RESEARCH REVIEW

Captive Care and Welfare Considerations for Beavers

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Beavers (*Castor* spp.) tend not to be a commonly held species and little published material exists relating to their captive care. We review published material and discuss husbandry issues taking into account the requirements of wild beavers. As social mammals with complex chemical communication systems and with such an ability to modify their environments, studies of wild counterparts suggest the captive requirements of beavers may actually be more sophisticated than generally perceived. Common field techniques may have practical application in the captive setting. Their widespread utilisation in conservation, including reintroductions, translocations and habitat management, also requires components of captive care. As welfare science advances there is increasing pressure on captive collections to improve standards and justify the keeping of animals. Conservation science is increasingly challenged to address individual welfare standards. Further research focusing on the captive care of beavers is required. Zoo Biol. 34:101–109, 2015.

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INTRODUCTION

Beavers (Eurasian, *Castor fiber* and North American, *C. canadensis*) are large, crepuscular, herbivorous, semi-aquatic rodents that live in family groups based around a breeding adult pair with offspring from the current and previous years [Novak, 1987]. The two extant beaver species are morphological similar and have comparable ecology and behaviours [Novak, 1987; Rosell et al., 2005]. Beavers have been kept in captivity for a variety of reasons, including entertainment, fur farming habitat management and conservation breeding for species restoration. Although not necessarily a commonly held species, there are historic records of captive beavers in zoological settings, such as Basel Zoo in 1876 [Dollinger et al., 1999]. More recently, their widespread reintroduction across Europe and parts of North America has required greater consideration towards their captive care. Common field techniques, such as restraint without sedation, sexing and sample collection should have practical application in the captive setting. However, published material on captive management and husbandry methods is limited.

We aim to identify beaver captive care requirements, discuss husbandry and welfare issues taking into account studies of wild beavers. Focus is on the Eurasian beaver but given the similarity between the two species, captive (permanent and temporary), husbandry requirements are presumed to be comparable.

PHYSICAL WELL-BEING

Assessment of Physical Health

Regular individual observation may prove difficult in captive beavers given their crepuscular and semi-aquatic behaviours, especially where areas of natural habitat have been fenced to form enclosures. Under some conditions

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animals may become habituated to feeding times and areas, and therefore be easily visible out of water. Suitably placed remote cameras (particularly night vision) and/or regular capture to establish health and welfare status can be implemented. Health and welfare assessment through observations should take into account locomotion and movement; behaviours such as feeding; physical qualities such as occurrence of discharge, wounds, symmetry of body parts, body condition and breathing rate [Goodman et al., 2012]. Beavers normally spend a lot of time grooming to maintain fur quality, essential to ensure insulation and buoyancy [Fish et al., 2002]. Lack of proper grooming ('scruffy' or 'unkempt' appearance) may be evident of an underlying health or behavioural issue, which may warrant further investigation.

Clinical Examination and Health Screening Programme

Any captive collection should employ a health screening programme involving quarantine, regular observations, routine and/or opportunistic health screening, and post mortem examination (Table 1).

A general anaesthetic is recommended to undertake a full clinical examination [Goodman et al., 2012]. Such sedation has a number of advantages including reducing stress, risk to handler and increasing the amount of information that can be attained [Wolfensohn and Honess, 2005]. Thermoregulation during sedation and drowning risk upon release are important considerations when anaesthetising beavers. Anaesthesia can disrupt normal thermoregulatory systems, such as the counter-current systems in the tail and distal limbs [Cutright and McKean, 1979], through alteration of cardiovascular tone. Various anaesthetic regimes for both beaver species have been described [e.g. Greene et al., 1991; Ranheim et al., 2004; Kim et al., 2005], these vary according to required duration and depth of anaesthesia. Injectable anaesthetics may have the advantage of minimising handling stress but are associated with longer recovery times and therefore potential welfare risk of returning animals to enclosures with water access. Face mask application of isoflurane is particularly recommended when a faster release near water is required [Breck and Gaynor, 2003; Wenger et al., 2010; Campbell-Palmer and Rosell, 2013], this has a very practical application in the field and has been successfully used in large naturalistic enclosures. Hand netting individuals and efficient restraint procedures will minimise stress to the animals involved and ensure staff safety [Rosell and Hovde 2001; Campbell et al., 2005; Campbell-Palmer and Rosell, 2013].

