



A retrospective review of mortality in lorises and pottos in North American zoos, 1980–2010

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ABSTRACT: Patterns of mortality in captive animals can reveal potentially problematic care practices or other risk factors that may negatively impact animal health and population sustainability. We reviewed death records (necropsy and/or histopathology reports) for 367 lorises and pottos born between 1980 and 2010 that were housed in 33 North American zoos and related facilities. Our sample included 20 *Loris tardigradus nordicus*, 72 *L. t. tardigradus*, 109 *Nycticebus coucang*, 133 *N. pygmaeus*, and 33 *Perodicticus potto*. In all 5 groups, neonates (animals <30 d old) or geriatric animals accounted for the majority of death reports. Neonate deaths were most commonly attributed to stillbirth, trauma, and multi-systemic disease (septicemia or other infection). Animals that survived the first month of life were likely to live to adulthood or the geriatric stage. For all species, the most commonly cited causes of death were renal disease, multi-systemic illness, and trauma. Over 50% of all the animals studied displayed some renal pathology upon postmortem analysis. Across species, other organ systems in which >20% of animals showed signs of disease included the cardiovascular and hemolymphatic, endocrine and metabolic, gastrointestinal, and immunologic systems. Our results indicate that reducing neonatal mortality is a major priority for sustaining these species in captivity, and common practices for managing groups during the perinatal period should be carefully scrutinized. Other areas in need of further investigation are environmental contributions to neoplastic and infectious disease, and dietary contributions to chronic degenerative conditions.

KEY WORDS: Lorisid primate · Epidemiology · Zoo veterinary care · Infant mortality

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INTRODUCTION

Lorises (genera *Loris* and *Nycticebus*) are strepsirrhine primates that dwell in forested habitats across Southeast Asia. Slender lorises include at least 2 species in India and Sri Lanka (Brandon-Jones et al. 2004), and the slow lorises are a radiation of species extending through Indonesia into southern China. Ongoing investigations are revealing increased diversity within the genus *Nycticebus* (Munds et al. 2013), just as it is becoming clear that all loris species are declining in the wild (Nekaris & Jayewardene 2004, Nekaris & Nijman 2007, Iseborn et al. 2011). In recent years, the pet trade has had an increasingly

devastating impact on wild slow loris populations (Nekaris et al. 2010, Nekaris & Campbell 2012). Many animals rescued from this illegal trade have suffered physical injuries that make reintroduction to the wild impossible, and the need for sanctuary housing grows along with the popularity of lorises as pets (Nekaris & Jaffe 2007). Zoos that have historically housed lorises thus may have the opportunity to contribute to *in situ* conservation efforts by providing sanctuaries with information on captive loris husbandry and veterinary care.

Zoo populations of slender and slow lorises are found in Europe, Asia, and North America. North American zoos have historically housed the pygmy

slow loris *Nycticebus pygmaeus*, and a hybridized population of *N. coucang*, *N. bengalensis*, and *N. javanicus*, all managed as *N. coucang* (common name: slow loris). North American zoos have also housed 2 subspecies of red slender loris: *Loris tardigradus tardigradus* and *L. t. nordicus*, although the North American captive population of the latter is now extinct. According to Fitch-Snyder & Schulze (2001), the history of slow and slender lorises in North America dates back to late 19th/early 20th century exhibits at the Philadelphia and Bronx zoos, while a breeding population of pygmy slow lorises was established in North America in 1987. In addition to slender and slow lorises, North American zoos are home to a small population of an African lorid: the potto *Perodicticus potto*. Pottos are thought to be widespread throughout sub-Saharan Africa, but their true taxonomic and conservation status is largely unknown (Grubb et al. 2003).

Pygmy loris numbers are increasing in zoos, and currently they are the only lorid species nearing sustainability in North American collections (Kuhar et al. 2011). Populations of other lorid species are small (<15 ind.) and declining. Although *L. t. nordicus* is no longer found in captivity in North America, there are still some individuals managed in Europe. Research into reproduction, as well as veterinary and social needs, may play an important role in maintaining viable populations of these species in captivity (Schulze 1998).

High infant mortality and traumatic death appear to be major impediments to population growth in lorises and pottos. Debyser (1995) analyzed mortality trends for strepsirrhine juveniles in zoos and primate centers and found that more offspring died prior to weaning in *N. coucang*, *L. t. tardigradus*, and *P. potto* than the 13 lemur and galago species that were also surveyed. Sutherland-Smith & Stalis (2001) reviewed mortality in lorises from the San Diego Zoo (1982 to 1995) compared to Duke University Lemur Center (1980 to 1994). Those data showed that in addition to trauma, significant contributors to captive loris morbidity and mortality include dental, renal, and respiratory diseases. The present study expands on this research (with some sampling overlap) and seeks to describe more comprehensively the factors contributing to mortality in captive lorises and pottos.

We reviewed postmortem records for *L. t. nordicus*, *L. t. tardigradus*, *N. coucang*, *N. pygmaeus*, and *P. potto* born between 1980 and 2010 that lived in North American zoos. Our primary aim was to describe major sources of mortality in these species. In a companion to the present paper, we also surveyed facili-

ties that are currently housing lorid primates to determine how animals are actually cared for in practice (Fuller et al. 2013). These studies set the stage for future hypothesis-driven research examining associations between environmental design, diet, health, and animal behavior. Ultimately, our goal is to identify husbandry concerns and areas of research most urgently needed to address the health, welfare, and population sustainability of lorises and pottos in the care of sanctuaries and zoos.

MATERIALS AND METHODS

Study population

We requested full medical records from all North American zoos and related facilities for animals born between January 1, 1980 and December 31, 2010 representing 5 species: *Loris tardigradus nordicus*, *L. t. tardigradus*, *Nycticebus coucang*, *N. pygmaeus*, and *Perodicticus potto*. Animals and facilities included in these populations were identified by consulting North American Regional Studbooks for each species as of October 2010. Species groups are also based on studbook data. Studbooks were accessed using Poplink v. 1.3 and 2.1. *L. t. nordicus* and *L. t. tardigradus* have separate studbooks and were treated as separate populations here. In contrast, *N. coucang*, *N. bengalensis*, and *N. javanicus* have historically been grouped as one species in North American facilities, and the population's hybrid status is uncertain; for these reasons, they are treated as a single population (referred to as *N. coucang*) here.

