Universidade de Trás-os-Montes e Alto Douro
Escola de Ciências Agrárias e Veterinárias – Departamento de Ciências Veterinárias

Quality of Life and Management of Geriatric Zoo Mammals

Dissertation of Integrated Masters in Veterinary Medicine

Érica Muriel Palmeira Rebelo

Supervisor: Professor Doutor Bruno Jorge Antunes Colaço

Vila Real, 2019

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Declaro que esta dissertação de mestrado é resultado da minha pesquisa e trabalho pessoal e das orientações do meu supervisor. O seu conteúdo é original e todas as fontes consultadas estão devidamente mencionadas no texto e na bibliografia final. Declaro ainda que este trabalho não foi apresentado em nenhuma outra instituição para obtenção de qualquer grau académico.

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Abstract

Ensuring the well-being of a captive animal throughout its whole life is one of the major concerns of today's zoological facilities. As a result of the growing concern and awareness about animal welfare and ethics, modern zoos evolved to put in first place species conservation, animal care and well-being. In addition to this paradigm shift, the last decades were also accompanied by a great scientific and technological evolution in the areas of Veterinary Medicine and Biology. These factors, among others, have led to an increase in animal longevity and, consequently, in the number of geriatric animals in the care of zoos.

Every multicellular organism undergoes a gradual deterioration of its morphological and functional characteristics and mechanisms, called senescence. This aging process can have a negative impact on the body's ability to withstand organ damage and return to homeostasis, leading to a number of degenerative age-related changes.

By taking a demographic approach to quantify the representativeness of the geriatric mammal population in three zoological facilities, it was possible to determine that this demographic group represented, on average 13.84% of the total mammal population.

A thorough analysis of geriatric morbidity and the age of diagnosis is required to improve the management and quality of life geriatric zoo mammals. To determine the pattern of morbidity of this demographic group, the prevalence and age at diagnosis of selected disorders was investigated, per taxonomic family. Musculoskeletal disorders represented the morbidity category with highest prevalence, followed by urinary system disorders. The prevalence of the selected disorders, as well as the proportion of deaths by euthanasia and non-euthanasia events, shows great variation between different taxonomic families. The most frequently over-looked *antemortem* diagnostics belonged to the hepatic, cardiovascular, urinary and neoplasia morbidity groups.

The evaluation of quality of life in this context is an area of great interest, with constant development and conception of new methodologies. The aging process is, inevitably, accompanied by numerous biological changes that have the potential to affect an individual's quality of life. It is, therefore, of utmost importance to systematically evaluate the quality of life of each animal in order to identify certain changes in the management of the collection, as well as assist decision-making regarding euthanasia. The assessment of quality of life of selected individuals was also carried out, by observation and behavior interpretation, which revealed to be a useful way of evaluating quality of life in geriatric individuals.

This dissertation aims, first and foremost, to promote a greater awareness amongst the scientific and zoo communities regarding the management and veterinary care of geriatric zoo mammals, encouraging the investigation, discussion and implementation of guidelines to improve the quality of life of this demographic group. The data collected provides the veterinary team and animal care staff with an overview of the issues inherent to biological aging and allows the identification of potential measures and solutions regarding environment design, husbandry, nutrition and veterinary care to improve the management and quality of life of geriatric zoo mammals.

Keywords: Geriatric, Quality of Life, Morbidity, Demography, Mammals, Zoo

Resumo

Atualmente, a manutenção da qualidade de vida de um animal em cativeiro é umas das principais preocupações dos jardins zoológicos contemporâneos. A crescente preocupação e maior conscientização por parte da sociedade com aspetos ligados ao bem-estar animal levou a que os jardins zoológicos evoluíssem no sentido de colocar em primeiro lugar o bem-estar dos animais ao seu cuidado. As últimas décadas foram também acompanhadas por uma grande evolução científica e tecnológica nas áreas da Medicina Veterinária e Biologia. Estes fatores, entre outros, levaram a um aumento da longevidade e, consequentemente, do número de animais geriátricos ao cuidado dos jardins zoológicos.

Todos os organismos multicelulares sofrem uma deterioração gradual dos seus mecanismos biológicos funcionais, designada de senescência. O processo de envelhecimento pode ter um impacto negativo nos mecanismos de controlo homeostático, levando a uma série de alterações degenerativas relacionadas com a idade.

De modo a quantificar a representatividade da população geriátrica foi realizada uma análise demográfica da população de três coleções zoológicas distintas. Concluiu-se que os mamíferos geriátricos representavam uma parcela significativa da população de mamíferos total, com uma percentagem de 13.84%.

O estudo da população geriátrica permitiu a identificação e descrição das morbidades por família taxonómica, assim como a determinação da idade de realização do diagnóstico das patologias selecionadas. Os distúrbios musculoesqueléticos foram a categoria de morbidade com maior prevalência, seguidos por distúrbios do sistema urinário. A prevalência das patologias selecionadas, bem como a proporção de óbitos por eutanásia e não-eutanásia, mostraram uma grande variação entre diferentes famílias taxonómicas. As patologias mais frequentemente não diagnosticadas *antemortem* pertenciam aos grupos de morbidade hepática, cardiovascular, urinária e neoplasia.

A avaliação da qualidade de vida neste contexto é, portanto, uma área de grande interesse, com constante desenvolvimento e conceção de novas metodologias. Inevitavelmente, com o avançar da idade, os indivíduos experienciam inúmeras alterações biológicas que têm o potencial de afetar a sua qualidade de vida. A avaliação sistemática da qualidade de vida de cada animal é, portanto, de extrema importância de modo a permitir identificar determinadas modificações na gestão da coleção, assim como auxiliar a tomada de decisões relativamente à eutanásia.

A abordagem desta temática visa promover uma maior sensibilização em relação aos cuidados de maneio e médico-veterinários dos animais incluídos neste grupo demográfico, incentivando a investigação, discussão e implementação de diretrizes para uma melhoria da qualidade de vida deste grupo demográfico. A informação contida na presente dissertação visa fornecer à equipa veterinária e de cuidado animal uma visão multidisciplinar em relação a questões intrínsecas ao envelhecimento biológico, a fim de identificar potenciais alterações nas instalações, procedimentos de maneio e nutrição, para melhoria da qualidade de vida da população em estudo.

Palavras-chave: Geriatria, Qualidade de vida, Morbidade, Demografia, Mamíferos, Zoo

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List of Abbreviations and Acronyms

AZA	Association of Zoos & Aquariums
CV	Cardiovascular
e.g.	*exempli gratia*
F	Female
i.e.	*id est*
Integ.	Integumentary
M	Male
Max	Maximum
Min	Minimum
MLE	Median Life Expectancy
MS	Musculoskeletal
NSAID	Nonsteroidal Anti-Inflammatory Drugs
SSL	Survival Statistics Library
SSP	Species Survival Plan

Chapter I - Literature Review

1. Introduction

Humans are innately attracted by the unfamiliar. Man's inquisitive nature was what led our ancestors to travel the world, navigate the unknown and always wonder about what exists around the corner. It was the curious nature of man and the desire to acquire knowledge that allowed evolution and drove us to seek information about what we don't know and what we have never seen. The exotic, the unfamiliar, the bizarre have always been an object of attraction. Perhaps this trait was what originated the wish of keeping exotic animals, along with the constant need for entertainment. In the past, in most societies, this egocentric behavior allegedly showed no concern with the animals' needs or with the possible negative outcomes of taking these animals into captivity. The desire to display unknown creatures as signs of power and wealth also meant to demonstrate human supremacy and influence in the natural world, regardless of the positive or negative outcomes. This was the case for ancient menageries, from the Queen Pharaoh Hatshepsut's exotic animal collection, in 3500 B.C in Hierakonpolis, Egypt[1,2], to the menageries in the Aztec society in the 1500s[2].

It was only around the 18th century that European menageries started to become concerned about ensuring animal well-being and comfort, through influence coming from the menageries of Asia and India. These societies displayed collections of animals that were housed in large facilities under conditions that ensured their comfort[2]. Later, during the 19th century, some newly created collections began defining themselves as zoological gardens, or simply zoos. These institutions wanted to make clear that their purpose was education and science rather than simply entertainment. Zoological gardens differentiated from the older concept of menageries by focusing on animal husbandry, exhibition design, education, veterinary medicine, research and conservation[2]. The first welfare legislation extends back to 1876, created in the United Kingdom and addressed general animal welfare regulations[3].

Carl Hagenbeck, who worked as a merchant of wild exotic animals in Germany during the end of the 18th century, opened the first zoo that attempted to better mimic animals' natural habitats, by using open enclosures instead of barred cages[2,4]. As pointed out by Kallipoliti[4], Hagenbeck *"invented the naturalistic exhibit in which obviously man-made landscape elements are avoided in favor of concealed barriers and simulations of natural landscapes"*. Hagenbeck's ideas were the basis of the great transformation of zoos throughout the 20th century, especially during the 1970s. The social justice movements and the increasing concern about rights and welfare, led to an intense pressure from the public to establish further and stricter regulations and standards. During this time, great advances in the medical field were made, and the creation of the AZA led to more cooperation between zoos and increased research and conservation activities[5].

Today, the 21st century ideal zoos are committed to promoting welfare of animals through the implementations of high standards concerning housing, sanitation, nutrition, ethology and veterinary care. Modern zoos evolved to put in first place species conservation, animal care and well-being. The growing concern about animal welfare and ethics was even more notorious in the past two decades, which were accompanied by an even greater development of modern technology, increased research, modernization and improved veterinary care, than in the 1970s. These factors, among others, such as the constant development and publication of animal care manuals, have led to better husbandry, veterinary care and nutrition of these animals. Consequently, this led to an increase in the longevity and subsequently to a growing number of captive aging animals in zoological collections. It is believed that the conditions provided in captivity, which eliminate predation and competition for resources, and offer appropriate nutrition, comfort and health care, contribute to the extension of longevity. These conditions allow captive animals from a wide range of taxa to outlive their wild counterparts[6]. An above-average life expectancy is considered a sign of successful management of zoo animals. Longevity is one of many parameters by which husbandry and preventive health care success can be quantified[7]. As captive husbandry and veterinary care continue to improve, we can expect an increase in longevity, similarly to what occurred in the end of the 20th century. In a little over 50 years, the maximum longevity of captive gorillas increased from 34.4[8] to 60 years[9]. The increased longevity in captive species means an increased number of individuals in the care of zoos, so it is believed that this demographic group is becoming more well-represented in the total captive population.

Regarding exotic and zoo animals, there is little consensus in the literature concerning when to consider an animal old. In small animal medicine it is agreed that one should use the word "senior" when referring to an animal that has reached 60% of their lifespan; and "geriatric" when an animal is in the last 25% of their average life expectancy[10]. The establishment of a percentual limit is particularly important to tackle the differences existent between dog breeds. Some authors might also say that pets in their last 10 percent of their lifespan qualify as geriatric[11]. However, when referring to captive wild animals, to the moment, there is no objective way to define a "geriatric" individual. Since both genetics and life events influence the way an animal ages and because aging is an individual process, chronological age does not necessarily match with biological age, which makes it difficult to pinpoint the age at which an individual is considered geriatric[12]. Nevertheless, it is necessary the existence of an objective way of classifying different stages of life, that should be used for reference.

Contributing to the obvious lack of an objective and agreeable way to draw the line between senior-geriatric, there is also scarce reliable and up-to-date sources of data regarding life expectancy and other demographic measures in wild and captive species. The Median Life Expectancy (MLE) of the most common species housed in AZA accredited or North-American zoos is freely available as the Survival Statistics Library (SSL)[13], providing a useful and easily interpreted insight on animal survivorship. This statistical measure means that 50% of the individuals in a given population die before reaching the MLE, and 50% live longer than the MLE. In order to simplify this complex matter and to provide better comprehension to the reader, henceforth the term "geriatric animals" refers to those older than 0.85 of the Median Life Expectancy (see Chapter II for explanation on MLE calculation and interpretation)

Zoological facilities face a number of practical and ethical difficulties inherent to the management and care of wild captive animals, which, as we've seen, are complex and challenging. Dealing with very limited availability of data in regard to veterinary reference values, behavioral baselines, standardized animal care guidelines as well as basic demographic measures, can be extremely challenging[14]. Moreover, challenges associated with caring for these animals are under-represented in the literature. The fact that only relatively recently zoological institutions have started to experience a growth in the aging population has led to a very limited ability to determine the best way to care for these animals. The number of individuals of a given species in one institution that reach old age is not sufficient for the caretakers to determine the best management methods only from personal experience. It is, therefore, of utter importance to conduct research and studies that address the issues that accompany these animals as they live to be older and older. The publications written concerning this matter, even though of limited number, made great scientific and practical contributions for the study, management and care of geriatric zoo animals[14–18].

2. The Aging Process: The Biology of Senescence

"Old age: the crown of life, our play's last act."
Marcus Tullius Cicero

In a similar way in all mammal taxa, old age brings its complications. The physical and mental health decline are normal consequences of the aging process as functional and morphological issues start to surface[19,20]. The aging process is accompanied by physiological changes related to the decline of biological functions, which can eventually lead to a degenerative pathological process. However, we must clarify that aging should not be considered a disease. While the physiological time-related deterioration of functional mechanisms is a mandatory event to every living organism, the occurrence of chronic, age-related conditions is not[21].

In most wild animal populations, there are only sporadic records of age-related diseases, in part because most animals do not live enough to develop these conditions and, if they did, it would jeopardize their survival[20]. The rate of aging is different for every species and is dependent on a number of factors, which, to a large extent, are genetically based[22]. Not surprisingly, not only there is immense variation in the rate of aging, but also in the biological consequences of senescence amongst species and individuals.

The body's ability to withstand organ damage and return to homeostasis is a characteristic thought to decrease with age[23]. There are a number of theories that propose to provide an explanation for the existence of aging. These theories fall into two main categories: The "Programmed theories" and the "Damage or error theories"[24]. The programmed aging theories imply that senescence follows a biologically predetermined timeline, whereas the damage or error aging theories claim that the cumulative damage suffered by an organism throughout its life is the reason for aging[24,25].

Regardless of the reasons for aging, growing old is an inevitable part of life. The aging process is accompanied by changes in all the body's cells, tissues and organs, thus explaining structural and functional deterioration in elderly individuals. This process, however, occurs in different ways and rates amongst species and individuals. Thus, the events outlined in this chapter described as biological consequences of the aging process, do not necessarily occur at the same rate or extent in every individual[23].

In the succeeding part of this chapter, time-related changes shall be described as per body system, as well as pathological disorders associated with the senescence-associated referred events.

2.1 Musculoskeletal System

Besides the obvious integumentary signs of aging, such as graying and dullness of hair, aging animals experience a series of musculoskeletal degeneration signs. The body composition changes as body fat tends to increase and lean mass and bone mineral density to decrease. Fragmentation of cartilage and collagen is accompanied by loss of both flexibility and muscle mass[10,26].

Degenerative joint disease, or osteoarthrosis, refers to a slowly evolving articular disease caused by degeneration of the articular cartilage. Occasionally, the terms "osteoarthritis" and "osteoarthrosis" are used interchangeably. However, they have distinct meanings: while the term "osteoarthritis" indicates that inflammation is present, the latter is a broader term. Osteoarthrosis is the product of life history and presence of predisposing factors – such as obesity, genetics, trauma, morphological features - which lead to mechanical changes and result in damage to the joint components[27,28]. The degradation of these structures can lead to an inflammatory process, but age-related arthritis is not necessarily an inflammatory process[27]. Henceforth, the term "osteoarthrosis" or "Degenerative Joint Disease" will be preferred as it refers to the primary morphological and structural process.

Although osteoarthrosis is a disease that's mainly related to aging and the "wear and tear" process, there are a number of predisposing factors that influence the onset of this process. The manifestation of this disease can be prematurely enhanced by husbandry and housing factors, like inadequate substrate, such as concrete[29].

Degenerative joint disease can affect any articulation of the body, including the articular facets of the vertebrae, which is often associated with disc space collapse due to the age-related desiccation of the nucleus pulposus, named degenerative disc disease[27].

Osteoarthrosis is the most common musculoskeletal disorder in aging humans, affecting between 60% and 70% of adults aged 60 years old and older[30]. Age-related osteoarthrosis has also been reported in exotic felids[17,18,31], bears[20,32], primates[33–36], procyonids [37] and elephants[38,39]. Animals suffering from a degenerative skeletal disorder might present lameness, alterations in gait, reluctance to move, decreased activity, joint swelling, stiffness and decreased range of motion[32,33]. Regarding nonhuman primates, osteoarthrosis has been documented in captive and free-ranging macaque populations older than 15 years old, affecting between 55% and 79% of the individuals, respectively[32,35]. Adkesson and Rubin[33] noted that, in general, captive aging non-human primates tend to show stifle, hip, interphalangeal and spinal osteoarthrosis. In the case of arboreal and quadrupedal aged non-human primates, these animals tend to present primary elbow osteoarthrosis. Given the tendency to hide pain, wild captive mammals with severe radiologic changes may only present mild clinical signs, so one should always assume that pain is present in an affected individual[33].

Weight reduction, nutraceuticals and modifications in the enclosure are measures that might help in managing osteoarthrosis[32]. Nutraceutical chondroprotectives like glucosamine and chondroitin sulfate can be used in the management of degenerative joint disease. These substances might help in supporting joint health by inducing synovial fluid production and cartilage repair. Solid scientific data does not exist and further studies are needed, but there is anecdotal evidence that it might help in managing progression of the disease and attenuation of clinical signs[40]. A research project carried out in free-ranging rhesus macaques concluded that increasing parity of up to 7 births in this species can be beneficial in the retention of bone mineral density, which seems to contribute in the reduction of the effect of bone loss from aging, while lower parity is associated with earlier osteoporosis[41]. Bellino and Wise[42] reported that the estrogen decline experienced after fertility cessation or menopause can accelerate bone loss and decrease bone mineral density in Old World Monkeys.

Facing the suspicion or diagnosis of an age-related degenerative skeletal disorder one should direct the treatment towards pain management and improvement of quality of life. Affected individuals should receive long-term treatment and potential concurrent diseases should be assessed in order to choose the best therapy. The use of NSAIDs is contradicted in animals with diagnosed kidney or hepatic disorders[43].

2.2 Alimentary System

Aging is also characterized by a number of changes in the gastrointestinal system. Older animals usually present certain changes in the oral cavity, characteristically age-related. Such changes include gingival retraction and hyperplasia, dental calculus and tartar accumulation, as well as oral tumours[26]. Periodontal disease and tooth loss are a common occurrence in both captive and wild elderly animals[27]. Alveolar demineralization owing to calcium deficits and periodontitis can lead to tooth loss. Fat infiltration within the salivary glands can result in decreased salivary secretions causing xerostomia[26]. Dental disease appears to be a significant cause of morbidity in a number of older captive species, namely apes[27,44], large felids[18] and bears[20]. Captive apes appear to frequently suffer from periodontitis, tooth loss, and bone resorption while the presence of caries is rarely seen. These conditions seem to be influenced by the age-related wear, inadequate diets and acid erosions caused by regurgitation and reingestion[27]. Dental calculus and abscesses have also been reported in aged captive large felids[18]. Kitchener[20] reported the high prevalence of dental disease in captive aged bears, namely broken canines, caries, and abscesses. Diabetes mellitus and cardiovascular disease are potential systemic contributing factors to these disorders[45].

It is of uttermost importance to systematically assess nutritional status and systemic health in order to maximize tooth preservation[27]. Animal care staff should be vigilant and attentive to the occurrence of clinical signs and behaviors that may indicate an abnormality in the oral cavity, such as difficulty eating or reluctance to do so, chewing unilaterally, dropping of food or increased chewing time, reluctance to drink cold water, swelling of gums, apparent abscesses or swellings and foul odor of the mouth[46].

