JZAR www.jzar.org JOURNAL OF ZOO AND AQUARIUM RESEARCH

EAZA

JZAR Evidence-based practice

OPEN ACCESS

Evidence-based practice

Life support system management strategies to improve pinniped eye health: a case study of a long-nosed fur seal *Arctocephalus forsteri*

Jose Miguel Pereira Gomes[1], Mason Hill[1], Gregory McDonald[1], Michael Lynch[1], Chris Eccles[2] and Bruce Eernisse[3]

[1]Melbourne Zoo, Zoos Victoria, Melbourne, Australia
[2]PCA Global, San Diego, USA
[3]Banggai Consulting Limited, Hong Kong

Correspondence: Jose Miguel Pereira Gomes, email; jgomes@zoo.org.au

Keywords: disinfection by-products, eye health, fur seal, life support system, pinniped, training

Article history:
Received: 17 Feb 2020
Accepted: 09 Sept 2020
Published online: 31 Octo 2020

Abstract

Eye health issues have commonly been reported in captive pinnipeds. Excessive exposure to UV light, poor enclosure design features and suboptimal water quality have all been associated with eye pathology in pinnipeds. A long-nosed fur seal *Arctocephalus forsteri* developed corneal disease shortly after introduction into a new facility. Medical therapies provided some alleviation of symptoms, but long-term sustained improvements in eye health were only achieved after life support system modifications. These modifications centred on lowering the production of disinfection by-products by removing most of the organic matter before applying ozone to the system. The reduction in eye pain following improvements in water quality were also critical for the keepers to be able to train the fur seal to receive eye drops voluntarily.

Background

Marine mammals in general and pinnipeds, in particular, have been kept under human care with very high survival rates since at least 1970. This is likely the result of institutions gaining experience with species and of the evolution of husbandry practices (Roberts and Demaster 2001). Advances in our understanding of voluntary medical procedures, behaviour modification, environmental enrichment and other cross-disciplinary fields have contributed to the high standards used by modern animal care facilities (Brando 2010).

One of the key aspects of positive welfare for pinnipeds is to be able to maintain good eye health, given their susceptibility to develop ocular ailments. This has been reported both in the wild (Gerber et al. 1993) and under human care (Greenwood 1985). Some of the risk factors contributing to ocular lesions include advanced age, previous ocular disease, history of fighting and exposure to UV light or inappropriate shade (Colitz et al. 2010a; 2010b). Additionally, Gage (2011) argues that presence of bromine, chlorine, ozone oxidant spikes, solar-reflective pools (such as light blue-coloured pools), and insufficient anti-oxidants present in the diet offered can also contribute to poor eye health.

Consideration of the whole range of suggested risk factors for poor eye health in pinnipeds, and the various life support system/water filtration systems used by facilities housing pinnipeds, make the management of optimal water quality a complex topic. The aim of this descriptive study is to explore the possibility that modifications to the life support system might result in an improvement in ocular health in pinnipeds. The paper also briefly describes how these modifications can influence the training of voluntary medical behaviours.

Between 2015 and 2018, Melbourne Zoo housed three long-nosed fur seals *Arctocephalus forsteri* and one Australian fur seal *Arctocephalus pusillus doriferus* in a 900 m^3 system, built in 2009, that includes the seal pool and its associated life support system (LSS). The LSS primarily uses a combination of mechanical and chemical filtration. The latter relies on the application of ozone to neutralise organic matter and sterilise the exhibit water. The pool depth varies between 1 m (back of house area) and 5.5 m in the exhibit pool. The exhibit is located outdoors, and the majority of the site is protected from the sun by shade panels that only allow sunlight to reach the animal area when the sun is at a very low angle. New seawater collected from Port Phillip Bay is added to the system weekly without undergoing any pre-treatment. The system's characteristics are presented in Table 1.

A female long-nosed fur seal moved from Marineland of New Zealand to Melbourne Zoo in March of 2015. Whilst at Marineland, the fur seal was housed with three females of the same species for most of the time. This facility was situated on the beachfront, and used pumped water straight from the ocean, filtered naturally through gravel, into the pump wells before entering the pools. The pools were completely drained, cleaned and refilled once a week. The system was a flow-through setup, with new water continuously coming to the pools and pushing the existing water to the overflow (unknown flow rate). The fur seal spent most of her time in a space with three small pools (depth just under 2 m), and occasionally had access to larger pools. Given the constant supply of new water from the ocean, most water parameters were not measured on a regular basis. Water disinfection by oxidants was not used at this facility, and the temperature ranged between 10–20°C. Due to international quarantine requirements, an ultraviolet steriliser was added to the system, a month before the move to Melbourne (S. Murray, personal communication, 23 August 2020).