In total, 1 unaccredited zoo and 32 of 35 zoos (91%) accredited by the Association of Zoos and Aquariums (AZA) where a lorid primate died during this time period contributed medical records to this study, representing a total of 367 animals. The total number of records received for each species were: 20 (10:9:1 (male:female:unknown) out of 25 *L. t. nordicus* (80%), 72 (31:29:12) out of 80 *L. t. tardigradus* (90%), 109 (50:52:7) out of 152 *N. coucang* (72%), 133 (59:57:17) out of 173 *N. pygmaeus* (77%), and 33 (17:11:5) of 37 *P. potto* (79%). Across species, this sample included 167 males (45.5%), 158 females (43.0%), and 42 animals of unknown sex (11.4%).

The majority of records (241; 66%) were formatted using MedARKS or ARKS (International Species Information Systems), but the sample included other electronic formats and hand-written records. Additionally, one facility elected to provide summaries of necropsy and histopathology findings rather than

submitting full records. Medical records included in this study varied greatly in detail and scope. Necropsy reports were available in 247 (67%) of the records received, and 214 (58%) included a histopathology report.

Independent samples' *t*-tests with equal variances assumed were used to compare mean age at death for males compared to females within each species studied (IBM SPSS Statistics v. 21).

Organ system classification and cause of death

Data for each animal were entered into a Microsoft Access database. Age at death, sex, and death type (spontaneous, euthanasia, or unknown) were recorded for each animal. Based on their age at death (x), the animals within each species were categorized into 1 of 4 age groups: neonate: $x \leq 30$ d old; juvenile: $30 \text{ d} < x \leq 1 \text{ yr}$; adult: $1 \text{ yr} < x \leq$ geriatric; and geriatric. Age at which an animal was considered geriatric varied by species and was calculated as 75% of the mean lifespan of all animals in our study population that reached adulthood (i.e. excluding neonates and juveniles). *L. t. nordicus* were considered geriatric at 9 yr old, *L. t. tardigradus* at 10 yr, *N. coucang* at 9 yr, *N. pygmaeus* at 8 yr, and *P. potto* at 12 yr. One year was chosen as a common cutoff point between juveniles and adults based on published reports of age at first reproduction in these species (Charles-Dominique 1977, Fitch-Snyder & Schulze 2001).

Diagnoses from necropsy and histopathology reports were used to determine which organ systems showed evidence of pathology at the time of the animal's death. Organ system classifications were based on Hope & Deem (2006) and included the following categories: cardiovascular and hemolymphatic; central and peripheral nervous system (CNS); dental; endocrine and metabolic; ear, nose, and throat (ENT); gastrointestinal; hepatic and biliary; immunologic (including lymph nodes); integumentary; musculoskeletal; ocular; renal (including the urinary bladder); reproductive; respiratory; and whole body.

Records were also reviewed to determine the cause of each animal's death or primary reason for being euthanized. If a cause of death was not clearly indicated in the medical report, one was identified based on organ system pathology described in the record. In addition to the organ systems listed above (see previous paragraph), cause of death included the following categories specific to neonates: maternal neg-

lect; stillborn and abortion; and unexplained neonate death. Deaths for neonates were considered unexplained when no diagnosis was given, whether or not a necropsy and/or histopathology exam was performed (and available in the record). For all other age classes, the cause of death was only listed as unknown if the record contained a necropsy and histopathology report but a primary cause of death was still unclear. When a histopathology report was not available and the cause of death was not clearly stated in the record, the cause of death was undeterminable and was listed as an incomplete record. For all age classes, in clear cases of environmental or social injury, the cause of death was listed as trauma, even if death was more immediately attributable to septicemia or infection subsequent to the initial insult.

RESULTS

Age-specific patterns of mortality

For all animals in the present study, mean age of death, regardless of death type, was 7.7 yr (SD: 7.1 yr). The mean age at death for each species was: 8.9 yr (SD: 6.6, range: 0 to 18.7 yr) for *L. t. nordicus*, 8.0 yr (SD: 7.3, range: 0 to 21.5 yr) for *L. t. tardigradus*, 9.5 yr (SD: 6.8, range: 0 to 24.3 yr) for *N. coucang*, 6.4 yr (SD: 6.3, range: 0 to 21.9 yr) for *N. pygmaeus*, and 6.2 yr (SD: 9.0, range: 0 to 25.7 yr) for *P. potto*. Taking into account only animals that reached adulthood, the mean age at death for each species was: 11.8 yr (SD: 4.7 yr, $n = 15$) for *L. t. nordicus*, 12.7 yr (SD: 5.1 yr, $n = 45$) for *L. t. tardigradus*, 11.8 yr (SD: 5.6 yr, $n = 88$) for *N. coucang*, 10.1 yr (SD: 5.1 yr, $n = 84$) for *N. pygmaeus*, and 15.6 yr (SD: 7.3 yr, $n = 13$) for *P. potto*. Mean age at death for individuals that reached adulthood was nearly equal for males and females in every species tested, and there were no significant differences in lifespan based on sex.

For all species except *L. t. nordicus*, death most commonly occurred spontaneously (Table 1) rather than as a result of euthanasia. Neonate mortality (death within the first 30 d of life) was high for each species, most strikingly the potto, in which 60.6% of the sample population died by 30 d of age (Table 2). Of all the animals in this study, 30.2% (111/367) died as neonates. For all species, mortality during the juvenile period was relatively low. Generally, mortality was greatest in neonate and geriatric groups (Table 2).

