Environmental enrichment for Killer whales *Orcinus orca* at zoological institutions: untried and untested

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ABSTRACT

Despite a history in zoological institutions stretching back more than 50 years, with associated improvements in husbandry and breeding, the keeping of Killer whales *Orcinus orca* in zoos and aquariums has become highly controversial. The recent decision to stop the current breeding programme in the USA does not obviate the need to continue to improve husbandry as the whales in zoological institutions today will survive for decades to come. In this paper we outline several novel ideas for enriching the lives of Killer whales through provision of intergroup communication, and enhancement of feeding methods, health and fitness, and the ambient environment, all of which are aimed at eliciting natural behaviours seen in the wild. The enrichments proposed here may require adaptation for use with Killer whales and many could be modified for use with other cetacean species. We believe that by providing species-appropriate enrichment, both the welfare and educational value of Killer whales and other cetaceans can be greatly enhanced in the future.

Key-words: enrichment; environmental; feeding; fitness; health; killer whale; social; welfare; zoological institutions.

INTRODUCTION

In the past when an animal species came into captivity for the first time, it was often controversial and sensational (Allin,1998; Croke, 2006). Sometimes, because of a lack of knowledge about the animal's behavioural and psychological needs, they could also prove difficult to keep alive and troublesome to breed (Ellis & McCosker, 1991; Riley, 2016).

In 1850 a male Hippopotamus *Hippopotamus amphibius* called 'Obaysch' arrived at London Zoo, UK (Blunt, 1976). This animal was an overnight sensation as the 'hippo craze' swept London that season and *The Hippopotamus Polka* was written for piano in his honour (St Mars, 1850). Obaysch survived until 1878 and sired one surviving calf, a female called 'Guy Faulkes'. At the time of writing, the keeping of Hippopotamus in zoological institutions is neither controversial nor difficult, although it is not always done as well as it should be. In contrast and despite their huge popularity, in recent years the keeping of cetaceans has become highly controversial, such that none is now kept in the UK. No species is more controversial than the Killer whale *Orcinus orca*. But why are Hippopotamus and Killer whales viewed so differently, despite both belonging to the same Order of mammals, the Cetartiodactyla [i.e. the Cetacea (whales and dolphins) and Artiodactyla (even-toed ungulates) are now merged into Cetartiodactyla]? In zoological institutions both species are kept in large concrete pools and they are spectacular mammals that attract attention. Perhaps it is because of the greater perceived intelligence of cetaceans (whales, dolphins and porpoises) and their complex social lives. In contrast, much less concern is directed at the grass-chomping, lumbering Hippopotamus despite their own complex social lives, even though they are frequently kept in pairs, which does not replicate the polygynous mating system of the species. Hippopotamus are the closest living relatives of cetaceans but the keeping of cetaceans remains highly controversial despite good husbandry and breeding success for many species.

Killer whales do not have a long history in captivity with the first individual recorded in 1961 at Marineland of the Pacific, Palos Verdes, CA, USA, where in 1977 the first successful live birth occurred (Andrews, B., & Roebeck, 2016). In the waters off British Columbia and Washington, 263 Killer whales were caught between 1962 and 1973, 50 of which were kept for oceanaria (Bigg & Wolman, 1975). Interest in the species continued to grow when in 1964 a young male was kept in a dry dock and looked after by staff from the Vancouver Public Aquarium, BC, Canada (Newman & McGeer, 1966).

Since that time, a number of authors have mentioned how tractable and adaptable Killer whales are in the captive environment (Newman & McGeer, 1966; Spencer *et al.*, 1967; Griffin & Goldsberry, 1968), and in recent years successful breeding has been frequent (Amend, 2016). Reproductive processes, and the subsequent rearing of offspring, are essential and enriching components of an animal's normal behavioural repertoire.

Killer whales have an extraordinary ability to learn and adapt their behaviour, and may even exploit people for their own benefit (Hoyt, 1981; Abramson *et al.*, 2013). In the late 19th and early 20th centuries, Australian shore-based whalers were alerted to the presence of Humpback whales *Megaptera novaeangliae* by a male Killer whale called 'Old Tom', who attracted the whalers' attention by performing at the whaling station (Crew, 2014). The whalers followed the Killer whale to the Humpback whales, which they slaughtered, giving the Killer whales access to the tongues and lips of the Humpbacks to feed on (Wellings, 1964, cited in Dahlheim & Heyning, 1999). Killer whales can also be trained to carry out complex tasks outside zoological institutions. Two, named 'Ahab' and 'Ishmael', and two Short-finned pilot whales *Globicephala macrorhynchus,* 'Morgan' and 'Pip', have been used by the American military to retrieve equipment lost at sea (Bowers & Henderson, 1972).

However, in recent years there has been increasing criticism by animal-activist groups of both the fact that Killer whales are being kept at zoological institutions and also the way in which they are being maintained. This criticism, which has been reported widely in the media, culminated in the controversial documentary film *Blackfish* (2013).

This criticism and its impact on share prices led SeaWorld, USA, to announce in March 2016 that it would no longer breed Killer whales as a long-term plan to wind down the keeping of this species in its zoological institutions. The organization had already announced that it would end performances where the whales were trained to perform tricks for treats. Instead the theme park would introduce encounters, inspiring natural orca behaviour (A. Jamieson, 'SeaWorld decides to stop killer whale breeding program', *The Guardian,* 17 March 2016, https://www.theguardian.com/us-news/2016/mar/17/seaworld-to-stop-breeding-killer-whales-orcas-blackfish).