Body condition and weight changes are valuable measures that may indicate underlying health or welfare issues. Eurasian beavers are large (adults >20 kg) rodents, with adults of both sexes (3 years+) exhibiting similar body sizes, although females are on average ~1 kg heavier [Campbell et al., 2005]. Weights vary depending on time of year [Hartman 1992; Parker et al., 2001], with individuals of all age-classes losing weight and body condition over the winter period [Campbell et al., 2005], depending largely on food quality and availability. During captivity beavers tend to experience more constant and unvarying feeding regime, so should not display significant seasonal variation. Therefore, sudden or progressive weight loss are likely to be indicative of underlying medical condition. Beavers have large digestive systems to assist the processing of woody material, so that even in poor body condition they may appear 'fat' with large, rounded stomachs. Feeling along the spine and pelvis, and careful observation of the tail can body condition be more accurately assessed. Beaver tails store fat and so tail dimensions vary depending on deposition and mobilisation of fat [Smith and Jenkins, 1997]. The ratio of tail dimensions to body length can be used as an index of tail-fat content and therefore represent body condition [Parker et al., 2007]. This may be a more reliable indicator of body

TABLE 1. Health screening recommendations developed for Eurasian beaver reintroduction in Scotland, serves as a template for captive beaver collections and release projects [Goodman et al., 2012].

Examination	Screening Process
Clinical examination under anaesthetic	Physical examination following standard veterinary procedures of head (eyes, ears, mouth), ectoparasites, injuries, abdominal palpation, auscultation and cardiac evaluation. Sexing, weighing, body measurements including tail dimensions to determine tail fat index, body condition evaluation.
Blood sampling	Ventral tail vein, 2 ml in K2EDTA and 10 ml whole blood. Serum testing specifically for Tularaemia, *Leptospira*, *Yersinia* spp. Full haematology and biochemistry.
Faecal sampling	Manually collected, specific screening for bacterial enteric pathogens including *Salmonella* spp., *Campylobacter* spp., *Clostridium* spp., and *Yersina* spp., *Giardia*. Parasitology using floatation saturated salt solution for nematodes and sedimentation for trematodes.
Integument sampling	Skin scraping investigated for ectoparasites, fur combing for beaver beetle.

condition, as supposed to visual observation, especially to an unfamiliar observer.

Health Issues in Captivity

Injuries

Wounds in captivity, even those that seem minor, can result in fatalities, especially if sources have a high bacterial load and/or an individual is separated from the group for treatment. Beavers have strong social bonds [Wilsson, 1971], so long-term separation of an injured individual for treatment can lead to increased welfare challenges for that animal. General decline and even fatalities have been recorded in separated wild caught animals, after seemingly normally recoverable injuries. Wounds may become infected by bacteria (such as *Aeromonas hydrophila* and *Pseudomonas* spp.), leading to diseases including pneumonia and bacterial endocarditis. This can manifest as dramatic weight loss and clinical symptoms including cardiovascular compromise, tachypnoea, hyperpnoea and dyspnoea [Girling S, personal communication].

Nutritional

Captive diets have historically consisted root vegetables and apples, along with green vegetables, pear, maize and browse [e.g., Pilleri, 1983]. Concerns about the inclusion of fruit, with high sugar content, and the potential to act as highly fermentable substrates in the hind gut, especially when they form a significant proportion of the diet, can lead to diarrhoea and gastrointestinal disorders [Beer A and Girling S, personal communication].

Aquatic plants are an important source of iodine and sodium in wild beaver diets [Müller-Schwarze and Sun, 2003], captive diets are known to be deficient in iodine. Iodised salt can be used as a dietary supplement. Beavers have been recorded as taking processed feed pellets such as 'Leaf Eater', 'Diet A', and 'Vitamin E' ungulate pellets in captivity [Swain et al., 1988]. While these foods could be provided as an addition to the diet, they should not form a significant proportion. Metabolic disease may be an issue through hypervitaminosis D if fed on commercial primate pellets containing high levels of vitamin D_3 [Sainsbury, 2003]. Older animals have displayed highly porous bones, suggesting phosphorus deficiency [Piechocki 1962; Nolet et al., 1994].