Table 1. Recorded type of death for lorises and pottos in North American facilities, 1980–2010. Data are % of total for each species or for all species, followed by number of individuals in parentheses. N: total sample size

Death type	<i>Loris tardigradus nordicus</i> N = 20	<i>Loris tardigradus tardigradus</i> N = 72	<i>Nycticebus coucang</i> N = 109	<i>Nycticebus pygmaeus</i> N = 133	<i>Perodicticus potto</i> N = 33	Total N = 367
Euthanasia	45.0 (9)	29.2 (21)	30.3 (33)	30.1 (40)	21.2 (7)	30 (110)
Spontaneous	40.0 (8)	69.4 (50)	63.3 (69)	67.7 (90)	69.7 (23)	65.4 (240)
Unknown	15.0 (3)	1.4 (1)	6.4 (7)	2.2 (3)	9.1 (3)	4.6 (17)

Table 2. Distribution of loris and potto deaths by age class in North American facilities, 1980–2010. Data are % of total for each species or for all species, followed by number of individuals in parentheses. N: total sample size; x: age at death

Age class	<i>Loris tardigradus nordicus</i> N = 20	<i>Loris tardigradus tardigradus</i> N = 72	<i>Nycticebus coucang</i> N = 109	<i>Nycticebus pygmaeus</i> N = 133	<i>Perodicticus potto</i> N = 33	Total N = 367
Neonate (x ≤ 30 d)	25.0 (5)	31.9 (23)	15.6 (17)	34.6 (46)	60.6 (20)	30.2 (111)
Juvenile (30 d < x ≤ 1 yr)	0	5.6 (4)	3.7 (4)	2.3 (3)	0	5.2 (19)
Adult (1 yr < x ≤ geriatric ^a)	20.0 (4)	15.3 (11)	24.8 (27)	21.1 (28)	9.1 (3)	17.7 (65)
Geriatric	55.0 (11)	47.2 (34)	56.0 (61)	42.1 (56)	30.3 (10)	46.9 (172)

^aCutoff age for geriatric animals was based on 75% of the mean adult lifespan in this population: *L. t. nordicus*: >9 yr, *L. t. tardigradus*: >10 yr, *N. coucang*: >9 yr, *N. pygmaeus*: >8 yr, and *P. potto*: >12 yr

Table 3. Primary cause of death or reason for euthanasia in lorises and pottos housed in North American facilities, 1980–2010. Data are % of total for each species or for all species, followed by number of individuals in parentheses. N: total sample size, followed by number of individuals that were male:female:unknown in parentheses

Cause of death	<i>Loris tardigradus nordicus</i> N = 20 (10:9:1)	<i>Loris tardigradus tardigradus</i> N = 72 (31:29:12)	<i>Nycticebus coucang</i> N = 109 (50:52:7)	<i>Nycticebus pygmaeus</i> N = 133 (59:57:17)	<i>Perodicticus potto</i> N = 33 (17:11:5)	Total N = 367 (167:158:42)
Cardiovascular and hemolymphatic	0	4.2 (3)	3.7 (4)	4.5 (6)	6.1 (2)	4.1 (15)
Central nervous system	0	2.8 (2)	0	2.3 (3)	3.0 (1)	1.6 (6)
Endocrine and metabolic	0	0	2.8 (3)	0.8 (1)	0	1.1 (4)
Ear, nose, and throat	0	0	2.8 (3)	0.8 (1)	0	1.1 (4)
Gastrointestinal	5.0 (1)	0	6.4 (7)	1.5 (2)	0	2.7 (10)
Hepatic and biliary	5.0 (1)	5.6 (4)	5.5 (6)	3.0 (4)	0	4.1 (15)
Immunologic	0	0	0	0.8 (1)	0	0.3 (1)
Integumentary	0	1.4 (1)	0	1.5 (2)	0	0.8 (3)
Musculoskeletal	0	2.8 (2)	2.8 (3)	5.3 (7)	0	3.3 (12)
Ocular	5.0 (1)	0	0	0.8 (1)	0	0.5 (2)
Renal	25.0 (5)	18.1 (13)	19.3 (21)	15.0 (20)	6.1 (2)	16.6 (61)
Reproductive	0	0	3.7 (4)	0.8 (1)	3.0 (1)	1.6 (6)
Respiratory	10.0 (2)	4.2 (3)	2.8 (3)	5.3 (7)	15.2 (5)	5.4 (20)
Multi-systemic	5.0 (1)	19.4 (14)	22.9 (25)	15.8 (21)	15.2 (5)	18.0 (66)
Trauma	5.0 (1)	13.9 (10)	10.1 (11)	10.5 (14)	9.1 (3)	10.6 (39)
Unknown	0	0	1.8 (2)	0.8 (1)	0	0.8 (3)
Incomplete record	20.0 (4)	4.2 (3)	5.5 (6)	7.5 (10)	6.1 (2)	6.8 (25)
Maternal neglect (neonates)	10.0 (2)	1.4 (1)	0.9 (1)	6.8 (9)	6.1 (2)	4.1 (15)
Stillborn or abortion (neonates)	0	4.2 (3)	5.5 (6)	9.8 (13)	12.1 (4)	7.1 (26)
Unexplained neonate death (neonates)	10.0 (2)	18.1 (13)	3.7 (4)	6.8 (9)	18.1 (6)	9.3 (34)

Organ system pathology and cause of death

For all the lorises and pottos in this study, multi-systemic disease was the most frequent cause of death or euthanasia, followed by renal disease and trauma (Table 3). Many animals were stillborn or died as neonates due to maternal neglect or other unexplained reasons. Only 2 to 6% of deaths were attributed to diseases in each of the cardiovascular and hemolymphatic; gastrointestinal; hepatic and biliary; musculoskeletal; and respiratory systems. Less than 2% of deaths were attributed to each of the remaining organ systems.

For all animals (Table 4), the most common organ system showing lesions or abnormalities at death was the renal system, with 50% of all animals in the study affected. Over 40% of all lorisids sampled also showed pathologies in the respiratory and hepatic and biliary systems. Across species, organ systems in which >20% of animals showed signs of disease included the cardiovascular and hemolymphatic; endocrine and metabolic; gastrointestinal; and immunologic systems. Specific diseases affecting >20% of animals in each species are detailed in the following subsections.

