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A retrospective analysis of post-mortem findings in New Zealand weka (*Gallirallus australis*), 1995–2022

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ABSTRACT

Aims: To determine the major causes of mortality in weka (*Gallirallus australis*), and to investigate associations between causes of mortality and captivity status, age, sex, decade of submission, and season.

Methods: Necropsy records were obtained from the Massey University School of Veterinary Science/Wildbase Pathology database (Palmerston North, NZ) for weka submitted between 1 January 1995 and 22 March 2022. Causes of mortality were classified into categories based on aetiology. Frequency of diagnosis was tested for association with region of submission, captivity status, age, sex, decade, and season of death.

Results: A total of 156 necropsy reports were included in this study, of which 96 (61%) were from wild weka, 57 (36.5%) were captive, and three (1.9%) were of an unspecified captivity status. Weka were submitted from 12 regions across New Zealand. There were 65 (41.7%) adults, 16 (10.3%) juveniles, and 75 (48.1%) weka of an undetermined age among the 156 submissions. Of the weka with a known sex, there was a similar distribution between sexes with 27 (17.3%) males and 29 (18.6%) females. A cause of death was determined in 132/156 (84.6%) cases, with 24/156 (15.4%) cases having an unknown diagnosis. The leading cause of mortality in weka was traumatic injury, which occurred in 65/156 (41.7%), followed by infectious and/or inflammatory diseases in 26/156 (16.7%), and degenerative and/or nutritional conditions affecting 20/156 (12.8%) cases. The distribution of the primary causes of death was found to be dependent on captivity status ($p < 0.001$). Traumatic and toxic causes of death were more frequent in wild than captive weka. The cause of death was also dependent on season ($p < 0.001$). There was a significant difference in cause of death between summer and all other seasons (spring $p = 0.008$; autumn $p < 0.001$; winter $p < 0.001$) and between autumn and winter ($p = 0.008$).

Conclusion: Trauma was identified as the most significant cause of mortality in the free-living weka necropsied. The inherent and uncertain submissions biases, and low case numbers over a long period of time, means that temporal patterns and the effect of captivity status on causes of mortality should be interpreted with caution.

Abbreviations: BCS: Body condition score; DOC: Department of Conservation; TB: Tuberculosis

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Introduction

The weka (*Gallirallus australis*) is a brown flightless rail endemic to New Zealand. Four distinct weka taxa are recognised today: the North Island weka (*G. a. greyi*), western weka (*G. a. australis*), Stewart Island weka (*G. a. scotti*), and the buff weka (*G. a. hectori*) (Beauchamp *et al.* 1999). Although their natural lifespan is estimated to exceed 15 years, this is seldom achieved in contemporary natural environments (Beauchamp *et al.* 1999). Since the arrival of European settlers in the nineteenth century, weka populations have declined considerably – some to extinction in certain regions. The population of weka prior to European settlement has not been established, however weka were believed to be widespread and abundant

across the North, South, and Stewart Islands in varying densities (Beauchamp *et al.* 1999). Population estimates in 2012 were approximately 11,000 North Island weka, 50,000–100,000 western weka, 38,000–58,000 buff weka (on Chatham and Pitt Islands), and 8,000 Stewart Island weka. Based on these estimates, a current population in the range of 71,000–118,000 mature individuals is suspected (BirdLife International 2022). The Department of Conservation (DOC) has attributed the following conservation statuses to weka: the North Island and buff weka have a status of “at risk – relict,” the western weka of “not threatened,” and the Stewart Island weka of “nationally vulnerable” (Robertson *et al.* 2021). Of the four weka subspecies, only the North Island weka was attributed

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a “better” conservation status from the previous assessment in 2016, while the remaining subspecies have had “no change” in conservation status (Robertson *et al.* 2021).

Although populations have fluctuated over the decades, with some success in the reintroduction of weka to certain mainland areas and off-shore islands, the overall population trend has been downward (Beauchamp 1997a; Beauchamp *et al.* 1999). The reason behind these fluctuations is poorly understood. Disease has been postulated to be a contributing factor to the declines, however there is little evidence to support this (Beauchamp 1997b; Beauchamp *et al.* 1999). Detailed reports have identified several ecological factors that affect weka population dynamics, such as climate (Beauchamp 1997a), predation (Beauchamp *et al.* 2000; King 2017; Watts *et al.* 2017), habitat destruction (Beauchamp *et al.* 1999), competition with introduced species (Beauchamp 2000; Shaw and Pierce 2002), and poisoning (Hunter *et al.* 2014).

The susceptibility of weka to avian diseases has not been fully evaluated. Most susceptibility data come from clinical cases, limited surveillance testing, and necropsy data. Based on a limited number of published reports, it would appear that weka are susceptible to at least avipoxvirus (Ha *et al.* 2011), avian tuberculosis (TB; Alley *et al.* 2017), and avian malaria (Derraik *et al.* 2008). Pritchard *et al.* (2021) describe the deaths of several weka on Waiheke Island after exhibiting neurological signs. Necropsy evaluation and histopathology of the brains of two weka revealed meningoencephalitis by bacterial agents (*Enterococcus* sp. and *Escherichia* sp.), and a fungus, *Trichosporon* sp.

To sustain existing weka populations and to promote future abundance, an understanding of the principal causes of mortality and their effect on population dynamics is necessary. Obtaining this information through active surveillance methods can be challenging to implement, time-consuming, and expensive (Kelly *et al.* 2021). Retrospective analysis of necropsy records can be used to gain insight into causes of death. This method relies on the submission of birds for post-mortem evaluation, which is an inherently biased sample and therefore not representative of the weka population as a whole. As such, post-mortem records cannot provide accurate data on the prevalence or incidence of specific causes of mortality in the population. Despite this, they can be useful for detecting (re)emerging disease and spatio-temporal patterns that may be overlooked by more targeted active surveillance methods (Kelly *et al.* 2021). The aim of this study was to determine the major causes of mortality in weka submitted to Massey University (Palmerston North, NZ) between 1995 and 2022, and to investigate associations between causes of mortality and captivity status, age, sex, decade of submission, and season.

