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ENVIRONMENTAL CONSIDERATIONS

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Introduction

Marine mammals maintained under human care depend on us for their needs. We are their stewards and, as such, decide all aspects of their housing, feeding, social structure, and enrichment opportunities. Environmental considerations are paramount to the health and welfare of these animals. Captive marine mammals require clean water, nonreflective pool surfaces and surroundings, acceptable acoustical environments, stable social groupings, and enough space to perform all of their natural behaviors. Air quality is also important, as some pathogens are spread in dust and aerosols (see **Chapter 19**). Within the United States, standards for animal care are regulated by the Animal Welfare Act (AWA), which is enforced by the United States Department of Agriculture (USDA 2013). Minimum standards specific to marine mammals are found in Part 3—Standards, Subpart E "Specifications for the Humane Handling, Care, Treatment, and Transportation of Marine Mammals." In Canada, the Canadian Council on Animal Care (CCAC 1993) sets the guidelines for the care and use of marine mammals.

Pool and Exhibit Design

Facility design has evolved greatly in the past 25 years, from simple pools meeting minimum federal standards to larger, more complex exhibits built to resemble the native habitat of the species housed. Modern exhibit design facilitates the natural behaviors and general health of the animals and is more aesthetically pleasing to the viewing public. It encompasses the layout of the entire habitat, from the public viewing areas to the back holding areas, including water filtration, the mainstay of life support systems. All marine mammals require a body of water in which to live. Cetaceans and sirenians spend their entire lives in water, while pinnipeds, polar bears (*Ursus maritimus*), and sea otters (*Enhydra lutris*) require an acceptable area to haul out of the water. A good design addresses concerns about pool and exhibit materials, noise above and under the water, air quality, lighting, shade, adequate space for the animals to perform all of their natural behaviors in and out of the water, managing social groupings, and ensuring neonatal survival.

Pools should be constructed to ensure marine mammals can perform all of their natural behaviors. While minimum standards for most managed marine mammal species within the United States are set by the USDA Animal Welfare Regulations, greater areas for swimming and depth for diving may be of benefit to the animals. While the optimal shapes of pools have been debated, ensuring the animals can move freely in three dimensions should be the basis of the design. Modern facilities have pools that allow the animals to carry out all of their natural behaviors in all three dimensions—width, length and depth.

Modern pool areas should be designed to provide shade for animals. Lack of shade and other risk factors have been correlated with development of cataracts and lens luxation in captive pinnipeds (Colitz et al. 2010a; see **Chapter 23**). Further, there is anecdotal and circumstantial evidence that bright blue and other reflective pool paint colors have been associated with ocular disease in pinnipeds (Colitz et al. 2010b; Gage 2012). Exposure to excessive amounts of UV light may be exacerbated by animals habituated to looking toward the sun for fish rewards or to consume their daily diets. Keepers and trainers should strive to offer fish in such a way that the animal is protected from looking directly at the sun. At facilities where the public is allowed to feed the marine mammals, strategic shade must be provided, so animals are not forced to look directly toward the sun to obtain their fish offerings.

Modern display facility pools should also be designed to minimize the risk of accidental introduction of foreign bodies by the public. This is always a risk for animals on public display. Close contact between visitors and animals may result in accidental introduction of objects like sunglasses, hats, and other materials to the pool with which animals may interact. Ingestion of foreign bodies is a concern in captive marine mammals, and removal of these objects is often necessary (Stoskopf 2016). Efforts to train animals to retrieve objects, as opposed to swallowing them, have been helpful in some settings (Stoskopf 2016). Design considerations should also include careful scrutiny of vegetation that may be placed in the vicinity of marine mammal pools. Debris should not be permitted to drift into the pool. Pine needles and oak leaves, for example, may be a source of trauma, causing damage to ocular tissues. Further, some vegetation may be toxic, and animals may access material unexpectedly. A beluga died several weeks after ingesting 20 lbs of oak leaves (*Quercus spp.*) that had blown into her pool (Mergi et al. 2012). The authors speculated that esophageal damage caused by the oak leaves provided a portal of entry for a fatal infection with *Aspergillus* sp.

