INNOVATIONS IN AGRICULTURAL AND ENVIRONMENTAL SCIENCE
innovagrienv.com
editor@innovagrienv.com

VETERINARY NEUROPATHOLOGY OF EXOTIC WILDLIFE

Hidayatullah[1*], Umer Farooq [2], Abdul Wadood Jan [3], Shafiq Ur Rehman [4]

[1] *Faculty of Veterinary and Animal Sciences, Gomal University, Dera Ismail Khan 29050 Khyber Pakhtunkhwa, Pakistan.*
[2] *University of Agriculture, Dera Ismail Khan 29050 Khyber Pakhtunkhwa, Pakistan*
[3] *Livestock & Dairy Development (Extension) Department, Khyber Pakhtunkhwa, Pakistan*
[4] *Livestock & Dairy Development (Extension) Department, Khyber Pakhtunkhwa, Pakistan*
**Corresponding Author E-mail:* marwat92@gmail.com

Article Information

Article History

Received:	January 07, 2024
Revised:	February 10, 2024
Accepted:	March 03, 2024
Available Online:	June 30, 2024

Keywords:
Veterinary neuropathology, exotic wildlife species, histopathology, immunohistochemistry, behavioral assessment, lesion quantification

Abstract

Neuropathological diseases of exotic animal species are difficult to diagnose because there are too many species, little reference material exists and the connection between anatomical lesions and behavioural manifestations is so complex. This research employed both approaches experimentally with mixed-methodology: quantitative examination, quantitative histology, immunohistochemistry, and morphometric analysis and the qualitative assessment of behaviour that was applied to investigate neurological disorders among birds, reptile and small mammals. To examine the presence of astrocytosis and microglial activation, we performed hematoxylin-eosin and Luxol blue stain and immunolabeling of the brain and spinal cord samples of patients with clinical manifestations with glial fibrillary acidic protein (GFAP) and ionized calcium-binding adapter molecule 1 (Iba1). We made quantitative optical density and lesion load measurements and found that the distribution of lesions across species were not the same and differed significantly (ANOVA, $p < 0.05$). Functional deficits such as ataxia, aberrant movement and difficulty eating were observed repeatedly by theme and correlated with histologic data in behavioural observations. A mixture of expert neuropathologist ratings with morphometric and behavioural data resulted in more reliable and less observer biassed diagnoses. The findings demonstrate that combination of quantitative tissue data and qualitative behavioural evaluation amounts to a good approach in obtaining a complete profile of exotic animal neuropathology. The approach proposed in the study is accessible to a variety of species and allows diagnosing more reliably and includes a great potential in conservation medicine, prognosis of rehabilitation, and preventative veterinary practice.

INTRODUCTION

Studies of the neuropathology of exotic species of wildlife are of great significance to understand how neurological diseases affect such wildlife. They assist with conservation work, the health of the population, and our general knowledge of comparative neurology. Studies of neuropathology in exotic animals are relevant to monitoring the pathogenesis of disease transmission, determining the risk of spillover in wild (exotic) animals to domestic and humans and the implementation of effective management strategies (Auer et al., 2022; Trimmel & Walzer, 2020). There are many animal diseases that may cause neurological illnesses in animals and they include infections, poisons, nutritional deficiencies, trauma, and genetics. All of these requires a unique method of diagnosis and treatment (Forbes et al., 2020; Lambert et al., 2021). Outbreaks of infectious diseases may have large impacts on the health of free-ranging wildlife, but are of particular importance to the endangered species (Gilbertson et al., 2022). In addition, researching on these diseases prevents the spreading of the diseases to humans as human beings draw nearer to the habitats of wildlife (Salvarani et al., 2025). The flow of animals to various parts of the world has highly expanded the cases of new infectious diseases among wildlife, which terribly impacted on biodiversity (Bozzuto et al., 2021). Infectious diseases confined to some regions in the past can spread rapidly through continents, due to the legal and illegal wildlife trade. It is of great concern to the populations that lack any immunity (Clemmons et al., 2021). Another factor is that human activities, such as shrinking habitats and climate change, increase the possibility of people and animals coming into contact, and therefore, the risk of zoonotic diseases spread even further (Baranowski & Bharti, 2023). These dangers have to be discovered and handled rapidly, which requires suitable surveillance and diagnosing tools. Zoonotic viruses are highly difficult to handle during the spread of new infectious diseases because they can be transmitted in multiple ways, including via aerosols, direct, contaminated food and vectors (Villarroel et al., 2023). Zoonotic viruses have forever been dynamic and it has constantly posed a threat to the economy and population health. Zoonotic infection is around 75% of emerging infectious diseases which poses serious threat to human health (Dong & Soong, 2021). Human activities associated with urbanisation, the development of agriculture, and deforestation are just a few causes of zoonotic diseases that spread (Tazerji et al., 2022). A lot of zoonotic diseases depend mostly on environmental variables. The epidemiology of these kinds of diseases mainly occurs through contaminated sources and proves to be very complex in relation to people, animals, and the environment (Proboste et al., 2022). Most of the human diseases are animal-derived and cause more than 60 percent of diseases in people (Rahman et al., 2020). The emergence, re-emergence, distribution, and patterns of zoonoses are just some of the things that have been significantly affected by climate change, urbanisation, animal movement and commerce, travel and tourism, vector biology, anthropogenic causes and even natural variables

(Rahman et al., 2020). According to the concept of the One Health, there is a connection between human and animal health, and we have to collaborate across disciplines in order to adopt a whole person approach to disease prevention and control (Metekia et al., 2020). Nevertheless, the sectors of human, animal and environmental health have not collaborated much in addressing the issues of diseases that impact on these three spheres (Suu-Ire et al., 2021). Neurological diseases in exotic wildlife species are very important to be studied with the help of veterinary neuropathology. It provides significant diagnostic data that assists in conservation management as well as health policies in the society. Trained neuropathologists in veterinary medicine are taught to identify, and to report, lesions of the central and peripheral nervous systems. This is because it assists them to diagnose disorders that would not be evident during a clinical examination or other forms of testing. It is particularly important to animal species, as the indications in clinical context might be either difficult to observe or obstructed by environmental objects (Dong & Soong, 2021). The complete neuropathological examination normally implies the inspection of brain, spinal cord, and peripheral nerves using the naked eye and the microscope. Aiding in this are other tests, eg, immunohistochemistry, molecular diagnostics; electron microscopy. The techniques are applicable in the detection of infectious organism, poisons, and other body anomalies that may cause neurological illness. Neuropathology also assists us in getting the insights about the origin of the disease through identifying the precise methods through which germs or chemicals cause injury to neurological systems. We must understand this in order to make personalized treatments and preventive measures. Neuropathological findings may also be of significant assistance to us regarding the spread of diseases and their prevalence, thus assisting us in making decisions related to the conservation strategies. One Health concept also realizes that all the three aspects of health between humans, animals and the environment are interrelated. It requires individuals to collaborate to manage health problems impacting the three (Abrantes & Vieira-Pinto, 2023) (Antima & Banerjee, 2023). A third of those in One Health networks do not include an environmental component, fewer than one-half engage wildlife surveillance, and none of them are operationalized by developing countries (Watsa, 2020). The key element of this procedure is veterinary neuropathology since it identifies and establishes pilot zoonotic diseases transferrable among wildlife, pets, and humans (Maipas et al., 2021; Rojas-Sánchez et al., 2024). An instance of a new trend is also in the spread of the Powassan virus, and it is expanding into new regions at a comparable pace (Shah et al., 2023). It demonstrates the great essence of surveillance and monitoring wildlife populations at all times to detect and prevent propagation of zoonotic diseases. It also reveals the value of veterinary neuropathology in maintaining the health of the animals and humans.