Materials and methods

Weka necropsy records were obtained from the Massey University School of Veterinary Science/Wildbase Pathology database. The database is jointly owned by DOC and Massey University and is maintained by the Wildbase Pathology department at the School of Veterinary Science. Native wildlife species can be submitted by DOC staff, veterinarians, and other wildlife conservation management programmes to Massey University for post-mortem examination. The database was accessed on 22 March 2022 using the inclusion criteria of all weka submitted between 1990 and March 2022. Necropsy data were provided on 201 submissions between 1995 and 2022. Forty-five of the 201 weka were excluded from the analysis based on the following criteria: advanced autolysis preventing meaningful evaluation ($n = 13$); incomplete reports with missing necropsy data precluding inference of a primary cause of death ($n = 4$); incomplete carcass submission ($n = 1$); and weka that were euthanised and submitted as part of an ongoing avian TB management/monitoring programme independent of health status ($n = 27$). The remaining 156 records were deemed eligible for the study.

Weka were recorded as adult or juvenile if explicitly stated or based on extrapolation from weight and body condition score (BCS) assessment at the time of necropsy. A weka weighing < 400 g with a good BCS ($BCS \geq 2.5$ on 1–5 scale, $BCS \geq 4$ on 1–9 scale, or descriptive terms implying adequate fat and reserves) was classified as juvenile, while weka weighing $> 1,000$ g were classified as adult regardless of BCS. The age of weka falling into the zone between these measurements could not be reasonably assumed and were therefore listed as unknown. Weka were classified as male or female if explicitly stated or based on the pathologist's comments in the necropsy records relating to sex-specific organs. If there was insufficient information to determine sex, it was classified as unknown. The location was reported as the location where the weka died as noted in the necropsy records. This was then further classified into region of origin based on the 16 administrative divisions of New Zealand (Figure 1).

Weka were reported as wild, or captive based on the classification given in the necropsy database. Weka were considered captive if they were in captivity at the time of death, presuming that the length of time in captivity was sufficient to have been a factor in the cause of death. If no captivity status was listed, and there was insufficient information in the history provided to determine status, the weka's status was classified as unknown.

Submission dates were further classified based on decade of submission and Southern Hemisphere seasons. The dates were organised based on the decades of 1995–1999, 2000–2009, 2010–2019, and

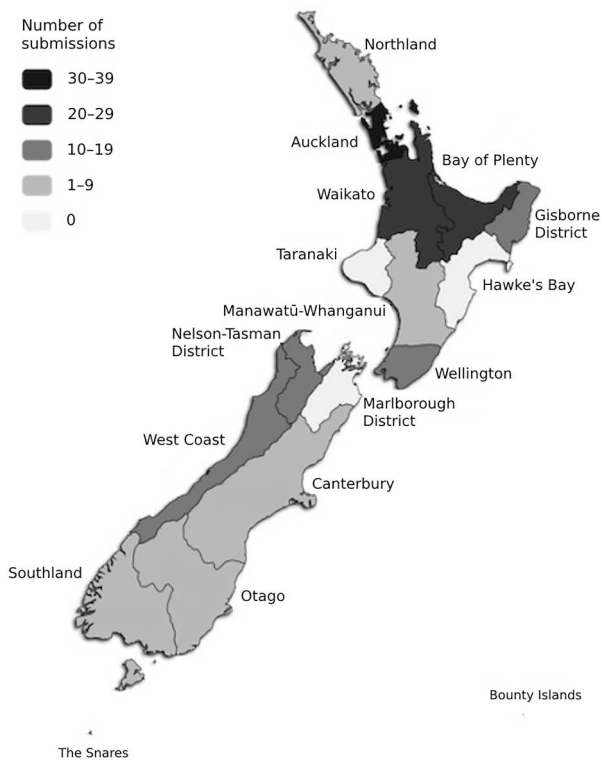


Figure 1. Frequency of submission stratified by geographical region of origin of 156 weka (*Gallirallus australis*) submitted for necropsy (1995–2022) and recorded in the Massey University School of Veterinary Science/Wildbase Pathology database.

2020–2022. The mean number of submissions per year per decade was calculated. This mean was used for statistical analysis to account for incomplete decades at both ends of the data set. The months of December, January, and February were classified as summer; March, April, and May as autumn; June, July, and August as winter; and September, October, and November as spring.

Each necropsy report was evaluated to identify the primary cause of death which was defined as the condition that initiated the sequence of events ultimately leading to death. If a primary cause of death was not clearly stated in the report, author NW determined the primary cause of death based on the case history, gross post-mortem findings, histopathology, any ancillary tests performed, and consultation with a veterinary pathologist where needed. If there was insufficient information to determine cause of death, the death was reported as unknown. The primary cause of death was further grouped into broad categories that reflected the pathogenesis of the disease or condition. The following broad disease categories were used: congenital, degenerative and/or nutritional, infectious and/or inflammatory, iatrogenic, metabolic, neoplastic, toxic, traumatic, and unknown. The congenital category included any death relating to a pathological defect that was present at birth. The degenerative and/or nutritional category encompassed any cause of death where the history

suggested that health progressively worsened over time, or the death was due to a nutrient-related condition. Infectious and/or inflammatory causes of death included any disorders where the primary pathological tissue response was inflammatory, regardless of whether an infectious organism was identified. If the cause of death was the direct result of medical or human intervention, the death was listed as iatrogenic. If birds were euthanised due to intractable illness or the severity of their injuries, their deaths were classified as the underlying cause of euthanasia. Metabolic causes included any disease process that disrupts the normal metabolism of the body. Neoplastic causes of death included conditions related to pathological and/or uncontrollable tissue growth or proliferation. Toxic causes of death were attributed to birds where toxin ingestion was confirmed by analyses of stomach contents, ancillary testing, or presumed based on gross post-mortem or histopathology findings. Cause of death was categorised as unknown if there were no significant lesions, or if the pathology noted was considered insufficient to result in death.

Statistical analyses

Proportions of weka in each category were calculated, and associated 95% CI calculated using the Pearson–Klopper method. The frequency of each diagnosis was compared across the variables of region of submission, captivity status, age, sex, decade of submission, and season using a Fisher’s exact test for independence. Global comparisons were considered statistically significant if $p < 0.05$, and where variables contained more than two categories, non-overlapping CI were used to identify categories with different proportions. The analyses were carried out in R version 4.2.1 (R Foundation for Statistical Computing, Vienna, Austria) in RStudio (Posit, Boston, MA, USA).