Otters, otariids, and odobenids are capable of climbing; therefore, fencing and walls should be of sufficient height and strength to contain these animals. Sea otters and walrus (*Odobenus rosmarus*) are notorious for dismantling or damaging their enclosures. Care should be taken to prevent access to structural components such as nuts and bolts, or to window sealant or gaskets.

Lighting

Lighting intensity and duration ought to reflect conditions encountered by the animal in its natural habitat. This may entail supplying additional lighting for species housed indoors or providing shade to prevent overexposure in outdoor facilities. Lighting for indoor facilities must "provide uniformly distributed illumination which is adequate to permit routine inspections, observations, and cleaning of all parts of the primary enclosure" (USDA 2013). It is generally desirable to provide natural lighting, but a mixture of candescent and incandescent light is acceptable, to aim for periodicity of lighting similar to that in an animal's natural environment (Geraci 1986). Interestingly, polar species tolerate local ambient cycles without detriment (Sweeney and Samansky 1995).

Pinnipeds housed indoors should have a mechanism for photoperiod to be adjusted to provide natural variation appropriate for the species. Mo et al. (2000) reported abnormal molt cycles in harbor seals (*Phoca vitulina*) maintained without appropriate variation in photoperiod.

Air Quality

Air quality is of particular concern for cetaceans, especially given their predilection to develop pneumonia as surface air is inhaled deep into the lungs without being filtered by nasal turbinates (Ridgway 1972). Consequently, noxious fumes (i.e., chlorine), heavier-than-air by-products of disinfection (i.e., volatile organic compounds), or particulate debris (i.e., dust, construction debris) present at the air–water interface are considered risk factors for lung disease. Cetaceans, in particular, should be protected from aerosolized debris, which can be generated by nearby construction, environmental dust storms, nearby pressure washing, or contaminates dislodged from overhead structures (see **Chapter 19**). Porous shade structures may be a risk factor for introduction of pathogens and aerosolized debris. Material such as dust, debris, and bird fecal material may collect on the overhead material during the dry season and then be introduced into the pool in significant amounts with the first seasonal rainstorm. The risk may be increased following a prolonged dry season. Cetaceans housed in indoor enclosures may benefit from having high-efficiency particulate air (HEPA) filtration systems that are cleaned regularly (Martony et al. 2016).

Noise

Noise levels above and below the water must be considered when creating an optimal environment for marine mammals. Noise generated by filtration systems, nearby attractions, traffic, and activities or events held in proximity to marine mammal pools or haul-out areas may be disruptive to the animals. Evaluating the levels of the sounds generated near enclosures, as well as measuring noise levels underwater using a hydrophone, should be included in modern marine mammal husbandry protocols. Standards for acceptable levels of noise exposure have not been established for captive marine mammals, despite considerable research on impacts of noise on wild marine mammals (Southall et al. 2007).

Life Support (Water) System Design

Water quality is critically important to the health and well-being of marine mammals, and appropriate life support systems (LSS) must be designed to meet their needs. There are many challenges when designing life support systems for these animals. The objective is to remove pathogens and organic material from the water without causing harm to the animals. Sterilization of water is no longer the goal for modern marine mammal life support systems (Van Bonn et al. 2015). Water for marine mammals should be clean but maintain a balance of organisms with the goal of creating an optimal marine biome. Overoxidizing the water can result in spikes or excessive concentrations of oxidants in the water, or a buildup of unwanted by-products of disinfection that may be unhealthy for the resident animals (Latson 2009, 2016). Excessive microorganisms must still be managed. This is most commonly accomplished by using oxidants judiciously, including ozone, trace chlorine, and/or UV light (see below).

Source Water

Marine mammals may be housed in sea or bay pens where the quality of the water is dependent upon the condition of the ocean or bay water. Tides that move the water through their enclosures or the amount of water flow provided by other means also influences the quality of their water. Housing marine mammals in sea or bay pens may pose a risk of exposure to natural contaminants, such as harmful algal blooms, or man-created contaminants such as petroleum spills or other pollutants. Protocols to protect these animals from harmful contaminants should be in place.

