.
	1.5 Changes in shade and homogeneity of skin color.
	1.6 Possible physical injury.
Equipment	2.1 Bubbles emerging from oxygen diffuser.
	2.2 Uninterrupted power supply and power supply not overheating.
	2.3 Pump operating correctly and not overheating.
	2.4 Water flow constant and correctly orientated.
	2.5 Water level stable with no appreciable leakages.
	2.6 Water clear and uncontaminated.
	2.7 Water quality parameters within acceptable limits.

ACCLIMATIZATION AND RECOVERY

At the termination of a transport specimens should be acclimatized to local water parameters by slowly replacing the water in the transport tank with water from the quarantine facility (refer Chapter 11 for more information about specimen acclimatization). If the elasmobranch appears to be healthy, prophylactic treatments (e.g., anti-helminthic baths, antibiotic injections, etc.) may be applied (Mohan, pers. com.). Serious abrasions, punctures, or lacerations should be evaluated and may require the application of an antibacterial agent or possibly sutures (Murru, 1990). Handling should be kept to a minimum and excess external stimuli avoided.

Reversal of immobilizing drugs should be coincident with specimen release. Once a specimen starts to swim normally, muscle tissue will be flushed with fresh, oxygenated blood. This process will cause metabolic by-products sequestered in the tissues and extra-cellular spaces to move into circulation. High concentrations of toxins may enter delicate organs and possibly compromise recovery (Cliff and Thurman, 1984). In addition, immobilizing drugs may be flushed into the bloodstream and renew their paralyzing effects. During this period the animal may be disorientated and exhibit defense responses to external stimuli (Gruber and Keyes 1981; Smith, 1992).

When released, some pelagic and demersal elasmobranchs will lie on the bottom of the aquarium. Walking while holding the shark in the water column, flexing its caudal peduncle, and

stroking its dorsal surface have all been recommended as techniques to increase ventilation, assist venous return, and facilitate recovery (Clark, 1963; Gruber and Keyes, 1981). These techniques require excess handling and do not simulate normal swimming behavior. In addition, these techniques may actually compound the effects of hyperactivity and prematurely flush systemic circulation with high concentrations of toxic metabolites. As long as an elasmobranch is ventilating voluntarily, allowing it to lie in a current of oxygen-rich seawater avoids these complications (Hewitt, 1984; Smith, 1992; Stoskopf, 1993).

It is preferable to allow specimens to recover in an isolated and unobstructed tank. Once a recovering elasmobranch is swimming freely it is important that a program of post-transport observation be implemented. Feeding the animal within 24 hours of transport is not recommended (Smith, 1992). If a suitable isolation facility is available, a comprehensive quarantine regime should be seriously considered before the specimen is introduced into the destination exhibit (Andrews, pers. com.).

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