Results

Two-hundred and one weka were submitted to Massey University/Wildbase pathology department for post-mortem evaluation over a 27-year period between 1 January 1995 and 22 March 2022. Of the 156 submissions that met the inclusion criteria of this study, the mean number of weka submitted per year by decade was: 1.6 (SD 3.05) between 1990 and 1999; 6.5 (SD 2.9) between 2000 and 2009; 7.5 (SD 5.2) between 2010 and 2019; and 2.7 (SD 4.6) between 2020 and 2022. There was no significant difference in the distribution of cause of death between the decades ($p = 0.10$).

Of the 156 necropsied weka, 96 (61.5 (95% CI = 53.4–69.2)%) were wild, 57 (36.5 (95% CI = 29.0–44.6)%) were captive, and three (1.9 (95% CI = 0.4–5.5)%) had an

Table 1. Number of wild and captive weka (*Gallirallus australis*; n = 156), submitted for necropsy (1995–2022) and recorded in the Massey University School of Veterinary Science/Wildbase Pathology database stratified by region of submission, age and sex.

Variable	Total		Wild		Captive		Global p-value ^c
	Number	Proportion (95% CI) ^a	Number	Proportion (95% CI) ^b	Number	Proportion (95% CI) ^b	
Region							< 0.001
Northland	4	2.6% (0.7–6.4)	4	100% (39.8–100)	0	0% (0–60.2)	
Auckland	33	21.2% (15.0–28.4)	32	97.0% (84.2–99.9)	1	3.0% (0.08–15.8)	
Waikato	22	14.1% (9.1–20.6)	1	4.5% (0.1–22.8)	21	95.5% (77.2–99.9)	
Bay of Plenty	25	16.0% (10.6–22.7)	8	32% (14.9–53.5)	17	68.0% (46.5–85.1)	
Gisborne	15	9.6% (5.5–15.4)	15	100% (78.2–100)	0	0% (0–21.8)	
Manawatū-Whanganui	8	5.1% (2.2–9.9)	1	12.5% (0.3–52.3)	7	87.5% (47.3–99.7)	
Wellington	10	6.4% (3.1–11.5)	6	60% (26.2–87.8)	4	40% (12.1–73.8)	
Nelson-Tasman	11	7.1% (3.6–12.3)	11	100% (71.5–100)	0	0% (0–28.5)	
Canterbury	3	1.9% (0.4–5.5)	0	0% (0–70.8)	3	100% (29.2–100)	
West Coast	10	6.4% (3.1–11.5)	10	100% (69.2–100)	0	0% (0–30.8)	
Otago	6	3.2% (1.0–7.3)	3	50% (11.8–88.1)	2	40% (5.3–85.3)	
Southland	5	3.2% (1.0–7.3)	3	60% (14.6–94.7)	2	40% (5.3–85.3)	
Unknown	4	2.6% (0.7–6.4)	2	50% (75.0–99.4)	0	0% (0–60.2)	
Age							0.004
Adult	65	41.7% (33.8–49.8)	32	49.2% (36.6–61.9)	32	49.2% (36.6–61.9)	
Juvenile	16	10.3% (6.0–16.1)	15	93.8% (69.8–99.8)	1	6.3% (0.16–30.2)	
Unknown	75	48.1% (40.0–56.2)	49	65.3% (53.5–76.0)	24	32.0% (21.7–43.8)	
Sex							0.35
Male	27	17.7% (11.7–24.2)	15	55.6% (34.3–74.5)	11	40.7% (22.4–61.2)	
Female	29	18.6% (12.8–25.6)	12	41.4% (23.5–61.1)	17	58.6% (38.9–76.5)	
Unknown	100	64.1 (56.0–71.6)	69	69.0% (59.0–77.9)	29	29.0% (20.4–38.9)	

^aProportion of total submissions.

^bProportion of submissions for each variable category. Birds with unknown captivity status are excluded from these totals.

^cFisher's exact test of independence comparing wild and captive weka populations.

unknown captivity status. The wild weka originated from various locations including mainland reserves, private land, and off-shore islands. The captive birds originated from zoological wildlife parks, DOC or privately owned captive facilities, veterinary hospitals, and rehabilitation centres. The cause of death was unknown in 24 (15.4 (95% CI = 10.1–22.0)%) cases. There was no difference in the proportion of unknown diagnoses between wild and captive weka ($p = 0.37$).

Weka were submitted from 12/16 administrative regions of New Zealand (Figure 1). The captivity status of weka was dependent on the region of submission ($p < 0.001$; Table 1). The Auckland, Gisborne, Nelson-Tasman, and West Coast regions submitted a higher proportion of wild than captive weka. In contrast, Waikato submitted a higher proportion of captive than wild weka. There was no evidence of a difference in the captivity status of weka submitted from other regions.

There was a higher proportion of wild juvenile birds submitted than captive juvenile birds ($p = 0.004$). The

sex of weka submitted was independent of captivity status ($p = 0.35$).

The distribution of cause of death is summarised in Table 2. The distribution of the primary causes of death was not significantly associated with age ($p = 0.083$) or sex ($p = 0.11$), but was associated with captivity status ($p < 0.001$). Traumatic and toxic causes of death were more frequent in wild weka than captive weka. Of the 12 weka that died of a toxic cause, anticoagulant toxicity accounted for 11 (91.7 (95% CI = 61.5–99.8)%) of the cases, with the remaining death being an unknown toxin.

Traumatic injury was the leading cause of mortality in weka (Table 2). The type of trauma was associated with captivity status ($p < 0.001$; Table 3). Wild birds were more likely to die from motor vehicle trauma and predation compared to captive birds. Conversely, captive birds were more likely to die from intraspecific aggression compared to wild birds. Dogs were the leading predator, being responsible for 15/31 (48.4 (95% CI =

Table 2. Primary cause of death of captive and wild weka (*Gallirallus australis*; n = 156) submitted for necropsy (1995 and 2022) and recorded in the Massey University School of Veterinary Science/Wildbase Pathology database.