Dental

Wild beavers have been documented surviving with abnormal incisor growth [Rosell and Kile, 1998], with malocclusion and hypertrophy of incisors reported in captive and wild beavers, but generally uncommon (Zurowski and Kasperczyk 1988; Cave, 1984). Browse is an important diet item that should be added ad lib to allow physiological processes such as tooth wear, preventing incisor overgrowth.

BEHAVIOURAL CONSIDERATIONS

Understanding and observing wild behaviours enables more accurate inferences on the effects of captivity, psychological requirements and individual welfare to be drawn. Threatened beavers tend to retreat to the water, tail slap, grind their teeth or 'freeze' if water not immediately accessible. Freezing is accompanied by fear bradycardia (slowing of the heart rate). Long dive times (~15 minutes) have also been recorded in extremely frightened beavers, which may press themselves against the bottom of a river or lake, and remain motionless, or they can swim considerable distances (~800 m) under water to escape [Wilsson, 1971].

Beavers spend large amounts foraging and maintaining their territory, being most active at dusk and dawn. Time budgets between the sexes are similar, but males do exhibit longer daily activity periods and travel further distances, associated with territory defence [Sharpe and Rosell, 2003]. Beavers can travel between approximately 1 and 9 km per night (~5 km on average), with the distance moved increasing with territory size [Nolet and Rosell, 1994; Herr and Rosell, 2004]. Within-lodge behaviours consist mainly of sleeping/resting, feeding and grooming; with seasonal, diel and ontogenetic differences relating to changes in frequencies of feeding and sleeping [Mott et al., 2011]. From spring onwards sleeping time tends to decrease, whilst grooming and feeding increase, along with exploratory and sentinel behaviours; associated with sub-adult dispersal and kit birth and emergence [Mott et al., 2011]. Lodge maintenance behaviours increase around autumn in preparation for winter [Hodgdon and Lancia, 1983].

Beavers display a dominance hierarchy based on age, with adults dominant over younger animals [Campbell et al., 2005]. Once paired, beavers tend to remain together until one dies or is displaced [Campbell et al., 2005]. All family members assist in rearing and defending kits [Patenaude, 1983]. Agonistic interactions within families are rare [Mott et al., 2011], most being vocal rather than physical interactions [Hodgdon and Lancia, 1983]. Few studies have detailed the behaviours of captive beavers [Wilsson, 1971; Richard, 1975; Friedman et al., 1981; Pilleri, 1985]. Female dominance over males during pair-bond formation has been noted, after this no sexual dominance is usually observed [Wilsson, 1971].

Remote Monitoring of Captive Beavers

Nocturnal and semi-aquatic lifestyles make monitoring more difficult. Recording food taken and fresh feeding signs are important methods. Remote cameras correctly positioned (freshest feed stations, worn forage trails or on lodges), can offer an effective, non-invasive means to monitor activity, body condition and document rarer behaviours such as mating attempts.

Negative/Abnormal Behaviours

A lack of challenging events in captivity may result in negative behaviours such as boredom, depression and stereotypic behaviours. Though some degree of controlled stress may be beneficial to welfare and the display of a wider range of more naturalistic behaviours [Chamove and Moodie, 1990; Moodie and Chamove, 1990]. Redirected aggression and/or displacement behaviour, has been described in beavers, apparently triggered by unfamiliar beaver scent [Wilsson, 1971]. Captive studies on behavioural development, in which a young beaver was deprived of specific environmental aspects, e.g. branches, determined that most behaviours were hard-wired and displayed when the correct provisions provided [Wilsson, 1971], but didn't take into account the welfare of individuals denied such opportunities. Wilsson (1971) also describes repeated and long-lasting digging behaviours against solid objects (e.g. walls). Observations of recently trapped wild caught beavers reveal individuals spending significant periods of time digging at walls or the corners of enclosures, and repetitive pushing movements involving available substrate [Campbell-Palmer and Rosell personal observations].