Shortly after arrival at Melbourne Zoo, the first observations and records of 'squinty eyes' were registered. Medical examinations were undertaken, but during the early stages of this investigation, determining the primary causal factor leading to eye pain was difficult. Causes considered for this condition were trauma, excessive exposure to UV light and sensitivity to fluctuations in water chemistry parameters. Although further investigation is required in this area, it is hypothesised that genetics can also play a role in pinniped ocular disease (Colitz et al. 2010b). This fur seal's sire had unhealthy corneas and the dam had healthy eyes (S. Murray, personal communication, 23 August 2020).

The eye disease was characterised during a general anaesthetic procedure, in June 2015. Lesions were characteristic of chronic bilateral keratitis (inflammation of the corneas) and the integrity of the corneas of both eyes was significantly compromised, detected by the superficial uptake of ophthalmic stain (Fluorets 1mg, Bausch and Lomb, Auckland, New Zealand) across large areas of each cornea. The seal was medically managed with episcleral cyclosporine implants and oral Meloxicam (Apex Labs, Somersby, NSW) anti-inflammatory treatments. In addition, the seal underwent two types of surgical procedure to stimulate the healing of the cornea (grid keratectomy and diamond burr superficial keratectomy). While these procedures and medications provided some relief, the seal continued to be frequently observed with squinty eyes, especially the left eye. A full timeline of her eye health issues is presented in Table 2.

Action

Given the lack of a previous history of eye disease for this fur seal (S. Murray, personal communication, 23 August 2020) and its appearance soon after the move to Melbourne, water quality was suspected to be playing a role. This was somewhat counterintuitive, given that the other seals sharing the same space did not show similar problems. In-house investigations and water testing were unsuccessful at identifying any water chemistry element that could be considered the root cause of the issue. However, this continued to be a suspected possibility, so much so that, in August 2017, a move to another institution was considered as an option with the rationale that a change in environment may resolve the issue. Later that year, it was decided to involve two international life support system consultants to gain a better understanding of whether or not some elements within the filtration system could be contributing to the seal's eye discomfort.

It was initially hypothesised that disinfection by-products could be one of the contributing factors for the observed behaviours. Oxidising agents such as chlorine, ozone, and bromine can interact with dissolved compounds and form disinfection by-products

Table 1. Seal pool and Life Support System (LSS) Characteristics

Seal pool and LSS section	Measurement
Seal pool depth	1–5.5 m
Seal pool volume	600 m^3
Total system volume	900 m^3
Turnover rate	54 min
Sand filter flow rate	380 m^3/hr
Filtration rate (velocity)	35 m^3/hr
Ozone contact side-stream	26% of sand filter flow
Ozone contact time	186 sec
Ozone contact dose rate	Variable; up to 240g/hr
Foam fractionator flow rate	340 m^3/hr
New water intake	13 m^3/week

Table 2. Timeline of Observations and Procedures (March 2015–May 2018)

Date	Observations and procedures
March 2015	Arrived at Melbourne Zoo.
April 2015	First reports of eye pain (mainly left eye). Started oral medication.
July 2015	Diagnosed with chronic keratitis in left eye. Examined under anaesthesia; placed episcleral cyclosporine implants.
August 2016	Developed a large corneal ulcer in left eye. Examined under anaesthesia; grid keratectomy; replaced episcleral cyclosporine implants.
April 2017	Recurrence of large corneal ulcer in left eye. Examined under anaesthesia; grid keratectomy.
July 2017	Intensification of chronic keratitis in left eye. Examined under anaesthesia; diamond burr superficial keratectomy; replaced episcleral cyclosporine implants.
May 2018	Left eye pain still observed.

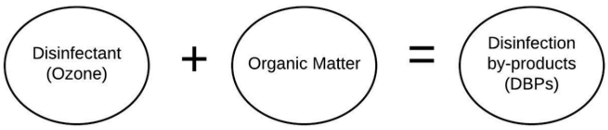

Figure 1. Formation of disinfection by-products.