Cause of death	Total		Wild		Captive	
	Number	Proportion (95% CI) ^a	Number	Proportion (95% CI) ^b	Number	Proportion (95% CI) ^b
Congenital	1	0.6% (0.02–3.5)	0	0% (0–97.5)	1	100% (2.5–100)
Degenerative/nutritional	20	12.8% (8.0–19.1)	10	50% (27.2–72.8)	10	50% (27.2–72.8)
Infectious/inflammatory	27	17.3% (11.7–24.2)	8	29.6% (13.8–50.2)	19	70.4% (49.8–86.3)
Iatrogenic	2	1.3% (0.2–4.6)	0	0% (0–84.2)	2	100% (15.8–100)
Metabolic	3	1.9% (0.4–5.5)	2	66.7% (9.4–99.2)	0	0% (0–70.8)
Neoplastic	2	1.3% (0.2–4.6)	0	0% (0–84.2)	2	100% (15.8–100)
Toxic	12	7.7% (4.0–13.1)	10	83.3% (51.6–97.9)	2	16.7% (2.1–48.4)
Traumatic	65	41.7% (33.8–49.8)	54	83.1% (71.7–91.2)	10	15.4% (7.6–26.5)
Unknown	24	15.4% (10.1–22.0)	12	50% (29.1–70.9)	11	45.6% (25.5–67.2)

^aProportion of total submissions.

^bProportion of submissions for each cause of death category. Birds with unknown captivity status are excluded from these totals.

Table 3. Causes of traumatic injury as a primary cause of death of captive and wild weka (*Gallirallus australis*; n = 65) submitted for necropsy (1995–2022) and recorded in the Massey University School of Veterinary Science/Wildbase Pathology database.

Trauma type	Total		Wild		Captive	
	Number	Proportion (95% CI) ^a	Number	Proportion (95% CI) ^b	Number	Proportion (95% CI) ^b
Unspecified trauma	8	12.3% (5.5–22.8)	6	75% (34.9–96.8)	2	25% (3.2–65.1)
Intraspecific aggression	6	9.2% (3.5–19.0)	0	0% (0–45.9)	6	100% (54.1–100)
Ballistic	5	7.7% (2.5–17.0)	5	100% (47.8–100)	0	0% (0–52.2)
Vehicle trauma	11	16.9% (8.8–28.3)	11	100% (71.5–100)	0	0% (0–28.5)
Predation	31	47.7% (33.1–60.4)	30	96.8% (83.3–99.9)	1	3.2% (0.082–16.7)
Cage or trap trauma	4	6.1% (1.7–15.0)	3	75.0% (19.4–99.4)	1	25.0% (0.63–80.6)

^aProportion of total submissions.^bProportion of submissions for each trauma category.

30.2–66.9%) deaths, followed by mustelids (7/31; 22.6 (95% CI = 9.6–41.1)%), and cats (1/31; 3.2 (95% CI = 0.082–16.7)%). The type of predator was not stated for the remaining 8/31 (25.8 (95% CI = 11.9–44.6)% deaths.

Infectious and/or inflammatory conditions were the second most frequent cause of death (Table 2). Of the 27 weka affected, various conditions across multiple

Table 4. Primary causes of mortality of weka (*Gallirallus australis*; n = 156) submitted for necropsy (1995–2022) and recorded in the Massey University School of Veterinary Science/Wildbase Pathology database.

Cause of mortality ^a	Number
Congenital: heart anomaly	1
Degenerative / nutritional	20
Starvation	12
Hepatic fibrosis / failure	2
Osteoarthritis ^b	1
Renal failure	1
Congestive heart failure	3
Peripheral neuropathy ^b	1
Infectious / inflammatory	27
Parasitic: nematodiasis and protozoal (coccidia, trichomonad type)	1
Bacteraemia: <i>Pasteurella multocida</i> (1), unknown organism (2),	3
Enteritis: <i>Mycobacterium ssp. avium</i> (1), unknown organism (1)	2
Bronchopneumonia/air sacculitis: <i>Pasteurella multocida</i> (2), aspergillosis (4), unknown organism (1)	7
Ingluvitis	1
Upper respiratory infection ^b	1
Encephalitis	1
Salpingitis / oophoritis / metritis	6
Endophthalmitis ^b	1
Osteomyelitis ^b	1
Myocarditis	3
Iatrogenic	2
Leg band injury	1
Handling injury: fractured fibula	1
Metabolic: gout: visceral, renal, or articular	3
Neoplastic	2
Lymphoid leukaemia	1
Oviduct cystadenomas	1
Toxic	12
Anticoagulant toxicity	11
Unknown toxin	1
Traumatic	65
Predation: dog (15), mustelid (7), cat (1), unspecified (8)	31
Vehicle trauma	11
Unspecified trauma	8
Intraspecific aggression	6
Ballistic	5
Cage or trap trauma	4
Unknown	24
Total	156

^aNumber of weka assigned to each sub category is shown in brackets.^bWeka euthanised due to severity of injury or illness

body systems were identified (Table 4). *Aspergillus* spp. was the causative organism in 4/27 (14.8 (95% CI = 4.2–33.7)%) cases of bronchopneumonia and/or air sacculitis. *Pasteurella multocida* was isolated in two cases of bronchopneumonia/air sacculitis, and there was one case of systemic bacteraemia (3/27; 11.1 (95% CI = 2.4–29.2)%). Avian TB, from *Mycobacterium ssp. avium*, was identified as the primary cause of death in 1/27 (3.7 (95% CI = 0.09–19.0)%) weka with infectious and inflammatory conditions. Avian TB was also diagnosed as an incidental finding in 2/156 (1.3 (95% CI = 0.15–4.6)%) other weka that died from unrelated causes (not included in Table 4 as it was not the primary cause of death).

The third most frequent cause of death in weka was degenerative and/or nutritional diseases, with an even distribution between captive and wild weka (Table 2). Of the 12 weka that died of starvation, seven (58.3 (95% CI = 27.7–84.8)%) were captive and five (41.7 (95% CI = 15.2–72.3)%) were wild. Both cases of hepatic fibrosis/failure, the single case of renal failure, and the single case of peripheral neuropathy occurred in captive birds. Two of the congestive heart failure cases occurred in wild weka, and one was a captive bird. The single case of osteoarthritis occurred in a wild weka.