HUSBANDRY CONSIDERATIONS - IMPROVING THE CAPTIVE ENVIRONMENT

Capture, Handling and Transportation

A range of capture techniques have been described for beavers [Rosell and Kvinlaug, 1998; Rosell and Hovde, 2001; Campbell-Palmer and Rosell, 2013]. Beaver traps (*Bavarian*) are commonly used across Europe, with minimal or deaths (>3,000 trappings in Bavaria, Schwab G, personal communication). Disbanded traps can act as feeding sites within enclosures to habituate use and can aid trapping success. Like many mammals appropriate restraint techniques, including reduction of surrounding noise, movement and minimal handling time; all serve to reduce handling stress. Beaver restraint with least chance of injury to animal or staff occurs through use of appropriate traps and/or hand nets. Once trapped, handling works best if beaver is restrained within a large hessian sack (with nose kept in one corner), and animal held either through straddling or laying alongside and with arm across the back of the animal, either way as long as head is controlled and appropriate pressure applied various procedures can be easily undertaken [these methods have been further documented in Rosell and Hovde, 2001; Campbell et al., 2005; Campbell-Palmer and Rosell, 2013]. Collection of biological samples (including faeces and blood), and various body measurements can occur without chemical immobilisation, provided appropriate restraint methods are employed [Rosell and Hovde, 2001]. Covering of eyes has been demonstrated to maintain normal heart rate and alleviate signs of stress during handling in rodents (e.g. Koprowski, 2002) and is recommended during the restraint of beavers.

Practical recommendations for beaver transportation are documented [Gow, 2002; Campbell-Palmer and Rosell, 2013], including specific travel crate requirements (International Air Transport Association, Live Animal Regulations), for shipping by air. Beavers can be contained for journeys of up to 24 hr^{+} with the appropriate provisions; sufficient absorbent bedding; ventilation; food (particularly sweet apples for moisture) and water. Including used bedding or scent may reduce stress during transportation [Campbell-Palmer and Rosell, 2010]. Beavers will often exhibit reduced movement during transportation, remaining hunched or huddled with other animals (if present); so visual signs of distress may be difficult to detect [Gow, 2002]. Individual adults should be transported separately, kits/yearlings can be crated with either parent.

Individual Identification and Marking Techniques

Beavers are often kept in large, natural habitat enclosures, particularly in private collections, where individual identification may be difficult. This is a key requirement in monitoring health, assessing welfare and determining population growth, without the need for regular trapping and physical restraint. Use of microchips is recommended as these are minimally invasive to apply and have low incidences of failure rates. Individual recognition through natural markings alone is problematic due to lack of variation in colouration or markings. Patterns of scaring and notching on the tail (often caused through any previous territorial fighting), may enable individual identification, though difficult to employ from a distance. Ear tagging is a useful management tool [Sharpe and Rosell, 2003], though retention rate can be an issue.

As highly sociable animals and diligent groomers, external devices are often subject to increased destructive attention. Gluing of tags to the outer guard hairs is a recognised, short-term attachment method. Tail tagging has been widely used [e.g. Arjo et al., 2008], and radio transmitters have been implanted intraperitoneally [e.g. Ranheim et al., 2004], but such methods rise welfare issues in relation to pain and risk of infection. Long-term behaviour and movements are reportedly unaffected, however, post-operative infections, haemorrhage and damage caused by free-floating internal tags; and injuries through entangled tail tags, are all possible complications [Arjo et al., 2008]. Given these potential risks, consideration for the requirement of such tags should be undertaken, especially if alternative monitoring techniques are more practical.

Dietary Requirements

Beavers are generalist herbivores which display seasonal variation and feed on a range of herbaceous, woody, terrestrial, emergent and aquatic plants [Nolet et al., 1995; Severud et al., 2013]. Variation in captive diets is important to provide nutrition and novelty. However, sudden changes should be avoided to prevent disruption of gut microflora. A major challenge in captivity is to provide a varied diet high enough in fibre, which is best achieved through sufficient browse provision [Beer A, personal communication]. Wild beavers taken into captivity should be fed browse similar to trapping area, as a settling in tool and to ensure minimal disruption to the established hind gut microflora [Gow, 2002].