(Figure 1), which have been linked to eye issues, especially when used in high concentrations (Stamper and Semmen 2012; Latson 2016).

The life support system associated with the seal pool consists of two independent and parallel loops. Soiled water from the pool surface passes through course screens into a foam fractionator/ protein skimmer with ozone injection and then returns to the seal pool via a degasification tank. Soiled water primarily from the bottom of the pool passes through the sand filters. A portion (10%) then passes through an ozone contact chamber, where ozone is applied. Water then returns to the seal pool via a degasification tank.

Once a day, at 1100, the keepers manually backwash all sand filters. Backwash flow is sent to the backwash recovery tank. Water lost from the seal pool during the backwash process is replaced by recovered backwash water from the saltwater storage tanks. Once the backwash is finished, the backwash recovery system resumes operating independently.

In the backwash recovery system, water is initially sent to the sand filters for mechanical filtration, then to another ozone contact chamber, before returning to the backwash recovery tank. A foam fractionator/protein skimmer also filters some of the water in the backwash recovery tank. After a period of 12 hours of treatment in backwash recovery, the water is transferred to the Saltwater Storage Tanks for later use. A full representation of this system can be seen in Figure 2.

The assessment and review of the life support system undertaken in the first half of 2018 recommended several procedural changes aimed at reducing disinfection by-products, including regular calibration and maintenance of probes, inspecting and replacing sand filter media, regular servicing of the overflow skimmer strainer. For the purpose of this case study, the focus is on the delayed use of ozone disinfection into the backwash recovery tank, identified during the assessment and noted to have the greatest impact on the seal's eyes.

The backwash recovery system was previously run on a 12-hr per day cycle with the sand filtration and ozone disinfection operating simultaneously for the entire length of time. The modification introduced in late June 2018 consisted of delaying the ozone disinfection for the first six hours of the 12-hr period. This resulted in the sand filters operating alone for the first six hours, mechanically removing, and automatically backwashing the trapped waste out of the system, and thereby reducing the amount of organic matter in the water before adding ozone to it. For the following six hours, both sand filters (mechanical filtration) and ozone (chemical filtration) were used. The ozone was now acting on a water body with less organic matter, which resulted in lower disinfection by-product formation. This modification will be referred to as BWR (backwash recovery).

Shortly after this modification, the keepers noticed a correlation between the seal's eye health and bromine levels in the water. In saltwater, bromide reacts readily with ozone to form oxidants, including hypobromous acid and bromate, a process that influences key water parameter measures, such as total bromine (as an indicator of total residual oxidants). Detecting this correlation triggered a second modification relevant to this case study. The new approach was to keep the ozone generator output as low as possible in the seal pool as long as the levels of ammonia and enterococcus were kept within the accepted ranges. This modification will be referred to as SP (seal pool). The location within the life support system where these changes took place were labelled as *** in Figure 2.

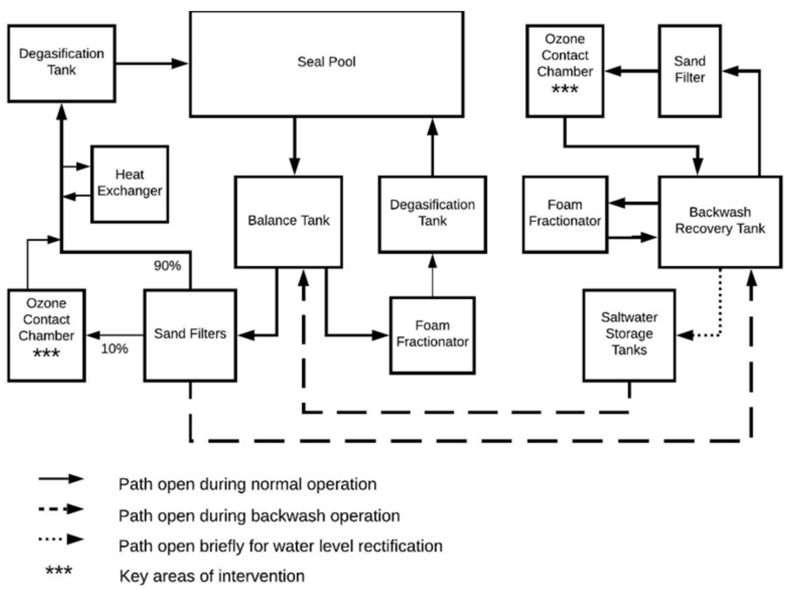

Figure 2. Life support system water pathway.