Of the 156 weka examined, 48 (30.8 (95% CI = 23.6–38.6)%) died during the autumn, 39 (25.0 (95% CI = 18.4–32.6)%) during the spring, 35 (22.4 (95% CI = 16.2–29.8)%) during the summer, and 34 (21.8 (95% CI = 15.6–29.1)%) during the winter months. Excluding unknown causes of death from the analysis, the cause of death was dependent on season ($p < 0.001$; Figure 2) with the distribution of cause of death in summer being different to that in all other seasons ($p < 0.008$ in all cases), and between autumn and winter ($p = 0.008$). Traumatic death was more frequent in autumn (28/40; 70 (95% CI = 53.5–83.4)%) than summer (9/31; 29 (95% CI = 14.2–48.0)%). Death by infectious and/or inflammatory conditions was more frequent in summer (16/31; 51.6 (95% CI = 33.1–69.8)%) than all other seasons (spring = 5/33, 15.2 (95% CI = 5.1–31.9)%; autumn = 4/40, 10.0 (95% CI = 2.8–23.6)%; winter = 2/28, 7.1 (95% CI = 0.9–23.5)%). Death by toxic causes was more frequent in winter (8/28; 28.6 (95% CI = 13.2–48.7)%) than autumn (1/40; 2.5 (95% CI = 0.06–13.1)%) and summer (0/31; 0 (95% CI = 0–11.2)%).

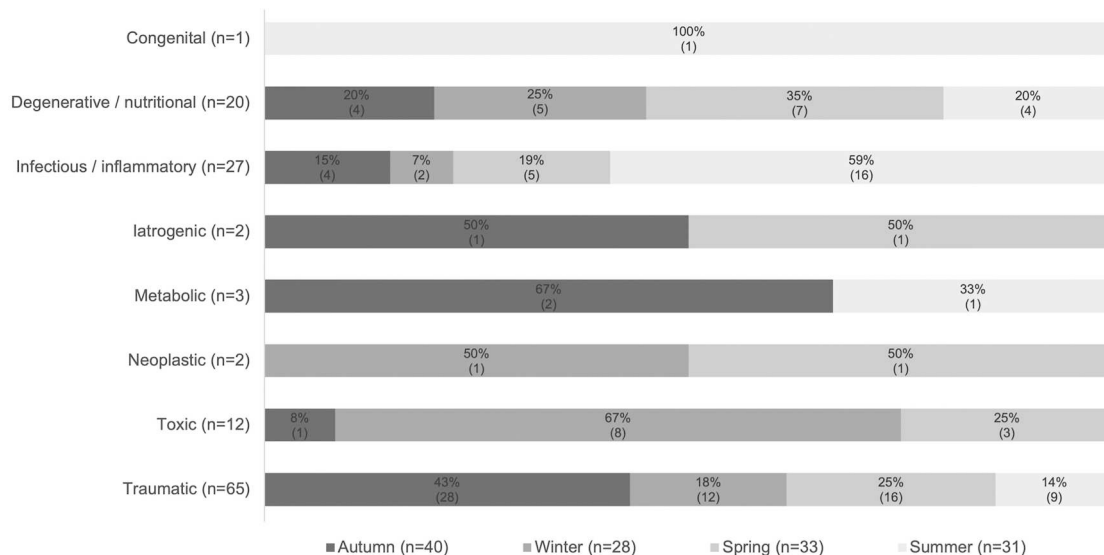


Figure 2. Primary cause of death stratified by season of submission of weka (*Gallirallus australis*; n = 132) submitted for necropsy (1995–2022) and recorded in the Massey University School of Veterinary Science/Wildbase Pathology database. Weka with an unknown cause of death (n = 24) are excluded.

Discussion

Necropsy reports can provide a useful means of disease surveillance; however, they are not representative of all weka mortality cases. Not all weka that die are recovered and/or submitted for necropsy, therefore this is not a comprehensive report, and the inherent submission bias associated with necropsy records needs to be taken into account when interpreting findings. Furthermore, given the lack of specific population details, the results provide no means of calculating the prevalence or incidence of disease. Despite these limitations, this study was able to identify major causes of mortality in weka, provide useful disease susceptibility data, and identify temporal trends worth exploring further.

Submission

The Auckland region had the highest number of submissions, followed by Waikato and Bay of Plenty. The regional distribution of cases in this study differs from the estimated population sizes and distribution described by Beauchamp *et al.* (1999). These findings highlight the inherent source of bias associated with necropsy records, and therefore the sample in this study should not be considered representative of the weka population as a whole. Most of the weka submitted from the Auckland region originate from actively monitored wild populations on Kawau, Rotoroa, and Great Barrier Islands (Beauchamp 1997b). In contrast, the large number of captive submissions from the Waikato region are attributed to a single captive facility. Weka that are part of actively monitored populations, closer to human settlement,

or part of captive programmes are more likely to be recovered and submitted for necropsy.

There are many factors that influence submission of a dead bird for necropsy evaluation. In a comparable study by Gulliver *et al.* (2023), the submission rate of kiwi for post-mortem examination in the Massey University School of Veterinary Science/Wildbase Pathology database was 1,005 submissions over a 10-year period, in comparison to 201 weka over a 27-year period in this study. Weka likely have lower submission numbers relative to population size due to larger free-living and highly dispersed populations, perceived value, and conservation programmes with mainly short-term projects (Beauchamp *et al.* 1999).

Causes of mortality

Traumatic injury was more frequently identified as a primary cause of death in wild weka compared to captive weka. Captive weka are typically housed in controlled environments, thereby limiting the risk of traumatic injury from extrinsic sources. Despite this, two captive weka in this study succumbed to unspecified trauma resulting in death. The circumstances around their deaths were unknown and cited as “misadventure.” It is likely that traumatic causes of death are greatly under-represented in this dataset due to submission bias. Weka that are found deceased on the road-side typically do not require post-mortem examination to determine cause of death, and are therefore less likely to be submitted. Furthermore, predated weka are likely to be, at least partially, eaten and digested by their predator, preventing carcass recovery and submission. In regions where weka are abundant, they can develop a “pest status” reputation

among residents that could potentially increase the likelihood that weka would be purposefully killed by humans. In this study, five weka were identified as dying from ballistic trauma. Four of these were found dead together, presumably all killed by malicious human intent. The body of the fifth weka was placed on the steps of Parliament along with 24 other native birds in protest at the use of the poison sodium fluoracetate (1080).