Marine parks are often criticized because it is claimed that the longevity of cetaceans in zoological institutions is less than that of those in the wild. Maximum longevity is often cited as a measure of success of a species in captivity, although such records generally indicate 'outliers' rather than the normal longevity of a given species (Walraven & Duffy, 2017). Killer whales are long lived in the wild; 29 years on average for males up to a maximum of 50–60 years, and an average of 50 years for females up to a maximum of around 80–90 years (Dahlheim & Heyning, 1999). Approximately half the life span of female Killer whales is post reproductive. This long post-breeding period is thought to contribute to the success and reproductive fitness of the pod (Foote, 2008). The overall rate of mortality of Killer whales in North American oceanaria was recorded as being relatively low at 4·7% year^{-1}, although the sample size was small (n = 31), with males faring better than females (Hui & Ridgway, 1978; Ridgeway, 1979). Further information was published examining the few individuals held in Europe with survivorship described as 'reasonably good' (Greenwood & Taylor, 1985).

More recent research, comparing the mortality rates of captive and wild Killer whales, indicated that they have similar life expectancies (Robeck *et al*., 2015), although Jett & Ventre (2015) reanalysed the data in this study and showed that although survival has improved it is still below that found in the wild. However, longevity is a crude and not very meaningful measure of success, especially if the Killer whales in zoological institutions have a poor quality of life. Given this situation and that there are *c.* 56 Killer whales in zoological institutions (Amend, 2016), could they benefit from the application of species-specific environmental enrichment?

At the time of writing, most Killer whales are held in concrete pools that lack environmental complexity and it is these environments that attract criticism from animal-activist groups. It can be argued that this husbandry style echoes the traditional bear pit that persisted for centuries in zoos, which has only recently been replaced by (mostly) larger, naturalistic enclosures. So what can be done to change the concrete pools of Killer whales and other cetaceans to make them stimulating and engaging environments?

Care must be taken when changing a sterile concrete pool into a more stimulating and interesting one. By suddenly changing the environment, an animal may experience distress, which could have a negative impact on its welfare. An animal may even behave abnormally in a newly enriched environment, just because it has changed and is devoid of familiar features that act as landmarks (Rees, 2000; Mellor *et al.*, 2015).

However, there can be no improvements to husbandry and welfare in zoos, aquariums, laboratories or marine parks if there is no process in place to manage this transition. The worst possible outcome would be for a change to be made that impacts negatively on the animals involved despite the best intentions of staff. Therefore, for all the Killer whales that are in zoological institutions, and perhaps from a naïve standpoint regarding our lack of direct experience, can we nonetheless come up with more creative approaches to their husbandry?

The authors have decided to apply the same criteria in developing enrichment techniques for Killer whales as they would for any species. No judgement is being made as to whether Killer whales should be kept in zoological institutions or not. However, even in the light of SeaWorld's decision not to breed this species in the future, Killer whales will be in zoological institutions for decades to come and it is important that their husbandry is continually improved to benefit their welfare.

Our starting point for improving welfare is to understand the behaviour and ecology of the species in the wild throughout its geographical range, so we can understand better what social and ecological factors are important to the species in question and to understand how adaptable or inflexible the species is under varying ecological and climatic conditions. Fortunately, there is a good amount of relevant research in the literature about Killer whales in the world's oceans, which has been reviewed for key information about social behaviour, diet, and sensory and communicatory capabilities.

The behaviour of Killer whales in the wild, like many species, is complex and varied in response to widely varying ecological conditions. Different populations have different vocal dialects, diets and social behaviours, and some, though superficially similar, may indeed be genetically and morphologically divergent and are sometimes regarded as different species or in the process of speciation (Foote *et al.*, 2009, 2013; Morin *et al.*, 2010; Foote, Vilstrup *et al.*, 2011; Foote, Morin *et al.*, 2011). In the North Pacific and southern oceans three different ecotypes of Killer whales coexist (giving a total of six ecotypes), which have different morphologies, diets and social structures. However, the basic social unit for all ecotypes appears to be the matriline, which in resident populations comprises an adult breeding female, her daughters and sons, and her daughters' young, although the size and length (one to four generations) of the matriline may vary with different ecological and social conditions (Ford, 2009; Beck *et al*., 2012). Beyond the matriline, Killer whales associate in an ascending hierarchy of pods, clans and communities, which show varying levels of association and relatedness between matrilines (Ford, 2009). Males and females tend to stay in their natal matrilines, with opportunities for mating with unrelated Killer whales occurring when groups come together. However, males may disperse temporarily from natal matrilines to visit other pods for mating (Foote, Vilstrup *et al.*, 2011).

In the wild, Killer whales can swim large distances, especially in transient populations. For example, in one study a transient Killer whale, feeding on pinnipeds, travelled an average of 114 km per day and four fish-feeding resident Killers whales travelled on average 56 km per day (Andrews, R. D., *et al*., 2008). However, these values vary widely depending on the study area concerned (Fearnbach *et al*., 2014; see also Visser, 1999).

