EAZA Best Practice Guidelines
YELLOW-FOOTED ROCK WALLABY

(Petrogale xanthopus)

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EAZA Preamble

Right from the very beginning it has been the concern of EAZA and the EEPs to encourage and promote the highest possible standards for husbandry of zoo and aquarium animals. For this reason, quite early on, EAZA developed the “Minimum Standards for the Accommodation and Care of Animals in Zoos and Aquaria”. These standards lay down general principles of animal keeping, to which the members of EAZA feel themselves committed. Above and beyond this, some countries have defined regulatory minimum standards for the keeping of individual species regarding the size and furnishings of enclosures etc., which, according to the opinion of authors, should definitely be fulfilled before allowing such animals to be kept within the area of the jurisdiction of those countries. These minimum standards are intended to determine the borderline of acceptable animal welfare. It is not permitted to fall short of these standards. How difficult it is to determine the standards, however, can be seen in the fact that minimum standards vary from country to country.

Above and beyond this, specialists of the EEPs and TAGs have undertaken the considerable task of laying down guidelines for keeping individual animal species. Whilst some aspects of husbandry reported in the guidelines will define minimum standards, in general, these guidelines are not to be understood as minimum requirements; they represent best practice. As such the EAZA Best Practice Guidelines for keeping animals intend rather to describe the desirable design of enclosures and prerequisites for animal keeping that are, according to the present state of knowledge, considered as being optimal for each species. They intend above all to indicate how enclosures should be designed and what conditions should be fulfilled for the optimal care of individual species.

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Furthermore, we thank all the 10 institutions which participated in our survey:

Summary

Endemic from Australia, the yellow-footed rock wallaby (YFRW) is listed as Near Threatened (IUCN, 2016) because its habitat is fragmented and declining (probably not much greater than 20,000 km^2) and its population is likely to be less than 10,000 mature individuals. Due to its IUCN status, YFRWs in are under intensive level of management under an *Ex-situ* Programme (EEP) in European zoos. The purpose of this programme is to secure a genetically healthy and sustainable captive population which may serve as a backup population for the wild.

This species is closely follow-up by the Australian government and deep cooperative conservation efforts are implemented between the EEP and the Australian government. It is an Ambassador Agreement (AA) species and the Department of the Environment and Water Resources (DEW) of Australia ensures that all holding institutions meet the husbandry and management requirements for the species, following their own Australian Animal Welfare Standards and Guidelines.

These Best Practice Guidelines combine all our current knowledge about general biology and husbandry requirements to provide a high level of well-being for YFRWs in captivity. It is addressed to YFRWs holders to get the most up to date knowledge on housing this emblematic species in the appropriate and best possible way, and for future holders which should be prepared to offer to the animals optimal housing and care. Regularly consulting the Guidelines and sharing them with all staff members (especially keepers!) is recommended. Holders are advised to contact TAG members with any concerns or queries about YFRWs husbandry.

Section1. Biology and Field Data reflects our current knowledge of this species in the natural environment using the most recent taxonomic information. The philosophy behind this is that *ex-situ* conservation can be used more effectively as a conservation tool if it is part of an integrated approach to species conservation (IUCN, 2014). The potential need for a conservation role of an EAZA *ex-situ* population has therefore been decided in consultation with *in-situ* specialists. This section provides wide and actual information.

Section 2. Management in Zoos covers housing and exhibition, nutrition, food presentation, welfare and enrichment, social structure, behaviour, and veterinary care. This part was written relying on one survey realized in March-April 2021 among all the 10 European institutions housing YFRWs. Control of breeding is an essential component of successful managed programmes and comprehensive information to assist zoo veterinarians to decide on the most appropriate contraception method for their animals is provided. Managed programmes rely on control of breeding and movement of animals between zoos. This document provides advice on birth control, handling, and transportation. A comprehensive veterinary section provides information on current knowledge on all aspects of medical care. It is essential that YFRWs are provided with complex environments and there is detailed practical information on environmental enrichment and medical training.

Section 3: References & Appendices includes, amongst other documents, a summary of references to each section and examples of appropriate YFRWs diet provided in different EEP institutions.

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List of abbreviations

BPGQ: Best Practice Guidelines Questionnaire

HR: Heart Rate

MCH: Mean Corpuscular Hemoglobin

MCHC: Mean Corpuscular Hemoglobin Concentration

MCV: Mean Corpuscular Volume

M&M TAG: Monotreme and Marsupial TAG

PY: Pouch Young

RR: Respiratory Rate

YFRW: Yellow-footed Rock Wallaby

Section 1: Biology and field data

1. Taxonomy

Class	Mammalia
Sub-class	Theria
Infraclass	Metatheria
Order	Diprotodontia
Sub-order	Macropodiformes
Family	Macropodidae
Sub-family	Macropodinae
Genus	Petrogale
Species	*Petrogale xanthopus*, Gray 1855, Flinders Ranges, South Australia, Australia

1) Infraclass Metatheria (Marsupialia)

The infraclass of Metatheria has diverged from the Theria in the Jurassic, around 160 million years ago (Luo *et al.*, 2011). It contains all the seven marsupial orders, equivalent to more than 300 living species. All marsupial mammals share a reproductive strategy, giving birth to undeveloped young nursing them in a pouch or marsupium, and having prolonged investment in lactation (Aplin & Archer, 1987; May-Collado *et al.*, 2015). Marsupials mostly inhabit Australasia and America (Nilsson *et al.*, 2010).

Figure 1 : Global geographic repartition of marsupial species

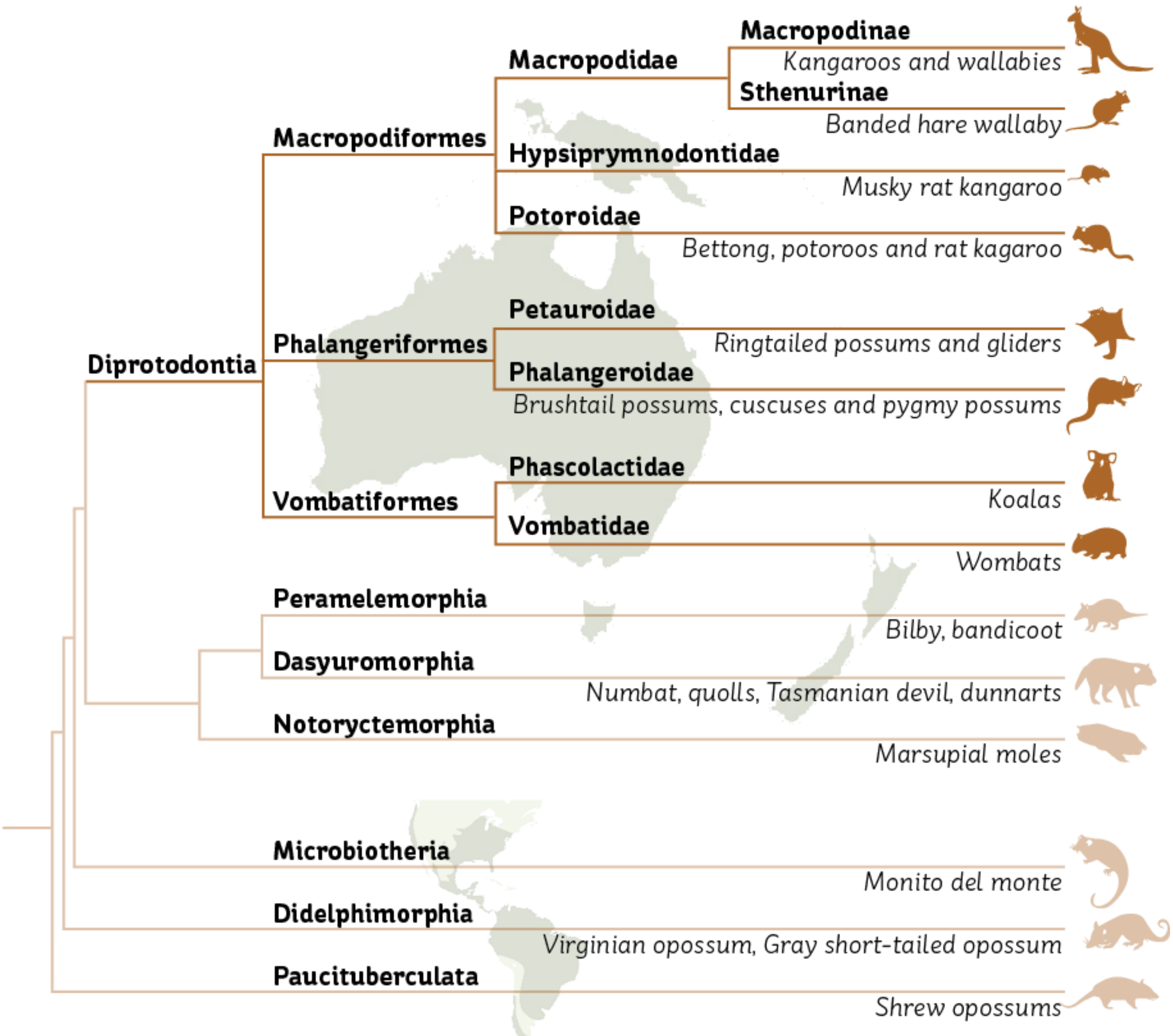


Figure 2 : Phylogeny of the Metatheria infraclass

2) Order Diprotodontia

The phylogeny of the Diprotodontia is still controversial but this order represents the largest one in marsupials with more than 125 living species. The Integrated Taxonomic Information System (ITIS) classified them into three sub-orders:

- Vombatiformes which encompass the wombats and koalas,
- Phalangeriformes composed of possums and gliders, which are entirely arboreal,
- Macropodiformes composed of kangaroos and wallabies.

The Diprotodontia are characterized by two key anatomical features. Their name comes from the meaning "two front teeth”. All diprotodonts species have a pair of large, procumbent incisors on the lower jaw and lack lower canines. Most of them have three pairs of incisors in their upper jaws, but this number is reduced to only one pair in one family, the wombats (Meredith *et al.*, 2009). The second trait distinguishing diprotodonts is "syndactyly", a fusing of the second and third digits of the foot up to the base of the claws, which leaves the claws themselves separate. Digit five is usually absent, and digit four is often greatly enlarged. Syndactyly is generally considered as an adaptation to climbing locomotion. However, many modern diprotodonts are strictly terrestrial and have developed further adaptations to their feet. Most of the living (and extinct) diprotodonts are herbivorous, but few species specialized for nectarivory, folivory, and insect-omnivory (Aplin & Archer, 1987).

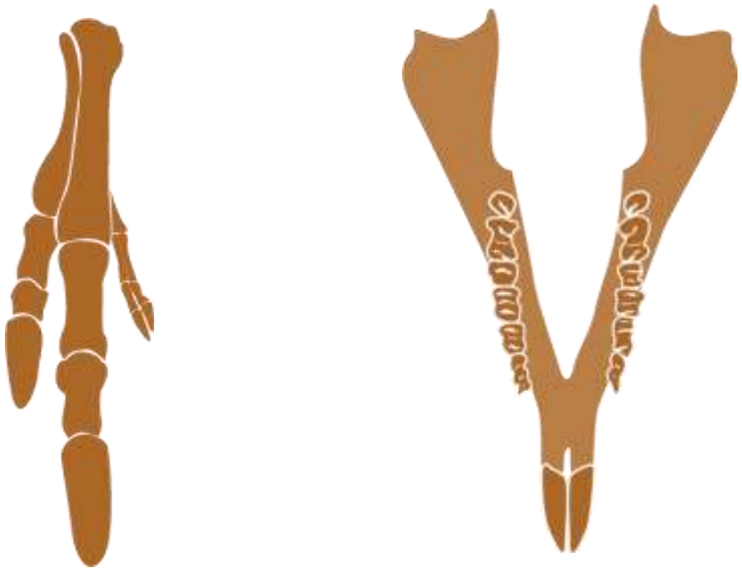


Figure 3 : Two anatomic key features of diprotodonts: The lower jaw (right) and the syndactyly (left)

3) Sub-Order Macropodiformes

The Macropodiformes, as well known as macropods, are divided in three families:
- Hypsiprymnodontidae,
- Macropodidae,
- Potoroidae.

4) Family Macropodidae

This is the second largest family of Marsupials and is composed of two sub-families:
- Sthenurinae represented by a single extant species, the banded hare-wallaby;
- Macropodinae (~60 extant species).

Macropodids live in all regions and habitats of mainland Australia, New Guinea, Tasmania and on some nearby islands (van Dyck & Strahan, 2008).

5) Sub-family Macropodinae

This sub-family is composed of 10 genera:
- Dendrolagus (tree-kangaroos),
- Dorcopsis (New Guinean forest wallabies),
- Dorcopsulus (lesser dorcopsises),
- Lagorchestes (hare-wallabies),
- Macropus (kangaroos, wallaroos and wallabies),
- Onychogalea (nail-tail wallabies),
- Petrogale (rock-wallabies),
- Setonix (quokka),
- Thylogale (pademelons),
- Wallabia (swamp wallabies).

6) Genus Petrogale

The brush-tailed rock wallaby *(Petrogale penicillata)* was the first species of rock-wallabies to be described in 1825 (Gray, 1827). Dr. John Edward Gray originally described it as *Kangurus penicillatus*. The species name *penicillata* is derived from the Latin *penicillus* meaning brush. Gray officially removed it from the genus Macropus but named a new genus *Petrogale* (*petro* = rock, *gale* = weasel) in 1837 (Gray, 1837).

The genus *Petrogale* is the most diverse macropod genus and presents a high level of speciation. Species inhabit complex rocky habitats such as cliffs, gorges, outcrops and escarpments (Van Dyck and Strahan 2008) which have encouraged phylogeographical isolations and their rapid diversification (Potter *et al.*, 2014). In total, 23 species have been described, currently grouped into 16 species (Eldridge and Close, 1992).

Figure 4 : Illustrations of the six different species of *Petrogale*hold in captivity (Toni Llobet, Lynx Edicions©) From top left to bottom right : *Petrogale persephone ; Petrogale concinna canescens ; Petrogale penicillata ; Petrogale lateralis lateralis ; Petrogale xanthopus celeris* and *Petrogale xanthopus xanthopus.*

7) Species yellow-footed rock wallaby (*Petrogale xanthopus)*

This species has a discontinuous geographical distribution and is divided into 2 subspecies:
- *Petrogale xanthopus xanthopus Gray, 1855* in South Australia and New South Wales (NSW),
- *Petrogale xanthopus celeris Le Souef, 1924* in Queensland.

Dr. Gray originally described it as the yellow-legged rock kangaroo in 1855 from two specimens (one male and one female) collected in the Flinders Ranges (South Australia) by the naturalist Frederick Strange (Eldridge, 1997). Dr. Gray mentioned that *P.xanthopus* has "all the markings of *P.lateralis* but differs in being much paler and yellow colour" (Gray, 1855). He named the species *xanthopus* (*xanthos* = yellow, *pus* = foot). The Queensland population was originally described as *Petrogale celeris* by Le Souef in 1924 but is now considered as a subspecies of *Petrogale xanthopus* (Sharman *et al.*, 1995).

2. Morphology

1) Body size

Table 1 : Body size of *Petrogale xanthopus xanthopus* and *Petrogale xanthopus celeris*

	P.x.xanthopus	***P.x.celeris***
Head-Body	From 480 to 600 mm	From 560 to 600 mm
Tail length	From 570 to 700 mm	From 565 to 675 mm
Weight	From 6 to 11 kg	From 6 to 12 kg

YFRWs are medium-sized wallabies with a stocky build. Their head and body length can range from 480 to 650 mm, with an average of 600 mm. Their long and un-tapped tail measures from 570 to 700 mm, with an average of 690 mm. They have large hind feet which are marked with short claws and thick, course pads. Adult males and females weigh respectively an average of 8 and 6 kg, with males occasionally weighing over 11 kg.

Sexual dimorphism: males are slightly larger with apparent testis; in female pouch opening can be seen.

2) General description

The YFRW is one of the most brightly coloured Australian macropods. Large and robust, it is easily recognised by its colours and distinctive patterns. It has a thick fawn-grey coat with a dark brown mid-dorsal stripe from crown of head to centre of back. It presents characteristic white cheek, flank and hips stripes. Its chest and belly are light-coloured and its ears and limbs vary from rich orange to bright yellow. YFRWs are easily identified from other rock-wallabies by their distinctive tail. Their tail is long, cylindrical, blunt-ended and irregular banded with dark brown and golden-brown. The pattern and colours of the tail are variable, with the tail tip differing from dark brown to white (Wilson & Mittermeier, 2015).

Table 2 : General description of *P.x.xanthopus* and *P.x.celeris* (Wilson & Mittermeier, 2015)

Body part	*P.x. xanthopus*	*P.x. celeris*
Body shape	Large and robust	More gracile
Body colour	Grey dorsally, white ventrally	Paler
Above eyes	None	Light orange-brown
Ears	Orange	Gray-brown
Arms and legs	Rich orange to bright yellow	Orange-brown
Dorsal stripe	Dark brown	Black
Hip strike	Brown-and-white	Indistinct
Base of tail	Orange-brown	Light orange-brown
Tail annulation	Dark brown	Less pronounced

Picture 1 : Full-face and side profile photos of an adult *Petrogale xanthopus xanthopus*
(© Eric Isselée / Life on White)

3) Atypical anatomy

The general body shape of all species of Macropodids is the result of their distinctive locomotion adaptation. They are characterized by relatively enlarged and powerful hind limbs with an enlarged fourth digit that carry with a smaller fifth digit the main weight of the body (Hume *et al.,* 1989). The first digit is absent and the second and third digits are exceedingly small and syndactylous. The tail is robust, large, and non-prehensile which provides balance during bipedal locomotion or stabilisation during slower quadrupedal movements, for example, during feeding or fighting. These adaptations allow Macropodids to have two different modes of locomotion: the 'saltatorial' locomotion (bipedal hopping) when moving at speed and the 'pentapedal' locomotion using their tail as a 'fifth limb' at slow speed (Gavin *et al.*, 2010).

Petrogale species have a characteristic diprotodont dentition, with a large single pair of forward-projecting lower incisors and a large diastema between these and the first premolars. They have moderate molar ridges in comparison with other species of the genus Macropus. This allows them to be intermediate browsers/grazers (Lim *et al.*, 1987) and to have a diverse diet. Like all species of rock wallabies living in arid environment and eating grasses, YFRWs have a curved tooth row.

Macropodids are characterized by their marsupium, a specialized pouch for protecting, carrying, and nourishing undeveloped foetus. In *Petrogale* species, it is a well-developed fold of skin with a single anteriorly opening that covers four teats, each associated with a mammary gland. The joey remains attached to one of the teats until it reaches the juvenile stage.

Extant monotremes and marsupials have a pair of epipubic bones but have been lost in all extant placental mammals (*Figure 5* and *Picture 25 p.56*). These two rod-like bones are thin and articulate from the pelvis pubic rami with a hingelike synovial joint. Each of them swings ventrolaterally in the belly wall when they are depressed (Reilly & White, 2003). All mammals have four abdominal hypaxial muscle series wrapped between the pelvis, ribcage, and spine: the internal and external obliques (oblique layers), the rectus abdominis (longitudinal layer) and the transversus abdominis (transverse layer). Mammals with epipubic bones have an additional muscle, the pyramidalis. Each epipubic bone is connected to the femur by the pectineus muscle and to the ribs and vertebrae by the pyramidalis, rectus abdominis, and external and internal obliques. In modern marsupials, they are called "marsupial bones" because they might be a mechanism to support the marsupium. They would serve as an attachment site for abdominal muscles and therefore strengthen the abdominal wall in females. All abdominal hypaxial muscles would act to elevate the belly and the epipubic bones and support the pouch or young attached to the mammary glands (White, 1989). However, the function of the epipubic bones is still controversial. This hypothesis would suggest that epipubic bones are only functional in females bearing young but they are present as well in males. Some researchers suggest that the epipubic bones have another original function; they assist locomotion because they are connected to the femur (White, 1989). According to this hypothesis, the epipubic bones act as levers to stiffen the trunk during locomotion, and aid in breathing (*Reilly et al*., 2009).

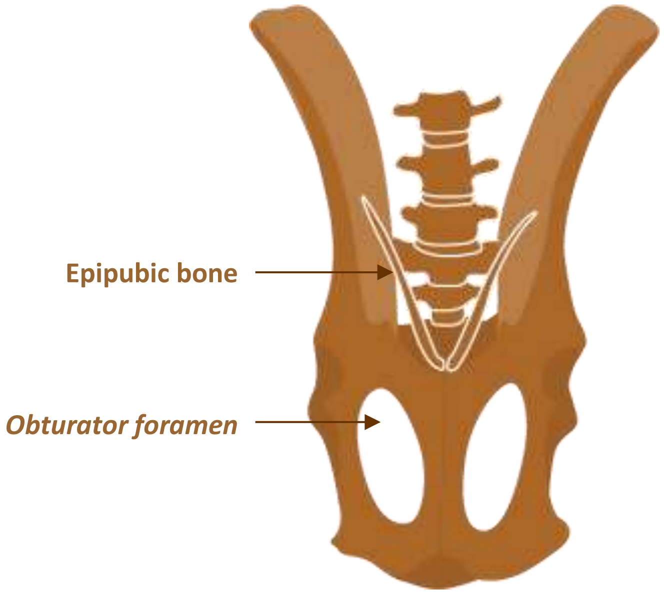


Figure 5 : Anatomy of the epipubic bones in Macropodids

Their heart differs from the typical eutherian heart as well as the heart of other macropods:

- The septo-marginal trabeculum, a band of cardiac muscle, is absent,
- The right atrio- ventricular valve is quadri-cuspid,
- The left atrio-ventricular valve has only two cusps, as in eutheria, but not other macropods,
- Two pulmonary veins open close together into the dorsal wall of the left atrium as opposed to four in eutherians (Gannon *et al*., 1989),
- External jugular is particularly large.

3. Longevity

Robinson (1994) estimated that the life expectancy of both sexes is at least 10 years in the wild. The studbook data shows similar life span in captivity; only 10% of the population live after 11 years and 6 months old. Nevertheless, the record of individual longevity in captivity is 24 years old for a female, and 19 years old for a male.

4. Zoography and ecology

1) Distribution

YFRW is endemic to Australia, where it has a highly disjunct and patchy distribution in South Australia, New South Wales, and Queensland. The subspecies *P.x.xanthopus* is found across the Flinders Ranges, Gawler Ranges, and Olary Hills in South Australia, and in the Gap and Coturaundee Ranges in New South Wales (Dovey *et al.*, 1997), while the subspecies *P.x.celeris* is only distributed in Adavale-Blackall in southwestern Queensland (Potter *et al.*, 2020).