Marine mammals may also be housed in engineered pools with water systems that can be open (flow-through), semiopen, or closed. Pools with a continuous flow of water from a natural source are called "open" systems. Filters, while generally not necessary, may be added to open systems to improve water clarity and turnover. As with open water pens, contingency plans should be in place in the event that natural (harmful algal blooms) or man-made contaminants (oil spills) from incoming water enter the system and become a concern.

Pools maintained without a continuous flow of water are designated as semiopen or closed systems. In semiopen systems, the pools are managed with a periodic flow of natural seawater and may be augmented by the use of LSS or a filtration system. Closed systems are more intensely managed using an LSS, since in these systems, all water is recirculated, and new water is only added to replace water lost to evaporation or filtration management. Sterilization, temperature control, and removal of solids, water contaminants, and by-products of disinfection are processes incorporated into system design to maintain acceptable water quality. Water changes or additions are made as needed in closed systems to maintain salinity, pH, and other water parameters (see below).

Water for semiopen or closed systems may come from an ocean or bay, or may be fresh water originating from a well or municipal source. When municipal fresh water is used as the source water, depending on the species of marine mammal being maintained, salt or a seawater salt product is added to maintain appropriate salinity. For pinnipeds, sodium chloride rather than "Imitation Ocean" products are acceptable for salinizing water. Salt products that are bromine-free are preferred, because bromine combines with nitrogenous waste to create toxic by-products. Bromine is discussed in more detail below.

Municipal fresh source water may have high chlorine levels, often over 2–3 ppm. This may contribute to ocular, dermatologic, or respiratory damage (Gage 2012). Chlorine levels in source water may vary by season and should be tested regularly to ensure that unhealthy levels of chlorine are not being added directly to the marine mammal pools. Methods to remove excess chlorine may include carbon filters, sodium thiosulfate treatment, or holding pools where the chlorine may dissipate from the water naturally or through heavy aeration. Municipal water may also contain chloramines or other additives and should be tested to ensure animals are not exposed to unwanted contaminants.

Filtration

Filtration requirements vary with system design, water source, and species of animals being housed. Stamper and Semmen (2012a) have provided an overview of filtration and water conditioning principles for zoo veterinarians. Biological and mechanical filtration are commonly integrated into designs for treatment of marine mammal pool waters. Further, water conditioning and sanitation—also referred to as chemical filtration—are critically important aspects of filtration for marine mammal systems and are highly regulated in the United States (see below). Fundamental concepts of system design and life support system components have been reviewed (Spotte 1992; Stamper and Semmen 2012a; Francis-Floyd, Petty, and Yanong 2016).

Biological Filtration Biological filters function to remove nitrogenous wastes (ammonia, ammonium nitrite, and some nitrates) from aquatic systems mainly by aerobic nitrification, although some anaerobic processes occur. They are designed to provide a large surface area on which beneficial bacteria may grow. Heterotrophic bacteria use mostly organic substances as energy sources, whereas autotrophic bacteria focus on inorganic compounds. Biological filters usually consist of bacteria attached to a solid matrix such as gravel, sand, or plastic beads, where the bacterial populations can become dense, impairing filter efficiency. Bacterial colonization also occurs on the surfaces of submerged system components such as pool walls or pipes. The high-pressure sand filters and bead filters may also serve as biological filters, if not exposed to disinfectants or oxidizing agents.

Beneficial bacteria, including *Nitrosomona* spp., *Nitrobacter* spp., and related organisms, will grow in the biological filters, and biofiltration occurs when these bacteria actively break down organic compounds. These bacteria are capable of detoxifying nitrogenous wastes, such as ammonia to nitrites, and then nitrites to nitrates. Nitrates are typically removed by water exchange, or less commonly by anaerobic denitrification systems. Because of the use of living bacteria to metabolize nitrogenous wastes, systems that are equipped with biological filtration may rely on sterilization methods other than chlorination to maintain acceptable coliform counts.