https://doi.org/10.19227/jzar.v8i4.525

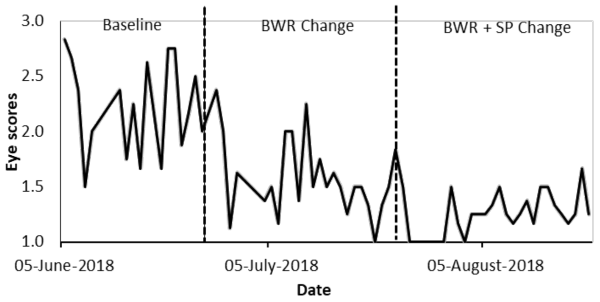

Figure 3. Left eye scores measured across three different life support system conditions.

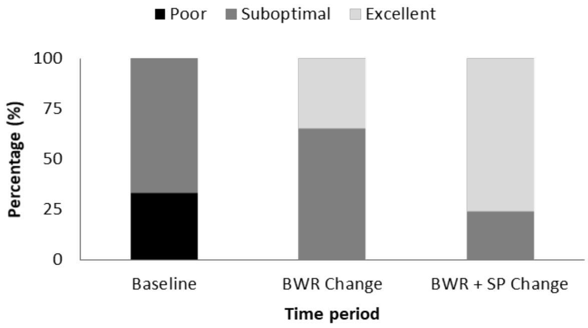

Figure 4. Welfare scores percentage across three different life support system conditions.

A simple pain scoring index was developed to keep track of the seal's eye health over time (Table 3). The keepers made these observations either during training sessions or outside of that context. A minimum of two and a maximum of four observations were made per day, collected between 0730 and 1700.

Consequences

The seal's left eye was the most commonly affected. For this reason, the data presented here used the values collected for this eye. The scores were averaged per day and then analysed over three distinct periods: Baseline: 5 to 25 June; BWR change: 27 June to 22 July; and BWR + SP change: 23 July to 20 August. Throughout these periods, noticeable improvements were observed and measured (Figure 3). The eye pain scores progressed from an average of 2.22 during the baseline period to an average of 1.27 in the BWR + SP change period.

To better understand how the seal's welfare progressed over time, eye scores were arranged into three categorical variables: poor, suboptimal and excellent. With this arrangement, it was observed that during the baseline period, the seal scored in the suboptimal category 66.7% of the time and 33.3% of the time in the poor category. When she reached the BWR + SP change period, just a few months later, her left eye health progressed to acquire excellent scores 75.9% of the time and suboptimal scores 24.1% of the time (Figure 4).

Following this, eye scoring was performed intermittently for the remainder of 2018 and 2019. The seal's eyes kept improving beyond the immediate aftermath of the life support system modifications. For example, observations collected between 1 and 25 August 2019 revealed a ratio of 88% of the days scored as excellent, 12% of the days scored as suboptimal, and no days scored as poor. Given the obvious improvements in eye health, oral medication was discontinued in October 2018.

Total bromine went from an average of 0.79 g/m^3 in the baseline period, to 0.67 g/m^3 in BWR change and 0.52 g/m^3 in BWR + SP change. As mentioned previously, the early detection of a correlation between total bromine levels and the seal's eye scores resulted in the SP change, with the aim of further reducing the presence of bromine to the absolute minimum required. Beyond the timeframe of this case study, the concentration of total bromine in the system kept decreasing, and as of December 2019 it is routinely kept below 0.1 g/m^3. Water quality parameters, specifically ammonia and enterococcus levels, have been maintained at target levels (Table 4).

Before the life support system modifications, the veterinary and keeping teams tried to implement a regime of eyedrop medication administered voluntarily to the seal. This behaviour was easily maintained with all the other seals at Melbourne Zoo, but for this seal, it proved to be an extremely difficult task. The keepers spent nearly two years working on this behaviour with little progress. When conducting this training, avoidance behaviours were common (lowering of the neck, closing her eyes, additional squinting). However, after implementing the life support system modifications, the training progressed at a much faster pace and was considered complete after only seven weeks (Figure 5).

