# Fijian Bats:
# Interactions between people and bats and a preliminary investigation into zoonotic pathogens

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# Abstract

Conservation is an increasingly important global crisis, especially for the conservation of keystone species such as bats. In Fiji, five of the six species of bats are considered threatened to critically endangered on the ICUN Red List. Human encroachment in wild places and habitat loss, are invariably leading to increased contact between people and wildlife. Interactions between humans and bats can be both beneficial and detrimental to each species. This pilot study was undertaken to identify and quantify these interactions in Fiji and recognise the Fijian people's perception of bats. People were interviewed across the three main islands of Fiji; Viti Levu, Vanua Levu and Taveuni. Throughout these islands, bats were generally perceived as positive. The majority of participants consume and come into contact with bats, or with their urine, faeces, blood and saliva. Young adults and men are more likely to come into contact with bats in Fiji than women. Quantifying these interactions and identifying other risk factors for bat exposure is an important step in targeting conservation efforts, community engagement and education. Through understanding these inter-species dynamics, at risk groups for possible zoonotic pathogen exposure have been identified. Education efforts towards bat conservation and public health risks can be more effectively developed when directed to at risk groups. This education material can build upon the positive perceptions surrounding bats and their importance in Fiji biodiversity.

A survey was also carried out for selected zoonotic pathogens *Leptospira* sp., *Histoplasma* sp., coronaviruses and paramyxoviruses. Pooled urine and faecal samples were analysed for selected potentially zoonotic pathogens. We identified four genetically distinct *Leptospira* sp. in urine from *Pteropus tonganus* and samples collected at a *Notopteris macdonaldi* roost site. These findings contribute new information to the understanding of leptospirosis in Fiji, which is a nationally notifiable disease with a significant disease burden. Developed with a One Health focus, this pilot study provides baseline data for current disease status and up to date advice regarding public health information, guidelines and education.

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## Ethics and permissions

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# Chapter 1 Literature Review

Bats have important roles in global ecosystems (Boyles et al., 2011; Ghanem & Voigt, 2012; Wilson & Graham, 1992) However, interactions between bats and humans creates problems for both sides (Voigt & Kingston, 2016). Bat populations throughout the world are diminishing as a result of habitat loss and change, and directly through hunting and deliberate destruction of roosting areas (Wiles & Brooke, 2009). For people, a number of zoonotic epidemics have arisen from reservoirs in bat populations (Chua et al., 2002; Clayton et al., 2013; Mackenzie et al., 2001; Wang & Cowled, 2015) ). To understand human-bat interactions and mitigate these problems, we need to understand cultural differences in the way people interact with bats (Bhattacharjee et al., 2018; Castillo-Huitrón et al., 2020; Cousins & Compton, 2005; Hoffmaster et al., 2016; Kamins et al., 2015; Kretser et al., 2009; Lim & Wilson, 2019; K. Suwannarong et al., 2020). To date, there has been little study of bats and people in the Pacific islands.

As an archipelago of over 300 islands, Fiji has a diverse range of landscapes and climates attributing to the nations biodiversity. The Fijian archipelago is an example of a remote oceanic group of islands, where the fauna have been isolated from continental populations (Gillespie et al., 2017). This means that the people, the bats and their pathogens are unlikely to have similar dynamics to other global populations. This thesis aims to carry out a preliminary investigation of the interactions of bats and people in Fiji, as well as a pilot survey for potentially zoonotic pathogens shed by bats.

## 1.1 Fijian Bats

Bats, order Chiroptera, are the only native mammal to Fiji, similar to many other islands in the Pacific archipelagos. Bats play a very important ecological role worldwide, particularly seed distribution and pollination of many plants in agroforests and agriculture (Fenton & Simmons, 2014; Francis, 2008; Kunz et al., 2011; Stewart & Dudash, 2017). In Fiji, pteropodid bats (family Pteropodidae) contribute to the dispersal of seed and pollen from 42% of rainforest plants of which 96% of these are valued by traditional landowners (Scanlon, Petit, Tuiwawa, et al., 2014). Insectivorous microbats consume a large volume of agricultural pest species and are therefore thought to play an important role in pest management (Boyles et al., 2011; Hutson et al., 2001; Rodríguez-San Pedro et al., 2020). There are six species of Chiroptera endemic to the Fiji islands - *Pteropus tonganus* (Pacific flying-fox), *Pteropus samoensis* (Samoan flying-fox), *Notopteris macdonaldi* (Fijian blossom-bat), *Mirimiri acrodonta* (Fijian monkey-faced bat), *Chaerephon bregullae* (Fijian mastiff-bat/free-tail bat), and *Emballonura semicaudata* (Pacific sheath-tailed bat) (Flannery, 1995; Palmeirim et al., 2005).

### ***1.1.1 Pteropus tonganus* (Pacific flying-fox)**

The Pacific flying-fox is a nocturnal, frugivorous species and is responsible for seed dispersal, especially long distance distribution, of many important native forest and agroforest species (Flannery, 1995; Scanlon, Petit, Tuiwawa, et al., 2014). Unlike in the Cook Islands where it shows a preference to roost away from civilization (Cousins & Compton, 2005), in Fiji the Pacific flying fox is found in large colonies roosting in urban, peri-urban and undisturbed forests (Palmeirim et al., 2005; Scanlon, Petit, & Bottroff, 2014). The most common pteropid fruit bat and native mammal in the Pacific with a distribution across 11 island nations, *P. tonganus* is listed as Least Concern on the International Union for Conservation of Nature's Red List of Threatened Species (IUCN Red List, 2020) (Carvajal & Adler, 2005; Lavery et al., 2020). Despite the extensive distribution, the population is susceptible to extreme weather events, such as local population declines and genetic bottlenecks during and after cyclones (Russell et al., 2016). Following cyclones, populations have been reported to decrease up to 80% in Tonga (McConkey et al., 2004) and 90% in Samoa (Pierson et al., 1996), and bat behaviours change due to a change in food and roost availability (Gilbert et al., 1997; Pierson et al., 1996). There is no total population estimate available, however over half the population of subspecies *P.t. tonganus* is thought to inhabit Fiji (Palmeirim et al., 2005).

### *1.1.2* **Pteropus samoensis *(Samoan flying-fox)***

On the IUCN Red List the conservation status of the Samoan flying-fox is Near Threatened and it is found in Samoa, American Samoa and Fiji. *Pteropus samoensis* is listed on Appendix I of CITES due to the commercial hunting of the species in Samoa and America Samoa for export to Guam and the Northern Marianas (Scanlon et al., 2020). The Fijian population is subspecies *P.s. nawaiensis*. This species is more dependent on forest and is found on medium to large islands in Fiji where there is established native forest (Banack, 2001). Like the Pacific flying-fox, the Samoan flying-fox is a frugivorous pteropid bat which roosts in trees alone or in small groups, or occasionally found roosting with other pteropid bats, e.g. *P. tonganus*. The Samoan flying-fox is smaller with paler (grey/white) fur around the neck and can be diurnal after cyclones (Palmeirim et al., 2005; Wiles & Brooke, 2009). Genetic analyses show both inter- and intra-archipelago variation in *P. samoensis* in Fiji and Samoa. Understanding the intraspecific genetic variation is important for conservation, understanding population dynamics and ecology as *P. samoensis* has a low likelihood of supplementing the local population (Russell et al., 2016).

### *1.1.3* **Notopteris macdonaldi *(Fijian blossom-bat)***

*Notopteris macdonaldi* is a small Pteropididae bat that roosts in limestone caves with high ceilings and wide cave entrances in Fiji and Vanuatu (Flannery, 1995). It has been found on Vanua Levu and Taveuni, however the only maternal roosts recorded are four caves on Viti Levu, Fiji – Tatuba, Wailotua, Wainibuku and Kalabo (Palmeirim et al., 2005; Palmeirim et al., 2007; Scanlon, Petit, & Bottroff, 2014). In 2008, a survey across four bat roosts (Saweni/Tatuba, Wailotua, Kalabo and Wainibuku) found each site had between ~200-2000 individuals (Scanlon, Petit, & Bottroff, 2014; Scanlon, 2009). *N. macdonaldi* is listed as Vulnerable on the IUCN Red List due to the species' limited and fragmented distribution, and projected decline (Scanlon, 2019b). The nectivorous bats are an important pollinator of several endemic forest species some of which are valued by humans e.g. *Barringtonia* spp. fruits are used as fish poison and wood for timber products; and *Dillenia biflora* has medicinal uses, is a useful timber, and is a habitat for endangered frogs (Scanlon, Petit, Tuiwawa, et al., 2014).

### *1.1.4* Mirimiri acrodonta *(Fijian monkey-faced bat)*

*Mirimiri acrodonta* is restricted to one cloud forest at narrow elevation range, Des Voeux Peak, Taveuni, Fiji and is listed as Critically Endangered on the IUCN Red List (Helgen et al., 2008). Very little is known about the behaviour, reproduction or ecology of this species which was discovered in 1978 with only six individuals being caught to date (Flannery, 1995; Hill & Beckon, 1978; Scanlon, Petit, & Bottroff, 2014). The exact diet is unknown however unidentified pollen and fruit have been found in the guano and on fur samples from a single individual (Scanlon, Petit, Tuiwawa, et al., 2014).