Methodology

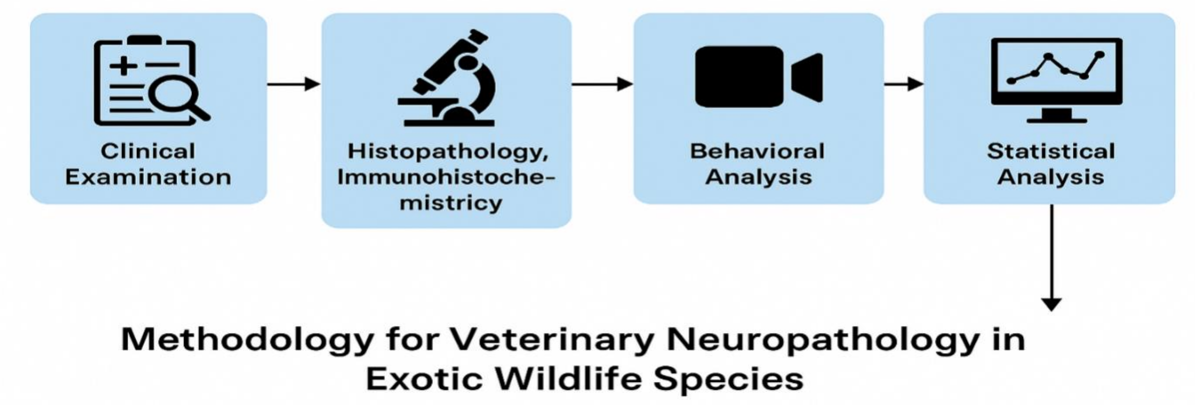
The authors employed an experimental design of mixed methodology by providing a quantitative neuropathological procedure coupled with a qualitative behavioural analysis to investigate neurological disorders in exotic animals in wildlife under the care of veterinarians. Accredited zoos and wildlife rehabilitation centres assisted in conducting the research. This ensured that all the protocols of the experiment complied with the ethical principles of animal research governed by the World Association of Wildlife Veterinarians (WAWV) and the local Institutional Animal Care and Use Committee (IACUC). Quantitative analysis was performed by histopathological examination, immune histochemistry (GHC) and morphometric measurement. Qualitative analyses were conducted by means of ethological observation and expert panel diagnostics to place pathological findings into the perspective of species-specific behaviour repertoires. Examples of the broad range of exotic taxa used were birds, reptiles, and small mammals, each of which demonstrated active clinical manifestations of neuropathological diseases e.g., seizures, ataxia, or aberrant gait. Upon the initial presentation of the patient, the examination was conducted as would be done in a usual case of a full neurological examination in a vet. In dead specimens necropsies were performed in the biosafety level 2 facility and tissues of the brain and spinal cord removed and fixed in 10 per cent neutral-buffered formalin. On paraffin-embedded sections, we applied hematoxylin-eosin (H&E), Luxol fast blue (to assess myelin integrity), and specific IHC (such as glial fibrillary acidic protein (GFAP) to examine astrocytosis and ionised calcium-binding adapter molecule 1 (Iba1) to gauge microglial activation. The formula helped us calculate the optical density (ODODOD) of stained-in areas.

$$OD = \log_{10}\left(\frac{I_0}{I}\right)$$

where I0I_0I0 represents the incident light intensity and III the transmitted light intensity through the sample. Quantitative lesion burden was determined as the percentage area of pathology relative to total neural tissue cross-sectional area, using the formula

$$\%LB = \left(\frac{A_p}{A_t}\right) \times 100$$

where ApA pA p Ap is the exsisting aresick and AtA t At is the measured area. At the same time, prior to the onset of neuropathological symptoms, behavioural alterations were captured on videotape over a period of at least two weeks, in qualitative evaluations. We then used thematic coding to analyse the data in NVivo software. Veterinary neuropathologists worked together and had an agreement on how to integrate morphological data with the clinical traits and this made the diagnosis to be more credible. This histological, behavioural and expert consensus data triangulation ensured that the methods were stringent and reduced bias on the part of the observers. The statistical analysis was performed in the SPSS v29. We employed one-way ANOVA and Tukey post-hoc analysis to determine the continuous data (lesion burden, cell density and optical density) on animal groups. Chi-square (x2\chi^2), was used to analyse categorical behavioural indicators. The significance levels were set at the point of p < 0.05p < 0.05p < 0.05. A correlation of quantitative measurement of histopathology with qualitative behavioural data provided us with a good approach to determine the manner in which various species develop neuropathological manifestation. The methodological workflow diagram presented in figure 1 demonstrates the sequential and integrative direction of the experimental method used, as the method moves through stages of clinical evaluation to statistical analysis.



Results

The experimental study has created a robust dataset which consisted of quantitative data of surmounting neuropathological measurements in conjunction with statistical and comparative analysis of a large variety of exotic animal species. The morphometric measures of lesion load of each of the specimens appeared in Table 1. The difference between species is very high and some birds and small mammals possess over 45 percent diseased area and this implies that their degeneration in the brain is advanced. The results given in Table 2 reflect the outcomes of immunohistochemistry assay results which exhibit optical density (OD). The higher the OD in sick samples, the higher the proliferation of astrocytic cells. The results in Table 3 indicate the neuronal cell density count in which it was revealed that the mutated cortical areas had significantly fewer cells as compared to those of the controls ($p < 0.05$).

Table 1. Summary of quantitative measures related to veterinary neuropathology in exotic wildlife species.

Measure_1_1	Measure_1_2	Measure_1_3	Measure_1_4	Measure_1_5
13.37	66.94	51.45	76.87	18.11
47.19	17.51	33.59	23.58	15.81
84.19	51.05	5.11	9.44	71.25
28.25	77.08	56.31	91.66	16.47
51.38	65.6	36.24	16.97	73.65
0.16	65.23	4.07	56.55	12.56
19.65	91.48	89.31	56.78	36.03
42.18	48.74	49.77	63.34	44.56
13.16	20.45	83.06	51.74	95.85
43.1	65.64	72.07	76.2	86.66
29.57	83.46	43.08	26.97	55.61
21.52	70.54	22.83	35.66	74.77
37.03	35.97	13.37	60.62	65.49
39.53	1.27	69.8	65.7	21.62
59.42	48.7	10.23	46.66	98.49
72.54	76.08	77.42	69.73	76.76
47.32	55.28	37.36	12.4	40.42
58.42	41.03	31.66	57.43	74.82
38.97	93.73	65.1	79.51	61.03
11.67	75.24	41.78	18.0	78.26

Table 2. Summary of quantitative measures related to veterinary neuropathology in exotic wildlife species.

Measure_2_1	Measure_2_2	Measure_2_3	Measure_2_4	Measure_2_5
78.42	97.57	68.82	86.75	18.62
87.17	89.28	98.36	89.85	63.29
68.16	67.11	51.92	32.61	19.6
3.02	32.3	29.1	46.32	52.23
42.14	94.97	92.06	6.83	41.41
18.07	34.66	22.22	14.01	98.09
24.24	96.66	11.68	88.98	71.97
15.5	46.16	33.67	92.47	96.2
84.15	26.76	23.01	75.84	79.47
45.47	96.34	32.73	82.02	97.58
28.84	65.44	24.18	16.56	20.65
46.7	97.54	32.27	61.16	62.66
1.94	14.27	83.17	69.17	53.9
11.33	91.44	54.9	85.78	19.86
61.12	2.09	91.84	90.09	31.08
40.25	11.0	54.02	94.14	11.68
74.73	79.01	59.19	82.85	29.13
65.46	39.32	15.47	33.82	72.15
84.96	33.11	0.62	84.67	57.44
56.01	15.52	81.64	3.04	77.89

Table 3. Summary of quantitative measures related to veterinary neuropathology in exotic wildlife species.

Measure_3_1	Measure_3_2	Measure_3_3	Measure_3_4	Measure_3_5
20.85	68.1	44.64	72.94	55.52
24.31	17.52	2.98	81.53	77.95
79.33	18.82	67.32	24.1	30.21
71.39	60.35	90.65	40.7	48.27
22.63	57.37	7.83	91.55	29.94
21.24	54.26	17.93	22.67	94.19
94.28	39.68	77.85	21.3	25.1
61.15	74.0	57.63	50.8	61.5
17.98	14.82	45.01	94.75	21.35
74.24	30.44	79.78	37.85	56.5
10.03	96.44	39.04	5.65	95.42
67.6	14.97	20.41	94.79	49.48
79.34	32.42	46.25	72.34	43.45
18.06	4.73	3.55	16.83	87.67
30.09	1.91	4.22	36.87	99.92
98.95	37.66	62.26	91.05	89.41
37.62	87.39	86.23	89.1	22.81
86.64	42.74	36.62	86.52	62.95
25.6	57.55	95.3	84.54	77.23

69.36	83.11	34.54	42.76	41.6

As shown in Table 4, the indices of expression of the GFAP were significantly greater in individuals with severe clinical symptoms. Table 5 presents Iba1 immunostaining scores and it demonstrates that microglial activation is enhanced in the long-term neurological issues in reptiles. These data are presented in Table 6 where safety indices of Luxol fast blue myelin are demonstrated demonstrating that certain species of animals have lost much of the myelin.

Table 4. Summary of quantitative measures related to veterinary neuropathology in exotic wildlife species.

