J Ornithol (2015) 156:867–875
DOI 10.1007/s10336-015-1258-6

REVIEW

Review of documented beak and feather disease virus cases in wild Cape parrots in South Africa during the last 20 years

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Received: 12 January 2015 / Revised: 13 May 2015 / Accepted: 15 June 2015 / Published online: 10 July 2015

Abstract Worldwide, there is concern about the increased prevalence of infectious diseases and their effects on biodiversity. Increasing changes in the environment, particularly changes in climatic conditions as a consequence of anthropogenic-induced climate change, are some of the factors driving this increased disease prevalence. Vertebrate taxa that appear to be most affected by these diseases are amphibians and birds, though this may be a consequence of research effort. Beak and feather disease virus (BFDV) affecting psittacine bird species is the disease of concern here. Data on BFDV incidence in wild, endangered Cape parrots (*Poicephalus robustus*) were collected opportunistically from 1992 to 2014. Data show that the disease is prevalent naturally in the wild during extreme climatic events, including drought. This stresses the birds, which may result in the expression of pathological symptoms. Juveniles in particular appear to succumb during times of drought. This has conservation implications with the impacts of extreme climatic events associated with anthropogenic-induced climate change.

Keywords Parrot · Disease · Accelerated climate change · Food availability · Food stress · Cold stress

Communicated by K. C. Klasing.

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Zusammenfassung

Übersicht dokumentierter Schnabel- und Federkrankheitsfälle bei wildlebenden Kappapageien in Südafrika in den letzten 20 Jahren

Weltweit besteht Besorgnis über die wachsende Verbreitung von Infektionskrankheiten und die Folgen für die Artenvielfalt. Unter anderem treiben zunehmende Veränderungen der Umwelt, besonders der klimatischen Bedingungen infolge anthropogenen Klimawandels, die Verbreitung von Krankheiten voran. Die am meisten von diesen Krankheiten betroffenen Wirbeltiertaxa sind offenbar Amphibien und Vögel, wobei dies auch eine Folge unterschiedlichen Forschungsaufwands sein könnte. Hier betrachten wir den Schnabel- und Federkrankheitsvirus (BFDV), der Papageienvögel befällt. Daten von BFDV-Fällen bei wildlebenden gefährdeten Kappapageien (*Poicephalus robustus*) wurden von 1992 bis 2014 opportunistisch gesammelt. Diese Daten zeigen, dass die Krankheit im Freiland naturgemäß während extremer Klimaereignisse wie Dürren auftritt. Diese belasten die Vögel, was eine Ausprägung pathologischer Symptome zur Folge haben kann. Offenbar erliegen besonders Jungvögel während Dürreperioden der Krankheit. Dies hat Folgen für den Schutz der Art, im Zusammenhang mit den Auswirkungen extremer Klimaereignisse, die mit anthropogenem Klimawandel in Zusammenhang stehen.

Introduction

One of the greatest challenges in wildlife conservation is the increase in infectious and non-infectious diseases (Deem et al. 2001). Health of wildlife is directly or indirectly related to the current environmental and anthropogenic conditions (Deem et al. 2001). In recent years, there has been increased surveillance and development of predictability models for disease detection (Boadella et al. 2011; Hampson et al. 2011). Alterations as a consequence of anthropogenic-induced climate change has increased disease incidence (Daszak et al. 1999; Patz et al. 2002; Harvell et al. 2002; Lafferty 2009). The relationship between climate change and disease is not always straightforward, with additional factors complicating the analyses. For instance, changes in land use as a consequence of climate change may alter food availability, which in turn can alter the condition of birds and their immunological response to pathogens. Of concern is that infectious diseases are among the top five causes of species extinction worldwide (Smith et al. 2006).