To the knowledgeable visitor, any animal that is known to range over these distances has the potential to elicit a negative reaction to captivity, as it is not possible to provide this amount of space in zoological institutions. For example, Polar bears *Ursus maritimus* roam over thousands of square kilometres in the wild, but are necessarily confined at best to a few thousand square metres in zoos (Clubb & Mason, 2003). However, it is the quality (characteristics) of the area that an animal is given to inhabit that matters, rather than the amount (quantity) of space provided (Hediger, 1950). Large animals only cover these distances because they have to find sufficient food and mates. Inevitably their ranging behaviour is adaptable in response to the availability of local resources in the wild. Therefore, Killer whale ecotypes that feed on fish tend to range over smaller areas than those that prey on mammals, which occur at lower population densities (Wilson & Mittermeier, 2014).

In this paper, the authors go beyond the concrete pool to suggest a number of potential ways of enriching the lives of Killer whales that build upon their natural behaviours and adaptability. Our aim is to provide enrichments that elicit natural behaviours seen in the wild as part of the normal behavioural repertoire of the species. Because these behaviours are integral to the species in question, it is unlikely that they will habituate to these stimuli and become unresponsive to these enrichments. In our previous studies, we have developed species-specific enrichments based on natural behaviours that are used daily by zoological institutions throughout the world without any suggestion of habituation (Law *et al.*, 1997; Law & Reid, 2010).

None of the ideas in this paper has been tried and fully tested yet, although they have been made available to some holders of Killer whales, as they are in the best position to develop the concepts further and implement changes where applicable. Only practical experience will identify which ideas will ultimately be successful, albeit perhaps after varying degrees of modification and adjustment.

The focus will be on four areas for suggested enrichment ideas: social, feeding, health and fitness, and environmental.

SOCIAL

Vocal communication

Living in stable matrilineal groups and in a hierarchy of other social groupings, Killer whales communicate with each other using a wide variety of sounds (Ford, 1989). It may be enriching to simulate the matrilinear group structure in zoological institutions to maintain group structure and cohesion, but we think it is possible to go far beyond this in social communication to recreate communicatory links at higher levels of social association. Given that there are several groups of Killer whales in zoological institutions (*c.* 56 individuals at 15 facilities: Amend, 2016) and that satellite-communication systems are relatively cheap and easy to maintain, would it be possible to link some or all populations in zoological institutions together so that they can communicate with their distant counterparts (Fig. 1)? A baffle and/or volume-control option could be placed between the communicating groups to give the impression of distance and this could be altered depending on the nature of the communications between groups, which vocally could move closer or further away from each other, depending on the type of communication. The baffle and/or some form of volume control is essential because without it, the clarion calls of fellow Killer whales occurring suddenly in a group’s pool, although an unknown whale cannot be seen, may be confusing or threatening, rather than enriching. Building distance into such communication systems would not be difficult. There is no reason why communication channels could not remain open 24 hours a day and perhaps groups could choose when and with which other groups they communicate. The basis for such choice has already been developed. An acoustically operated on–off switch has been used by Bottle-nosed dolphins *Tursiops truncatus* to control an underwater hose that they played with (Berglind, 2005). It may also be possible to extend this ‘contact/identification’ channel to resident groups of wild Killer whales, where new voices could be heard (Fig. 1). This form of enrichment could provide a mechanism for control of a stimulus and this control itself may be enriching.

It is possible that communication between some of the groups and individuals will be complicated by the various dialects that Killer whales are known to have (Deecke *et al.,* 2000). From studies on vocal learning, it is known not only that dialects are passed from mother to calf directly but also that modifications to these can take place as their calls are also influenced by horizontal transmission between groups (Deecke *et al.*, 2000). Furthermore, research has shown that Killer whales have considerable vocal plasticity and are capable of contextual learning (Musser *et al.,* 2014). Resident Killer whales have also evolved vocalization strategies that may help them to avoid detection by their salmonid prey and communicate on a different frequency than transient groups (Foote & Nystuen, 2008). So the ability of Killer whales with different dialects to learn how to communicate with each other is highly probable, and would provide fascinating opportunities for research into vocal communication, vocalization and vocal-control learning in cetaceans.

FEEDING

Self-activated feeders

An electronic feeder could be developed that is activated by a Killer whale visiting a number of 'trigger' locations either under water or above. For example, a series of haul-out locations around the pool could be fitted with simple alarm-system beams. When the beam at a location has been visited and broken by the whale hauling itself out a set number of times, the feeder would be activated to release food. Each haul-out location could be programmed with different trigger rates, so they all require a different number of visits before food is issued and these could be changed periodically to provide a more stimulating task. For some feeders it may also be preferable to release food from a number of locations under water at the bottom of the pool to protect against aggression. Some feeding devices could be set to operate only at night-time, to keep the animals occupied when the institution is closed and to encourage the whales to use their echolocation during darkness. Small dead fish and/or octopus may offer an interesting night-time location challenge in low light levels.

Suction feeding

Many cetaceans, including Killer whales, use suction feeding to access food items (Werth, 2000, 2006). Opportunities for suction feeding could be given to Killer whales at zoological institutions in a couple of ways. For example, an arrangement of boulders could be provided that has the interstices seeded with fish that are too small for a Killer whale to access directly [equivalent to a log-pile feeder used for felids (Law *et al.*, 1997)]. Alternatively, blind-ended tubes of varying diameter could be placed in a structure (e.g. an artificial boulder) and partly filled with fish. The Killer whales would soon learn to access this inaccessible food using suction [as seen in bears (Law *et al*., 1992)] providing a stimulating problem to solve, especially as the size, amount and species of food items can be varied daily.