Aging has also been reported to be accompanied by a decrease of smooth muscle tone, which may affect the peristaltic function of the gastrointestinal system. A decrease in gastrointestinal secretions is also to be expected, including salivary and gastric secretions, which may result in emesis, flatulence, gastric atrophy and reduced digestive ability. Nutrient absorption is also affected by a diminished output of pancreatic enzymes, reduction of intestinal epithelial cell replacement and renewal and villous atrophy[10,26].

The aging process is accompanied by a change in the composition and stability of gut microbiome, more specifically due to the shift in the proportion of beneficial bacteria[47,48]. Aging animals, such as primates and rodents, may suffer from gut dysbiosis influenced by age-related phenomena, such as immune dysfunction and chronic inflammation, leading to mal-absorption, constipation and prolonged intestinal transit time[47,49].

A gradual decline in liver function is an inevitable effect of the aging process. There are degenerative structural and functional changes, including the decrease in the number of hepatocytes and an increase of the lipid content inside these cells[50].

2.3 Respiratory System

Regarding the respiratory system, the most common consequences of aging include obstructive lung disease, chronic bronchitis, and increased susceptibility to infection[50]. The aging process is accompanied by a number of degenerative changes in function and structure. The degeneration of tissues and cells results in a decrease in volume and increase in viscosity of mucous, weakening of respiratory muscles, reduced cough reflex and ciliary paralysis - which may lead to retention of materials[10,26].

As a result of the aging process, there is increased risk of pulmonary fibrosis, which results in a loss of elastic fibers and decreased pulmonary capacity. There is also a reduction in both capillary blood volume and oxygen diffusion[10,26,50]. The decrease in oxygen transport and perfusion results in hypoxemia, which is a major factor in producing signs of senility, frequently seen in older animals[50].

The occurrence of respiratory disorders in both aging apes[27] and Amur Leopards[51] has been reported in the literature.

2.4 Cardiovascular System

Domestic animals in the last third of their average lifespan suffer a 30% decrease in cardiac output[50]. The age-related decreased oxygen diffusion and intramural coronary atherosclerosis are factors influencing the functioning of the aging heart. There's also myocardial and valvular fibrosis, which decrease the cardiac muscle's contractility and directly affects the cardiac output[10,26]. The vascular system undergoes a series of structural changes that compromise blood flow and perfusion in tissues and organs. Changes in the structural components of blood vessels cause thickening of the walls, especially regarding capillaries of the glomerular tufts and pituitary gland, as well as reduced elasticity and increased thickness of the wall of the aorta[50].

Cardiovascular disease is an important topic regarding great apes, since it's the leading cause of death in captive individuals[27,28,52–54]. It is known that the prevalence increases with age, although deaths in adult individuals have also been reported[27,28,54]. According to Lowenstein and colleagues[27], a review of Species Survival Plan populations revealed that cardiovascular disease was the leading cause of death of captive bonobos (45%), gorillas (41%), chimpanzees (38%) and orangutans (20%). In these animals, the occurrence of idiopathic myocardial fibrosis and cardiomyopathy was predominant. It is believed that hypertension is an underlying condition in the development of fibrosing cardiomyopathy in great apes[55,56]. Post-mortem examination reports showed a high prevalence heart lesions, such as left ventricular hypertrophy, which may suggest the occurrence of hypertension in captive populations[27,55].

It is believed that caloric restriction can be highly beneficial due to its alleged protective effects, at least in rhesus monkeys[36,57]. These effects include a 50% prevalence reduction of not only cardiovascular diseases but also neoplasms and endometriosis, and improved survival[57].

2.5 Urinary System

The biologic price of senescence includes progressive functional and structural degeneration of the kidney. With variable clinical implications, age-related changes to the urinary system are roughly equal in every aging subject[10,58]. The decreased renal function in these individuals is caused by a number of changes such as decreased glomerular filtration rate and renal perfusion, thickened capillary walls of glomerular tufts and ischemic atrophy and fibrosis of peritubular tissue[10].

Chronic kidney disease occurs when these structural and functional changes are irreversible[34]. The process of renal failure is accompanied by a reduction of renal blood flow and consequently diminished glomerular filtration rate and loss of functional nephron[26]. A decreased kidney function has a number of systemic consequences. Uremia can shorten the life span of erythrocytes, and a concomitant deficient erythropoietin production will certainly threaten the production of red blood cells by the bone marrow, leading to a non-regenerative anemia[26,59].

Chronic kidney disease appears to be highly influenced by diet. Captive diets are not equivalent to the regime in the wild, and intake of diets with inadequate nutritional composition, namely elevated protein content, may cause hemodynamic changes that accelerate the progression of the disease[60,61]. Captive animals of old age suffer from the cumulative effect of inappropriate diets fed throughout their whole lives, thus supporting the importance of proper nutritional management[15,18]. Once renal insufficiency is established, treatment and nutritional management should be immediately implemented and targeted to alleviate clinical signs and delay further progression of the disease[18].

Chronic renal failure has been documented in captive geriatric zoo mammals, such as exotic felids[18,51,60], polar bears[61] and primates[15,36]. These animals presented unspecific clinical signs such as polydipsia, polyuria, weight loss, vomiting and lethargy[61]. Renal disease seems to be highly prevalent in chimpanzees, being the second leading cause of death in the captive population[15]. Newkirk and colleagues[31] concluded that the development of tubulointerstitial nephritis in exotic felids was significantly associated with increasing age. Furthermore, the data collected allowed to conclude that long-term use of NSAID in exotic felids is associated with structural and functional kidney damage, similarly to what is largely documented in domestic animals[31].

The loss of sphincter tone has also been documented in geriatric pets[10,50,62] and is one of the main causes for urinary incontinence in these animals. Incontinence may occur as a result of neuromuscular and vascular changes, hormonal imbalance, diminished cortical control and senile involution[50]. Anecdotally, is has also been reported in elderly zoo mammals, namely large felids.

2.6 Endocrine System

The endocrine system is one of the most fundamental and complex body systems. It regulates a vast number of an organism's biological function, such as reproduction, metabolism, blood pressure, digestion and stress response. Therefore, it comes as no surprise that the age-related loss function of endocrine organs affects a number of systems.

Type II Diabetes Mellitus is a condition in which cells do not adequately use insulin to uptake glucose. In some situations, insulin production may also be compromised. The elevated levels of glucose in the blood may lead to numerous health conditions in both humans and nonhuman primates, including vision problems, decreased kidney function, nerve damage, and heart and circulation problems[63]. Type II Diabetes Mellitus is related to obesity and insulin resistance which in turn may be related to a number of factors in captive animal husbandry, including stress, diet, exercise, and contraception[64]. Biological aging is accompanied by metabolic changes characterized by insulin resistance, changes in body composition – lean and fat mass ratio-, and decline in growth hormone, insulin-like growth factor-1 (IGF-1), as well as sex steroids[65]. Together with the husbandry-related factors, Type II Diabetes Mellitus prevalence seems to be influenced by the aging process.

Type II Diabetes Mellitus is experienced by many species of nonhuman primates, especially in older obese animals, and it's characterized by fasting hyperglycemia and glucose intolerance[63]. In a study carried out in North American zoos, it was concluded that apes had the highest mean age of onset of the disease, followed by Old World monkeys, prosimians, and New World primates[64]. Many of the clinical findings associated with disease can be reduced by weight loss, caloric restriction, high fiber low-glycemic index diet and oral hypoglycemic therapy[64].

The endocrine system decline is also accompanied by changes in the thyroid gland, with a common occurrence of atrophy, hyperplasia, reduction of functional tissue[65]. There is also a decrease in response to triiodothyronine (T_3) and thyroxine (T_4). The adrenal gland also shows signs of age-associated deterioration, such as thickening of the capsule and trabeculae, hyperplasia and atrophy[50]. It has been described that both adrenal and parathyroid hyperplasia are frequent in older captive nondomestic felids[66].

2.7 Central Nervous System

The aging brain undergoes several molecular and morphological changes that are usually accompanied by behavioral and cognitive dysfunction. These events have been described in a number of species[67–69] and include neuronal loss, reduced neurogenesis, lipofuscin and inclusion bodies accumulation, fibrosis of the meninges, amyloid substance deposition, retraction of cerebral gyri and widening of sulci and brain atrophy[67,68]. According Youssef and colleagues[68] the occurrence of amyloid plaques has been described in species such as *Pongo spp., Gorilla spp., Saimiri sciureus* and *Saguinus spp.* The appearance of so-called senile plaques, which results from accumulation of beta amyloid substances, parallels a similar phenomenon in humans with Alzheimer's disease and can cause cognitive impairment[67,68].

Nondomestic felids also appear to experience cognitive dysfunction and behavior abnormalities associated with age[66,70]. Post-mortem examinations in aged large felids verified the presence of brain abnormalities related to accumulation of beta amyloid substances and changes in T phosphorylation[70], causing cognitive impairment. Furthermore, it has been described that neuronal lipofuscinosis is significantly associated with age in nondomestic felids[66], not being necessarily associated with the occurrence of clinical signs.

2.8 Immune System

The immunosenescence refers to the age-related deterioration of the immune system. Aging is a complex process which affects a number of physiological functions, including the immune response. Such deterioration predisposes geriatric individuals to increased morbidity and mortality related to infectious processes and development of age-related disorders[27].

The process of senescence is characterized by a number of changes which increase the risk of developing a neoplastic process, such as the cumulative effect of lifelong exposure to carcinogens, decline in antitumor defense, less immune competence, decreased DNA repair, damaged tumor suppressor genes and defects in biological responses[10,71]. Reduced functional reserve of multiple organ systems and an increase prevalence of chronic diseases may cause various clinical signs that may mask neoplasia.

2.9 Reproductive System

Age-associated changes within the reproductive system are intrinsically connected to the endocrine system functional decline. Nevertheless, regarding reproduction one can say that there is a significant diversity of reproductive characteristics across taxa. Thus, there is great variability in the way aging affects the reproductive function and anatomy across mammalian species[72]. Female New World Monkeys and Prosimians do not experience a progressive decline in fertility as they grow older, but rather an abrupt reproductive decline near the end of life. Nevertheless, it is believed to exist a decline in maternal fitness causing increased infant mortality rate[73]. On the other hand, Old Word Monkeys and some apes experience a process analogous to perimenopause, with gradual decline of reproductive fitness[74].

2.10 Special Senses

Biochemical and biophysical changes that go with the aging process are some of the factors contributing to the degeneration of ocular tissues. The occurrence of ocular disease is also influenced by predisposing factors such as trauma, nutritional deficiencies and genetics[75]. Thus, older animals often suffer from ocular diseases such as cataracts due to the cumulative effect of predisposing factors and age-related physiological tissue degeneration. Nuclear sclerosis is also a common finding in older dogs and occurs as a result of increased density of the lens fibers [50].

Captive pinnipeds are known to have a high prevalence of ocular diseases[75–78]. Captivity may result in an extended lifespan, which allows the development of age-related changes. A series of husbandry factors and practices predispose pinnipeds in captivity to develop ocular disease such as lens luxation and cataracts[75]. A study involving 111 pinnipeds concluded that the occurrence of cataracts was increasingly higher with age. The prevalence was 87% in animals aged between 21 and 25 years old and 100% in those older than 26 years old[78]. The onset of disease is influenced by the cumulative effects of several other factors that may contribute significantly to ocular disease in pinnipeds are trauma, enclosure characteristics, husbandry, nutritional deficiencies, and genetic predisposition[75].

Ocular diseases in aging non-human primates has also been described in various studies[58,79–81]. Age-related conditions include decreased visual acuity, cataracts, macular degeneration and corneal leucoma. Hypertension can also have ocular related consequences, such as retinal vascular arteriosclerosis[27].

The reduced hearing ability is also thought to be common in geriatric dogs, and occurs mainly due to fibrosis of the cochlear blood vessels, reduction in the number of hair cells and degeneration of the ganglia[50]. The sense of smell might also be affected in older individuals as a result of degenerative changes of the mucosa and changes in the vascular and nervous systems[50].

3. Management and Quality of Life

Animal caretakers, veterinary staff and collection managers should focus on establishing an adapted holistic management approach regarding the management of geriatric animals in their care. This can be achieved by understanding age-related biological consequences, assessments of quality of life, special husbandry and nutritional requirements, palliative care and criteria for euthanasia. Creating a working group to design and establish a plan for senior/geriatric animals is essential, as provides different insights and allows the creation of roles[82]. Such team should consist of key staff members with specific roles – that are closely entwined - and that can provide expertise in different areas. Ideally, the working group should include:

- The veterinary team: the veterinary doctor(s) and nurses are responsible for the medical management of the animals, including preventive health care program, clinical examination, diagnosis and treatment plan. Occasionally, a consulting veterinarian can be included, as to provide specialized insight and expertise;
- The curator(s) is responsible for overseeing all aspects of animal management, as well as collecting and analyzing information from both zookeepers and the veterinary team so as to make decisions and identify possible changes on husbandry, nutrition and housing;
- Zookeepers provide information that can only be obtained when working with the animals on a daily basis. Thus, behavioral changes and clinical signs are usually primarily recognized by zookeepers, who should be able to recognize and report such changes to the veterinary team and curators. Treatment plans are usually to be conducted by zookeepers, according to the instructions provided by the veterinary team.

The plan should be carefully and objectively analyzed as a whole by all members of the working group and decisions should be made as a team[82]. Represented on Fig. 1 are the proposed steps to help design a multidisciplinary geriatric plan.

Figure 1 – Main topics in a Geriatric Animal Health Care and Management Plan

3.1 Selection of individuals

When designing a geriatric animal health care and management plan, the working group shall agree upon the best way to select individuals. The significant individual aging rate variation is a significant barrier in objectively classify an individual as "geriatric". This variation can therefore be accounted for by taking into consideration three domains, that might help the working group in the characterization of an geriatric animal: chronological age, or the time elapsed since the animal's birth; physiological age, or the morphophysiological changes comparing to a younger self; and demographic age, or the comparison between the chronological age of that animal with the rest of the population[83–85]. As previously stated, in this dissertation, the geriatric population corresponds to animals older than 0.85 of the MLE for the species. This classification could also be used by the animal care team, as a guideline.

3.2 Preventive Health Care Program and Clinical Examination

A comprehensive preventive health care program should be the foundation of the veterinary medical program of any collection of captive wild animals. The medical management of the collection should include as follows:

1. Daily Health Monitoring
2. Routine physical examination
3. Vaccination
4. Nutrition

3.2.1 Daily Health Monitoring

The daily monitoring of the animals in the collection will allow the early detection of diseases and consequently improve the chance of successful treatment. The daily observation is usually performed by the animal caretakers, who should be provided with guidance and knowledge by the veterinary team. A relationship of open communication should be accomplished between the two parts, so that accurate information on the animal's condition can be easily shared and understood. The veterinary team should be responsible for instructing the animal care team on the recognition of certain clinical signs and behaviors that could indicate a health problem.

Health monitoring should include, apart from frequent observation, regular weighing of the individuals. An unexplained sudden or progressive weight loss might indicate a potential health problem that should be investigated.

3.2.2 Routine Physical Examination

Generally speaking, a routine physical examination is recommended for every species, with some exceptions, at least every other year[86]. Routine physical examinations should be a part of preventive medicine protocols for aging patients. These examinations allow the collection of samples for analysis and performance of noninvasive imaging procedures, thus allowing the identification of problems before they aggravate or even arise and are useful when assessing pharmacologic safety. Due to the untamed nature of the animals one deals with at a zoo, anesthesia or sedation is usually necessary to conduct a complete physical examination. Regardless of the animal's age, there is always a risk associated with chemical immobilization. However, aged individuals are at a greater risk due to the higher prevalence of degenerative and chronic diseases. The anesthetic procedure should be preceded by an assessment of the risks, taking into consideration health status, attitude and body weight. If possible, risk assessment should include conscious venipuncture for evaluation of blood parameters[18,87].

The physical examination of an anesthetized animal should include, but should not be limited to: blood tests, urine analysis, fecal sampling for culture and/or parasitology, vaccination, ultrasound, radiology and dentistry procedures[88].

In certain species, it's possible to carry out at least part of these examinations without need for anesthesia. Animals that are deemed at risk for anesthetic complications should be trained for these procedures using positive reinforcement, in order to avoid resorting to anesthesia and to allow performing these assessments as frequently as needed.

3.2.3.1 Anesthesia

Animals of advanced age are considered of higher anesthetic risk because of changes in cardiovascular and respiratory function, and higher prevalence of disease processes[87].

As previously discussed, it is important to evaluate individual risk factors so one can assess the animal's fitness for anesthesia. Dangerous animals that are not trained for venipuncture are difficult to perform a pre-anesthetic exam on[88]. Pre-anesthetic blood work should include a complete blood count and serum chemistry in order to assess organ function, overall health and nutrition and hydration status. Important parameters include packed cell volume, total protein, blood urea nitrogen and blood glucose[88].

Table 1 - American Society of Anesthesiologists' categories of anesthetic risk (Adapted from ASA[89])

Category	Definition
ASA I	Normal healthy patient with no detectable disease
ASA II	Slight or moderate systemic disease causing no obvious incapacity (e.g. aging,
ASA III	Mild to moderate systemic disease, causing mild symptoms (e.g. moderate pyrexia, anemia or hypovolemia)
ASA IV	Extreme systemic disease constituting a threat to life (e.g. toxemia, uremia, severe hypovolemia, cardiac failure)
ASA V	Moribund or dying patients

Only after obtaining all the information from a preanesthetic evaluation one can establish a safe anesthetic protocol. As described by Hall[90], The American Society of Anesthesiologists (ASA) Patient Status Scale[89] can provide a useful way of categorizing the animal when evaluating anesthetic risk (Table 1), thus making it possible to implement a safe protocol. If immobilization is to be performed in a diabetic animal, there are a few anesthesia related considerations to be made. The fasting period before the procedure should be minimized and blood glucose levels should be monitored during and after the procedure[91].

Considering that a decrease in the muscle mass is an age-related physiological change[10], careful dart selection and placement is essential when using a remote drug delivery system. The location of the darting procedure should also have an adequate design, to avoid a fall from a shelf during anesthetic induction which could easily result in a fracture[33]. This is a valid thought for any and every animal but is particularly relevant for elderly patients. Ideally, animals should be trained for hand-injections to reduce stress and ensure the procedure is uneventful.

As stated in the "American Animal Hospital Association Senior Care Guidelines for Dogs and Cats"[92], during anesthesia the animal should be closely monitored and the vital parameters (heart rate, respiration rate, oxygen saturation, blood pressure, body temperature) should be recorded by a trained veterinary team member. Intravenous or subcutaneous fluid support is crucial; type of fluids and rate of administration should be selected cautiously, considering renal or cardiac dysfunctions[92].

"There are no safe anesthetic agents, there are no safe anesthetic procedures. There are only safe anesthetists." - Robert Smith, MD

3.2.4 Vaccination

Immunosenescence is the term given to the age-related deterioration of the immune system and is characterized by a decline in the immunological response leading to increased susceptibility to infections and a weakened response to vaccination[71].

The inherent advantages of vaccination in zoological collection is a subject of controversy. In zoological facilities, recommended vaccination protocols are designed according to the geographic location and epidemiological status of certain infectious diseases. The increased susceptibility to infection makes vaccination particularly important for animals at higher risk of serious complications from influenza, such as gorillas with cardiac disease or aging animals with reduced mobility and/or concurrent disease syndromes[93]. Noncore vaccines are only required by animals deemed to be at risk of contracting specific infections. Carrying out of vaccination for each animal should take into account the potential risks and benefits of each type of vaccine[94]. It is necessary for clinicians to exercise careful judgment on the need to vaccinate the collection, particularly when referring to aging animals.