Neoplasia was responsible for the deaths of 10.6% (39/367) of animals; all of these cases occurred in pygmy and slow lorises, with the exception of 1 potto (Table 5). Medical records included 81 reports of distinct neoplastic growths in 66 animals; 39 of these

were fatal. All neoplasms occurred in geriatric animals, with the exception of 2 adult *N. coucang* and 4 adult *N. pygmaeus*. Both neoplasias reported for *L. t. nordicus* occurred in males, as did 5 of 6 cases in *L. t. tardigradus*. Neoplasia occurred equally between the sexes in *N. pygmaeus* (13 cases in males and 14 in females) and *Perodicticus potto* (1 male and 1 female), but was more common in female *N. coucang* (20 cases) than male (9 cases).

Most animals that experienced traumas were neonates that died as a result of bite wounds (Table 6). Only cases in which cannibalism clearly occurred prior to death were counted as traumas. Often, cases were classified as unexplained neonate deaths because the carcass was scavenged, but it was not possible to determine if this occurred pre- or post-mortem. Several cases in which conspecific bite wounds led to necrosis, cellulitis, or other infection occurred, most commonly in *Nycticebus* spp. All traumas thought to be related to mortality, even if cause of death was listed under another organ system, are detailed in Table 6.

Loris tardigradus nordicus

The primary cause of death was attributed to renal pathology in the majority of the *L. t. nordicus* in this study (Table 3). Records refer to renal failure (2/5) or glomerulonephritis, nephritis, and general glomeru-

Table 4. Percent of lorises and pottos with pathology diagnosed by organ system upon postmortem examination in North American facilities, 1980–2010. Data are % of total for each species or for all species, followed by number of individuals in parentheses. N: total sample size

Organ system	<i>Loris tardigradus nordicus</i> N = 20	<i>Loris tardigradus tardigradus</i> N = 72	<i>Nycticebus coucang</i> N = 109	<i>Nycticebus pygmaeus</i> N = 133	<i>Perodicticus potto</i> N = 33	Total N = 367
Cardiovascular and hemolymphatic	30.0 (6)	26.4 (19)	33.0 (36)	32.3 (43)	18.2 (6)	30 (110)
Central nervous system	20.0 (4)	16.7 (12)	15.6 (17)	16.5 (22)	18.2 (6)	16.6 (61)
Dental	5.0 (1)	4.2 (3)	4.6 (5)	3.0 (4)	0	3.5 (13)
Endocrine and metabolic	15.0 (3)	12.5 (9)	35.8 (39)	19.5 (26)	18.2 (6)	22.6 (83)
Ear, nose, and throat	15.0 (3)	4.2 (3)	14.7 (16)	6.0 (8)	12.1 (4)	9.3(34)
Gastrointestinal	15.0 (3)	8.3 (6)	36.7 (40)	22.6 (30)	21.2 (7)	23.4 (86)
Hepatic and biliary	15.0 (3)	47.2 (34)	51.4 (56)	42.9 (57)	27.3 (9)	43.3 (159)
Immunologic	5.0 (1)	9.7 (7)	35.8 (39)	23.3 (31)	9.1 (3)	22.1 (81)
Integumentary	0	6.9 (5)	5.5 (6)	7.5 (10)	0	5.7 (21)
Multi-systemic	5.0 (1)	19.4 (14)	22.0 (24)	14.3 (19)	12.1 (4)	16.9 (62)
Musculoskeletal	10.0 (2)	11.1 (8)	14.7 (16)	15.0 (20)	6.1 (2)	13.1 (48)
Ocular	25.0 (5)	19.4 (14)	4.6 (5)	6.8 (9)	3.0 (1)	9.3 (34)
Renal	50.0 (10)	41.7 (30)	57.8 (63)	51.9 (69)	33.3 (11)	49.9 (183)
Reproductive	15.0 (3)	9.7 (7)	22.9 (25)	12.8 (17)	9.1 (3)	15 (55)
Respiratory	25.0 (5)	47.2 (34)	46.8 (51)	46.6 (62)	30.3 (10)	44.1 (162)
Whole body	20.0 (4)	12.5 (9)	11.0 (12)	17.3 (23)	18.2 (6)	14.7 (54)

Table 5. Neoplasia reported for lorises and pottos in North American facilities, 1980–2010. n: number of cases for each species; (–) no cases reported. Number of superscripts indicates number of cases that were identified as the primary cause of death for each cancer type