### *1.1.5* Chaerephon bregullae *(Fijian mastiff-bat/Fijian free-tailed bat)*

*Chaerephon bregullae* is only found on Fiji and Vanuatu and is listed as Endangered on the IUCN Red List (Waldien et al., 2019). In Fiji, it is found on 2 islands – Vanua Levu and Taveuni, however only one roost is known. Nakanacagi Cave, Vanua Levu, is the only recorded maternal colony and may represent 95% of the global population (Bat Conservation International, 2018; Scanlon, Petit, & Bottroff, 2014). These nocturnal, insectivorous microbats are the subject of the most active conservation efforts for the Chiroptera species in Fiji (Flannery, 1995; Palmeirim, 2008; Palmeirim et al., 2005; Scanlon, Petit, & Bottroff, 2014).

### *1.1.6* Emballonura semicaudata semicaudata *(Pacific sheath-tailed bat)*

In 2005, Carvajal and Adler (2005) concluded *E. semicaudata* was the second most widely distributed mammal in the Pacific across 8 archipelagos. This insectivorous microbat roosts in limestone cave dwellings or cliff over-hangings across smaller islands in Fiji (Flannery, 1995; Hutson et al., 2001). Subspecies *E. s. semicaudata* has disappeared from Samoa and America Samoa, with no recent data on the populations from Tonga or Vanuatu (Bonaccorso & Allison, 2008). Recent studies in Fiji have found that this species has undergone a range reduction and may now be extinct in Viti Levu and the Yasawa's where it was previously recorded (Palmeirim et al., 2007; Scanlon, Petit, & Bottroff, 2014). Due to this dramatic decline and extirpation from many islands, *E. semicaudata* is listed as endangered on the IUCN Red List, 2008 (Bonaccorso & Allison, 2008). However, it has been recommended (Flannery, 1995; Palmeirim et al., 2005; Scanlon, Petit, & Bottroff, 2014) that subspecies *E.s. semicaudata* be upgraded to critically endangered as the majority of caves where the species has previously been reported are now abandoned and bat detector surveys were not successful in finding roosts.

## 1.2 Interactions between people and bats

The timing of the colonisation of the Fijian archipelago by bats is currently unknown, but it predates human immigration events by several million years (Colgan & Soheili, 2017). Chiroptera are present in the fossil record (Worthy & Anderson, 2009b). The phylogeography of Fijian bats in prehistoric times may have been shaped by the Pacific's tectonic history as there have been major changes in the island arcs over this extended time frame. Fiji was first settled by Lapita roughly 2950-3050 cal. BP (Clark & Anderson, 2009b; Sheppard et al., 2015). Skoglund et al. (2016) modelled population movements including the first settlement of people in remote Oceania based on genetic characteristics. The immigration of people into the archipelago caused a wave of faunal extinctions, but there is, as yet, no evidence for the pre-historic extinction of any bat species in Fiji caused by humans (Clark & Anderson, 2009b). There is limited information available about the early interactions of bats and people in Fiji but it is likely they were a food source for early human colonisation of Fiji.

More recently, due to human encroachment and agricultural development of primary forest, there has been increased interactions between humans and bats. Interactions include hunting and consumption of bats, guano mining, human-wildlife conflicts around farming, and cave tourism (Luskin, 2010; Palmeirim et al., 2007; Scanlon, Petit, & Bottroff, 2014; Voigt & Kingston, 2016).

### *1.2.1 Hunting*

The consumption of wild animals, sometimes termed bushmeat, has historically been a vital source of protein for people, however this practice presents challenges for both humans and wildlife (Nielsen et al., 2017; Rushton et al., 2005; Willcox & Nambu, 2007). These challenges include depletion of threatened species sometimes to extinction locally (e.g. *Pteropus tokuae* in Guam (Wilson & Graham, 1992)), transmission of zoonotic diseases, and pressure on ecosystems with the loss of key pollinators and seed dispersants (Voigt & Kingston, 2016). Zoonotic diseases can be shed through bodily fluids, tissue and vectors making animal harvest and consumption a risk of exposure to zoonotic disease if present (Wolfe et al., 2005). Hunting may be small scale, only harvesting what is needed as a family or village, or larger scale, being sold in markets with a commodity chain (Kamins et al., 2011; Mickleburgh et al., 2009; Nielsen et al., 2017). Bats have historically been hunted for bushmeat in Africa, South America, Asia and the Pacific, with some countries still hunting for consumption (Mickleburgh et al., 2009; Mildenstein et al., 2016).

Studies focusing on the hunting and consumption of bat in Fiji are absent, however all survey studies of bats in the archipelago mention that it is on-going but reduced (Flannery, 1995; Palmeirim et al., 2005; Scanlon, Petit, & Bottroff, 2014). One study in the Pacific focused on this practice in Niue, where firearms are used to hunt bats, during a 2-month annual period coinciding with the fruit season. During a 1999 study, 60 hunters were interviewed reporting a combined harvest of 1155 flying foxes (*P. tonganus*) that year. This is well above the estimated 401-803 bats per annum which would be sustainable based on estimated population growth, life span, and population size (Brooke & Tschapka, 2002).

Although the practice of hunting bats for consumption has decreased and in some areas is limited only to celebratory occasions, four of the six species found in Fiji are recorded to still be consumed (Scanlon, Petit, & Bottroff, 2014). These are the Pacific sheath-tailed bat, Fijian blossom-bat, Samoan flying-fox and Pacific flying. In contrast to other pacific nations (e.g. Niue (Brooke & Tschapka, 2002), New Caledonia (Oedin et al., 2019)) where hunting of bats often involves the use of fire-arms, common hunting methods described in Fiji are with the use of sticks or stones, or smoking out cave colonies to then catch by hand (Flannery, 1995; Mickleburgh et al., 2009; Palmeirim et al., 2005; Scanlon, Petit, & Bottroff, 2014)

### *1.2.2 Guano mining*

Guano (accumulations of dried bat faeces) is often collected (or mined) for use as fertiliser (Hamilton-Smith, 1998; Sothearen et al., 2014). This practice has decreased or ceased in some areas with the availability of commercial fertilisers, however in some caves it remains a very valuable and mining is on-going (IUCNSCC, 2014; Sothearen et al., 2014). The disruption that guano mining has on roosting bats is substantial leading to population declines or cave abandonment (Furey & Racey, 2016; Hutson et al., 2001).

In Fiji, Wailotua cave is one of the five sites where *N. macdonaldi* roost. Previously a commercial guano mine was set up with iron cart tracks placed through the cave system to transport it out (Palmeirim et al., 2005; Worthy & Anderson, 2009a). This has since stopped but guano is still collected by villagers for personal use. Bat guano is also collected for personal use as a fertiliser from Nakanacagi cave (Malotaux, 2012).

### *1.2.3 Human encroachment*

As human colonisation of the Fijian archipelago has expanded, deforestation has followed, resulting in encroachment on native forests and loss of roosting and foraging habitat for bats. (Luskin, 2010; Palmeirim et al., 2005; The UNCCD National Focal Point, 2006; Scanlon, Petit, & Bottroff, 2014). However, fruit plantations can be a food source for bats. Predominant fruit plantations in Fiji include mangoes, pawpaw, breadfruit and coconut, and all are reported to be fed on by *P. tonganus*, *P. samoensis* and *N. macdonaldi* (Luskin, 2010; Palmeirim et al., 2005; Scanlon, Petit, & Bottroff, 2014; Scanlon, Petit, Tuiwawa, et al., 2014). This not only causes damage to the fruits and conflict with orchardists, but there is a high probability that the saliva, urine and faeces of bats will contaminate the fruits being picked, therefore humans can have direct contact with bat excrement posing a route for the transmission of zoonotic disease (Aziz et al., 2016).

Human encroachment on bat habitat can also be in the form of disturbance and habitat degradation (Hutson et al., 2001; Palmeirim et al., 2005; Wiles & Brooke, 2009). For example, Kalabu cave's entrance is used as a rubbish tip affecting the roosting site of *N. macdonaldi*. In the Yasawas, a key roost for *E.s. semicaudata* is now abandoned and significant graffiti is present (Malotaux, 2012; Scanlon, Petit, & Bottroff, 2014).

However, some bat species are more tolerant of human disturbance. *P. tonganus* has many reported roosts in urban or peri-urban areas which may increase direct and/or indirect contact with this species compared to a rural area where they are roosting away from villages (Palmeirim et al., 2005).

### *1.2.4 Tourism*

Bat viewing tourism provides opportunities for education and conservation initiatives to be shared with tourists and the local people (Pennisi et al., 2004). In addition, this can provide an economic benefit to the locals. It is estimated that bat viewing in the Southwestern United States generates US$6.5 million annually (Bagstad & Wiederholt, 2013). Careful planning, management and thorough impact assessments are required to avoid negative impacts of unregulated tourism (Furey & Racey, 2016).