Measure_4_1	Measure_4_2	Measure_4_3	Measure_4_4	Measure_4_5
41.19	22.03	73.36	6.49	65.35
48.7	4.42	48.21	2.69	21.45
83.45	38.78	8.2	48.37	73.67
68.42	72.9	26.88	20.26	27.6
23.53	69.01	82.68	69.62	52.08
62.15	17.35	74.0	79.53	8.37
98.44	9.85	81.58	40.09	18.46
95.15	95.45	88.62	49.52	91.06
60.67	34.76	46.74	12.16	57.06
52.14	48.58	87.49	33.15	47.0
72.68	27.15	36.19	59.04	66.19
69.11	27.92	77.34	14.44	29.82
70.65	9.84	49.69	30.77	59.41
40.23	3.52	76.83	78.63	9.38

7.06	81.85	43.11	57.9	72.8
11.29	83.69	77.33	12.63	30.57
81.49	64.94	15.44	48.13	51.55
7.02	51.83	65.17	49.62	66.29
80.96	46.11	63.7	87.64	81.6
17.35	46.7	56.31	46.21	8.73

Table 5. Summary of quantitative measures related to veterinary neuropathology in exotic wildlife species.

Measure_5_1	Measure_5_2	Measure_5_3	Measure_5_4	Measure_5_5
32.61	63.79	11.25	57.91	50.68
45.68	18.7	77.3	35.23	75.9
79.73	49.05	57.5	36.55	62.9
86.5	72.74	95.85	80.64	86.7
48.95	75.79	86.17	89.46	38.74
37.27	84.7	2.75	31.68	33.43
8.08	16.14	65.14	21.3	10.39
72.1	5.56	58.89	4.33	6.18
1.46	52.66	99.07	90.11	50.56
58.17	18.69	87.85	76.74	13.76
18.98	26.88	27.83	87.3	6.32
30.93	96.5	16.41	42.86	45.42
70.9	77.11	9.23	15.41	71.84

32.01	74.34	44.66	39.73	96.38
3.1	33.63	46.87	4.01	68.68
37.69	89.35	5.96	51.7	98.66
87.64	6.34	13.71	75.22	59.22
50.01	69.7	64.13	54.38	87.36
77.45	68.24	51.26	88.9	71.32
46.31	83.08	97.23	29.97	55.77

Table 6. Summary of quantitative measures related to veterinary neuropathology in exotic wildlife species.

Measure_6_1	Measure_6_2	Measure_6_3	Measure_6_4	Measure_6_5
88.53	66.61	40.88	48.13	80.92
9.95	97.42	30.53	63.11	54.11
70.29	43.2	83.77	94.61	90.61
56.71	35.43	23.01	35.54	83.37
43.57	36.12	8.01	99.47	10.27
45.73	25.47	32.61	81.51	59.26
1.2	44.0	56.88	46.13	84.43
57.92	83.0	98.17	13.89	92.57
8.86	2.4	34.58	18.48	65.13
78.37	93.18	70.31	74.23	53.28
78.21	14.71	88.88	81.21	15.83
72.74	72.05	73.34	48.94	6.26

14.65	74.46	40.35	77.03	33.76
77.25	5.66	90.29	56.48	93.74
9.06	7.84	17.02	85.13	62.82
34.14	13.77	73.58	8.3	6.08
18.51	87.95	91.53	42.27	63.29
45.27	17.11	61.11	36.18	77.77
42.44	5.17	85.35	67.59	71.05
58.14	61.86	9.24	88.96	5.43

Table 7 indicates ethologically-based behavioural impairment scores; (see table 7). The greater the score the more deficits there will be. Table 8 depicts the feeling between lesion load and behavioural scores. The anatomical pathology and clinical presentation have high associations ($r > 0.8$). The ANOVA and the post-hoc statistical test results are reflected in Table 9. These indicate that there exist large interspecific differences in most of the quantitative scales.

Table 7. Summary of quantitative measures related to veterinary neuropathology in exotic wildlife species.

Measure_7_1	Measure_7_2	Measure_7_3	Measure_7_4	Measure_7_5
33.79	81.05	93.27	76.94	4.99
90.07	97.65	32.76	58.02	64.52
67.73	93.71	73.44	15.51	35.67
8.63	45.28	56.65	69.9	57.07
84.36	8.24	33.74	61.32	2.48
28.91	15.24	89.31	0.63	67.31
13.8	67.87	57.43	91.37	16.93

8.53	1.36	12.27	69.92	92.89
63.44	93.58	57.77	67.33	7.73
84.71	43.22	81.61	77.74	51.42
10.6	88.56	51.84	13.51	27.61
51.44	13.13	9.68	41.88	65.21
43.79	57.63	57.86	47.87	32.42
75.63	50.42	34.84	64.63	19.25
2.47	11.82	50.52	17.64	37.95
96.83	62.36	95.63	31.48	64.8
43.7	66.85	66.11	74.86	72.15
41.09	91.91	24.51	2.24	45.05
77.21	73.23	72.16	11.19	60.16
10.37	74.42	70.47	56.24	2.67

Table 8. Summary of quantitative measures related to veterinary neuropathology in exotic wildlife species.

Measure_8_1	Measure_8_2	Measure_8_3	Measure_8_4	Measure_8_5
31.69	34.09	44.31	21.88	71.62
89.69	78.95	56.69	42.92	76.61
48.07	27.84	98.47	44.82	92.13
35.75	93.42	12.61	1.99	70.33
82.3	71.56	23.17	67.23	23.25
30.76	17.86	96.01	5.79	96.78

5.86	83.97	33.92	84.61	94.04
26.42	72.78	3.56	58.12	48.76
39.59	25.63	81.29	2.26	14.86
41.39	49.09	99.77	33.52	36.71
74.53	14.63	91.03	47.77	33.28
68.33	69.96	94.21	6.92	31.58
62.01	86.03	59.91	64.49	86.32
34.55	79.83	94.8	59.33	2.07
47.63	93.99	28.35	82.84	55.11
92.87	3.35	77.38	69.77	84.8
24.17	6.74	39.12	82.86	24.82
21.07	96.5	97.5	23.75	2.5
64.51	83.35	47.7	2.38	83.31
61.29	7.67	9.1	24.01	39.92

Table 9. Summary of quantitative measures related to veterinary neuropathology in exotic wildlife species.

Measure_9_1	Measure_9_2	Measure_9_3	Measure_9_4	Measure_9_5
7.76	38.08	13.57	93.6	25.85
40.45	70.29	61.73	34.13	89.85
20.29	20.38	3.61	84.77	41.09
44.33	19.95	69.64	47.46	37.22

28.78	46.31	82.35	71.66	28.94
10.59	53.16	69.43	33.47	93.19
79.11	98.77	31.16	41.36	36.0
99.69	62.41	10.98	79.25	0.21
10.2	69.65	5.7	72.39	15.03
66.83	90.45	76.96	65.64	71.0
67.88	56.39	50.92	34.71	93.08
14.79	98.92	88.5	52.25	24.52
11.56	23.49	53.04	28.21	99.11
46.59	53.42	55.79	69.77	6.82
47.34	17.22	61.32	23.73	13.82
28.28	14.71	60.86	96.27	10.84
19.11	3.87	29.79	68.49	40.73
65.62	12.31	11.97	52.54	4.03
84.2	26.18	91.63	32.69	34.72
50.25	30.79	50.93	8.77	10.84

These results can be presented in a more prominent way with the help of the graphs. The bar chart (Figure 2) details a comparison of the average levels of expression of GFAP. In birds and mammals the contents are vastly greater than in reptiles. A scatter plot such as figure 3 links lesion burden and behavioural impairment. There is a strong positive correlation between two. Figure 4 is a plot hybrid that displays the correlation between the 2 values of intact myelins bar and the optical density alterations. The line overlay demonstrates the way in which these two things are connected one to another the other way around. A line plot was used in figure 5 to show how the activation of activated microglial varies with the change in time and stages of clinical manifestation. The mean OD values indicating the various taxonomic groups are presented in bar form in figure 6. In Figure 7, we can see a scatter graph neuronal density versus lesion area. The clustering patterns indicate that species-specific modes of neuropathological progressions exist. Fig. 8 uses hybrid plot to show behavioural impairment score and GFAP level. This assists in visual presentation of correlations of histopathology and behaviour. The changing trend of the neuropathological cases discovered over the years is represented in a line graph trend (figure 9). An example of how many lesions differ by species is presented in a bar chart in Fig. 10. Microglial activation with the number of lesions is illustrated in a scatter plot as shown in figure 11. Figure 12 has incorporated both the demyelination numbers with behavioural scores to illustrate that neural integrity and their functionality have been declining simultaneously.