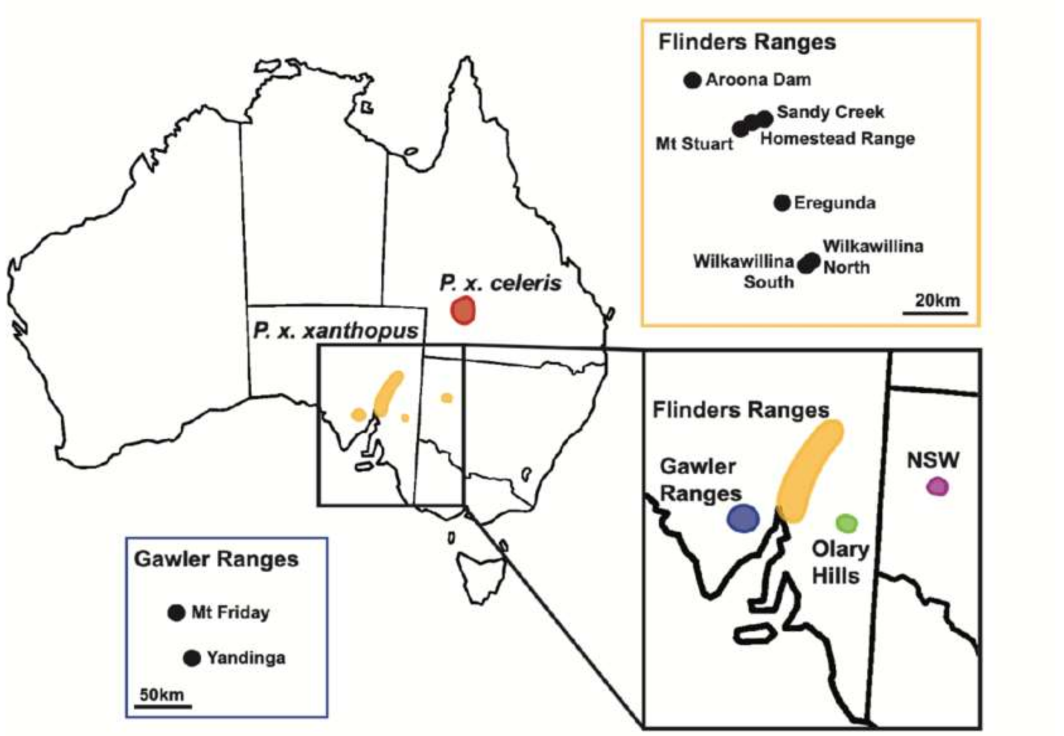


Figure 6 : Distribution map of *Petrogale xanthopus* in Australia. The yellow patches represent the distribution of the subspecies *P.x.xanthopus*; the red population highlights the distribution of *P.x.celeris* (from Potter *et al.*, 2020)

2) Habitat

Their common name is unequivocal, YFRWs inhabit rocky outcroppings, cliffs, and ridges, often at low topography, in semiarid and arid environments, associated with permanent or semi-permanent water sources (Eldridge, 2008). The climate is characterised by an average of 150-250 mm annual rainfall, although in the southern Flinders Ranges it could reach 450 mm annually (Copley, 1983), and temperatures can reach up to 50°C in the shade during summer season (Lim *et al.*, 1987).

The presence of rock piles and narrow cracks running into the cliffs are crucial for the species (Lim *et al.*, 1992). The YFRWs use the outcrops and fissures as shelters from extreme outside temperatures and predators (Copley, 1983; Miller, 2001). In these habitats, the dominant vegetation is Mulga scrub (Dawson, 1983) but the rocky outcrops also provide a greater diversity and abundance of vegetation than in surrounding areas, which are consumed by the YFRWs (Strahan, 1995).

3) Threats

YFRW populations encounter three major threats: wildfires, predation and competition with domestic and introduced herbivores such as goats, rabbits and sheep in their rocky habitat.

The past decade, Australia is subject to intense seasonal wildfires which destroy the habitat of the YFRWs and impact food availability. Many YFRWs that escape from wildfire are left displaced, without food or water and often injured.

The most significant predator is the introduced fox (Lapidge & Henshall 2001). It has contributed significantly to the decline of YFRW populations. They are excellent rock climbers, although they cannot kill adults in the wild, but they hunt vulnerable juveniles, thus reducing the numbers of wallabies reaching maturity (Miller, 2001).

Goats and sheep are two of the few species that can invade their relatively safe rocky environment. Because they share the same diet as wallabies, they have created unprecedented competition for resources and have forced them to move elsewhere for food and water.

Historically, the Aboriginal people had known and hunted YFRWs for thousands of years, and it was an integral part of their legends and traditions. Originally found in large groups (up to sixty individuals), the populations declined drastically due to their hunting for pets from the 1880s to 1920s and land clearance for agriculture (Maxwell *et al.* 1996). Humans have hunted YFRWs and Macropodids in general both for their meat and skins and for sport, though this species is now protected from hunting by law.

4) Conservation Status

IUCN Red List	CITES	NSW Status	EAZA Regional Collection Plan
Near Threatened	Not listed	Endangered	EEP

Current Population Trend: Unknown

The YFRW is listed as Near Threatened because its range of occurrence is probably not much greater than 20.000 km² and is highly fragmented (Copley *et al.*, 2016). The species is close to be classfied as Vulnerable. It is listed as Endangered under the U.S. Endangered Species Act.

The entire population of YFRW is estimated to be less than 10,000 mature individuals in the wild. Populations fluctuate depending on rainfall (Sharp & McCallum, 2010). Intensive surveys in South Australia (from 1993 to 2008) encountered that over 6,000 individuals currently live in South Australia. There are less than 100 individuals in New South Wales, and the size of the population in Queensland is unknown. The overall population trend of the species is unknown. In 1996, Maxwell *et al.* showed that the general population declined in the Flinders Ranges and some colonies in the Olary Hills and Gawler Ranges have gone extinct. However, over the last few decades, populations have increased in some areas due to fox and goat control measures (including in the Olary Hills, the Flinders and Gawler Ranges). Reintroductions of captive-bred individuals have been successful in South Australia and Queensland (Lapidge, 2000 & 2005).

5. Diet and feeding behaviour

YFRWs are intermediate browsers/grazers. Generalist herbivores, their diet is diverse. They feed a wide variety of herbaceous plants, classified into 5 main categories: grasses, forbs (herbaceous ephemeral species) and browse (perennial species including trees and woody shrubs), plants with stellate trichomes (Malvaceae, Solanaceae and Amaranthaceae) and Chenopodiaceae (both flat and round leaved, including some saltbush and bluebush) (Copley & Robinson, 1983). Their diet is seasonal, and the species consumed vary with rainfall. During the drought season, browse form the main component of their diet with 44% of consumption (Dawson & Ellis, 1979; Lapidge, 1987). In good seasons, they feed mainly forbs and grasses and a smaller percentage of browse (Lapidge, 1997). Some Northern populations can survive without access of water source (Wilson *et al*., 1976). Many southern populations are dependent of permanent or semi-permanent source of water (Sharp, 2011) and YFRW colonies are usually found within 5km of a water source (Lim *et al*., 1992).

6. Reproduction

Like other Macropodids species (with four species exceptions), the reproductive cycle of the YFRW is characterized by embryonic diapause (Renfree & Shaw, 2014), during which the embryonic blastocyst remains in a dormancy state and does not immediately implant in the uterus (Fenelon *et al.*, 2014).

Females can support 3 litters at a time: - one in embryonic pause in the uterus conceived following a post-partum oestrus - one in development and remaining full-time attached to one teat in in the pouch -the third living out of the pouch but returning (head only) occasionally to nurse (*Figure 7*). Their oestrus cycle lasts from 30 to 32 days and they have a gestation period of 30 to 32 days. In fact, females ovulate and mate within a day after giving birth following a post-partum oestrus (Poole *et al.*, 1985). The new embryo will be in a lactation-controlled embryonic quiescence until the full removal of the previous young from the pouch (Renfree & Shaw, 2014). Pouch life then lasts anywhere from 194 to 204 days. Sexual maturity is reached in males at about 590 days and in females at about 540 days after birth (Poole *et al.*, 1985). With this typical reproductive cycle, it is very common for the female to be pregnant 365 days a year. They can breed all year long in captivity (Poole *et al.*, 1985), but their reproduction is more seasonal in the wild, being affected by drought and increasing during periods of effective rainfall (Lim *et al.*, 1987). Most pregnancies end up in singleton but twins have already been rarely reported.

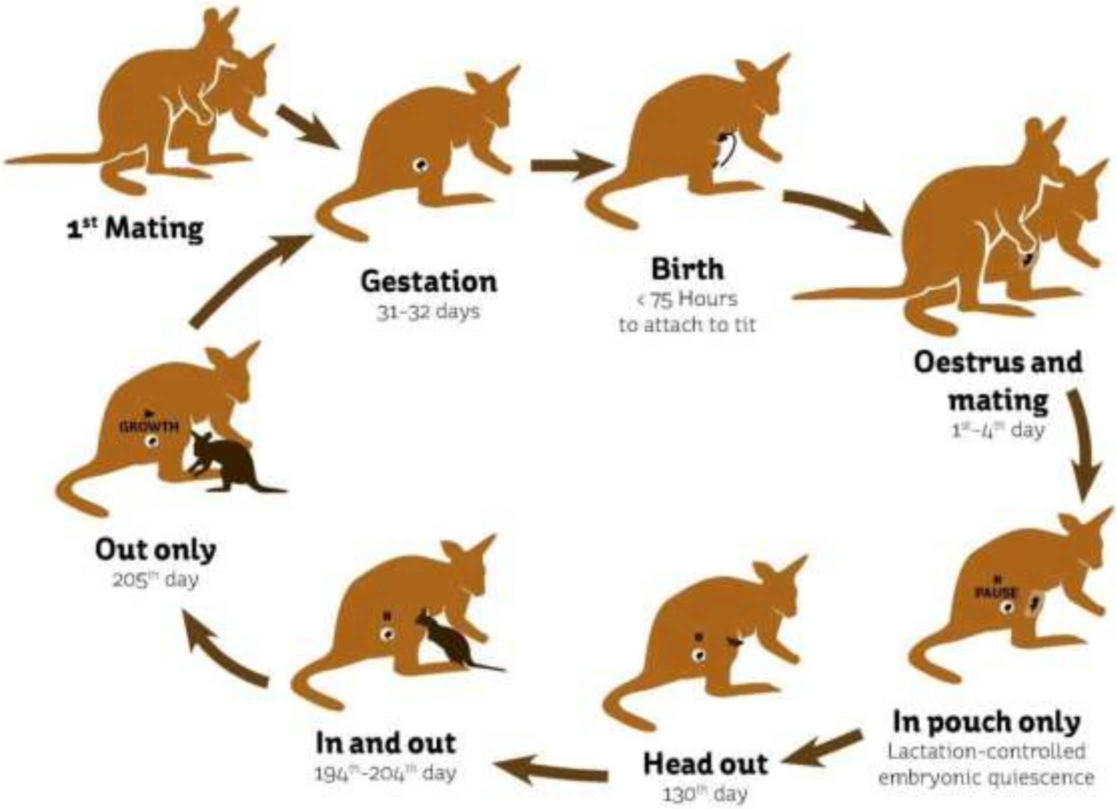


Figure 7 : Reproductive cycle of yellow-footed rock wallabies

In other Macropodids species the time between first pouch exit and permanently out of the pouch is a month or more. During this time the young learn to become an independent adult, but it can return in its mother if any threat arises. However, in YFRW this period of interim pouch life can last only 7 to 10 days in some cases. The young will continue to nurse for another few months, but it is physically on their own and don't have the safety of its mother pouch (Lim & al, 1987). Young are vulnerable to predation in the wild and stress-related illness in captivity during this interim life stage.

7. Behaviours

YFRWs are largely nocturnal during dry season, crepuscular or partially diurnal in other months. They leave the protection of the rocks to forage and feed at dusk and they are less active during the day. They shelter in caves, rocks and rock crevices and usually bask in sun in cooler seasons (Lim *et al.*, 1992). Males appear to be more active than females during the day and night. They have several resting spots throughout their range, while females often return to their resting spot just before sunrise. During the winter, both sexes appear to be active throughout the day and night (Lim *et al.*, 1987).

They live in family groups of six to eight adults. These groups are usually composed of an adult male, several adult females and their offspring (including juvenile males). Group home range is probably delimited by the distribution of shelter sites (Lim *et al.*, 1992). Larger colonies are made up of these smaller family groups. The colony size (up to 120 individuals) is determined by the number of available shelter sites, and the amount of food and water resources (Lim *et al.*, 1992).

YFRWs do not have a high level of social behaviours and most non-breeding interactions occur while individuals feed in groups (Lim *et al.*, 1992). They engage mostly nose-to-nose behaviours in conspecific interactions. They usually do not show aggressive conspecific interactions and usually avoid aggression. During aggressive confrontation for dominance, the two combatants initiate an aggressive hop often leaping toward each other, sniff, hiss and paw, and chase the other rival (Coulson, 1989). Strong bonds are formed between adults only during mating and with occasional allogrooming between a male and female. Males also engage in an olfactory courtship ritual with the females and nose the cloaca or the pouch of the female. If the female is unresponsive, aggressive chasing may occur. A clucking vocalization and lashing of the tail often accompany male arousal (Coulson, 1989).

Males show particular mating behaviours including tail wagging and clicking, followed by scratching of the female's tail and finally grasping the female around the chest (Miller, 2001). Breeding usually involves only the dominant male. During copulation, which can take up to 45 minutes, the male mounts the female from behind, places his forearms between the female's thighs and presses his head and chest against her back. Most breeding activity is between resting and feeding periods, often intermixed with foraging (Lim & al, 1987). After a female gives birth, mother/young interaction is minimal - the offspring is not assisted into the pouch and interaction is limited to cleaning the joey. Once the offspring leaves the pouch, frequency of interaction increases, the mother and young will communicate by clucking and grunting, play, and will groom each other (Lim *et al.*, 1987, Coulson 1989).

When they are frightened or alarmed, they run away into a crevice in their rocky habitat and wait quietly until danger has passed. If continued to be pressed, they will charge right past the presumed danger to escape (Williams, 1999).

Section 2: Management in zoos

This part was partly written relying on a survey conducted in March-April 2021 among all European holders. A questionnaire was sent to all 10 institutions housing YFRWs, all of which answered. This questionnaire was realized under supervision of Dr. Benoît Quintard, YFRW (*Petrogale xanthopus*) EEP coordinator and under consent of the M&M TAG. In the following text, it will be written BPGQ (Best Practice Guidelines Questionnaire) when it refers to the survey.

1. Housing

YFRW housing is quite unique compared to other macropods due to their specific rock-climbing behaviours. The enclosures for the species should therefore consider this specificity.

YFRWs require space that promotes positive well-being and opportunities to express their behavioural repertoire. Space is measured in three dimensions (width, length and height), and the vertical dimension is very important for this species with these unique rock-climbing behaviours. Moreover, we should keep in mind that the qualitative aspect of the enclosure, and therefore the development of this space, is as much important as the size. However, a big space without vegetation or rock structures is considered inferior in complexity and opportunities compared to a smaller, but well thought out and adjusted habitat reflected of aspects that are meaningful to wallabies.

In all temperate countries, a combination of inside and outside enclosures is an essential requirement in support of optimal well-being for the wallabies. Geographical differences and climatic conditions must be considered when designing wallaby indoor and outdoor habitats. In northern latitudes, wallabies are expected to spend more time inside while it might be the reverse in southern latitudes; this difference should be reflected in how habitats, including back of house areas, are designed.

1) Indoor enclosure

Indoor enclosures are necessary to protect wallabies against the vagaries of climate and thus to avoid rain and cold, especially in temperate countries. The animals are also protected from predators, and to some extent from some pathogens. However, indoor enclosures are often smaller than outdoor enclosures. Wallabies can cope with cold temperatures; they can be managed in free access outdoor/indoor most of the time. When the temperatures are lower than 0°C, it is recommended to make sure they have different shelter options but don't need to be locked in necessarily. The indoor accommodation can be composed of a network of several rooms connected to each other by sliding doors, creating a more complex environment and permitting the easy management of the group: for example, an injured wallaby or a new individual can be isolated.

Given the fact that wallabies can be left outdoor most of the time, the indoor housing is more often not visible to the public. The indoor area can serve as a retreat point for the animals, as well as retreat areas provided in the outdoor areas. However, the caregivers should have the possibility to observe the animals in any part of the inside enclosure: no matter how (through mesh or windows, or use of cameras) but they must be able to see all animals in order to notice any problem. Always keep in mind that if animals are locked in for the night, they will spend more time inside than outside, even during summertime and so wallabies should not be locked inside in summertime.

a) Spatial requirements

The larger the enclosure can be, the better it is for the YFRW welfare. Nevertheless, the size of the enclosure is only one important aspect of the quality of the overall environment of the animal. Moreover, it is important to keep in mind that YFRWs are rock-climbing animals. This is the reason why the complexity of platforms is at least as important as the size in square meters.

For a group of 10 to 15 animals, the M&M TAG recommends to have a minimum of 3 indoor boxes. A breeding group of about 10 YFRWs needs an indoor enclosure with a surface of at least

30m². Australian Animal Welfare Standards and Guidelines for macropods states that YFRWs should have a minimum of 40m² for 2 animals, and increase by 25% for each additional female and 50% for each additional male.

b) Substrate

In order to clean and disinfect easily, the floor (generally concrete or epoxy) must preferably be sloped approximately 5%. Drains should be placed outside the enclosure wherever possible.

Litter is useful to absorb urine and faeces, provides comfort to the animals, gives the possibility of foraging and can constitute an element of play. This litter can be straw, sawdust, wood chips or bark; any natural nontoxic substrate would be suitable. It has to be easy to clean 2 or 3 times per week. M&M TAG definitely recommends adding another substrate like straw in at least one of the boxes.

Picture 2 : Litter used in indoor enclosure
(© Parc zoologique et Botanique de Mulhouse)

c) Temperature

The M&M TAG recommends a temperature around 18°C for YFRW indoors. The inside heating can be done by lamps, radiators or central heating. Part of the heating can be done with subfloor heating. This will avoid having a cold concrete floor and add an overall comfort for the animals. However, this subfloor heating cannot be the only heating source as it could lead to circulation issues. Plastic curtains can be used to keep warmth inside the indoors when the outside door is open.

d) Humidity

Most institutions do not monitor the humidity of the YFRW's indoor environment. However good management of the humidity is important for the health and this parameter should be taken into consideration. In their home range weather is very dry and humidity varies between 50 and 90%. The M&M TAG therefore recommends a humidity above 50%, which can be achieved by sprinkling the substrate or by installing humidifiers and/or containers with water near the heating points if the humidity is too low in the YFRW indoors.

e) Ventilation

Ventilation allows the supply of oxygen, the evacuation of carbon dioxide, ammonia, and bad smell. It must therefore be sufficient, with a minimum of approximately 10 to 15 renewals per hour. It can be natural, through doors and hatches, or mechanical through extraction systems. Wallabies should be given free access most of the time, doors open 24/7, which should aid in appropriate ventilation.

f) Doors

The doors should be a minimum of 80 cm high and 50 cm wide. These doors can be up in height, 1,20m for instance at Mulhouse zoo, as they prefer to move at higher levels and it is an easy way to assure a specific access for the YFRWs to their indoor areas in case of mixed-species exhibit.

Picture 3 : Indoor elevated door
(© Michel Foos, Parc Zoologique et Botanique de Mulhouse)

g) Indoor shelters

YFRWs like to hide in elevated shelters to rest. Shelters should be placed at different levels in the indoors. An easy way to fulfil this need is to put vari-kennels in height as described in the P*icture 4.* Sawdust or any other bedding can be placed inside to higher the comfort of the animals. The top of these vari-kennels should be protected with a flat and easily cleanable surface as they like to stand and defecate on them. Sides and fronts of the kennels can be, partly, covered with sturdier safe materials, to create more shade or darker areas.

Picture 4 : Indoor facilities and Vari-kennels disposal at Besançon zoo (left) and Parc Zoologique et Botanique de Mulhouse (right) (© Benoît Quintard)

2) Outdoor enclosure

Access to the outside should preferably be left to the choice of animals. This day time free access can be considered even when it is freezing if sun is shining and it's not too windy. Being outside during the day in snowy conditions is not an issue either.

Simulating the natural habitat of rock wallabies is highly desirable, however, YFRWs can be exposed to many germs and a control of pests and potential predators is needed. Most outdoor substrates are cleaned naturally by sun, rain and time, and therefore do not require special maintenance except removing faeces on a daily basis. It is important to provide clean drinking water, both in- and outdoors. In the same way as for the inside enclosure, additional outside enclosures are recommended to separate individuals if necessary, as well as provide rotation and exploration.

For a group of 10 to 15 YFRWs, the M&M TAG recommends to have at least a paddock ($150m^2$ minimum, which can be used to separate isolated animals) and a big outside enclosure. The total area of the outside environment should be minimum 100 m^2per individual (1000-1500 m^2 for the all group). *Australian Animal Welfare Standards and Guidelines for macropods states that YFRWs should have a minimum of 40m2 for 2 animals, and increase by 25% for each additional female and 50% for each additional male*