There is minimal bat tourism advertised in Fiji. Only one company advertises a tour that includes visiting Wailotua cave to see the Fijian blossom bat (https://www.talanoa-treks-fiji.com/waterfall-cave/). Sigatoka Sand Dunes National Park has a resident bat roost in the mahogany tress and visitation to the park is possible (National Trust of Fiji Islands, 2020). Kayaking to neighbouring islands (locally known as "Bat Island") off a resort in Vanua Levu is advertised on their website however seeing the bats is not a feature (https://korosunresort.com/complimentary-activities/). A kayak site mentions "exotic birds and giant fruit bats" can be seen while travelling along a canyon however bats viewing does not appear to be the main part of the itinerary (http://www.riversfiji.com/middle-navua-river). Tours to Naihehe cave, Viti Levu, are available. This cave was believed to once house *E. semicaudata* however it is speculated that the bats abandoned the cave due to these visitations (Palmeirim et al., 2005).

## 1.3 Conservation management

The distribution and conservation status of bats in Fiji has sporadically been documented over the past 40 years. The total population of all six species is declining due to a combination of factors such as deforestation, habitat and roost degradation, roost disturbance, natural weather events (cyclones), and consumption (Flannery, 1995; Malotaux, 2012; Palmeirim et al., 2007; Scanlon, Petit, & Bottroff, 2014; Wiles & Brooke, 2009).

NatureFiji-MareqetiViti (NFMV) is the only Fijian non-government organisation (NGO) focusing on nature conservation and sustainable management (NatureFiji-MareqetiViti, 2017). NFMV projects focus on education and communication, establishing and expanding protected areas, threatened species research and conservation, sustainable management of forests, and management of invasive species. A six year project focused on bats in Fiji lead to the rediscovery of *M. acrodonta*, an updated cave inventory, and production of awareness materials on all six species. Since this project, collaboration with international researchers and community awareness projects is ongoing (Thomas, 2015) but limited material has been published in the peer-reviewed scientific literature.

As of 2014, Fiji has 48 terrestrial formally protected areas covering 488 km2 or 2.7% of its land area. Further sites have been proposed however approval documentation is unavailable/unknown (SPREP & DoEF, 2013; SPREP & NSW, 2018). Part of Nakanacagi cave, the only maternal colony of *C. bregullae*, was declared a bat sanctuary in 2018 after being purchased by the National Trust of Fiji, Rainforest Trust and Bat Conservation International. With support of Nakanacagi village and surrounds, rangers are trained to protect the sanctuary and education awareness programs are run in nearby schools (International, 2018; NatureFiji-MareqetiViti, 2018). The Rainforest Trust purchased adjoining forest to extend the protected area in late 2019. The additional 34 acres (total of 54 acre reserve) includes the rest of the cave system and surrounding forest habitat which in turn increases the protection surrounding the bats, and ensuring no further forest degradation (Rainforest Trust, 2019). Fiji has a National Protected Areas Committee (PAC) that was established in 2008 under section 8(2) of Fiji's Environment Management Act 2005, in order to advance Fiji's commitments under the Convention on Biological Diversity (CBD)'s Programme work on Protected Areas (PoWPA) (SPREP & DoEF, 2013).

In previous surveys in Fiji, recommendations have been made around cave conservation and awareness efforts such as gating off cave entrances to stop human access, limiting numbers of people on tours and torch brightness, and decreasing deforestation (Malotaux, 2012; Palmeirim et al., 2005). Villages appear to be engaged and interested with visitors that are conducting research about the bats in their area. However it is unclear if these interactions and new shared knowledge around the importance of their local species is having a lasting effect or making changes (Malotaux, 2012; Scanlon, Petit, & Bottroff, 2014).

Conservation recommendations around *P. tonganus* and *P. samoensis* focus on further research to identify how much stress current hunting is having on the population, as well as protecting primary and well-established secondary forests as this appears to be an important roosting habitat for *P. samoensis*. As the species are sometimes considered pests due to human-bat conflict around agroforests and plantations, education is important to highlight the importance of the species for seed dispersal of their crops as well as the native forests (Luskin, 2010; Scanlon et al., 2020; Scanlon, Petit, & Bottroff, 2014; Scanlon, Petit, Tuiwawa, et al., 2014; Wilson & Graham, 1992).

A special interest group, Emerging Wildlife Conservation Leaders Bat Group and Advisory Committee, in collaboration with Bat Conservation International created guidelines for minimizing the negative impact to bats and other cave organisms from guano harvesting (Hutson et al., 2001). The guidelines are broad and are not directed at any particular region as guano mining is a global practice but there are some key points and considerations designed to be adapted across multiple sites. Fiji depends on the work of local NGOs and universities for research and for advice about priority species and recovery plans for threatened and endangered species (SPREP & DoEF, 2013).

## 1.4 Bats and zoonotic disease

A zoonotic disease is a disease caused by a pathogen which is transferred from animals to humans. There are many common or well-known zoonotic pathogens such as protozoa (*Toxoplasma* spp.), bacteria (*Salmonella* spp.), viruses (Rabies), and fungi (*Microsporum* spp. causing dermatophytosis). Humans can become infected through direct contact (bitten or scratched), indirect (faecal-oral route through contaminated food, water or surfaces), and vectors (mosquitos, fleas and ticks) (Kruse et al., 2004).

Bats are known carriers of many zoonotic and potentially zoonotic pathogens worldwide (Hayman et al., 2013; Wang & Cowled, 2015). In Australasia, Pacific and South-East Asia viruses from Rhabdoviridae (e.g. Australian bat lyssavirus (Banyard et al., 2011)), Paramyxoviridae (e.g. Nipah virus and Hendra virus (Clayton et al., 2013; Field et al., 2011)), Bunyaviridae (e.g. Hantaviruses (Queen et al., 2015)), Togaviridae (e.g. Chikungunya virus (Queen et al., 2015)), and Coronaviridae (e.g. SARS-CoV-2 (Zhou et al., 2020)) families have been isolated. The two virus families this thesis will focus on are Coronaviridae and Paramyxoviridae.

The bacteria and fungi of zoonotic concern I will be focusing on in this thesis include two organisms that have been recovered from bats and their excrement; *Leptospira* spp. and *Histoplasma* spp (Dietrich et al., 2015; Fenton & Simmons, 2014; Monchy et al., 1998).

### 1.4.1 *Leptospira spp.*

*Leptospira* is a genus of spirochete bacteria with species varying in pathogenicity causing leptospirosis in mammals, including humans. Humans typically become infected via direct contact with urine of infected animals, or contact with a source of water that has been contaminated with infected animal urine (Lau et al., 2018). Infection does not always lead to clinical disease and may result in asymptomatic/chronically infected carriers excreting the bacteria in urine (Adler & de la Peña Moctezuma, 2010; Levett, 2001). A wide range of mammalian species test positive for *Leptospira* spp. (orders Rodentia, Didelphimorphia, Lipotyphla, Carnivora, Artiodactyla, Perissodactyla, Chiroptera, Primates) and are commonly identified as reservoir hosts (Desvars et al., 2011). There is evidence of *Leptospira* infection in over 50 species of bat through a variety of detection methods including serology, polymerase chain reaction (PCR) and bacterial culture (Cox et al., 2005; Dietrich et al., 2015). Field studies show the bacteria is intermittently shed or may be cleared completely after initial infection. It is unknown if any human cases of leptospirosis are due to bat-borne *Leptospira* spp. (Dietrich et al., 2015).

Leptospirosis is more common in tropical climates and is an important zoonotic disease of the Pacific Islands (Guernier et al., 2018; Lau et al., 2016). Leptospira is endemic in Fiji, the first case reported in mid 1900's (Guernier et al., 2018) with an incidence of 51.6 per 100,000 population and case fatality rate of 1.34% in 2016 (http://www.health.gov.fj/wp-content/uploads/2018/03/MoHMS-Jan-July-Report-2016.pdf). Leptospirosis is a nationally notifiable disease and the recommended response to individual cases and disease outbreaks is outlined in Fiji's Communicable Disease Surveillance and Outbreak Response Guidelines (MoHMS Fiji, 2010; MoHMS Fiji, 2016). Clinical signs include fever, headaches and myalgia advancing to renal or hepatic insufficiency. In 2016 two serological laboratory diagnostic tests were available - *Leptospira* Rapid Diagnostic Tests (SD *Leptospira* IgM) and ELISA IgM (Panbio). A positive result on either of these tests is classified as a probable case however definitive diagnosis requires further testing. For confirmation, samples are sent internationally to a laboratory with the capacity to perform PCR, isolation of *Leptospira* spp. from clinical specimens, and microscopic agglutination test (MAT) (MoHMS Fiji, 2016).