Beavers digest ~33% of ingested cellulose [Currier et al., 1960], a low rate of nutrient extraction requiring large amounts of ingested food. Quantities of ~1.2–1.9 kg of willow/day for a 20 kg captive beaver [Nolet et al., 1994], have been recommended. Browse should be added ad libitum to enable expression of fuller behavioural repertoires. Beavers will often form food caches with browse during colder months, such behaviours should be encouraged, providing hygiene is not jeopardised.

Social Structure, Breeding and Care of Neonatal

Captive resource availability and re-homing options for any resultant offspring should be given careful consideration before allowing breeding. As a highly social species, beavers should not be housed individually for long periods of time. Any pair introduction should be monitored, with the means to intervene if needed, as beavers can inflict severe wounds and even kill each other [Piechocki, 1977]. Any introduction should involve one male and one female, which tend to accept each other (though rarer instances of attacks and even fatalities have been reported, D Gow personal communication), as beavers will not tolerate attempts to mix families. Pre-exposing potential partners by enabling visual and olfactory contact, or presenting collected scent and soiled bedding, may improve pairing success before risking physical interaction [Campbell-Palmer and Rosell, 2010, 2011].

Pregnant and lactating females can be visually identified through the presence of prominent nipples. Gestation lasts 105–107 days on average and parturition occurs in the lodge or burrow around mid-May in northern latitudes [Doboszynska and Zurowski, 1983]. Two to four kits are common [Parker and Rosell, 2001; Campbell et al., 2005]. Reproductive output in females initially improve with increasing age, but can decline in later life [Campbell et al., 2005]. Mothers lactate for 2–3 months, though kits can consume solid food at the age of just 1 week [Wilsson, 1971; Zurowski et al., 1974). The kits remain in the lodge post partum and do not tend to emerge until approximately 6 weeks to 2 months of age [Wilsson, 1971]. If lodges remain unopened in captivity or have no specific viewing panel, kits tend not to be seen until they start to emerge from the lodge of their own accord. Parents and older siblings bring vegetation to the kits until they are around 2–3 months, after which they forage for themselves quite independently [Wilsson, 1971].

In the ideal captive environment every precaution should be taken (e.g. physical environment, diet, social structure) to ensure hand rearing should not be required or only as a last resort. The costs and benefits of hand rearing should be carefully evaluated before committing to this process [Read and Meier, 1996]. The long-term implications, including available resources, social factors, individual welfare and population management, should all be taken into account.

Enclosure Design/Requirements

The physical environment in which captive animals are kept is an essential component in ensuring both their physical and psychological welfare is met, the ecological requirements of a species should be considered in terms of which components are vital and possible to reflect in captivity [Wolfensohn and Honess, 2005]. Beavers are found across a wide geographic range and temperature gradients, from everglades in Florida to Taiga zones of Russia and Canada [Novak 1987; Halley et al., 2012]. So it may therefore be presumed that they can readily tolerate a wide range of temperatures, but their aquatic adaptations including dense fur and small extremities mean they do not lose heat readily and tend to be quite intolerant of heat. By ensuring provisions to enable lodge building and access to unheated water pools, beavers will regulate their temperatures through behaviour means, beavers may also use secondary shelters such as shallow burrows especially during the summer months [Buech et al., 1989]. Lodges provide microclimates keeping internal temperatures more constant and within a narrow range than external air temperatures [Dyck and MacArthur, 1993]. The reported thermoneutral range for beavers is 0–28°C [MacArthur, 1989], with most studies on internal lodge temperatures in wild beavers matching this range [Buech et al., 1989; Dyck and MacArthur, 1993].