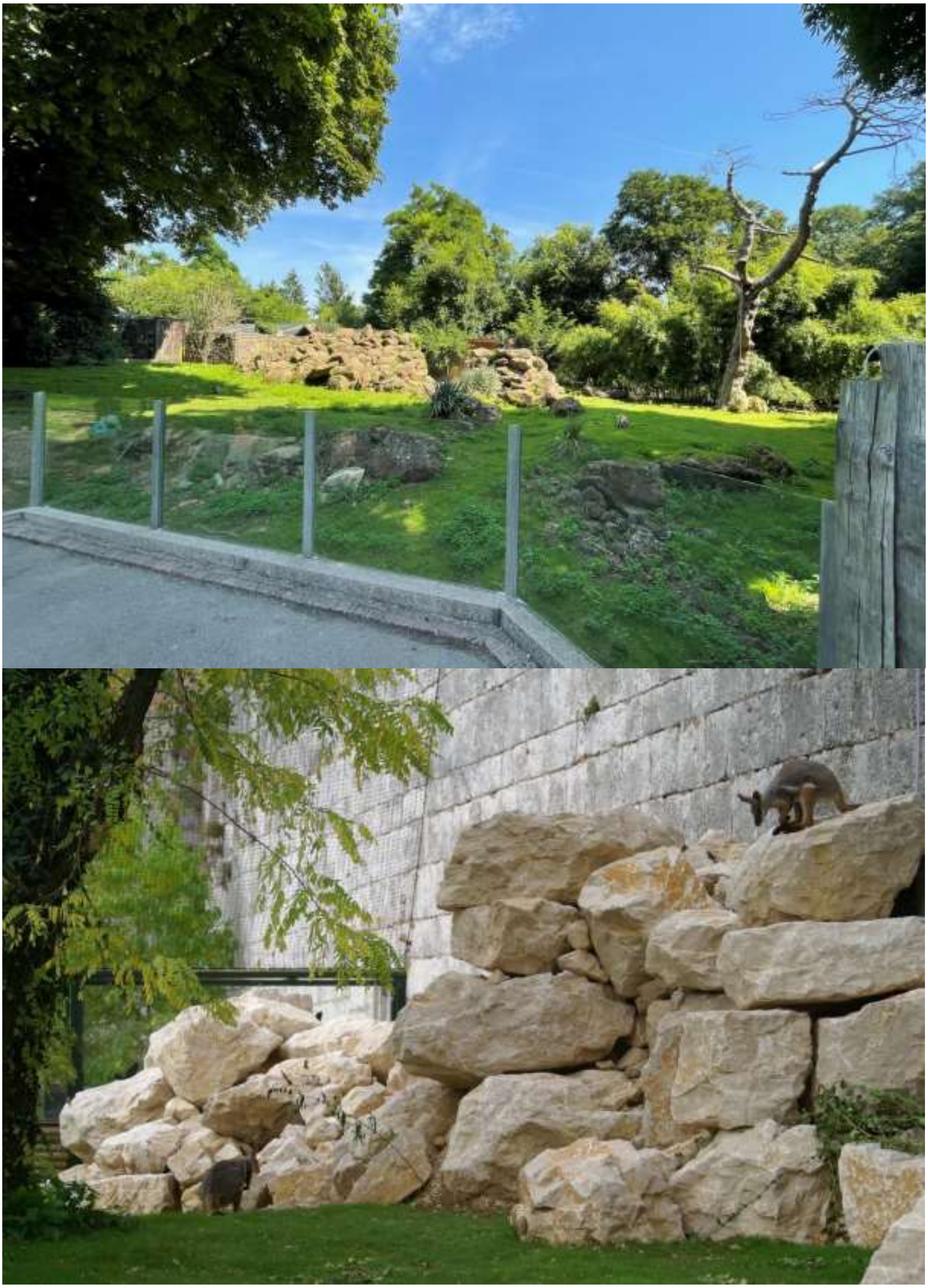
Picture 5 : An adult YFRW in the snow
(©Parc Zoologique et Botanique de Mulhouse (left) ; © Besançon Zoo (right))

a) Enclosure furniture

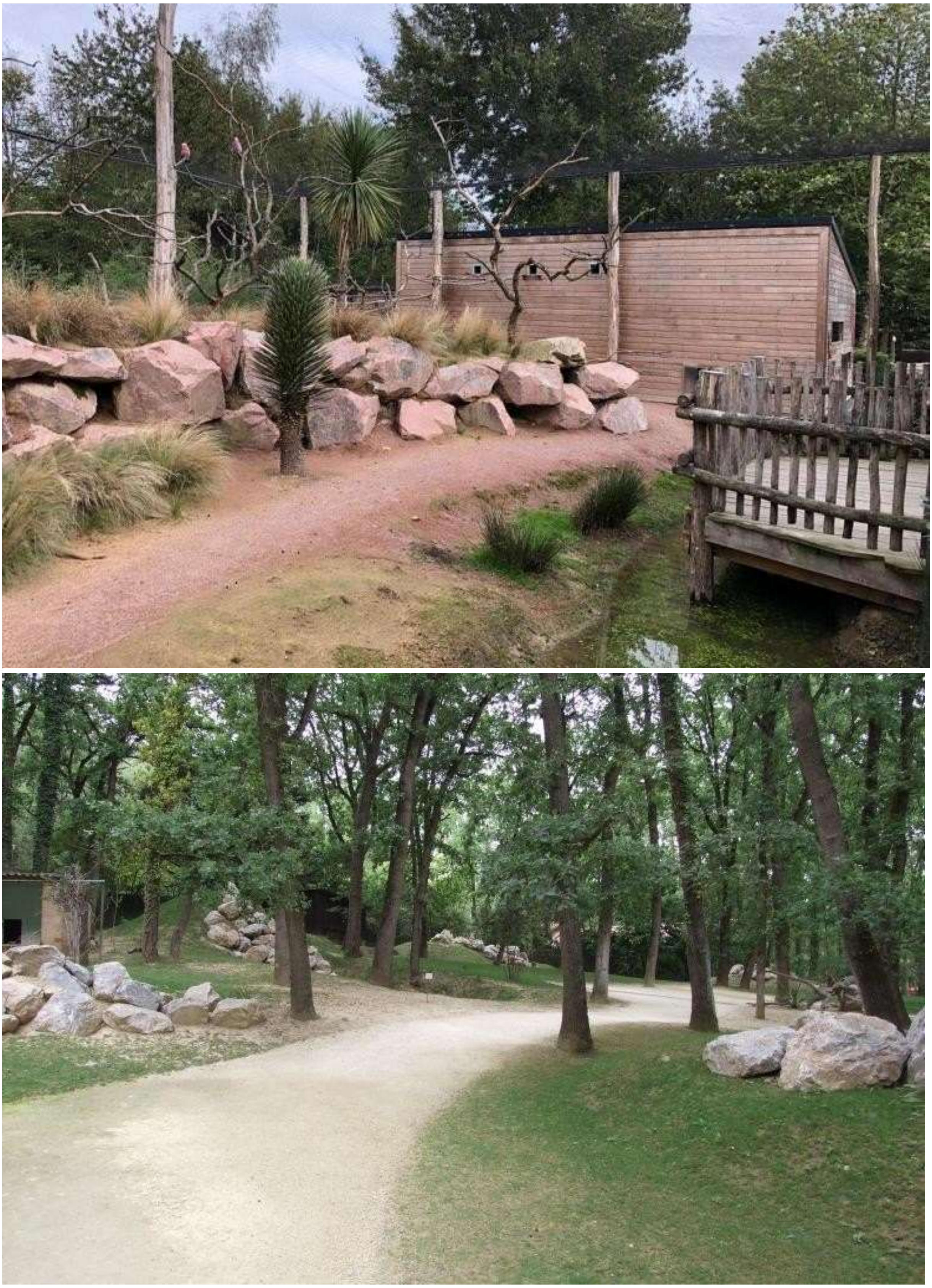
The environment of YFRWs needs to be complex enough to allow them to express a large part of their behavioural repertoire. Vertical spaces and ledges are important for rock-wallaby activity. It is really important that they can play, climb, jump, run but also hide to avoid the different sources of negative stress, potentially coming from visitors and/or other animals in the group. Recreating the natural environment using rockworks or naturally available features is preferred. The essentials are:

- High enough (ideally one should be 3m high or more),
- Complexity through different cavities, for the animal to rest and sleep, and/or hide from the other individuals, the visitors and the sun),
- Enough in number: at least 2 rockworks to provide enough shelters and avoid tensions in the group - the females can have a matriarchal order and dominate one mound with lesser females moving to the smaller mounds. Males tend to go where they want and aggression only becomes an issue when a female is in season. When rock mounds are limited, higher levels of aggression will occur.

Enclosure furnishing must also include rock crevices, caves, overhangs, low growing shrubs/bushes and small shade trees.



Picture 6 : Example of a complex environment at Mulhouse zoo (top) (© Alexandre Petry) and Besançon Zoo (Bottom) (©Benoît Quintard)



Picture 7 : Example of a complex environment at La Boissière du Doré Zoo (top) and African Safari (Bottom) (©Alexandre Petry) *b) Barriers and containment*

The barriers must represent an impassable obstacle for the animals. Besides, they must ensure that visitors remain outside of the animals' enclosures. They must be robust and enduring to be YFRW and predators' proof. *Table 3* summarizes several advantages and disadvantages of each type of barrier. The barrier should allow visual access for the visitors for no more than ½ or ⅔ maximum of the enclosure perimeter, to promote optimal animal welfare through areas for reprieve and be seclusion.

Table 3 : Advantages and disadvantages of different types of barrier

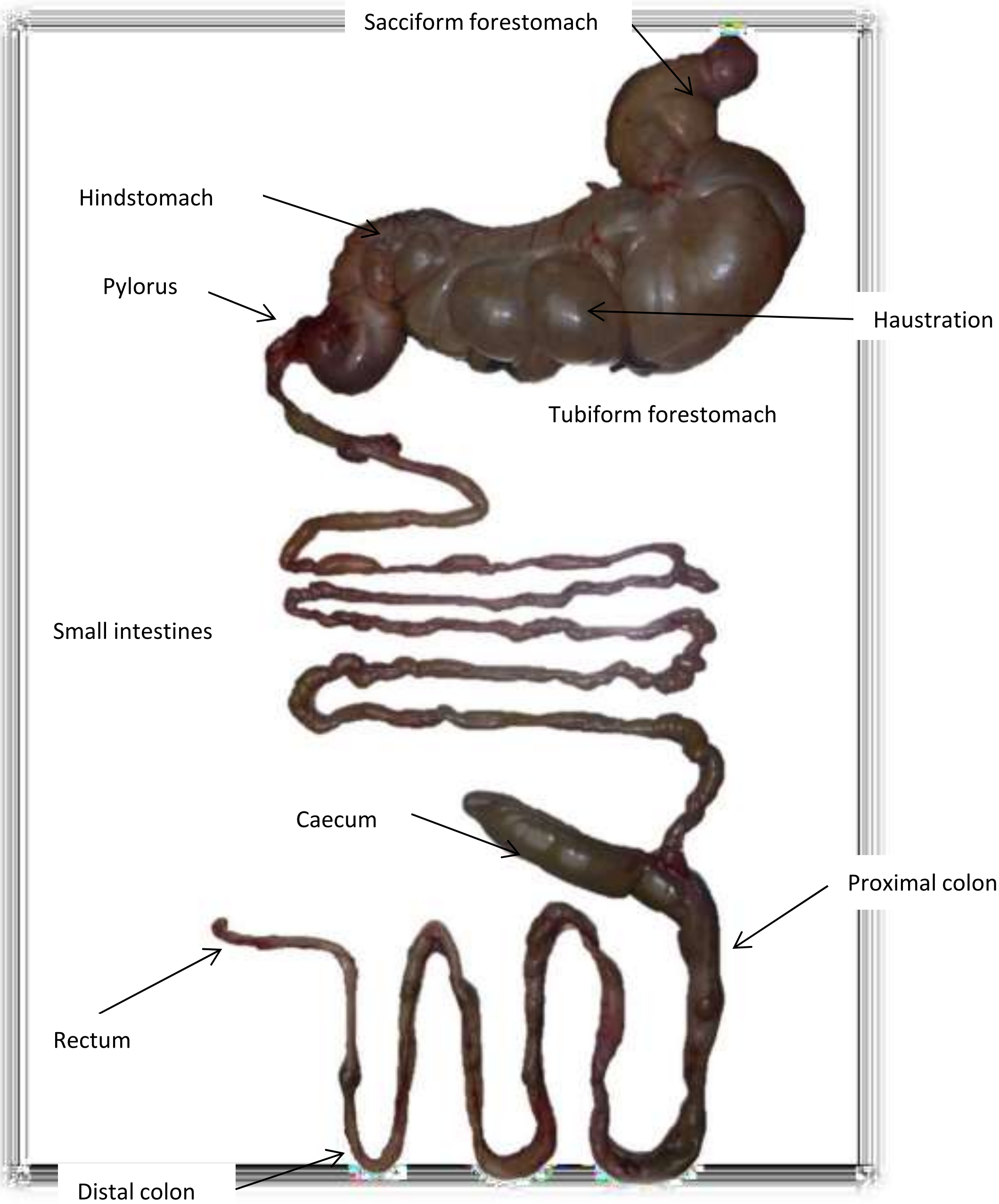
Type of barrier	Advantages	Disadvantages
Walls (concrete, cement, wood)	Easy to build Natural shelter (wind, sun) Safe	Not esthetical
Dry moat	Natural barrier Good landscape integration	Cannot be the only barrier
Wire mesh	Easy to build Safe	Not esthetical Possible transmission of disease
Electric fences	Discreet Good complement in combination with other types of barriers Cheap Efficient versus predators	Risks of escape (if short-circuit with vegetation) Risks of electrocution
Glass walls and glass windows	Aesthetical Safe	Shorter distance between animals and visitors

Most of the time, the outdoor enclosures are a mix of several types of barriers. Whatever the containment (or the combination of them) used, it should be at a minimum of 1.80 m in height with no footholds at any point. However, as yellow-footed rock-wallabies are very agile and flightier than other macropod species, the preferred fence height is 2m, with an inward overhang of approximately 60cm at 45°. If a fence is used, posts should be placed outside the enclosure so that animals running along the fence cannot harm themselves on them. It is recommended to avoid an enclosure with only glass walls because the animal needs to have sides out of the view of the public. Fences should be relatively straight (180°) or curved, and ideally they should have no corners with angles ≤ 90° but curves of approximately 45 degrees are preferred. Any fence angle change must be clearly visible to the wallabies. Injuries can be reduced by covering any square corners with a loosely supported fan of standard rabbit netting.

If a mesh is provided in the enclosure it should be a 50mm x 50mm chain link fence with either 2.5mm or 3mm thickness is preferred. At the least, mesh diameter must be sufficiently small to ensure that the enclosed wallabies cannot get their heads caught. Deer fencing is not considered adequate as the wallabies can get their heads or legs caught in the fencing.

2. Feeding

YFRWs are considered as intermediate feeders (browsers and grazers) correlating with their dentition and gastrointestinal (GI) anatomy (*Picture 8*). They are foregut fermenters, but the anatomy of their stomach is quite different and has been described in detail (Vogelnest & Portas, 2019).



Picture 8 : Complete digestive tract of a Yellow-footed rock-wallaby
(© Benoît Quintard)

1) Basic diet

Captive diets should reflect the nutritional composition of the natural diet, with sufficient and appropriate fibre and digestible energy. The diets of intermediate grazer/browsers tend to be lower in fibre and higher in digestible energy. In the absence of fresh grass and browse, YFRWs are often fed hay ad libitum, vegetables and commercial pellets or kibble especially designed for wallabies and kangaroos (Vogelnest & Portas, 2019).

According to the BPGQ, frequently offered foliage include ash tree, hazel tree, butterfly bush, elm tree, plane tree, hornbeam, mulberry tree, willow tree, linden tree, maple tree, bamboo. Some examples of diets offered in EEP institutions can be found in Appendix 1.

2) Special dietary requirements

Hay with a high proportion of stalk versus leaf should be avoided because of potential oral trauma that may predispose to progressive periodontal disease ("lumpy jaw"; see *section 2. 7. 6)*) (Vogelnest & Portas, 2019).

Obesity, dental and GI diseases are concerns when animals are fed diets with excess digestible energy (Vogelnest, 2015). Therefore, foods high in sugar and/or starch should be restricted. Lapidge (2005) found that captive YFRWs had lower circulating vitamin E levels than free-ranging counterparts, but animals reintroduced to the wild increased their vitamin E levels to those of wild animals within 6–12 months. It is unclear if the increase in vitamin E was because of high levels of vitamin E in the natural food items or because of decreased stress levels in a natural environment (Dierenfeld, 1988; Lapidge, 2005; Vogelnest & Portas, 2019). A balanced diet containing a complete pelleted feed to supplement browse, hays and vegetables should provide adequate levels of vitamin E. The diets of the YFRW should be analysed to ensure levels of vitamin E (>100 IU/kg diet dry matter) are sufficient to reduce the risk of developing myopathy (see section 2. 7. 5)) (Vogelnest & Portas, 2019).

Calcium-based uroliths have been reported in YFRWs (Bryant & Rose, 2003; Nowakowski *et al*., 2021). Excessive amounts of calcium consumed, either by unintentionally increasing the calcium to phosphorus ratio in the diet or consumption of plants grown in high-calcium soil, high levels of vitamin D and possibly hypovitaminosis A may be contributing factors in the development of calcium-based uroliths (Bryant & Rose, 2003; Lindemann *et al*., 2013). Therefore, the authors recommend avoiding lucerne in the diet and to favour grass hay. Use of kangaroo or wallaby pellets with a Ca/P ratio under 1.5 are also advised.

3) Method of feeding

Food should be distributed in clean suitable containers such as one-meter-long robust plastic containers or aluminium trays. Food should be placed in shaded areas to ensure it won't spoil during hot weather. Several containers should be used to maximize foraging and ensure all individuals in the group feed equally. Food should be varied and given daily.

4) Water

Water must always be provided ad libitum in both indoor and outdoor enclosures. The containers should be large enough to allow the animals the opportunity to immerse their forelegs for cooling purposes (if no pond is available) and kept in shaded areas and away from the fence line. Containers made from safe and solid materials can be used as long as YFRWs have an unhindered access to clean, fresh and uncontaminated water. More than one sources of water are desired to allow all members of the family to drink.

3. Social environment

1) Group structure and size

YFRWs are socially monogamous and live in groups. They need to be kept this way when they are under human care. Both males and females exhibit strong territorial behaviour to other members of the same sex. They appear to show linear dominance hierarchies and adult males and females form relatively stable relationships. Aggression by the dominant female has resulted in the death in captivity of subordinate females. Adult males will fight for dominance when a female is in oestrus. Young males nearing sexual maturity have been known to be severely stressed and even killed by adult males. In the wild, several mature males can stay within the group as they have the opportunity to run away from each other. In an exhibit this is more difficult and the coexistence of several males must be managed with care. The group can be composed of an adult male and several females, more than four, depends on the exhibit size. Some juvenile males can stay in the group for up to 2-3 years, especially if the exhibit is large enough. For example, at Mulhouse Zoo, one adult male shares the exhibit with five others juvenile males which range from 1 to 3 years in age.

It is important to maximize the number of resources necessary such as shelters, sunbathing places, and access to water and food. When the colony is multi-males, it is necessary to limit the amount and times they are kept in confined spaces (e.g. indoor) or they should be kept apart when inside. In general, it is best to avoid keeping isolated animals for too long. The presence of more than one adult male can reduce the breeding success because of the severe stress of the females and the too many conflicts between males.

a) Management of surplus males-females:

Unisex group of males or females can help in the management of the captive population. For bachelor group of males, we recommend avoiding housing them with or near other female wallabies and even near other macropod species.

b) Moving the youngsters:

Generally, male wallabies are transferred from a zoo to another before they reach the age of 3. It corresponds with the start of serious conflicts with the dominant male. Young females might be mated by their father as early as 550 days old. Pouch checking should thus be performed from this time on, or the young females should be transferred to another institution.

2) General behaviour repertoire and communication

YFRWs are most active at dawn and dusk. At noon, they are often resting on rock piles to take sunbathes. To maximize visitor's visibility, it is recommended that the rocky area is in a location with exposure to extend hours of sun.

Social behaviours in YFRWs are infrequent as the individuals often ignore each other. Interactions include sniffing, hissing, stamping, pawing, and chasing. Allogrooming is rare but appear sometimes between a mother and her infant or between a male and a female before copulation. Unlike other marsupials, females can sometimes leave their young in a rocky cavity; this should be kept in mind in their daily management, especially when locking animals inside for the night.

To threaten other individual, wallabies use several aggressive behaviours such as overt threat (dips head and leans forward in a pouncing posture toward the other), foot-thumping or kicking ground (stationary or in small moving), exaggerated self-grooming close to another animal and mouth open with visible teeth toward the other animal. Agonistic behaviours are biting, striking, cuffing, kicking with back leg, tail grasping or chasing.

The foot-thumping or kicking ground is also used in situation of stress for example when the care staffs want to catch or move YFRWs inside. As a prey species, wallabies are vigilant animals. When a caregiver approaches them, they are supposed to get up and move away (unless they are habituated and comfortable with caretakers). If unhabituated animals do not move, they probably have a health-related problem.

3) Introduction methods

Like most other macropods, this species is normally easy to introduce. Prior to introduction, the authors recommend keeping the future 'room-mates' in two adjacent exhibits for several days, where visual and olfactory contacts are possible. Positive signs during this period are sniffles between the two individuals or moments spent next to each other separated by the grid.

For the introduction, a maximum of doors should be opened, in order for animals to move around as freely as possible. Some chasing behaviours can be observed during the introduction, but the excitement normally goes down very quickly. If the introduction occurs within the outside enclosure, the new incomers should have the possibility to explore the enclosure on their own before introducing them to the rest of the group.

When more than one animal need to be introduced to a group, the introduction can be done with access to the outdoor exhibit, but only if the new animals have had access to the outdoor space and are familiar with it. If only one animal needs to be introduced to a group, it is better to do the introduction inside as the single animal can be very stressed during outdoor exploration.

4) Mixed species exhibit

Mixed-species exhibits are more and more common in zoological institutions because of their educational values and for the benefits of inter-species interactions. Calm and rather social, YFRWs are perfect candidates for this kind of exhibit with other Australian species. 90% of the European holders currently keep this species in a mixed exhibit. Red kangaroos, emus and YFRWs have been held together. This has resulted in fighting between males of the different species, causing minor injuries in open spaces and more serious injuries in confined spaces. In some rare cases young yellow-footed rock wallabies may cause stress to male kangaroos and have already been seen "mating" with females kangaroo.

All mixed species should have fully access to proper food, water and shelters without any disturbance. Exhibit size could be relevant to interspecific aggression. Large exhibits, with an adequate number of rock piles do not record aggression amongst species as much as smaller exhibits where opportunity to get away is limited. For example, at Mulhouse, the red kangaroos cannot access to the inside room of the YFRWs because the doors are on top of a mound of rocks and not directly on the ground (≈ 1 m 20 height). The kangaroos are less agile and cannot go inside the space of the YFRW.

The M&M TAG encourages zoos to try mixed species enclosures, but it is important to keep in mind that all the situations are different, and the examples mentioned here are just to give an idea of what is done in EAZA zoos. All trials (successes or failures) should be reported to the EEP coordinator. To maximize the success of the mixed exhibit, we recommend taking your time and to wait all the species discover on their own the exhibit for 1 or 2 days before any introductions. This kind of exhibit has to be well observed and the situation can change very fast in case of birth, sick or old animals.

Table 4 : Mixed exhibit actually done in European Zoos with YFRWs (BPGQ)

Mammals	**Latine name**
Red kangaroo	*Macropus rufus*
Common wallaroo	*Macropus robustus*
Parma Wallaby	*Macropus parma*
Swamp wallaby	*Wallabia bicolor*
Red-necked wallaby	*Macropus rufogriseus*
Birds	**Latine name**
Common emu	*Dromaius novaehollandiae*
Bush Thich-knee	*Burhinus grallarius*
Masked lapwing	*Vanellus miles*
Maned duck	*Chenonetta jubata*
Magpie goose	*Anseranas semipalmata*
Blue-winged kookaburra	*Dacelo leachi*
Papuan eclectus	*Eclectus roratus*
Gallah	*Eolophus roseicapilla*
Straw-necked ibises	*Threskiornis spinicollis*

4. Breeding

1) Reproductive strategies

To effectively manage the reproduction of an YFRW group, it is important to understand the reproductive status of each individual in order to avoid mature offspring entering in breeding situation with their parents or siblings.

2) Pregnancy and parturition

There are no physical exterior signs of oestrus in female wallabies. Therefore, it is difficult for the care staff to detect it. However, males can detect the reproductive status of the females and it is easy to see which females of the group are in oestrus by observing male behaviours (e.g., chasing, mounting).

It is difficult to detect the gestation as it is truly short, and the parturition is hardly detectable. In some rare cases birth can be detected by the observation of a mucus plug (which can be soft or very fibrinous, like smooth muscle structure) on the floor of the enclosure or on the female's cloaca (*Picture 9* and *Picture 17*). Without regular pouch check, keepers first observe the joey when it is 130 days old.