Cases of human leptospirosis are reported yearly in Fiji however outbreaks are most common during the wet season, especially after flooding events (Ghosh et al., 2010; Togami et al., 2018). Domestic animals (cattle, dogs, sheep, goats and pigs) and wild animals (mongoose, rats and mice) have tested positive to antibodies to a range of *Leptospira* serovars (Collings, 1984). *Leptospira* species are divided into antigenically distinct serovars for more accurate classification (Levett, 2001). An eco-epidemiological study found important risk factors for human infection include people living in a rural setting, poor access to clean water, close proximity to river, high rainfall, high poverty rate, presence of pigs and high cattle density (Lau et al., 2016)

### *1.4.2 Histoplasma spp.*

Histoplasmosis is a systemic fungal disease in humans caused by *H. capsulatum*, a soil saprophyte (Linder & Kauffman, 2019). Infection occurs after inhalation of the spores commonly from bird and bat faeces resulting in higher incidences in cave visitors (Jülg et al., 2008; Linder & Kauffman, 2019; Lyon et al., 2004). Immune compromised people are more susceptible to clinical disease caused by *H. capsulatum* and incidence of disease may be under reported (McLeod et al., 2011). There are eight clades of *H. capsulatum* that have a geographic distribution (Teixeira et al., 2016). This pattern of distribution is matched by skin tests in humans, which show pockets of endemic exposure and clinical disease is reported in these same areas (Chakrabarti & Slavin, 2011). In the environment, *Histoplasma* spp. have been isolated both via PCR and culture in faecal samples either directly from the species of interest (e.g. Chiroptera) or from pooled environmental samples (Holz et al., 2018; Lyon et al., 2004; Reid & Schafer, 1999).

In Asia-Pacific, histoplasmosis has been documented since 1948 in Australia and India in 1954 (Chakrabarti & Slavin, 2011). It is still prevalent throughout Asia and Australia however little to no reports are present from the South Pacific island nations, e.g. Fiji (Chakrabarti & Slavin, 2011). Systemic human mycoses in Fiji are sporadically reported/published and include chromomycosis and mycetoma (Monchy et al., 1998). As a zoonotic organism, histoplasma has the potential to cause significant illness and therefore exploring its presence in Fiji is beneficial to local public health.

### *1.4.3 Paramyxoviridae*

There have been many paramyxoviruses isolated from bat species worldwide, however the main viruses from this family which have demonstrated zoonotic potential are Hendra virus, Nipah virus and Menangle virus (Anderson & Marsh, 2015). Hendra virus, genus

*Henipavirus*, is shed by flying foxes (Pteropus spp.) in Australia and is pathogenic to horses causing a range of clinical disease with a high case fatality rate. Humans can become infected after close contact with infected horses with the disease potentially leading to death. Nipah virus, genus *Henipavirus*, causes a severe and potentially fatal disease in pigs and humans. Pigs are not always implicated as an intermediate host. There have been outbreaks in Malaysia, Singapore, India and Bangladesh (Clayton et al., 2013; Mackenzie et al., 2003). Menangle virus, genus *Rubalavirus*, caused an outbreak in Australia with pigs as an intermediate host and several *Pteropus* spp. serum were positive on virus neutralization leading to the conclusion that this was another zoonotic paramyxovirus shed from flying foxes (Philbey et al., 1998). Paramyxoviruses have been isolated or detected in bat urine, saliva, serum, uterine fluid and foetuses (Anderson & Marsh, 2015; Chua, 2003; Clayton et al., 2013; Rahman et al., 2010). To date, no paramyxovirus disease associated with bats has been recorded in Fiji.

### *1.4.4 Coronaviridae*

In humans, coronaviruses cause a range of diseases, from the common cold through to severe acute respiratory syndrome (SARS), Middle East respiratory syndrome (MERS) and COVID-19 (coronavirus disease caused by SARS-CoV-2) (Cui et al., 2019; Lim et al., 2013; Wu et al., 2020). Coronaviruses have been isolated from bat guano however virus shedding is intermittent (Dominguez et al., 2007; Drexler et al., 2011; Ge et al., 2015; Gouilh et al., 2011; Hu et al., 2017; Memish et al., 2013). The global COVID-19 pandemic caused by the novel coronavirus, SARS-CoV-2, is believed to have originated in China and may have links to the live wildlife trade (World Health Organisation, 2020; Wu et al., 2020). Although the exact transmission chain from bats to people is unknown, its recent ancestors can be found in bats (Zhou et al., 2020). Fiji has recorded 56 cases of novel coronavirus cases from international travel and subsequent community transmission (as at 19 February 2021) (http://www.health.gov.fj/wp-content/uploads/2021/02/February-19th-Updates.pdf). No other disease caused by potentially zoonotic coronaviruses have been reported in Fiji.

## 1.5 Bats as zoonotic disease vectors in Fiji

There has been little study of bats as vectors or reservoirs of zoonotic disease in Fiji. In 1971, a disease investigation into mosquito-borne infections included sera from 84 bats (unspecified insectivorous and fruit) for virus isolation and 44 bats for serology. No arboviruses were isolated however 5/44 bat sera samples had positive titres against Murray Valley encephalitis virus (Maguire et al., 1971). To date this is the only published disease investigation incorporating bats in Fiji. Due to the close proximity to Australia and South East Asia where paramyxoviruses, coronaviruses and *Leptospira* have been isolated from bats, it is important to investigate the potential presence of these zoonotic pathogens in Fiji.

I hypothesise that there will be regional variation in the presence of these pathogens, and that the persistence of these organisms may be affected by Fiji's relative geographic isolation and smaller bat population sizes. Of the organisms I propose to survey, only *Leptospira* spp. is recognised as an important zoonotic disease in Fiji. Previous studies in Fiji of the risk factors for human leptospirosis have not investigated contact with bats (Collings, 1984; Lau et al., 2016).

# Chapter 2 People and bats in Fiji – perceptions and interactions

## 2.1 Background

People's perceptions and beliefs influence their interactions and behaviours, and this is reflected in wildlife-human interactions (Knezevic, 2009; Kretser et al., 2009; Mogomotsi et al., 2020). Studying and understanding these perceptions and interactions can lead to improved wildlife conservation efforts, improved wildlife and human health, reduction of human-wildlife conflicts, and a deeper understanding of community health and growth (Carter et al., 2020; Castillo-Huitrón et al., 2020; König et al., 2020; Okech et al., 2017).

Wildlife are a potential reservoir for zoonotic pathogens, and an increase in human-wildlife contact results in a higher risk of infection if a pathogen is present (Kruse et al., 2004; Walsh et al., 2017). Bats (order Chiroptera) are known reservoirs for such pathogens and have been linked to/possibly implicated in recent disease outbreaks such as COVID-19, SARS, MERS and Hendra virus disease (Anderson & Marsh, 2015; Chua et al., 2002; Clayton et al., 2013; Cui et al., 2019; Drexler et al., 2011; Field et al., 2011; Ge et al., 2015; Gouilh et al., 2011; Jia et al., 2003; Lim et al., 2013; Mackenzie et al., 2003; Wang & Cowled, 2015; Wu et al., 2020). In these examples there is known or suspected transmission via an intermediate host from which humans come into contact and become infected (Wang & Cowled, 2015). It is also possible for infectious zoonotic pathogens to transfer straight from bats to humans – e.g. Rabies virus and possibly Ebola virus (Banyard et al., 2011; Marí Saéz et al., 2015). In Fiji, known interactions between people and bats include hunting and consumption, human-wildlife conflict around farming, bats roosting within human communities (e.g. Presidential grounds in the capital, Suva), and through cave tourism (Flannery, 1995; Malotaux, 2012; Palmeirim et al., 2005; Scanlon, Petit, & Bottroff, 2014). By quantifying these interactions and taking into consideration the demographics of the local human population, it is possible to identify groups of people at risk if zoonotic pathogens are present in bat species in Fiji.

Bats are a key bioindicator taxa given their ecological importance in ecosystem niches, susceptibility to habitat change (both human-induced and natural), climate change and fluctuations in food availability (insectivorous, frugivorous, etc.) (Jones et al., 2009). The conservation of all bat species is important for the maintenance of stable ecosystems, and for their economic value, whether directly through consumption, or indirectly through seed dispersal of agricultural crops (Boyles et al., 2011; Ghanem & Voigt, 2012; Hutson et al., 2001; Mickleburgh et al., 2009; Wiles & Brooke, 2009). In Fiji, 96% of the plant species serviced by bat species are valued by humans for economic, medicinal, and cultural uses (Scanlon, Petit, Tuiwawa, et al., 2014). As five of the six species of bats in Fiji are listed as threatened to critically endangered on the International Union for Conservation of Nature (IUCN) Red List, conservation of all species is critical (Bonaccorso & Allison, 2008; Lavery et al., 2020; Scanlon, 2019a, 2019b; Scanlon et al., 2020; Waldien et al., 2019). Population monitoring studies have identified a decrease in roosting sites and other possible threats to the Fijian bat population (Scanlon, Petit, & Bottroff, 2014). Few studies, however, have explored the details of how human-bat interactions, and the perceptions surrounding bats, may impact conservation efforts (Flannery, 1995; Malotaux, 2012; Palmeirim et al., 2005; Palmeirim et al., 2007; Scanlon, Petit, & Bottroff, 2014; Scanlon & Petit, 2015).