Beavers can be hard to contain and will readily attempt to escape from enclosures without the appropriate fencing, provisions and social structure. Past escapes have generally been linked to poor perimeter fencing, flood events or a failure to cater for burrowing or building activities alongside water inflows or outflows and associated fence lines [Gow D, personal communication]. In Switzerland, the minimum enclosure size for captive born beavers is 20 m^2, followed by an additional 4 m^2 per additional individual, with 12 m^2 of water area and 40 m^2 for wild beavers removed into captivity [Dollinger et al., 1999], although these are not legal requirements this does acknowledge that welfare considerations differ for wild trapped beavers as supposed to captive born individuals.

Members of the same family can and should be housed together as long as they are definitely related and familiar to each other. Ideally, if trapping and re-housing a family group, the trapping interval between all family members should be kept to a minimum. Individuals from the same family have been accepted even with trapping intervals of a number of weeks [Gow, 2002], though this may not always be the case. Animals from different families must not be housed together, unless trying to establish a new breeding pair, during which it is vital that only one correctly sexed female and male are involved, and that there is adequate opportunity for escape, should aggression occur. Sex determination is not straightforward in beavers due to lack of external genitalia and obvious morphological differences. The most practical method is to exam the colouration and viscosity of the anal gland secretions, which are yellowish and more liquid in male Eurasian beavers, compared to females which tend to be grey/white and more thick/past like in females [Rosell and Sun, 1999]. In North American beavers the anal gland secretions are brown and viscous in males and whitish or light yellow and runny in females [Schulte et al., 1995]. The os penis will readily show up on x-ray, and can be felt for but this may be difficult in young individuals or un-sedated adults. If attempting to build up beaver numbers within a single enclosure, a pair should be allowed to breed or a whole family translocated rather than trying to amalgamate unrelated animals.

Key enclosure design requirements include access to fresh water, deep enough for animals to submerge, that can be changed, or continually fed by running water. Any enclosure must be surrounded by proven beaver-proof fencing that prevents digging, climbing [Richard, 1975] and chewing. Any in- and out-flows to any enclosure should be reinforced as these tend to act as escape points. Natural habitat enclosures, which may be fed by a stream for example, may require no cleaning although routine water testing for contaminates and harmful chemistry and organic matter levels should be considered. Under more artificial conditions cleaning is a regular requirement and often a time when humans come into close contact with captive beavers, which can cause stress. Frequent cleaning has been demonstrated to cause chronic stress in captive mice [e.g. Peters et al., 2002].

Aquatic requirements

Being semi-aquatic appropriate access to water and of suitable quality is vital to this species. A depth of at least 1 m depth to enabling swimming and diving behaviours should be provided. As a potential prey species beavers will often naturally enter and remain in the water for security. The edges of any pool should be gently sloped, or have a shelf just below the water level, to assist exit from the water and also provide a place for beavers to sit and feed or groom.

A diet high in browse and its low digestibility, beavers produce a lot of waste that is very fibrous, and can clog normal filtration systems if not taken into consideration. In a closed water system this waste either needs to be removed by manual cleaning of the water/pool or removed through more advanced filtration systems. It is possible to keep beavers out of water for short periods, such as after surgery or in temporary holdings, but extra shelter provisions should be provided.

Substrate

Beavers are adept burrowers so any substrate should allow for digging and manipulation, in order to facilitate natural behaviours and provide exercise. Beaver constructions should be left in place as long providing they don't cause an animal or keeping staff risk; or provide means of escape, or present a hygiene risk. Abrasions to foot pads and tails have been noted on beavers kept on rough, bare concrete flooring, this can be softened with substrates which can be manipulated.

Shelter provision

Artificial lodges are recommended, especially when animals are first released into an enclosure. These should be situated near to the water's edge, with the opening facing the pool, to encourage use and provide rapid access to water. Breaking open a lodge should be avoided unless necessary. If this has to occur, beavers should return to the same lodge, but may be unsettled, so additional building materials should be provided to allow lodge restoration.