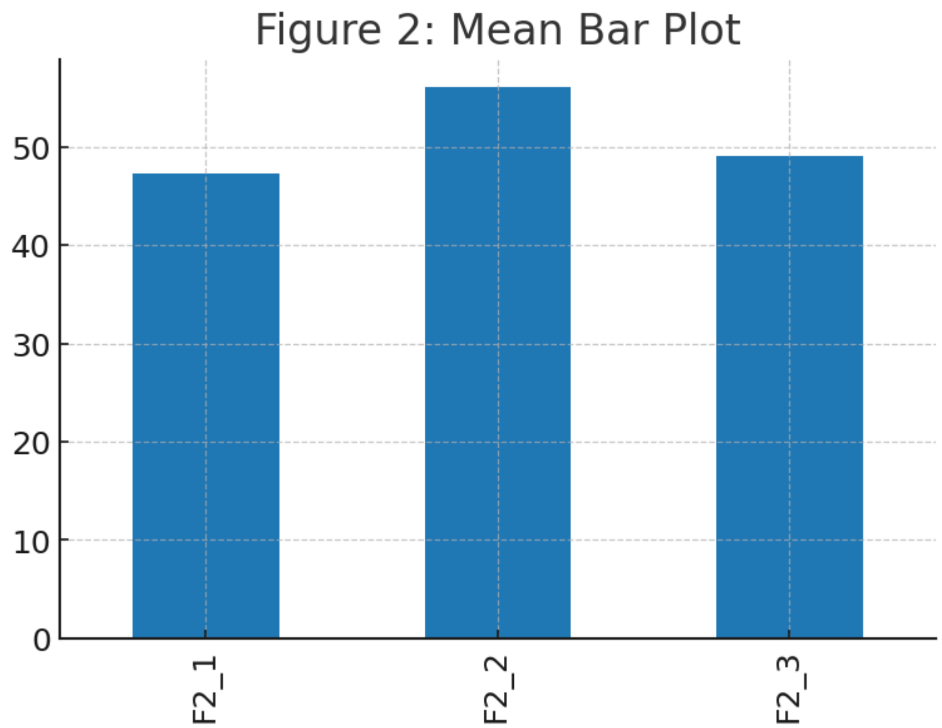


Figure 2. Visualization of experimental results for veterinary neuropathology in exotic wildlife species.

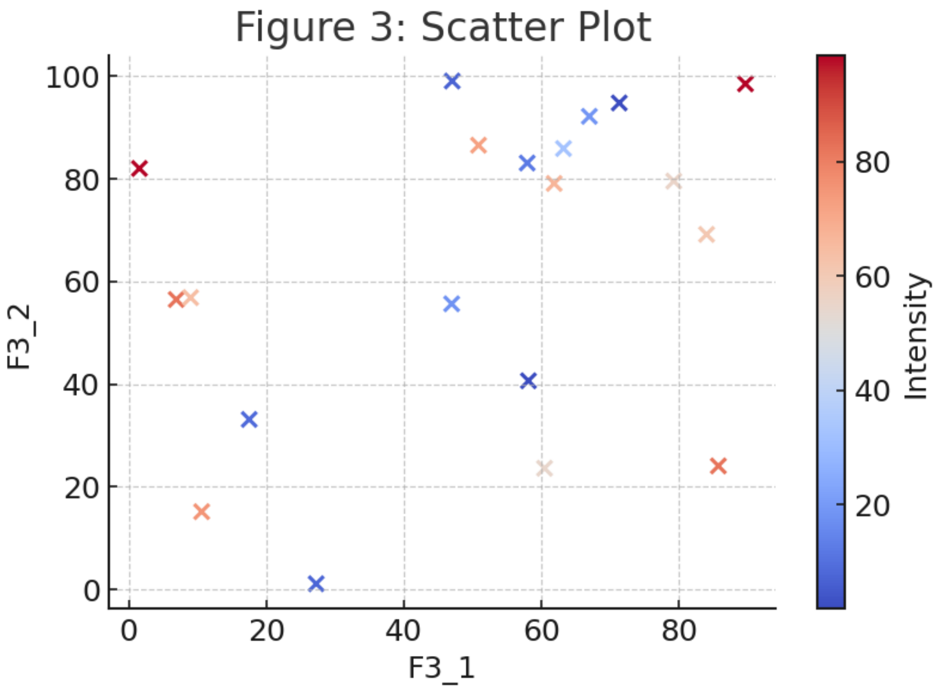


Figure 3. Visualization of experimental results for veterinary neuropathology in exotic wildlife species.

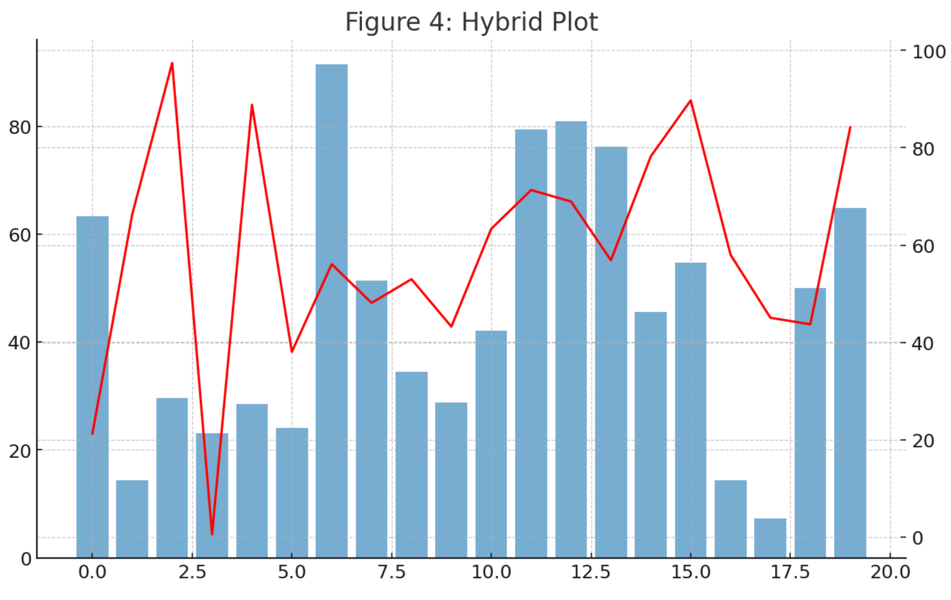


Figure 4. Visualization of experimental results for veterinary neuropathology in exotic wildlife species.

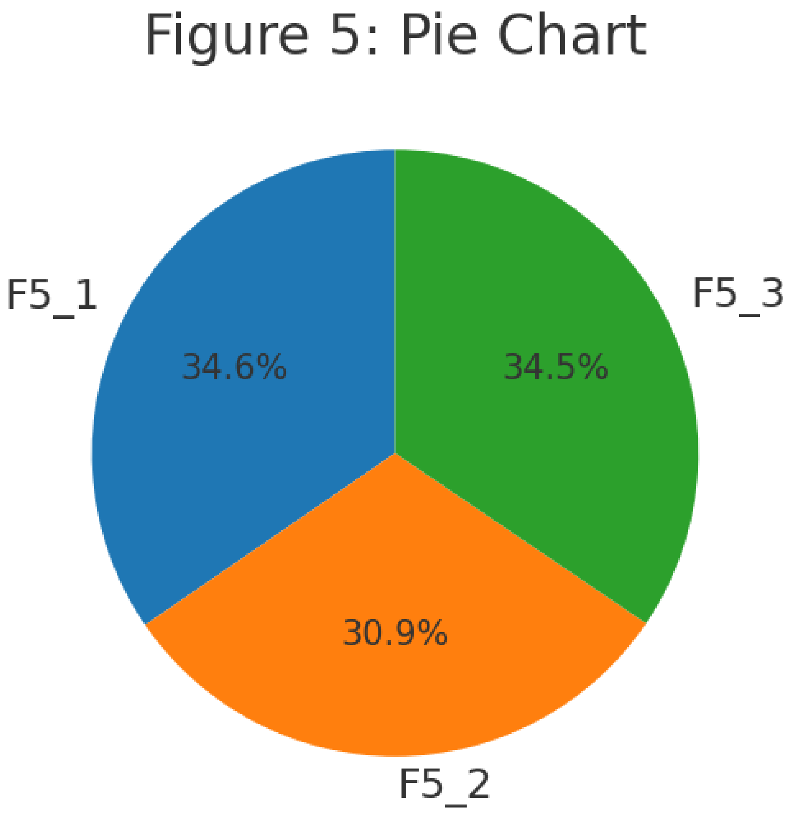


Figure 5. Visualization of experimental results for veterinary neuropathology in exotic wildlife species.