Over 300 islands make up the archipelago of Fiji with a population of over 884,887 (Fiji Bureau of Statistics, 2018a). Just over half the population is male (50.7%) however females account for majority (nearly 60%) of the older population (75+ years old). Over half the population (55.9%) lives in urban areas compared to 44.1% in rural. (Fiji Bureau of Statistics, 2018a). The major industries with paid employees are wholesale and retail trade, repair of motor vehicles (17%) followed by accommodation and food services, manufacturing, agriculture, forestry and fishing, and information and communication (Fiji Bureau of Statistics, 2020). In 2017, 7.8% of females were unemployed compared to 2.9% of men, with a higher rate of unemployment in urban areas (5.7%) than in rural areas (2.9%) (Fiji Bureau of Statistics, 2018b). Fijian culture is diverse with a history of being colonised by Lapita people (Clark & Anderson, 2009a), later Melanesian, then became a British colony in 1874. There are three main ethnicities – iTaukei (indigenous Fijians primarily Melanesian and Polynesian decent), Indo-Fijian and indigenous Rotuman (Stetter, 2021).

Understanding these details is important not only for bat conservation and public health, but also for engaging communities in citizen science. For example, Rego et al. (2015) studied the interactions and ideas surrounding bats in villages on the border of a biological reserve in northern Brazil. Over 90% of participants perceived bats to be negative. There was a strong belief that bats caused harm and disease, although some participants mentioned their use of bats in traditional medicine. In the Cook Islands, Cousin and Compton researched human-bat interactions, hunting pressures on *Pteropus tonganus* for consumption, as well as the perceptions from local communities (both adults and children). The study highlighted areas for targeted education efforts, identified groups interested in learning more and being involved in conservation efforts, as well as the need for (and likely acceptance of) controlled hunting (Cousins & Compton, 2005). In Fiji, there is little available information on what the local perspectives on bats are, and how this might affect their conservation.

This study aimed to investigate the perceptions of bats by people in Fiji and to quantify the reported frequency and types of interactions between bats and people. The goal of this research was to identify priority areas and approaches for education and conservation, as well as identifying at risk groups to any zoonotic diseases that may be present in Fijian bats.

## 2.2 Materials and Methods

### *2.2.1 Ethics and Permits*

This study was approved by the Fijian Ministry of Education, Heritage and Arts (MOEHA), and included letters of support from the Ministry of iTaukei Affairs, Ministry of Health, Department of Environment, University of South Pacific (USP) and NatureFiji-MareqetiViti (NFMV). MOEHA also reviewed and approved Human and Animal Ethics (RA 35/18).

Informed consent was obtained from participants prior to the interview using the specifically designed Free and Prior Informed Consent (FPIC) form (Appendix 1). This form outlined the study's purpose and methodology, the confidentiality of the participants and results, the storage and distribution of those results, and the contact details of the primary researcher and supervisors.

### *2.2.2 Participants*

Participation was restricted to adults aged 18 years or older. Interviews were undertaken in villages/communities near reported bat roosting sites. The aim was to interview an even spread of men and women with varying roles within the community. Participants were in part nominated/selected by the village chief, but were also determined by who was home at the time the village was visited, and who was sitting around at "grog time". The numbers were bolstered by interested village participants who learnt of the questionnaire via word of mouth. The risk factors for zoonotic disease exposure that were investigated included gender, age, religion, and education level. Information about an individual's status/role in the community was also collected, however, there was little consistency in the reporting, so this data was not analysed as a potential risk factor.

### *2.2.3 Location*

In accordance with the requirements of the Fijian Ministry of iTaukei Affairs, local guides were employed to assist the research group by liaising with village chiefs, translating interviews and facilitating transport. The guides were previous employees/contractors of USP and engaged through the University. The three main islands (Viti Levu, Vanua Levu and Taveuni) were chosen due to ease of access, time limitation and pre-existing contacts established by the two supporting organisations, USP and NFMV. Villages visited were selected due to proximity to known bat roosting sites (published or local knowledge). In some locations, participants were visiting relatives or had married into the village. They answered the questions as if they were in their native/mother village, thereby broadening the survey distribution (Figure 1).


*Figure 1: Map of interview locations. The physical location of the interviews (marked in blue) and the responders home location (marked in yellow).*

### *2.2.4 Survey Design*

The questionnaire was conducted as 10-15 minute face to face interviews. The questionnaire was divided into two sections; the first to identify perceptions of bats, and the second to identify interactions with bats (*Appendix 2*). Part 1 consisted of 12 questions asking how people perceived the diversity, diet, and behaviour of bats, the benefit or disadvantage of bats, their role in environment, the impact of bats, harm from bats, and consumption of bats. Part 2 comprised 17 questions regarding contact and interactions, including inquiries about injury, consumption, hunting, preparation, medicine, and guano mining, with options to identify other uses/contact with bats. The questionnaire was a mixture of multiple choice and open questions to allow both quantitative and qualitative data to be collected.

Participants were asked to provide their gender, age category, religion, region and education level to assess if these groupings are risk factors or predictors.

To decrease the language barrier, the questionnaires were translated to Bau Fijian prior to undertaking fieldwork (*Appendix 3*). Initially, questionnaires were printed out for individual participants to have the option to self-fill, however printing was stopped after the first 35 interviews due to only 1 participant wanting to self-fill and the rest wanting the interviewer to complete for them. All interviews were conducted by the primary researcher and responses were transcribed at the time. In addition, thirty-four percent of the interviews were voice recorded to ensure no information was missed. In villages, the local guide was present for translating if necessary. The fieldwork took place over a single 7-week period in August-October 2018.

### *2.2.5 Analysis*

Here we provide qualitative and quantitative analyses. Qualitative results were tabulated in Microsoft Excel then filtered in grouped into keywords, common themes and trends in responses. Quantitative results were tabulated in Microsoft Excel and analysed through R (version 3.5.2)(R Core Team, 2018) and plotted using ggplot (Wickham, 2016). We used logistic regression to model the risk factors for past and current consumption, contact and carcass preparation of bats using the glm function in the base R statistics package. The key covariates age and education were correlated so age and gender were used with and without interactions and tested the differences between the models using Akaike Information Criterion (AIC). We assumed models were different if the AIC difference ($\Delta$AIC) was greater than 2. Detailed results are in Appendix 4.

## 2.3 Results

Questionnaires were completed for 197 participants with 1 partially completed. The interviews took place in 19 villages or towns with answers relating to 49 locations (Figure 1). Of the 198 interviews 68 were voice recorded. Men represented 54.5% (108/198) of participants with the remaining 45.5% (90/198) women. The age distribution of participants is illustrated in Figure 2.

The years of education of the study participants (Figure 2) ranged from 3 years to 13+ years (participants who had completed, or were studying, a tertiary qualification or trade were recorded as 13+ years). Women had more years of formal education with 43.8% of women under 30 years of age having completed 13+ years of education, compared to 18.2% of men under 30 years of age.

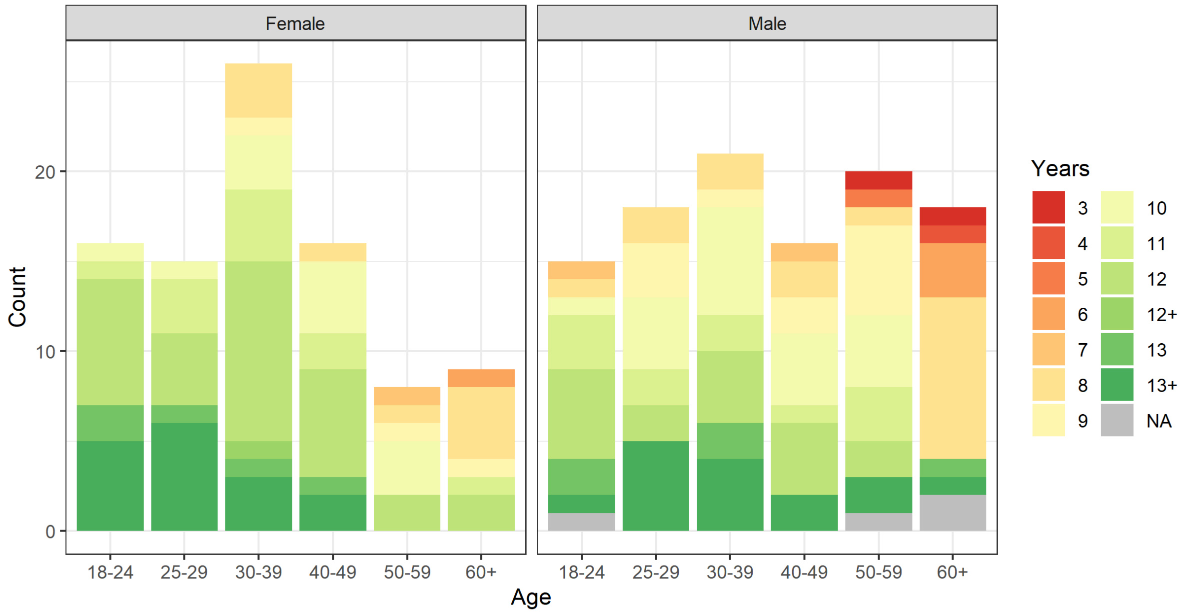


*Figure 2: Age distribution, education in years (colours) and gender of participants*

The participants reported a variety of religions that were classified into the main groupings of Catholic, 'Christian', Methodist, other Christian, Hindu or no religion. Methodist was the most common religion (51.5%) (Appendix - Table 10). Only six participants identified as a religion other than a Christian denomination (all six were Hindu). All six of these participants recorded no contact with bats, consumption, or guano mining, however 4/6 of them visit bat roost sites. It is possible that religion may be an indicator of exposure risk to bats. This may also be true of ethnicity, for although ethnicity was not specifically asked/specified in the survey, these six individuals identified as Indo-Fijian, whereas the majority of citizens are iTaukei Fijian. With so few Hindu participants, however, this observation is not of statistical significance and needs to be interpreted with care.