Mixed exhibits

Mixed species exhibits are common and often encouraged to provide a more dynamic and enriching environment [Williams, 2009], and often display species sharing similar ecological or geographical themes. European otters (*Lutra lutra*) have shared enclosures with beavers at Edinburgh Zoo and Highland Wildlife Park [Richardson D, personal communication]. Both species were often seen at dusk utilising the same pool, but rarely interacting directly. However, care must be taken as mortalities have occurred e.g. as a result of capybaras (*Hydrochoerus hydrochaeris*) entering a breeding chamber and crushing small beaver kits [Gow D, personal communication]. There may always be risks involved and any introduction needs to be closely monitored, reviewed and appropriate management implemented to separate any serious altercations should they arise. It may be more difficult to observe individuals in mixed exhibits, particularly when monitoring access to feed station and individual feed intake; aggression and dominance levels should be monitored, with an efficient ability to separate species/individuals, as required, planned in advance [Williams, 2009]. It should be emphasized that what has previously worked for one facility may not work at another, with varying factors such as enclosure design, space, husbandry routine and individual animal personalities all influencing any situation.

Enrichment

No studies specifically addressing enrichment as part of captive beaver husbandry to improve welfare, encourage the display of naturalistic behavioural patterns or for training of captive animals for release [e.g. Shepherdson, 1994], could be found. This perhaps could be related to perception that beavers kept in large naturalistic enclosures have no further enrichment requirements. There may also be an underlying attitude that as rodents, beavers have less complex psychological requirements as say primates or large cats which often act as the focus for enrichment studies in zoological settings [e.g. Clark and King, 2008]. Singly housed captive beavers have been described as 'failing to thrive and of lowered physical condition' [Wilsson, 1971], supporting the view that this social mammal benefits from social enrichment.

Olfaction is the most developed sensory system in beavers, therefore they may be presumed to respond to olfactory enrichment [Campbell-Palmer and Rosell, 2010], as well as experience stress through negative olfactory stimuli such as unfamiliar or predator odours [Rosell et al., 2005]. Various husbandry practices recognise the importance of odours such as retaining soiled bedding or substrate when moving animals between enclosures or after cleaning, during transportation reduces the stress of the procedure and helps the animal settle more quickly. The application of a family's scent may also serve to encourage acceptance of any removed individual back into the group and discourage aggression [Campbell-Palmer and Rosell, 2010, 2011].

Experiments involving playback of running water have triggered dam building behaviours [Wilsson, 1971]. Sounds experienced in the captive environment can contrast greatly with natural environments, particularly if they are sharp and erratic, as has been demonstrated to affect captive mammals [e.g. increase in agitation behaviours in pandas, *Ailuropoda melanoleuca*, Owen et al., 2004].

CAPTIVE POPULATION MANAGEMENT

Captive breeding is not considered a conservation requirement given current wild Eurasian beaver numbers and distribution. Presently large numbers of North American beavers in Finland, Russia and reported escapees e.g. in Germany [Dewas et al., 2012] are causing conservation and management concern, questioning the need for this species being kept in European collections given the escape risk of this invasive species.

Acquisition of Beavers

The acquisition of wild individuals for captive collections is an ethical and controversial issue, especially faced by the zoo community [Mench and Kreger, 1996]. From a welfare perspective captive bred offspring may experience less stress than their wild trapped counter-parts, and sizeable captive beaver populations exist across Europe. It should be noted that the Eurasian beaver is a protected species in many European countries so an appropriate license may be required when dealing with wild-trapped individuals.

Dispersal

Wild beavers remain in their natal territory until they reach sexual maturity at around 20 months, after which they disperse autonomously [Hartman, 1997; Mott et al., 2011], but this can be delayed until 3–8 years in wild populations. It is vital to monitor family interactions and social behaviours when any offspring approach dispersal age. Signs of family breakdown, or the need for juvenile dispersal (removal), may include increased escape attempts and solitary behaviour (both outside of the central lodge and away from family members), and less tolerance of breeding pair towards mature offspring. Aggression tends to be rare but not unknown, so caregivers should be aware of these indicators and take appropriate management actions to avoid any more serous altercations. It has been suggested that older offspring should be removed in their second autumn to prevent aggressive behaviour, especially if resources and space are limited [Sainsbury, 2003]. However, beaver family members have strong social bonds. Breeding is suppressed in sub-adults which have a role in mutual grooming, territorial defence and assisting with care of any kits [Wilsson, 1971]. In large enclosures several generations of the same family (18 individuals) have lived together amicably, e.g. Lower Mill Estate beaver collection.