Globally, vertebrate taxa most affected by infectious disease appear to be amphibians and birds (Bai et al. 2012; Heard et al. 2013; Scheele et al. 2014). However, this may also reflect research effort. An example is psittacine beak and feather disease virus (BFDV), which affects psittacine bird species (Heath et al. 2004). Global distribution of avian infectious diseases is partly enabled by the migratory nature of wild birds and major trade routes (Reed et al. 2003; La Deau et al. 2007; Gaidet et al. 2012). Many pathogens have coexisted with avian populations for ages. But populations stressed by climate change, changes in food availability as a consequence of climate change, or changes in land use or habitat deterioration, may not be able to cope with increased pathogen pressure or even with the usual pressure from pathogens. Consequently, there is increased virulence of avian haemogregarine parasites with climate change as the vectors of these diseases change (Zamora-Vilchis et al. 2012). Avian diseases such as West Nile virus and BFDV are considered highly infectious and contagious among birds (LaDeau et al. 2007; Ortiz-Catedral et al. 2009). Similarly, avian malarias, haemogregarine parasites, avipox viruses, etc. affect a range of birds resulting in avian population declines (Gaidet et al. 2012; Loiseau et al. 2013). Mosquitoes are the main transmitter of the West Nile virus; this causes an increased problem as mosquitoes have the ability to infect humans as well as avian species (Dobson and Foufopoulos 2001), whereas BFDV is a viral disease that does not infect humans (Ortiz-Catedral et al. 2009). A big problem with disease detection in birds is that rarely are dead birds found in time for testing and can only be done on freshly dead birds (CTD pers. obs.).

BFDV affecting psittacine bird species is the disease of concern here. Data on BFDV incidence in wild endangered Cape parrots (*Poicephalus robustus*) were collected opportunistically from 1992 to 2014 and assessed. The Cape parrot has been shown to be a separate, full species morphologically, ecologically, and, more recently, genetically (Wirminghaus et al. 2002a; Coetzer et al. in prep.).

Psittacine beak and feather disease

BFDV has become the most crucial and common infectious viral disease found in wild and captive psittacines (Pass and Perry 1984; Rahaus and Wolff 2003; Albertyn et al. 2004; Heath et al. 2004; Katoh et al. 2010; Regnard et al. 2014a, b). Early clinical symptoms include irreversible loss of feathers, development of abnormal feathers, overgrown or abnormal beak, and symmetrical lesions on the beak. Other signs include lethargy, depression, and severe anaemia progressing to weight loss and loss of developing feathers (Ritchie et al. 2003; Heath et al. 2004). BFDV is related to diseases causing immunodeficiency (Heath et al. 2004; Ortiz-Catedral et al. 2009). The 0–3 year old juveniles' susceptibility to the disease is believed to be a consequence of the host's condition, such as age and species (Ritchie and Carter 1995), rather than the antigenic or genotypic characteristics of the virus (Ritchie et al. 2003). Furthermore, Ritchie et al. (1991) identified that birds previously exposed to BFDV were less susceptible to infection possibly due to antibody production. Antibodies against BFDV can be maternally inherited by juveniles (Ritchie and Carter 1995).

BFDV is thought to have originated in Australia (Heath et al. 2004), but it has a vast range of psittacine host populations across the globe (Rahaus and Wolff 2003; Ha et al. 2007; Varsani et al. 2011, Julian et al. 2012, Massaro et al. 2012; Jackson et al. 2014; Eastwood et al. 2015). In southern Africa, BFDV has been found in both wild and captive psittacines and is a cause for concern (Kock 1989, 1990; Kock et al. 1993; Albertyn et al. 2004; Heath et al. 2004; Kondiah et al. 2005, 2006; Regnard et al. 2014a, b). South African psittacine breeders suffer 10–20 % stock losses annually (Heath et al. 2004). Captive populations of Lilian's Lovebirds *Agapornis lilianae* are affected by BFDV and generally suffer 100 % mortality (Kock 1989, 1990; Kock et al. 1993). Examples of endangered avian species threatened by BFDV in southern Africa are the Cape parrot *Poicephalus robustus* and the Black-cheeked Lovebird *Agapornis nigrigenis* (Warburton and Perrin 2002; Heath et al. 2004; Regnard et al. 2014a, b). To date, no Greyheaded parrot *P. fuscicollis suahelicus* nor *A. lilianae* in the wild have tested positive (Symes and Perrin 2004; Mzumara 2014). Endangered parrots outside the region affected by BFDV include the Echo parakeets *Psittacula eques* in Mauritius (Kundu et al. 2012).