Some participants reported different answers for small insectivorous bats and large fruit bats, therefore the total number of answers reported varies from 197-204.

### *2.3.1 Perceptions*

#### *2.3.1.1 Bat numbers and types encountered*

Participants were asked how many types of bats they had seen and to describe the differences e.g. colour and size. Local names were frequently used, however this varied depending on location and some names were used for different species depending on the area e.g. Beka lulu on Taveuni described the Fijian Flying Fox (*Mirimiri acrodonta*) whereas on Vanua Levu this name described the Samoan flying fox (*Pteropus samoensis*) for some participants. Two or more species of bat were seen by 55% (109/198) of participants in their area, commonly the Pacific flying fox (*P. tonganus*) and the Samoan flying fox. Bat populations were perceived to be increasing in the local area by 56.9% (115/202) of participants, decreasing by 21.8% (44/202), both increasing and decreasing by 6.4% (13/202), and 14.4% (29/202) of participants saw no change in population size/numbers (Figure 3). A single participant reported no bats locally in her area so did not comment.

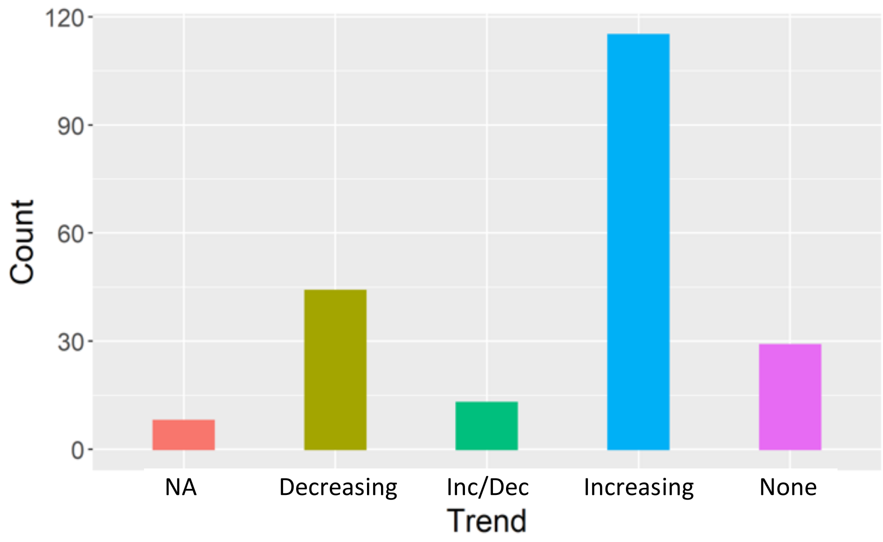


*Figure 3: Reported bat population trends –no response (NA), decreasing, both increasing and decreasing (Inc/Dec), increasing, or no change (none)*

Older participants reported "bats used to hang in the trees like chains all link(ed) up and you could take a stick and throw it at the top one so the rest all fall down." Some participants referred to recent changes since Cyclone Winston in 2016, and/or suggested there was seasonal variation. One 60+year old male participant on Taveuni commented: "Before Winston thousands and thousands (of bats), after there is not as many - people ate them all as they lost their trees and breeding places". Another male participant from the same village commented: "(After) Cyclone Winston more than 1000's of bats were killed in different villages. (People were) not choosing by size or threatened status – (it was) more than 3 months before seeing another bat. Can see from edge of village the decrease. Count the bats flying over at night time and compare. Would talk about it at grog time - the decrease and what we can do about it. Most agree to stop cutting down big trees where they rest. If (I am) asked to give advice - please stop killing bats because they are very important and inform them the importance of bats, and show them the identifications."

### *2.3.1.2 Perceptions of bats as good vs. bad*

The participants generally had a positive impression of bats with 63.1% (125/198) believing bats were good, 6.1% (12/198) said bats were bad, 29.8% (59/198) said they were both good and bad, and 1% (2/198) felt neither good nor bad.

The most common reason given for a positive impression was bats as a source of food (72.8%, 134/184). Bats are perceived to be clean, healthy, and tasty. Other reasons included bats are positive for farming and forests as they are responsible for seed dispersal and pollination (7.6%, 14/184), they signal ripe fruit (4.9%, 9/184), they provide manure for gardens and crops (2.2%, 4/184) and they can control insects (1.1%, 2/184). Bats were also perceived to be positive as they signal bad weather such as cyclones (4.3%, 8/184) and are harmless (2.2%, 4/184).

The main reason (71.8%, 51/71) for a negative perception about bats was they eat the fruit which was either destined for personal consumption or selling and therefore caused a loss of income. Other reasons included bats were noisy at night-time (8.5%, 6/71), they cause harm and bite (5.6%, 4/71), and they smell bad (4.2%, 3/71).

### *2.3.1.3 Role and influence of bats*

Responses to “What role do bats play/have in the environment?” were open and subsequently categorised into the following groupings: no role, not sure, seed dispersal/replantation/pollination, weather, alarm, manure, source of food, or other. 11 respondents identified more than one role of bats in the environment bringing the total number of responses to 211.

Just over one quarter (27.5%, 58/211) of respondents felt that bats have no role in the environment. A similar number, (27%, 57/211) identified that bats were involved in seed dispersal, replantation of fruit and forest trees, and pollination. One respondent who answered “no role” did note that “bats provide manure which is useful for farming and the garden”. Another noted they “will try to save bats rather than kill them because they are useful, make killing sustainable as (they) know they are good”. Although 15.2% (32/211) responded that they were not sure of the role of bats, many respondents who answered “no role” or “not sure” noted that bats eat fruits.

Further roles that were reported included acting as an alarm/indicator for changing weather, alarm for cyclones or alarm for waking up (9%, 19/211), providing manure/fertiliser to the environment (3.8%. 8/211), and providing a source of food for people (1.4%, 3/211). “Other” roles were identified by 16.1% (34/211) of participants including “clean up insects that try to eat the fruits”, “eat the fruits that humans waste or cannot reach”, and “attract tourism”.

Bats were perceived to have an influence (either positive or negative) on the day-to-day lives of 12.2% (24/197) of respondents. Positive reasons included source of food, source of income through tourism, insect control for their crops, and dispersing seeds for new fruit trees. Negative influences are through a loss of income from damage to fruits, and a loss of sleep due to noise at night.

#### *2.3.1.4 Bats as a cause of harm*

Bats were reported to cause harm to humans through biting and/or scratching by 55.6% (110/198) of the participants. Two participants mentioned disease in other countries but not in Fiji. Another two participants commented that bats “cause diseases - when people eat the breadfruit that the bats have eaten then they get sick in the stomach”.

Many participants made special notes on the lack of harm from bats: “they don't harm us - we harm them”, “Kind animal, only harm us if we try to do something to them but in the end they are nice.” “Animal given by God so doesn't do any harm to humans so let them live”, “Good animals. Don't harm humans.” “They are good and don't harm, just eat fruits and go on their way.”

#### *2.3.1.5 Who consumes bats as food*

When asked who consumes bats, the majority (56.6%, 111/196) of participants stated that people in rural areas or villages were the ones that consumed bats, with 14 participants further detailing that bats were consumed only by the poor or Fijians in villages. A further 17.4% (34/196) reported only iTaukei Fijians consume bats, 11.2% (22/196) reported everyone consumes bats, and 2.6% (5/196) reported that only poor people ate bats. Other responses to who used bats as food (12.2%, (24/196)) included anyone, only some people, people in the highlands/inland, or on remote islands. “Anybody can” was generally followed by “wealthy people from the city visiting a village during bat season”, “even the richest men eat bats” or “it doesn’t matter about status”. One interviewee reported that people with higher social status and men were more likely to consume bats.

It was suggested by a guide on the coral coast that those who live near the ocean have more protein options than those further inland, and so consumption would be higher in the inland villages than on the coast. The definition of coastal varies depending on the study e.g. urbanization, agriculture, tourism. In this survey we found no variation between coastal vs inland as all villages surveyed consumed bat, however quantity consumed was not analysed. Of the *P. tonganus* roosts visited, the only roosts that were close to housing were in urban areas – Suva, Nausori and a resort on Taveuni. All other roosts were further away, at least 1hr walk from villages. This could be an indicator that hunting pressures from the people have forced them into more remote areas, or it could be seasonal variation of where food is available.

#### *2.3.1.6 Other perceptions regarding bat behaviour and diet*

Along with the types of bats seen, their perceived population trends and the role of bats in the environment, participants were asked further questions regarding bat diet and activity. This was to further understand the level of knowledge of participants with respects to bat ecology and understand further about local bat behaviour. These results are summarised in the Appendix - Table 11, Table 12, and Table 13.