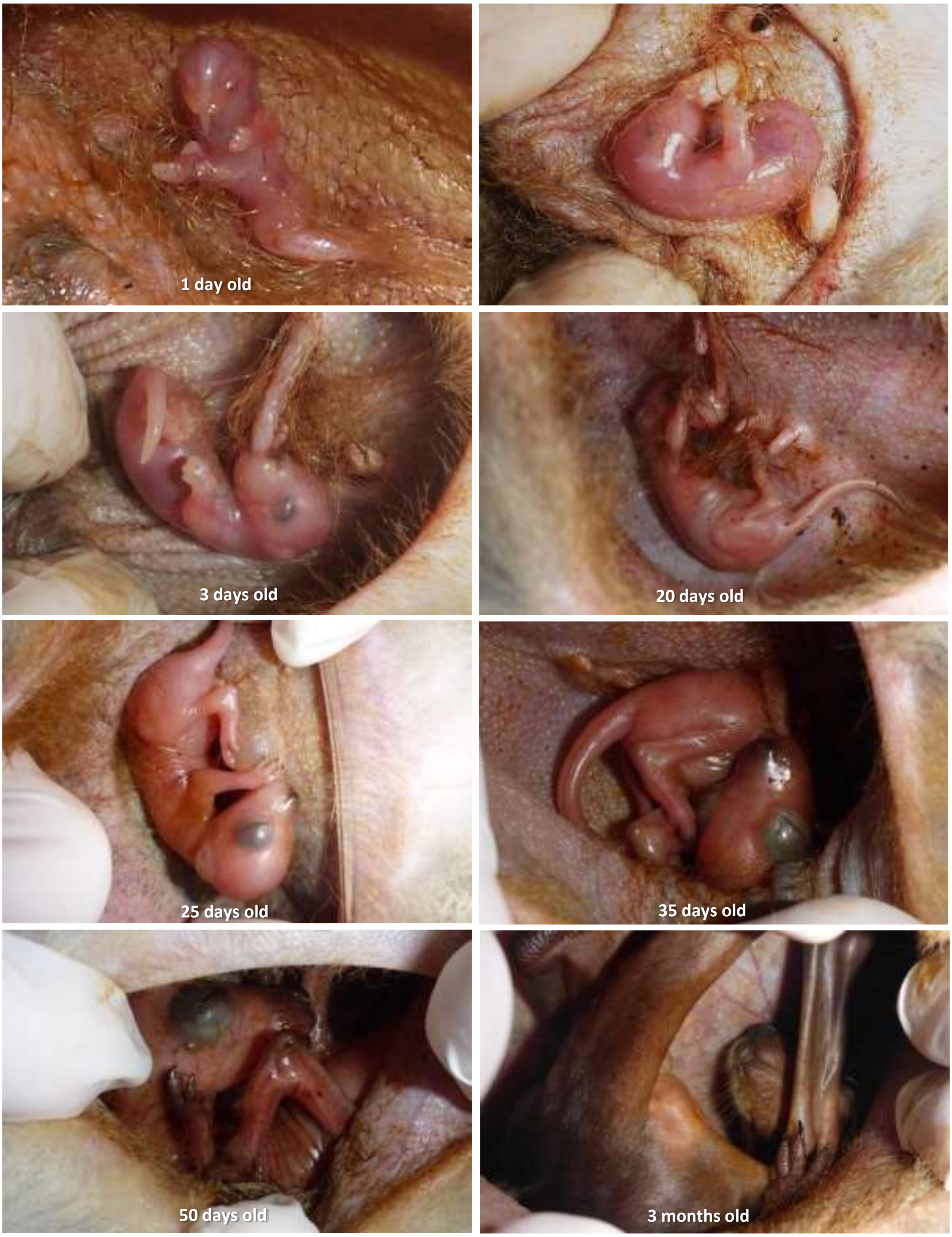
Picture 9 : Mucous plug on a YFRW female's cloaca
(© Benoît Quintard)

3) Development of the joey

At birth, joeys weight only a few grams. Around 130 days old, the pouch starts to be bigger and keepers can see a foot, an arm, the head or the tail of the joey outside it (*Picture 10*). Some weeks later the whole body of the joey can be seen.

Around 6 months old, the young wallabies start to explore their environment on their own and eat solid food. They sometimes go back to the pouch to drink milk and sleep. At one year of age, they are totally independent and they still spend some time near their mother.

Picture 10 : Female YFRW with joey (bumpy pouch, head out, head and forearms out)
(© Benoît Quintard)



Picture 11 : Different development stages in pouch of a YFRW joey (estimated ages)
(© Benoît Quintard)

4) Pouch-check

Pouch-checks are very important for the management of captive populations. It is very important to train females to be pouch checking to minimise any stress during this handling (see section2.5.1). Pouch-checks can be useful to:

- Determine the precise date of birth by measuring foot and tail by using a calliper and to compare with the tables. This will help compiling an accurate studbook with no discrepancies with physiological data,
- Sex the joeys (opening of the pouch for the females, testis for the males) (*Picture 12)*,
- Identify the joey when in pouch to be sure of affiliation,
- Perform population management by pouch management (pouch checking with euthanasia of a furless joey under 45 days old),
- Increase the number of females in the managed YFRW population,
- Limit the number of surplus males when there is lack of institutions for housing bachelor males.

Picture 12 : Sex identification of joeys in pouch: females (top left and right) and males (bottom left and right) (© Benoît Quintard)

5) Hand rearing

As YFRWs are prolific and breeding is not an issue in this species, hand rearing is generally not recommended. Very specific cases could be discussed with the EEP coordinator. It is really important to consider all possible negative effects before resorting to hand-rearing; the risks can be important, with the development of behavioural abnormalities. The situation must be monitored carefully, and the infant must go back to his group as soon as possible. In any case, contact the EEP coordinator before starting a hand rearing procedure.

6) Cross-fostering

Cross-fostering means cases of transfer from joey of one species to the pouch of another species of macropods. This technique can be considered as a viable option to raise young wallabies and as a tool to accelerate breeding in captive breeding programs, for species closely taxonomically related and of similar size. YFRWs are good candidates to receive joeys from other species as it has already been successfully done with *Petrogale penicillata* joeys (Taggart *et al.* 2005). This procedure can be practiced if the pouch check routine is well framed.

One anecdotical case of cross-fostering of a joey Goodfollow Tree Kangaroo has been described by McLelland *et al.* in 2015. This type of cross-fostering is generally not recommended and should only be emergency solutions as it may bring discomfort to the adoptive mother which might not support the entire growth of the cross-foster young.

5. Population management

In the past, the Yellow-footed rock wallaby in EAZA and AZA was managed as one population, but this has now been split. There is limited interest to continue with the species in AZA. The AZA population is decreasing, and AZA does not want to import new animals anymore.

The YFRW EEP population only represents 2% of all terrestrial diurnal macropods species held in European zoos and is one of the only wallaby/kangaroo species with a concerning IUCN status. The Monotreme and Marsupial TAG aims towards establishing a sustainable *ex situ* insurance population for the Yellow-footed rock wallaby in EAZA, as the species will benefit from having a second insurance population outside ZAA for the future in case of catastrophic events in the species' natural range.

In 2021, the EEP population is represented by 71 animals held in 10 zoological institutions. With 5 founders (supposedly not related), the genetic diversity is currently 84% (the inbreeding rate was relatively high with 0.17 due to the size of the founding population).

Keeping the species *ex situ* provides an important opportunity to engage the public with conservation education of marsupials in general. Education of the public should, wherever possible and feasible, be linked with fundraising activities for recommended *in situ* projects. There is cooperation in place with the Royal Society of South Australia for the protection of the Aroona sanctuary population. In 1996, this site received a reintroduction of a Yellow-footed rock wallaby population (12 animals) in the Flinders Ranges (the 1st macropod reintroduction in Australia). Since then, the work mainly focusses on population monitoring (more than 40 animals exist as of 2020), and pest control measures (mainly against foxes). It is important to maintain and intensify conservation efforts by implementing protective measures in the wild, and we hope that zoos will continue to give their support to this program.

6. Animal management

1) Animal training

Formal training for voluntary medical and husbandry behaviours is used in a wide variety of species and should also be considered for YFRWs. It consists of learning specific behaviours in order to improve animal wellbeing, increase positive interactions, decrease stressful situations, and avoid risks for the animals or care staff. It provides choice and control for the animals, to actively choose to voluntarily collaborate with the caregivers. Originally, medical training was mainly used with large mammals (e.g. elephants, rhinoceros, sea lions …). Nevertheless, it has been extended to other animals, including kangaroos and wallabies.

YFRWs are not easy to train because as a prey species they are shy and prefer to get out of the way. Keepers should take the time to desensitize the animal to their presence, including accepting reinforcement, and being handling. Animal training should use positive reinforcement. Positive reinforcement is the application of a desired consequence in order to effectively maintain or increase the likelihood that this specific behaviour will reproduce again, this through the addition of a motivating or enhancing stimulus such as a piece of food (for YFRWs peanuts are for instance a suitable reward), or a desired object.

A specific effort should be considered regarding female pouch-check training. This process should always be performed at a same specific location (*i.e* along the barrier of an indoor room). The first step would be to train females to remain at the same position, with body display. When this step is fully performed, the second step would be that females accept to be touched on their belly by the keepers/veterinarians. Then they should be desensitized on their pouch, by slowly opening it, training after training. It is a long but necessary process to minimize stress during pouch-checks. All these steps can be easily applicable on any kind of YFRW trainings, such as the target training.

Medical training can facilitate the daily routine examination but with time, the objective should be:

- Voluntary auscultation,
- Voluntary weighting,
- Voluntary pouch check.

Picture 13 : Medical training on an adult YFRW for voluntary weighting for voluntary weighting (© Besançon zoo)

2) Handling

YFRWs should ideally be trained to collaborate in their care, including the aforementioned behaviours. If this is not possible or in emergency situations, they should be captured in an indoor enclosure without any sharp item inside. Animals need to be handled by the basis of the tail. If needed, they can then be held gently around the neck and hind legs with the other hand. Other acceptable capture and restraint methods include capture bags, deep hoop nets, a race made of hessian. Keep in mind that YFRWs can bite and kick with their hind limbs. For any additional details on capture method, please feel free to contact the EEP coordinator.

YFRWs can show hyperthermia secondarily to a handling during high temperatures or excessive chasing that cause a rise in body temperature. Furthermore, they are highly susceptible to capture myopathy. The staffs need to be careful and experienced to avoid too long chasing before capture. Those should ideally be realized in small indoor rooms without escape and hiding places.

Prevention can also be achieved by Vitamine E and Selenium supplementation prior and post capture. Hyperthermia can be managed by using wet fresh towels and steroids (Miller, 2001). If possible, medical training should always be prioritized over physical restraint. Always keep in mind that for long procedures, anaesthesia is recommended to avoid prolonged negative stress.

Picture 14 : Handling methods of YFRWs
(© Benoît Quintard)

3) Transportation

Accordingly to the IATA regulations, an institution willing to transport an YFRW should:

- Plan well, prepare well and execute effectively the transport,
- Minimize the degree of stress for the animal,
- Make sure the animal cannot injure himself in the crate,
- Shorten the travel as much as possible (for long distance, air transport should be the first consideration).

The animal should always be checked by a veterinarian before the transport. The veterinarian will check the YFRW is fit for transport:

- It should not show any sign of external parasite, wound or contagious disease typical to the species,
- A female should not travel with a joey in the pouch,
- It should travel singly.

Those restrictions can be alleviated if the animal is transported under veterinary supervision or for or following treatment or diagnosis (*i.e*: the YFRW is being transported to receive specific examination or treatment)

YFRWs will ideally be transported in large vari-kennel-type crates. Those are soft plastic-roofed, which avoid risks of head trauma when jumps attempts are made by the animal. Bedding materiel should place in the crate (ideally wood chips covered by hay) to absorb urine emitted during the transport. Food and water containers should be affixed inside the crate and possibility to fill them (from outside) should be available for long transports. As those vari-kennels can be used as indoors shelters (*Picture 15*), YFRWs can be habituated to the crates they will be transported in before the travel.

Picture 15 : Large vari kennels used for transportation.
(© Michel Foos Parc Zoologique et Botanique de Mulhouse)

The crate should always be labelled with the following informations:
- Live animal,
- Up/Bottom,
- Feeding/watering instructions.

7. Animal welfare

We have an ethical responsibility to provide to animals in zoos suitable environments that allow them to express their naturel behaviours (Brando & Buchanan-Smith, 2018). Professional zoos and aquariums (henceforth zoos) have seen a significant evolution, today promoting birth to death (Seidensticker & Doherty, 1996) and “24/7 across lifespan” (Brando & Buchanan-Smith, 2018). Being professional means continuing to ask if this is the best that we can be, if this is what is in the best interest of the animal 24/7 and an ‘animal-first’ approach, and to achieve the goals of education, research, conservation, and recreation goals (Brando & Coe, in revision).

The terms “animal welfare” and “animal well-being” have both been used over the years (Moberg 2000, p. 1), to describe the state of the animal, and are used in this section interchangeably. Even if the term “animal welfare” has not always been used, people have long been aware that animals are affected by their environment, nutrition, housing and handling, social structure, and interactions with humans (Hemsworth & Coleman, 2010).

One major trend gaining global support is to consider the animals' lives in terms of the Five Domain Model (Mellor & Beausoleil, 2015). The Five Domain Model is at the core of the Animal Welfare Strategy of the World Association of Zoos and aquariums (Mellor, Hunt, & Gusset 2015). It concerns four physical/functional domains: nutrition, environment, physical health, and behaviour, and the mental domain. A major feature of this approach is that animal welfare must be assessed in an integrated and holistic manner.

1) Assessing animal welfare

Monitoring of animal behaviour is a long-standing tool used to measure zoo animal welfare and allow evaluating the effectiveness of environmental enrichment or reduction in stereotypic behaviour. Different software to monitor and evaluate animal behaviour and opportunities to understand animal welfare such as ZIMS Care and Welfare, ZOOMONITOR, Welfaretrak, and TRACKS can be used, as well as technologies such as dataloggers recording e.g., locomotion, sleeping, location, and social preferences.

Animal welfare approaches is based on the observations, knowledge, and skills of animal care staff, and relies heavily on the keeper's knowledge as they know the individuals better than anyone else.

2) Choice and control

It is essential to provide animals with choice and control to meet their own needs and preferences when they want to. There is considerable empirical evidence that not having control of one's environment leads to behavioural and physiological problems (e.g., Mineka & Hendersen, 1985; Perdue, 2014). Several studies have shown simply having choices, whether they are acted upon, is rewarding to animals (e.g., Owen *et al.*, 2005; Leotti *et al.*, 2010; Kurtycz, Wagner & Ross, 2014).

While research for the YFRWs in zoos is lacking, there are some examples from other species of wallabies which could be informative. For example, observation of wallabies showed that the ability to choose a preferred surface was influenced by visitors, and that this behaviour differed from morning to afternoon. The animals would use the ditches more over the preferred grass, and less time was spent near to the viewing platform. The authors reported that some animals increased stereotypies, stress, and aggressive behaviour towards visitors. Thus, further studies on wallabies are needed to understand human-animal interactions (Lockley & Leadbeater, 2005). While research will be helpful and important, it is important to create 'equal' spaces, such as grassy patches being available away from visitors.

Troxell-Smith *et al.* (2017) found that the presence of food patches increased foraging behaviour, reduced inactive behaviours, and increased within-exhibit movement in Parma wallabies (*Macropus parma*). The authors also reported with the food patches an increased staying time when more visitors were around.

Rendle *et al.* (2018) investigated the effects of mixed-species housing on the parma wallaby (*Macropus parma*) in two different housing systems: mixed species (MS), with Patagonian mara (*Dolichotis patagonum*), and single species (SS). The authors found that wallabies housed in the MS exhibit foraging significantly less than the SS group. MS wallabies utilised less of their enclosure, with a notable preference for areas not frequented by the mara and the wallabies in the MS enclosure performed agonistic directional urination, a novel behaviour, not observed in the SS group. The authors highlight that this is evidence of species incompatibility. The monitoring of mixed-species enclosures can prevent negative welfare states and aid in the successful maintenance of this species under human care.

Captive Bennett's wallabies (*Macropus rufogriseus*) were studied to understand the impact of exhibit design on their activity budget and spatial distribution (Beaudin-Judd *et al.*, 2019). Animal behaviour in two open exhibits (i.e., physical interaction between animals and visitors permitted) to two closed exhibits (i.e., physical interaction between animals and visitors prohibited) was compared and spatial distribution was recorded on exhibit maps. A significant increase in feeding and interactive behaviours in closed exhibits in comparison to open exhibits were found. Functional space use was similar between both designs, and resting, locomotion, and vigilance did not vary with design. The authors highlight to consider the effect of habituation may be relevant.

Different species of macropods were studied by Meade *et al.* (2021), including the red-necked wallaby (*Macropus rufogriseus*) and the swamp wallaby (*Wallabia bicolor*), aimed to investigate whether proximity to zoo visitors impacted these animals in a free-range exhibit in an Australian zoo. They studied four target behaviours: visitor-directed vigilance, retreat, resting, and foraging. They reported that the proportion of individuals of each species of wallabies foraging or retreating was unrelated to visitor number. They found as pedestrian visitor number increased that the proportion of individuals exhibiting visitor-directed vigilance significantly increased. The proportion of individuals that were resting was significantly negatively related to visitor number for both wallaby species (Meade *et al.*, 2021).

8. Veterinary: Considerations for wellbeing

1) Routine Health Inspections

a) Daily health observations

Daily observations of the animals by the keepers allow an early detection of diseases, fundamental in an everyday routine at the zoo. Animals need to be counted (they are often in big groups and tend to hide in rocks) to make sure they are all in the enclosure and in good health. The keepers should pay particular attention to 1) food and water consumption, 2) the faeces aspect, 3) the behaviours of the animals (at least once a day), 4) tensions in the group considering that they often lead to fight between the individuals resulting in bite wounds or traumas.

The keepers should be able to recognize each individual and be familiar with the specific behaviour of each of them. They must report every day to the veterinarian department all unusual sign they can see and should also write it down in a report to keep a track of it.

b) Annual physical examination

Veterinarians should undergo health checks every time a YFRW is captured (for a pouch check for instance) or anaesthetized. During this physical examination it is recommended to check first the vital signs (HR, RR, temperature). Then, a complete physical examination can be performed: teeth, oral cavity, ears, eyes and skin. Vets should also weight the wallaby and estimate its body condition score. Body condition score can be estimated by palpation of muscle +/- fat covering thorax and pelvic region and by evaluating the vertebra coverage on the tail (*Figure 8*).This evaluation leads to a score from 1 (very underconditionned) to 6 (severely overconditionned). The perfect body condition score is 3/6.

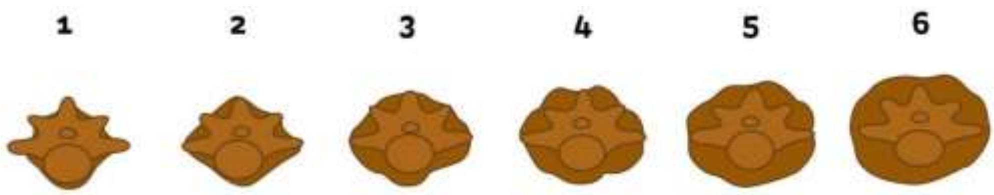


Figure 8 : Body scoring for YFRW on tail vertebras (After S Jackson, 2004)

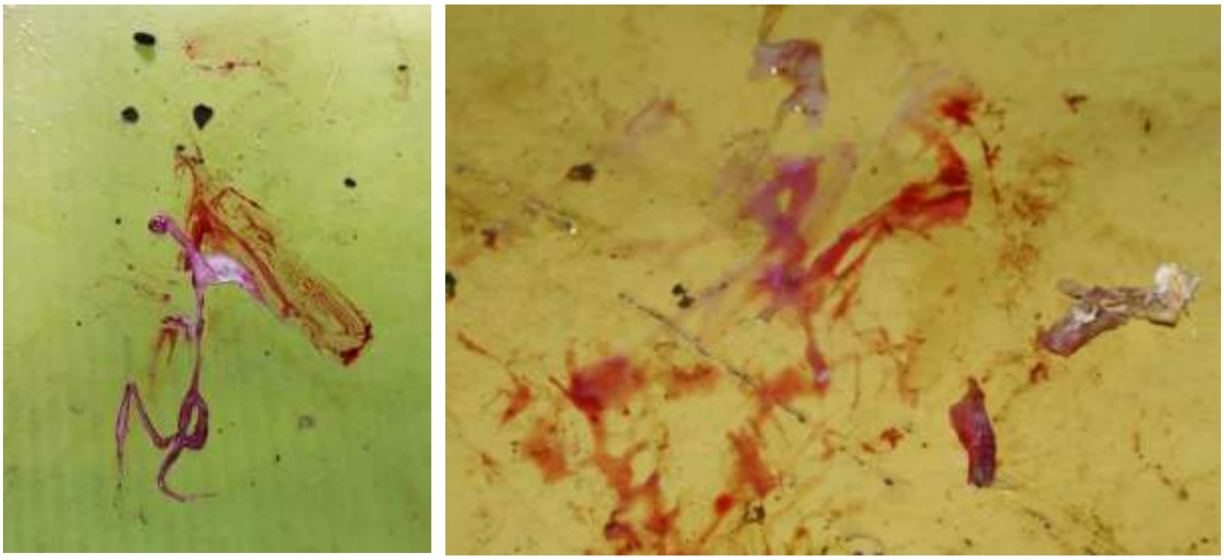
Colour of the mucosa and the capillary refill time should also be checked as well as a complete cardio-respiratory auscultation and an abdominal palpation. When thoracic abnormalities such as murmurs, wheezes, or crackles are detected, thoracic radiography, echocardiography, or an electrocardiogram should be performed, depending on the abnormal clinical sign. Likewise, a complete abdominal ultrasound can be performed especially to check the kidneys, spleen and liver. Blood can be collected for serum chemistry profile and complete blood count, and to store some samples in case of further studies or tests need. The EAZA has also established dedicated biobanking facilities for the European and Middle Eastern zoos: please consider sending them samples when available. It is important to perform complete blood count and serum chemistry profile once a year in order to have values of each individual to refer to if needed. Entering those results in ZIMS for medical database allows implementing the values of the species and so the expected intervals become more and more accurate.

Picture 16 : Different health checks on YFRW individuals: dental check (top left), routine pouch check (bottom left), cardio-respiratory auscultation (right)
(© Benoît Quintard)

c) Signs of illness

As other wild animals, YFRWs tend to hide their symptoms. The first signs observable by the keepers will be: reduced food intake, smooth faeces, blood in the enclosure, self-isolation, prostration, changes in locomotion. Once again, daily routine observation is fundamental in order to detect the first signs as early as possible. Wet forearms could for example be a sign of stress compatible with a lumpy jaw. As soon as one of these signs is observed it must be reported to the veterinarian and monitored as long as necessary.

N.B.: sometimes blood with mucous can be found on the floor of the enclosure (see *Picture 17*). This mucous plug is emitted by the female at the beginning of parturition.



Picture 17 : Mucous stopper emitted by the female before parturition
(© Benoît Quintard)

d) Medical training

Given the BPGQ only 20% of the European holders are currently practicing medical training with YFRWs, it is still possible and done in some institutions. Medical training on this species can be challenging being a prey species. Often the animals do not come close enough so a detailed training plan can aid in creating positive interaction, facilitating learning and the training to receive a reward from the caregiver directly. Medical training can also be instrumental in the management of aging animals, and in preventive care.

Initiating medical training with wallabies is highly recommended because it will increase positive welfare in the animals by reducing negative stressors. Training such as entering a crate, going on a scale, showing teeth, feet and tail or staying still for pouch examination can reduce the need to handle and capture the animals. It facilitates the routine examination, weigh control and pouch checks as well as early diagnosis of diseases. It increases trust and positive interactions between wallabies and care staff and are enjoyable for all.

e) Records

Medical records for each individual should be written down. Using an online database like ZIMS, to record medical history is highly recommended and very common in zoological institutions. A first basic record needs to include: Birth date and birth location, sex, name, species, local identifier, studbook number, transponder number, breeding status, parents, siblings, descendants and location in the facility. Then, aside of this basic record, medical history should include any information about the animal: weight (regularly updated), annual examination dates and remarks, every symptoms or unusual behaviour observed by the keepers, every samples / test results / treatment used, any anaesthesia records (including method used, vital signs values), complementary exams performed (radiographs, ultrasounds …). If it is a female all pouch-check notes and remarks have to be recorded.

It is also important for the keepers to write down every change realized in the enclosures and every time something different is proposed to the animals (like enrichment for instance).

2) Clinical techniques

a) *Identification*

The identification method used for the YFRW is transponders / microchip. They are permanently implanted subcutaneously between the shoulder blades (*Picture 18*). To ensure filiation, joeys can be implanted when they are still in the pouch of the mother as early as 3 months old. Transponders provide accurate identification when the animal is in hand, but do not help when trying to ID an animal in a group. Special features like facial markings (*Picture 20)* and pictures can be used by the keepers in order to identify each individual without having to hand capture it and read the transponder. Other type of identification such as ear tags can be used (*Picture 19*) but are not recommend by the EEP as special features are enough and harmless.