Teamwork

In the day-to-day management of Killer whales in zoological institutions it would be good to encourage cooperative behaviour between the members of a group for enhancing social cohesion. For example, it would be worth exploring methods of feeding that require the whales to work together in order to gain access to food. From observations in the wild it is known that Killer whales which hunt seals cooperate to create a wave that will wash a stubborn seal off an ice floe (Smith *et al*., 1981). The construction of a floating platform that contains a number of basins baited with fish could offer similar opportunities for Killer whales to work together to wave-wash and rock the 'ice floe' in order to tip the fish into the pool (Fig. 2a,b,c). This 'ice floe' would be tethered from above the pool (e.g. on a system of overhead gantries) with limited freedom of movement, to prevent the whales from ramming it into the pool walls and causing structural damage.

Observations of how the Killer whales approach and use these feeders would probably be required to perfect the design; however, we believe that the concept is viable. Killer whales at zoological institutions are fish eaters and would not normally use this behaviour (that we know of) to obtain their typical food. However, it seems likely that they would quickly work out a method for dislodging the fish from the feeder island and this behaviour could be used in an educational way to inform visitors about differences in diets and behaviours of Killer whale ecotypes. It would also offer research opportunities in the development of cultures and social learning in Killer whales. Opportunities could be offered to the Killer whales to 'spy hop' (to look at where the fish are placed on the floating platform 'ice floe' or a marker that would indicate where they are) in order to work out the best angle of approach, from which to create waves or to look for a visual signal that will tell them that the feeder has been stocked with fish.

As Killer whales are known to coordinate their hunting below and above the water surface (Simila & Ugarte, 1993), a feeding method could be designed that would allow these behaviours to be performed. A feeder that is activated only when the Killer whales vocalize together could encourage this process. The basis of such a system has been used with Bottle-nosed dolphins at the dolphinarium at Kolmården Djurpark, Sweden (Berglind, 2005).

The food offered to Killer whales could perhaps be more varied than just fish, perhaps better reflecting the diversity of wild diets. A form of scatter feeding by firing shoals of small dead fish into the pools for the whales to forage on could help increase activity levels. In the wild Killer whales sometimes feed on birds and Sea otters *Enhydra lutris* (Williams *et al.*, 1990; Hatfield *et al.,* 1998), so perhaps readily available alternatives, such as duck, rabbit or even larger mammals, could be added to the diet. The methods for offering these foods, and the way the whales consume them, would be different from those used with fish, bringing another form of diversity to their lives. Suitable filtration methods to deal with the waste from such forms of feeding would also need to be considered.

HEALTH AND FITNESS

Diving stamina

Killer whales have been recorded diving for up to 15 minutes and the deepest dive recorded in the wild was 173 m (Barrett-Lennard & Heise, 2006). However, a depth of 260 m was achieved by a trained Killer whale working with the US military (Bowers & Henderson, 1972). It is not possible to offer Killer whales the opportunity to dive so deeply at zoological institutions but it is worth considering whether it is possible to train them to hold their breath to simulate partly the deeper dives of their wild counterparts. From what is known about the tractability of Killer whales, it seems likely that this is a possibility. Such work has been carried out for Grey seals *Halichoerus grypus* at the Sea Mammal Research Unit, UK (Sparling & Fedak, 2004). The physical stamina of individuals could be gradually built up, using rewards to extend and maintain breath-holding times until they are similar to those of wild counterparts. When Killer whales dive, there is a related 50% reduction in their heart rate (Spencer *et al.*, 1967), and the blood-cell counts in whale and dolphin species are known to alter as the animals gain weight and dive deeper (Shirai & Sakai, 1997). Breath holding in zoological institutions may help to stimulate this change, if carried out at the appropriate stage of development.

Sensory stimulation and skin care

Killer whales in the north-eastern Pacific Ocean rub their bodies through kelp (Phaeophyceae) fronds or along smooth pebbles on the sea floor (Ford, 1989). This behaviour appears to be partly social and apparently pleasurable, but is also used as a form of exfoliation to help slough off old skin. At the time of writing, Killer whales in zoological institutions are groomed by their trainers using fingers and brushes to remove old skin (Hargrove & Chua-Eoan, 2015). The inclusion of a sloping boulder beach, which the whales can rub against, could be important for sensory stimulation and skin welfare. Similarly, it may be feasible to grow kelp or offer an artificial alternative for the whales. Kelp is fast growing (e.g. *Macrocystis pyrifera* grows up to 60 cm per day) and if the base of the primary stipe and the holdfast are protected in a safe area outside the enclosure (e.g. in a trench or hole), and the fronds and bladders are allowed to trail into the pool, it may be possible for the Killer whales to interact with and rip the top sections, but the alga will continue to regenerate, water quality and lighting permitting. For example, a kelp *M. pyrifera* forest has been grown for exhibit purposes at the Monterey Bay Aquarium, CA, USA (https://www.montereybayaquarium.org/animals-and-experiences/exhibits/kelp-forest). It may be possible to modify fire hoses in order to provide a suitable form of artificial kelp for Killer whales. Fire hoses have been used with bears, elephants, dolphins and False killer whales *Pseudorca crassidens* but further research for their use with Killer whales would be required (Cowan, 1997; Clark *et al.*, 2013; M. Kingston-Jones, pers. comm., 2016; V. Hare, pers. comm.; G. Laule, pers. comm.). Suggestions of how to naturalize kelp gradually into a new exhibit have been offered by Powell *et al.* (2013).