### ***2.3.2 Interactions with bats***

#### *2.3.2.1 Contact with bats and injury from bats*

Contact with blood, saliva, urine or faeces from a bat was reported by 51% (101/198) of participants. However, 64 participants that answered no to having direct contact with bats reported having contact in additional questions such as injury from bats, catching, preparing, and/or consuming bats, mining/using guano, and/or using bats for other uses. This increased the total to 83.3% participants having had contact with bats. Injuries, either through being bitten or scratched by a bat, were reported by 29.8% (59/198) of participants. Statistically, age and gender are predictors of bat contact, with older people (40-49 and 60+ years old) and males more likely to report contact with bats (Figure 4, Table 1).

No children were interviewed during the study however contact with bats or bat products (blood, saliva, urine and faeces) was observed during the research period. A group of 6 children were observed throwing around and playing with a freshly deceased Fijian blossom bat during one village visit. Children often accompanied the research team into caves or fruit bat tree roosts without shoes on.

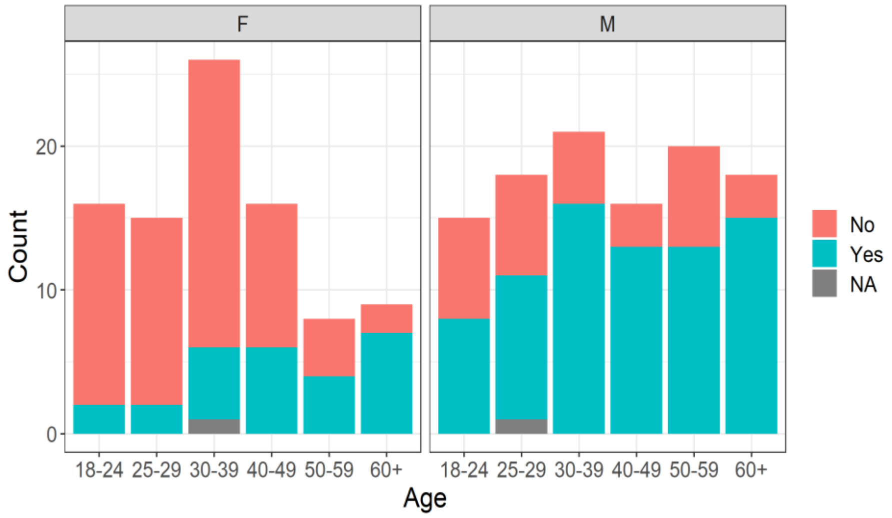


*Figure 4: Reported human contact with bats in Fiji, categorised by age and gender.*

*Table 1: Logistic regression model of contact between people and bats without age and gender interactions*

| Coefficients | Estimate (S.E) | p-value |
|---|---|---|
| (Intercept) | -1.75 (0.47) | 0.0002 |
| Age 25-29 | 0.18 (0.58) | 0.75 |
| Age 30-39 | 0.73 (0.53) | 0.16 |
| Age 40-49 | 1.32 (0.58) | 0.02 |
| Age 50-59 | 0.94 (0.59) | 0.11 |
| Age 60+ | 2.27 (0.68) | 0.008 |
| Male | 1.78 (0.34) | 1e-07 |

#### *2.3.2.2 Consumption of bats as food*

Participants were asked if they had consumed bat meat in the past, and if they currently consumed bat meat. If the answer was yes, then the quantity, frequency, source and how the meat was prepared was recorded. In the past 79.7% (161/202) of participants consumed bat meat. Age and gender were not predictors of previous bat consumption habits (Figure 5).

Bats were currently consumed by 27.5% (56/204) of responders, 24% (49/204) of responders will continue to eat bats and 48.5% (99/204) do not currently consume bat meat. Age and gender are predictors of current bat eating habits, specifically, men are more likely to eat bats than women, and older people more likely to eat bats than the 18-24 year old responders (Figure 5, Table 2).

However, these figures have fallen from 161/202 participants who said they had eaten them in the past (Figure 5). Logistic regression models with and without age and gender interactions were no different (ΔAIC <2) for either present or past bat eating. Older (40+ years) and male individuals were significantly more likely to say the do or will eat bats (Table 2), whereas only gender was significant when asked about past bat eating (Table 3).

*Table 2: Logistic regression model of current bat meat consumption without age and gender interactions*

| Coefficients | Estimate (S.E.) | p-value |
|---|---|---|
| (Intercept) | -1.3 (0.44) | 0.003 |
| Age 25-29 | 1.02 (0.54) | 0.06 |
| Age 30-39 | 0.55 (0.50) | 0.27 |
| Age 40-49 | 1.58 (0.55) | 0.004 |
| Age 50-59 | 1.19 (0.56) | 0.03 |
| Age 60+ | 1.5 (0.58) | 0.01 |
| Male | 0.78 (0.31) | 0.01 |

*Table 3: Logistic regression model of past bat meat consumption without age and gender interactions*

| Coefficients | Estimate (S.E.) | p-value |
|---|---|---|
| (Intercept) | 0.58 (0.44) | 0.19 |
| Age 25-29 | -0.18 (0.59) | 0.76 |
| Age 30-39 | 0.18 (0.55) | 0.74 |
| Age 40-49 | 0.41 (0.63) | 0.51 |
| Age 50-59 | -0.03 (0.64) | 0.96 |
| Age 60+ | 2.06 (1.11) | 0.06 |
| Male | 1.17 (0.39) | 0.003 |


Figure 5: Bat consumption by people in Fiji, categorised by past and present consumption habits, gender and age cohort.

In one village that is located near a large limestone cave home to a roost of Fijian blossom bats (*Notopteris macdonaldi*), bats are reportedly consumed more by those who are of higher status, the majority of whom are men.

Bats seem to be an important (and favoured) seasonal protein source to many communities. One woman from a village in east Viti Levu commented "In my village most people like to eat bats. Everyone is happy when someone catches one at night because it means they will have meat for the night. Other source of meat is wild pigs once every 2 weeks." It was also mentioned bats are a free source of meat: "Clean as only eat fruit. Eaten by poor people - kind of chicken so is a free chicken being caught in the night." (male, 40-49, Taveuni), "It is free meat unlike chicken, beef, etc. Very clean meat. Can't buy it." (female, 30-39, west Viti Levu).

*2.3.2.3 Other reported uses of bats*

In one village on Viti Levu, participants reported that 20-30 years ago a researcher from Europe (queried Germany) recommended they eat more bats for medicinal purposes to relieve back pain. This purpose was also mentioned by a participant on Taveuni. Two participants on Vanua Levu mentioned insectivorous bats can be used for "medicine", but exactly how or for what was not explained. Four participants report they use the faeces from Beka beka as medicine for cuts.

On Taveuni one participant reported previously using bat saliva to treat sore eyes and constipation. Another reported that the "skin of (a) bat will clean the stomach". On Vanua Levu, four participants from two villages reported that "the water which it (bat) is boiled in (is used) to cure diabetes, high blood pressure and heart problems" and "the water is medicine for heart attack, tachypnoea, (and to) drink only when (there is) a problem".

One participant saw her grandmother use the skin of the bat as a wound dressing on injured legs (after boiling it with salt). Another participant reported reading that "bat blood injected into people has medicine". Three participants who were market vendors reported "Chinese eat (the) head to be smart and for medicine", "Chinese people will buy them when they are on holidays for consumption/medicine" and "Chinese use it for medicine for asthma, and drink the blood". Other participants have heard of bats being used for medicine or the water that bats have been boiled in being consumed for medicine but did not know any further details about it.

One responder reported that the "benefit of eating bats is that they ease muscle pain" however this participant would not go out and catch one just for this purpose.

Nonmedicinal uses/symbols of bats reported included making jewellery from the jawbone, and the use of bats as a family/village emblem. Some people reported a belief that if a bat is seen flying during day and making noise, then someone is about to die.

#### *2.3.2.4 Hunting of bats*

Almost two-thirds of participants (62.8%, 130/207) had caught bats in the past. When asked if they were currently hunting, 79% reported no, 14.6% of people were currently active in bat hunting with the remaining 6.4% of participants recording that they intend to hunt bats in the future. Of the remaining 37.2% (77/207) of responders (some reporting separately for fruit bats and insectivorous bats) who reported never catching a bat, four individuals responded they would go along with the hunting party for fun (

Figure *6*).

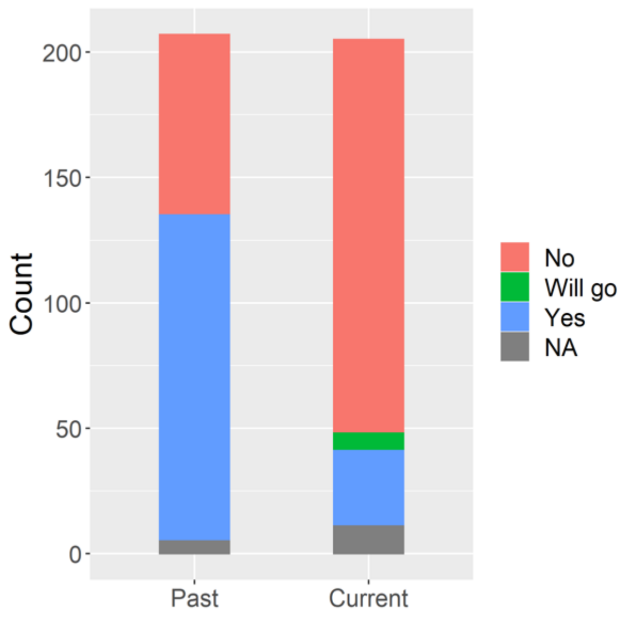


*Figure 6: Reported past and present bat catching habits*

Hunting methods for large fruit bats were limited to throwing sticks and rocks at them to knock them out of the tree or sky. In caves, bats were often caught by scaring them into nets or small dead-end chambers with the use of smoke/fire or loud noises. Comments about catching/hunting included "young kids are hunting and eating, only during the holidays and bat season (summer fruit season)." "Bats are getting harder to catch." And that its best to "carry bats in (your) armpit so (they) don't bite."