Picture 18 : Microchip reading on a young (left) and on an adult (right)
(©Michel Foos - parc Zoologique et Botanique de Mulhouse)

Picture 19 : Putting up a microchip on a young YFRW (left); ear tag on an imported YFRW (right)
(©Michel Foos - Parc Zoologique et Botanique de Mulhouse)

Picture 20 : Facial marking can help recognize individuals
(© Camille Mougin)

b) Anaesthesia

Usually fully conscious animals can be masked down with Isoflurane and oxygen if physical restraint is adequate. This method is good for short procedures when the animal can be released back into the enclosure in a timely manner. It is a safe method that does not include any chemical injection (Miller, 2001). However chemical protocols can be found bellow in case gas anaesthesia cannot be performed.

Chemical restraint protocols available:

- Dexmedetomidine (0.03mg/kg) + Ketamine (3.75mg/kg) + Midazolam (0.16mg/kg) IM (ZIMS)
- Medetomidine (40-125µg/kg) + Ketamine (3-5mg/kg) IM (ZIMS)
- Tiletamine + Zolazepam (2-3mg/kg) IM + medetomidine (40µg/kg) IM (Vogelnest & Woods, 2008)
- Alfaxolone (5-8mg/kg) IM, (1.5-3mg/kg) IV (Vogelnest & Woods, 2008)

Alpha-2 agonists are reversed with atipamezole (5 times the medetomidine dose IM) at least 30 to 45 minutes after injection if ketamine or tiletamine/zolazepam is used.

After induction, anaesthesia can be maintained by face mask but the animal should probably be intubated (*Picture 21*). Intubation is difficult due to the narrow gape and the dental arcade that makes visualization of glottis difficult.

Picture 21 : Intubation technique: maximal extension of the head in order to see the tracheal opening.
(© Benoît Quintard)

It is important to closely monitor an animal under anaesthesia in order to quickly detect any adverse effect (*Picture 22)*. Heart rate, respiratory rate, temperature, oxygen saturation, blood pressure and end-tidal C02 are some of the most important parameters to monitor at least every five minutes. The values should be written down on an anaesthesia sheet and after entered into ZIMS for medical.

Picture 22 : Monitoring on an anesthetized animal with a pulse oximeter (left) and a stethoscope (right) (© Benoît Quintard)

c) Injections, treatments' administration

YFRWs are herbivorous and therefore drugs required to have a systemic effect generally have improved absorption if not administered PO. Some drugs administered orally may bind to fibrinous ingesta rather than crossing the small intestinal wall into the circulation (Vogelenest & Portas, 2019). This is why it is recommended to use injectable antibiotics (Miller, 2001). IV injection can be performed via a catheter on different veins (see next paragraph). Very little pharmacological research has been done on macropods so published dosages are largely extrapolated from other species, and supported by anecdotal evidence of safety and apparent efficacy (Vogelenest & Portas, 2019).

d) Venipuncture

The most commonly used site for venepuncture is the lateral caudal vein or the ventral caudal vein (*Picture 23*). It is located at the base of the tail at the midpoint of the lateral aspect. Digital pressure or tourniquet can be used to occlude the vein. Likewise, when a catheter needs to be placed, it is usually done on the lateral caudal vein (*Picture 24*). This site can be used even on manually restrained animals. The femoral vein is also an easy site for venepuncture on anesthetized animals.

Picture 23 : Ventral tail vein punction site (left) and lateral caudal vein punction site (right) (©Michel Foos - Parc Zoologique et Botanique de Mulhouse)

Picture 24 : Catheter on the lateral caudal vein on an anesthetized YFRW.
(© Benoît Quinatrd)

e) Haematology and Biochemistry

Haematology results for YFRWs are largely similar to those of other marsupials (Lapidge, 2001). YFRW WBC counts are similar to those of *P. assimilis*, but slightly higher than those of other macropods (Lapidge, 2001). Higher WBC counts in Petrogale species may rather be an evolutionary adaptation to sedentary existence or isolation and may help prevent disease epidemics, which could potentially drive small isolated populations to local extinction. This explanation is supported by high WBC counts observed in other sedentary marsupials with a restricted distributional range, such as Southern Hairy-nosed Wombats (*Lasiorhinus latifrons*), Quokkas (*Setonix brachyurus*) and Tasmanian devils (*Sarcophilus harrisii*) (Lewis et al. 1968; Parsons et al. 1971a; Lapidge, 2001). In contrast, species with wide distributional ranges have relatively low WBC counts (Parsons et al. 1971a). Spencer and Speare (1992) suggested that Petrogale species have high WBC counts because they live in crowded colonies in the wild. Higher WBC counts post-release, where colonies were not crowded, do not support this idea. Haematology results for YFRWs are not dependent on age or gender. Haemoglobin and Red blood cell (RBC) counts were higher in summer and winter than autumn and spring for YFRWs.

Studies on broad-spectrum plasma biochemistry of marsupials are rare, although analysis of protein or albumin is more common (Lapidge, 2001). Plasma biochemistry results for YFRW generally showed similar values to other marsupials except urea and cholesterol. YFRW has the highest recorded urea and cholesterol concentrations for a macropod (Lapidge, 2001), and is more similar to *L. latifrons* which occupies a similar climatic environment (Lapidge, 2001).

Table 5 : Hematological normal values in yellow-footed rock wallabies (*Petrogale xanthopus*) (ZIMS, 2021)

Test	Units	Reference interval	Mean	Median	Lowest Data value	Highest Data value	Sample size	Animals
Red Blood Cell count (aut.)	*10^12 cells/L	3.71 - 6.70	5.29	5.30	1.68	7.50	842	308
Red Blood Cell count (man.)	*10^12 cells/L	4.00 - 6.57	5.41	5.50	4.00	6.58	43	25
Hemoglobin (aut.)	g/L	13 - 192	132	150	2	215	914	325
Hematocrit (aut.)	L/L	0.313 - 0.600	0.464	0.466	0.148	0.670	833	301
Hematocrit (man.)	L/L	0.255 - 0.580	0.439	0.440	0.130	0.620	289	128
MCV (reported)	fL	74.8 - 99.0	87.5	88.0	63.0	107.0	313	125
MCV (calc.)	fL	75.2 - 95.5	86.9	87.3	67.5	103.4	490	226
MCH (reported)	fmol	1.30 - 2.11	1.79	1.80	1.12	2.45	327	114
MCH (calc.)	pg	24.7 - 33.3	28.9	28.9	20.3	39.3	409	209
MCHC (reported)	g/L	281 - 383	331	331	241	439	276	110

MCHC (calc.)	g/L	290 - 375	330	330	262	405	476	218
Red Cell Distribution Width (aut.)	%	14.0 - 18.8	15.7	15.5	13.6	19.1	211	87
Nucleated Red Blood Cells (aut.)	/100 WBC	0 - 6	1	1	0	8	142	107
Nucleated Red Blood Cells (man.)	/100 WBC	N/A - N/A	0	0	0	4	27	12
Reticulocyte percentage (man.)	%	0.0 - 9.9	3.4	3.0	0.0	10.0	42	15
Platelet count (aut.)	*10^12 cells/L	0.029 - 0.342	0.146	0.128	0.001	0.486	564	252
Mean Platelet Volume (aut.)	fL	6.2 - 9.4	7.3	7.2	6.0	10.0	226	79
White Blood Cell count (aut.)	*10^9 cells/L	2.7 - 14.1	6.6	6.2	0.4	18.3	892	326
White Blood Cell count (direct.manual)	*10^9 cells/L	2.69 - 14.02	6.63	6.20	0.36	17.93	909	326
Estimated White Blood Cell count (man.)	*10^9 cells/L	2-14	5	5	2	14	68	33
Lymphocyte % (aut.)	%	9.2-74.9	37.7	35.9	1.4	84.6	246	97
Lymphocyte % (man.)	%	9.7-88	49	50	0	95	630	265
Lymphocyte absolute count (calc.)	*10^9 cells/L	0.56-6.912	2.858	2.544	0.071	10.168	642	264
Monocyte % (aut.)	%	0-9.3	3	2.2	0	11.4	244	96
Monocyte % (man.)	%	0-8.8	2.3	2	0	10	586	260
Monocyte absolute count (calc.)	*10^9 cells/L	0.022-0.777	0.199	0.124	0	0.941	525	230
Segmented neutrophil percentage (aut.)	%	14.1-86.4	55.9	59	3.3	88.2	243	96
Segmented neutrophil percentage (man.)	%	9-84.4	45.6	45	0	94	612	262
Segmented neutrophil absolute count (calc.)	*10^9 cells/L	0.501-8.953	3.147	2.527	0.156	11.365	634	264
Eosinophil % (aut.)	%	0-6.9	1.8	1.3	0	9.3	242	96
Eosinophil % (man.)	%	0-8.5	2.4	2	0	12	575	254
Eosinophil absolute count (calc.)	*10^9 cells/L	0-0.5	0.148	0.112	0	0.62	546	243
Basophil % (aut.)	%	0-1	0.2	0.1	0	1.2	237	95
Basophil % (man.)	%	0-1.5	0.3	0	0	3	471	221
Basophil absolute count (calc.)	*10^9 cells/L	0-0.127	0.031	0.019	0	0.16	271	127
Band form neutrophil percentage (aut.)	%	0-60.7	2.8	0	0	81	187	115
Band form neutrophil percentage (man.)	%	0-2	0.1	0	0	6	144	100

Table 6 : Biochemistry normal values in yellow-footed rock wallabies (*Petrogale xanthopus*) (ZIMS, 2021)

Test	Units	Reference interval	Mean	Median	Lowest Data value	Highest Data value	Sample size	Animals	Sample
Sodium (aut.)	mmol/L	134 - 155	143	143	133	159	111	63	P
Sodium (aut.)	mmol/L	130 - 154	144	144	123	165	402	213	S
Potassium (aut.)	mmol/L	2.6 - 9.0	4.4	3.9	2.3	9.4	102	61	P
Potassium (aut.)	mmol/L	2.9 - 7.8	4.9	4.6	2.5	11.3	394	210	S
Na:K ratio (reported)	ratio	10.1- 50.1	30.9	30.0	7.7	57.0	196	132	S
Na:K ratio (reported)	ratio	10.8- 49.8	31.2	30.0	7.7	57.0	208	141	S or P
Na:K ratio (calc.)	ratio	17.2- 46.0	31.2	30.9	13.5	60.9	152	96	S or P
Na:K ratio (calc.)	ratio	17.1- 45.7	31.0	30.9	13.5	51.0	137	90	S
Chloride (aut.)	mmol/L	92 - 110	100	100	89	111	64	42	P
Chloride (aut.)	mmol/L	90 - 109	99	99	81	112	330	176	S
Total Carbon Dioxide (aut.)	mmol/L	5.0 - 30.0	17.8	18.0	3.0	32.0	217	142	S or P
Total Carbon Dioxide (aut.)	mmol/L	4.5 - 30.0	17.3	17.0	3.0	32.0	180	124	S
Anion Gap (reported)	mmol/L	18.0- 58.0	37.1	36.1	13.0	60.0	132	96	S
Anion Gap (reported)	mmol/L	18.0 - 58.0	37.1	36.3	13.0	60.0	133	97	S or P
Calcium (colorimetry.auto.)	mmol/L	1.9 - 3.0	2.4	2.3	1.7	3.1	128	70	P
Calcium (colorimetry.auto.)	mmol/L	1.9 - 3.0	2.4	2.4	1.5	3.2	432	220	S
Phosphorus (colorimetry.auto.)	mmol/L	0.91 - 3.22	1.90	1.82	0.68	3.42	122	66	P
Phosphorus (colorimetry.auto.)	mmol/L	0.96 - 3.47	2.03	1.91	0.72	4.90	425	227	S
Ca:P ratio (calc.)	ratio	0.9 - 3.4	1.7	1.6	0.6	4.1	332	186	S
Ca:P ratio (calc.)	ratio	0.9 - 3.4	1.8	1.6	0.6	4.1	364	193	S or P
Magnesium (aut.)	mmol/L	0.62 - 1.44	0.97	0.96	0.62	1.44	53	43	S
Magnesium (aut.)	mmol/L	0.62 - 1.43	0.93	0.90	0.62	1.44	85	58	S or P
Glucose (colorimetry.auto.)	mmol/L	0.51 - 10.81	6.17	6.16	0.00	14.65	443	232	S
Glucose (colorimetry.auto.)	mmol/L	0.60 - 10.00	5.83	6.05	0.40	11.49	127	71	P
Urea Nitrogen (colorimetry.auto.)	mmol/L	5.4 - 16.2	11.0	11.0	3.2	22.0	443	235	S
Urea Nitrogen (colorimetry.auto.)	mmol/L	5.2 - 16.2	10.0	10.0	4.6	20.7	132	73	P
Creatinine (aut.)	µmol/L	27 - 233	93	97	27	248	111	68	P
Creatinine (aut.)	µmol/L	48 - 180	106	106	8	221	443	235	S
Urea	ratio	10.9 - 42.1	25.5	24.0	9.0	49.0	116	67	S or P

Nitrogen:Creatinine ratio (reported)									
Urea Nitrogen:Creatinine ratio (reported)	ratio	11.7 - 42.3	25.5	24.0	9.0	49.0	106	63	S
Urea Nitrogen:Creatinine ratio (calc.)	ratio	51.6 - 174.3	106.6	102.2	17.0	208.8	349	199	S
Urea Nitrogen:Creatinine ratio (calc.)	ratio	52.3 - 183.6	108.3	103.2	17.0	229.0	380	207	S or P
Uric Acid (aut.)	µmol/L	9-79	32	26	9	79	40	22	P
Uric Acid (aut.)	µmol/L	9-93	37	30	9	97	57	31	S or P
Alanine Aminotransferase (aut.)	U/L	8-55	23	20	5	64	117	67	P

f) Euthanasia

Euthanasia must be performed by a veterinarian and the molecules need to be kept in a locked safe. Before euthanasia the animal needs to be anesthetized for welfare reasons and in order to properly perform the intravenous injection. The injection is usually done in one of the tail vein via a catheter. The injection needs to be strictly intravenous since it can cause tissue necrosis and pain if injected perivascularly. If the injection cannot be intravenous other ways like intracardiac, intrarenal or intraperitoneal could be used but shouldn't be the first choice. The most common solutions are saturated sodium pentobarbital or tetracaine solutions.

g) Necropsy

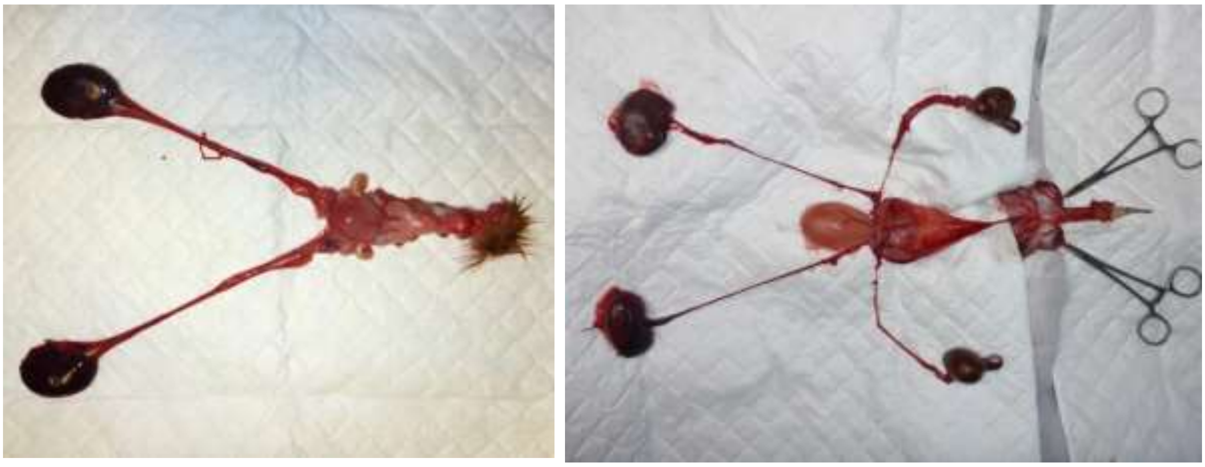
All animals which die in the zoo should be necropsied. The sooner the necropsy is performed the better it is to collect samples and to establish a proper diagnosis. If the necropsy cannot be performed right away, the body needs to be kept in a fridge to reduce the post-mortem autolysis process. Necropsy is first of all a good way to understand the circumstances of death and is also used by zoo veterinarians to monitor infectious diseases.

Necropsies need to be performed by an experienced veterinarian or pathologist following a strict safety protocol. They should be performed in a dedicated room, with proper protective measures (gloves, cleanable boats, lab coat). When a contagious process is suspected, those measures need to be strengthened (safety googles, facemask, shoe cover, disposable gowns …). The room and the equipment need to be cleaned then disinfected between every necropsy. The body need to be double-bagged and sent for incineration. The body can be stored in a -20°C freezer before the collect of the incineration company.

During each necropsy, pictures of all organs (normal or abnormal) have to be taken and samples of all normal or abnormal tissues should be stored at -20°C or in formalin in a bank for further analysis or research. At least heart, lung, liver, spleen and kidney should be sampled and stored routinely and be made available for the EAZA biobank. All the tissues and organs should be visually evaluated, measured, cut and palpated to avoid unseen lesions. A report must be written down and recorded in ZIMS. When the cause of death is not obvious at gross inspection, samples of every tissue in formalin need to be sent for histological analysis. It can also be performed routinely if your facility can afford it. Furthermore, when an infectious process is suspected samples need to be collected for bacterial / parasites / fungal or viruses screening depending on the suspicion of the veterinarian or pathologist.

Picture 25 : Necropsies of YFRW: epipubic bone which can be observed in males and females (left) and abdominal organs after opening the abdominal wall (right)
(© Benoît Quintard)

Picture 26 : Necropsies of a normal spleen with two tails (left) and a complete digestive tract (right)
(© Benoît Quintard)



Picture 27 : Necropsies of the urogenital tract of female (top left) and male (top right), and the three-part vagina (bottom left) in YFRW
(© Benoît Quintard)

3) Preventive health

a) Parasites management

Faecal examinations should be conducted routinely, at least twice a year and preferably in fall and spring to monitor parasite loads, and also every time it is necessary (diarrhea, loose stools …). If any pathologic parasite or bacteria is reported then appropriate treatment must be undertaken (the most common and safe treatments is ivermectin 0.2mg/kg once SC) and a control coproscopy realized at the end of the treatment. Treatment with febendazole must not be used for de-worming macropod because it depletes neutrophils in the blood causing septicaemia most often in the respiratory tract (Speare *et al.*, 2004). It is not recommended to treat routinely against parasites without doing any faecal check to prevent appearance of new parasite resistances against anthelminthic.

Maintaining a healthy environment is the best way to avoid disease problems (Miller, 2001). Since a lot of parasites pass on between the individuals via faeces, a complete daily cleaning of the enclosure allows stopping the spread in the group and prevent recontamination.

External parasites such as flies or ticks may represent a threat for YFRW especially because they can transmit diseases. A parasite management and preventive treatment can be undertaken mostly during risk periods.

b) Vaccination / Immunizations

No vaccination is mandatory in YFRW and 90% of the European holders do not use vaccination according to the BPGQ. However immunization against tetanus is available in some European countries and recommended in risk areas. YFRW can also be vaccinated against rabies with an inactivated vaccine and against *Bordetella bronchiseptica* with canine vaccine. Finally an intranasal toxoplasmosis vaccine is under trial (innocuousness is already demonstrated) (*Picture 28)*.

Picture 28 : Intranasal toxoplasmosis vaccine administration
(© Benoît Quintard)

c) "Pest" control

A lot of diseases as yersiniosis or toxoplasmosis for instance can be prevented by controlling the access of rodents, feral cats or cockroaches to the enclosure. Furthermore, young or diseased YFRWs are vulnerable to predation by foxes.

Pest control consists in maintaining a clean environment, limiting the access of food and food waste and limiting potential shelters. Special fences (electric fences for example) can be used especially to avoid contacts with big mammals like feral cats and foxes. For rodent traps or poison can be used to control their spread. The poison needs to be placed somewhere the wallabies or the animals of the zoo cannot eat it. It has to be used with great caution since some animals of the zoo can predate those rodents and eat them after they poisoned themselves. If traps are used they need to be controlled regularly.

While transmission of disease needs to be monitored and prevented, attention to the wellbeing of undesired animals need to be considered. Methods of control need to be humane and suffering of any kind must be prevented at all times.

d) *Quarantine & Introduction*

Before a transfer some tests need to be performed in order to make sure the animal is in good health and doesn't represent a threat for the other wallabies from its future group. The complete medical history as well as relevant group medical history has to be sent to the receiving zoo. Beyond any national and legal test requirements, the recommended tests to be performed before a transport can include:

- Faecal analysis for bacteria (including *Salmonella, Campylobacter, Shigella, Yersinia*) and parasites with faeces collected on three days,
- General health check with biochemistry and complete blood count,
- *Toxoplasmosis* serology can be useful to know the status of the animal

Those tests should ideally be performed within 30 days before shipment and appropriate treatment has to be realized before departure. Once the new individual arrives in the receiving zoo, quarantine can again be performed and then it has to be introduced gradually into the group see section 2, 3.3).

e) *Infirmary*

When an YFRW is severely injured or affected by a disease it is often isolated away from the group in order to ease the treatment. The best way to do it is to block out a space inside the original enclosure where it can be isolated, to reduce its activity but still allow it to see and hear its group. Indeed, if an YFRW is isolated in the veterinary clinic it will cause high stress levels and darken the prognosis of recovery. It can also trigger some pathologies that are linked to stress in YFRWs like capture myopathy or cardiac failure. The sooner an individual can return to the group the better this is for its welfare.

f) *Mixed-species exhibits*

Mixed-species exhibits have become standard practice amongst zoos worldwide with a wide range of taxa being successfully managed this way (Clark & Melfi, 2012). YFRWs can be presented in mixed exhibits with other macropods like red kangaroos, walaroos, parma wallabies, swamp wallabies, red-necked wallabies … but also with other species such as birds (see section 2, 3.4). A successful combination of species can be both enriching and greatly improve breeding prospects (Hosey *et al.*, 2013). Species compatibility requires high consideration, as this can have an influence on animal well-being and welfare.

Mixing can also have sanitary consequences: for instance when they are mixed with a fish-eating species it increases the risk of erysipelas infection to which YFRWs are susceptible.

4) Overview of diseases in yellow-footed rock wallabies

Lumpy jaw is the most important health problem for macropods in captivity (Muranyi, 2000), however it is not the case in YFRWs since they seem less predisposed to this disease and therefore only few cases are reported in this species (Rendle, 2019). On the other hand, diseases like toxoplasmosis and capture myopathy are really important in number of incidents.

On the ZIMS database (see *Table 7* and *Figure 9*) we can see that parasite infestations are the most represented diseases in captive YFRWs followed by wound problems: Bites, laceration, abrasion, cage mate, dental diseases, traumas and finally nephrolithiasis.