Wave machines

Killer whales in zoological institutions live in millpond conditions compared with their wild counterparts, which experience a wide variety of sea conditions, including strong currents and tides. The use of wave machines in aquatic exhibits is not new (Bell & Kelly, 1987; Chin, 1987; Farwell *et al.*, 1987) but the exercise and challenges they can offer have not been extended for use with cetacean species.

Breathing rates and patterns will vary in stormy water conditions as the whales pass through the waves, improving stamina and adding to their behavioural versatility. It is important for Killer whales to be able to swim against strong currents and high waves in order to forage successfully throughout the year. If these conditions can be better replicated in zoological institutions, this would be an important step forward in improving the physical welfare of Killer whales. The whales would also benefit mentally from this challenging activity, as they would need to change and adapt their behaviour to cope with the turbulent, variable water conditions, especially if their food was carried by the waves or currents in the pool, or the whales had to swim against the currents to access food. In association with this and acting as a cue to the changing conditions, underwater recordings of the sea in rough-weather conditions could be played, harmonized with the actions of the wave machine.

ENVIRONMENTAL

Soft surfaces and pools

Undoubtedly, pools for Killer whales could be improved if they had some soft surfaces but this is difficult to achieve, especially if the individuals in a pool are prone to nibbling the structure’s surfaces. However, perhaps if the environment is made sufficiently complex the Killer whales may be less likely to interact in this way with softer surfaces. Thick rubber blocks embedded into the poolside walls, where no edges are free to be chewed on, could provide a more interesting, less harsh and more tactile surface than concrete or tiles.

To promote mental welfare, quiet shaded areas, where the whales could withdraw to rest, may be worthwhile in reducing tensions between group members and to provide an area to retreat from the public. At the bottom of these withdrawal pools cooler water could be maintained to create a more benign restful environment. If large boulder substrates were added, this may provide a relaxing and stimulating area for the whales to be in. However, if substrates are not carefully selected, they could be swallowed by the whales or chewed, causing damage to the teeth and gut. Large, smooth, roller-bearing surfaces, similar to those used on production lines, could be carefully installed into the pool floor or walls for the whales to rub against. With careful design, being mindful of filter intakes, it may be possible to use coral sand as a substrate for Killer whales, just as it is often used in shark tanks in commercial and zoological aquariums (Mohan *et al*., 2004). Cleaning these convoluted surfaces could be difficult and time consuming so, for speed and convenience, mini airlift (dredging) devices could be used to vacuum debris from the pool floors. The concern about ingestion of substrates has to be put into context. There used to be similar reservations associated with zoo and laboratory animals, particularly primates, that had been kept in sterile environments for years. However, when given access to naturalistic conditions the primates transitioned to their new environments successfully (Chamove *et al.*, 1982).

Echolocation

It is possible that Killer whales at zoological institutions can never use their voices to their full extent because they are surrounded by hard surfaces. Their voices cannot disappear into the distance as they would in the open sea but, instead, there is always a quick returning echo. However, is it possible to allow Killer whales to shout louder; for example, by creating areas where they can echolocate in a manner that their vocalizations do not bounce back in a confusing way? The question is, can ‘acoustic distance’ be created for Killer whales in zoological institutions? One approach might be to create areas that are carpeted with sound-absorbing rubber, similar to the acoustic-absorbing tiles used on nuclear submarines (Roland, 2009) (Fig. 3).

With acoustic-absorbing tiles fitted into areas of the pool, the Killer whales could exercise full-volume acoustics that will disappear into the distance, before apparently finally returning weakly from afar. If this could be achieved, how could they be stopped from swimming into this conceptual distance and injuring themselves? These sensory areas would only be placed in small sections, not covering the whole expanse of the pool. As the Killer whale draws nearer to these areas, narrow patches of less sound-absorbent materials embedded in the tiles would return an ‘image’ to the whale and alert it to the presence of a barrier. Indeed, it seems likely that acoustic-absorbing tiles would never be so sound absorbent that they could not be detected by the Killer whales and it would be possible to make them a different colour tone (Killer whales have monochromatic vision) so they could be seen. However, we recommend the use of patches of less sound-absorbent material embedded in the tiles as a precaution until trials with live animals can be undertaken.

Ambient sounds and ancestral memories

It has been observed that the noise of life-support systems, pumps and filtration plants are prominent contributors to the unnatural soundscape of aquatic exhibits (Scheifele *et al.*, 2012). Sounds are also produced by public-address systems, areas where entertainment/shows are taking place and noisy visitors (Scheifele *et al.*, 2012). Although a recent survey has found that, in general, pools in zoological facilities are equivalent to or quieter than coastal ocean regions inhabited by many small cetaceans, particularly at the frequencies where they hear well (M. Xitco, pers. comm.), is there a way of providing a more natural soundscape for Killer whales?

