Introduction

Modern zoos are dedicated to management and conservation of wild animals in captivity and in the wild [4]. Not too long ago, however, zoos were menageries; places where people came to gawk at strange creatures [3]. The wild was thought of as an endless source of additional "specimens" to replace those that died after having been consigned to iron barred cages. The motto of the noted animal collector Frank Buck (1884-1950) was "bring ‘em back alive", but it was many years before these animals were kept under conditions allowing them to breed, reproduce and live out their full life spans. Zoo pathologists and veterinarians have been important players in the quest to keep them alive in captivity, and in the wild [2].

Zoos

Living wild animals have been kept in collections (menageries) in many cultures since ancient times, www.wta.org.za/info/history/zoos.htm. Early Egyptians brought African animals into captivity around 1500 BC, and a major zoo was established in Alexandria in 280 BC. The more modern concept of "zoo" began in Europe in the 1700’s. The earliest zoos were Vienna- Schoenbrunn (1752), Paris (1793), London (1826), Berlin (1844), and Zoo Basel (1874). Taronga Park Zoo was founded in the 1920’s, www.sil.si.edu/ondisplay/zoos/explore.htm . The Philadelphia zoo lays claim to being the first in North America (Chartered in 1859, open July 1, 1874). It was followed by Chicago Lincoln Park Zoo in 1868, Cincinnati Zoo in 1881, Smithsonian National Zoo in 1889, and the Bronx Zoo in 1899. The San Diego Zoo was founded by Dr. Harry Wegeforth in 1916, and Chicago Brookfield Zoo was chartered in 1925 and opened in 1934. Later in the 20th century several "animal theme parks" were founded, which combine zoo or aquarium with components of an amusement park. These include Busch Gardens in Tampa (1959), SeaWorld San Diego (1963), 6 Flags Marine World (begun as Marine World Africa USA in Vallejo, California in 1986), and the Disney’s Animal Kingdom, which opened in Orlando Florida in 1998.

There are currently 229 zoos and aquariums that are members of the American Zoo and Aquarium Association (AZA) [4]. In Europe, zoos are accredited by the European Association of Zoos and Aquaria (EAZA), www.zoos-worldwide.de/land/europe/europe.html .

Pathology and Research in Zoos – Past and Present

Several zoos were founded by scientists or by scientific societies, and anatomy and anatomic pathology were an integral part of their research efforts. In the 1800’s and early 1900’s prossection was often performed by scientists, anatomists or medical doctors.

The research institution of the Philadelphia Zoo, founded in 1901, was the first such institution of it’s kind in any zoo. Initially, necropsies were performed by Dr. HC Chapman MD in the laboratories of the medical school of the University of Pennsylvania, but in 1905 the "Pathological Laboratory and Infirmary" was built, again a zoo world first. This lab later became know as the Laboratory of Comparative Pathology, and in 1935 was renamed the Penrose Research Laboratory after its founder and early zoo president C.B. Penrose MD. This lab was directed by Dr. Herbert Fox, MD (1908-1942), followed by Dr. HL Ratcliffe MD (1942-1969), Robert Snyder DSc (1969-1989), Virginia Pierce VMD (1989-1997) and John Trupkiewicz, DVM, Dipl ACVP (1997-present).
In the 1930s, while Dr. Charles R Schroeder was the veterinarian at the New York Zoological Society’s Bronx zoo, necropsies were performed by pathologists and their interns at Mt. Sinai Hospital in the Bronx. In later years, the society partnered with The Animal Medical Center in New York City. Veterinary pathology residents performed many of the necropsies. Dr. Tracey McNamara DVM, Dipl ACVP became the first "in residence" pathologist at the Bronx Zoo/Wildlife Conservation Society, and held the Schiff Family Distinguished Scientist in Wild Animal Pathology endowed chair. In the 1940s, Director Belle Benchley of the San Diego zoo use pathologists in San Francisco for special help with difficult cases or in outbreaks. Later MD pathologists from local hospitals or the zoo veterinarians performed the necropsies. The San Diego Zoo hired Lynn Griner DVM, PhD (Comparative Pathology) as it’s first veterinary pathologist in 1964, in which capacity he served until 1978. Lynn was succeeded by Dr. Gerald Cosgrove MD, and Dr. Marilyn Anderson, DVM, PhD, Dipl ACVP who served until 1994, Linda Lowerstine DVM, PhD, Dipl ACVP (1994-1996), and Bruce Rideout DVM, PhD, Dipl ACVP (1996 to present). Since 1975 Pathology has been a division of the Center for Reproduction of Endangered Species, the research branch of the Zoological Society of San Diego. The first director, and founder of CRES, was Dr. Kurt Benirschke MD, honorary Dipl ACVP.