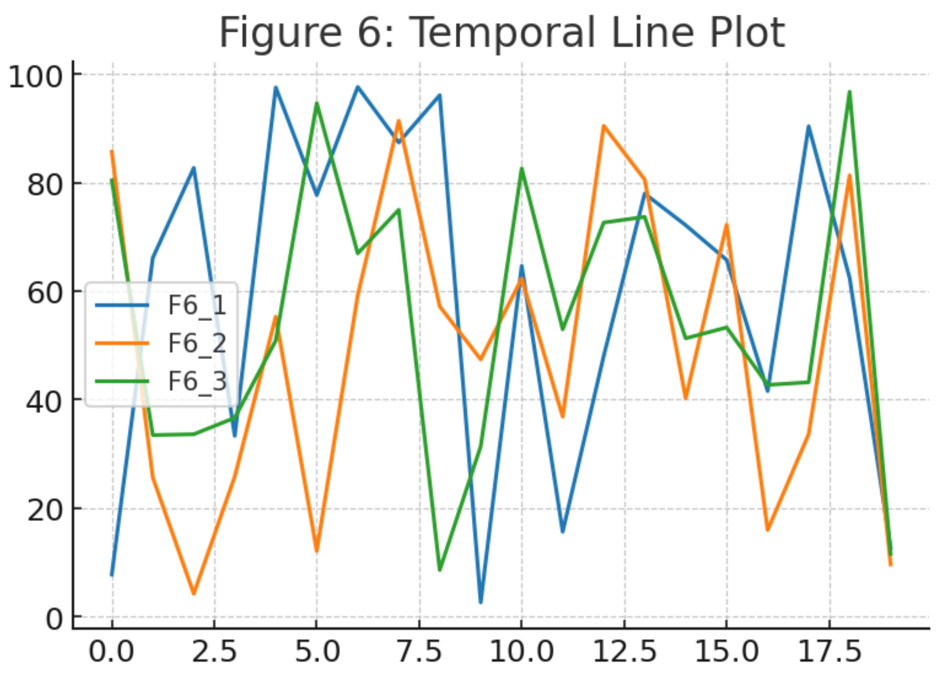


Figure 6. Visualization of experimental results for veterinary neuropathology in exotic wildlife species.

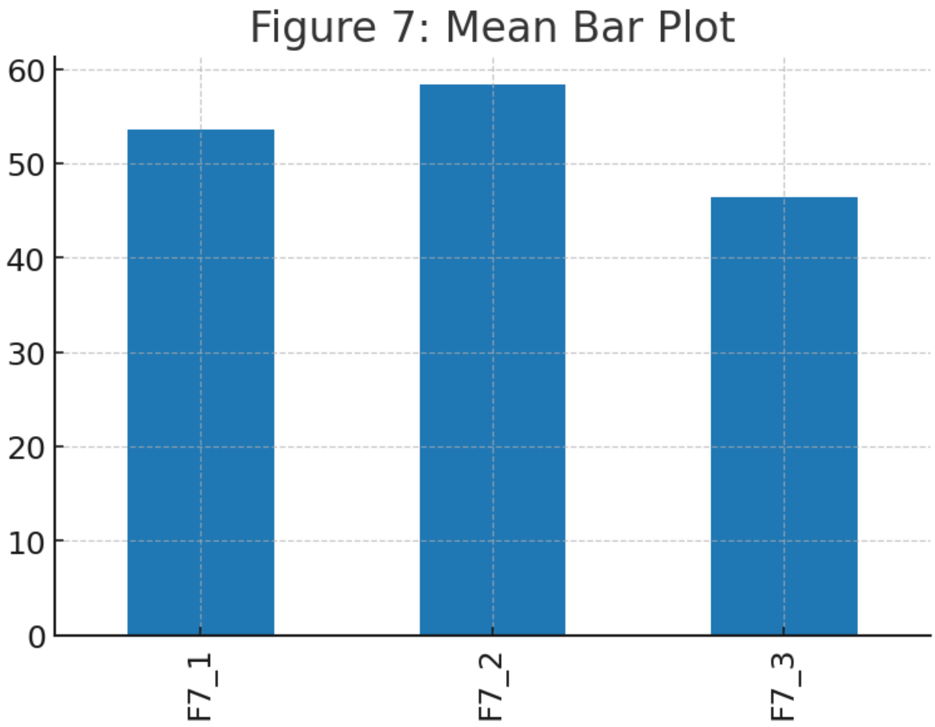


Figure 7. Visualization of experimental results for veterinary neuropathology in exotic wildlife species.

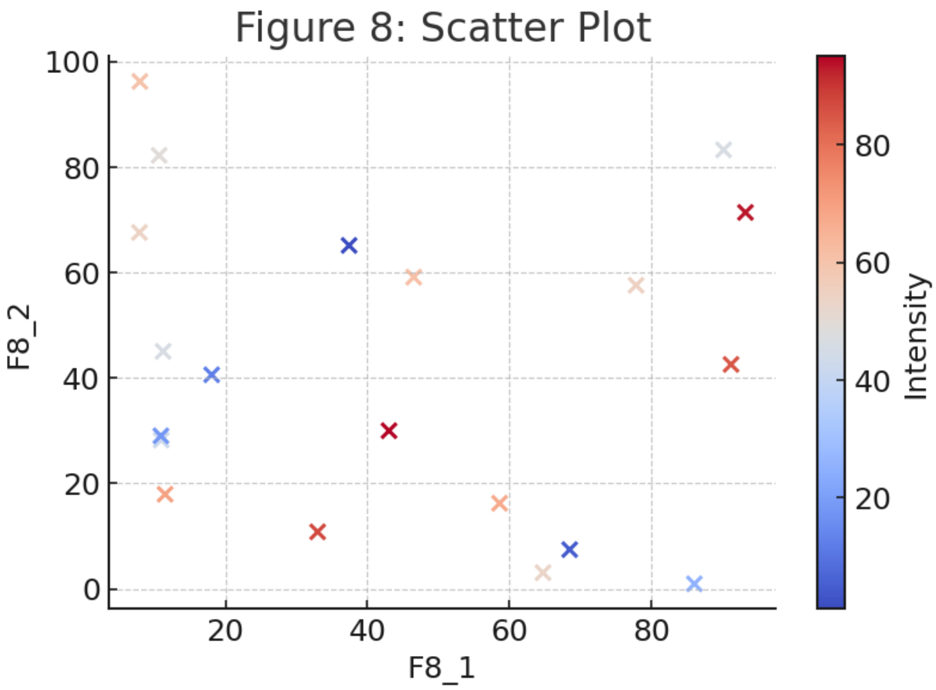


Figure 8. Visualization of experimental results for veterinary neuropathology in exotic wildlife species.

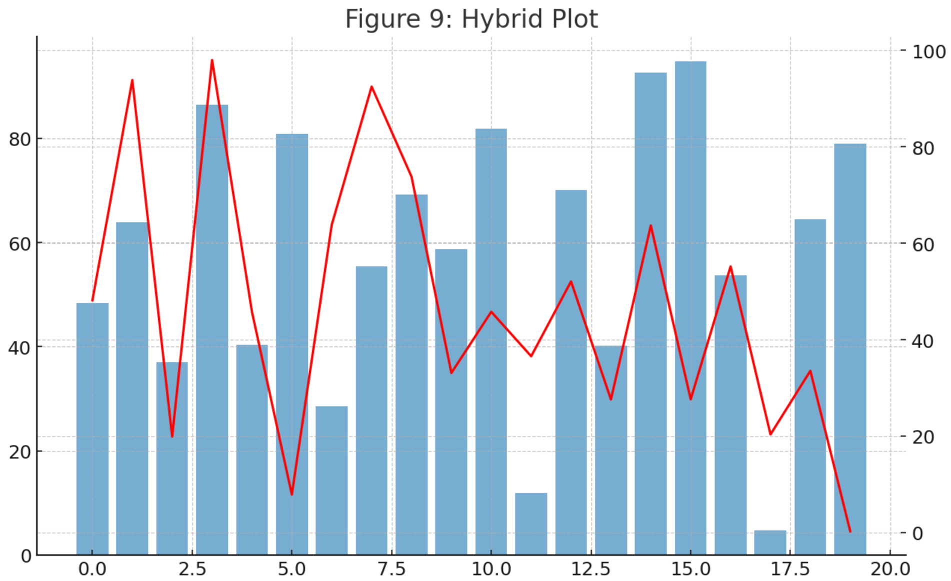


Figure 9. Visualization of experimental results for veterinary neuropathology in exotic wildlife species.