3.2.5 Nutrition

Age-related physiological changes may affect feeding, appetite, nutritional requirements and nutrient absorption. These changes include higher prevalence of periodontal disease (that might affect mastication), decreased enzyme secretion - namely, salivary and pancreatic enzymes-, reduced appetite, impairment of sensory nervous system, decreased lipid absorption from GI tract, increase of body fat percentage and decrease in lean mass and reduced excretion of waste products[10,95,96].

According to Bellows[96] it is clear that older animals show a decline in energy requirements because of a decrease in both basic metabolic rate and activity levels. This physiological metabolic rate decline is caused mainly by the shift in body lean/fat mass distribution[96].

Elderly animals ought to receive diets adjusted to their limitations. Individual body condition should be assessed regularly, teeth wear should be monitored closely and, ideally, energy content should be adjusted[97]. Further adjustments should include softening of hard food, addiction of extra water for a chronic renal failure patient, and give preference to the animals preferred foodstuffs, while still maintaining a balanced diet[46].

3.3 Quality of Life

Inevitably, the final stages of life are accompanied by physical and mental transformation which may potentially affect the quality of life of geriatric patients. However, the impact of such age-related changes in one's life may be minimized if they are properly recognized and addressed. The systematic evaluation of animal well-being in this context is, therefore, of utmost importance. The constant development and conception of new methodologies to infer quality of life from animal behavior helps animal care professionals in the identification of certain changes in the management of the collection, as well as assist decision making regarding euthanasia.

Yeates[98] states that "quality of life" can be defined as a concept that outlines the perception of an individual's value of its own life. It's a multidimensional concept that relates the animal's experiences and its perception; it's a broad idea that extends over time and is particular to that individual. There is no objective way or unit of measurement of quality of life.

The terms "welfare" and "quality of life" shouldn't be used interchangeably. Yeates[98] postulates that an animal presents good or bad welfare at any given point, but quality of life refers to the animal's welfare over an extended period of time. Quality of life assessments should not rely on a single moment in time, but on the cumulative effects of a set of moments, as this concept is dynamic and not static.

The "5 Domain Model for Quality of Life" was developed as an alternative approach to the widely used "Five Freedoms" to facilitate animal welfare understanding and assessment[99]. The "Five Freedoms" paradigm is considered by Mellor to be an unattainable concept of quality of life, as it tries to reflect utopic principles that do not provide appropriate measurement of animal welfare. This model provides examples of how internal and external factors cause negative and positive experiences, the combined effects of which give rise to an animal's welfare status. Nutritional, environmental and physical health domains can be further classified as survival-related factors, and behavior is a situation-related factor. These domains are in close relationship with each other, and Mellor[99] believes welfare is achieved as a result of the balance between positive and negative experiences. The 5 Domains Model considers 2 distinct types of physical/functional domains, classified as significant to the welfare of an individual: internal domains, labelled "Nutrition", "Environment" and "Health"; and an external domain, labelled "Behavior". The 5th domain, "Mental State", is the result of cumulative effect of internal and external domains.

Behavior may be described as *"all processes by which an animal senses the external world and the internal state of its body, and responds to changes which it perceives"*[100]. In order to recognize abnormal behavior, one should be able to recognize normal behavioral repertoire for a given species. However, what is normal for a certain group of animals can be abnormal for a given individual, as normalcy can vary from subject to subject.

The evaluation of an individual's quality of life is vital as it allows us to identify any deviation from the normal behavior repertoire of that individual and assess the need of enclosure modifications, husbandry alterations, diet and nutritional adjustments, and deciding on the necessity of euthanasia. According to Mellor the balance of positive and negative experiences makes it possible to categorize and define a quality of life scale (Table 2)[99].

Table 2 - Quality of Life Scale (Reproduced from Mellor[99])

Classification	Description
A good life	The balance of salient positive and negative experiences is strongly positive. Achieved by full compliance with best practice advice well above the minimum requirements of codes of practice or welfare
A life worth living	The balance of salient positive and negative experiences is favorable, but less so. Achieved by full compliance with the minimum requirements of code of practice or welfare that include elements which promote some positive experiences
Point of balance	The neutral point where salient positive and negative experiences are equally balanced
A life worth avoiding	The balance of salient positive and negative experiences is unfavorable, but can be remedied rapidly by veterinary treatment or a change in husbandry practices
A life not worth living	The balance of positive and negative experiences is strongly negative and cannot be remedied rapidly, so that euthanasia is the only humane option

As previously discussed, due to the lack of an objective way to determine which animals are considered geriatric, the list of animals to be assessed should be determined by the working group, by taking into consideration the three parameters we can judge an animal's aging: chronological age, physiological age and demographic age. Quality of life assessments in aging animals should be carried out not only to provide insight and perception of the right moment to perform euthanasia, but most importantly to improve the animal's well-being during old age.

Due to every animal's unique perception of a "good quality of life", it is not possible to standardize a quality of life assessment. It is, therefore, a complex evaluation that should assess every domain relevant and valued by an individual. The analysis of quality of life is useful as a holistic approach that reflects every aspect influencing the animal's apparent satisfaction with its own life.

It's imperative to recognize that there's an individual variation in the perception of the domains necessary to ensure a positive quality of life. Because of the animal's lack of verbal communication skills, the judgement of quality of life relies, unavoidably, on human perception. This makes this evaluation vulnerable to subjective connotation and susceptible to interpretation bias, as each observer may have a distinct interpretation of an ambiguous situation[101]. As a result of the absence of an objective method to determine an animal's point of view regarding the value of its own life, animal welfare at any given point should be inferred from behavior. Due to the animals' inability to verbalize, one must rely on the animal's body language and expression of certain behaviors in order to understand the individual's perception towards any given situation or moment. The expression of certain behaviors will allow us to evaluate if the animal is in pain, distress or discomfort.

The presence or absence of a behavior of the normal repertoire can be used in reference to evaluating animal welfare. An abnormal behavior can be classified as quantitative (increased or decreased frequency of a behavior, e.g. repetitive locomotion) or qualitative (demonstration of a behavior normally not perceived in an animal in a good welfare state, e.g. self-injury). This behavioral deviation can be attributed either to an adaptive mechanism in responsive to the environment or to a pathologic process. When considering behaviors as a measurement for welfare, one should determine whether the behaviors are a meaningful indicator of good or poor welfare[102].

Quality of life assessment forms should be created and used for the objective collection of information that will allow the overall and internal analysis of an animal's condition. It should comprise questions that cover all domains to be evaluated and should be of easy comprehension to avoid misinterpretation. The form ought to be filled out for each individual animal and must contain information such as identification of the individual (House name/Identification number, Species, Sex, Date of birth, Current age); questions addressing health status (diseases diagnosed, treatments, clinical signs), nutrition (current diet), enrichment and a behavioral assessment.

3.4 Environment, Housing and Group Management Considerations

As previously professed in this dissertation, age-related physiological can lead to a number of physical and mental consequences that will inevitably change the way these animals are able to respond to and utilize their surroundings.

The overall decline in an individual's both mental and physical domains associated with aging may, or may not, have an impact on social status and interactions[14]. Depending on the species social structure and whether animals are maintained in group situations, an individual might be regarded as weaker, worthless and consequently lose its position in social hierarchy. This can affect access to food and can lead to aggression, ostracization and bullying by other members of the group. In some cases, it might useful to conduct separate feeding routines, provide visual barriers or even separate animals from the group. In some species, the quality and quantity of social interactions may also be influenced by the aging process. For example, in some species of macaques, with advancing age, males tend to become more social, while females tend to withdraw from social interactions[103].

Decreased mobility is one of the most noticeable effects in geriatric animals. The onset of degenerative joint disease can severely affect the animal's ability to locomote and can even confine the animal to a particular site of the exhibit. For example, it may become impossible for the animal to climb, jump onto high structures, leap between gaps or confidently ambulate in some types of surface[103]. In addition to veterinary treatment, husbandry and enclosure design modifications should take place in order to improve the animal's quality of life. The provision of soft substrates and rubber mats may help in the locomotion of these animals. Furthermore, the installment of non-slippery and non-flexible structures is worth considering, as geriatric animals with decreased mobility tend to prefer stable and fixed furniture[103]. Thus, elements such as flexible walkaways, rope and swings should be replaced by stable and steady structures. In addition, ramps can be also installed to ease access to different parts of the enclosure. Vertical climbing structures are often avoided by animals with impaired mobility[103]. Thus, furnishing the enclosure with ramps, or even steps, can provide ease of access and decrease the probability of falls. When designing and installing different components of an enclosure, one should also take into consideration the width of perches and climbing structures, in order to maximize comfort and safety[103].

Thermoregulation may become less efficient as a consequence of reduced body mass, adipose tissue redistribution and alterations in the fluid-compartmentalization[84]. Some modifications to the enclosure may make the environment more appealing and comfortable to older animals. By providing additional heat sources and thermo-neutral materials and substrates, one is allowing the animal to make behavioral adjustments to thermoregulate[103]. Enrichment elements and furniture should be composed of wood or plastic, and, for floor coverings and beddings, the provision of extra wood shavings, straw, bark and blankets can be beneficial for older animals[103].

When one is dealing with animals with impaired sight, the animal care team should create a consistent routine and a safe and appropriate environment[46]. Animal enrichment should be adapted to the visual impairment, thus focusing on olfactory, auditory and tactile stimuli. In this way, there is stimulation of the animal's senses, which are essential for mental and physical health[46]. The placement of tactile and olfactory markers can also help the animal navigate its environment through non-visual senses. Zookeepers should also ensure consistent placement of food and water or the implementation of hand-feeding sessions, if possible.

The adaptation of indoor and outdoor enclosures and exhibits to animals' limitation doesn't necessarily follow any rule or guideline. Experimentation should be made, even if the animal doesn't seem immediately interested in the new set-up. Sharing experiences and structures adapted to suit an animal's mobility issue amongst the zoo community could be extremely beneficial.

3.5 Palliative Care and Euthanasia

The World Health Organization describes palliative care as *''an approach that improves quality of life of patients and their families facing problems associated with life threatening illness through the prevention and relief of suffering by early identification, impeccable assessment and treatment of pain and other problems, and physical, psychosocial and spiritual care''*[104]. Such approach can and should be applicable to both human and animal care. If it's decided by the quality of life team that the animal in question is imminently dying but its welfare is not being affected and pharmacological therapy is efficient, the animal may eligible to receive humane and ethical care during its last moments. End-of-life care must rely on 3 central principles: Emphasis on comfort and relief of pain and anxiety; ensuring quality of life and respect for the animal's needs[105].

Palliative care should be dedicated to providing comfort and quality of life for the animal and must not be a tool used to prolong life beyond what is wise. Pain management is crucial as chronic age-related conditions usually undermine an animal's well-being. Pain medication should, therefore, be administered as needed and its efficacy must be addressed and reviewed, as needed[106].

It is important that quality of life is assessed regularly to make sure one is not prolonging the animal's life beyond what's reasonable. As humans, we tend to put an anthropomorphic view, even if unconsciously, when we judge the animals' perception of their own lives. It is of utmost importance to be able to recall that an animal does not value extended life *per se* since it does not have the ability to see beyond the present moment. Therefore, the focus of the medical management of the geriatric patient, which is experiencing age-related disorders, should be controlling pain and suffering, by implementing pain control therapy and other measures to improve quality of life[107]. When the quality of life assessments show that it's no longer possible to ensure the animal's comfort and well-being, immediate action must be taken.

After the careful analysis of the quality of life assessment, the team should analyze therapeutic possibilities or environmental modifications, or if this animal is to be considered for euthanasia. The animal-human bond established between the zoo staff members and the animals in their care is usually and strong as the bond between pets and owners. Due to the deep personal attachments with the animals, it might be useful to resource to objective methods to aid in decision-making[108]. Defining unique behaviors and traits of an animal can ease this decision. This method consists in the determination of 3-5 normal behaviors that seem to be key elements in the animal's perception of quality of life. When the individual ceases to experience 2/3 or 3/5 of the key behaviors, the most reasonable call is for the animal to be humanely euthanized. By establishing these key behaviors, the animal care team can make a decision, as objectively as possible.

Management considerations often also weigh on the decision to euthanize a geriatric animal. Apart from the animal's quality of life, facilities often take into consideration other elements when euthanasia is being discussed. These factors, that fall into the category of population management[108], include cases of animals no longer reproductively active or not genetically important for the population. Logistical and monetary aspects may also weigh on the decision when the cost, space and time needed to accommodate and care for a geriatric animal are not reasonable. All in all, these considerations are legitimate, relevant and, if completely justified, ethically acceptable.

3.6 Postmortem examination

The *postmortem* examination, or necropsy, is an essential tool for the veterinarian. The information obtained from a complete necropsy – which should include both macroscopic and microscopic examination – can be useful in several ways. The information obtained is essential to determine the etiology of a disease, the cause of death in unexplained or natural deaths, and the etiological process. It can also be useful to confirm an *antemortem* diagnosis or to provide new information on a process that went unnoticed or unexplained in clinical examinations. In this way, necropsies are useful in the clarification of clinical signs, allowing to confirm, correct or refute a diagnosis. The information obtained from *postmortem* examination is extremely valuable for the living conspecifics, by providing a crucial educational tool for veterinarians and contributing to the understanding of the disease process. Necropsy findings should also be reported to the relevant parties, such as zookeepers and curators, as to enhance comprehension of both disorders and associated symptomatology, as well as promote discussion and implementation of preventive measures. By increasing the accuracy of interpretation of clinical signs and diagnosis, living specimens will benefit from early diagnosis, treatment and management.

Chapter II - A Demographic Approach to the Geriatric Mammal Population in Zoos

1. Introduction

The number of geriatric individuals in zoological collections is thought to be increasing. A number of events associated with technological, scientific and even social and cultural modernization and evolution, led to a more successful management of zoo animals. With an increased number of animal species outliving their wild counterparts[6], and an increased longevity observed in captive animals[8,9], this demographic group is believed to become progressively more represented in zoological collections.

The demographic categorization of exotic mammals species is a challenging process. Since one should take into consideration a vast array of species, with very distinct characteristics, it is not yet decided on the most objective criteria to consider when classifying an animal as geriatric. Since both genetics and life events influence the way an animal ages and because aging is an individual process, chronological age does not necessarily match with biological age, which makes it difficult to pinpoint the age at which an individual is considered geriatric[12]. This variation, at both individual and taxa levels, can be accounted for by considering three domains, that might help in the characterization of a geriatric animal: chronological age, or the time elapsed since the animal's birth; physiological age, or the morphophysiological changes comparing to a younger self; and demographic age, or the comparison between the chronological age of that animal with the rest of the population[83–85]

2. Aims

The aim of this chapter is to analyze the size, structure, and distribution of the living geriatric population of three zoos. A secondary objective of this study was to calculate the Median Life Expectancy for relevant species for the purpose of this dissertation, with no MLE value available from the literature .

3. Materials and Methods

The study population of this study comprises animals from three different zoological facilities (Zoo 1, Zoo 2 and Zoo 3). For ethical reasons, and as requested, the names of the institutions will not be disclosed, and the animals shall not be linked specifically to any of the zoos. Two of these facilities are located in Europe, while one is located in North America.

Since physiological age is more liable to subjectivity, as to standardize the methodology, only the chronological and demographic ages were considered in the selection of individuals. The demographic age was determined by comparison of the chronological age with the Median Life Expectancy for the population. As to standardize this demographic age amongst species, the ratio of MLE was used. The study population consisted of living individuals aged ≥ 0.85 of the MLE for that species, using data from the Survival Statistics Library[13]. The ratio of MLE was calculated as follows:

$$MLE\ ratio = \frac{Chronological\ age\ of\ the\ animal\ (years)}{MLE\ value\ for\ the\ species\ (years)}$$

For example, the MLE ratio of a Ring-Tailed lemur can be calculated by dividing the age of the animal (Age = 16.67 years) by the MLE value for the species (MLE Ring-Tailed Lemur = 16.5). The MLE ratio is 1.01, which is almost the same value of the MLE for the species (which ratio is considered 1.00).

The MLE means that the half of the population died before reaching this age, and the other half survives past this age. The MLE ratio puts in perspective the age of the animal in relation to the rest of the population, and it's a value that can be compared between different individuals from different species, because it represents a ratio and not an absolute value.

The data compilation and analysis relied on Microsoft Excel® software.

a) Calculation of MLE

In 5 relevant species for this dissertation - Livingstone Fruit Bats (*Pteropus livingstonii*), Golden Lion Tamarins (*Leontopithecus rosalia*), Black Lion Tamarins (*Leontopithecus chrysiopygus*), Alaotran gentle Lemurs (*Hapalemur alaotrensis*) and Malagasy Giant Jumping Rats (*Hypogeomys antimena*) - no MLE was available in the literature. The mortality records of each zoo were analyzed and the MLE was calculated. This calculation was performed according to the methodology used in the Survival Statistics Library[13]. The mortality local records for each selected mammal species were analyzed using information compiled on Species360. Age at death of every individual of the species in question was noted and the median value was calculated. Individuals deceased before the first year of age were excluded, as to match the methodology of the SSL.

b) Living geriatric population

After careful analysis of the animal records on Species360 from each three facilities, a total of 88 living individuals from 35 species were selected and are represented in Table 3. Out of a total of 88 subjects, 44 were females (50.00%) and 44 were males (50.00%). Only those species whose MLE is available or could be calculated were considered (see Appendix A for a table showing MLE, 0.85 of MLE and longevity data regarding selected and relevant species for this dissertation).

Table 3 - Study population. Living geriatric animals, by species, at three zoological facilities

Species	N	Species	N
Bat, Livingstone's fruit (*Pteropus livingstonii*)	10	Monkey, Common Squirrel (*Saimiri sciureus sciureus*)	3
Bat, Rodrigues Fruit (*Pteropus rodricensis*)	3	Okapi (*Okapia johnstoni*)	1
Capybara (*Hydrochoerus hydrochaeris*)	1	Orangutan, Sumatran (*Pongo abelii*)	3
Colobus, Black-and-white *(Colobus angolensis angolensis*)	3	Otter, North American river (*Lontra canadensis*)	3
Gibbon, Lar (*Hylobates lar*)	2	Panda, Red (*Ailurus fulgens fulgens*)	2
Gorilla, Western lowland (*Gorilla gorilla gorilla*)	4	Rat, Malagasy Giant jumping (*Hypogeomys antimena*)	2
Kangaroo, Matschie's tree (*Dendrolagus matschiei*)	1	Saki, White faced (*Pithecia pithecia*)	2
Lemur, Alaotran Gentle (*Hapalemur alaotrensis*)	3	Sloth, Hoffmann's two-toed (*Choloepus hoffmanni*)	1
Lemur, Black and White Ruffed (*Varecia variegata*)	2	Sloth, Linne's two-toed (*Choloepus didactylus*)	2
Lemur, Mongoose (*Eulemur mongoz*)	1	Tamarin, Bearded Emperor (*Saguinus imperator subgrisescens*)	4
Lemur, Red ruffed (*Varecia rubra*)	3	Tamarin, Black Lion (*Leontopithecus chrysiopygus*)	2
Lemur, Ring Tailed (*Lemur catta*)	5	Tamarin, Cotton Top (*Saguinus oedipus*)	2
Lion (*Panthera Leo*)	1	Tamarin, Golden lion (*Leontopithecus rosalia*)	1
Loris, pigmy slow /*Nycticebus pygmaeus*)	1	Tamarin, Pied (*Saguinus bicolor*)	11
Macaque, Lion-tailed (*Macaca silenus*)	2	Tenrec, Lesser Madagascar hedgehog (*Echinops telfairi*)	
Macaque, Sulawesi crested (*Macaca nigra*)	1	Tiger, Amur (*Panthera tigris altaica*)	1

Meerkat (*Suricata suricatta*)	1	Zebra, Chapman's (*Equus quagga*)	1
Monkey, Black Howler (*Alouatta caraya*)	2		
Total	88		

4. Results

a) Calculation of MLE

The results of the calculation of the Median Life Expectancy for 5 selected species are shown in Table 4.