A key consideration in closed water systems is the handling of organic carbons, which are released in the water from the animal's faeces. In a closed system, these will build up and thus, it is common practice to oxidise them with chlorine or ozone and/or to remove them through foam fractionation/protein skimmer (Joseph and Antrim 2010; Stamper and Semmen 2012; Latson 2016).

Melbourne Zoo relies on both ozone application and foam fractionation/protein skimmer to reduce the number of organic carbons in the water where the fur seals live. The ozonation process can lead to the creation of disinfection by-products which can be harmful to pinnipeds (Stamper and Semmen 2012; Latson 2016). The other fur seals living in this space did not appear to suffer from any eye afflictions during the time period reported

Table 3. Eye score key for tracking eye health.

Score	Description
1	Eye open; no signs of squinting
1.5	During 30 sec of observation, there are 5 sec or less of mild squinting
2	Eye occasionally shut or squinting for more than 5 sec in a 30 sec observation
2.5	Eye is observed both firmly shut and partially open in a 30 sec observation
3	Eye is firmly shut

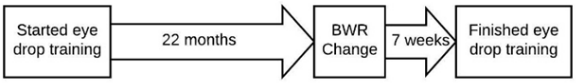

Figure 5. Timeline of eye drop training.

here. Additional research is needed to determine why different individuals may be more prone to eye disease than others.

The seal's chronic keratitis and ulcers in the left eye triggered several common practice treatments, such as oral medication, episcleral cyclosporine implants and keratectomy procedures. However, a noticeable and long-lasting improvement in eye health was only achieved when several changes were implemented to the life support system. These changes were able to achieve the goal of generating fewer disinfection by-products. Given that pinnipeds can be highly sensitive to these by-products, it is hypothesised that reducing the organic matter load before applying ozone and therefore resulting in fewer disinfection by-products is an approach worth exploring.

Chlorine, ozone, bromine and ultraviolet light can cause injuries themselves or when combined with organic compounds. Studies describing these interactions, specifically for pinnipeds, are rare, but a description of some of the common factors affecting pinniped eye health have been offered by Latson (2016). Other factors, including shade, time of year, pool paint colours, previous eye conditions in the animal and its age can all contribute to poor eye health in pinnipeds (Colitz et al. 2010b; Gage 2011). This case study focuses mainly on changes that affect the water quality, but consideration must be given to all these other factors, when dealing with pinniped eye health issues.

Table 4. Water parameters and target ranges. *Measured daily

Parameter	Target range	Notes
pH*	7.6–8.3	Adjusted with sodium bicarbonate
Total Ammonia*	0 ppm	
Temperature*	<24◦C	Maximum temperature limited by a chiller
Pool ORP*	<650 mV	
Salinity*	28–34 ppt	Adjusted with evaporated sea salt to compensate for rainfall
Unionised ammonia (NH_3–N)	<0.05 ppm	
Nitrite (NO_2–N)	<0.01 ppm	
Nitrate (NO_3–N)	<20 ppm	
Phosphate*	<0.5 ppm	Managed using lanthanum chloride dosed upstream of the filters
Total alkalinity as CaCO3	110–160 ppm	
Free bromine*	<0.5 ppm	
Combined bromine*	<0.5 ppm	
Total bromine*	<0.6 ppm	
Enterococci bacteria	<34 MPN/100ml	Rolling average; IDEXX method

In a backwash recovery system where organic load is the most concentrated, it is recommended to remove as much organic matter as possible prior to the application of disinfectants. It is common practice in LSS design to inject chlorine or ozone downstream of sand filters or after other removal of the bulk of the organic load, as opposed to within the sand filter (Stamper and Semmen 2012). This case study suggests the need to take this principle further with the inclusion of a time delay of some hours to allow for the removal of organic matter via sand filter treatment and backwashing, foam fractionator export, or other means. Disinfectant should be applied after this time delay when organic matter has been reduced in the backwash recovery system. Additionally, ozone application directly into the water where the animals live is strongly discouraged, as long as water parameters likely to be directly impacted by this change (e.g. ammonia, enterococcus) can be carefully monitored.