The natural sound of the marine environment and the other animals that live within it are available as recordings from many websites; for example, http://macaulaylibrary.org/ and http://sounds.bl.uk. The underwater vocalizations of numerous seal and fish species, as well as the calls of others cetaceans, could be used to stimulate and reinforce ancestral memories, increasing the animal's sensory stimulation and providing calmer ambient conditions (Li *et al.*, 2011; Panksepp & Biven, 2012). Furthermore, Killer whales are capable of learning new sounds and can mimic the calls of other species they hear in their habitat (Foote *et al.*, 2006).

Toothwear

The condition of the teeth of Killer whales in zoological institutions has aroused criticism from animal-activist groups and the media, because severe breakage and wear is said to occur when the whales grip the steel bars of the gates separating individuals, or when they bite the concrete around the edges of pools (Jett & Ventre, 2013). If these are the principal causes, pools and gates should be re-designed to avoid these problems. Instead of bars, the gates could be made of solid metal, with small apertures cut through them that would allow the movement of water and a view to the other side. The holes would need to be of a size and shape that limits the potential of a whale to grip the edges and chew. Sharp corners in pools or those around the edges could be flattened out to present a less attractive surface for the animals to engage with. It may also prove to be the case that it is possible to provide an outlet for frustrated chewing behaviour by offering the Killer whales whole-mammal or bird carcasses to feed on. Another possible cause of severe tooth wear is erosion of the teeth, owing to regurgitation of gastric acid caused by gastritis (P. Kertesz, pers. comm.). Freshly exposed pulp in the teeth only causes pain when touched directly but the second stage of pain begins perhaps some weeks later when pulpitis sets in from bacterial infection. When the pulp becomes necrotic and the canal/pulp chamber is able to drain, there is no pain; however, the risk of infection remains from systemic bacteraemia, which may turn to septicaemia or cellulitis (P. Kertesz, pers. comm.).

Some populations of wild Killer whales are known to experience substantial tooth wear and exposed pulp cavities. North Pacific Killer whales, which feed on shark species that have extremely tough and rough skin surfaces, sometimes have their teeth worn down to the gums (Ford *et al.*, 2011). Dental anomalies also occur in other populations, which are as yet not certainly attributable to any particular cause. For example, in two Killer whale ecotypes in the north-east Atlantic, Type 1 showed extensive apical tooth wear that increased with age, whereas Type 2 showed little or no apical tooth wear (Foote *et al.*, 2009). These two ecotypes are sympatric and weakly genetically differentiated, and they also have different numbers of teeth and body markings. Type 1 Killer whales appear to be dietary generalists that feed on mackerel, herring and seals, whereas Type 2 animals appear to specialize in feeding on baleen whales (Mysticeti). However, it is not clear what causes tooth wear in Type 1 animals, although it has been suggested that it could be caused by suction feeding (Foote *et al.*, 2009). A subadult male Killer whale stranded in North Uist, Western Isles, Scotland, UK, in 2014 had the teeth on one side of the jaw, upper and lower, worn to the gum but those on the other side were mostly unworn (Plate 1). Presumably, this occurred because of a particular and as-yet unknown feeding method, which favoured excessive tooth wear on one side perhaps through interaction with substrate or another asymmetric feeding technique. Further research into the feeding habits of wild populations of Killer whales would provide more information about such health issues.

It would appear, therefore, that extensive tooth wear is frequent in wild populations, depending on age, diet and feeding method, and so cannot necessarily be viewed as a product of captivity. However, what is important for animals in zoological institutions is that worn teeth should be treated medically to prevent them from becoming a route for infection through exposed pulp cavities, resulting in abscesses in the jaws and septicaemia.

With the range of enrichments that have been proposed in this paper, and the suggested modifications to gates and pool edges, it should be possible to reduce the likelihood of the Killer whales becoming bored and frustrated, and remove opportunities to bite or chew unsuitable/unnatural surfaces and objects as frequently, thereby also reducing the levels of abnormal tooth wear sometimes observed in zoological institutions.

CONCLUSION

The ideas set out in this article need to be assessed scientifically to evaluate their impact and effectiveness. Some could cause short-term negative stress but, with imagination and perseverance, could provide long-term gains in cetacean welfare.

As individuals that have been involved for many years with issues of welfare and the care of animals in zoological institutions, the authors agree that much could be done to improve the care of many species, including Killer whales. We are also aware that change can be frustratingly slow to happen. The politics of organizations that house the animals and the politics of those against wild animals in captivity, and indeed the issues of governments and agencies intending to save species in the wild, mean that change rarely happens quickly.

However, unless the people that do care for these animals make moves to create change, it cannot happen at all. The animal keepers in zoological institutions are dedicated to the welfare of the animals in their charge. We hope that this article will provide an opportunity for those involved in the finance, husbandry and welfare of Killer whales and other cetaceans, to enrich the lives of the animals in their care, so that seeing these species in captivity is no longer considered a controversial experience.