Organ system	<i>Loris tardigradus nordicus</i> (n = 4)	<i>Loris tardigradus tardigradus</i> (n = 6)	<i>Nycticebus coucang</i> (n = 34)	<i>Nycticebus pygmaeus</i> (n = 35)	<i>Perodicticus potto</i> (n = 2)
Cardiovascular and hemolymphatic	–	–	–	Sarcoma (heart)	–
Central nervous system	–	–	Ependymal (brain)	Astrocytoma (brain stem ^a) Ependymoma (cerebrum ^a)	–
Endocrine and metabolic	Adenoma (parathyroid) Myelolipoma (adrenal)	2 adenoma (1 adrenal, 1 thyroid)	Adenoma (adrenal) Carcinoma (pancreas ^a)	Adenoma (thyroid) Sarcoma (pancreas)	–
Ear, nose, and throat	–	–	Squamous cell carcinoma (larynx/pharynx ^a)	Squamous cell carcinoma (tongue ^a)	–
Gastrointestinal	–	–	Sarcoma (large intestine ^a)	Lymphosarcoma (small intestine ^a)	–
Hepatic and biliary	–	Adenoma (liver) Hepatoma (liver)	2 adenoma (both liver) 4 carcinoma (all liver ^{a,a,a}) Unspecified mass (liver ^a)	Adenocarcinoma (liver) Adenoma (liver ^a) Lymphosarcoma, leukemic (liver ^a)	–
Immunologic	–	–	–	Lymphoma (spleen) 2 lymphosarcoma (both spleen ^a)	–
Integumentary	–	–	–	Spindle cell sarcoma (dorsum ^a)	–
Musculoskeletal	–	–	Adenocarcinoma (skeletal muscle ^a) Spinal mass	Fibroma (tarsal region) 3 fibrosarcoma (2 lumbar ^{a,a} , 1 elbow ^a) Osteosarcoma (rib ^a)	–
Ocular	–	Melanoma (iris)	–	–	–
Renal	–	Carcinoma (kidney)	Adenocarcinoma (kidney ^a) Carcinoma (bladder ^a)	Leiomyosarcoma (bladder ^a) Spindle cell sarcoma (kidney ^a)	Adenocarcinoma (kidney)
Reproductive	Granulosa cell tumor (ovary)	–	2 adenocarcinoma (1 mammary, 1 uterus ^a) Carcinosarcoma (uterus ^a) 2 leiomyoma (both uterus ^a) Multiocular mass (mammary) Prostate mass Uterine mass ^a	Adenoma (seminal vesicle) 2 carcinoma (1 testis, 1 uterus) 2 leiomyoma (both uterus ^a) Granulosa cell tumor (ovary) Leydig cell tumor (testis) 2 unspecified testicular masses	Carcinoma (endometrium ^a)
Respiratory	Carcinoma (bronchioalveolar)	–	2 adenoma (both lung) Carcinoma (lung)	Carcinoma (lung ^a)	–
Multi-systemic	–	–	Unspecified mass (abdominal) 2 adenocarcinoma ^{a,a} 2 lymphosarcoma ^{a,a} Sarcoma ^a Transitional cell carcinoma	Unspecified mass (abdominal ^a) Lymphoma ^a Lymphosarcoma (leukemic) Metastatic histiocytic round cell tumor ^a	–

^aCases cited as the primary cause of death or reason for euthanizing the animal

Table 6. Circumstances surrounding traumas related to death in lorises and pottos in North American facilities, 1980–2010; (–) no cases reported

Trauma type	<i>Loris tardigradus nordicus</i>	<i>Loris tardigradus tardigradus</i>	<i>Nycticebus coucang</i>	<i>Nycticebus pygmaeus</i>	<i>Perodicticus potto</i>
Bite wounds and cannibalism	1 neonate (housed with dam and other (?) cagemates, bite wound and fall during intragroup aggression)	5 neonates (1 from conspecific neighbor, others could have been dam or sire) 2 juveniles (1 from cagemate, other could have been dam or sire)	5 neonates (1 killed by dam, 2 with suspect sire or other male; 2 could have been dam or sire) 1 juvenile (suspect male cagemate)	6 neonates (1 suspect sire; 1 conspecific neighbor; housing situation unclear for others)	1 neonate
Infection/disease secondary to bite wound	–	1 adult (septicemia) 2 geriatric (1 septicemia from month-old bite wound; 1 lung edema possibly related to bite wound thought to have healed)	1 juvenile (cellulitis and necrosis on hands and feet, bite from dam or male neighbor (?)) 3 adults (1 severe necrotizing myositis of bite wound from cagemate; 1 cellulitis from cagemate bite; 1 had chronic sinusitis resulting from bite received as an infant from dam) 1 geriatric (euthanized for neoplasia, also had other recent problems including bite wounds)	1 neonate (septicemia from hand mutilated by mother) 1 juvenile (cellulitis, history of chronic, poorly healing bite wounds) 1 geriatric (purulent abscess from bite wound) 1 geriatric (infected bite from armadillo)	–
Cases of scavenging presumed to have occurred postmortem	1 neonate	10 neonates	1 neonate	6 neonates	2 neonates
Head trauma/traumatic fall	–	1 neonate 1 adult (related to metabolic condition?)	–	4 neonates (3 incurred during intragroup aggression) 1 juvenile (possible fall related to maternal neglect?) 1 geriatric (spinal fracture, age-related?)	2 neonates
Other	–	–	1 neonate (maternal over-grooming) 1 adult (interspecific predation) 1 adult (accident involving cage furnishings)	1 adult with fetus (interspecific predation) 1 geriatric (bite wounds contributed to decision to euthanize, cause of death listed as renal failure)	–

lopathy. There were no deaths attributed to neoplasia in this species, although some neoplastic growths were discovered in necropsy (Table 5).

The renal and cardiovascular systems were most commonly affected by disease in *L. t. nordicus* (Table 4). Animals suffering from renal disease had a group of diagnoses including nephritis, glomerulonephritis, fibrosis, renal infarcts, and distention. One case of cystitis was also included in the renal category. Cardiovascular and hemolymphatic diagnoses included cardiomyopathy, leukocytosis, fibrosis, myocarditis, endocarditis, and epicarditis. CNS diseases included 2 cases of hemorrhage and notes of age-related histological changes in the

brain. Ocular changes included synechiae, cataracts, blindness, and nerve fiber degeneration. Respiratory illnesses included pneumonia, serositis, mineralization, metaplasia, and 1 case of a benign bronchioalveolar adenocarcinoma. Whole-body changes of note included anorexia, serous atrophy of adipose tissue, and dehydration.

Loris tardigradus tardigradus

Cause of death in the red slender loris was most commonly attributed to multi-systemic disease (Table 3). Many of these deaths (5/14) were attrib-

uted to septicemia, 1 to hepatitis secondary to bacterial infection, and 1 to infection-associated granulomatous lesions attacking multiple organ systems. In the remaining cases, animals were geriatric or had problems affecting multiple organ systems with no obviously primary condition. Deaths involving the renal system were also common, and were attributed generally to renal failure (6/13), fibrosis (1/13), or glomerulonephritis or nephritis (6/13).