Initially, the National Zoological Park of the Smithsonian Institution used the Armed Forces Institute of Pathology (AFIP) and pathologists at National Institutes of Health for pathology support. The first "in-house" pathologist, and the first ACVP board certified pathologist at any zoo, was Dr. Robert Sauer, who served for 4 years in the late 1960’s. There was a hiatus of several years before the next pathologist, Dr. Richard Montali, DVM, Dipl ACVP, assumed the position from 1975 to 2004. Dr. Montali has been one of the most influential zoo pathologists in the US and is well know for his extensive publication record as well as his mentorship of numerous residents.

In Europe, as early as 1928, the Zoological Society of London employed a "Research Anatomist" Solly Zuckerman - www.archiveshub.ac.uk/news/zazzsl.html at the Animal Hospital and Pathology Laboratories of the London Zoo in Regent’s Park. Later, under his tenure as Director of London Zoo research was conducted through the Nuffield Institute of Comparative Medicine, the Wellcome Institute of Comparative Physiology. London’s Regent’s Park Zoo was well known for scientific research, which included published accounts of animal necropsies. Dr. RN Twisleton-Wykeham-Fiennes was the pathologist for The Zoological Society of London in the 1960’s and 1970’s. He was noted for his numerous publications including Diseases of Simian Primates (1972). London Zoological Society’s Institute of Zoology currently has divisions of Animal Health and Welfare and Wildlife epidemiology, both with pathology as a component, www.zoo.cam.ac.uk/iov/index.htm.

Another major zoo in Europe with a very active pathology/research department was TierPark Berlin in East Berlin, which was home to the East German Academy of Science’s Institute of Zoo and Wildlife Pathology (Forschungsstelle für Wirbeltierforschung). This institute was the major player in zoo and wildlife pathology for more than 4 decades (1950s-1990s). Dr. Rudolph Ippen of that institution developed the annual International Symposium for Diseases of Zoo and Wild Animals, which began in 1959 and continues to this day on a biannual basis, alternating with the meeting of the European Association of Zoo and Wildlife Veterinarians. Transatlantic collegiality was fostered by early zoo pathologists such as Drs. Kurt Benirschke and Lynn Griner, who regularly attended those meetings and contributed to the proceedings. There were also pathologists emphasizing the pathology of "special species" in European Universities. Dr. Per Zwart in the Division of Diseases of "Other Animals" in the pathology department pathology at the Veterinary School in Utrecht, the Netherlands is a notable example. An active pathology program in Utrecht today emphasizes companion and avian bird diseases. Dr. H.H. Reichenbach-Klinke, Munich, Germany, published major texts on the diseases of Fish, Amphibians and Reptiles in the early 1960’s.

Currently only 11 zoos or aquaria recognized by the American Zoo and Aquarium Association (AZA) have in house pathology programs: the Wildlife Conservation Society (New York zoos and aquari) (2 Dipl ACVP, 1 qualified), the Philadelphia Zoo (1 Dipl ACVP), the National Zoological Park (1 Dipl ACVP and one vacancy), Disney’s Animal Kingdom (1 Dipl ACVP), the Chicago consortium of 3 institutions (Brookfield Zoo, Lincoln Park Zoo and Shedd Aquarium) (2 Dipl ACVP), Saint Louis Zoo (1 Dipl ACVP in St Louis and 1 open position at Darwin Research Station in the Galapagos), SeaWorld of San Diego (1 Dipl ACVP), and the Zoological Society of San Diego (San Diego Zoo and Wild Animal Park - 6 Dipl ACVP). All together these programs employ 15 ACVP diplomates. There is also an ACVP diplomate at the London Zoological Society and one at African Safari in Puebla, Mexico. Australia’s Taronga and Western Plains Zoo Australian Registry of Wildlife Health have a full time veterinary pathologist (temporarily held by a US citizen Dipl ACVP). There may be additional international zoos with pathology departments of which I am not aware.

Other zoos have developed partnerships with local veterinary schools/ veterinary diagnostic labs or medical school comparative pathology departments for pathology support. Examples of this would be the Sacramento Zoo, Six Flags Marine
World and Mickey Grove Zoo, with UC Davis, The Knoxville Zoo and University of Tennessee, Baltimore Zoo and the Johns Hopkins Medical School, Milwaukee Zoo and the University of Wisconsin, Toronto Zoo in Canada with the Ontario Veterinary College, University of Guelph. Before the LA County Laboratory was closed, the pathology for the LA Zoo was performed in that county laboratory under the direction of Dr. Edwin Howard DVM, PhD, Dipl ACVP and later Jay Holshuh DVM, Dipl ACVP. At many of the collaborating pathology departments there are ACVP diplomates, with special interest in zoo and wildlife pathology, who oversee the gross necropsies and histopathology. This paradigm is also in place in other parts of the world. For example, in Brazil, the University of Sao Paulo Veterinary School provides pathology support for the Sao Paulo Zoo and in Mexico Zoologica Guadalajaran collaborates with the Universidad Autonomia de Guadalajaran, and Chapultepec Zoo with the Universidad Nacional Autonomia de Mexico in Mexico City.