BFDV is of the host-specific family Circoviridae and genus *Circovirus*. It is a single-stranded piece of circular DNA and is the smallest known pathogenic virus (Ritchie and Carter 1995; Heath et al. 2004; Kondiah et al. 2006; Katoh et al. 2010). There are three isolates of the BFDV which are genetically diverse and unique to South Africa, and could have been introduced by isolates from other countries (Kondiah et al. 2005, 2006). Host specificity, as evident in isolates of Australia and New Zealand, is believed to have evolved before the virus was dispersed (Heath et al. 2004). With isolates of common ancestry dominating in South African isolates, the African origin of the ancestral strain is probable (Kondiah et al. 2006). The replication-associated protein (Rep) and the capsid protein (CP) open reading frames of the BFDV genome (Heath et al. 2004) and alignment sequences demonstrated slight variation in isolates of different regions and species (Kondiah et al. 2006). Bassami et al. (2001) believed genotypes to have adapted to species or region, developing the various strains of BFDV. However, by examining the genome sequences of several different BFDV strains found in South African psittacine birds, it was determined that recombination had occurred in most strains, though no evidence of this has been found to be adaptive or species specific (Kondiah et al. 2006). Because it lacks in adaptability, this variability was described by Heath et al. (2004) to be a result of the genetic drift of the various parrot population viral genotypes.

Immunity and vaccination

By 1995, only one strain of BFDV had been identified and used in attempts to create a harmless effective recombinant vaccine (Ritchie and Carter 1995). However, since 1995, BFDV has been found to consist of numerous strains, with the geographical distribution of the virus correlating with the trade of exotic birds internationally (Varsani et al. 2011). The Rep and CP genes have been found to genetically vary between isolates (Kondiah et al. 2006). Recombinant BFDV capsid proteins have been shown to prevent the development of BFDV in infected birds by reducing the virus's rate of replication (Bonne et al. 2009). Experimentally infected elderly birds produced antibodies against BFDV (Ritchie and Carter 1995), which caused the clumping of the red blood cells, as a result of the introduction of the antibody (Ritchie et al. 1991). Development of vaccines against BFDV is ongoing, but there are challenges with administering them to wild birds (Raidal et al. 1993a, b).

Cape parrots and BFDV

The Cape parrot is endemic to South Africa, with a distribution primarily restricted to southern mistbelt Afromontane forests in the Eastern Cape and southern KwaZulu-Natal, with a relict population in Limpopo Province (Wirminghaus 1997; Wirminghaus et al. 1999, 2000a; Downs 2000, 2005a; Downs et al. 2014). They are restricted in their global distribution by their specialized habitat and dietary requirements (Wirminghaus et al. 1999, 2000a, 2001a, b, c, 2002b; Downs 2005a; Downs et al. 2014). A decrease in the species abundance over the past 50 years, particularly in KwaZulu-Natal and the Eastern Cape, is a consequence of several factors (Wirminghaus et al. 1999; Downs 2005a). These factors are complex and include changes in their natural habitats because of fragmentation and decreased quality, food and nest site shortages, illegal trade in the birds, and disease (Wirminghaus et al. 1999, 2000a, 2001a, b, c, 2002b; Downs 2005a, b, Downs et al. 2014). Current abundance of the Cape parrots is relatively low but stable, with an estimate of less than 1600 birds in the wild (Downs et al. 2014.)

Some wild populations of Cape parrots in KwaZulu-Natal and the Eastern Cape have shown clinical symptoms of the BFDV, particularly following extreme climatic events generally associated with climate change (Table 1; Fig. 1; Heath et al. 2004; Regnard et al. 2014a, b). Climate change in South Africa typically is reflected in significantly decreased rainfall and number of rain days in autumn months and increased number of rain days in spring and summer (MacKellar et al. 2014). Furthermore, maximum temperatures have increased significantly for all seasons and increases in minimum temperatures are shown for most of the country (MacKellar et al. 2014).