Topical eye drops are a common treatment practice for pinnipeds with keratitis (Grande et al. 2017). Marine mammals under human care are routinely trained to voluntarily participate in their healthcare and medical procedures without the need for restraint (Brando 2010). Training voluntary administration of topical eye drops proved to be extremely challenging and time consuming for this seal, especially when compared with how efficient this practice was with the other fur seals housed at Melbourne Zoo.

Friedman (2009) lists the hierarchy of behaviour modification procedures from the least intrusive options to the most intrusive ones. Antecedent arrangement and positive reinforcement training get listed as some of the least intrusive procedures, which makes them great tools for optimal animal welfare. However, before using them, the animals' medical, nutritional and physical conditions should be considered and addressed. This case study seems to support this approach, given that before the life support system modifications were implemented, the keepers were fairly unsuccessful at training the seal to receive voluntary eye drops. Once the life support system changes were implemented, the keepers were able to train the behaviour very quickly, likely because the animal had a significantly less painful eye due to water quality improvements.

Given the complexity of factors particular to each facility housing pinnipeds and how these can affect their ocular health, further research is merited to generate a more comprehensive understanding of these interactions. It is suggested that careful consideration be given to the life support system and an assessment of whether an efficient reduction of organic matter is occurring before the application of disinfectants, such as chlorine or ozone. The application of these chemicals to a water body with a high organic load has the potential to create disinfection by-products, and pinnipeds can be highly sensitive to them. Water quality improvements can be crucial to decrease eye pain and thus constitute an important first step to allow keepers to train the animals for voluntary medical behaviours (e.g. eye drops).

Acknowledgements

The authors would like to show their gratitude to the entire Veterinary and Wild Sea teams at Melbourne Zoo, Zoos Victoria, Australia; Craig Thorburn, Regional Head of SEA LIFE Marine Programs and Engagement, Asia Pacific; Ed Latson MS, DVM, Saint Louise University; and Dr Craig Adams, Utah State University.

References

Brando S. (2010) Advances in Husbandry Training in Marine Mammal Care Programs. *International Journal of Comparative Psychology* 23(4): 777–791.

Colitz C., Renner M., Manire C., Doescher B., Schmitt T., Osborn S. et al. (2010) Characterization of progressive keratitis in Otariids. *Veterinary Ophthalmology* 13: 47–53.

Colitz C., Saville W., Renner M., McBain J., Reidarson T., Schmitt T. et al. (2010) Risk factors associated with cataracts and lens luxations in captive pinnipeds in the United States and the Bahamas. *Journal Of The American Veterinary Medical Association* 237(4): 429–436.

Friedman S. (2009) What's wrong with this picture? Effectiveness is not enough. *Journal Of Applied Companion Animal Behavior* 3: 41–45.

Gage L. (2011) Captive Pinniped Eye Problems, We Can do Better! *Journal of Marine Animals and Their Ecology* 4(2): 25–28.

Gerber J., Roletto J., Morgan L., Smith D., Gage L. (1993) Findings in pinnipeds stranded along the central and northern California Coast, 1984–1990. *Journal of Wildlife Diseases* 29(3): 423–433.

Grande F., Fiorucci L., Macrelli R., Saviano P. (2017) Incidence and management of ulcerative keratitis in a pinnipeds population under human care. *Veterinary Medicine and Animal Sciences* 5(1): 1.

Greenwood A. (1985) Prevalence of ocular anterior segment disease in captive pinnipeds. *Aquatic Mammals* 1: 13–15.

Joseph B., Antrim J. (2010) Special considerations for the maintenance of marine mammals in captivity. In *Wild Mammals in Captivity: Principles and Techniques for Zoo Management* (2nd ed., pp. 181–216). Chicago: University of Chicago Press.

Latson F.E. (2016) Concerning Oxidants in life support systems. Buffalo, NY: Central Park Animal Hospital. Retrieved from http://www.centralparkah.com/images/oxidant_in_LSS_3.pdf

Roberts S., Demaster D. (2001) Pinniped survival in captivity: annual survival rates of six species. *Marine Mammal Science* 17(2): 381–387.

Stamper M.A., Semmen K.J. (2012) Advanced Water Quality Evaluation for Zoo Veterinarians. In *Fowler's Zoo and Wild Animal Medicine* (pp. 195–201). WB Saunders.