At some zoos, the clinical veterinarians perform the gross necropsy and send tissues to commercial veterinary diagnostic labs (e.g. IDEXX, ANTECH). There are at least 2 ACVP diplomates, who have completed residencies with an emphasis on zoo pathology, who are special consultants for commercial labs. In addition, there are two private veterinary diagnostic services dedicated to zoo, aquarium and companion avian, exotic pet pathology each with 2 ACVP diplomates.

ACVP diplomates are also involved in the pathology of free ranging wildlife, either in the context of zoo-based conservation and outreach or working through state and federal wildlife agencies. The position of "wildlife pathologist" in many wildlife agencies requires neither a veterinary degree, nor formal training in veterinary pathology. However, there are several diplomates of the ACVP working in this arena. Examples are the 2 ACVP diplomates in disease investigation at The National Wildlife Health Center in Madison, 2 ACVP pathologists at Wyoming State University Diagnostic Lab, and 1 at Colorado State University.

Contributions of Pathologists Specializing in Zoo and Wildlife Pathology

**Historical Archives for Wild Animal Pathology / Data Storage and Retrieval**

Pathology archives provide a valuable resource for retrospective research on diseases of zoo animals. The hand written pathology reports archived in card files at the Bronx Zoo date back to the late 1890’s. The Penrose Research Laboratory at the Philadelphia Zoo has archived the original reports and glass slides beginning from 1901 when Dr. Charles Penrose and Ellen P. Corson-White began performing necropsies. Dr. Ippen maintained an extensive specimen archive including wet tissues, slides and case reports from TierPark Berlin. Specimens were cataloged using a punch card system. Retrieval was manual, using a stylus to exclude cards without the organ system or etiology of interest. Dr. Lynn Griner at San Diego Zoo also used a Terminex punch card system for case storage and retrieval [1]. That system was later changed to a SNOMED computer based system. The pathology archives at the Zoological Society of San Diego encompasses reports, glass slides, blocks, and other specimens from over 22,000 necropsy cases dating from July 1, 1964. This archive is accredited by the American Museum Association. Dr. Montali of the National Zoo developed his own computer-based retrieval system for the pathology archives at that institution.

The new ZIMS (Zoological Information Management System) project may provide a prototype for zoo pathology report storage and retrieval and allow collaboration between zoo pathology departments. This will enable the zoo community to put individual diseases into a broader context with which to assess impact on captive populations. At least one veterinary pathologist is actively involved in the pathology data portion of ZIMS, www.zims.org/.

**Disease Surveillance and Recognition of New Diseases**

Zoo and wildlife pathologists have made extensive contributions to our knowledge of diseases affecting wild animals through case-based and basic research. Early research at Philadelphia Zoo identified nutritional diseases as the cause of over one third of zoo animal deaths. Tuberculosis was also a major killer of primates, and the first tuberculin testing of primates was performed at Penrose Research Lab in 1911. The identification of mycobacterial diseases of "cold blooded" animals in 1929 was also a first, as was discovery of the woodchuck hepadna virus and an association between hepadnaviruses and liver cancer in the 1970’s.

Zoo pathologists have been important for the identification of several important diseases of captive wild animals. Callitricid hepatitis has caused deaths in collections of rare and endangered New World Primates [7]. Recognition that this disease is caused by LCM and that it enters primate collection through feeding "pinkie" mice or through rodent pests has led to changes in dietary and pest control management. Elephant husbandry practices have been changed by the important discovery of herpesviruses of elephants associated with poor calfhood survival, and by research on Mycobacterium tuberculosis infections in Asian elephants [11]. The wide range of primate species infected by simian immunodeficiency viruses was first recognized...
in studies of zoo collections [5]. And canine distemper virus vaccine studies helped to protect exquisitely sensitive exotic carnivores such as red pandas [6].

Captive breeding of wild animals in zoos must be regulated, and there is increasing interest in using chemical or surgical contraceptive techniques. To this end, systematic post mortem examination of reproductive tracts of zoo animals correlated with reproductive and contraception history has led to recommendations for and against certain types of contraception [9]. Recent news worthy contributions of zoo pathology include the identification of West Nile Virus as the cause of death of zoo birds at the Bronx Zoo in 1999 which lead to WNV being recognized as a new zoonotic agent sweeping the United States [12]. A zoo pathologist and a wildlife pathologist (both ACVP diplomates) were among the team of investigators who discovered that the dramatic and ecologically devastating decline of vulture populations in Pakistan was due to a nonsteroidal anti-inflammatory drug with high residues in live stock on which vultures were feeding [10].