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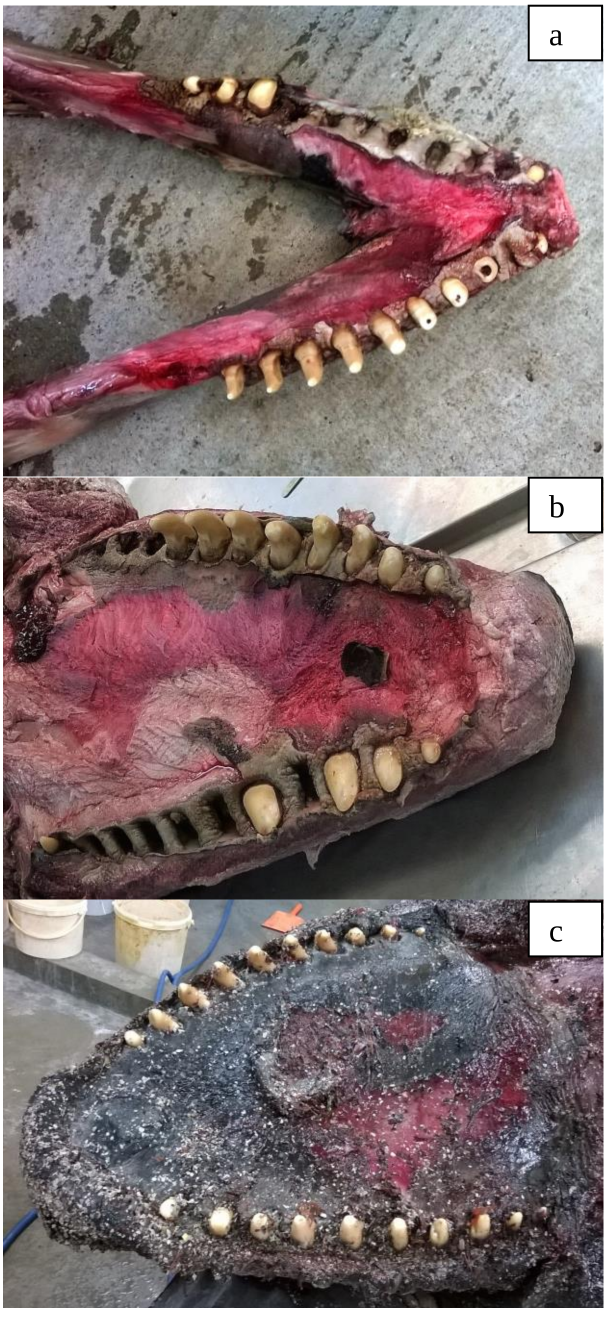

Plate 1. Occlusal views of the jaws of wild Killer whales *Orcinus orca* **stranded in the Western Isles, Scotland, UK, showing different levels of tooth wear. Subadult male stranded on North Uist (National Museums Scotland register no. NMS.Z.2015.142.78), showing asymmetric tooth wear on the (a) lower and (b) upper jaws. The teeth on the upper and lower left-hand jaws are mostly worn to the gum, but those on the other side were mostly unworn. For a female Killer whale stranded on the Isle of Tiree (NMS.Z.2016.118), excluding the missing teeth in the anterior part of the jaws, tooth wear is limited in the remaining teeth in both the lower and (c) upper jaws.** *A. Kitchener, National Museums Scotland*.