In some cases, the type of predator was stated in the necropsy report based on the nature of the injury sustained and bite marks on the carcass (inter-canine distance). In this study, dogs were the leading predator followed by mustelids and cats. This is in keeping with previous reports on predation of weka. A study by Bramley (1996) found ferrets and feral cats to be significant threats to adult weka and chicks in the Gisborne region. An attempt to establish a weka population in the Karangahake Gorge in the Waikato region failed due to predation of most of the introduced weka by a single dog and ferrets (Beauchamp *et al.* 2000). Furthermore, stoats were implicated in the death of multiple weka in the Kenepuru Sounds in the Nelson-Tasman region (Beauchamp *et al.* 1999). Data from monitoring programmes on the post-release survival of weka that have been re-introduced into locations with existing mammalian predator populations support the notion that predation is a leading cause of death among weka (Bramley and Veltman 1998; Beauchamp *et al.* 2000; Watts *et al.* 2017).

Intraspecific aggression was the leading cause of traumatic death in captive weka. Intraspecific aggression amongst social bird species can occur in both captive and wild settings and is typically associated with dominance hierarchies, territorial control, and mate selection (MacLean and Beaufrère 2014). The high prevalence of intraspecific aggression in captive settings is likely due to the increased density of birds in a controlled environment resulting in resource competition. Any disruption to an established dominance order, such as the addition of new individuals to a pen or perceived illness, can result in intraspecific aggression (MacLean and Beaufrère 2014). Given that weka are generally territorial birds, care should be taken in captive settings to mimic the species-typical social arrangements that would be seen in the wild (Beauchamp *et al.* 1999; Greggor *et al.* 2018).

More captive weka died of infectious and/or inflammatory conditions than wild weka, however the effect of captivity status was not statistically significant as the 95% CI overlapped. Captive weka tend to have more human observation and therefore are more likely to be monitored, treated for chronic conditions, and reach an older age. Furthermore, stress factors (e.g. overcrowding, social stresses) and increased exposure to infectious agents (e.g. contamination of food or

water sources) associated with captive settings may predispose birds to infection (Alley and Gartrell 2019). A causative organism was isolated or highly suspected in seven of the infectious and/or inflammatory cases. *P. multocida* is an opportunistic pathogen and is usually associated with septicaemia and bronchopneumonia following trauma. The bacterium is shed in the faeces by a variety of wild birds and mammals and can sometimes be spread through contaminated food sources in captive settings. *Aspergillus* spp. are opportunistic fungal pathogens that are transmitted by inhalation of spores in the environment (Winter *et al.* 2022).

One weka died of enteritis caused by *Mycobacterium* ssp. *avium* (avian TB) and an additional two weka that died of unrelated causes had lesions consistent with avian TB as an incidental finding at post-mortem. All three were from the same captive facility. An additional 27 weka were excluded from this study due to euthanasia as part of an ongoing TB control programme at the same facility. Weka are thought to be a spillover host for *M. avium*, with infection believed to occur primarily by the oral/alimentary route (Alley and Gartrell 2019).

The leading cause of death in the degenerative and/or nutritional category was starvation. Weight measurements are a useful tool for assessing the stability of a weka population. Beauchamp *et al.* (1999) suggest that weka are at immediate risk of death if their weight drops below 580 g for males and 450 g for females. Furthermore, a median weight of female and male weka of less than 600 and 780 g, respectively, is an indicator that a population is under stress. Although not noted in any of the necropsy reports in this study, Beauchamp *et al.* (1999) suggest the presence of clear stress lines on the growth bars on the remiges (large wing feathers) of weka are indicative of periods of stress, often due to reduced food availability in the previous summer.

There was no evidence of a difference between the proportion of wild and captive weka that died of degenerative and/or nutritional conditions. Interestingly, more captive weka ($n=7$) died of starvation than wild weka ($n=5$). One would expect wild weka to be at greater risk of starvation due to inconsistent food supply, thereby making them more susceptible to periods of malnutrition. Captive weka, on the other hand, tend to be housed in more controlled environments where food supply is monitored. However, given the territorial nature of weka, it is possible that there is more resource aggression in a captive environment, which could result in malnutrition of non-dominant weka. Another possible explanation for this finding is the criteria that were used for classification of captive weka in this study. A weka was classified as "captive" if it was in captivity at the time of death. Captive submissions came from a variety of facility types. The environment in which they are

housed and the degree of human intervention is likely to vary between facilities depending on the intended outcome of captivity, for example long-term residents, breeding programmes, veterinary care, rehabilitation, or quarantine for translocations. It is possible that malnourished wild weka are more likely to end up in a captive situation because they are easier to catch for translocations, or more likely to require veterinary care or rehabilitation. Additionally, captive weka that die of malnutrition are more likely to be submitted for post-mortem evaluation than wild weka where carcass recovery is more challenging. This once again highlights the inherent submission bias associated with necropsy records.

Toxin ingestion was responsible for the deaths of 12 weka in this study. Eleven cases were confirmed or presumed to be due to anticoagulant toxicity. The lethal dose of brodifacoum in weka has not been determined. Ground-based poisoning operations pose significant risk to weka due to their scavenging nature, resulting in both primary and secondary poisoning (Empson and Miskelly 1999). In contrast to the current study, Gulliver *et al.* (2023) evaluated post-mortem records of 1,005 kiwi (*Apteryx* spp.) and identified only a single case of death from anticoagulant toxicity. Despite the fact that weka and kiwi are both ground-dwelling birds and occupy similar habitats, it would appear that weka are more susceptible to toxin ingestion. Both weka and kiwi are omnivores, feeding predominantly on invertebrates, fruits, seeds, and berries confined to the ground. Weka, however, are more indiscriminate foragers, and have also been reported to prey on lizards, rodents, and the eggs of other ground-nesting birds (Carpenter *et al.* 2021). The inadvertent poisoning of non-target species is a recognised side effect of pest eradication programmes in New Zealand. Despite this, the significant benefits to the overall ecosystem are considered to outweigh the short-term losses. This is exemplified by pest eradication programmes on Kapiti Island where, although significant weka mortality occurred during the operation, the surviving weka were quick to redistribute and began breeding prolifically (Empson and Miskelly 1999). Although the weka population was quick to recover, one must also consider the resulting genetic bottleneck effect and its consequences to the population over time.