In addition to metabolism of nitrogen by-products, biological filtration may be affected by organic carbon added to the system (Stamper and Semmen 2012b). Organic material is continually introduced to the system from urine and feces, the addition of food, epithelial cells from sloughed skin or hair, and certain types of source water, such as natural seawater. Total organic carbon (TOC) is the sum of all dissolved organic carbon (DOC) plus particulate organic carbon (POC). The DOC contains refractory organic matter, which is not degraded by biological filtration, but can be removed by being bound to an adsorbent. A common adsorbent is activated charcoal, which has a limited life span and must be chemically regenerated or replaced. Total organic carbon may also be precipitated and trapped by flocculation. This process in which TOC is precipitated and trapped in the filters as flocculants and sediments was commonly employed in older life support systems. Alum and cationic polyelectrolytes (positively charged polymers) are common flocculants. Since flocculation aggregates and increases a portion of the POC, and even converts some of the DOC to particulate matter, it improves filtration efficiency and thus reduces oxidant demand (Robinson 1979; Gregory 1989). Modern life support systems often include protein skimmers (or foam fractionators) to aid in the removal of DOC and POC, which can significantly reduce the load of organic compounds on biological filtration systems.

Foam Fractionators Foam fractionators are used to remove organic compounds in water before they break down to nitrogenous waste. These units can significantly reduce the load on biological filtration systems and enhance DOC and POC removal (Spotte 1992). Some organic compounds behave as surfactants and will concentrate at the air–water interface. These will be drawn to air bubbles generated in a contact chamber, and their hydrophobic ends "attach" as the water is passed through a chamber and forced into contact with the column of fine bubbles. The surface of the bubbles attracts proteins and other organic substances and carries them to the top chamber where the foam collects and is voided from the system. This method physically removes the organic compounds from the life support system. Ozone may be introduced into the foam fractionator and will efficiently oxidize pathogens within the fractionator. Larger systems or pools may require several foam fractionators in series, while individual smaller pools may be managed with a single unit.

Mechanical Filtration Mechanical filtration, specifically granular media filtration, is used to remove particulate waste and particulate organic carbon (POC). Two types of mechanical filter systems exist: pressurized and vacuum (or gravity feed) filters. These mechanical filters are generally constructed of sturdy steel, fiberglass, or plastic vessels built to hold sand or other filter media such as plastic bead media. Water passes through sand filters under pressure and with a high flow rate. These filters must be backwashed regularly to remove the waste and particulate material that is trapped by the sand particles. Backwash water is either treated in a backwash recovery system and recirculated back to the animal pools, or discarded to the sewer or wastewater system.

Foam on the pool surface is an indicator of excessive protein in the system that has not been properly broken down and removed. The presence of foam may indicate that the sand filters, or another part of the LSS, are not functioning properly. Channels that can develop in the sand filters over time may allow water to pass through without removing the solids, leading to a protein buildup in the system, which causes excessive foam production. The sand filters must be maintained regularly to ensure there are no channels forming in the media. Foam (or protein) fractionators are often incorporated into newer systems to help solve this problem.

Plastic bead filters are increasingly being used in the design of marine mammal life support systems and have several advantages over sand filters. They operate at a lower pressure, require less energy to operate, have lower backwash water loss rates, and do not cake or form channels, and the media rarely needs replacement. The bead systems were developed for use in aquaculture systems, or those housing display fish and other aquatic animals, but are becoming more popular for use in marine mammal systems.

Chemical Filtration Chemical filtration involves the use of additives or water treatments to improve water clarity, remove colored compounds, and decrease contamination with infectious agents. Because of the importance of maintaining low coliform counts in systems housing marine mammals, a discussion of chemical filtration options has been incorporated into the discussion of sanitation and disinfection methods provided later in the chapter.