Table 4 - Calculation of Median Life Expectancy in 5 species

Species	*n*	M/F/ Ind.	Max Age at Death	Min Age at Death	MLE (years)
Bats, Livingstone Fruit (*Pteropus livingstonii*)	51	35/16/0	25.35	1.82	11.84
Tamarin, Golden Lion (*Leontopithecus rosalia*)	62	33/27/2	23.82	2.00	12.10
Tamarin, Black Lion (*Leontopithecus chrysiopygus*)	25	14/11/0	20.89	7.87	15.03
Lemur, Alaotran gentle (*Hapalemur alaotrensis)*	5	4/1/0	26.07	4.57	17.43
Rat, Malagasy Giant Jumping (*Hypogeomys antimena*)	45	17/30/0	14.35	1.18	5.21

b) Living geriatric population

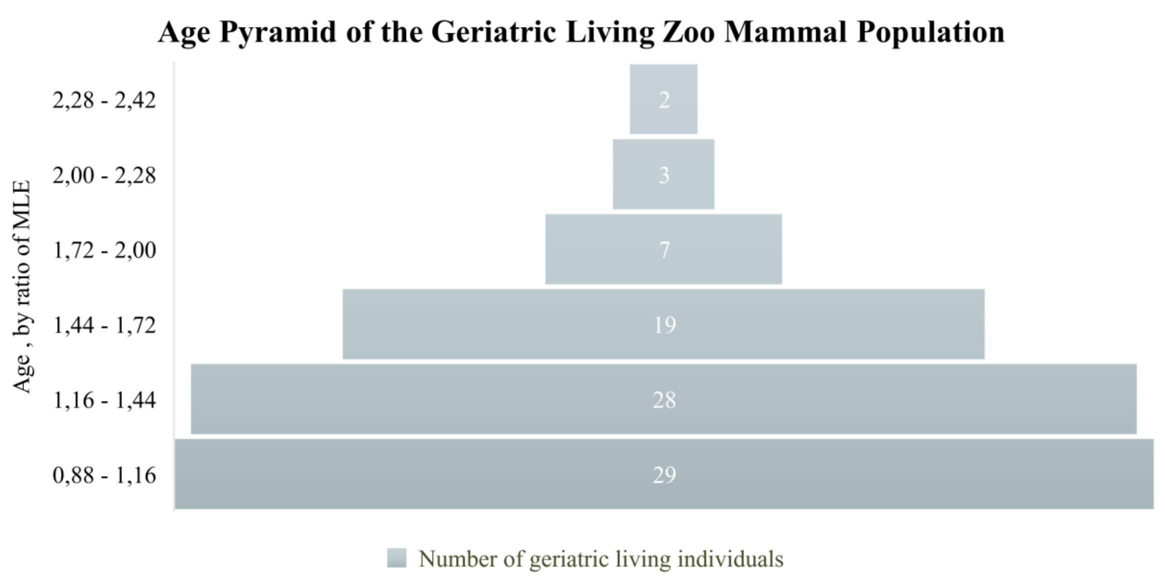
The maximum age of the living population encountered in the analyzed records was of 49.22 years of age, and the minimum was 6.06 years. The ratio of MLE was calculated for each animal and the arithmetic mean MLE ratio was 1.36 of MLE. The maximum MLE ratio value was 2.30, from a Livingstone Fruit Bat aged 27.25 years-old; and the minimum MLE ratio was 0.88, from a Mongoose Lemur aged 20.13 years-old.

Looking separately at the number of living geriatric mammals in comparison to the total living mammal population at the three zoological facilities analyzed, we can conclude that, with an arithmetic mean of 13.84% of geriatric animals, this demographic group represents a significant portion of the captive animal collections (Table 5).

Table 5 - Proportion of the geriatric living mammal population in relation to the total living mammal population, at three zoological facilities

	Geriatric Living Mammal Population	Total Living Mammal Population	Percentage of Geriatric Mammals
Zoo 1	46	232	19.83%
Zoo 2	18	182	9.89%
Zoo 3	24	212	11.32%

Graph 1 represents a population pyramid that illustrates the age structure of the geriatric living population of this study. The population is distributed along the horizontal axis, divided in 6 groups by ratio of MLE, and the horizontal length of each bar represents the number of individuals in each group. The age is represented as per ratio of MLE and is depicted on the vertical axis. The youngest age groups are represented at the bottom and the oldest at the top. The shape of the age pyramid reflects the mortality of individuals as they grow older.



Graph 1 – Geriatric living study population structure by age, as per ratio of MLE

c) Species Longevity

Through the analysis of the local animal mortality records and living geriatric population of the zoological facilities in study, longevity records superior than those reported in the literature were detected, regarding 9 distinct species (Table 6). There is no known published reference on the longevity of captive or wild Alaotran Gentle Lemurs (*Hapalemur alaotrensis*).

Table 6 – Species with higher longevity than reported in the literature

Species	Sex	Status	Age	Max age reported
Bat, Livingstone's Fruit ***(Pteropus livingstonii)***	Female	Alive	27.25	15.00[109]
Bat, Rodrigues Fruit ***(Pteropus rodricensis)***	Male	Dead	28.43	28.00[109]
Otter, North American river **(*Lontra canadensis*)**	Male	Dead	30.11	27[109]
Rat, Malagasy Giant Jumping **(*Hypogeomys antimena*)**	Male	Dead	14.35	12.60[109]
Saki, White-faced ***(Pithecia pithecia)***	Male	Dead	36.17	36.00[109]
Sand cat **(*Felis margarita*)**	Female	Dead	15.52	13.9[109]
Tamarin, Bearded Emperor ***(Saguinus imperator subgrisescens)***	Female	Dead	25.99	23.70[109]
Tamarin, Black Lion ***(Leontopithecus chrysiopygus)***	Female	Dead	20.89	17.90[109]
Tamarin, Pied ***(Saguinus bicolor)***	Male	Alive	22.33	19.00[109]
Lemur, Alaotran Gentle **(Hapalemur Alaotrensis)**	Male	Dead	26.07	No Data

5. Discussion

The calculation of the Median Life Expectancy for Livingstone Fruit Bats (*Pteropus livingstonii*), Golden Lion Tamarins (*Leontopithecus rosalia*), Black Lion Tamarins (*Leontopithecus chrysiopygus*), Alaotran gentle Lemurs (*Hapalemur alaotrensis*) and Malagasy Giant Jumping Rats (*Hypogeomys antimena*) was made using local data from the analyzed zoological facilities, thus it may not accurately reflect the global MLE. An exception to this statement is the case of the Livingstone Fruit Bats (*Pteropus livingstonii*), which total captive population is housed at the zoos in study. Nevertheless, the use of local MLE is a helpful tool in the demographic categorization of the resident populations.

Regarding the selected species with higher longevity than reported in the literature[109], it must be mentioned that studbooks for these species were not consulted, as they are of restricted use and accessibility. The unavailability of this dataset was a barrier on the confirmation of the veracity of this information. Consequently, one cannot completely affirm that these longevity records are a true reflection of the reality.

The difference in the proportion of geriatric individuals in different facilities is evident, with a variation of nearly 10 percentage points. This may be explained by management-related factors, since it is only normal to expect that different institutions have distinct protocols and conduct, regarding several aspects of the management of the collection. Plus, there is a variation in the number of individuals from the same species housed in a single institution, which represent a large portion of the geriatric individuals in the total population, i.e. a zoological facility may have in the collection a large number of individuals of one single species, which naturally comprises a larger number of geriatric individuals. Percentage-wise these individuals are better represented in the total mammal population, even though they only represent individuals from one species.

As previously stated, geriatric mammals are well-represented in the total population, with an average of 13.84% of geriatric individuals at the three zoological facilities analyzed. It is interesting to compare these values to the ones obtained in United Kingdom and United States of America human population census, in which geriatric population (i.e. age-65-and-older individuals) represents 18.00% and 15.24%, respectively[110,111].

The distribution of the population by ratio of MLE allows the representation of the evolution of the population numbers, as it tends to decrease overtime, thus depicting increased mortality of individuals as they move away from the median life expectancy age.

Regarding the ratio of males and females in the living geriatric mammal population (50.00% and 50.00%, respectively), we can say that these values are in agreement with the characteristic of the total living mammal population in these facilities, since the proportion of males and females in these collections is 50.57% and 49.43%, respectively.

6. Conclusion

The analysis of the results obtained in this study allows us to conclude that:

1. Geriatric mammals represent a significant portion of the total mammal populations considered;
2. There is equal representation of living male and female geriatric individuals, which matches the characteristics of the total population;
3. The number of individuals of the study population tends to decrease as the individuals grow older, depicting mortality events associated with age;
4. The information regarding survivorship measurements in zoo mammals is under-represented in the literature. The demographic analysis of zoological populations should be carried out and published in ways that allow of easy access and interpretation. This information is of great practical relevance, as it allows veterinarians and zoo staff to better manage the collection, allowing the establishment of a better plan for intervention. It provides professional with another tool for the demographic classification of individuals, since it allows the calculation of demographic age, rather than just relying on chronological and physiological ages;
5. The MLE values are valuable in the demographic categorization of individuals. By expanding the calculation of MLE values to other geographic locations, other than AZA accredited facilities, might be interesting in order to compare the differences of survivorship measurements, as well as to provide more data to zoological facilities.

Chapter III - Morbidity Profile of Geriatric Mammal Population in Zoos

1. Introduction

Every multicellular organism undergoes a gradual deterioration of its morphological and functional characteristics and attributes, called senescence. This aging process can have a negative impact on aging individuals, with alteration of functional mechanisms[72].

The final stages of life are accompanied by a number of physical and mental challenges, that require a different approach in order to ensure the best possible quality of life. Furthermore, not only different species show different prevalence of degenerative disorders but there is also significant individual variation on the occurrence of certain disorders and age of onset. Thus, it is difficult to standardize management methods and veterinary care. The animal caretakers, veterinary team and curators have to rely on experience, improvisation, consultations with colleagues and some extrapolation from distinct species when making decisions and adjustments to ensure that most suitable care can be provided[46].

When dealing with pets, veterinarians mostly rely on the owners' perception of the animal's quality of life, clinical signs and behavioral issues. In zoological medicine, zookeepers can provide the same assessment as pet owners. In these facilities, zookeepers are ultimately the people more familiar with the animals in their care, and are the primary responsible people for recognizing and reporting of any abnormality regarding the health or behavior of group or individual animal. Therefore, it's essential that caretakers understand typical presentations of welfare states, in order to avoid misinterpretation or negligence by disregarding such information. Staff should be educated on how to recognize and report physical and behavioral changes, so the veterinary staff can arrange for adequate medical care and solutions to improve the animals' health condition and quality of life[82].

A preventive health care approach is required when dealing with aging animals. Addressing potential health issues before they actually surface can improve the chances of treatment/attenuation of medical conditions. This can be predicted to some extent by assessing the individuals' genetic background, environment, nutritional and medical history, as well as species and population genetic tendency to develop certain disorders[105].

2. Aims

The present study aims to identify the morbidity pattern of the geriatric population of three zoological facilities. The identification of the prevalence of medical issues in this demographic group is essential, in order to promote early surveillance and monitoring, as well as to plan strategies for intervention. A thorough analysis of geriatric morbidity and the time of diagnosis is required to improve the management and quality of life of this population. Furthermore, the comparison of the *antemortem* and *postmortem* examination findings is essential as it allows the identification of potentially overlooked conditions. This study aims to provide baseline data and to promote and encourage further and more specific studies on this matter.

3. Materials and Methods

The study population of this study comprises animals from three different zoological facilities. For ethical reasons, and as requested, the names of the institutions will not be disclosed, and the animals shall not be linked specifically to any of the zoos. Two of these facilities are located in Europe, while one is located in North America. The data compilation and analysis relied on Microsoft Excel® software.

Using local animal records, information about the totality of both dead and living animals was collected, at each zoo. From this population, species with MLE available from the SSL – or that could be calculated- were selected. The ratio of MLE, using the MLE value for the species, was calculated for each animal and geriatric individuals were identified. The ratio of MLE was calculated as follows:

$$MLE\ ratio = \frac{Chronological\ age\ of\ the\ animal\ (years)}{MLE\ value\ for\ the\ species\ (years)}$$

Since the number of geriatric individuals representing each species was not sufficient to conduct a species-specific morbidity profile, 6 different taxonomic groups (Table 7) were formed and the morbidity analysis was made at the taxonomic family level. Medical records for each individual were carefully analyzed, using data from Species360. Subjects with incomplete medical records were excluded from the study. For better comprehension, a visual representation of the methodology used is pictured on Figure 2.

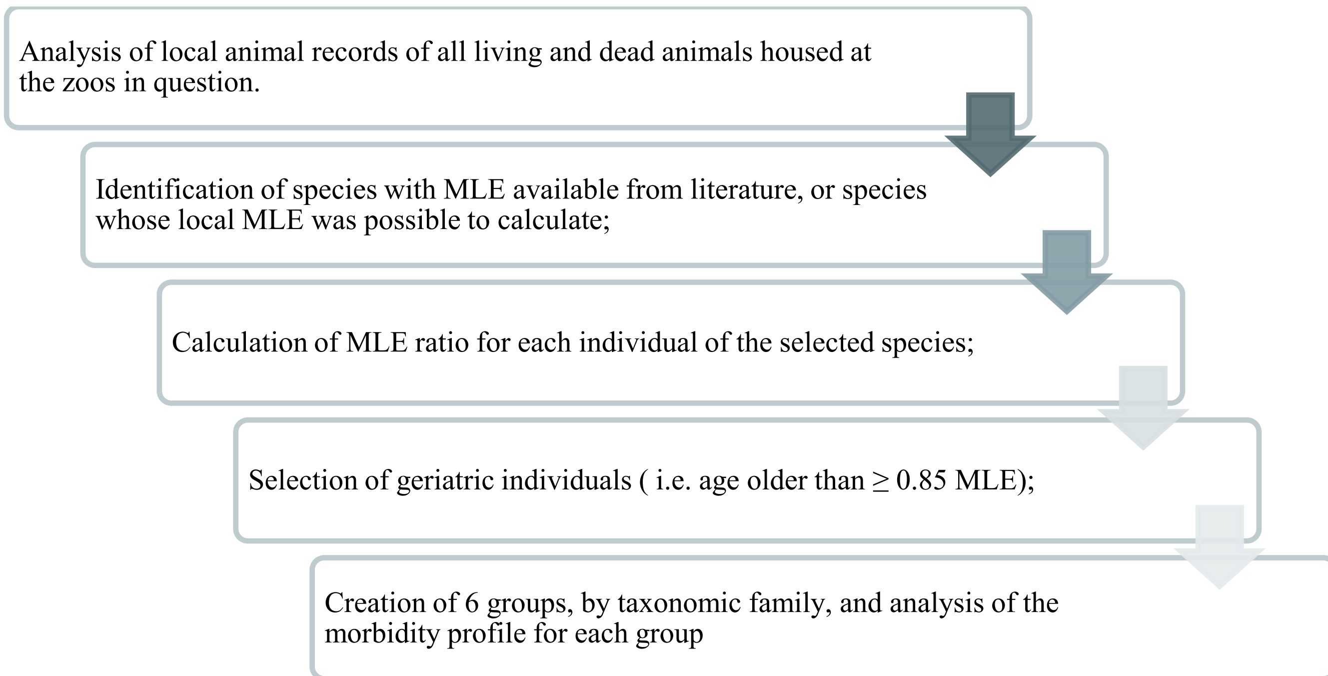


Figure 2 - Schematic representation of the methodology used in this study

The selection of geriatric individuals resulted in a study population of 197 individuals from 22 different mammal species, selected from both living (*n*=65) and dead (*n*=132) geriatric subjects. In this study population, 98 individuals were male (49.75%) and 99 were female (50.25%).

Table 7 - Study population as per Taxonomic family

Family	Species	Living/ Deceased	Sub-Total	Total
Lemuridae	Lemur, Alaotran gentle (*Hapalemur alaotrensis*)	3/5	8	29
	Lemur, Black and white ruffed (*Varecia variegata)*	2/4	6	
	Lemur, Mongoose (*Eulemur mongoz*)	1/0	1	
	Lemur, Ring-Tailed (*Lemur catta)*	5/6	11	
	Lemur, Red Ruffed (*Varecia rubra*)	3/0	3	
Callitrichidae	Tamarin, Bearded Emperor (*Saguinus imperator subgrisescens*)	4/3	7	59
	Tamarin, Black Lion (*Leontopithecus chrysiopygus*)	2/19	21	
	Tamarin, Golden Headed Lion (*Leontopithecus chrysomelas*)	1/0	1	
	Tamarin, Golden Lion (*Leontopithecus rosalia*)	0/3	3	
	Tamarin, Cotton Top (*Saguinus oedipus*)	2/4	6	
	Tamarin, Pied (*Saguinus bicolor)*	11/10	21	
Pteropodidae	Bat, Livingstone's Fruit (*Pteropus livingstonii)*	10/22	32	65
	Bat, Rodrigues Fruit (*Pteropus rodricensis*)	3/30	33	
Cercopithecidae	Monkey, Common Squirrel (*Saimiri sciureus sciureus*)	3/2	5	18
	Macaque, Sulawesi Crested (*Macaca nigra*)	1/7	8	
	Macaque, Lion-Tailed (*Macaca silenus*)	2/0	2	
	Colobus, Black-and-white (C*olobus angolensis*)	3/0	3	
Felidae	Lion (*Panthera leo)*	1/5	6	15
	Tiger, Amur (*Panthera tigris altaica*)	1/5	6	
	Sand Cat (*Felis margarita)*	0/3	3	
Hominidae	Gorilla, Western Lowland (*Gorilla gorilla gorilla*)	4/3	7	11
	Orangutan, Sumatran (*Pongo abelii)*	3/1	4	

a) Prevalence of morbidity categories by taxonomic family

The review of the medical records of each living and dead geriatric individual selected for the morbidity profile was made using local records of each institution, using Species360. For the analysis of the morbidity profile for each group, the disorders identified during review of the medical records were grouped into 11 different categories, as shown in Table 8. Some of the disorders are intrinsically connected to disorders from other groups. For example, in the Neoplasia morbidity groups, we might have disorders associated with other categories (e.g. Hepatocellular carcinoma is a malignancy of the liver. This disorder is exclusively categorized as "Neoplasia", and not "Hepatic").

The morbidity profile was made at the taxonomic family level and disorders diagnosed during *antemortem* and *postmortem* examination were included and not differentiated. Both living and dead animals were considered for this part of the study. The prevalence of selected morbidities by category was calculated for each taxonomic family. Selected morbidity categories with null prevalence were disregarded and are not displayed in the graphs.

Table 8 - Classification of the morbidities in study population

Category	**Disorder**
Musculoskeletal	Stifle osteoarthritis Coxo-Femoral osteoarthritis Elbow osteoarthritis Spondylosis deformans Digit ankylosis
Integumentary	Chronic pododermatitis Chronic dermatitis
Oral Cavity	Periodontal disease Dental abscesses
Gastrointestinal	Dysbiosis

Cardiovascular	Valvular regurgitation Chronic myocardial fibrosis Hypertrophic cardiomyopathy
Urinary	Chronic interstitial nephritis Glomerulonephritis Urinary incontinence
Hepatic	Cholestasis Cirrhosis
Cognitive	Cognitive dysfunction
Neoplasia	Hepatocellular carcinoma Squamous cell carcinoma Lymphoproliferative neoplasia Pancreatic neoplasia Thyroid carcinoma
Sensory	Cataracts Nuclear sclerosis
Endocrine	Diabetes mellitus

b) Age of diagnosis of selected morbidity categories

The most common disorders for each group were identified as well as the time of diagnosis, allowing to detect the life stage these disorders were diagnosed at. Using the date of diagnosis and the date of birth, age of diagnosis was calculated and the ratio of MLE. Age is, therefore, represented as MLE ratio. Only the disorders diagnosed after the age when animals of a population are considered geriatric were regarded, and one-time events such as trauma or infectious diseases outbreaks in the group were not considered, as well as congenital issues, as it would complicate the identification and analysis of prevalence of degenerative and chronic disorders. Both living and dead animals were included in this study. Diagnosis made during *postmortem* examination were not included, but those made exclusively in these conditions are specified in the table, as to match the diagnosed morbidity groups in each family.

c) Multimorbidity

The association of disease co-occurrence was also analyzed on both living and dead animals, as per taxonomic family, in order to identify the prevalence of multimorbidity, which can be defined as the presence of two or more chronic medical conditions in an individual[112,113]. Multi-morbidity can have a negative impact on quality of life and may hinder the success of pharmacological therapy.

d) *Antemortem* vs. *Postmortem* diagnosis

The retrospective investigation of the medical history of the dead geriatric population allowed the identification of the disorders diagnosed in each selected animal. These disorders were then grouped into two categories, depending on when the diagnosis was made: *antemortem* or *postmortem*. A comparison between these two categories was made, per category of morbidity and per taxonomic family.