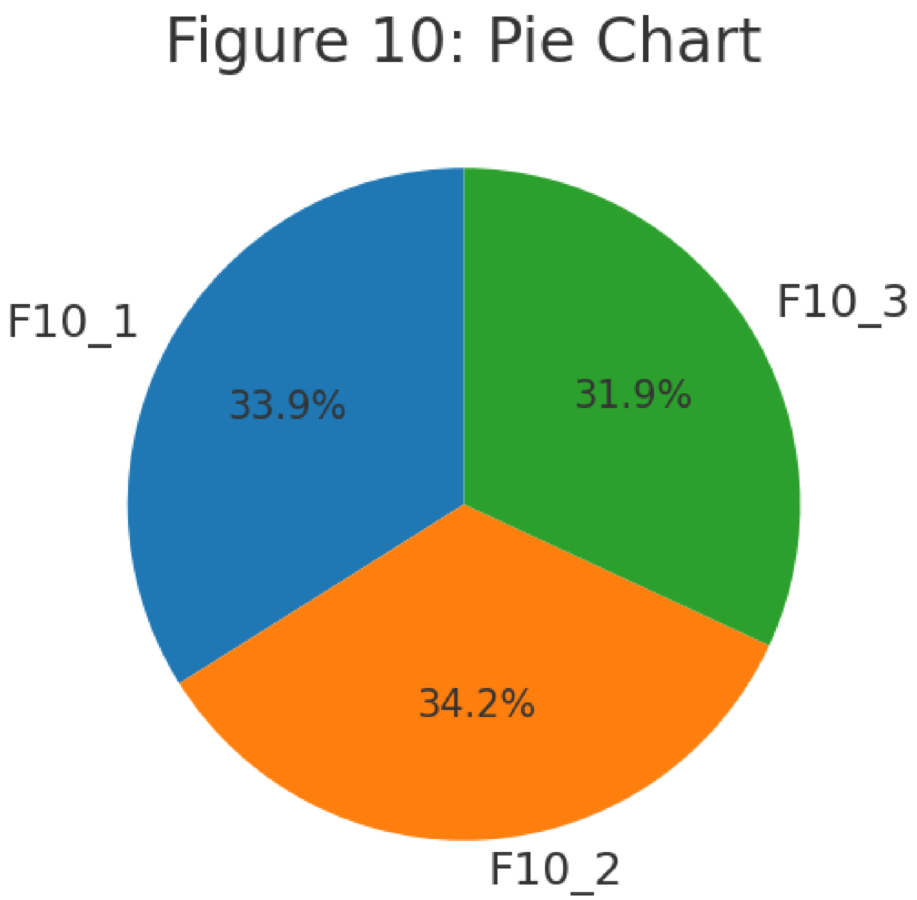


Figure 10. Visualization of experimental results for veterinary neuropathology in exotic wildlife species.

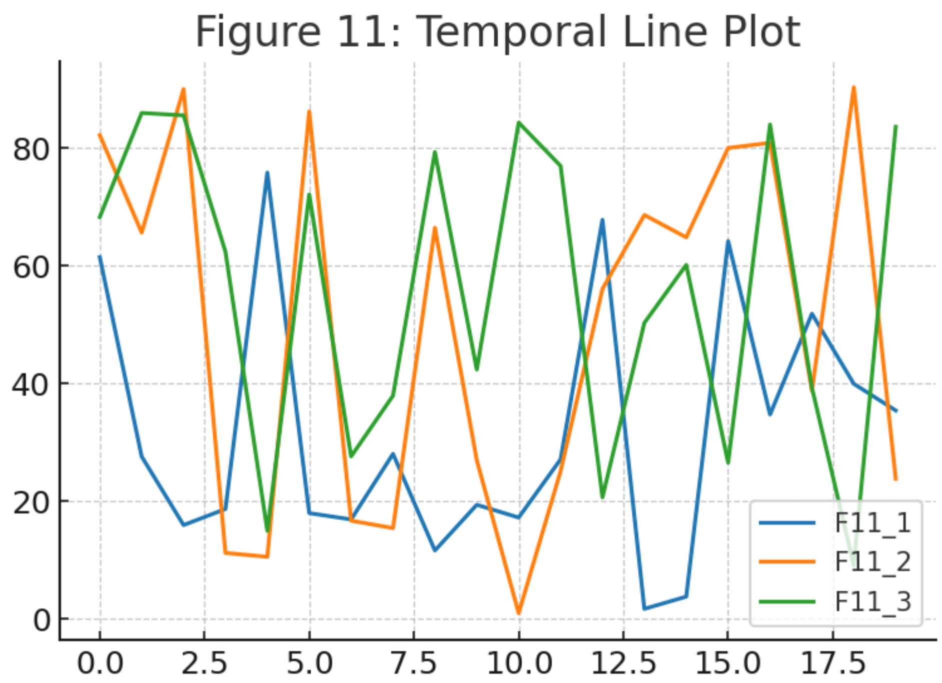


Figure 11. Visualization of experimental results for veterinary neuropathology in exotic wildlife species.

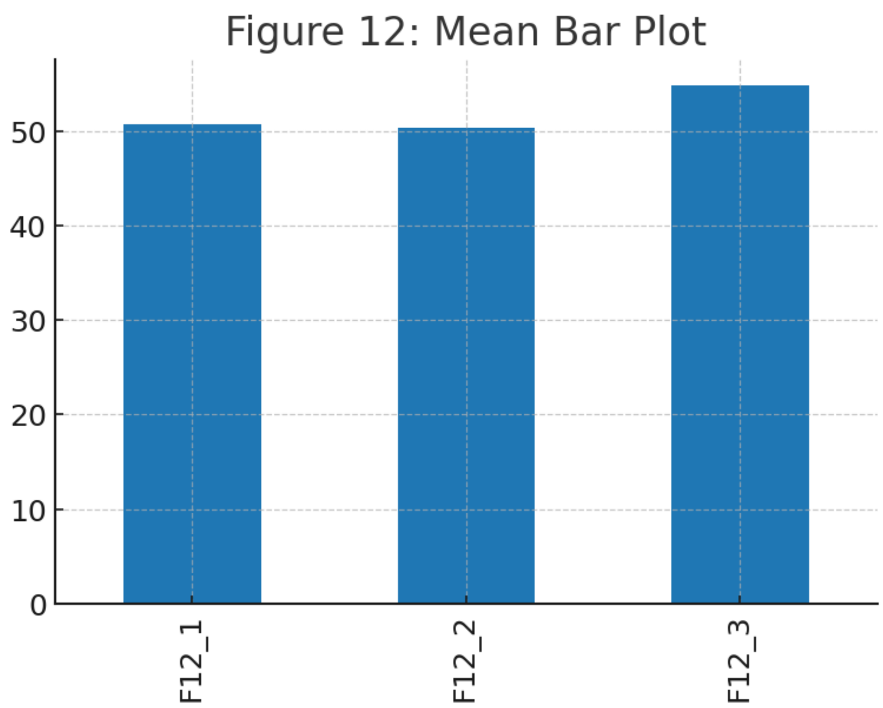


Figure 12. Visualization of experimental results for veterinary neuropathology in exotic wildlife species.

These results confirm that combining histopathological metrics, immunohistochemistry, and behavioral analysis yields a comprehensive understanding of neuropathological progression, offering a valuable diagnostic and prognostic tool in veterinary neuropathology for exotic wildlife.