Coliform Counts

Coliform growth has been used as an indicator of sanitation and water quality, as well as the effectiveness of a life support system, although detection is affected by culture method, presence of competing bacteria, and stress on bacteria in sample handling. The USDA, under 3.106(b)(1), "Water Quality, Bacterial Standards," requires that the coliform bacteria count cannot exceed 1000 MPN (most probable number)/100 ml of pool water. If the test results indicate that excess bacteria are present (i.e., >1000 MPN/100 ml), then two additional tests must be run 48 and 96 hours after the original test. If the average count, for the three tests combined, is less than 1000 MPN/100 ml, then no further action is required. If the test results indicate an excessive bacterial load, corrective action must be taken immediately. This may be water exchange, sterilization, or some combination of techniques. Water testing must be repeated and demonstrate acceptable bacterial counts.

Water Turnover

The water turnover rate is how often the pool volume is exchanged per unit of time and is important to maintain water quality by treating and removing organic waste and particulate matter. An optimal turnover rate for most marine mammal systems is moving the full pool volume through the LSS in 2 hours or less. Turnover rates of once or twice per day could be acceptable depending on the volume of water and the size and number of animals in the pool. The results of coliform testing may be used as a rough indicator of the adequacy of the water turnover rate.

Chlorination

Chlorine inactivates pathogens and is commonly used to control coliform levels in marine mammal pools. When chlorine is added to an aquatic system as a gas or as salts of hypochlorous acid (i.e., sodium or calcium hypochlorite), it forms hypochlorous acid (HOCl) and hypochlorite (OCl^-); together, these molecules are referred to as "free chlorine." Of the two, HOCl is substantially more effective as a sterilant (Stamper and Semmen 2012a). These are very reactive molecules, and sterilization efficacy is affected by organic content, pH, and temperature of the water. Formation of HOCl is favored by lower pH; however, seawater is typically maintained in the pH range of 7.5–8.3 (Stamper and Semmen 2012c). When organic matter containing nitrogen and ammonia is present in pool water treated with chlorine, by-products called chloramines are formed. Measurements of "total chlorine" include all chloramines, as well as the free chlorine mentioned above. Determining the concentration of chloramines requires an indirect calculation in which the concentration of free chlorine is subtracted from the concentration of total chlorine.

Formation of chloramines in marine mammal systems has been reviewed by Stamper and Semmen (2012a). Free ammonia combines with free chlorine to produce a suite of chloramines, referred to as combined chlorine. These are monochloramine (NH_2Cl), dichloramine ($NHCl_2$), and trichloramine (NCl_3). Although the chloramines are oxidizers, they are not as effective as free chlorine. Importantly, they are also more irritating than free chlorine (Stamper and Semmen 2012a). In addition to the formation of chloramines in the system as part of the chlorination process, municipal water suppliers typically add chlorine and/or chloramines for disinfection. These chemicals may therefore be introduced during water changes if incoming water is not pretreated to remove them. Marine mammals exposed to excessive chloramines may develop skin or eye irritation and corneal lesions (Latson 2009; Gage 2012).

Chlorine levels should be measured at least once daily, and there should be little change in values from day to day. Ideally, there should be no more than 0.2 ppm change of total chlorine from one day to the next. Larger spikes could indicate a problem with the chlorine distribution system and could cause discomfort to the animals. Total chlorine levels should not exceed 1.0 ppm and optimally should be maintained well below that level, with free chlorine at approximately 50% of the total (Dold 2015). Modern systems are designed to maintain optimal water quality using minimal-to-no chlorine by incorporating other methods, such as ozone or UV light, to control pathogens. Emergency chemicals, such as sodium thiosulfate, should be available in case of an accidental overchlorination of a system.

Chlorination is inappropriate as a means of routine disinfection in systems housing sea otters and fur seals as it can damage their fur.

Bromine

Bromine is not acceptable for use as a disinfectant for marine mammal LSS (Latson 2009, 2016; Liviac et al. 2010; Plewa, Wagner, and Mitch 2011). Bromine reacts with organic materials, forming brominated organic compounds, which will persist in the water, and a water change is necessary to eliminate them. Bromine in marine mammal pools forms bromamines and hypobromous acid, which in turn react with organic matter in the water to form brominated disinfection by-products that can be harmful to human or animal health (Latson 2009, 2016; Liviac et al. 2010; Plewa, Wagner, and Mitch 2011). Seawater and some commercial seawater salt mixes contain bromine; therefore, as a precaution, by-products of bromine should be identified and monitored to ensure optimal water quality. Public water systems are required to routinely measure purgeable organic compounds (deleterious by-products of bromine and other compounds), so these test results should be available from municipal water authorities.