Trauma and neonatal mortality were significant in this group as well (Table 6). Of the 10 deaths attributed to trauma, 2 were bite wounds (with subsequent infection in 1 case) that led to juvenile deaths, and 6 others were neonate deaths. Traumatic deaths in neonates occurred due to traumatic bone injury (1/9), aggression from a neighboring animal (1/9), and within-group aggression leading to bite wounds and death (5/9). Additionally, 1 neonate death was attributed to maternal neglect and 14 were unexplained. Like *L. t. nordicus*, there were no deaths attributed primarily to neoplasia in *L. t. tardigradus*.

Overall, the most common pathologies affecting *L. t. tardigradus* occurred in the hepatic and biliary and respiratory systems (Table 4). Liver disease was common, and included cirrhosis, hepatitis, hyperplasia, congestion, fibrosis, lipidosis, vacuolar change and degeneration, and 1 presumptive case of hemosiderosis. Reports of liver neoplasias included 1 hepatoma and a hepatocellular adenoma. One animal reportedly suffered from an obstruction in the gall bladder and another from cholangitis. In the respiratory system, pneumonia was commonly reported. Other respiratory changes included atelectasis, hemorrhage, congestion, hemosiderosis, edema, fibrosis, and bronchitis. Cardiovascular issues included congestive heart failure, myocardial atrophy, fibrosis, myocarditis, and congestion. Vascular problems were also common, and included vasculitis, histiocytosis, arteriopathy, atherosclerosis, and thrombosis. Renal disease was a common finding, and in addition to the common renal changes listed above for *L. t. nordicus*, there was 1 report of a renal cyst and 1 of a renal cell carcinoma (Table 5).

Nycticebus coucang

Like the red slender loris, the most common causes of death for slow lorises were multi-systemic and renal diseases (Table 3). Neoplasia (Table 5) affecting multiple organ systems accounted for several (6/23) cases, and included 2 adenocarcinomas and 2 lymphosarcomas. Septicemia was responsible for 3

deaths and infections for 5 deaths. One animal reportedly died from toxicosis, but a toxin was never identified, and the remaining cases were all attributed to non-infectious disease processes (often age-related) affecting multiple organ systems. Renal diseases included 2 neoplasias, cases described generally as renal failure (7/21), and nephritis, including pyelonephritis and glomerulonephritis (12/21).

After renal and multi-systemic disease, trauma was the most frequent cause of death in slow lorises (Table 6). Most victims of trauma (6/11) were neonates. One animal was euthanized due to pathological maternal over-grooming, and the others died following bite wounds and neglect from parents. Two juveniles died of trauma as a result of parental aggression: one from multiple skull fractures and the other from necrosis and cellulitis resulting from bite wounds. Three adults died as a result of traumatic events. One animal developed cellulitis secondary to wounds received from a conspecific, while another escaped an enclosure and was attacked by an ocelot. A 4 yr old male succumbed to acute heart failure following an immobilization made necessary because the loris had become entangled in a cargo net used as exhibit perching.

Neoplasia was common in slow lorises; including the cases above, 17.4% of animals (19/109) died or were euthanized due to neoplasia, meaning it was one of the leading causes of death in captive slow lorises (Tables 3 & 5). All 3 reproductive neoplasias affected females and were uterine in origin. Other notable causes of death were 2 probable cases of diabetes mellitus. Four animals died from focal infections: myocarditis, otitis, rhinitis, and a chronic abscess of the thigh muscle.

Overall, >45% of slow lorises showed some lesions or abnormality in their hepatic and biliary, respiratory, and renal systems. Common liver diseases reported were hemosiderosis, hepatic lipidosis, hepatitis, and vacuolar change. The most common renal lesions were due to nephritis, glomerular or pyelonephritis. Diseases affecting the bladder occurred in 8 animals, including cystitis (6 cases), serositis, and 2 bladder cancers. Pneumonia was the most common respiratory finding, although several neoplasias were reported in this organ system as well (Table 5).

Several other organ systems showed a prevalence of disease of >20%. Cardiovascular disease noted at death included cardiomyopathy, fibrosis, endocarditis, and myocarditis. Diseases of the endocrine and metabolic system targeted the adrenal glands (adrenitis, amyloidosis, hemosiderosis), pancreas (mainly hyperplasia), and thyroid (goiters, cysts). The

most common gastrointestinal diseases were enteritis and gastritis, in addition to parasitism in the gastrointestinal tract. Immunological changes noted at death included histiocytosis, hyperplasia, and neoplasia of the lymph nodes, and splenitis and congestion affecting the spleen. Nine animals showed evidence of hemosiderosis affecting the spleen and/or lymph nodes. Reproductive diseases affected females more than males and included cervicitis, pyometra, plancentitis, and ovarian cysts. Reproductive neoplasms occurred in several animals (Table 5), including cancers of the uterus, ovary, and prostate. Two geriatric animals, 1 male and 1 female, had mammary neoplasms. In general, cases of neoplasia were largely limited to geriatric animals.

Nycticebus pygmaeus

Neonatal mortality had a significant impact on the study group, accounting for 34.6% of deaths in our sample of pygmy slow lorises (Tables 2 & 3). Trauma (11/46) and maternal neglect (9/46) caused neonate deaths in 43.3% (20/46) of cases. When cases of unexplained neonate death that reference carcass scavenging are included, this total increases to 50%. Traumas experienced by neonates included head trauma (4/11), inter-group aggression (1/11), and intragroup aggression (6/11). In several cases, neonates were cannibalized, and 1 infant was euthanized after losing several limbs. Four mature pygmy lorises died as a result of trauma. Two adults died from what was thought to be an acute toxicosis, but a toxin was never identified. One geriatric male died of septicemia following infection from an armadillo bite, and a 3 yr old gravid female was killed by an ocelot after escaping her home enclosure (Table 6).