Table 7 : Petrogale xanthopus morbidity and mortality analysis (Zims, 2021)

Medical Problem	Total Diagnoses	Resolved Medical Issues				Currently Active Issues			
		Diagnoses	Duration (days)			Diagnoses	Duration (days)		
			Mean	Median	Range		Mean	Median	Range
Parasite Issues	103 (76 animals)	88 (65 animals))	432	366.5	0-1833	15 (15 animals	4465	4148	2168-6981
Wound problems	14 (14 animals)	13 (13 animals)	73	11	0-379	1	62	62	62-62
Dental disease	12 (11 animals)	11 (10 animals)	58	21	1-296	1	698	698	698-698
Trauma	12 (9 animals)	12 (9 animals)	23	21.5	0-59	0	N/A	N/A	N/A
Nephro-lithiasis	8 (7 animals)	5 (4 animals)	413	54	0-1558	3 (3 animals)	745	753	652-832

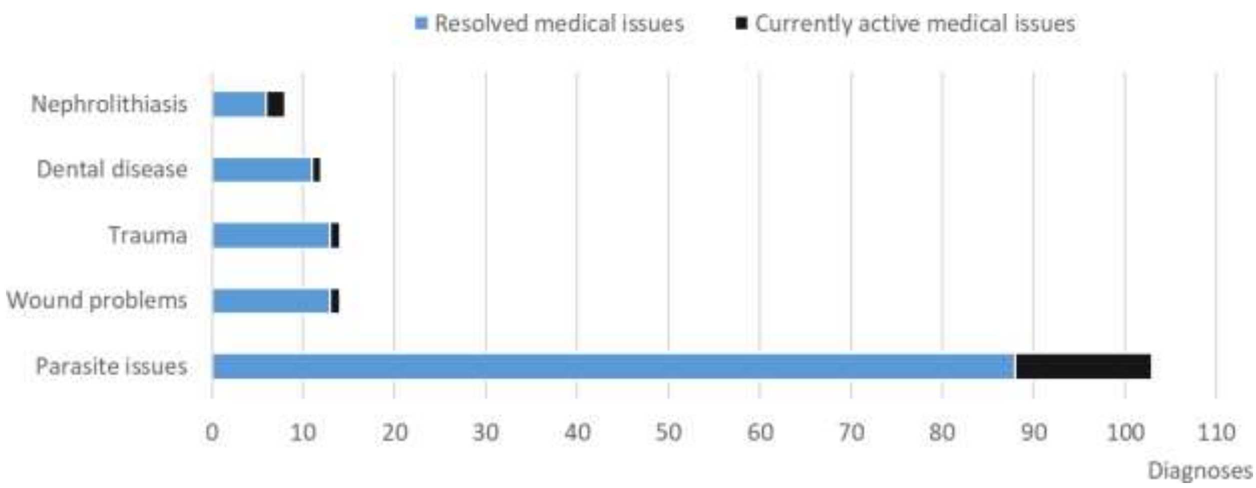


Figure 9 : Overview of diseases in Petrogale xanthopus in ZIMS medical (ZIMS, 2021)

In preparation for the reintroduction of *P. x. xanthopus* to Aroona Sanctuary, Conaghty and Schultz (1998) surveyed diseases in captive and wild *P. x. xanthopus* and found little variation in microflora and parasite loads (100% had *Salmonella,* 30% *Eimeria spp.*), with no pharmacological intervention deemed necessary in preparation for release. All serological tests for Macropodid Herpesvirus (MHV), Wallal virus and Toxoplasma in captive *P. x. xanthopus* and three wild animals were negative. Skin scrapings and hair samples of captive YFRWs revealed *Aspergillus versicolor* and *Heterodoxus ampullatus* present at low levels. Both are known to be common in wild YFRWs (Conaghty & Schultz 1998). Ecto-parasites were observed on 29% of animals before release, but they are known to be common on captive and wild macropods (Speare *et al.* 1989; Conaghty & Schultz 1998).

In the following part non-infectious and infectious diseases will be described. Some are well known and described in YFRWs but some are not and are thus extrapolated from what is known on other macropods.

5) Non-infectious diseases

a) Traumatic injuries

Traumatic injuries tend to be common in YFRWs first of all because of conflicts in the group, especially between males or because of poorly designed facilities. Great care should thus be paid in group composition and exhibit design. Those conflicts can lead to bite or claw wounds that can be from superficial to severe. YFRWs are also susceptible to head traumas, fractures or vertebral luxation caused by falls. Facial injuries are common and can be associated with soft tissue damages or mandible and/or maxilla fracture. The origin of a traumatic injury needs to be found in order to prevent it in the future. Secondary bacterial infection especially for facial injuries are common and soft tissue cellulitis, necrosis and osteomyelitis are common sequelae (Vogelnest & Woods 2008).

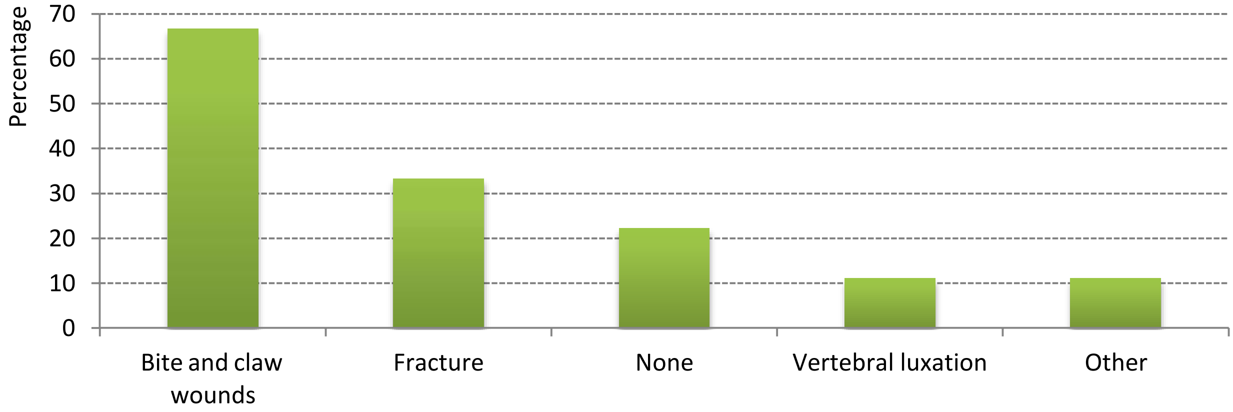


Figure 10 : Traumatic injuries reported by European holders of YFRWs (BPGQ)

Traumatic injuries treatment depends on the gravity of the lesions. For mild cases, local disinfection and use of non-steroidal inflammatory drugs are often enough to ensure recovery. In more severe cases, surgery under anaesthesia is often indicated.

b) Skin pathologies

The majority of skin pathologies in YFRW are caused by infectious agents (Herpesvirus, Dermatomycoses) or by traumas.

Cutaneous neoplasms are also frequent skin pathologies in older Macropods, and like squamous cell carcinomas affecting generally the pinnae and nasal planum. Definitive diagnosis is achieved by submitting biopsy tissue from the lesion for histopathology. Surgical excision can be undertaken if lesions are detected early enough (Vogelnest & Woods 2008). Like any other species, YFRWs can have cysts (see *Picture 29*) or warts that can be surgically removed if it bothers the animals or create lesions. Stress-linked alopecia (linked to overgrooming or not) can be observed in adults. Hand-reared PY can also be affected by xeroderma and stress or physiological alopecia (Vogelnest & Woods 2008).

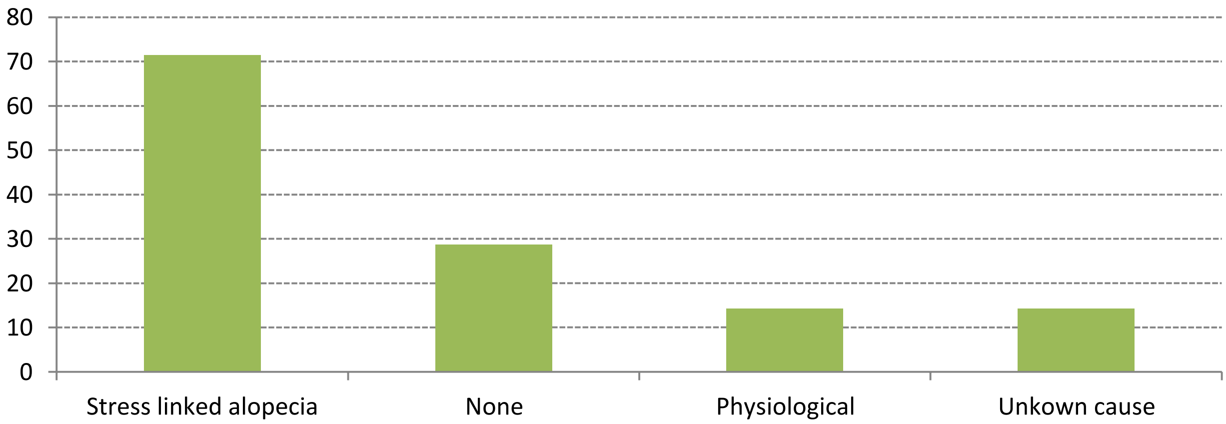


Figure 11 : Skin pathologies ever reported by European holders of YFRWs (BPGQ)

Picture 29 : Mammary cyst on a female YFRW
(© Benoît Quintard)

c) Dental diseases

As described in part 7.3) dental diseases are common in YFRWs. Periodontal disease occurs in both captive and free-ranging animals. Clinical signs include scale accumulation, gingivitis, gingival recession and periodontitis. Scale in captive animals tends towards large amounts of soft crumbly plaque (see *Picture 30*). Risk factors for scale accumulation and periodontal disease are first the diet (see *section 2. 2.*), excessively fibrous hays and hays containing sharp awed grasses should be avoided but scale accumulation also seems to be individual dependent (Vogelnest & Woods, 2008).

These lesions can be seen on a routine oral cavity examination. Removal of calculus via ultrasonic or hand-scaling is indicated. In severe cases parenteral antibiotic therapy is often indicated. Dental abscesses are also frequent in macropods; surgery is often indicated for surgical debridement of the abscess and sometimes dental extraction (Vogelnest & Woods, 2008).

Picture 30 : Severe scale formation on all teeth of an old YFRW
(©Michel Foos - Parc Zoologique et Botanique de Mulhouse)

d) Cardiovascular

Cardiomyopathy can occur in YFRW secondary to *Toxoplasma gondii*-induced myocardial necrosis / exertional and nutritional myopathies and encephalomyocarditis virus infection (Vogelnest & Woods, 2008). Cardiac failures are rare but can be caused by capture myopathy (see *section 2, 7. 4) g)*), severe shock, overdose of immobilization drugs or intense stress level. Preventing those causes is a good way to prevent cardiac failures (Miller, 2001).

e) Gastro-intestinal diseases

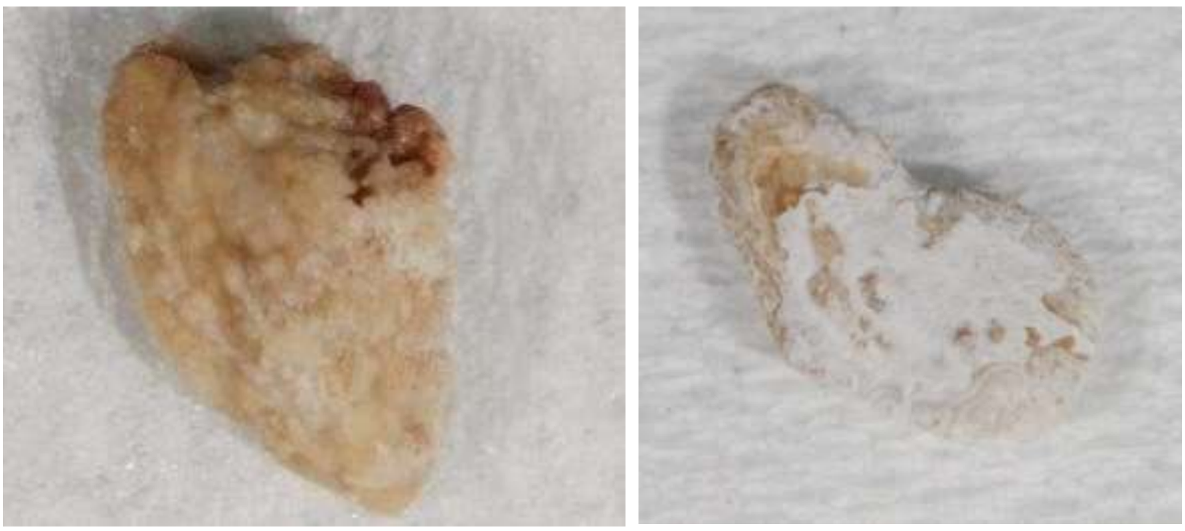
Intestinal diseases are mostly caused by pathogens (see *section 2, 7.5)*) and some of them can lead to cloacal and rectal prolapses or intussusception. Affected animals need to be anesthetized and prolapse tissue reduced and replaced. Purse-string suture have to be applied on the cloaca for 76hr. Those prolapses are often associated with coccidiosis, candidiasis, severe diarrhoea or inappropriate grooming techniques (Vogelnest & Woods, 2008).

f) Uro-genital diseases

Renal calculi are occasional necropsy findings. In some instances, they may be associated with clinical signs attributable to nephritis including pyuria, haematuria, dysuria and crystalluria (Vogelnest & Woods, 2008). Those calculi can sometimes go into the ureter and cause an ureteral obstruction that induce intense abdominal pain, lethargy, anorexia, renal pelvis dilatation, hyperkalaemia and acute renal failure. Diagnosis methods for stones are ultrasonography, urianalysis and radiographs (with or without contrast product). The treatment is often surgical when the diagnosis is made ante mortem.

In male macropods urethral obstruction are also possible and may be associated with dysuria, stranguria, haematuria, abdominal distension and discomfort, dehydration, lethargy and depression. In this case urethral catheterization is not possible because of the presence of paired valve-like cusps 2-3cm proximal to the external urethral orifice which creates an anatomical barrier. Treatment rely therefore only on surgical approaches (Vogelnest & Woods, 2008).

To prevent uroliths (and especially calcium oxalate or calcium carbonate) limiting dietary vitamin D and calcium and ensuring adequate vitamin A intake can be done (Vogelnest & Woods, 2008). In YFRWs it seems that calcium carbonates stones (*Picture 31*) are the most frequent as well as in other species such as tammar wallabies (Liptovszky *et al.*, 2014; Nowakowski *et al.*, 2021). To prevent calcium carbonates stones formation, the Ca/P ratio of the diet need to be close to 1 and food too rich in calcium must be withdrawn of the diet (Nowakowski *et al.*, 2021).



Picture 31 : Calcium carbonate urolith of an YFRW (© Benoît Quintard)

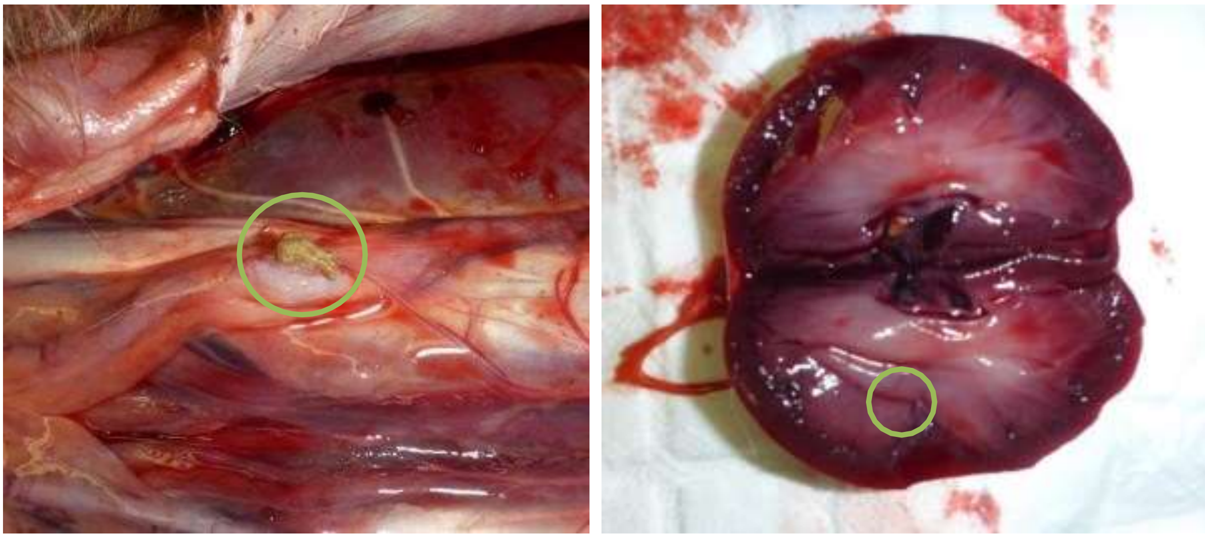
Renal failures (as in domestic animals) are found in YFRWs with the same clinical signs with same diagnostic method. However, no effective treatment has yet been determined, cases typically progress despite any supportive therapy. These animals need to be closely monitored and euthanized when the well-being can no longer be assured (Vogelnest & Woods, 2008).

Ovarian cysts are also occasional necropsy findings with no obvious clinical signs *ante-mortem*.

g) Ophthalmological diseases

The most common ophthalmological disease is corneal ulceration following trauma, prolonged anaesthesia or in dehydrated PY. Clinical signs include blepharospasm, epiphora and corneal opacity. The lesions are typically unilateral. A detailed ocular examination with fluorescein staining should be performed. Simple ulcers are likely to resolve with topical antibiotic therapy assured (Vogelnest & Woods, 2008).

Unilateral cataracts occur sporadically in adult macropods subsequent to a range of ocular disease processes. Cataract surgery in macropods has already been described but it should be kept in mind that glaucoma is an extremely common sequela to cataract surgery necessitating globe enucleation (Vogelnest & Woods, 2008). One retinopathy has also been reported in the BPGQ but the etiology is not certain yet.



Picture 32 : Necropsy of urolith in the right ureter of a YFRW causing a hydro ureter (left) and renal urolith *(right)* (© Benoît Quintard)

h) Muscular diseases

Capture myopathy is one of the most frequent diseases in captive YFRWs. It can be caused by excessive physical activity, stress and anxiety (after a poorly executed capture or during / after transport for example). It may also be due to a lack of Vitamin E and Selenium in the diet. Capture and restraint attempts during high ambient temperatures increase the risk of capture myopathy and hyperthermia. Animals that survive an initial episode may die per acutely following a second episode of exertion or stress (Miller, 2001).

The symptoms are dyspnoea, tachypnoea, tachycardia, hyperthermia, limb stiffness or paralysis, muscular tremors and fasciculation, neck twisting, reluctance to move, myoglobinuria. Those symptoms are often followed by lateral recumbency with inability to rise and then death a few days or weeks after (natural or euthanasia) (Miller, 2001). This disease is well known and is now easily prevented. The prevention consists in using safe capture techniques, promoting medical training when possible / applicable, avoiding stress exposure, complementing diet with proper

Vitamin E and Selenium levels. Vitamin E injection after a tough capture or just before transport is highly recommended (Miller, 2001).

The treatment needs to be initiated quickly and effectively. Vitamin E and Selenium injections associated with benzodiazepine sedation is indicated. Fluid therapy is needed to counteract the shock and to prevent the development of myoglobinuric nephrosis. Corticosteroids or flunixin meglumin can be used. If the animal is hyperthermic muscles should be wrapped in ice wet towels.

Captive-bred yellow footed rock wallabies reintroduced to areas of their former range in Queensland and South Australia showed a rapid and sustained increase in plasma Vitamin E concentrations and physical condition, with post-release values significantly higher than pre-release captive levels. This can explain why captive YFRWs are more touched by this disease than free-ranging ones but it doesn't explain why their Vitamin E plasma concentrations are lower (Lapidge, 2005).

i) Diet linked diseases

As detailed just above, capture myopathy and uroliths can be diet linked diseases. Obesity is also common in captive macropods (Vogelnest & Woods, 2008) but YFRWs do not tend to be particularly affected especially since the diet has been well studied.

On the other hand, YFRW can show hypoglycaemia. It is precipitated by periods of hypothermia, stress, infections in PY and manifests as lethargy, muscular twitching, ataxia and bradycardia before progressing to hypoglycaemic seizures and coma. Blood glucose value under 5mmol/L is diagnostic. Treatment consists of warmed 10% glucose (20mL/kg IV) and provision of a warm thermal environment and management of any predisposing problems (Miller, 2001).

j) Neoplasia

A wide range of neoplasms have been reported in marsupials but mostly on dasyurids. Concerning YFRW other Petrogale species no neoplasms have been described in the literature yet or reported by the authors in the BGGQ. The only known tumours in macropods have been reported in the Macropus gender (Canfield *et al.*, 1990). Squamous cell carcinomas, systemic lymphoma, pouch basal cell epithelioma, mammary adenocarcinoma, dermal lymphosarcoma, lymphosarcoma, melanomas, adenomatous proliferation of intrahepatic bile duct or intrapancreatic duct, lung adenocarcinoma, trichoepithelioma have been described in Macropus sp. species (Canfield *et al.*, 1990).

No typical non-infectious neurological, endocrine or bone diseases are described in YFRW this is why they are not described above.

6) Infectious diseases

a) Bacterial diseases

Oral necrobacillosis / Lumpy Jaw

Petrogale xanthopus was found to have a significantly lower prevalence of lumpy jaw compared to the red kangaroo, the red-necked wallaby and the tammar wallaby (Rendle, 2019). However, prevalence of lumpy jaw is significantly greater in the European region (19.7%) than the Australian region (12.6%) ($p < 0.0002$) and odds ratios (OR) determined that European macropods were four times more likely to die than to survive lumpy jaw than their Australian conspecifics.

This disease is a polymicrobial disease including *Fusobacterium necrophorum* as the major agent and other mixed bacteria such as *Actinomyces, Nocardia, Bacteriodes pyogenes* that penetrate gums. Lumpy jaw results in a decline in bacterial diversity in the oral cavity (Antiabong *et al.*, 2013). YFRW manifests suppurative lesions of the facial soft tissue and bones, which may lead to osteomyelitis in long standing infection. Clinical signs can include: facial swelling, wet forearms associated with ptyalism *(Picture 33)*, weight loss linked to inappetence and dysphagia, halitosis, tongue flicking, decay of jaw bone, loss of teeth, ocular discharge, blepharospasm, conjunctival hyperaemia, unilateral nasal discharge. Signs of systemic illness may be apparent following haematogenous spread and will reflect location of secondary abscesses (Miller & Fowler, 2015).

In order to prevent the disease, tools and footwears used by the keepers need to be cleaned between enclosures and ideally, they need to be specific for 1 enclosure (Rendle *et al.*, 2018). Food should be distributed on easily cleanable high platforms because wallabies tend to defecate in their food which can lead to oral infection. Unbalanced diet containing soft food with low roughage content and or coarse feed pellets which cause injuries to the gingiva are also considered as predisposing factors of lumpy jaw disease (Antiabong *et al.*, 2013). Furthermore, stress management is highly important to prevent the disease as it induces immunodepression.

Picture 33 : Wet forearms can be an indicator of lumpy jaw. (© Benoît Quintard)

The treatments are diverse depending on the severity of the symptoms: Tooth extraction, abscess irrigation, surgical debridement of necrotic bone and copious lavage with saline and topical chlorhexidine (solution, gel, varnish). Initial, frequent and aggressive therapy under anaesthesia improves success (Miller & Fowler, 2015). Antimicrobial therapy is recommended after a proper antibiogram and the association of a few dominant bacterial community in lumpy jaw should be considered as a possible target for therapeutic control of the disease since external changes, are likely to cause disruptions which may require longer time to recover. However, care must be taken to target core pathogens involved in the disease in order to avoid the establishment of a new climax community which do not have competition from other microbes and/or are incompatible with the host – an important observation that has been put forward in the report of Socransky and Haffajee in 2005 (Antiabong *et al.*, 2013). Unfortunately, some cases can lead to euthanasia if the case is too severe.