Ozone

Most modern marine mammal facilities incorporate ozone (O_3) into their LSS for both sterilization and maintenance of water clarity. Ozone is generated by passing a high AC voltage across a discharge gap in the presence of oxygen. The effectiveness of an ozone system for controlling pathogens is based on the contact time the ozone has with the water and the power of the ozone generator. Ozone systems use different methods to transfer the ozone gas into the water, followed by a method to degas, or remove the undissolved ozone from the water. The removed gas is then passed through an ozone destruct, which uses a catalyst to convert ozone back to oxygen. Ozone in solution can decompose and oxidize materials in two ways. (1) Molecular ozone can react with oxidizable compounds directly (though this process is short-lived and directly affected by pH, bicarbonate level, TOC level, and temperature). The immediate reaction products are free radicals, hydroperoxide species, and unstable ozonide intermediates. (2) The second pathway is the indirect action of the oxidizable compounds with radicals formed as ozone decomposes. Once in solution, the half-life of ozone in pure water at 20°C is approximately 165 minutes.

Ozone chemistry is influenced by the presence of bromide (Br^-), a component of both fresh water and seawater. It is often a contaminant of granular sodium chloride and thus is found in artificial seawater, too. Ozonation in the presence of bromide is less efficient because Br^- is regenerated from the intermediate oxidation product OBr^-, causing the catalytic destruction of O_3 and ultimately increasing the ozone demand (Spotte 1992). Ozone is a powerful oxidant, and water in direct contact with animals should be ozone-free. The free radicals in ozone can cause cellular damage. If eye problems are noted and other chemical spikes or noxious by-products of disinfection are not identified, the water from the animal pools should be tested for residual ozone (Gage 2012). There are inexpensive test kits available that will identify the presence of ozone. Facilities where ozone is used should have the ability to test for its presence to ensure there is no residual ozone in the animal pools. Ozone activity is measured by testing the ozone reduction potential, or ORP, of the water. For optimal activity, ORP should be ≥700 mV (Stamper and Semmen 2012b); however, this must be eliminated from the system before treated water comes back into contact with animals. To minimize damage to eyes, water in contact with marine mammals should have an ORP <400 mV (Stamper and Semmen 2012b).

UV Light

Ultraviolet light has been shown to be an adequate method of water disinfection and uses ultrashort wavelengths of light to kill microorganisms. Use of UV light in aquatic animal life support systems has recently been reviewed (AALSO 2016). Mercury lamps are frequently used for marine mammal systems, with the efficiency of the sterilizer dependent on the wattage of the bulb, age of the bulb, exposure time within the unit, and deposits on the quartz sleeve. This method is also commonly used in home aquariums, albeit on a much smaller scale. When dealing with the volumes associated with larger pools, the water must be exposed to the UV radiation for sufficient time and in sufficient quantity, so thin layers of water are passed by an array of lamps or bulbs. This is a contact method of disinfection, and the microorganisms must be directly exposed to the light energy. For marine mammal pool water, this requires a high side-stream flow (diversion) of the circulating water to the lamps. Without sufficient flow past the lamps, the coliforms in the pool water can quickly overcome the decrease in coliforms seen in the fraction of treated water. UV disinfection may be best used in combination with other disinfection techniques. This combination may decrease the amount of chlorine or other oxidants necessary to maintain the quality of the water for the animals.