There are many more examples of diseases that have been discovered through zoo pathology and research [8]. Identification of new diseases still relies to a large extent on routine gross and histologic examinations, but immunohistochemistry, and molecular diagnostics are being applied increasingly in zoo pathology. The Pathology Division at the Zoological Society of San Diego Molecular Diagnostic Laboratory begun in 1998 is the first of its kind.

Captive Breeding and Conservation
The American Zoo and Aquarium Association oversees coordinated efforts on behalf of captive breeding of animals in zoos, www.aza.org/. Special attention is given to rare or endangered species, or species rarely held or difficult to keep in captivity. Species Survival Plans (SSPs), Taxon Advisory Groups (TAGs) and discipline specific advisor groups (e.g. Nutrition Advisory Group, Contraception Advisory Group) are the mechanism by which captive husbandry is coordinated. Several veterinary pathologists serve on these advisory groups, providing valuable insight into morbidity and mortality, effects of diet changes, and effects of contraception on species of interest.

In addition to advisory roles via the AZA, veterinary pathologists are often called upon to serve on committees and panels such as US Fish and Wildlife Service Endangered Species Recovery Plans or other regulatory and advisory panels. For example ACVP pathologists serve on the Hawaiian forest bird, black footed ferret and Channel Island fox recovery teams, and the Working Group on Unusual Marine Mammal Mortality Events (National Marine Fisheries Service), and the Mountain Gorilla Veterinary Project.

Training Future Zoo and Wildlife Pathologists
The first zoo based pathology residency training program was that at the National Zoo. Initially it consisted of rotations for the AFIP veterinary pathology residents that began in the mid 1970’s. Over 65 AFIP pathology residents rotated through the NZP over the next 30 years. In addition NZP developed it’s own pathology residency funded by Friends of the National Zoo (FONZ). The aim was to produce board certified veterinary pathologists with specialization in zoo and wildlife pathology. Thirteen residents have been in this program 10 of whom are board certified, two never sat the boards, and one is still in training. Of the graduates, 7 are active in zoo or wildlife pathology, and one is a wildlife veterinarian. The others have gone into research, industry or diagnostic labs. This has been the most influential residency program in zoo pathology.

In the late 1970’s and early 1980’s there was a short-lived residency program at the San Diego Zoo. Year long rotations were offered to residents in training at veterinary schools. Most of the residents came from the New York State Veterinary School at Cornell. One of the trainees has gone on to an academic career with a zoo/wildlife pathology emphasis. The program was revived in 2000 with the joint ZSSD/ UC Davis Zoo and Wildlife pathology residency. Residents spend 2 years at UC Davis Veterinary Medical Teaching Hospital and the third year at San Diego Zoo. So far 7 individuals have entered the program. Two graduates are diplomates of ACVP and two will sit the boards in 2004. Two are employed in zoos and two are in PhD programs. San Diego also has a veterinary pathology fellowship position for individuals who have completed a residency and want additional zoo pathology experience.

Additional zoo and wildlife pathology residency training programs are currently offered at the WCS/Bronx Zoo, and the Chicago zoos in conjunction with the University of Illinois, College of Veterinary Medicine and Loyola Medical School. Other training programs with opportunities for zoo, wildlife, exotic pet and aquatic pathology include: North Carolina State University, University of Florida, University of Georgia, The Johns Hopkins University, Angell Memorial Animal Hospital and Tufts University, Michigan State University, University of Minnesota, University of Pennsylvania, University of Tennessee, Ontario Veterinary College (University of Guelph) and Armed Forces Institute of Pathology, www.acvp.org/training/.
In addition to residency training, many zoo pathologists have been involved in continuing education and outreach internationally, by teaching at zoos, veterinary schools and research stations. Prominent among these are lecture series and workshops coordinated by the World Conservation Union (IUCN)/ Captive Breeding Research Specialty Group (CBSG), www.cbsg.org/ and Zoo Conservation Outreach Program (ZCOG), www.zcog.org/eng/index.htm.

Summary
From the early efforts of medical doctors, with an interest in comparative medicine and pathology, to today’s modern zoo pathology programs with board certified veterinary pathologists, zoo pathology has contributed to the improved management of wild animals in captivity and in the wild. Zoo and wildlife pathology is becoming increasingly recognized as a specialty within veterinary pathology. Although the numbers of veterinary pathologists fully employed in the field are still low, training programs are serving to bolster those numbers and to ensure the health of future populations of zoo and wild animals.

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References