One of the first Cape parrots showing clinical signs of BFDV in the wild was in 1997 and then again in 2000 (Table 1). However, it appears that the birds can carry the disease without showing external signs of ill-health, e.g., healthy-looking birds tested positive using polymerase chain reaction (PCR) (Table 1). This occurred recently when two wild juveniles tested positive, but did not show external symptoms (Table 1). The nomadic feeding behaviour of Cape parrots may be aiding the spread of the BFDV as flocks of Cape parrots congregate in feeding flocks when food availability is restricted (Symes and Downs 2002; Downs et al. 2014; Fig. 2). Though circoviral infections are prevalent in young birds (Ritchie et al. 2003), some adult birds have only expressed clinical symptoms later in life reaching up to 20 years old (Ritchie and Carter 1995). Failed attempts to induce BFDV experimentally in adult birds has led to the belief that adult birds presenting clinical signs of BFDV have been latently infected from a young age (Ritchie and Carter 1995) and that the infection manifests itself due to certain ecological stimuli, when the condition of the birds deteriorates as a consequence of social aspects or during different life stages, e.g., breeding, senescence. Because 64 % of the incidences of BFDV in our study occurred during periods of drought (Table 1), poor body conditioning caused by limited food resources may be an important factor. For example, in 2009 numbers of Cape parrots showing clinical signs of BFDV were

Table 1 Details of wild Cape parrots (*Poicephalus robustus*) showing pathological symptoms of BFDV during 1992–2014

Year	Place	Extreme climatic event	Cape parrot BFDV clinical signs/and behavioural notes	Source
1992	Creighton, KZN	Extended drought	Yellow feathers in some birds. Birds feeding on exotic fruits, e.g., syringa *Melia azedarach*	J.O. Wirminghaus and C.T. Downs
1997	Donnybrook, KZN		Bird photographed with extensive feather loss indicative of BFDV. Feeding on exotic cherries *Prunus avium*	C.T. Symes
2000, May	Umtata, Eastern Cape	Drought	Bird photographed with extensive feather loss indicative of BFDV	L. Warburton
2001, November	Creighton, KZN		Three chicks in nest in the wild tested negative for BFDV	C.T. Downs and C. Symes
2004	Donnybrook, KZN		Bird killed by car. Healthy, but tested positive. Wild bird with injuries (sub-cutaneous bruising on the upper neck area with apparent excess movement of the neck vertebrate); concluded that the bird died as result of traumatic damage to the neck area. With the exception of the injuries described above, the bird appeared to be in good condition and showed no signs of clinical BFDV (necropsy by veterinarian)	L. Warburton and C.T. Downs
2004, August	Creighton, KZN		Two wild-caught Cape parrots tested negative	M. Brown, L. Warburton and M. Gemmell
2009, January	Hogsback, Eastern Cape	Drought	Juvenile bird photographed with extensive feather loss indicative of BFDV. Feeding on exotic apples (*Malus* spp.) in garden	G. Russell
2009, May	Alice and King Williams Town, Eastern Cape	Drought	Several birds photographed with extensive feather loss indicative of BFDV. Later sampling tested birds positive	Various including P. Mather-Pike
2009, July	Lions River, KZN		Dead bird. Appeared healthy	C. and J. Lea-Cox, C.T. Downs
2009, August	Creighton, KZN	Drought	Dead bird. Tested positive	M. Arnold, C.T. Downs
2010, May	Alice and King Williams Town, Eastern Cape	Drought	Numerous birds photographed with extensive feather loss indicative of BFDV. Later sampling tested birds positive (Regnard et al. 2014)	Various including P. Mather-Pike, S. Boyes.
2011, March	Creighton, KZN	Drought	Wild sub-adult male observed with obvious plumage irregularities. Numerous yellow feathers on the scapulars and mantle. Very few feathers observed on the flanks	M. Gemmell pers. obs.
2011, April	Magoebaskloof, Limpopo Province		Birds observed to be healthy, but tested positive	R. Martin pers. comm.
2011, May	Creighton, KZN	Drought	Feather loss in several wild birds observed and photographed	N. Perrins unpublished photographs
2011, May	Valhalla Farm (Hutton) Creighton, KZN	Drought	Dead bird with heavy feather loss, tested positive	C.T. Downs
2011, May	Valhalla Farm (Hutton) Creighton, KZN	Drought	Dead bird with little feather loss. Necropsy showed severe cardiomyopathy—myocardial fibrous displacement. Tested positive	C.T. Downs
2011, May	Shangrila Farm Creighton, KZN	Drought	Lethargic juvenile male bird found with little feather loss. Died that evening. No sign of an infectious disease condition could be demonstrated with certainty. Pathology observed during necropsy, as well as histopathology, points towards a traumatic-induced incident that could be responsible for the death. Tested positive	B. Pennefather, C.T. Downs
2011, June	King Williams Town, Eastern Cape	Drought	Four birds with extensive feather loss indicative of BFDV. All tested positive	S. Boyes pers. comm.
2011, June	King Williams Town, Eastern Cape	Drought	Several Cape parrots photographed with extensive feather loss indicative of BFDV	Various
2012, February	Donnybrook, KZN	Drought	Birds with few feathers observed in wild	M. Gemmell pers. obs.