By-Products of Disinfection

Ozone, chlorine, or bromine will oxidize compounds in the water, and when dissolved organic material is present, by-products of disinfection are produced. These by-products may be irritating or toxic to the animals (Latson 2009, 2016; Liviac et al. 2010; Plewa, Wagner, and Mitch 2011). Nitrogen-containing compounds, monochloramine, dichloramine, and especially nitrogen trichloride are irritating to eyes and mucous membranes. Carbon-containing by-products include trihalomethanes, examples of which are trichloromethane (chloroform) and tribromomethane (bromoform), both of which are known to cause liver damage (Liviac et al. 2010; Plewa, Wagner, and Mitch 2011). These compounds are volatile and may vaporize and linger in the air immediately above the water, posing a risk of inhalation by marine mammals. More complex carbon by-products that are not as volatile may also be produced and may build up to significant levels if the pool water is changed infrequently. The presence of the by-products of disinfection in the water may also contribute to ocular and respiratory disease. Many of these harmful by-products of disinfection are infrequently identified or measured in marine mammal pools.

Water Quality Parameters

Salinity

Optimal salinity for managed marine mammals is similar to ocean salinity and is often maintained between 27 and 32 parts per thousand (ppt). Marine cetaceans and sea otters must be housed in saltwater systems but may be kept in fresh water during transport or for certain medical conditions (Dold 2015). Lower salinity may have an impact on the health of the skin and eyes, especially in cetaceans, as well as the comfort level of the animals. Many otariids and phocids have been successfully managed in fresh water systems, but saltwater systems are considered a more appropriate environment. Eye problems may be associated with pinnipeds housed in fresh water systems (Gage 2012). Sodium supplementation is recommended for pinnipeds maintained in fresh water systems to minimize concerns of hyponatremia. Supplementation of 3 g NaCl/kg of fish fed has been recommended (see **Chapter 29**). Natural habitats for sirenians include saltwater, brackish water, and fresh water environments (Reep and Bonde 2006). Captive manatees (*Trichechus manatus latirostris*) have been held successfully in both saltwater and fresh water, but when housed in a marine system, they need to be continually offered a source of fresh water, such as a garden hose (see **Chapter 43**).

pH

Marine mammals have been managed without notable problems in water with a wide pH range, from 7.0 to 8.5. Ocean pH is approximately 8.1. Measuring pH daily is required for marine mammals housed in the United States unless they are maintained in open systems with a natural exchange of seawater. Because pH plays a key role in the chemical reactions that involve many of the chemical oxidants mentioned above, daily monitoring of pH is critical to assess the dynamics of these interactions. For example, as the pH increases, the amount of chlorine added to the pool for pathogen control must be increased to achieve the same results. Water systems using chlorine-based oxidants will be more effective for water sterilization at a lower pH. Thus, there is a balance between the desire to maintain optimal ocean pH and the pH for which these LSSs best operate (Latson 2009).

Temperature

Specific temperature ranges for marine mammals are derived principally from the husbandry experience of zoos and aquaria. The USDA regulations (USDA 2013) stipulate that air and water temperatures encountered by marine mammals must "not adversely affect their health and comfort," yet acceptable ranges are not provided. Sweeney and Samansky (1995) present general guidelines for water temperature minima and maxima for polar, temperate, and tropical species of pinnipeds and cetaceans. Species-specific ranges are provided elsewhere (see **Chapters 29 and 40–45**). Facilities should incorporate heaters and chillers into system design to modulate both air and water temperatures, particularly if subject to diurnal and seasonal extremes in outdoor enclosures. Manatees maintained at temperatures ≤20°C for as little as 2–3 days may develop signs of cold stress syndrome, a potentially fatal condition (see **Chapter 43**).

Ammonia

Ammonia in aqueous systems exists in two forms, ammonia (NH_3) and ammonium $\left(NH_4^+\right)$. Together these parameters are referred to as total ammonia nitrogen. These are also referred to as the unionized and ionized forms of ammonia, respectively, and clinical interpretation in the context of fish medicine has been reviewed (Francis-Floyd, Petty, Yanong 2016). In systems designed to house fish, removal of ammonia is accomplished by water exchange or biological filtration, described above. In systems designed to house marine mammals, water exchange and sanitation to maintain appropriate coliform counts, coupled with mechanical removal of particulate debris, may be more important than biological filtration per se.