The most common causes of death in pygmy slow lorises were renal and multi-systemic diseases. Renal diseases cited as the cause of death were renal failure (6/20), nephritis (10/20), and 1 case in which a kidney abscess led to peritonitis and eventual death. Two animals died from complications related to cystitis, which led to bladder necrosis in 1 case. Renal neoplasms were considered the primary cause of death for 2 animals (Table 5): 1 geriatric male (14 yr) developed a spindle cell sarcoma in the kidney, while an adult (7 yr) female was euthanized due to a leiomyosarcoma of the bladder. Three additional neoplasias were listed as multi-systemic deaths (3/19), all for geriatric animals. Other deaths coded as multi-systemic included cases of septicemia (7/19), other infectious processes (5/19), and non-infectious dis-

ease processes and aging (6/19). Neoplasias reported as the primary cause of death were found in nearly every organ system and accounted for 14.3% (19/133) of pygmy loris deaths overall (Table 5).

The organ systems most frequently affected at death for the pygmy loris are described in Table 4. Organ systems that showed pathology for >20% of animals were the cardiovascular and hemolymphatic, gastrointestinal, hepatic and biliary, immunologic, renal, and respiratory systems. Neoplasia was common throughout all organ systems (Table 5).

Perodicticus potto

Most of the pottos in this study died as neonates (Tables 2 & 3). All reported cases of trauma involved neonates, and 2 of 7 unexplained neonate deaths involved scavenged bodies. Two additional neonate deaths were attributed to maternal neglect and 1 to a systemic infection. Additionally, 3 of 5 respiratory deaths occurred in neonates.

The majority of other deaths occurred in geriatric animals. Multi-systemic causes of geriatric death were all related to multiple organ failure with associated shock. Other geriatric deaths were attributed to cardiomyopathy, endocarditis, renal failure, and 1 endometrial carcinoma, representing the only death attributed to neoplasia in all pottos (Table 5).

Lesions occurring in >20% of animals were found in the gastrointestinal, hepatic and biliary, renal, and respiratory systems (Table 4). Gastrointestinal pathologies included esophagitis, enteritis, and colitis. Liver conditions reported were cirrhosis, hepatitis, congestion, and necrosis. Most renal pathologies were varieties of nephritis; however, a geriatric male and female were both diagnosed with polycystic renal disease. The majority of respiratory disease cases were pneumonia. Other interesting lesions discovered at death included 4 animals with rhinitis and extensive arteriosclerosis in 3 animals.

DISCUSSION

We reviewed medical records for 367 lorises and pottos that died in North American zoos over a 30 yr period. Our results clearly show that poor neonate survivorship is a major concern for individual health and welfare, as well as population management. However, animals that do survive the critical first month of life are likely to reach sexual maturity and live into the geriatric stage. Adult and geriatric ani-

mals are most likely to die of renal disease or multi-systemic issues such as systemic infections, neoplasia, or multiple organ failure. High neonate mortality was due to high stillbirth percentages as well as trauma, which was often inflicted by conspecifics. Adults also fall victim to trauma from cagemates, suggesting that greater efforts to address the social management of lorises in captivity would likely have positive impacts on population sustainability and animal health.

Other studies have also found exceptionally high infant mortality in loriform primates living in both zoo and sanctuary settings. Streicher (2004) summarized health problems experienced by pygmy lorises confiscated from the wildlife trade in Vietnam. Of the 15 deaths reported over an 8 yr period, 11 were animals <1 yr old; overall, 42% of the sanctuary animals died during their first year of life. Debyser (1995) found infant mortality to be higher among lorises and their close relatives compared to other strepsirrhines, and like others (Tartabini 1991, Streicher 2004), Debyser (1995) speculated that captivity-induced stress was likely an underlying cause of infant deaths involving maternal neglect and trauma.

Information about social conditions was difficult to infer from our medical records, but it was clear that infants in this group were killed by sires, dams, and other conspecifics. Several different fitness benefits have been hypothesized to explain infanticide among nonhuman primates, including male–male competition and resource competition (Hrdy 1979). Infanticide risk may be related to social density, which is interesting considering that cage sizes for captive pottos and slender lorises in North America are currently smaller than the minimum size recommended by Fitch-Snyder & Schulze's (2001) husbandry manual (Fuller et al. 2013). Deaths involving maternal neglect in the present study hint at a pattern similar to that described for captive *Galago crassicaudatus umbrosus* by Tartabini (1991). Failure to perform maternal behavior, for example due to poor socialization or stress related to the captive setting, leads to infant starvation and death, and the dead infant becomes a resource to consume (Tartabini 1991). If this is the case, then careful attention to postpartum maternal behavior and, if necessary, swift intervention may be important for saving infant lives. Maternal parity and litter sizes are also associated with infant survivorship (Pollock 1986), and new mothers or multiple births will likely require special attention.

Management of group composition around the perinatal period is likely to have a large impact on infant survivorship. Nekaris (2003) speculates that

paternal care may be one factor promoting the relatively greater fecundity of slender than slow lorises, and paternal care has also been observed in captive pottos (Frederick 1998). These kinds of socialization opportunities are important for the formation and maintenance of social groups, and the 2001 husbandry manual states that it is preferable to keep groups intact through births unless there is cause to suspect an individual needs to be removed (Fitch-Snyder & Schulze 2001). However, it is possible that social management practices surrounding parturition have changed in recent years, perhaps to address traumatic infant death. A 2010 survey of AZA facilities housing lorises showed that very few males and females were housed together during the period surrounding birth, although more facilities indicated that they had attempted this strategy in the past (Fuller et al. 2013). That survey also showed that a large number of animals in each species were solitarily housed on a perpetual basis (Fuller et al. 2013). It may be that efforts to increase the social wellbeing of captive lorises by providing social partners may be in conflict with strategies needed to minimize infant mortality. Given the tenuous status of these captive populations, isolating gravid females is probably a sound strategy until the proximate causes underlying infanticide are better understood.

It was often not possible in our study to distinguish between cases of infanticide, neglect, or trauma, or other possible causes of death, because infant carcasses were cannibalized. Although recovery of nutritional resources is a possible explanation for cannibalism, this behavior has been rarely observed in wild primates; if cannibalism is truly more prevalent in captive and reintroduced animals, then it is likely pathological in nature (Tartabini 1991, Dellatore et al. 2009). However, lack of tissues for necropsy renders it impossible to determine if infants actually died due to congenital or other disease states, or if infants were neglected by mothers because they were weak or ill. Greater efforts should be made to promptly remove deceased infants so that postmortem exams can clarify these issues.