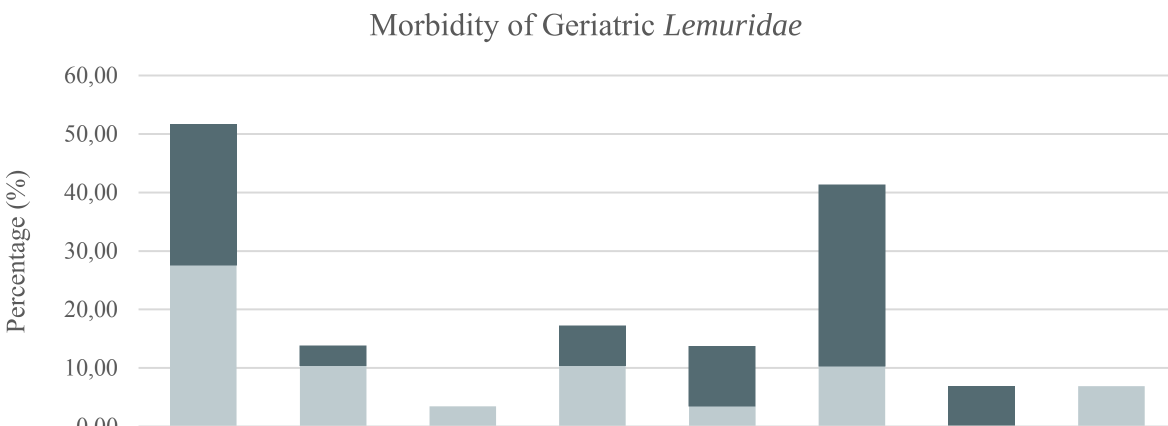
e) Proportion of Euthanasia and Natural/Non-euthanasia deaths

In the case of the deceased animals, *postmortem* reports were reviewed, and the cause of death was categorized as “Euthanasia” or “Natural/Non-euthanasia”.

4. Results

a) Prevalence of morbidity categories by taxonomic family

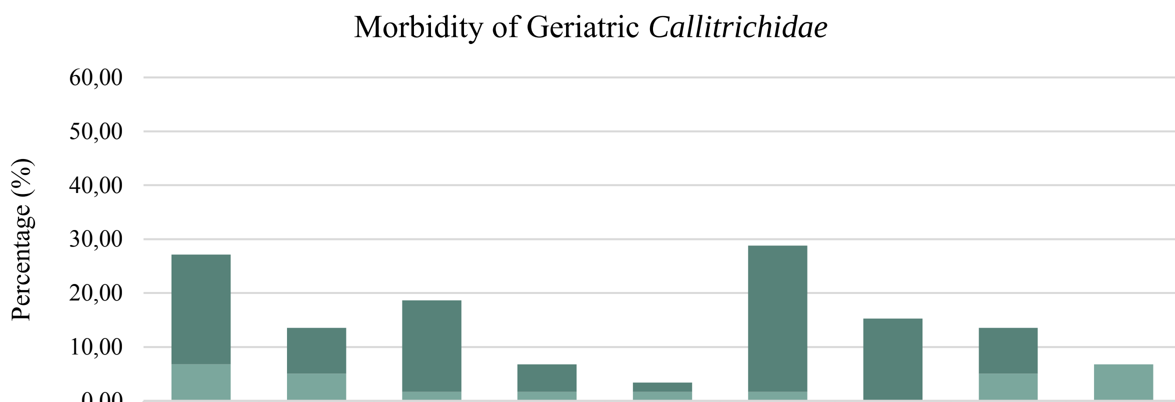
Regarding the animals from *Lemuridae* family, the morbidity group with highest prevalence was the musculoskeletal, with a total of 51.73% (*n*=15) affected animals. Urinary disorders were the second most commonly diagnosed morbidities, with a total prevalence of 41.37% (*n*=12). Sensory disorders, namely cataracts and nuclear sclerosis, were also a common finding in this group, with a total of 17.24% (*n*=5) affected animals (Graph 2).



	MS	Oral Cavity	CV	Sensory	Neoplasia	Urinary	Hepatic	GI
Dead (%)	24,14	3,45	0,00	6,90	10,34	31,03	6,90	0,00
Alive (%)	27,59	10,34	3,45	10,34	3,45	10,34	0,00	6,90

Graph 2 - Prevalence of selected morbidities in geriatric *Lemuridae*. Abbreviations: MS: Musculoskeletal; CV: Cardiovascular; GI: Gastrointestinal

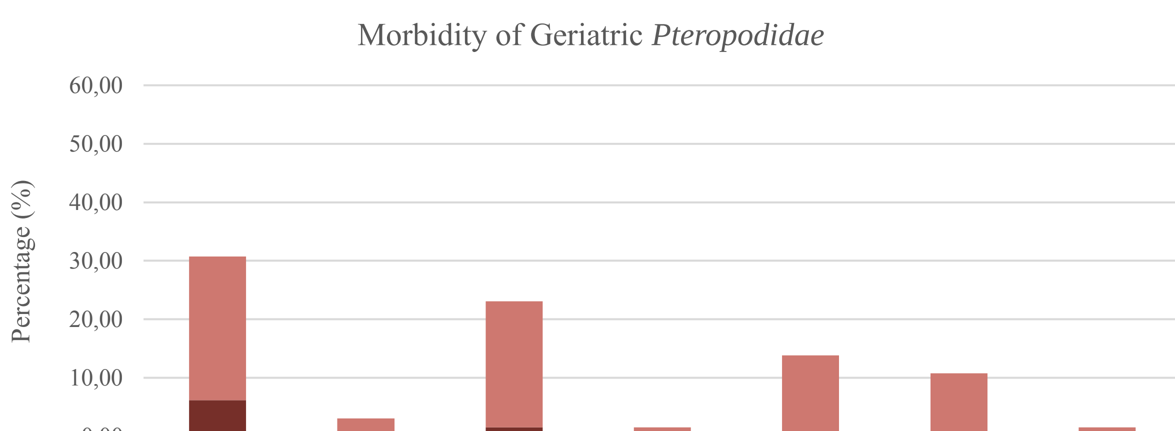
In the *Callitrichidae* family, as depicted in Graph 3, the most commonly diagnosis was of urinary disorders, with a total of 28.81% (*n*= 16) affected individuals, followed by musculoskeletal disorders, with a total of 27.12% animals. Of the analyzed disorders, neoplasia was the least commonly diagnosed (*n*=2).



	MS	Oral Cavity	CV	Sensory	Neoplasia	Urinary	Hepatic	GI	INTEG
Dead (%)	20,34	8,47	16,95	5,08	1,69	27,12	15,25	8,47	0,00
Alive (%)	6,78	5,08	1,69	1,69	1,69	1,69	0,00	5,08	6,78

Graph 3 - Prevalence of selected morbidities in geriatric *Callitrichidae*. Abbreviations: MS: Musculoskeletal; CV: Cardiovascular; GI: Gastrointestinal; INTEG: Integumentary.

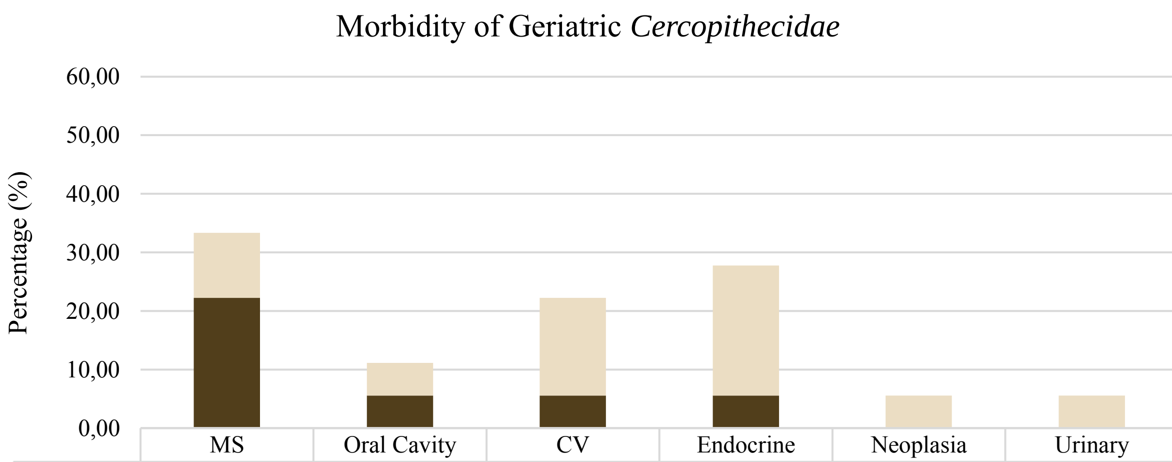
The study population of the *Pteropodidae* family shows a significant prevalence of Musculoskeletal disorders, with a total of 30.77% (*n*=20) affected individuals. The occurrence of cardiovascular abnormalities was also detected on a significant number of individuals (23.08%; *n*= 15) (Graph 4). Sensory and Gastrointestinal disorders were rarely found in these individuals.



	MS	Oral Cavity	CV	Sensory	Urinary	Hepatic	GI
Dead (%)	24,61	3,08	21,54	1,54	13,85	10,77	1,54
Alive (%)	6,15	0,00	1,54	0,00	0,00	0,00	0,00

Graph 4 - Prevalence of selected morbidities in geriatric *Pteropodidae*. Abbreviations: MS: Musculoskeletal; CV: Cardiovascular; GI: Gastrointestinal

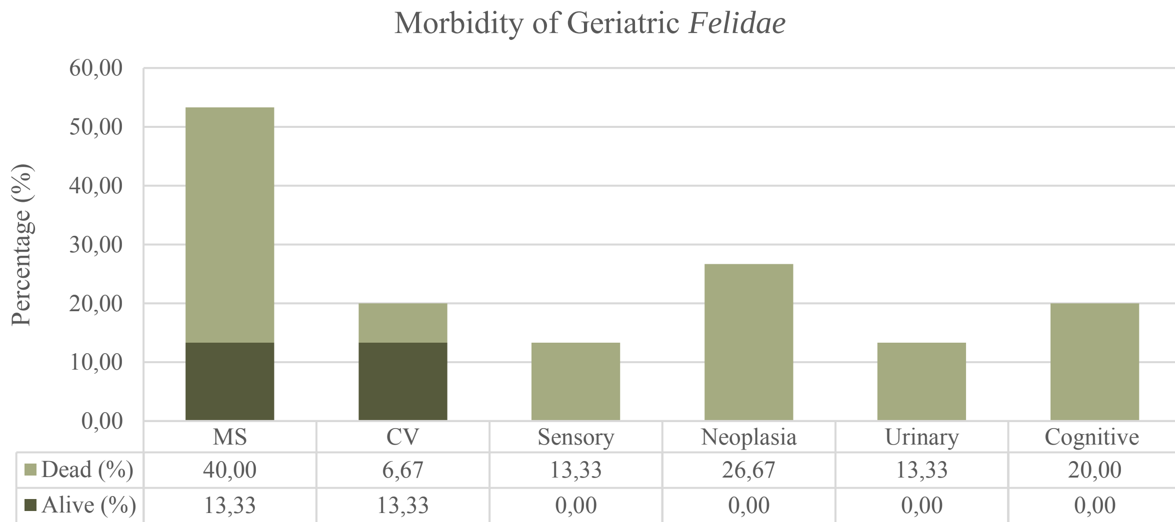
Concerning *Cercopithecidae*, there is a substantial prevalence of musculoskeletal, endocrine and cardiovascular disorders, as seen in Graph 5. This is the only group where endocrine disorders, namely Diabetes mellitus, were diagnosed, with a prevalence of 27.78% (*n*=5). Musculoskeletal disorders had a prevalence of 33.33%, while cardiovascular disorders were diagnosed in 4 animals (22.23%).



	MS	Oral Cavity	CV	Endocrine	Neoplasia	Urinary
Dead (%)	11,11	5,56	16,67	22,22	5,56	5,56
Alive (%)	22,22	5,56	5,56	5,56	0,00	0,00

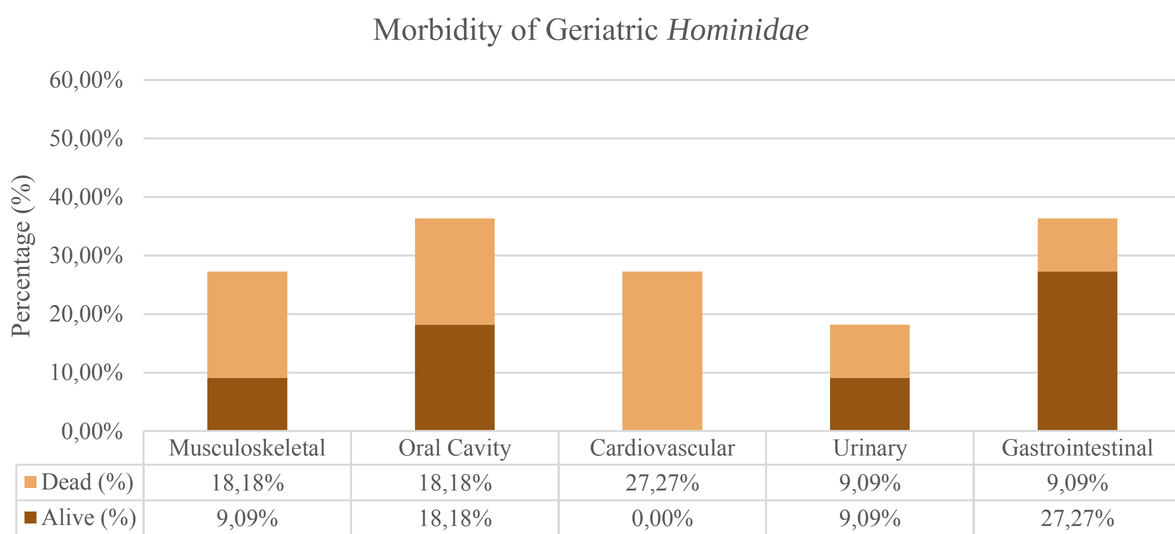
Graph 5 - Prevalence of selected morbidities in geriatric *Cercopithecidae*. Abbreviations: MS: Musculoskeletal; CV: Cardiovascular.

As seen in Graph 6, in *Felidae*, the better represented morbidity categories are Musculoskeletal, with a prevalence of 53.33% (*n*=8), Cardiovascular, with a prevalence of 20.00% (n=3) and Cognitive, with a prevalence of 20.00% (*n*=3). This was the only taxonomic family where cognitive dysfunction was diagnosed.



Graph 6 - Prevalence of selected morbidities in geriatric *Felidae*. Abbreviations: MS: Musculoskeletal; CV: Cardiovascular;

In the *Hominidae* family, there most commonly identified groups of disorders were the Oral Cavity and Gastrointestinal category, with an equal prevalence of 36.36% (n=4). The second most relevant finding was the occurrence of cardiovascular disorders, with a prevalence of 27.27% (*n*=3), as depicted in Graph 7.



Graph 7 – Prevalence of selected morbidities in geriatric *Hominidae*

Overall, the most frequently diagnosed morbidity category was the Musculoskeletal group, with a total of 68 cases, followed by Urinary disorders, with 43 reported cases.

b) Age of diagnosis of selected morbidity categories

The minimum, maximum and arithmetic mean of age of diagnosis are represented in Table 9, by ratio of MLE. In order to better illustrate this concept, we shall take the example of the *Cercopithecidae* family. This line of thought can be followed for interpretation of the rest of the data represented in this table. The youngest geriatric animal (i.e. the animal with the lowest MLE ratio) from this Family diagnosed with a disorder from the Musculoskeletal category was a Lion Tailed Macaque (*Macaca* silenus) aged 23.80 years-old (MLE ratio = 0.89), at the time of diagnosis. We can consider this MLE ratio to be the minimum age of diagnosis of this morbidity category, in this taxonomic family. The same applies to the maximum age of diagnosis. The mean corresponds to the arithmetic mean of age of diagnosis, in each family, regardless of the category of morbidity.

The *Cercopithecidae* family was the group with earlier diagnosis of the selected morbidity categories, with a mean age of diagnosis of 1.03, which in Common Squirrel Monkeys (*Saimiri sciureus* sciureus) corresponds to 14.48 years of age; in Sulawesi Crested Macaques (*Macaca nigra*) to 15.14 years of age; in Lion-Tailed Macaques (*Macaca silenus*) to 27.39 years of age and in Black-and-White Colobus (*Colobus* angolensis) to 18.75 years of age.

The *Pteropodidae* family was the group with later diagnosis of the selected morbidity categories, with a mean age of diagnosis of 1.47, which in Livingstone Fruit Bats (*Pteropus livingstonii*) corresponds to 17.4 years of age; and in Rodrigues Fruit Bats (*Pteropus rodricensis*) corresponds to 19.99 years of age in males and 24.49 years of age in females.

In relation to the age of diagnosis for each category, regardless of the taxonomic family, the results are shown in Table 10. The Musculoskeletal group was the category with the lowest MLE ratio of minimum age of diagnosis, but also the one with the highest MLE ratio of maximum age of diagnosis, i.e. animals are diagnosed with these disorders at earlier ages, but also at later stages. These disorders are also the most frequently diagnosed in our study population. Gastrointestinal disorders were the diseases diagnosed at younger ages, between 0.94 and 1.41 values of MLE ratio, with an average of 1.13, along with Cardiovascular disorders. Overall, regardless of the category, these selected are diagnosed, on average at 1.24 ratio of MLE. The average minimum age of diagnosis is in agreement with the MLE value, being the ratio of 1.03. This means that, around the age corresponding to the MLE value for the species, is the earliest time these disorders are diagnosed at.