In order to prevent lumpy jaw, the yellow-footed rock wallabies need to be fed with solid but not sharp food (high quality browse) in order to strengthen the gums and to emphasize good chewing habits.

Picture 34 : Osteomyelitis caused by chronic lumpy jaw on a Bennet wallaby (© Benoît Quintard)

Mycobacteriosis

Mycobacteriosis is reported in a variety of macropods, emphasising the ubiquitous presence of mainly opportunistic mycobacteria in the environment (Ladds, 2012). In macropods different *Mycobacterium* species have been isolated such as *Mycobacterium avium, M. avium subsp. paratuberculosis*, *M. intracelllare, M. ulcerans, M. chitae, M. fortuitum, M. smegmatis, M. abscessus* and various others (Miller & Fowler, 2015).

The transmission of mycobacteriosis occurs by inhalation, puncture wounds or abrasions. A review of cases in macropods published up to 1986 revealed that lesions of mycobacteriosis were seen most frequently in spleen and lymph node and less often encountered in bone, the respiratory system, then liver, in that order. The typical lesion in macropods varies from small miliary foci to massive nodules with an internal consistency varying from purulent to caseous. 'Grittiness' due to mineralisation occurs sometimes but is not a common finding (Ladds, 2012). The clinical signs depend on the location of the lesions and are not evident until late in the course of the disease. They can be various such as are weight loss, dyspnoea, lameness, abscesses, neurologic signs, blindness, ulcerative to granulomatous skin lesions (Miller & Fowler, 2015).

Intradermal tuberculin skin testing produces inconsistent tests results and is therefore of limited diagnostic value (Vogelnest & Woods, 2008). Radiography can be useful to localize the sites of infection. Treatment is not recommended and euthanasia recommended when infection is confirmed (Miller & Fowler, 2015).

Bordetella bronchiseptica: Rhinitis, pneumonia

There are several reports of illness or mortality of wallabies associated with *Bordetella bronchiseptica* infection (Ladds, 2012). This bacteria is transmitted by inhalation of aerosols, direct contact or contact with infected nasal secretions.

Infected YFRWs present serous to mucopurulent nasal discharge, intermittent sneezing, coughing, increased respiratory effort, reduced exercise tolerance, weight loss and diffuse, audible crackles can be heard on thoracic auscultation.

At necropsy, marked mucosal congestion; ulceration and necrosis of the soft, cartilaginous, and bony tissues of the nasal passages and sinuses; peritracheal inflammation and marked pulmonary congestion and consolidation are apparent (Miller & Fowler, 2015).

Long-term antibiotic treatment is indicated after culture and antibiogram, symptomatic therapy is also recommended (nebulization with acetyl cysteine +/- antibiotics in saline, bromhexine hydrochloride, thermal support). The affected animals need to be isolated during treatment in order to prevent spreading of the disease. In order to prevent infection, if the area is at risk, vaccination with commercial canine vaccines can be done (Miller & Fowler, 2015).

Pouch infection: *Pseudomonas aeruginosa, Klebsiella spp., Proteus spp., Candida albicans…*

Pouch infection is described as common in captive YFRWs (Debin, 2006) even if not reported in the BPGQ. A lot of bacteria are at stake especially *Pseudomonas aeruginosa.* Pouch infection often occurs when the outside part of the enclosure is small with reduced physical activity. The typical clinical sign is a damp pouch that emits an unpleasant smell. A swab of the pouch can be sent for bacteriology and antibiogram. Treatment is easy by cleaning the pouch with chlorhexidine and then drying it. Local antibiotic therapy is undertaken, and in advanced cases, systemic antibiotherapy can be done (Debin, 2006).

Tetanus *Clostridium tetani*

Tetanus, resulting from infection of wounds with *Clostridium tetani*, is is the most important clostridial disease of captive macropods (Vogelnest & Woods, 2008). However, opinion on its significance in these species is divided. It is reported in several macropod species (Ladds, 2012) but not to this day in YFRW. Transmission occurs through spores entering the body following penetrating injuries or contamination of wounds (Miller & Fowler, 2015).

Signs, which may be of sudden onset and rapid progression, include protrusion of the nictitating membrane, dilation of nostrils, ptyalism caused by inability to swallow, marked muscular rigidity with clonic spasms precipitated by sensory stimulation. Mastication becomes impossible, pulmonary oedema develops, and death occurs within several days (Ladds, 2012) Post-mortem changes include marked opisthotonos, pulmonary congestion and rupture of the musculature of the hindlimbs (Vogelnest & Woods, 2008).

The diagnosis must be based on clinical signs but treatment is rarely successful. It consists in supportive care, tetanus antitoxin administration, penicillin and benzodiazepines to loosen up the muscles (Miller & Fowler, 2015). As mentioned in *Section 2, 7.2) b)*, vaccination is available and recommended especially in areas at risk.

Enterotoxaemia

It is caused by *Clostridium perfringens* and reported in young kangaroos and suspected in several species of captive and semi-free-ranging macropods (Vogelnest & Woods, 2008). Necropsy reveals petechiation on serous surfaces, and much translucent, straw-coloured fluid in body cavities. Treatment goes primarily through supportive fluid therapy and supportive care. Antibiotics such as Metronidazole and corticosteroids might be used and antibiotics such as ampicillin, clindamycin, lincomycin, amoxycillin, penicillin or erythromycin that are known to precipitate enterotoxaemia should be avoided. However the treatment is often non successful especially in severe cases (Harcourt-Brown, 2002). *Clostridium perfringens* strains are known to secrete more than 20 toxins or enzymes that could potentially be the principal virulence factor involved in lesion pathology (Rousselet et al., 2021). A vaccination with epsilon toxoids is available for cattle and is used off-labels in wild ruminants of zoological institutions. A recent study showed that a combined inactivated vaccine against several clostridial infections (*C. sordellii, C. perfringens types B, C and D, C. chavoei, C. septicum, C. novyi and C. tetani*) available in Europe (Miloxan ®) induced a high antibody response in 5 Bennett's wallabies (Rousselet et al., 2021).

Salmonellosis

In Australia, many serotypes of Salmonella have been isolated from wildlife, especially in macropods, but few reports relate particular isolates to clinical findings and even fewer describe lesions, then it appears so that macropods are asymptomatic carriers. *Salmonella typhimurium* seems to be the main serotype associated with disease (Ladds, 2012). The transmission is by fecal-oral route. Clinical signs are those of enteritis and septicaemia, diarrhoea is the most consistent sign (semi-formed faeces to haemorrhagic diarrhoea); anorexia, colic, dehydration and lethargy are also common signs. In orphaned macropod joeys, loose faeces may contain streaks of blood sometimes progressing to profuse bloody diarrhoea. Death may also occur without signs being observed.

Gross findings in fatal salmonellosis may include marked petechial and ecchymotic haemorrhages, pulmonary oedema, splenomegaly, and variably normal to fibrinohaemorrhagic intestinal mucosa, with luminal diarrhoea, fibrin, and blood, depending on the type of mucosal lesion (Ladds, 2012).

Yersiniosis

Yersiniosis is described in a variety of Australian native mammals including kangaroos, and red-necked wallabies (Ladds, 2012). The most common causative agent is *Yersinia pseudotuberculosis* although other *Yersinia* species have been isolated (Vogelnest & Woods, 2008). Yersiniosis is a zoonotic disease. *Yersinia* infects via the faecal-oral route, so lesions are distributed accordingly (Ladds, 2012). Cases typically occur following periods of stress, including cold wet weather (Vogelnest & Woods, 2008). Histologically, in affected portions of the intestine there is mucosal necrosis with mats of bacteria or aggregates of coccobacilli forming microcolonies visible in H&E sections, along the mucosal surface and within necrotic debris, often in gut-associated lymphoid tissue.

Pasteurellosis: *Pasteurella multocida*

Pasteurellosis, caused mostly by infection with *Pasteurella multocida*, is common in smaller species of macropods following cat attack (Vogelnest & Woods, 2008). Upper respiratory lesions in *P. multocida* infections are often found, extensive necrotic oral lesions are also frequent in infected animals. Gross lesions in macropods have included bronchopneumonia, fibrinous pneumonia or pleuropneumonia, lymphadenomegaly, hepatic congestion and ascites (Ladds, 2102).

Erysipelas

E. rhusiopathiae has been reported in kangaroos causing red lesions on the inner aspect of the hind limb, and erysipelas has also been diagnosed in a captive YFRW with septicaemia manifested by mucohaemorrhagic enteritis, epicardial petechiation and splenomegaly (Ladds, 2012). *E. rhusiopathiae* is zoonotic, usually causing localised digital cellulitis, termed 'erysipeloid', and, rarely, valvular myocarditis or septicaemia.

E. insidiosa was isolated from wallabies and kangaroos dying in a number of European zoos (Vogelnest & Woods, 2008). Affected animals typically die acutely or are found dead without exhibiting premonitory signs. Cases have occurred after periods of heavy rainfall and the disease typically occurs sporadically.

Like in any other species some other bacterial infection can be found in macropods but will not be detailed in these guidelines: *Escherichia sp.*, *Staphylococcus sp.*, *Streptococcus sp.*, *Arcanobacterium sp.*, *Dermatophilus sp.*, *Campylobacter sp.*.

b) Viral diseases

Macropodid *Alphaherpesvirus* (MaHV1 and 2); *Gammaherpesvirus* (MaHV3)

Alpha herpesviruses (Macropod Herpesvirus-1 and -2) have been associated with disease in a number of macropod species, always in captive animals from European, Australian and North American zoos (Smith & Whalley, 1998), although there is serologic evidence of wide exposure to herpesviruses in free-ranging macropods. These agents are capable of latency, have been detected in the trigeminal ganglion, and may recrudesce in immunocompromised animals. *Gammaherpesvirus* infection (Macropod Herpesvirus-3) has recently been reported in a captive collection of eastern grey kangaroos in North America and in a free-ranging animal in Victoria (Ladds, 2012), it is assumed that all macropod species are potentially susceptible to those viruses (Vogelnest & Woods, 2008). Transmission occurs by direct contact and possibly by aerosol inhalation over a short distance (Miller & Fowler, 2015).

Clinical signs for MaHV1 and 2 include depression, anorexia, pyrexia, dyspnoea, stridor, cutaneous and mucosal erythema, conjunctivitis, eyes and nostrils discharge, incoordination, vesicles of 2 to 3 mm in diameter in the labial and gingival mucosa and ano-genital region. Sudden death can also occur (Miller & Fowler, 2015). MaHV3 in captive collections has been associated with high prevalence of mammary tumours. This disease can provoke mild clinical signs like the ones of alphaherpeviruses but can also be more severe and in some cases lead to death (Miller & Fowler, 2015).

Diagnosis of herpesviruses is suggested by the pattern of gross and microscopic lesions and confirmed by virus isolation, PCR (nasal swabs), serology or presumptively, by electron microscopy on tissue sections (Ladds, 2012). Gross lesions include pulmonary congestion and oedema, conjunctivitis, mesenteric lymph nodes enlargement, hepatic and splenic congestion, multiple pale hepatic foci, diphtheritic plaques on mucosa of oesophagus and stomach, focal ulceration and necrosis of genitalia (Miller & Fowler, 2015). Positive animals should be isolated and a supportive care treatment can be undertaken.

Wallaby retrovirus

Viruses in the family Retroviridae have been documented to cause a wide range of clinical disease including neoplastic and immunosuppressive disorders in both domestic and nondomestic animals. Retroviral-induced disease is a potential risk to captive macropodidae collections. A study was conducted in 2008 in North American Captive Macopodidae (Georoff *et al.*, 2008). This study showed that serum antibody was detected in 37.5% of the YFRWs included in the study.

Poxvirus infection

The causative viral agent has not been characterized but dermatological, poxvirus-associated papillomatous proliferations in the skin of macropods (quokka, tammar wallabies, agile wallabies, swamp wallabies, wallaroos, red kangaroos, eastern and western grey kangaroos), are described in all ages, but mostly young animals (Ladds, 2012). It has not been yet described in captive wallabies in Europe.

Encephalomyocarditis virus

Encephalomyocarditis virus is a well-known virus in captivity because it can cause acute death in a broad range of hosts (Reddacliff *et al*., 1997) but in macropods it can easily be mixed up with cardiomyopathy. Clinical signs that have been described are sudden death, ataxia, depression, dyspnoea and other signs referable to cardiomyopathy (Miller & Fowler, 2015) but no cases have yet been described in Europe.

c) *Fungal diseases*

Dermatophytoses

Dermatophytoses are common in captive macropods and important to diagnose because of its zoonotic potential. *Microsporum gypseum* and *Microsporum canis* are the two most common agents responsible in YFRW but *Tricophyton mentagrophytes* is often found too (Boulton *et al*., 2013).

Clinical signs are typical: alopecia, erythema, scaling, crusting and hyperpigmentation. Two forms of the disease are recognised in macropod joeys. In the “classic” form there are discrete, sometimes multiple areas of alopecia with no erythema. In the more severe, generalised form, quite large areas may be involved and the skin is roughened and thickened with associated alopecia. There is a tendency for scabs to form. In young animals infection of the ears may lead to necrosis and sloughing of parts of the ear (Ladds, 2012).

Diagnosis can be done by fungal culture or trichogramm. The treatment can be topical (miconazole, enilconazole, terbinafine, iodine, chlorhexidine, ketoconazole, captan, silver sulfadiazine, lime sulfur, thiabendazole and clotrimazole), oral (itraconazole 5-10mg/kg pulse therapy thrice weekly, lufenuron 60mg/kg PO or fluconazole 40mg/kg once daily). If griseofulvin is chosen it needs to be used carefully because one case of ataxia in a joey following oral griseofulvin was once reported (Boulton *et al*. 2013).

Cryptococcosis: *Cryptococcus gatti, C. neoformans var. grubii*

Cryptococcosis is most commonly caused by two species, *Cryptococus neoformans* (consisting of two varieties - *C. neoformans* var. *grubii* and *C. neoformans* var. *neoformans*), and *C. gattii* (formerly *C. neoformans* var. *gattii* or *C. bacillosporus*) (Ladds, 2012).

C. gatti has been associated with pulmonary and multisystemic cryptococcosis in red-necked wallabies, parma wallabies, quokkas, long-nosed potoroos and a Gilbert’s potoroo. Cryptococcal meningitis has been observed in a swamp wallaby, quokkas and a spectacled hare-wallaby. Inhalation seems the most likely source of infection with haematological spread in multisystemic cases. Environmental sources of *C. gatti* include a range of *Eucalyptus* species. Leaf litter and/or cage furniture derived from eucalyptus in exhibits are considered potential sources of cryptococcosis in captive macropods (Vogelnest & Woods, 2008).

Aspergillosis

Respiratory aspergillosis has been observed in captive macropods including wallabies and wallaroos, but lesions were not described. Also *Aspergillus sp*. was isolated from and demonstrated within oesophageal tissues of a captive kangaroo (Ladds, 2012).

Candidiasis

Candidiasis is mostly caused in Australian native mammals by *Candida albicans.* Candidiasis has already been described in kangaroos, wallabies, wallaroos, and the musky rat-kangaroo. It may be localised in the gastrointestinal tract (common in hand-reared juveniles), cloaca, or skin, or be systemic (less common), so signs will vary accordingly (Ladds, 2012; Vogelnest & Woods, 2008).

Clinical examination of affected animals may reveal pale plaques or ulcers in the oral cavity on the tongue, gums and lips (which may be swollen), and pharyngitis of varying severity. Skin, especially around the mouth, may also be affected with erythema, cracking of the skin and plaques in unfurred PY. Infections are usually associated with stress and poor hygiene.

d) Parasitic diseases

YFRWs are hosts to a big array of parasites, in almost all organs systems. The majority of them have little or no impact on the health. Even heavy burdens of parasites appear to be well tolerated in this species (Miller, 2001).

Protozoa

- *Toxoplasmosis*

YFRWs are, like all macropods, susceptible to *Toxoplasma gondii* infection and to the development of clinical disease. Vertical transmission may occur in macropods (Parameswaran *et al*., 2009) but the most common transmission is via ingestion of sporulated oocysts in food contaminated with felid feces or in paratenic hosts. The disease may result from primary infection following oocyst ingestion or recrudescence of latent disease following a period of immune compromise (Miller, Fowler, 2015). Toxoplasma infection is reported in most macropod species (in which the disease is often fulminating) with minimal signs occurring before ultimate prostration and death (Ladds, 2012). The clinical signs that can be observed are varied: dyspnoea, tachypnoea, coughing, malaise, uncharacteristic docility, weight loss, anorexia, lymphadenopathy, diarrhoea, blindness, ataxia, circling, incoordination, dysphagia, pyrexia, keratitis, uveitis, chorioretinitis, unilateral or bilateral cataracts (Miller & Fowler, 2015).

Often no changes indicative of toxoplasmosis are observed at necropsy, and if present, such changes are quite variable in severity. In a detailed correlative gross-microscopic study of toxoplasmosis (Ladds, 2012 ; Portas, 2010), necropsy findings (when present) in macropods with fatal toxoplasmosis included: pulmonary congestion or consolidation, gastrointestinal reddening and ulceration, myocardial haemorrhages and pale streaks, splenomegaly, cerebral malacia, adrenal enlargement and reddening, pancreatic swelling, and lymphadenomegaly. In this comparative study, diffuse or patchy pulmonary congestion, oedema and consolidation were common in affected macropods (Ladds, 2012).

The treatment is often unrewarding: Atovaquone, clindamycin, sulfadiazine and pyrimethamine (with folinic acid), trimethoprim-sulfonamide for up to 30 days. Supportive care is really important (Miller, Fowler, 2015). Prevention is also important; cats must be excluded from feed sheds and enclosures. Unfortunately to this day attempts to vaccinate macropodids against toxoplasmosis have been unsuccessful (Portas, 2010), even if a new trial with nanoparticules administration is currently undergoing in a few French zoos.

- *Coccidiosis: Eimeria spp. and Isospora spp.*

The coccidia most commonly identified in macropods are *Eimeria* spp., more than 40 of which have been described. Clinical disease with lesions attributed to intestinal and or hepatic coccidiosis is reported in eastern and western grey kangaroos, red kangaroos, black-striped tammar, whip-tail, red-necked and parma wallabies (Ladds, 2012). Infection is transmitted by ingestion and especially in heavy environmental loads. The clinical disease is usually limited to the juveniles of less than 12 months. Clinical signs are loss of appetite, abdominal discomfort, lethargy, diarrhoea (often haemorrhagic), dehydration, dependent oedema, bruxism, common vestibule prolapse and, in some cases, sudden death (Miller & Fowler, 2015).

As in domestic animals, the gross changes seen in coccidiosis in wildlife may reflect the outcome of epithelial proliferation, inflammation with oedema or haemorrhage, or a combination of these changes. Lesions of coccidiosis involving both intestine and liver appear to be more common in tammar wallabies than in other macropods (Ladds, 2012).

Prevention measures include minimizing stress, optimizing nutrition, prevention of overcrowding, feeding off the ground, and sanitation of feeding and watering equipment. Exposure to sunlight and desiccation are effective means of cleaning the environment. Where environmental control is not adequate, the use of anticoccidial drugs can be helpful for both treatment and prevention. Treatment should be initiated on early suspicion of the disease: toltrazuril, antibiotics for secondary bacterial infection, (PO or SC preferred), homologous plasma transfusions, analgesia. They have little impact on existing infection but should help limit both subclinical and clinical disease and environmental contamination. (Keeton & Navarre, 2018)

- *Babesiosis*

Only one report of presumed *Babesia* infection in a rock-wallaby is available and it was unassociated with illness diagnosed by examination of a blood smear, then PCR (Ladds, 2012). *Babesia* is a common blood parasite transmitted by arthropod vectors (mainly ticks). Clinical signs are typically expressed in hand-reared pouch young between 6 and 13 months of age. They present failure to thrive, poor body condition, dehydration, pale mucous membranes linked to anemia, polydipsia, polyuria, inappetence, bruxism, lethargy, vision deficits, conjunctival and scleral haemorrhage, ataxia, seizures, recumbency. Treatment is a combination of supportive care, blood transfusions, imidocarb IV and prevention goes by tick and vector control.

- *Cryptosporidiosis*

Cryptosporidium a protozoan parasite has been described in a number of Australian marsupials, including the red, eastern and western grey kangaroos, the red-necked wallaby, the swamp wallaby, YFRW, Tasmanian and red-necked pademelons, and the bilby (Ladds, 2012).

Gross lesions associated with *Cryptosporidum* infection include distension of the intestines with gas and watery fluid, and perhaps congestion. Microscopically there may be mild to moderate villous atrophy, crypt hyperplasia, some focal necrosis with loss of epithelium, and light to moderate infiltration of the lamina propria with predominantly mononuclear cells. Some metaplasia of low columnar, cuboidal or even squamous epithelium may occur (Ladds, 2012).

Ectoparasites

A variety of external parasites have been found associated with YFRW including ticks, mites and lice. Mild skin lesions have been associated with the mite *Odontocarus* and an increase in numbers of lice (*Heterodoxus* species) occurs whenever an animal is not grooming itself. External parasites can be treated using commercially available insecticidal dusting powders (Miller, 2001).

- *Mange*

Among macropods, sarcoptic mange *(Sarcoptes scabei var. canis, S. scabei var. wombati)* has been reported in agile wallabies and a wild swamp wallaby. *Sarcoptes* infection is a zoonosis. Lesions in wallabies can be generalised or involve only anterior parts of the body, or the hind limbs or tail. Lesions consist of thick crusts, sometimes with deep fissures, alopecia and excoriations. Pruritus is frequent as well as secondary pyoderma (Holz *et al.*, 2011).

- *Ticks*

Tick infection is frequent in macropods. The infection is often asymptomatic but heavy burdens may results in anaemia (Miller & Fowler, 2015). Naïve animals infested with *Ixodes* *holocyclus* may develop ascending flaccid paralysis progressing to recumbency, eventually respiratory failure. Localized paralysis near the site of tick attachment is also possible. Tick management involve removal of ticks and the use of acaricidal preparations. Iron supplementation can be used is case of anaemia.

- *Mites*

Dermatitis associated with the larvae of *Odontacarus adelaideae* has been reported in YFRWs (O'Callaghan *et al.*, 1994). The clinical signs are extensive moist, pustular dermatitis affecting the inguinal, abdominal and axillary regions. Clusters of mites can be observed on the external pinnae and specimens can be collected for identification.

Endoparasites

A wide variety of common internal parasites can be found in YFRWs, and according to ZIMS database and BPGQ it is the most common cause of disease in captivity. These include 14 genera of *Strongyloides*, 3 genera of Protozoa and 3 genera of Cestodes. The majority of internal parasites result in little clinical illness and any health problems attributed to them are usually an indication of imperfect husbandry. Cleanliness is the best prevention method. Symptoms of internal parasites include weight loss, progressive anorexia and death if severe (Muranyi, 2000). Many nematodes can be treated with Ivermectin at 0.2mg/kg intramuscularly but cestodes and protozoa will not be eliminated by this commonly-used treatment (Miller, 2001) and therefore toltrazuril, praziquantel or metronidazole can be used depending on the parasite.

- *Strongyloides*

All macropod species are susceptible to infection. They are quite small worms (up to 4mm) present in the cardiac portion of the stomach (Vogelnest & Woods, 2008). They may cause severe inflammatory and erosive gastritis and the infection can in some cases be fatal. Gross findings are erythema, oedema and haemorrhage, especially near pylorus. Microscopical observations show severe erosion sometimes progressing to ulcers or abscesses. Larvae are present in 'tunnels' in epithelium with caudal ends protruding into gut lumen (Miller & Fowler, 2015).