Temporal patterns

In this study, the distribution of primary cause of death was not significantly associated with the decade of submission. Although the dataset used in this study spans a 27-year period, many of the significant population declines in weka, such as the marked declines seen in the East Coast region in the 1980s (Beauchamp 1997a), occurred prior to 1995. The dataset is therefore

not suitable for assessing causes of mortality relating to declines occurring prior to 1995. Furthermore, there are likely regional factors that contribute to the survival of sub-populations of weka. Targeted active surveillance programmes at a regional level may provide better means of assessing local factors that contribute to weka survival.

The highest number of submissions were in autumn, followed by spring, summer, and winter. Captive weka are more likely to be submitted year-round due to more consistent human observation and intervention, whereas wild weka are susceptible to adverse environmental factors such as weather events or food shortages, which may follow more seasonal patterns. Humans tend to spend less time outdoors during the winter months, which may contribute to lower rates of dead weka recovery. Furthermore, any species-specific monitoring is more likely to occur during breeding and dispersal periods in the spring and summer, thereby increasing the likelihood of dead weka being recovered by DOC and other conservation workers.

The distribution of primary cause of death was significantly associated with season. Seasonal patterns and the cyclical changes in the environment are likely to affect the susceptibility of weka to disease. Many factors are likely contributing, including environmental conditions, immunocompetence, and seasonal behaviour changes. Weka can reproduce year-round when food supplies allow; however, most of the egg-laying happens from late winter to early summer (Bramley and Veltman 2001). Juvenile weka tend to leave their home range 40–105 days after hatching, and do not tend to establish a new territory for 3–6 months thereafter (Beauchamp *et al.* 1999). This period of migration to establish new territories coincides with autumn, potentially putting young weka at higher risk of motor vehicle trauma or being pushed further afield into less suitable environments that require them to contend with predators.

Death by infectious and/or inflammatory conditions was more frequent in the summer than other seasons. Many endogenous factors are likely to contribute to the susceptibility of weka to infectious disease, such as immunocompetence, metabolic demands such as for reproduction and growth, and physiologic stress levels. Exogenous factors such as environmental conditions, food availability, and disease exposure will also contribute. For example, *Aspergillus* spp. fungi can multiply rapidly in wet conditions as seen in spring, and then disperse into the atmosphere when conditions are dry in summer (Arné *et al.* 2021; Winter *et al.* 2022).

Death by toxic causes was more frequent in winter than autumn or summer. Given that most of the toxic deaths were related to brodifacoum ingestion, the increased frequency of death due to toxin ingestion

occurring in winter months likely coincides with regional mammalian predator poisoning operations. It is possible that adverse climactic conditions occurring in the winter months influence food supply and thereby increase the likelihood that weka will scavenge bait. The influence of food availability on toxin ingestion requires further investigation.

Reporting

The post-mortem examination and reporting process for weka included in this study did not follow a standardised procedure. The signalment of weka submitted was inconsistently stated in the reports, resulting in small sample sizes when analysing these variables. Improved reporting of important signalment information in the database would be worthwhile for future descriptive studies such as this.

Necropsy reports did not always state a definitive cause of death and often there were multiple conditions occurring concurrently, making determination of the primary cause difficult. In most cases, gross post-mortem evaluation and histopathology were performed, however the degree of ancillary testing pursued varied. In many cases, a presumptive diagnosis was determined, but the necessary ancillary testing such as microbiology or toxicology, was not pursued to confirm the diagnosis. In these cases, the presumptive diagnosis was listed as the primary cause of death, but this may have resulted in some wrongly classified causes of death. Furthermore, even when all relevant ancillary testing is pursued, sometimes a definitive diagnosis cannot be determined. Many factors could influence the extent of ancillary testing performed including time, cost, individual pathologist variability, confidence in presumptive diagnosis, availability of tests, and necessity for a definitive diagnosis.

Conclusion

This results of this study can be used to guide conservation efforts directed towards improving weka survival. The results of this study suggest that trauma may be the most significant cause of mortality in free-living weka populations. The inherent and uncertain submission biases, and low case numbers over a long time period, mean that temporal patterns and the effect of captivity status on causes of mortality should be interpreted with caution. Despite this, the study does highlight the utility of necropsy records as a means of passive disease surveillance. The quality of the data derived from necropsy reports can be improved by standardising the database entry process to ensure signalment data such as age and sex are clearly stated. Having a centralised system for post-mortem evaluation of New Zealand's wildlife

species is an invaluable tool for creating a robust long-term dataset that can be used to inform and support conservation decisions.

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No potential conflict of interest was reported by the author(s).