The equilibrium that exists between ammonia and ammonium is governed by pH and temperature. As both parameters increase, the concentration of total ammonia favors the presence of unionized ammonia. Consequently, marine systems favor formation of ammonia (NH_3) due to the higher pH typically encountered in seawater. As described above, the presence of ammonia favors formation of chloramines, if the system is chlorinated as a means of maintaining appropriate bacterial counts in the water. As previously mentioned, chloramines are less effective at sanitizing the water and are more irritating to tissues (Stamper and Semmen 2012a). Furthermore, pools maintained at a higher pH typically require increased additions of chlorine to meet sanitation goals, further compounding the problem.

Nitrite and Nitrate

Nitrite is the second breakdown product created during aerobic nitrification of ammonia. Although highly toxic to fish, it has not been reported to be of concern in marine mammal systems. Nitrate is the end product of nitrification. Removal of nitrate from aquatic systems requires dilution by water exchange, or use of an anaerobic denitrification system (Stamper and Semmen 2012c). While these systems are increasingly common in large marine systems housing fish, they are rarely incorporated into marine mammal life support designs. Historically, nitrate has been considered relatively nontoxic. Nitrate has significant endocrine-disrupting and goitrogenic properties (Guillette and Edwards 2005, Eskiocak et al. 2005), and recommendations include maintaining concentrations ≤100 mg/L (Stamper and Semmen 2012c). Morris et al. (2011) were able to demonstrate that juvenile white-spotted bamboo sharks (*Chiloscyllium plagiosum*) exposed to 70 mg/L NO_3-N for 29 days developed histologic evidence of diffuse hyperplastic goiter. Garner et al. (2002) described goiter in neonatal dolphin (*Tursiops truncatus*) calves, and the etiology of the condition was not determined. In addition to nitrate, perchlorate is also recognized as goitrogenic and may be introduced as a contaminant from some municipal water supplies (Kimbrough and Parekh 2007). Inadvertent exposure to environmental goitrogenics may be worthy of consideration in such cases.

Special Considerations for Different Taxa

Cetaceans

Common environmental diseases in captive cetaceans frequently are related to air quality problems (see above) or ocular or dermal disease associated with excessive exposure to oxidants or their by-products. By-products of disinfection may include chloramines and volatile organic compounds, which are not only irritating to skin (Stamper and Semmen 2012a), but, if concentrated at the air–water interface, may contribute to respiratory irritation, or could be inhaled, absorbed into the body, and contribute to liver pathology (Plewa, Wagner, and Mitch 2011). Contaminants in city water, such as perchlorate, could contribute to health problems and in humans are considered goitrogenic.

Pinnipeds

The most common environmental problem in captive pinnipeds is ocular disease resulting from a variety of preventable factors. Excessive exposure to intense UV light can result either from pools and surroundings that are painted a solar-reflective color (i.e., light blue) or from inappropriate feeding procedures that cause the animal to look directly at the sun, even briefly. Preventative measures are strongly recommended, but once ocular damage has occurred, it is essential to have ample shade to provide comfort to the animal. Poor water quality, excessive oxidants in the water, and traumatic conspecific social interactions may also contribute to ocular disease. Hyperthermia is often of concern, sometimes resulting from inadequate cool haul-out areas. Pinnipeds are intolerant of heat, and if housed in areas where no pool is available, they must have access to shade at all times. If the ambient temperature is apt to persist over 27°C, then a pool of water or other means to allow the animals to thermoregulate are essential to their health and well-being. Hollow gunite structures built to create artificial rocks are known to accumulate heat from the sun throughout the day and often radiate substantial heat back into the exhibit. These structures or surfaces may be too hot for the animals to use to comfortably haul out either directly onto the surface or nearby, and other haul-out areas must be available to the animals. A lack of space or visual barriers when housing adult males together can be problematic, since adult male otariids are often incompatible during the breeding season. If housed in the same enclosure, there should be ample space for the subdominant animal(s) to retreat from the dominant male. Visual barriers are essential to allow animals areas where they can escape sight of one another.

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