- *Leishmaniosis*

Zoonotic leishmaniosis due to *Leishmania infantum* is a vector-borne disease endemic to southern Europe, where the disease is spread via the bite of sand flies of the genus *Phlebotomus*. Humans and especially domestic dogs are the main hosts in Europe, and dogs are the main reservoir for this infection (Montoya *et al.*, 2016). First described in wild red kangaroo (*Macropus rufus*), and then in wild black wallaroo (*Macropus bernardus*) and agile wallaby (*Macropus agilis*), *L. infantum* infection has since been confirmed in four captive Bennett's wallabies in the wildlife park Faunia. In all cases, the infection was diagnosed by PCR and the parasite was detected in several organs in vivo and/or post-mortem. Clinical signs were weight loss and anaemia and some individuals seem to be asymptomatic and then die suddenly. In 2011, a fatal case of naturally acquired leishmaniosis was described for the first time in a Bennett's wallaby (*Macropus rufogriseus rufogriseus*) kept in a zoo in Spain.

Rapid clinical manifestations and sudden death offer a very short window of action for veterinarians. After confirmation of the disease or if the disease is highly suspected, treatment need to be undertook quickly with antimonials and allopurinol following a standard treatment protocol for canine leishmaniosis of known efficacy (Montoya *et al.*, 2016). The typical protocol for dogs is: Maglumine antimonite 75-100mg/kg SID or 40-75mg/kg BID for 4 weeks + Miltefosine 2mg/kg PO SID for 28 days + Allopurinol 10mg/kg PO BID for at least 6-12months (Solano-Gallego *et al.*, 2011). This treatment allowed an ill Bennet wallaby to regain weight and body condition as an initial response to treatment, but unfortunately he died a few months later (Montoya *et al.*, 2016). Veterinarians in zoos and animal parks in endemic areas should therefore establish preventive measures such as sand fly control to avoid this infection in their animals (Montoya *et al.,* 2016).

- *Echinococcus granulosus*

Echinococcus granulosus, the causative agent of hydatid disease or cystic echinococcosis, is a generalist parasite. Infection of small macropodids with the larval stage of *Echinococcus granulosus* can cause fatalities as well as significant pulmonary impairment and other adverse sequelae (Barnes *et al.*, 2008). Barnes and al. used radiographic techniques to determine the prevalence and severity of pulmonary hydatid infection and growth rates of hydatid cysts in a wild population of *Petrogale penicillata*. The overall prevalence was 15.3% (9/59 animals) with 20.0% (8/40 animals) of adults infected. During the study period, the death of at least 1 infected animal was directly attributed to pulmonary hydatidosis (Barnes *et al.,* 2008).

There are limited treatment options: In the past, surgery was the only treatment, but actually chemotherapy, cyst puncture and PAIR (percutaneous aspiration, injection of chemicals and reaspiration) are used in humans (CDC, 2012). Unfortunately in wallabies treatment is often not performed and they either die quickly of the disease or are euthanized because their welfare is compromised (Barnes *et al.*, 2007a). Prevention goes by pest control, hygiene and treatment of the keepers' dog with an anthelmintic regularly (OIE, 2020).

- *Angiostrongylus* cantonensis

This parasite is responsible of neurological disease because of the migration of the rat lungworm *Angiostrongylus cantonensis* in abnormal hosts. It has been reported in captive rufous rat-kangaroos, western grey kangaroos, red necked wallabies, a western grey kangaroo, a parma wallaby/tammar wallaby hybrid, agile parma and tammar wallabies, purple-necked rock wallaby (*P. purpuricollis*) and a wallaroo in Australia (Vogelnest & Portas, 2019). The precise route of infection in infected macropods remains to be demonstrated. Infection often follows ingestion of L3 in several species of land mollusc (the intermediate hosts of the parasite); other potential routes of infection include ingestion of paratenic hosts or possibly larvae in snail mucus trails (Vogelnest & Woods, 2008). This parasite is expanding globally (Vogelnest & Portas, 2019) and is well described in other zoo species in Europe (Federspiel *et al.*, 2020) and represents a threat for captive YFRW population. Antemortem diagnosis is difficult. Advanced imaging such as MRI and multislice helical CT is used in human medicine. Serological tests have a low sensibility and specificity. Therefore necropsy and histopatghology of CNS tissues are required to confirm a diagnosis (Vogelnest & Portas, 2019).

In zoos prevention involves the control and removal of rats, slugs and nails. The use of anthelminthics is generally contraindicated and treatment in the early course of disease can be done by using high-dose corticosteroid therapy but prognosis is poor and recovery is rare even with treatment (Vogelnest & Portas, 2019).

- *Baylisascaris*

Baylisascaris sp., the common roundworm of raccoons and skunks, can cause devastating disease in many captive species of animals due to abnormal parasitic migration. The parasite is indigenous to North America and emerging in Europe. *B. procyonis* has an indirect life cycle with raccoons (*Procyon lotor*) as definitive host (DH) and more than 130 vertebrate species, including rodents, birds, wild carnivores, pets and primates as potential paratenic hosts (PH) (Al-Sabi *et al*., 2015).

Baylisascaris is not only a concern for zoo species, but it is a zoonosis, especially dangerous in a zoo/park setting where children abound. Two cases of central nervous system disease secondary to *Baylisascaris* on juvenile YFRWs have been described in Los Angeles Zoo (Stringfield & Sedgwick, 1997). Prevention of this disease goes mainly through pest control.

e) Toxicities

- *Anticoagulant poisons*

Second generation anticoagulant vertebrate pesticides such as brodifacoum may kill an animal after one feeding. They are considerably more toxic than first generation anticoagulant pesticides such as warfarin or pindone, which require multiple feedings in order to kill. Reports of pindone poisoning in free-ranging native mammals in Australia include western grey kangaroos (Ladds, 2012). Based on observations in dogs poisoned with first generation anticoagulants, signs do not occur until several days after exposure and include weakness, pale mucous membranes, poor capillary refill, epistaxis, vomiting of blood and rectal bleeding, extensive bruising dyspnoea and exercise intolerance (Ladds, 2012 ; Vogelnest & Woods, 2008). Blood may be coughed up and haemorrhages may be apparent in the skin or on mucous membranes. Affected animals are typically anaemic and elevations in ALP and CK are common. Lesions seen at necropsy include paler, with haemorrhage – ranging from petechiae to major extravasations – in or on various organs, and perhaps into the gut (Ladds, 2012).

Treatment involves correction of hypovolemia with crystalloids and/or homologous plasma or blood transfusions. Vitamin K1 (2.5-5mg/kg) is initially administered parentally then orally until coagulation profiles are normal (Vogelnest & Woods, 2008).

- *Plant poisonings*

A lot of plants can be poisonous for wallabies. The authors recommend every reader to check on zooplants.net whether the plant they want to give the wallabies or place in the exhibit is safe for YFRW or not. Only 7 common known poisonous plant will be described after (Ladds, 2012).

Yew (*Taxus baccata*) poisoning is described in red-necked wallabies which died within 24 hours of ingesting leaves of the plant. Necropsy revealed congestion of kidneys, myocardium, liver and lungs, and acute enteritis was apparent. Microscopic lesions in the brain were indicative of circulatory disturbance.

Rhododendron (*Rhododendron spp.*) toxicity was suspected in a young, hand reared, western grey kangaroo which was observed eating the plant several hours before initial signs developed. Signs were suggestive of gastrointestinal pain and spasm. After treatment with a range of agents over the following week the animal returned to normal. Lesions were not reported.

Lantana camara poisoning in red kangaroos captive resulted in hepatoxicity with secondary photosensitisation. At necropsy, in addition to jaundice, the liver was enlarged with pale yellow to red-yellow mottling. Microscopic changes included hepatocellular enlargement with vesiculation of the nuclei, and sporadic feathery degeneration of the cytoplasm.

Also in free-ranging red kangaroos, in areas where pyrrolizidine-containing plants occur (for example Senecio jacobaea (Ragwort)), hepatosis typical of pyrrolizidine alkaloidosis has been observed.

Parsonsia straminea (monkey rope, silk pod), a woody climbing vine, was associated with ataxia, grinding of teeth and cerebral oedema in eastern grey kangaroos kept in an enclosure in southeast Queensland.

Neuronal greenish pigmentation characteristic of chronic *Phalaris spp.* poisoning is recorded in captive red kangaroos and wallabies grazing *Phalaris spp.*-dominant swards. Animals show neurological signs (disorientation, ataxia, hypermetric gait, head tremors, hyperexcitability and collapse), chronic weight loss.

Poisoning following ingestion of the popular hedge and garden plant *Duranta erecta* (golden dewdrop, Sheena's Gold, Geisha Girl) is reported in kangaroos. Signs were those of drowsiness. Lesions were not described; in (sometimes fatal) poisoning in the dog and cat, there may be gastro-intestinal haemorrhage with melena.

Picture 35 : Photos of poisoning plants a) *Taxus baccata* b) *Rhododendron sp*. c) *Lantana camara* d) *Parsonsia straminea* e) *Phalaris aquatic f) Duranta erecta*

(©https://jardinage.lemonde.fr/dossier-555-lantana-camara-arc-ciel-couleurs.html; https://www.jardiner-malin.fr/fiche/rhododendron.htm; https://en.wikipedia.org/wiki/Parsonsia_straminea; https://pixers.fr/papiers-peints/taxus-baccata-avec-des-cones-murs-46308446; https://en.wikipedia.org/wiki/Phalaris_(plant; https://jardinage.lemonde.fr/dossier-2114-vanillier-cayenne.html)

9. Contraception

The information below was collected by the EAZA Reproductive Management Group (RMG). For additional information, see the EAZA RMG website www.egzac.org or contact contraception@chesterzoo.org. The EEP recommends not using any contraception before the female has expressed the first signs of oestrus which usually correspond with an observed birth.

Disclaimer: The EAZA RMG endeavours to provide correct and current information on contraception from various sources. As these are prescription only medicines it is the responsibility of the veterinarian to determine the dosage and best treatment for an individual animal under their care. The EAZA RMG can therefore not be held liable for any injury, damage or contraception failure in an animal. The EAZA RMG recommends that individuals managed within breeding programmes should not be contracepted without the agreement of the programme coordinator. No portion of this message may be copied or distributed without the express permission of the EAZA RMG www.egzac.org

1) Males

Surgical

If permanent contraception is desired, a surgical procedure is the recommended option in male marsupials. This procedure involves permanent contraception by surgical gonadectomy (castration) or the surgical interruption of a segment of the vas deferens (vasectomy). Side effects of castration should be similar to those in domestic species i.e. weight gain and the loss of secondary sex characteristics, but this is data deficient. Vasectomy should not impact testosterone-mediated behaviours.

Chemical

Gonadotrophin Releasing Hormone (GnRH) vaccine: GnRH vaccines, such as Improvac® (guideline below), cause the production of anti-GnRH antibodies by the immune system, neutralising endogenous GnRH activity. This results in a reduction of FSH and LH production by the anterior pituitary and, ultimately, in the inhibition of testosterone secretion from the testes and spermatogenesis.

- **GnRH Protein Conjugate (Improvac®): Intramuscular injection formulation -** Two injections of 400µg are given 35 days apart and boosters are usually administered every 6 months, although duration can vary between individuals. Latency to effectiveness can be up to 6 weeks so separation of the sexes is recommended if possible. In seasonal breeders initial injections should be administered at least 6 weeks prior to the breeding season. Improvac® is designed to be fully reversible; there is currently no reversals on the database however studies have shown reversibility in other species within a two-year period. It must be taken in to consideration that younger individuals will take longer to reverse in comparison to older individuals. Permanent changes to the reproductive system resulting in infertility has been seen in other species, notably in elephants. The effects of Improvac® have not been well researched in marsupials.

GnRH agonists such as Suprelorin® implants or Lupron® injections are not known to be effective in male marsupials.

2) Females

Surgical

If permanent contraception is desired, surgical removal of the ovaries (ovariectomy), removal of the ovaries and uterus (ovariohysterectomy), removal of the uterus (hysterectomy), or the clamping or blocking of the fallopian tubes (tubal ligation) are possible. Prior approval from the EEP coordinator is required as the procedures are not reversible. Weight gain can be a common side effect of ovariectomy, and can be managed by reviewing diet and food presentation.

Chemical

Gonadotrophin Releasing Hormone (GnRH) vaccine: GnRH vaccines, such as Improvac® (guideline below), cause the production of anti-GnRH antibodies by the immune system, neutralising endogenous GnRH activity. This results in a reduction of FSH and LH production by the anterior pituitary and, ultimately inhibition of ovarian follicular development.

- **GnRH Protein Conjugate (Improvac®): Intramuscular injection formulation -** Two injections of 400µg are given 35 days apart and boosters are usually administered every 6 months, although duration can vary between individuals. Latency to effectiveness can be up to 6 weeks so separation of the sexes is recommended if possible. In seasonal breeders initial injections should be administered at least 6 weeks prior to the breeding season. Improvac® is designed to be fully reversible; there are currently no reversals on the database however studies have shown reversibility in other species within a two-year period. It must be taken in to consideration that younger individuals will take longer to reverse in comparison to older individuals. Permanent changes to the reproductive system resulting in infertility has been seen in other species, notably in elephants. The effects of Improvac® have not been well researched in marsupials.

Gonadotrophin Releasing Hormone (GnRH) agonists: GnRH agonists, such as deslorelin (Suprelorin ®; guideline below) or leuprolide acetate (Lupron®), reversibly suppress the reproductive endocrine system, preventing production of pituitary hormones (FSH and LH) and subsequently gonadal hormones (oestradiol and progesterone in females). The observed effects are similar to those following ovariectomy, but are generally reversible. GnRH agonists first stimulate the reproductive system, which can result in oestrus and ovulation in females soon after the implant is placed. The stimulatory phase can be prevented in females by treatment with a progestin or oral birth control pills for 2-3 weeks.

- **Deslorelin acetate (Suprelorin®) subcutaneous implant:** 1 x 4.7mg implant is recommended for a **minimum** duration of 6 months and 1 x 9.4mg implant is recommended for a **minimum** of one year. Due to the initial stimulation of the reproductive system, sexes should be separated OR the first bout must also be supplemented with additional contraception e.g. oral megestrol acetate (2-5mg/kg body weight Ovarid®/Megace®) daily 7 days before and 7 days after placing the implant(s). Suprelorin® is designed to be fully reversible. Treatment should start at least 1 month before the breeding season. In macropods deslorelin treatment might not inhibit the reactivation of a quiescent blastocyst and subsequent birth, but successfully inhibits follicular development and post-partum oestrus (in 4/5 animals (Herbert *et al.*, 2004)). We have 8 records of reversals in marsupials in our database. Four yellow-footed rock wallabies gave birth to live young 2-4 years after being implanted with 1x4.7mg implants, and four red kangaroos reversed between 2 months and 4 years after being implanted with 2x4.7mg implants. It is unknown whether implants were removed. In eastern grey kangaroos, 9.4mg implants have lasted for three consecutive breeding seasons in some individuals (Herbert *et al.*, 2005; Wilson *et al.*, 2013). In order to increase the chances of a full reversal, place the implant subcutaneously in a place where is easy to locate to facilitate removal i.e. subcutaneously in locations with thinner skin such as the base of the ear, inner thigh or arm, or umbilical region. Note that these implants are not designed for removal and disintegration may be the case which complicates locating and removing the implant over time. The most common side effect of Suprelorin® is weight gain.

Progestin-based contraceptives: Progestin-based contraceptives function by interfering with fertilization by thickening cervical mucus, interrupting gamete transport, disrupting implantation, and inhibiting the LH surge necessary for ovulation (etonogestrel and levonorgestrel implants, medroxyprogesterone acetate injections).

- **Levonorgestrel implant (Norplant 2®/Jadelle®) Intramuscular or subcutaneous implant:** 1 rod of 75 mg should be sufficient for contraception in this species. Implants last 36 months in tammar wallabies (Wilson *et al.*, 2013) and anecdotal evidence suggests that implants last for 5-7 years in koalas. Treatment should start at least 1 month before the breeding season. In macropods progestogen treatment might not inhibit the reactivation of a quiescent blastocyst and subsequent birth, but successfully inhibits follicular development and post-partum oestrus thereafter (Nave *et al.*,2000). Norplant 2®/Jadelle® is designed to be fully reversible and the implants have been shown to be reversible in tammar wallabies following removal.
- **Medroxyprogesterone acetate (Depo-Provera®) Intra-muscular injection formulation:** The recommended dose is 5mg/kg body weight every 2-3 months respectively. Latency to effectiveness is approximately 1-3 days however it is recommended that sexes should be separated for one week or the first bout must be supplemented with additional contraception for 7 days. Treatment should start at least 1 month prior to the start of the breeding season. Depo-Provera® is designed to be fully reversible and we have one reversal recorded in a red kangaroo in the database. The female conceived approximately 5 months after the estimated expiry date. As Depo-Provera® is not an implant, you will need to wait until the product has cleared from the individuals' system before they can reverse. A side effect of Depo-Provera® is that females may develop male secondary sex characteristics and there may also be an increase in aggression. There may also be a deleterious effect on the endometrium following prolonged use.
- **Etonogestrel (Nexplanon ®/Implanon®): Subcutaneous implant –**The recommended dosage of Nexplanon®/Implanon® (etonogestrel 68 mg) for this species is ½ - 1 full implant. The implant is effective for approximately 2.5 – 3 years. If this is noticed and not desired, a higher dose is recommended. Nexplanon®/Implanon® is designed to be fully reversible, however we have no records of reversal in marsupials in the database. To increase the chances of a full reversal it is recommended that the implant is placed in such a way that facilitates removal (e.g. subcutaneously in the upper inner arm). A side effect of using Nexplanon®/ Implanon® is potential weight gain.
- **Megestrol acetate (Ovarid®/Megace®) Oral contraceptive:** 2-5mg/kg body weight is recommended for use 7 days before and 7 days after the placement of Suprelorin® implants to suppress the stimulation phase. Treatment should begin in anoestrus.

Porcine Zona Pellucida vaccine: The PZP antibodies interfere with fertilisation by binding to the ZP glycoprotein receptors that surround the egg of the vaccinated female, blocking the binding and subsequent penetration of sperm.

- **PZP vaccine: Intramuscular injection formulation -** The first injection would consist of ~100ug of PZP protein. The recommended dose is 2 injections given typically 2+ weeks apart then a booster every 8 months for most species. For seasonal breeders, treatment should start 1-2 months before the breeding season. Latency to effectiveness is approximately 2-3 weeks after the final injection in year 1 therefore separation of the sexes from the initial injection until 2 weeks after the final injection is recommended. Reversibility differs between species; however the longer PZP is given the longer it takes for a female to come back to being fertile. It is therefore suggested that an individual is on PZP for no longer than 3 years if you want the female to breed. (Please visit WWW.SCCPZP.ORG for more information on the product and protocols). There are no contraindications for use during pregnancy and lactation. This product cannot be used in the UK.

10. Specific problems

Specific issues have been detailed all along these Best Practice Guidelines. One should however keep in mind:

- The urolithiasis issue in this species and the great care that should be paid to the diet,
- Population management is complicated with pouch-checking; thus training should be promoted, especially in females.
- For the same reason: work on temporary contraception should be developed.

11. Recommended research

Recommended research in YFRW includes:

- Human-animal interactions to adapt training/walkthrough exhibits,
- Urolithiasis formation, diagnosis and treatment,
- Toxoplasmosis vaccination,
- Milk composition,
- Pouch microbiota.

For more information on this recommended research, please contact the EEP coordinator.

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Appendix

Appendix 1: Examples of Diet sheets

NB : Diets must provide suitable fibrous plant material as the major component of the diet.
Those diets are coming from different European institutions, they might not be gold standards but interesting examples of diet used since several years without any medical issues.

Diet sheet from Zoo 1

For 5 animals		Quantity
Daily	Hay and lucerne	Ad libitum
	Macropods pellets	250g
Monday	Cabbage	500g
	Carrot	300g
	Sweet potato	200g
	Onion	100g
Tuesday	Lettuce	300g
	Carrot	300g
	Sweet potato	200g
	Onion	100g
	Celery (stem)	100g
Wednesday	Cabbage	500g
	Carrot	300g
	Sweet potato	200g
	Onion	100g
Thursday	Cabbage	500g
	Carrot	300g
	Sweet potato	200g
	Onion	100g
Friday	Cabbage	500g
	Carrot	300g
	Sweet potato	200g
	Onion	100g
Saturday	Lettuce	300g
	Carrot	300g
	Sweet potato	200g
	Onion	100g
	Celery (stem)	100g
Sunday	Cabbage	500g
	Carrot	300g
	Sweet potato	200g
	Onion	100g

- Vegetables: 2cmx2cm pieces.
- They graze grass in their enclosure.
- Browse (when available): willow, elm, ashes, cherry plums, butterfly bush, mulberry and bamboo.
- Other items offered time to time as enrichment (little amounts): spinach, endives, aubergines, courgette, fennel.

Diet sheet from Zoo 2

For 1 animal		Quantity
Daily	Hay	Ad libitum
	Grass	Ad libitum
	Branches	Ad libitum
	Rabbit granule	0,03kg
	Carrot	0,19kg
	Apple (in winter)	0,025kg
	Beet root, kohlrabi, parsley root	0,13kg
	Chinese cabbage, cabbage, cauliflower, broccoli	0,1kg
Tuesday & Friday	Ears - dry	0,1kg

- Vitamin E
- Selen

Diet sheet from Zoo 3

Per group		Quantity adult	Quantity juvenile
AM	Mazuri macropods pellets	100g	50g
PM Monday & Friday	Kale	106g	53g
	Carrot	65g	32g
	Onion	66g	33g
	Turnip	92.4g	46.2g
	Fennel	238g	119g
PM Tuesday & Saturday	Pak Choi	66g	33g
	Carrot	82g	41g
	Cauliflower	308g	154g
	Celeriac	46.2g	23.2g
	Aubergine	105.6g	52.8g
PM Wednesday & Sunday	Chicory	301.4g	151g
	Carrot	65g	32g
	Broccoli	158.4g	79.2g
	Mooli	132g	66g
	Fennel	237.6	118.8g
PM Thursday	Kale	145.2g	72.6g
	Carrot	65g	32g
	Onion	66g	33g
	Celery	88g	44g
	Aubergine	105.6	52.8g

- Browse and lucerne should be available at all time

Diet sheet from Zoo 4

For 16 animals		Quantity
AM Daily	Saint-Laurent® macropod pellets	1.2kg
PM Monday & Friday	Cauliflower (without leaves)	4kg
	Carrot	2.4kg
	Onion	530g
	Round turnip (without leaves)	480g
	Zucchini	2.4kg
Tuesday & Saturday	Lettuce	5.5
	Carrot	2.4kg
	Cauliflower (without leaves)	4kg
	Beetroot	480g
	Eggplant	1.2kg
Wednesday & Sunday	Lettuce	5.
	Carrot	2.4kg
	Broccoli (without leaves)	1.3kg
	Long turnip (without leaves)	1.3kg
	Zucchini	2.4kg
Thursday	Broccoli (without leaves)	3.2kg
	Carrot	2.4kg
	Onion	530g
	Apples	1.6kg
	Eggplant	1.2kg

- Hay must be given at will
- Quantities of food must be adapted according to the group and the leftovers.
- Food items that must not be given in case urolithiasis are diagnosed : leek, fennel bulb, chicory, spinach, celery (root or stalk), cabbage leaves, red cabbage, curly kale, beetroot leaves, broccoli leaves and stems, turnip leaves, dandelion leaves, lucerne, Swiss chard, curly lettuce, parsley.