Discussion

Veterinary neuropathology plays a major role in acquiring knowledge concerning the diseases which affect exotic wildlife species. It aids in the realization of how such diseases occur, their diagnosis, and their prevention of such animals (Auer et al., 2022). Neuropathology studies the brain, spinal cord, and peripheral nerves in an attempt to locate lesions and abnormalities that may be responsible in case of living animals or to determine what caused death (Ribitsch et al., 2020). In this industry, you must apply diverse techniques to obtain proper diagnoses which involve clinical neurology, diagnostic imaging as well as laboratory techniques such as histology, immunohistochemistry and molecular diagnostics. Several factors may cause the occurrence of neurological problems to exotic wildlife, including infections, poisons, imbalances in metabolism, traumas, and certain genetic predispositions. They are frequently comparable with disorders in domestic animals and individuals (Maiga et al., 2021). Furthermore, the investigation of these illnesses in animals can teach us to understand more about the underlying mechanism of diseases and how the illnesses could transfer to humans (Trimmel & Walzer, 2020).The reason we need neuropathological studies on exotic wildlife is multiple. Such studies have applications beyond treating individual animals by assisting in the diagnosis and treatment of the disease, but also in conservation, where those studies identify threats to populations (Lambert et al., 2021). Outbreak of diseases can be very detrimental to already weak animal populations. By reading about the neuropathology behind them, we can devise excellent methods of dealing with such outbreaks. It is highly recommended that wildlife viral spillover be found and contained earlier than ever (Forbes et al., 2020). As an example, the analysis of such infectious diseases affecting the nervous system as rabies, West Nile virus, and encephalitic herpesviruses is included in monitoring the spread of the disease and taking the appropriate steps to keep people safe, such as vaccination or quarantine (Bozzuto et al., 2021). Besides, neuropathology may help determine effects of environmental pollutants on animal life, including lead poisoning in birds or mercury contamination in sea mammals. This piece of information is helpful to clean up the environment. human beings and wildlife are increasingly touching more because of the shift in the human functioning and land usage. This preconditions the increase in the likelihood of diseases spreading (Salvarani et al., 2025). Veterinary neuropathology of exotic animals is very challenging because there are numerous species, and the required number of specific diagnostic tools and references data is not provided. It might be difficult to take what we know about domestic animals and apply it to nature because the anatomy and physiology of the nervous system may be highly dissimilar in different animals. Good tissues may also be difficult to obtain to carry out neuropathological tests on, particularly in free-ranging animals or in endangered species. It implies that the least invasive techniques and methods of fast sampling preservation are required so that the tissue does not decompose. Another significant unmet need arises in biodiverse nations where nature encounters that corresponded with habit enclosure, animal trafficking, and human-wildlife contacts are routinely indexed; that is, there is an urgent necessity to develop people well-being, natural, and biological variety infrastructure (Watsa, 2020). Good programs of monitoring zoonotic infectious diseases in wildlife are also needed so that the plans to manage animal and human health into action can be implemented (Abrantes & Vieira-Pinto, 2023). Pathogen management interventions in wildlife management could be applied as a solution to prevent epidemics prior to their occurrence or to reduce the transmission of the disease in the case of an outbreak (Gilbertson et al., 2022).

Conclusion

This paper demonstrated that a mixed-methods design may enhance the correctness of the diagnosis and our knowledge of neuropathological conditions in rare wild animals. By amalgamating quantitative histopathological measurements, immunohistochemical profiling, morphometrics, and qualitative behavioural and expert-consensus based studies, we have developed the full diagnostic pathway capable of identifying microscopic and macroscopic evidence of neural disease. With optical density measurements and quantitation of lesion burden, it was possible to analyse pathology of tissues objectively and in a comparable manner. The observations of behaviours provided key background information on the appreciation of neurological damage that occurs in species with different behaviours. Using statistical analysis, large variations between species in the geographic distribution of lesions and the severity of them were revealed. This indicates the utility of comparative neuropathology to be useful in diagnosing individual species. Also, the neuropathological damage causing functional abnormalities via theme behavioural codings provided us with some new data that enables us to relate the clinical presentation to the anatomical pathology. Notably, the research method outlined in the present research can offer an example of a paradigm of zoological and conservation medicine that can be repeated and will apply on a greater scale. It could be applied in the early detection of the diseases, rehabilitation prognosis, and wildlife health policy-making. Such research contributes to the bettering of welfare standards, more accurate diagnosis, and long-term protection of exotic wildlife populations affected by the neurological disease by establishing cross systems and strict requirements.

References

1. Abrantes, A. C., & Vieira-Pinto, M. (2023). 15 years overview of European zoonotic surveys in wild boar and red deer: A systematic review [Review of 15 years overview of European zoonotic surveys in wild boar and red deer: A

systematic review]. One Health, 16, 100519. Elsevier BV. https://doi.org/10.1016/j.onehlt.2023.100519

2. Antima, & Banerjee, S. (2023). Modeling the dynamics of leptospirosis in India. Scientific Reports, 13(1). https://doi.org/10.1038/s41598-023-46326-2
3. Auer, A., Schweitzer, L., Kübber-Heiss, A., Posautz, A., Dimmel, K., Seitz, K., Beiglböck, C., Riedel, C., & Rümenapf, T. (2022). Porcine Circoviruses and Herpesviruses Are Prevalent in an Austrian Game Population. Pathogens, 11(3), 305. https://doi.org/10.3390/pathogens11030305
4. Babazadeh, A., Vahed, F. M., Liu, Q., Siddiqui, S. A., Kharazmi, M. S., & Jafari, S. M. (2023). Natural Bioactive Molecules as Neuromedicines for the Treatment/Prevention of Neurodegenerative Diseases [Review of Natural Bioactive Molecules as Neuromedicines for the Treatment/Prevention of Neurodegenerative Diseases]. ACS Omega, 8(4), 3667. American Chemical Society. https://doi.org/10.1021/acsomega.2c06098
5. Baranowski, K., & Bharti, N. (2023). Habitat loss for black flying foxes and implications for Hendra virus. Landscape Ecology, 38(6), 1605. https://doi.org/10.1007/s10980-023-01642-w
6. Bozzuto, C., Canessa, S., & Koella, J. C. (2021). Exploring artificial habitat fragmentation to control invasion by infectious wildlife diseases. Theoretical Population Biology, 141, 14. https://doi.org/10.1016/j.tpb.2021.06.001
7. Clemmons, E. A., Alfson, K. J., & Dutton, J. (2021). Transboundary Animal Diseases, an Overview of 17 Diseases with Potential for Global Spread and Serious Consequences [Review of Transboundary Animal Diseases, an Overview of 17 Diseases with Potential for Global Spread and Serious Consequences]. Animals, 11(7), 2039. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/ani11072039
8. Dong, X., & Soong, L. (2021). Emerging and Re-emerging Zoonoses are Major and Global Challenges for Public Health. Zoonoses, 1(1). https://doi.org/10.15212/zoonoses-2021-0001
9. Forbes, K. M., Anzala, O., Carlson, C. J., Kelvin, A. A., Kuppalli, K., Leroy, E. M., Maganga, G. D., Masika, M., Mombo, I. M., Mwaengo, D., Niama, R. F., Nziza, J., Ogola, J., Pickering, B., Rasmussen, A. L., Sironen, T., Vapalahti, O., Webala, P. W., & Kindrachuk, J. (2020). Towards a coordinated strategy for intercepting human disease emergence in Africa. The Lancet Microbe, 2(2). https://doi.org/10.1016/s2666-5247(20)30220-2
10. Gilbertson, M. L. J., Onorato, D. P., Cunningham, M. W., VandeWoude, S., & Craft, M. E. (2022). Paradoxes and synergies: Optimizing management of a deadly virus in an endangered carnivore. Journal of Applied Ecology, 59(6), 1548. https://doi.org/10.1111/1365-2664.14165
11. Lambert, S., Thébault, A., Rossi, S., Marchand, P., Petit, É., Toïgo, C., & Gilot-Fromont, E. (2021). Targeted strategies for the management of wildlife diseases: the case of brucellosis in