Table 9 - Age of diagnosis of selected disorders, by category, as per Taxonomic Family, in ratio of MLE. Abbreviations: PM: *Postmortem*

Category / Family	***Lemuridae***				***Calitrichidae***				***Pteropodidae***				***Cercopithecidae***				***Felidae***				***Hominidae***			
	n	Min	Max	Mean	*n*	Min	Max	Mean	*n*	Min	Max	Mean	*n*	Min	Max	Mean	*n*	Min	Max	Mean	*n*	Min	Max	Mean
Musculoskeletal	15	0.86	1.60	1.21	16	0.85	2.70	1.27	20	1.14	2.23	1.61	6	0.89	1.62	1.17	8	0.93	1.62	1.31	3	1.03	1.32	1.13
Integumentary					4	1.13	1.62	1.32					-				-							
Oral Cavity	4	0.85	1.28	1.15	8	0.85	2.83	1.48	2	1.58	1.66	1.62	2	0.87	1.08	0.98	-				4	0.85	1.08	0.99
Gastrointestinal	2	0.92	1.38	1.15	7	0.94	1.62	1.18	PM				-				-				4	0.95	1.24	1.06
Cardiovascular	1	0.95	0.95	0.95	7	0.92	2.54	1.39	8	1.24	2.21	1.52	1	0.88	0.88	0.88	2	0.88	1.22	1.05	3	1.07	1.93	1.36
Urinary	12	0.93	1.50	1.23	11	0.85	2.83	1.25	1	1.35	1.35	1.35	PM				2	1.07	1.57	1.32	2	0.85	1.93	1.39
Hepatic	2	1.11	1.48	1.30	7	0.88	1.96	1.20	1	1.34	1.34	1.34	-				-				-			
Cognitive	-				-				-				-				3	1.06	1.53	1.35	-			
Neoplasia	4	1.09	1.30	1.20	2	1.30	1.81	1.56	-				PM				4	0.86	1.07	0.95	-			
Sensory	5	0.85	1.50	1.26	4	1.20	1.49	1.31	1	1.41	1.41	1.41	-				1	1.15	1.15	1.15	-			
Endocrine	-				-				-				5	0.94	1.51	1.10	-				-			
Mean		**0.95**	**1.37**	**1.18**		**0.99**	**2.16**	**1.33**		**1.34**	**1.70**	**1.48**		**0.90**	**1.27**	**1.05**		**0.99**	**1.36**	**1.19**		**0.95**	**1.50**	**1.19**

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Table 10 - Age of diagnosis of selected disorders, by category, in ratio of MLE, regarding all taxonomic families analyzed

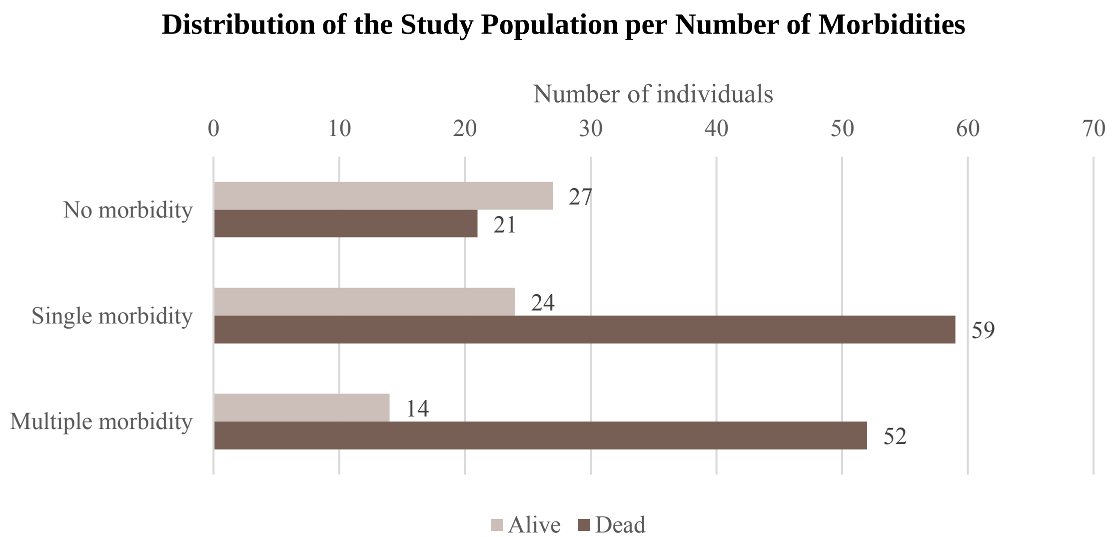
Category	*N*	Mean Min.	Mean Max.	Mean
Musculoskeletal	68	0.95	1.85	1.29
Integumentary	4	1.13	1.62	1.32
Oral cavity	20	1.00	1.59	1.24
Gastrointestinal	13	0.94	1.41	1.13
Cardiovascular	22	1.04	1.62	1.13
Urinary	28	1.01	1.84	1.31
Hepatic	10	1.11	1.59	1.28
Cognitive	3	1.06	1.53	1.35
Neoplasia	10	1.08	1.39	1.24
Sensory	11	1.12	1.31	1.22
Endocrine	5	0.94	1.51	1.15
Mean		1.03	1.57	1.24

c) Multimorbidity

Looking at multimorbidity, the results of frequency of morbidities per taxonomic family are displayed in Table 11. Graph 8 shows the prevalence of number of morbidities diagnosed in the living and dead population. Out of a total of 65 animals from the living study population, the number of animals displaying no appreciable disease was 27 (41.54%). The number of total living individuals diagnosed with a single morbidity was 24 (36.92%), whereas the occurrence of multiple morbidity was 14 (21.54%). In total, the number of dead geriatric individuals diagnosed with a single morbidity was 59 (44.70%), whereas the diagnosis of multi-morbidities was performed on 52 (39.39%) animals. The dead individuals that fall into the category of "No morbidity" (n= 21; 15.91%), include those with no specific disease diagnosed in life, death resulted from an acute trauma or accident - unrelated to any chronic condition - or *postmortem* examination was not performed, failed to pinpoint the cause of death or identify any disease process.

Table 11 - Distribution of study population per number of morbidities, categorized by taxonomic family

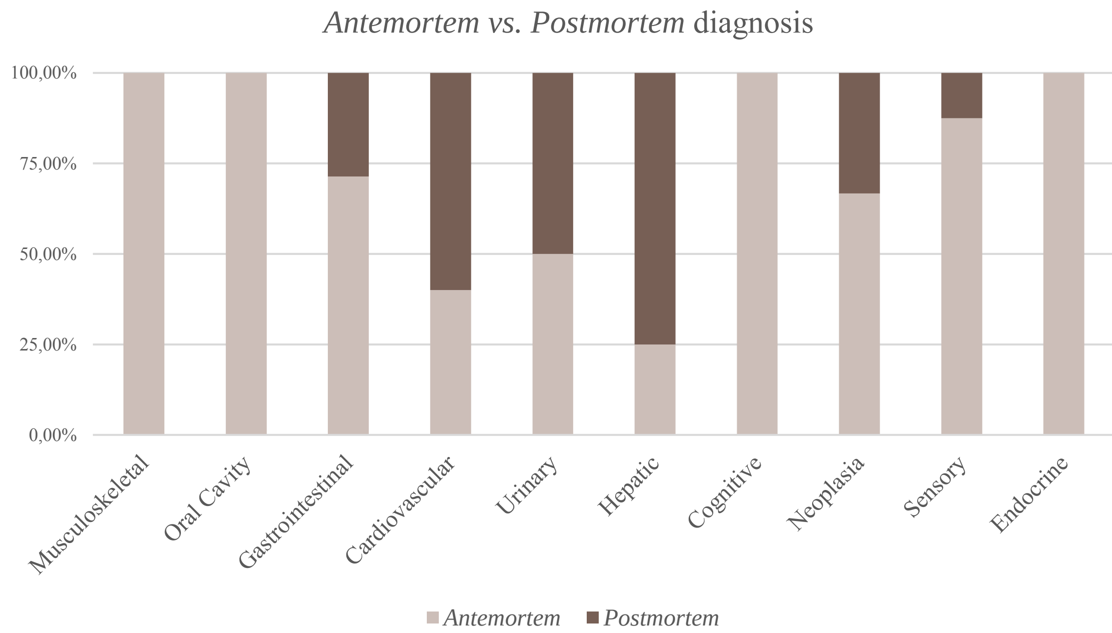
	Lemuridae		*Callitrichidae*		*Pteropodidae*		*Cercopithecidae*		*Felidae*		*Hominidae*	
	Alive	**Dead**	**Alive**	**Dead**	**Alive**	**Dead**	**Alive**	**Dead**	**Alive**	**Dead**	**Alive**	**Dead**
No morbidity	2	0	12	0	8	19	5	1	0	1	0	0
Single morbidity	7	8	4	19	5	21	2	5	0	5	6	1
Multiple morbidity	5	7	4	20	0	12	2	3	2	7	1	3



Graph 8 - Distribution of study population as per number of morbidities

d) *Antemortem* vs. *Postmortem* diagnosis

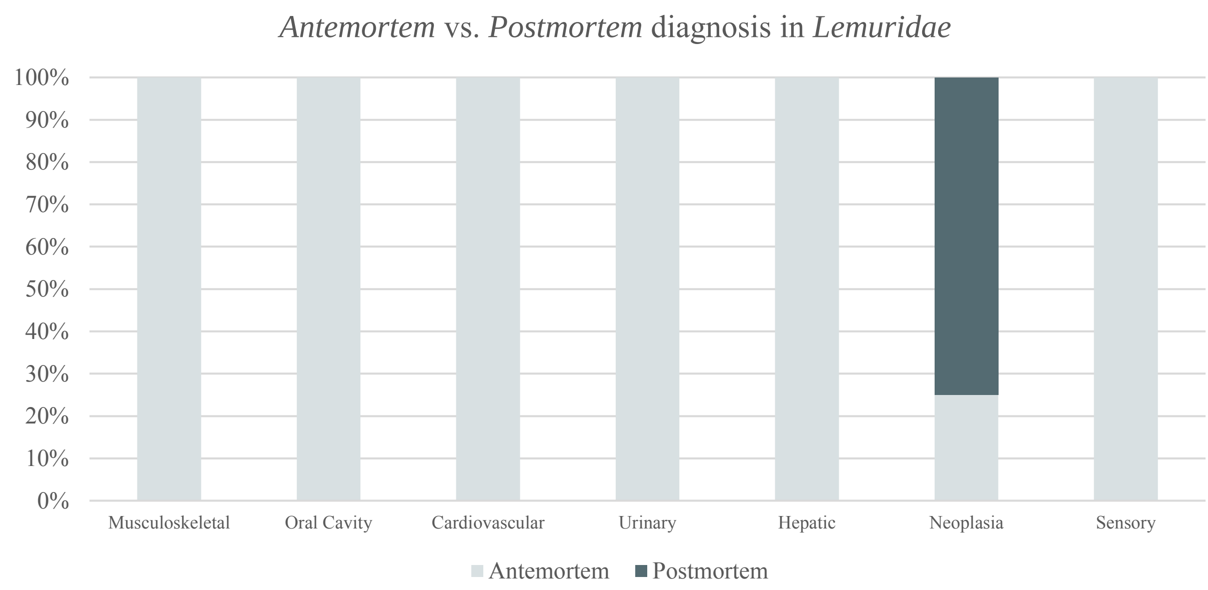
Graph 9 represents the comparison of clinical findings and *postmortem* findings in the dead geriatric population. Regarding the study population, disorders from Musculoskeletal, Oral Cavity and Endocrine categories were strictly diagnosed during *antemortem* clinical examination. As shown on the graphic representation, the most frequently overlooked *antemortem* clinical diagnosis were disorders from the Hepatic, Cardiovascular and Urinary categories, which were only detected, in a significant number of cases, during necropsy.



Graph 9 - Comparison of *antemortem* clinical diagnosis and *postmortem* findings in geriatric dead population, by category of morbidity

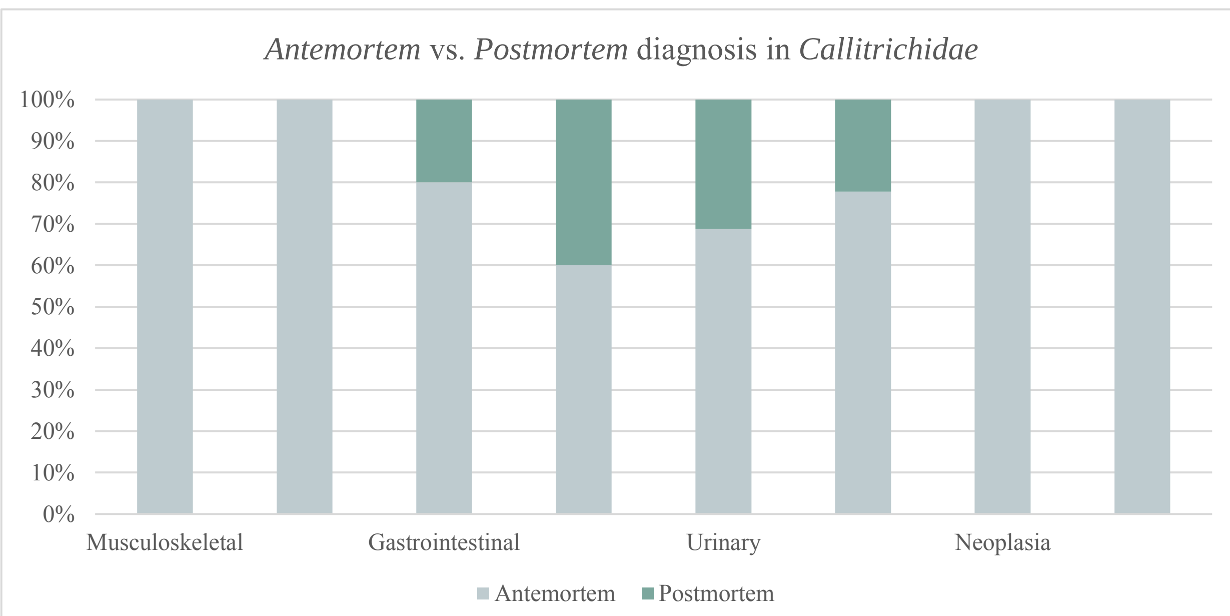
Looking specifically at each family allows us to explore this matter at the taxa level. Graphs 10 to 16 represent the diagnosis made during *antemortem* examinations in comparison to findings made exclusively during postmortem examinations. If a diagnosis was made when the animal was alive, and it was confirmed during necropsy, it was still categorized as a diagnosis made *antemortem*.

As depicted in Graph 10, regarding *Lemuridae*, every diagnosis was made during *antemortem* examinations, apart from neoplastic processes, which were diagnosed in 2 cases out of a total of 3 only during necropsy.

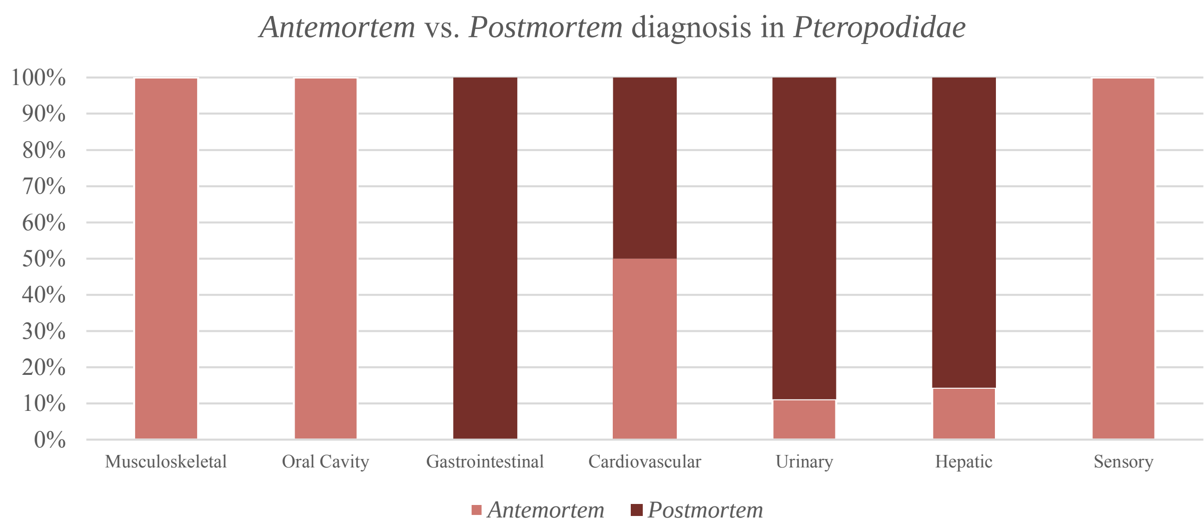


Graph 10 - Comparison of *antemortem* clinical diagnosis and *postmortem* findings in geriatric Lemuridae, per category of morbidity

In the case of callitrichids, commonly overlooked disorders in *antemortem* examinations include cardiovascular, urinary, hepatic and gastrointestinal abnormalities (Graph 11).



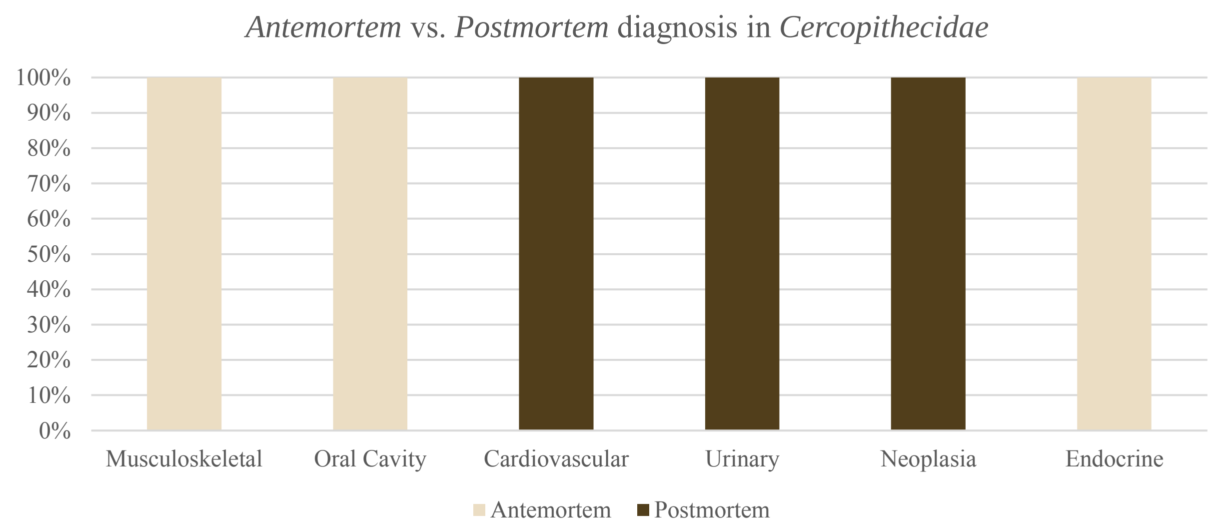
Graph 11 - Comparison of *antemortem* clinical diagnosis and *postmortem* findings in geriatric *Callitrichidae*, per category of morbidity



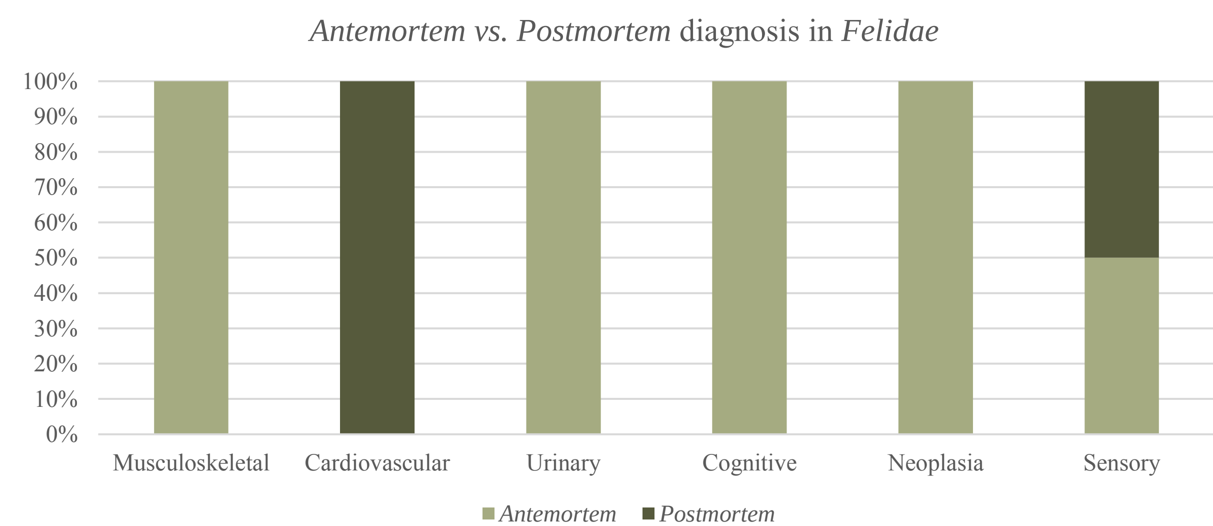
Graph 12 - Comparison of *antemortem* clinical diagnosis and *postmortem* findings in geriatric *Pteropodidae*, per category of morbidity

As shown in Graph 12, there is a significant rate of diagnosis made exclusively during necropsy in geriatric *Pteropodidae* regarding disorders classified as Gastrointestinal, Urinary, Hepatic and Cardiovascular.