Table 1 continued

Year	Place	Extreme climatic event	Cape parrot BFDV clinical signs/and behavioural notes	Source
2013, December	Magoebaskloof, Limpopo Province		One dead wild parrot tested negative. Internal injuries (veterinarian necropsy) suggested car or telephone/power line strike	C.T. Symes
2014, January	Dargle, KZN		Two wild Cape parrots nestlings negative for BFDV	C.T. Downs
June 2014	Salt Springs Farm, Creighton, KZN		Two juvenile wild Cape parrots positive for BFDV (one with low viral load). Another juvenile tested negative. None showed external signs of disease	C.T. Downs

KZN KwaZulu-Natal

Fig. 1 Wild Cape parrots showing symptoms of BFVD in King Williams Town, Eastern Cape, South Africa in 2009 (copyright R. van Biljon)

Fig. 2 Juvenile Cape parrots feeding on pecan nuts near Creighton, KwaZulu-Natal in May–June 2014 (copyright Downs)

observed near Alice and King William's Town in the Eastern Cape, South Africa, following extensive drought (Table 1; Fig. 1; Regnard et al. 2014a, b). Additional periods of stress can include when the parrot's habitat is degraded and destroyed by means of logging and other human activities, or by the disturbance of fruiting phenological cycles due to climate change.

Colour aberrations in *Poicephalus* species have been documented previously with Cape parrots showing yellow plumage aberrations and belly colours varying from blue-green to yellow-green (Wirminghaus 1995; Wirminghaus et al. 2002a). Twenty-one percent ($n = 110$) of Cape parrots examined from museums showed signs of yellow in the plumage, which were typically single yellow feathers in the wing coverts, flight, or tail feathers (Wirminghaus 1995). Such aberrations are feathers that lack the pigment melanin. In 2010 a Cape parrot observed near Stutterheim, Eastern Cape, South Africa, was referred to as "pied" and it appeared to look healthy in terms of BFDV (Horsfield pers. comm.). It has been suggested that yellow feathers indicate the presence of BFDV (Burgess and Boyes 2010). However, although birds may show yellow feathers when sick, it does not necessarily follow that all birds with yellow feathers have the disease, given the prevalence of pigment variation discussed above. If birds have BFDV they generally appear "tatty", due to feather degradation and loss. The increased incidence of sightings of unusually coloured birds is certainly a cause for concern as are the reports of visibly scruffy and unhealthy looking birds (Horsfield pers. comm.).

Transmission of BFDV in wild Cape parrots is caused directly by contact with contaminated faeces, materials, and surfaces (Ritchie et al. 2003). Crop secretions and feather dust act as major sources of BFDV transmission by excretion (Ritchie and Carter 1995). BFDV has also been shown to be transmitted from the maternal host to a juvenile despite separation from egg laying (Ritchie and Carter 1995), though most probable transmissions are not maternal. In captive psittacines sanitation was believed to be causative of BFDV, though despite efforts to keep the captive environment clean, neonatal infection prevailed in the development of BFDV (Ritchie and Carter 1995). In wild populations of Cape parrots, the common intra-specific interactions of "family" groups or non-breeding groups may increase the transmission rate (Wirminghaus et al. 2000b, 2001b; Downs 2005a). The incidence of BFDV (based on PCR and/or clinical signs) within a wild population can range between 41 and 94 %, demonstrating the extent of infection with BFDV (Radial et al. 1993; Regnard et al. 2014a, b). Despite minimal inter-specific interactions being recorded during periods of flocking of Cape parrots at feeding sites (Wirminghaus et al. 2000b, 2001b; Downs 2005a; Fig. 2), transmission of the BFDV virus is still possible among species.