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References

- Alley MR, Gartrell BD.** Wildlife diseases in New Zealand: recent findings and future challenges. *New Zealand Veterinary Journal* 67, 1–11, 2019. <https://doi.org/10.1080/00480169.2018.1520656>
- ***Alley MR, Buckle KN, Tana T.** Wildlife disease surveillance. *Surveillance* 44, 21–5, 2017
- Arné P, Risco-Castillo V, Jouvion G, Le Barzic C, Guillot J.** Aspergillosis in wild birds. *Journal of Fungi* 7, 241, 2021. <https://doi.org/10.3390/jof7030241>
- Beauchamp AJ.** The decline of the North Island Weka (*Gallirallus australis greyi*) in the East Cape and Opotiki regions, North Island, New Zealand. *Notornis* 44, 27–35, 1997a
- Beauchamp AJ.** Sudden death of Weka (*Gallirallus australis*) on Kawau Island, New Zealand. *Notornis* 44, 165–70, 1997b
- Beauchamp AJ.** Population density changes of adult North Island weka (*Gallirallus australis greyi*) in the Mansion House Historic Reserve, Kawau Island, in 1992–1999. *Notornis* 47, 82–9, 2000
- ***Beauchamp AJ, Butler DJ, King D.** Weka (*Gallirallus australis*) Recovery Plan 1999–2009. <https://www.doc.govt.nz/documents/science-and-technical/tsrp29.pdf> (accessed 14 October 2024). Department of Conservation, Wellington, NZ, 1999
- Beauchamp AJ, Staples GC, Staples ED, Graeme A, Graeme B, Fox E.** Failed establishment of North Island weka (*Gallirallus australis greyi*) at Karangahake Gorge, North Island, New Zealand. *Notornis* 47, 90–6, 2000
- ***BirdLife International.** *Species Factsheet: Gallirallus australis*. <https://datazone.birdlife.org/species/factsheet/weka-gallirallus-australis> (accessed 25 November 2022). Birdlife, Cambridge, UK, 2022
- Bramley GN.** A small predator removal experiment to protect North Island weka (*Gallirallus australis greyi*) and the case for single-subject approaches in determining agents of decline. *New Zealand Journal of Ecology* 20, 37–43, 1996
- Bramley GN, Veltman CJ.** Failure of translocated, captive-bred North Island weka *Gallirallus australis greyi* to establish a new population. *Bird Conservation International* 8,

- 195–204, 1998. <https://doi.org/10.1017/S0959270900003269>
- Bramley GN, Veltman CJ.** Directions for future management of North Island weka *Gallirallus australis greyi* to improve survival and productivity *in situ*. *Bird Conservation International* 10, 241–53, 2001. <https://doi.org/10.1017/S0959270900000204>
- Carpenter JK, Innes JG, Wood JR, Lyver PO.** Good predators: the roles of weka (*Gallirallus australis*) in New Zealand's past and present ecosystems. *New Zealand Journal of Ecology* 45, 3425, 2021
- Derraik JGB, Tompkins DM, Alley MR, Holder P, Atkinson T.** Epidemiology of an avian malaria outbreak in a native bird species (*Mohouo ochrocephala*) in New Zealand. *Journal of the Royal Society of New Zealand* 38, 237–42, 2008. <https://doi.org/10.1080/03014220809510558>
- Empson RA, Miskelly CM.** The risks, costs, and benefits of using brodifacoum to eradicate rats from Kapiti Island, New Zealand. *New Zealand Journal of Ecology* 23, 241–54, 1999
- Greggor AL, Vicino GA, Swaisgood RR, Fidgett A, Brenner D, Kinney ME, Farabaugh S, Masuda B, Lamberski N.** Animal welfare in conservation breeding: applications and challenges. *Frontiers in Veterinary Science* 5, 323, 2018. <https://doi.org/10.3389/fvets.2018.00323>
- Gulliver EL, Hunter SA, Vallee E, Castillo-Alcala F.** Causes of mortality of kiwi (*Apteryx* spp.) in New Zealand: a retrospective analysis of post-mortem records, 2010–2020. *New Zealand Veterinary Journal* 71, 75–85, 2023. <https://doi.org/10.1080/00480169.2022.2154716>
- Ha HJ, Howe L, Alley MR, Gartrell BD.** The phylogenetic analysis of avipoxvirus in New Zealand. *Veterinary Microbiology* 150, 80–7, 2011. <https://doi.org/10.1016/j.vetmic.2011.01.011>
- *Hunter SA, Gibson C, Chatterton J, Ritchie J, Fraser I, Alley MR.** Non-target brodifacoum poisoning in birds on Rotoroa Island. *Kokako* 21, 24–5, 2014
- Kelly TR, Pandit PS, Carion N, Dombrowski DF, Rogers KH, McMillin SC, Clifford DL, Riberi A, Ziccardi MH, Donnelly-Greenan EL, et al.** Early detection of wildlife morbidity and mortality through an event-based surveillance system. *Proceedings of the Royal Society B-Biological Sciences* 288, 20210974, 2021. <https://doi.org/10.1098/rspb.2021.0974>
- King CM.** Contemporary observations of predation on the buff weka (*Gallirallus australis hectori*) by ferrets in the South Island during the nineteenth century. *Notornis* 64, 52–5, 2017
- *MacLean R, Beaufrère H.** Gruiformes (cranes, limpkins, rails, gallinules, coots, bustards). In: Miller R, Fowler M (eds). *Zoo and Wild Animal Medicine*. Pp 155–63. Elsevier, St. Louis, MO, USA, 2014. <https://doi.org/10.1016/B978-1-4557-7397-8.00019-0>
- *Pritchard TT, O'Connell J, Alley M, Hunter S, Argilla L, Howard P.** Wildlife disease surveillance annual report. *Surveillance* 48(3), 43–50, 2021
- *Robertson HA, Baird KA, Elliott GP, Hitchmough RA, McArthur NJ, Makan TD, Miskelly CM, O'Donnell CFJ, Sagar PM, Scofield RP, et al.** *Conservation Status of Birds in Aotearoa New Zealand*, 2021. New Zealand Threat Classification Series 35, Department of Conservation, Wellington, NZ, 2021
- *Shaw WB, Pierce RJ.** *Management of North Island Weka and Wallabies in Kawau Island*. <https://www.doc.govt.nz/globalassets/documents/science-and-technical/dsis54.pdf> (accessed 10 October 2024). DOC Science Internal Series 54, Department of Conservation, Wellington, NZ, 2002
- Watts JO, Moore A, Palmer D, Molteno TCA, Recio MR, Seddon PJ.** Trial reintroduction of buff weka to an unfenced mainland site in central South Island, New Zealand. *Austral Ecology* 42, 198–209, 2017. <https://doi.org/10.1111/aec.12422>
- Winter DJ, Weir BS, Glare T, Rhodes J, Perrott J, Fisher MC, Stajich JE, Digby A, Dearden PK, Cox MP.** A single fungal strain was the unexpected cause of a mass aspergillosis outbreak in the world's largest and only flightless parrot. *iScience* 25, 105470, 2022. <https://doi.org/10.1016/j.isci.2022.105470>