On the analysis of Graph 13, we can conclude that while musculoskeletal, oral cavity and endocrine disorders were diagnosed exclusively in clinical examinations, disorders from the cardiovascular, urinary and neoplasia categories were only diagnosed in postmortem examinations.

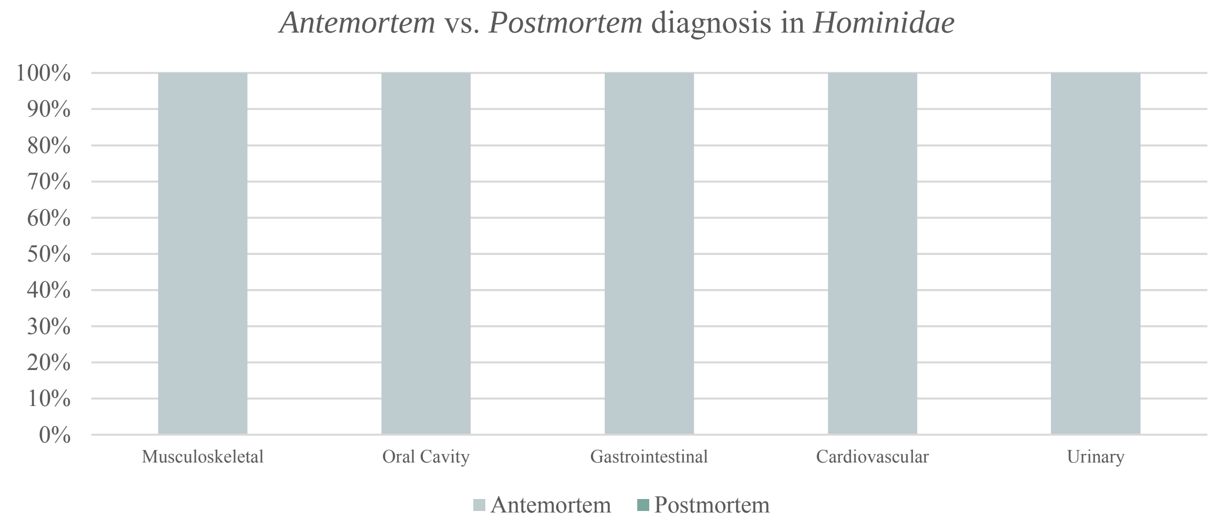


Graph 13 - Comparison of *antemortem* clinical diagnosis and *postmortem* findings in geriatric *Cercopithecidae*, per category of morbidity



Graph 14 - Comparison of *antemortem* clinical diagnosis and *postmortem* findings in geriatric Felidae, per category of morbidity

Concerning the *Felidae* study population (Graph 14), we can affirm that cardiovascular disorders were exclusively diagnosed during *antemortem* examinations , as well as half of the cases from the sensory category. The disorders from the remaining morbidity groups were diagnosed during clinical examinations.

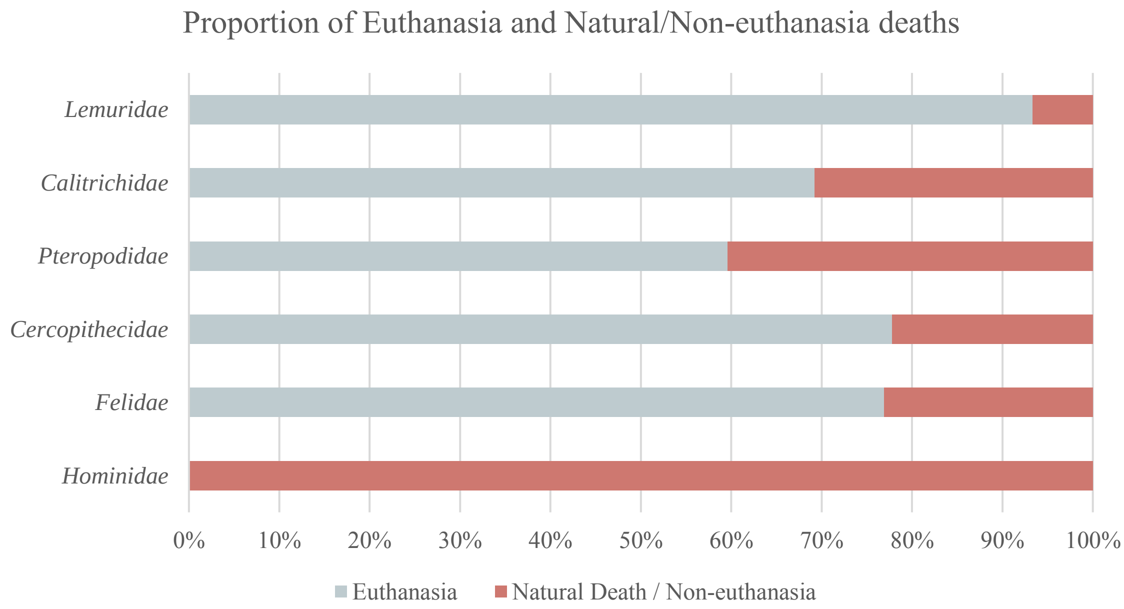


Graph 15 - Comparison of *antemortem* clinical diagnosis and *postmortem* findings in geriatric *Hominidae*, per category of morbidity

The analysis of Graph 15 allows us to conclude that every diagnosis was made during *antemortem* examinations in the *Hominidae* study population.

e) Proportion of Euthanasia and Natural/Non-euthanasia deaths

The retrospective investigation of the cause of death in geriatric dead individuals was noted as per taxonomic family and is represented in Graph 16. *Hominidae* represents the taxonomic family with higher rate of Natural death / Non-euthanasia (100.00%), while *Lemuridae* is the group with higher rate of Euthanasia (93.33%).



Graph 16 - Cause of death in geriatric individuals, by taxonomic group

5. Discussion

As shown in the results, animals from the *Felidae* family had a substantial prevalence of musculoskeletal disorders. In a retrospective study carried out at the Knoxville Zoo, United States of America, Kolmstetter and colleagues[17] analyzed the prevalence of degenerative spinal condition in 37 felids of the collection. This study concluded that degenerative spinal disease was common in large elderly felids at the Knoxville Zoo, with no evident sex predilection. Intervertebral disc disease results in evident clinical signs and both radiographic and histologic changes. Degenerative spinal disease in these animals has also been reported and associated with decreased activity, intermittent hind limb paresis and ataxia. These clinical signs usually become apparent between 10 and 19 years of age, and imaging techniques can demonstrate disc mineralization or herniation, spondylosis, and spinal cord damage[17,18]. These findings are consistent with our results, since the ages of diagnosis of musculoskeletal disorders in *Felidae* ranged from 14.82 years old to 20.3 years old (average 17.46 years). The prevalence of this disorder was also significant, occurring in 53.33% (*n*=8) of the animals from the *Felidae* family in our study. It is agreed that weight control and enclosure modifications can help minimize development and progression of spinal disease in nondomestic felids. Enclosure modifications include removal of climbing or elevated structures and substitution of concrete or hard surfaced floors with a softer substrate[17].

Nondomestic felids also appear to experience cognitive dysfunction and behavior abnormalities associated with age[66,70]. *Postmortem* examinations in aged large felids verified the presence of brain abnormalities related to accumulation of beta amyloid substances and changes in T phosphorylation[70], causing cognitive impairment. Furthermore, it has been described that neuronal lipofuscinosis is significantly associated with age in nondomestic felids[66], which does not have to be necessarily associated with clinical signs. Our findings were consistent with what is reported in the literature, since 33.33% (*n*=3) of the *Felidae* study population developed clinical signs associated with cognitive dysfunction. These individuals were dead at the time of data collection, and this diagnosis had been confirmed by compatible *postmortem* findings.

In a study carried out involving the North American Amur Leopard (*Panthera pardus orientalis*) captive population, cardiovascular disorders were also found to be a relevant cause of morbidity in geriatric individuals[51]. In our study, these findings were corroborated, with a prevalence of 20.00%, being the third most relevant cause of morbidity.

A study investigating the characteristics of spontaneous diabetes mellitus in animals from the *Cercopithecidae* family concluded that the prevalence in the geriatric population was of 19%[114]. In the *Cercopithecidae* study population considered for our study, the prevalence of diabetes was 27.78% (*n*=5), being the second biggest cause of morbidity.

Degenerative joint disease, cataracts and chronic renal disease has also been reported in aging captive *Lemuridae* species[115], as also described in our study. Ocular diseases in aging non-human primates has been described in various studies[58,79–81]. Age-related conditions include decreased visual acuity, cataracts, macular degeneration and corneal leucoma. Hypertension can also have ocular related consequences, such as retinal vascular arteriosclerosis[27]. The *Lemuridae* family population included in our study had a prevalence of ocular disorders of 17.24% (n=5) and was the third most relevant cause of morbidity in this group.

According to Lowenstein and colleagues[27], a review of Species Survival Plan (SSP) populations revealed that cardiovascular disease was the leading cause of death of captive bonobos (45%), gorillas (41%), chimpanzees (38%) and orangutans (20%). In these animals, the occurrence of idiopathic myocardial fibrosis and cardiomyopathy was predominant. It is believed that hypertension is an underlying condition in the development of fibrosing cardiomyopathy in great apes[55,56]. *Postmortem* examination reports showed a high prevalence heart lesions, such as left ventricular hypertrophy, which may suggest the occurrence of hypertension in captive populations[27,55]. In a study carried out in North American zoos, it was concluded that apes had the highest mean age of onset of the disease, followed by Old World monkeys, prosimians, and New World primates[64]. This study also concluded that many of the clinical findings can be reduced by weight loss, caloric restriction, high fiber low-glycemic index diet and oral hypoglycemic therapy [116]. In our study, cardiovascular disorders occurred in 27.27% of the analyzed subjects. Old-World Monkeys, or the individuals from the *Cercopithecidae* family included in this study, also showed a significant prevalence of cardiovascular disorders.

Regarding the occurrence of cardiac disease in *Pteropodidae* family, a study involving 5 geriatric Livingstone Fruit Bats (*Pteropus livingstonii*) concluded that age might influence the decline of diastolic function in this species[117], presumably as a result of myocardial stiffening. It has also been reported that cardiac failure is the leading cause of death in geriatric Livingstone Fruit Bats[118]. Our findings are consistent with the ones already reported, since there is a significant prevalence of cardiovascular disease in the *Pteropodidae* family. Musculoskeletal issues have also been reported in these animals[118], which is also depicted in our results.

A valid point for discussion consists on the fact that the information obtained regarding medical history for each animal was collected, almost entirely, from local records and communication with relevant parties. Furthermore, the study population may not be a fully representative sample of the real situation for both families and species, since the number of study subjects is not substantial, and some species are over-represented in the taxonomic groups.

When discussing and interpreting the results obtained regarding age of diagnosis of selected morbidity categories, one should take into consideration that age of diagnosis does not truly correspond to the actual age of onset of the disease. The diagnosis might be delayed by infrequency of clinical examinations due to management and clinical protocols, overlooking and misinterpretation of clinical signs and absence or active conceal of symptomatology by the animals. Thus, when interpreting the results regarding age of diagnosis of the selected disorders, one should assume that the age of onset is inferior to the age of diagnosis.

The performance of clinical examination in most wild captive species requires chemical immobilization and anesthesia. These procedures carry great risk for geriatric individuals[90] and, on the lack of a safe alternative for clinical examination, diagnostic procedures may not be performed and disorders might go undiagnosed or only recognized at later stages, when clinical signs are more apparent. In these cases, veterinarians should perform a risk assessment, by considering both situations: (1) Performing anesthesia in a geriatric animal, potentially causing its' death, but allowing the diagnosis of medical conditions; (2) or not performing the anesthetic procedure, leading to no diagnosis or treatment of a potentially life-threatening disease.

The temperament and the ease of manipulation of a certain species greatly influences the type and frequency of clinical examinations. In this study, we analyzed the age of diagnosis, as opposed to the age of onset, since the latter is nearly impossible to determine. The untamed nature of a number of species in this study might influence the frequency of clinical examinations, which are required, most of the times, to detect clinical abnormalities or confirm a diagnosis. Based on this assumption, one ought to expect that the diagnosis of disorders in animals from the *Felidae* family would occur at later stages, in contrast to early diagnosis in tamer and easily manipulated animals, such as the ones from the *Pteropodidae* family. However, this was not the case. The number of individuals included in this study is not substantial, thus, these findings might not be truly representative of the reality.

The mentioned challenges that zoo veterinarians face concerning *antemortem* clinical examinations might explain the rate of diagnostics made exclusively during *postmortem* examinations, as is the case of hepatic, cardiovascular and urinary disorders, as well as neoplastic processes. These disorders might be underdiagnosed in our study population, or they can be life-threatening to an extent that they are not diagnosed on time. Some of the morbidity categories can be considered non-life-threatening, but they might severely affect the quality of life of the individuals, e.g. musculoskeletal and sensory disorders. Although they do not directly pose a threat to the animal's ability to survive, they can affect the individual's quality of life to the point where it's sensible to perform euthanasia.

Overall, the most frequently diagnosed morbidity group in the geriatric zoo mammals of this study was the musculoskeletal category. This conclusion is consistent with the findings reported by Föllmi and colleagues[119] in a study involving 70 aged zoo mammals from 24 different species, in which 36.90% of these suffered from dysfunction of the musculoskeletal system. Regarding the prevalence of selected morbidity categories, one should account for the potential existence of significant differences in comparison to the global captive mammal population. Different populations of animals from the same species may have different predisposition to certain disorders, since this can be highly influenced by genetic lineage, as well as by other factors related to nutrition and management. So, two distinct groups of animals of the same species kept in different geographical locations may not demonstrate the same disorders.

By relating these last two topics, which refer to the prevalence of morbidities and diagnosis performed during *postmortem* and *antemortem* examinations, we can try to make some relevant and interesting conclusions. Overall, the disorders with the highest prevalence in the dead geriatric population (as previously stated, this only refers to the status of the study population, and not to when the diagnosis was made) were categorized as Urinary, Hepatic, Neoplasia and Cardiovascular. The disorders most commonly diagnosed exclusively during *postmortem* examinations, in these animals, also belonged to these categories. It is sensible to admit, even though we haven't done any correlation study, that these two findings are connected, as we can consider these disorders to be potentially life-threatening, and they may have played a role in the animals' death.

Concerning the proportion of euthanasia and natural/ non-euthanasia deaths we can affirm that there is significant variation among the analyzed taxonomic groups. The *Hominidae* family, which comprises Western Lowland Gorillas (*Gorilla gorilla gorilla*) and Sumatran Orangutans (*Pongo abelii*), had no reported cases of euthanasia in geriatric individuals, as opposite to other groups.

These findings might be explained by management-related reasons and protocols which may be distinct between species and taxonomic families.

The prevalence of no morbidity is, an one would unsurprisingly expect, higher in living individuals. In this study, we would expect to demonstrate the null occurrence of absence of morbidities in dead individuals since there should always be a biological abnormality for natural death or euthanasia. However, as previously explained, the dead animals in this group include those with no cause of death determined, which does not necessarily mean that there was no morbidity present. Not surprisingly, the occurrence of single morbidity and multiple morbidity was higher in dead individuals, whereas in living individuals, the occurrence of single and multiple morbidity tends to decrease. It is expected, as animals grow older that there is higher rate of multiple morbidities, except in the cases when a single morbidity may pose a large threat to the animal's survival.

6. Conclusion

The analysis of the results obtained in this study allows us to conclude that:

1. Overall, musculoskeletal disorders were more frequently diagnosed in geriatric zoo mammals, followed by urinary disorders;
2. The prevalence of disorders shows a great variation between different taxonomic families;
3. The most frequently over-looked *antemortem* diagnostics belong the Hepatic, Cardiovascular, Urinary and Neoplasia morbidity groups;
4. The management of the collection concerning the performance of euthanasia appears to vary between taxonomic families;
5. The prevalence of single and multiple morbidities is higher in dead individuals , and the occurrence of "No morbidity" is higher in living animals.

Chapter IV - Behavioral Assessment of Quality of Life

1. Introduction

The behavioral assessment method used by the San Francisco Zoological Society and described by Marrin, Watters and Krebs[16] consists on the implementation of a simple observation program that permits the evaluation of the balance between positive and negative experiences. It should include regular, systematic observation and discussion.

Ideally, the assessed animals are to be observed one to three times per day during two distinct situations: during free time and during interactions. During free time, the observer should describe the animal's behavior every minute for a total duration of five minutes. During interaction time, the observer should describe the animal's responsiveness to training sessions, shifting locations and feedings. Afterwards, every behavior observed during the observation period should be scored with a positive (+1), neutral (0), or a negative (-1) mark, in 8 categories, by answering the following questions:

- Positive / Negative / Neutral Overall: Is this behavior considered a positive, neutral or negative moment?
- Pain: Does this behavior suggest the animal might experience pain/discomfort?
- Activity: Is this behavior active or inactive?
- Physical health: Does this animal experience itself as physically healthy?
- Psychological health: Does this animal show a positive psychological status?
- Independence: Does this animal experience independence?
- Social: Does this animal experience proper social interactions?
- Environmental: Is this animal involved in a complex, appropriate environment?

The overall assessment of all the points addressed should be evaluated by the quality of life team. It should be decided how often should the assessments be conducted, which points should be monitored more closely, which modifications can be made, and, in the case of a likely upcoming euthanasia, which criteria should be established for that particular animal.

2. Aims

The aim of this study was to evaluate the quality of life of selected geriatric individuals, using the method proposed by Marrin and colleagues, and evaluate if this method allows a more focused evaluation of individual behaviors, the establishment of a numerical score and a chronological view of an individual's quality of life.

3. Material and Methods

To test this method, 4 individuals, from 3 distinct primate species were observed: 2 Sumatran Orangutans (*Pongo abelii*), 1 Lar Gibbon (*Hylobates lar*) and 1 Agile Gibbon (*Hylobates agilis*). These animals belonged to an European zoological facility and were chosen as subjects for this study as (1) they were considered geriatric, by being older than the 0.85 of the MLE for the population; (2) they were easily distinguished from other conspecifics, due to their physical attributes. The exception to the first condition is subject "G", an Agile Gibbon. The Median Life Expectancy is not available for *Hylobates agilis*, but the animal was, without question, considered geriatric and thought to benefit from a quality of life assessment.

The orangutans were housed together, along with other conspecifics, whereas both gibbons were housed together, with no other conspecific. While the indoor enclosures were specific to each species, the outdoor enclosure was shared by both groups, where it was possible for them to cohabit and interact.

For this study, a month-long behavioral assessment was conducted for each animal. Medical history for each individual was consulted and analyzed, and relevant staff members were consulted for expertise in the interpretation of behaviors. The individuals were observed for five minutes, during a total of six different occasions over the course of one month, and the behaviors displayed during this time were recorded. This observation was only carried out during free time. Afterwards, each behavior was scored as negative (-1) , neutral (0) or positive (+1), in eight categories: (1) Positive / Negative / Neutral Overall; (2) Pain; (3) Activity; (4) Physical Health; (5) Psychological Health; (6) Independence; (7) Social; (8) Environmental.