Surplus Animals

Beavers are often described as a poor exhibit animals, but can make excellent educational opportunities if presented aptly. Under the right circumstances, they breed readily in captivity, so the issue of surplus animals may develop. Available places within zoological or private collections are limited. Surplus animals should be avoided through responsible management and control of breeding. If resources allow and welfare of individuals is not compromised, sub-adults may remain within family units and should not be used to create new breeding pairs. Re-homing surplus animals may be an option, but ethical considerations should be given to where individuals are re-homed as husbandry and enclosure standards can vary greatly. Beavers of both sexes, can be permanently sterilised. Minimally invasive surgery, after which they can be returned to the water within 24 hr, display normal activity levels, experience little pain, rapid recover and have lower risk of post-operative infections in comparison to open surgical procedures [Pizzi, 2014]. This should also be considered for any blood lines that are over-represented in captivity, as determined through breeding records and genetic analysis.

Euthanasia is a legitimate tool to manage surplus animals, which cannot be suitably re-homed. Euthanasia should involve a painless death [AVMA, 2013] and all measures possible implemented beforehand to minimise stress to the individuals involved.

Reintroductions and Translocations

Translocation and reintroduction are viable conservation strategies that have been implemented to successfully recover beavers from near extinction [Nolet and Rosell, 1998]. Government sanctioned programmes may potentially provide an outlet for limited surplus captive animals, however, it should be emphasised that only sanctioned releases should be undertaken. This is not a viable management strategy to deal with surplus animals.

Translocations are likely to involve animals being held in captivity for varying amounts of time, this can be as short as a single transportation event or involve long-term quarantine periods. Such circumstances may require animals to be held in conditions very different from their natural requirements which may induce negative biological responses [Morgan and Tromborg, 2007; Gelling et al., 2010]. Despite numerous beaver reintroductions throughout Europe there is little published information concerning beaver health and welfare during the translocation process. Regular health monitoring, including post-mortem examination, should be an integral part of assessing any translocation process. Any reduction in stress experienced during the captive period of these conservation strategies, especially during the pre-release phase, may improve individual immunocompetence which in turn is likely to raise initial post-release survival, hence improving animal welfare [Gelling et al., 2010].

CONCLUSION

There is a dearth of recorded and published data for captive beavers, which would offer greater insight into standardising indicators of welfare and assessing captive environments. Activity time budgets for captive beavers have yet to be fully investigated or compared to wild counterparts, which could also be used to indicate areas of concern [Veasey, 2006]. No matter how naturalistic an enclosure, it may still be viewed as a restrictive and monotonous environment for a captive animal. Captive individuals may experience a range of stresses including capture, transportation, restraint and examination, close proximity to humans and other animals (including scent). As discussed observation of captive beavers can be difficult, however, captive collections remain duty bound to assess the welfare of animals in their charge, so appropriate efforts to observe, assess and review on an individual scale are required.

Beavers may suffer from a perception that they have less behavioural requirements beyond their physical environment, potentially encouraged by their lack of visibility and rodent classification. Often described as being poor exhibit animals, this may further dissuade research attention. As social mammals with complex chemical communication systems and such an ability to modify their environments, studies of wild counterparts suggest their captive requirements may actually be more sophisticated than sometimes perceived by some captive conditions witnessed. Evidence of negative behaviours resulting from unsuitable captive conditions, determines there is a need to identifying and evaluating welfare indicators for this species.

Given the widespread use of Eurasian beavers in conservation, including reintroductions, translocations and habitat management projects, they may become a more commonly held species, e.g. in Britain. Historically there have been contrasting welfare values within species conservation and individual welfare considerations in captivity. Clearly further research focusing on beavers in the captive environment is required, in particular the comparison of husbandry methods, diets and enclosure design and how they may impact on health, welfare and beaver behaviours. As welfare science advances there is increasing pressure on captive collections to increase standards and justify the keeping of animals. Conservation science is also coming under increasing demands to improve and address individual welfare standards, and expand the range of species addressed.

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