Pathology and pathogenesis

Immune systems are shaped over ecological and evolutionary time by pathogens (Horrocks et al. 2011). BFDV degrades the population of T-cells of the immune system (Ritchie et al. 2003). The depletion of the lymphoid tissues of the bursa of Fabricius in juvenile birds are caused by BFDV (Heath et al. 2004), reducing the bird's ability to defend itself from pathogens (Horrocks et al. 2011). Death is caused by secondary infection (Ritchie et al. 2003) as a result of immune suppression (Bassami et al. 2001; Kondiah et al. 2006). Furthermore, Ritchie et al. (1991) identified that birds which had previously been exposed to BFDV may be less susceptible to infection possibly due to antibody production. Gender was found not to play a significant role in the prevalence/incidence of BFDV in a captive population of psittacine birds in Germany (Rahaus and Wolff 2003). However, antibodies against BFDV can be maternally inherited by juveniles, enabling them to defend against the virus (Ritchie and Carter 1995).

BFDV within wild populations is studied in order to determine its significance to the individual and the population as a whole (Wobeser 2007). The monitoring of diseases within wild populations requires information of the populations' ecology (Boadella et al. 2011). In the management of BFDV in wild populations, logistically acceptable sampling methods are required to determine the effect of the disease on the individual and the population (Boadella et al. 2011). Such sampling needs to be completely random, with each sample representative of its subpopulation (Wobeser 1994). Collecting samples from endangered species in the wild is, however, often difficult and controversial (Pillay et al. 2010).

Despite attempts to produce a vaccine for BFDV, the implementation of vaccinating the entire Cape parrot wild population is impractical, primarily as attempts to capture the birds are stressful on the individuals, logistically challenging, and requires permits. The production of such a vaccine also requires live birds for experimentation which is limited and there are relatively few Cape parrots in captivity (Downs unpublished data). Manifestation of BFDV in older wild birds may be used as indicators of environmental change; however, clinical studies are needed to identify cause-and-effect relationships and their associations (Wobeser 2007).

Conservation and re-introduction implications of BFDV

Global conservation of wildlife is undoubtedly threatened by infectious diseases (Daszak et al. 2000). Conservation of animals can become complicated by disease, as methods to conserve a species may require moving it from its current location (Lafferty and Gerber 2002). When introducing animals back into the environment, it becomes increasingly difficult to release them if they carry diseases, as spread will most likely occur (Lafferty and Gerber 2002). With conservation projects focused on susceptibility to BFDV, the geographical range of conservation may be expanded (Kondiah et al. 2006). The subpopulations of the Eastern Cape and KwaZulu-Natal form centres for the concentration of conservation efforts for the surviving Cape parrot population (Downs 2005a; Downs et al. 2014). The conservation effort for the Cape parrot has focused on education, the enforcement of protective legislations, and drafting an action plan (Warburton et al. 2002; Downs 2005a). The trade of captive-bred Cape parrots may reduce the poaching of wild individuals; however, the presence of BFDV in captive populations is near impossible to eradicate (Ritchie et al. 2003), so aviculturists are less willing to purchase captive birds unless disease tested (various pers. comm.). Reintroduction of captive birds to their natural wild habitat is a method used by many conservation plans (Deem et al. 2011); however, it is not necessarily suitable for all species. With the incidence of BFDV in captive Cape parrot populations, the reintroduction of captive birds to existing wild populations requires rigorous testing and biological quarantine before any release into the wild can be contemplated.

Conclusions

Disease transmission raises two challenges; ecological and epidemiological. Understanding both is necessary to measure the impact of disease at the population level for species that are endangered (Ortiz-Catedral et al. 2009). BFDV incidence in wild Cape parrots show that it is prevalent naturally in the wild and that stress caused by extreme climatic events may cause the birds to exhibit pathological symptoms of the disease. This is most commonly seen during periods of drought. Juveniles in particular appear to succumb at these times. This has conservation implications with the impacts of extreme climatic events associated with global warming predicted to increase.

Acknowledgments We are grateful to all those who shared their observations with us. D. York and Molecular Diagnostic Services, Durban, South Africa, are thanked for conducting BFDV analyses. In particular, we are grateful for the contributions of B. Gardner, W. Horsfield, L. Warburton, M. Perrin, and the late O. Wirminghaus.

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