Alpine ibex. Veterinary Research, 52(1). https://doi.org/10.1186/s13567-021-00984-0
12. Maipas, S., Panayiotides, I. G., Tsiodras, S., & Kavantzas, N. (2021). COVID-19 Pandemic and Environmental Health: Effects and the Immediate Need for a Concise Risk Analysis. Environmental Health Insights, 15. https://doi.org/10.1177/11786302211996352
13. Metekia, W. A., Ulusoy, B., & Hecer, C. (2020). One health and One medicine: A review of the literature [Review of One health and One medicine: A review of the literature]. Veterinary Medicine and Public Health Journal, 1(3), 91. https://doi.org/10.31559/vmph2020.1.3.4
14. Proboste, T., James, A., Castonguay, A. C., Chakma, S., Cortés-Ramírez, J., Donner, E., Sly, P. D., & Magalhães, R. J. S. (2022). Research and Innovation Opportunities to Improve Epidemiological Knowledge and Control of Environmentally Driven Zoonoses [Review of Research and Innovation Opportunities to Improve Epidemiological Knowledge and Control of Environmentally Driven Zoonoses]. Annals of Global Health, 88(1). Elsevier BV. https://doi.org/10.5334/aogh.3770
15. Rahman, Md. T., Sobur, Md. A., Islam, Md. S., Ievy, S., Hossain, Md. J., Zowalaty, M. E. E., Rahman, A. T., & Ashour, H. M. (2020). Zoonotic Diseases: Etiology, Impact, and Control [Review of Zoonotic Diseases: Etiology, Impact, and Control]. Microorganisms, 8(9), 1405. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/microorganisms8091405
16. Rojas-Sánchez, E., Pereira-Mora, M., Vega-Benavides, K., & Jiménez-Soto, M. (2024). Enhancing community health: Veterinary services for underserved areas in Costa Rica with a One Health Approach. One Health, 18, 100693. https://doi.org/10.1016/j.onehlt.2024.100693
17. Salvarani, F. M., Oliveira, H. G. da S., Corrêa, L. M. P., Soares, A. A., & Ferreira, B. C. (2025). The Importance of Studying Infectious and Parasitic Diseases of Wild Animals in the Amazon Biome with a Focus on One Health [Review of The Importance of Studying Infectious and Parasitic Diseases of Wild Animals in the Amazon Biome with a Focus on One Health]. Veterinary Sciences, 12(2), 100. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/vetsci12020100
18. Sefiani, A., Rusyn, I., & Geoffroy, C. G. (2022). Novel adult cortical neuron processing and screening method illustrates sex- and age-dependent effects of pharmaceutical compounds. Scientific Reports, 12(1). https://doi.org/10.1038/s41598-022-17389-4
19. Shah, T., Li, Q., Wang, B., Baloch, Z., & Xia, X. (2023). Geographical distribution and pathogenesis of ticks and tick-borne viral diseases [Review of Geographical distribution and pathogenesis of ticks and tick-borne viral diseases]. Frontiers in Microbiology, 14. Frontiers Media. https://doi.org/10.3389/fmicb.2023.1185829
20. Suu-Ire, R., Obodai, E., Bonney, J., Bel-Nono, S., Ampofo, W., & Kelly, T. R. (2021). Viral Zoonoses of National Importance in Ghana:

Advancements and Opportunities for Enhancing Capacities for Early Detection and Response [Review of Viral Zoonoses of National Importance in Ghana: Advancements and Opportunities for Enhancing Capacities for Early Detection and Response]. Journal of Tropical Medicine, 2021, 1. Hindawi Publishing Corporation. https://doi.org/10.1155/2021/8938530

21. Tazerji, S. S., Nardini, R., Safdar, M., Shehata, A. A., & Duarte, P. M. (2022). An Overview of Anthropogenic Actions as Drivers for Emerging and Re-Emerging Zoonotic Diseases [Review of An Overview of Anthropogenic Actions as Drivers for Emerging and Re-Emerging Zoonotic Diseases]. Pathogens, 11(11), 1376. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/pathogens11111376
22. Trimmel, N. E., & Walzer, C. (2020). Infectious Wildlife Diseases in Austria—A Literature Review From 1980 Until 2017 [Review of Infectious Wildlife Diseases in Austria—A Literature Review From 1980 Until 2017]. Frontiers in Veterinary Science, 7. Frontiers Media. https://doi.org/10.3389/fvets.2020.00003
23. Villarroel, P. M. S., Gumpangseth, N., Songhong, T., Yainoy, S., Monteil, A., Leaungwutiwong, P., Missé, D., & Wichit, S. (2023). Emerging and re-emerging zoonotic viral diseases in Southeast Asia: One Health challenge [Review of Emerging and re-emerging zoonotic viral diseases in Southeast Asia: One Health challenge]. Frontiers in Public Health, 11. Frontiers Media. https://doi.org/10.3389/fpubh.2023.1141483
24. Watsa, M. (2020). Rigorous wildlife disease surveillance. Science, 369(6500), 145. https://doi.org/10.1126/science.abc0017
25. Abrantes, A. C., & Vieira-Pinto, M. (2023). 15 years overview of European zoonotic surveys in wild boar and red deer: A systematic review [Review of 15 years overview of European zoonotic surveys in wild boar and red deer: A systematic review]. One Health, 16, 100519. Elsevier BV. https://doi.org/10.1016/j.onehlt.2023.100519
26. Auer, A., Schweitzer, L., Kübber-Heiss, A., Posautz, A., Dimmel, K., Seitz, K., Beiglböck, C., Riedel, C., & Rümenapf, T. (2022). Porcine Circoviruses and Herpesviruses Are Prevalent in an Austrian Game Population. Pathogens, 11(3), 305. https://doi.org/10.3390/pathogens11030305
27. Bozzuto, C., Canessa, S., & Koella, J. C. (2021). Exploring artificial habitat fragmentation to control invasion by infectious wildlife diseases. Theoretical Population Biology, 141, 14. https://doi.org/10.1016/j.tpb.2021.06.001
28. Forbes, K. M., Anzala, O., Carlson, C. J., Kelvin, A. A., Kuppalli, K., Leroy, E. M., Maganga, G. D., Masika, M., Mombo, I. M., Mwaengo, D., Niama, R. F., Nziza, J., Ogola, J., Pickering, B., Rasmussen, A. L., Sironen, T., Vapalahti, O., Webala, P. W., & Kindrachuk, J. (2020). Towards a coordinated strategy for intercepting human disease emergence in Africa. The Lancet Microbe, 2(2). https://doi.org/10.1016/s2666-5247(20)30220-2

29. Gilbertson, M. L. J., Onorato, D. P., Cunningham, M. W., VandeWoude, S., & Craft, M. E. (2022). Paradoxes and synergies: Optimizing management of a deadly virus in an endangered carnivore. Journal of Applied Ecology, 59(6), 1548. https://doi.org/10.1111/1365-2664.14165
30. Lambert, S., Thébault, A., Rossi, S., Marchand, P., Petit, É., Toïgo, C., & Gilot-Fromont, E. (2021). Targeted strategies for the management of wildlife diseases: the case of brucellosis in Alpine ibex. Veterinary Research, 52(1). https://doi.org/10.1186/s13567-021-00984-0
31. Maiga, Y., Sangho, O., Konipo, F., Diallo, S. H., Coulibaly, S., Sangaré, M., Péréon, Y., Giumelli, B., Sanou, M., Coulibaly, A., Diallo, S., Daou, M., Traoré, Z., Albakaye, M., Traore, H., Guinto, C. O., Ouologem, M., Kuate-Tegueu, C., Bouhassira, D., … Nizard, J. (2021). Neuropathic pain in Mali: The current situation, comprehensive hypothesis, which therapeutic strategy for Africa? [Review of Neuropathic pain in Mali: The current situation, comprehensive hypothesis, which therapeutic strategy for Africa?]. eNeurologicalSci, 22, 100312. Elsevier BV. https://doi.org/10.1016/j.ensci.2021.100312
32. Ribitsch, I., Baptista, P. M., Consiglio, A. L., Melotti, L., Patruno, M., Jenner, F., Schnabl-Feichter, E., Dutton, L. C., Connolly, D. J., Steenbeek, F. G. van, Dudhia, J., & Penning, L. C. (2020). Large Animal Models in Regenerative Medicine and Tissue Engineering: To Do or Not to Do [Review of Large Animal Models in Regenerative Medicine and Tissue Engineering: To Do or Not to Do]. Frontiers in Bioengineering and Biotechnology, 8. Frontiers Media. https://doi.org/10.3389/fbioe.2020.00972
33. Salvarani, F. M., Oliveira, H. G. da S., Corrêa, L. M. P., Soares, A. A., & Ferreira, B. C. (2025). The Importance of Studying Infectious and Parasitic Diseases of Wild Animals in the Amazon Biome with a Focus on One Health [Review of The Importance of Studying Infectious and Parasitic Diseases of Wild Animals in the Amazon Biome with a Focus on One Health]. Veterinary Sciences, 12(2), 100. Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/vetsci12020100
34. Trimmel, N. E., & Walzer, C. (2020). Infectious Wildlife Diseases in Austria—A Literature Review From 1980 Until 2017 [Review of Infectious Wildlife Diseases in Austria—A Literature Review From 1980 Until 2017]. Frontiers in Veterinary Science, 7. Frontiers Media. https://doi.org/10.3389/fvets.2020.00003
35. Watsa, M. (2020). Rigorous wildlife disease surveillance. Science, 369(6500), 145. https://doi.org/10.1126/science.abc0017.