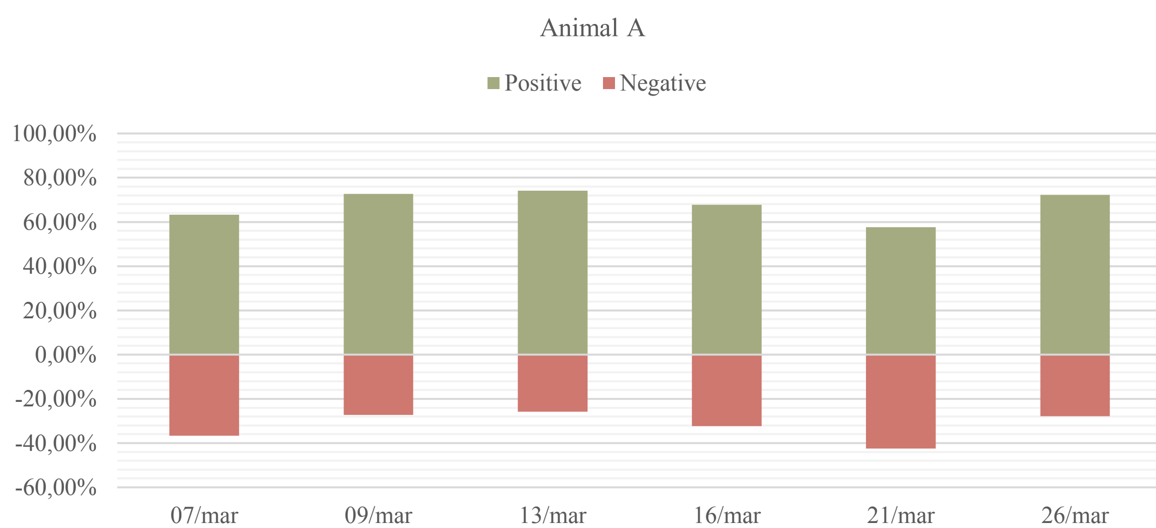
Following behavior observation and scoring, the percentage for negative and positive moments were calculated. The data compilation and analysis relied on Microsoft Excel® software.

4. Results and Discussion

The names of the animals were altered for anonymity purposes. The results of the assessment are displayed for each animal, as follows.

Animal A

Animal A is 35-year-old female Sumatran Orangutan (*Pongo abelii*) with a history of dental disease, otherwise with no known issues.



Graph 17 - Animal A Behavioral Assessment

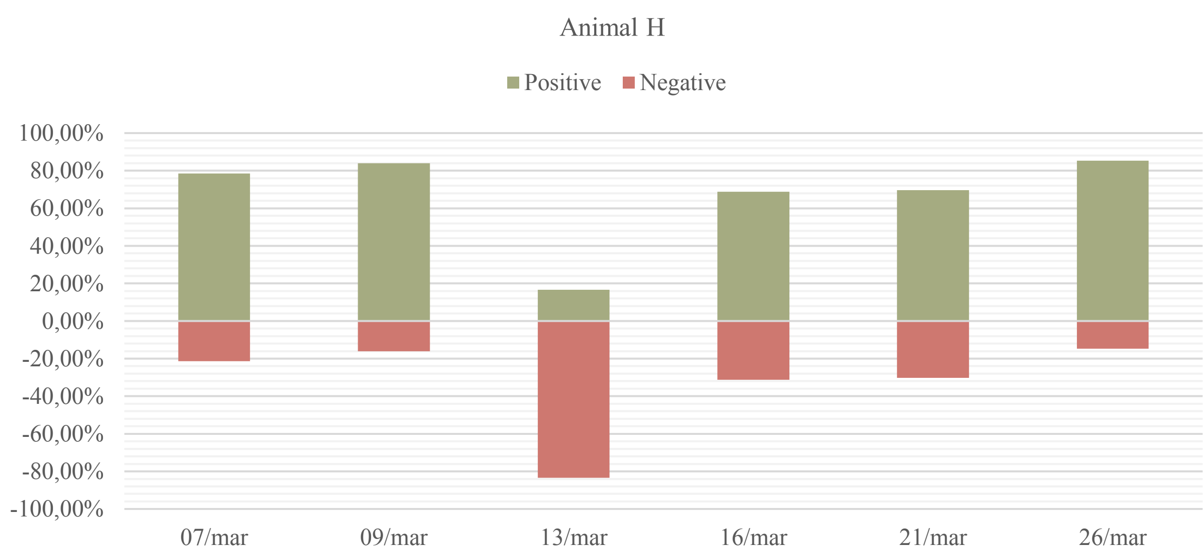
Graph 17 displays subject A's overall behavioral assessment results. Regarding individual domains, the analysis of this animal's behaviors allows us to conclude as follows:

- A's activity levels seem to be very satisfactory for her age. She frequently brachiates, explores the enclosure and interacts with her offspring.
- There are consistent positive behavioral indicators in the assessed domains, overall.
- A does not appear to demonstrate any potential pain indicators or any discomfort.

The overall classification was 67.96% of positive behaviors against 32.05% negative behaviors. We can consider this animal to have a good quality of life, according to Mellor's[99] standards. A few recommendations were made regarding the occurrence of some stereotypical behavior, which doesn't seem to be related to any coping mechanism, but rather to boredom.

Animal H

Animal H is 32-year-old female Lar Gibbon (*Hylobates Lar)* with a previous bone fracture, otherwise with no known issues. Housed with conspecific G.



Graph 18 - Animal H Behavioral Assessment

Graph 18 displays subject H's overall behavioral assessment results. Regarding individual domains, the analysis of this animal's behaviors allows us to conclude as follows:

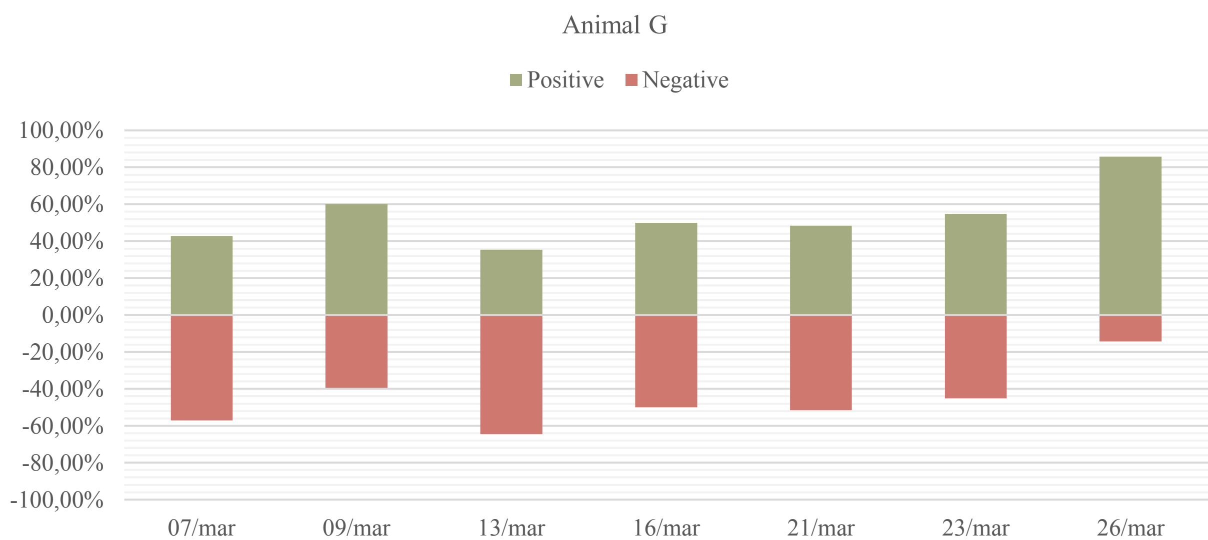
- H's activity levels seem to be adequate for her age. She frequently brachiates and explores the enclosure.
- H does not appear to demonstrate any potential pain indicators or any discomfort.

- There are consistent positive behavioral indicators in the assessed domains, overall.

Like every living organism, H experiences both negative (30.19%) and positive (69.89%) moments throughout the day. Thus, some days are better than others. Regarding H's behavioral balance during this month-long assessment, one can say that the days when she presented a higher amount of negative moments are not concerning, since this animal doesn't seem to show any discomfort or stereotypical behavior. The abnormal amount of time she spends self-grooming and grooming conspecific do not appear to be detrimental, but some enrichment could be beneficial. Overall, H has a good quality of life.

Animal G

Animal G is a 52-year-old male Agile Gibbon (*Hylobates agilis*) with nuclear sclerosis and degenerative joint disease. Housed with conspecific "H".



Graph 19 - Animal G Behavioral Assessment

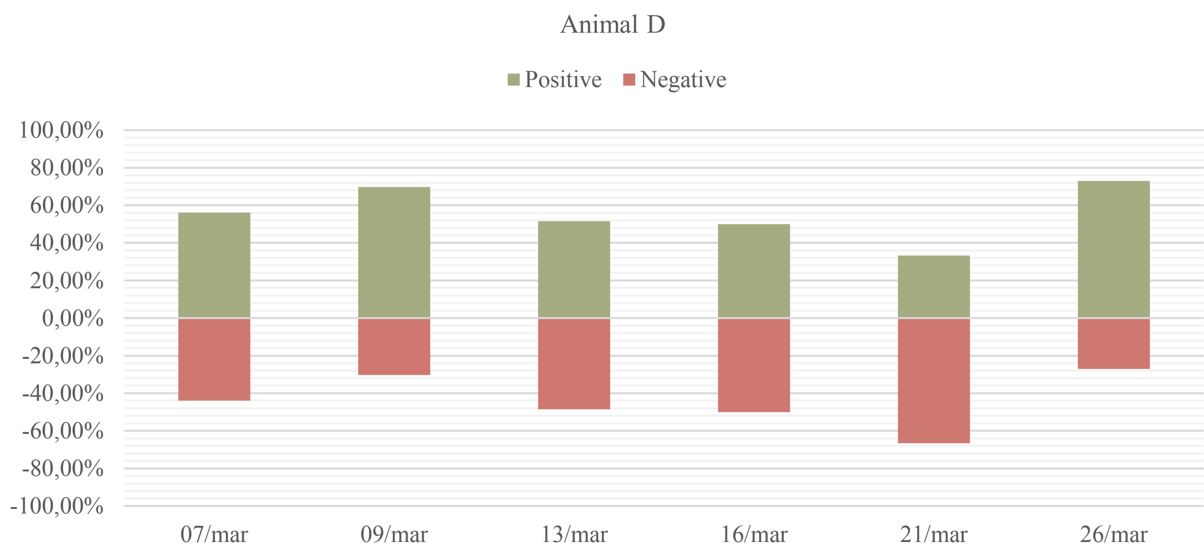
Graph 19 displays subject G's overall behavioral assessment results. Regarding individual domains, the analysis of this animal's behaviors allows us to conclude as follows:

- G's activity levels remain quite low overall. The low activity levels may represent some discomfort, lack of stimulation or may represent normal activity levels for his age.
- Potential pain indicators have been observed when the animal is brachiating and walking. During these behaviors, G seems to find some discomfort extending his hindlimbs.
- There are consistent negative behavioral indicators in multiple domains, however the amount of time observing this animal may not be fully representative of the reality. This data suggest G may have normal age-related inactivity, but also some degree of discomfort.

Based on data presented here, G maintains a balanced quality of life, according to Mellor's Quality of Life scale[99] with a percentage of positive and negative moments of 53.93% and 46.07%, respectively. It would be desirable to increase the amount of positive experiences in his day. The animal is still able to make choices, manage his social situation well and he maintains a good level of independence. The lack of interaction with the environment can be blamed on the absence of cognitive stimulation.

Animal D

32-year-old Male Sumatran Orangutan (*Pongo abelii*) with a history of behavioral issues.



Graph 20 - Animal D Behavioral Assessment

Graph 20 displays subject D’s overall behavioral assessment results. Regarding individual domains, the analysis of this animal’s behaviors allows us to conclude as follows:

- D’s activity levels seem to be very satisfactory for her age. He frequently brachiates and explores the enclosure and seems to demonstrate normal social interactions regarding his status.
- Potential Pain Indicators – D does not appear to demonstrate any potential pain indicators or any discomfort.
- There is consistent behavioral positive scoring in the assessed domains. The psychological domain seems to be the one scored more negatively, due to the amount of inactivity of abnormal behavior (rocking from side to side).

One can consider D to have good quality of life, with a percentage of positive behaviors of 60.00% and negative behaviors of 40.00%. Apart from the “rocking” behavior, he doesn’t seem to display any concerning behaviors.

5. Conclusion

Institutions often struggle to find a suitable approach to evaluate quality of life based on a behavior. In our view, this approach can be useful. Each species’ (and individual) behavior repertoire is unique and by evaluating a certain action considering different parameters, one is able to better evaluate the impact of that behavior in the animal’s quality of life.

Several quality of life assessment models have been used by companion animals veterinarians in order to educate and guide pet owners to make end-of-life decisions[10,101]. Some of these methods have been used by zoo veterinarians. However, caring for zoo animals presents unique challenges and some of the features of such quality of life assessment models are not applicable for wild captive animals. In view of this, quality of life assessment models and scoring systems adapted to zoo settings have been developed[16,106,119].

The tested method of assessing quality of life revealed to be an easy and useful technique. Ideally, it should be performed by staff members with experience and knowledge in animal behavior, so that misinterpretation of behaviors is minimized. This method allows the assessment of behaviors which, as previously postulated, can be considered the physical demonstration of the animal’s state of well-being. The collective analysis of all these behaviors allow the user to assess quality of life over a given period of time, allowing the perception of the evolution of the ratio between positive and negative moments. This perception is essential so as to identify the need to address medical and husbandry issues, plan the need of clinical examination, identify the need to conduct environment and management modifications and assess therapy effectiveness. By displaying this information in easily interpreted graphs, it is possible to draw a timeline and understand in which way the quality of life of the monitored animal is progressing.

Chapter V – Final Remarks

Every concept and analysis made in this dissertation was based on the Median Life Expectancy values calculated from local records or available from the SSL. The latter values were calculated based on the population housed in AZA accredited institutions, which is not the case for any facility in this study. The calculated MLE at institutional level may not be fully representative of the global captive population. However, as previously stated, these values provide a useful and easily interpreted insight on animal survivorship.

From the demographic point of view, the widespread practice of euthanasia may be skewing real biological survival statistics, such as longevity and median life expectancies, since biological potential is not reached. Plus, there is a significant discrepancy between the zoological facilities at the global level, from the euthanasia point of view, regarding geriatric zoo animals. While some facilities would rather practice euthanasia as soon as the typical aging clinical signs start to arise, others extend the animals' life as long it is still ethical to do so.

Even though growing old is an unavoidable process, if we better understand all of its implications at the cellular and organ systems levels– as veterinarians, as caretakers, as scientists – we might be able to positively influence aspects that impact quality of life and health, in order to treat and ameliorate clinical signs and complications commonly associated with the aging process. If such issues are recognized prematurely, it is possible to establish measures to decelerate the progression of the disease and subsequently reduce the prevalence of multimorbidity.

Geriatric animals can add immense value to a zoological collection. These individuals can be important from an educational point of view by being used as models for educating the public about conservation, acting as ambassadors for their species. They can also be used for research, providing useful information for the better management and care of future generations.

Although we achieved the goals initially set, we recognize some limitations to our study. The reduced number of total individuals in our study population, as well as the reduced number of individuals of each species, might pose a threat to the relevance of our results. In this preliminary approach to this topic, it would have been more beneficial to consider a smaller number of species, and a greater number of individuals per species. By including more zoological facilities in further geographical locations, one might be able to account for variations in terms of, for example, management-related factors and population genetic diversity. However, this was not possible as we were dependent on other factors . Even though more zoos were contacted and requested to contribute to this study, the participation rate was not as high as we initially envisaged. However, we understand that in these types of study, one is dealing with sensitive and confidential information, thus zoological facilities are often reluctant to participate. Nevertheless, in terms of qualitative data, we did capture some preliminary information that we consider relevant and that serves as a baseline for future studies.

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Appendix A

Table 12 - Compilation of MLE, 0.85 MLE and Longevity values in selected taxa, in years

Common Name	**MLE[13] (M/F)**	**0.85 MLE (M/F)**	**Longevity**
Bat, Livingstone's fruit (*Pteropus livingstonii*)	11.84	10.1	15[109]
Bat, Rodrigues Fruit (*Pteropus rodricensis*)	13.6 /16.6	11.56 / 14.11	28[109]
Capybara (*Hydrochoerus hydrochaeris*)	7.1/8.60	6.04 / 7.31	15.1[109]
Colobus, Black-and-white (*Colobus angolensis angolensis*)	18.2	15.5	35.3[109]
Gibbon, Lar (*Hylobates lar*)	16.6	14.1	50[120]
Gorilla, Western lowland (*Gorilla gorilla gorilla*)	31.70 /38.3	26.95 / 32.56	60[9]
Kangaroo, Matschie's tree (*Dendrolagus matschiei*)	13.2	11.2	26.9[109]
Lemur, Alaotran Gentle (*Hapalemur alaotrensis*)	17.33	14.7	-
Lemur, Black and White Ruffed (*Varecia variegata*)	18.4	15.6	39.4[121]
Lemur, Mongoose (*Eulemur mongoz*)	22.8	19.4	36.2[109]
Lemur, Red ruffed (*Varecia rubra*)	19.9	16.9	37.5[121]
Lemur, Ring Tailed (*Lemur catta*)	16.5	14.0	37.7[109]
Lion (*Panthera Leo*)	16.9	14.4	27[109]
Loris, Pygmy Slow (*Nycticebus pygmaeus*)	12.4	10.54	19.3[121]
Macaque, Lion-tailed (*Macaca silenus*)	26.6	22.6	40[109]
Macaque, Sulawesi crested (*Macaca nigra*)	14.7	12.5	34[109]
Meerkat (*Suricata suricatta*)	9.6	8.2	20.6[109]
Monkey, Black Howler (*Alouatta caraya*)	17.8	15.1	32.4[109]
Monkey, Common Squirrel (*Saimiri sciureus sciureus*)	14.6	12.4	30.2[109]

Okapi (*Okapia johnstoni)*	16.4	13.9	33.5[109]
Orangutan, Sumatran (*Pongo abelii)*	25.2/32.8	21.42 / 27.88	58[122]
Otter, North American river (*Lontra canadensis)*	12	10.2	27[109]
Panda, Red (*Ailurus fulgens fulgens)*	10	8.5	19[109]
Rat, Giant jumping (*Hypogeomys antimena)*	5.2	4.4	12.6[109]
Saki, White faced (*Pithecia pithecia)*	DD/11.60	9.9	36[109]
Sand cat (*Felis margarita*)	9.9	8.4	13.9[109]
Sloth, Hoffmann's two-toed (*Choloepus hoffmanni)*	15.2	12.9	32.1[8]
Sloth, Linne's two-toed (*Choloepus didactylus)*	16	13.6	36.8[109]
Tamarin, Bearded Emperor (*Saguinus imperator subgrisescens)*	7.8	6.6	23.7[109]
Tamarin, Black Lion (*Leontopithecus chrysiopygus)*	14.43	12.3	17.9[109]
Tamarin, Cotton Top (*Saguinus oedipus)*	11.5	9.8	26.2[109]
Tamarin, Golden lion (Leontopithecus rosalia)	12.1	10.3	31.6[109]
Tamarin, Pied (*Saguinus bicolor)*	10.6	9.0	19[109]
Tenrec, Lesser Madagascar hedgehog (*Echinops telfairi)*	8.40 / 7.3	7.14 / 6.21	19[109]
Tiger, Amur (*Panthera tigris altaica)*	16.0/14.30	13.6 / 12.16	26.3[109]
Zebra, Chapman's (*Equus quagga)*	15.3	13.0	38[109]