Traumas were a significant contributor to mortality of adult as well as immature animals. In several cases, animals died following bite wounds that were chronically non-healing, leading to necrosis and cellulitis. In one case, a 3 yr old adult slow loris died from chronic sinusitis from an infection that originated with a bite wound sustained from his mother as a neonate. It has been speculated that a chemical produced by the brachial gland, mixed with slow loris saliva, may be the source of toxicity in bites

(Krane et al. 2003). In addition to a major peptide component homologous to the cat allergen Fel-d1, loris venom contains a number of volatile compounds that suggest it plays a role in communication as well as anti-predator defense (Hagey et al. 2007). Necrotic bite wounds have also been reported in sanctuary-housed pygmy lorises (Streicher 2004), and more information on the chemical structure and physiological role of loris venom may aid caretakers in the treatment and management of wounds.

Across the species in the present study, renal disease was the second most common cause of death, and the renal system exhibited the greatest frequency of lesions at death compared to all other organ systems. Renal changes such as glomerulosclerosis and nephritis are known to be prevalent in captive strepsirrhines and are often age-related (Burkholder 1981, Fitch-Snyder & Schulze 2001, Junge 2003). Renal disease appears to occur more frequently in lorisoids (lorises, pottos, and galagos) than lemur species (Boraski 1981). Iron storage disease, or hemosiderosis, is a common pathology in lemurs (Benirschke et al. 1985), but was not very prevalent in the lorises and pottos in the present study.

A review of necropsies of *Loris tardigradus* housed at a German university revealed several cases of cholelithiasis or gallstones, all of which were composed of cholesterol and were speculated to be related to dietary factors like the presence of egg yolk and the reduced insect composition in the captive diet (Plesker & Schulze 2006). Of the 2 cases of gallstones in the present study, 1 occurred in *L. t. tardigradus* and 1 in *L. t. nordicus*, but none were reported for slow lorises or pottos. We also recorded 1 case of diabetes mellitus in *L. t. tardigradus*, 5 in *Nycticebus coucang*, and 2 in *N. pygmaeus*. Captive lorises are prone to obesity (Ratajszczak 1998, Fitch-Snyder & Schulze 2001), but body condition was not reported consistently at death, so its role in the development of degenerative diseases is not evident here.

It seems likely that diet is a contributing factor to non-infectious and degenerative diseases in captive lorises. The low metabolic rate characteristic of lorises is associated with a natural diet high in toxic secondary compounds from insects and plants (Wiens et al. 2006). It is tempting to speculate that metabolic derangement may occur when a diet this specialized cannot be replicated in the captive setting. The Mysore slender loris *Loris lydekkerianus lydekkerianus* feeds almost exclusively on animal prey, many of which are toxic species (Nekaris & Rasmussen 2003). New data from the field has highlighted the importance of nectars and exudates in the

slow loris diet (Tan & Drake 2001, Starr & Nekaris 2013); at one study site in India, *N. bengalensis* fed almost exclusively on exudates during the winter season (Swapna et al. 2010). Lorises often obtain gums by gouging at trees, and the lack of opportunities to perform this behavior in captivity may be associated with periodontal disease (Nekaris 2009).

We were surprised by how rarely dental disease was indicated on histopathology and necropsy reports of the animals we studied. It seems likely that in this study, many necropsy reports did not include notes of missing teeth or gingival disease that may have occurred many years earlier and/or seemed unrelated to the immediate cause of death. Dental disease has previously been reported as a major source of morbidity for Asian lorises in captivity (Sutherland-Smith & Stalis 2001). In a sample of 25 *Loris tardigradus* at a German university, 7 individuals had missing or loose teeth, or severe calculus at death, and another 4 animals showed evidence of inflammation and infection secondary to dental disease (Plesker & Schulze 2013). In the present study, several cases were noted in which a retrobulbar or other facial abscess occurred secondary to dental infection. Dental disease may play an under-recognized role in loris health, and more efforts should be made to institute preventative care during routine exams (Plesker & Schulze 2013) and to identify dental abnormalities or infections at necropsy.

Around 10% of the animals in our sample died as a result of neoplasia. A malignant lymphoma that occurred in a slow loris in this sample has been previously described elsewhere and was thought to be caused by a herpes viral infection (Stetter et al. 1995). Our sample also overlaps with neoplasias reported for the Duke Lemur Center (DLC), which contributed records to this study, and at which cases of neoplasia have been thoroughly described (Remick et al. 2009, Zadrozny et al. 2010). However, cases of hepatic neoplasia were reported from 4 additional facilities in the present study, suggesting liver cancer may play an important role in mortality for AZA loris populations as a whole. Our results concur with those reviewed by Remick et al. (2009), that neoplasia in lorises and pottos, like other strepsirrhines, commonly occurs in the digestive (including liver), hematopoietic (here, these were generally classified as multi-systemic), and reproductive systems. Little research has addressed the etiology of cancers affecting captive strepsirrhines, and further research into the role of diet (Bingham et al. 1976, Cowgill et al. 1989), exhibit lighting (Navara & Nelson 2007, Fuller et al. 2013), and other factors contributing to neoplasia is needed.

CONCLUSIONS

After reviewing death records spanning 30 yr for all lorises and pottos in North American zoos, it is clear that social management remains a challenge in these species. Deaths due to trauma are common and most likely to affect neonates and juveniles before they have the opportunity to reproduce. These trends suggest that targeting efforts to improve infant survival could have major benefits for the sustainability of captive populations. Animals that live to adulthood are likely to die as a result of infectious agents, neoplasia, or degenerative changes. Renal disease remains a major source of pathology for all lorises and pottos, and further investigation is needed to understand its etiology. A greater understanding of the role of diet in the development of non-infectious disease is also needed.

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