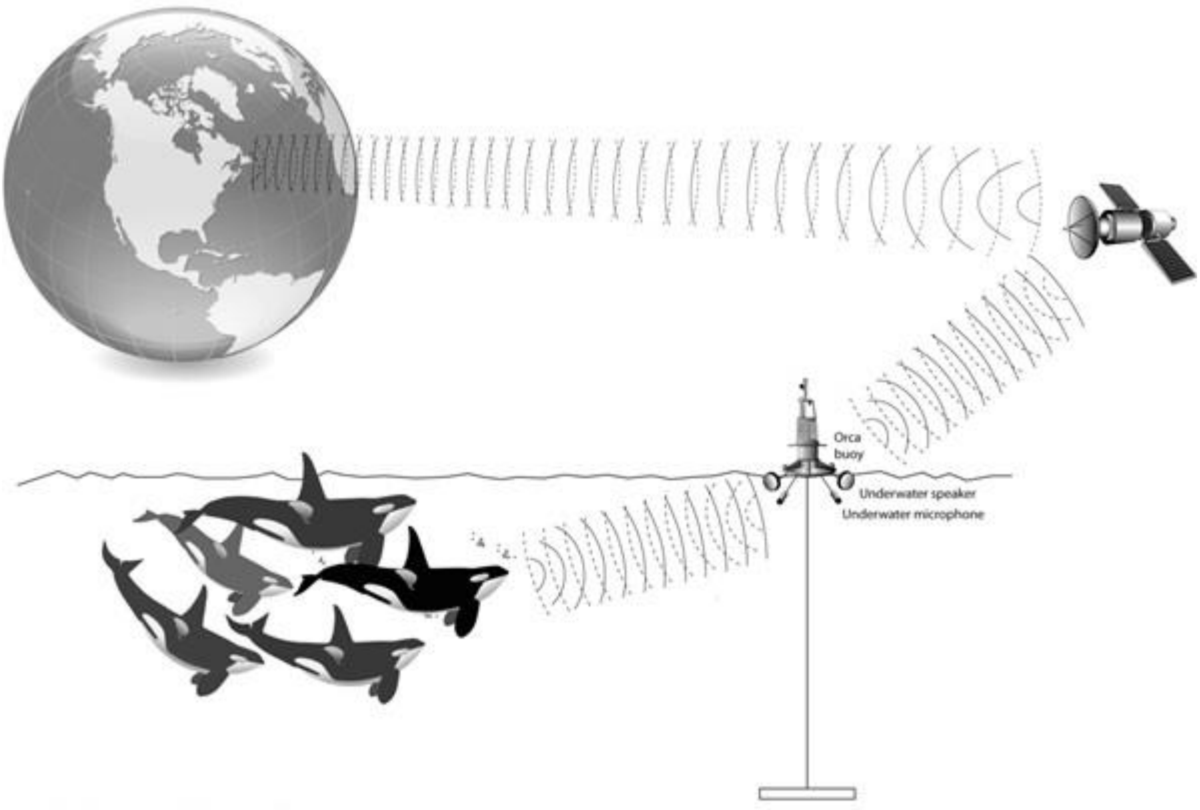

Fig. 1. The use of satellite technology to link Killer whales *Orcinus orca* **at zoological institutions with those living at other institutions and others in the wild. The whales at the institutions could control an on/off switch to allow or shut off communication.** *Rosanne Strachan Law.*

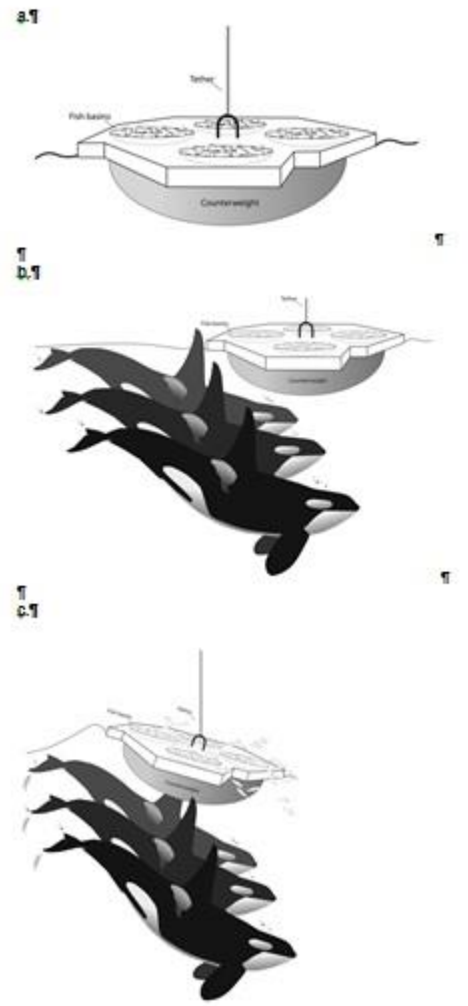

Fig. 2. 'Ice-floe' whale feeder, tethered from above the pool (e.g. using overhead gantries): a, proposed construction; b, Killer whales *Orcinus orca* **approach the whale feeder and create a wave using their flukes; c, wave upsets the feeder and washes the fish out of the basins.** *Rosanne Strachan Law.*

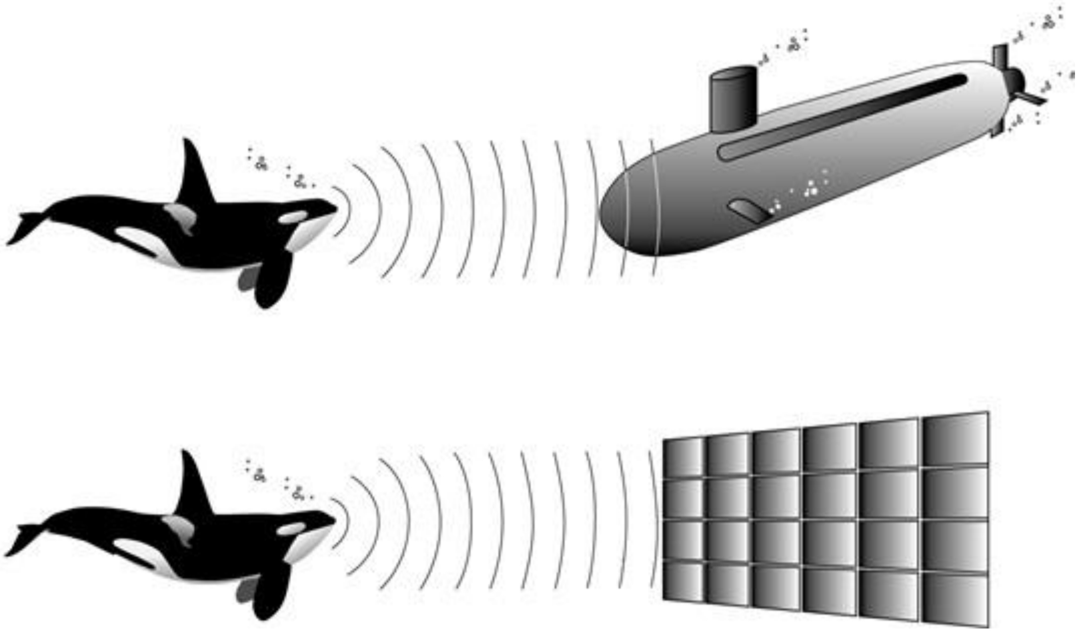

Fig. 3. Killer whales *Orcinus orca* **could echolocate at sound-absorbing rubber tiles, such as those used to clad nuclear submarines (Roland, 2009).** *Rosanne Strachan Law.*