Catching and consumption of insectivorous bats has changed in one village on Vanua Levu since the nearby cave was protected as it is the only known maternal colony of Fijian mastiff/free-tailed bat (*Chaerephon bregullae*). One resident (male, aged 18-24 years) made further comments on hunting and consumption within the village: "People from Dreketi will order cooked bats and come and buy (both sizes). In the village (they) just share and don't sell. Ancestors (have been) killing bats for 100's of years, (but they) haven't been killing the little ones for the last 3-5yrs, still eat big ones every year in guava season. Personally, (I) don't want to go and kill them. Climb a tree to catch the big bat, stomp on their heads, put in bag, running between trees for 3-4hrs (at night). 4yrs ago went to different guava plantation and caught 10 x 25kg bags and then put them in the freezer to keep for later that day/night. If you see bats when out doing something else e.g.

fishing – (people) will stop everything to catch a bat. See (the big bats) in mangroves near river roosting.”

#### *2.3.2.5 Preparation of bats as food*

A majority of responders (65.5%, 131/200) reported being involved in preparing bats as food. In our statistical analysis the model without age and gender (AIC=239) was a better model ($\Delta AIC > 2$) than that with interactions (AIC 245). Age was a predictor of who prepared bats as food, with older people more likely to report being involved in preparing bats as food (Table 4).

*Table 4: Logistic regression model of the preparation of bats as food without age and gender interactions*

| Coefficients | Estimate (S.E.) | p-value |
|---|---|---|
| (Intercept) | -0.40 (0.40) | 0.32 |
| Age 25-29 | -0.21 (0.51) | 0.69 |
| Age 30-39 | 1.08 (0.48) | 0.026 |
| Age 40-49 | 1.47 (0.56) | 0.009 |
| Age 50-59 | 0.62 (0.55) | 0.25 |
| Age 60+ | 2.66 (0.82) | 0.001 |
| Male | 0.41 (0.33) | 0.21 |

In general, participants reported preparing bats weekly during bat season, boiling approximately 1-5 large fruit bats at a time. Some participants reported cooking between 30-100 per "season" (summer fruit season was referred to as bat season). Either the pot size or number of bats caught were reported to be the determining factors as to how many bats would be prepared at a time. The bats were generally deceased prior to cooking however they were not always dead when brought back to the village. Some participants reported being bitten or scratched when catching the bats out of bags to cook them.

Up to 200 Fijian blossom bats (*N. macdonaldi*) would be cooked at one time in one village but only once a year. In another village, the Fijian mastiff/free-tailed bats (*C. bregullae*) were no longer allowed to be harvested. Historically a household would cook up to 50 of these species at a time when harvested (approximately twice a year).

### *2.3.2.6 Use of bat guano as garden fertiliser*

Collecting guano for fertiliser was reported as a current activity by 5.6% (11/196) of people, with a further 7.7% (15/196) of people reported collecting in the past. A total of 13 participants were currently collecting, with the additional two people either moving into an area where guano is commonly used or who had recently learned about its use as a fertiliser (Appendix - Figure 9). In this survey, bat guano was reported to be sourced from bats living in caves with the exception of two participants who reported using or knowing of the use of guano from large fruit bats by opportunistically collecting droppings from under the fruit trees.

Residents near to Wailotua cave report in the 1930-40's there was commercial (Mr Lauchardt) guano mining in Wailotua Cave with old tracks and electrical wiring from lighting still remaining in the cave. Residents reported still collecting guano for fertiliser approximately 10-25kg 1-2 times a year for personal use. One participant used to sell the guano to nearby villages but no longer does this.

Guano is still collected/mined from the cave in Nakanacagi. On average it is collected once a year with amounts varying from as little as 1 x 10kg bag up to 20 x 25kg bags. Most participants responded that it was only for personal use but two people also reported selling guano for $7-10/bag.

One participant on Vanua Levu reported going once with a friend and collected 20 bags guano each weighing approximately 7kg from a cave. Everything collected was for his friend's private use as garden fertiliser. On Taveuni, a participant reported currently using small amounts of guano once to twice a year for compost/gardening. It was either purchased or given as a gift. They reported having seen guano in the market being sold as a fertiliser for agriculture.

#### *2.3.2.7 Visits to bat roosting sites*

Visiting bat roosts (trees or caves) was reported by 57.4% (113/197) of responders. This was for a variety of reasons including for work, interest/recreation, hunting, or because the bats lived around their house. Hunting included searching for bats specifically or opportunistically coming across bat roosts while out pig hunting, fishing in the mangroves, or prawn and eel fishing in the caves. Visits to roosts while working was when either the roosts were present in the farming area or when taking tourists to see bats either in bat caves or in tree roosts. Many participants showed genuine interest in visiting roosts to watch the bats and learn what they do during the day, or to monitor their numbers if they had not been seen in the village recently. Two participants would visit roost trees to haze or scare the bats away for making noise or stealing fruit.

#### *2.3.2.8 Actions on finding a sick or injured bat*

Participants reported that if they found a sick or injured bat, they would kill and eat the bat (28.4%, 56/197), leave it alone (25.4%, 56/197), care for it (12.2%, 24/197), or kill it to give away to someone to eat or bury/cremate the bat (9.6%, 19/197). Other answers included moving the animal, and either killing, caring, or leaving alone depending on how the bat looked. A few participants noted that they would not know if it was sick or not.

### *2.3.2.9 Current bat education and conservation*

Participants were asked if they had any further comments regarding bats at the end of the questionnaire. Most reiterated their previous answers and comments that bats were healthy, clean animals that were good for eating. Some participants, especially males, expressed interest in learning more about bats, their importance and conservation efforts: “More information for people to preserve how they breed to protect them so they can multiply” (Male, age 50-59 years, Taveuni), “Bats are getting more precious now and we should be more educated. We need to decrease development and cutting down trees as the lower soil needs more nutrient/fertiliser from bat poo.” (Male, age 60+ years, Taveuni). “Only known about it for eating. It would be good to have more education.” (Male, age 40-49 years, Taveuni). NFMV had started outreach and education programs prior to this study - “NGO's have come to do workshops to increase education about bats.” Subjectively, respondents appeared to be more aware and educated regarding the role of bats in the environment compared to those whom had not participated in these programs. Further research would need to be conducted to fully review the effectiveness of such education programs.

## 2.4 Discussion

This survey aimed to understand the perceptions of Fijian people about bats and to quantify the type and frequency of any interactions reported between bats and people. My goal in carrying out this study was to identify priority issues that may be affecting community engagement in bat conservation in Fiji. A secondary objective was to identify potential points of zoonotic disease exposure between bats and people in Fiji. The results of this study show a high frequency and variety of interactions between bats and people in Fiji. This presents numerous avenues for zoonotic disease exposure including the use of bats as food and bat guano as garden fertiliser. While there appears to be a change in many Fijian's perspectives about bats, this study highlights many sociological factors which are likely to affect the conservation of bats in Fiji.

Community engagement with wildlife has recently become a key focus point for many studies about wildlife conservation (Hacker et al., 2020; Mogomotsi et al., 2020; Saylors et al., 2021; Trewhella et al., 2005). People often have negative perceptions surrounding bats which subsequently has a negative impact on conservation efforts of the order (Musila et al., 2018). By engaging communities with their local wildlife, conservation efforts can be more successfully implemented and maintained (Hacker et al., 2020; MacPhail & Colla, 2020; Trewhella et al., 2005). In order to do so, understanding the community demographics, perceptions and values provides a better insight project design and realistic goals (Hacker et al., 2020; K. Suwannarong et al., 2020; Kanokwan Suwannarong et al., 2020). In Fiji, community engagement was key in not only securing the protection of, but in ongoing management of Nakanacagi cave - the invaluable maternal roost site of *C. bregullae* (Bat Conservation International, 2018; NatureFiji-MareqetiViti, 2018). This positive outcome (decrease in roost disturbance and preservation of habitat) should be built upon in other key roosting sites across the country. Additionally, a general increase in education surrounding bats in Fiji (leading to greater involvement in bat population monitoring).

As well as community science (MacPhail & Colla, 2020), and environmental education programs (Trewhella et al., 2005), a similar concept for locally-managed marine areas (which are already in place in Fiji (Kim et al., 2017)) could be investigated for land areas in Fiji. While bats do not appear to have a direct source of income for most participants in this study, there is a high consumption of bat meat which does appear to be a seasonal delicacy and sometimes dependency (as a means of free protein). Engaging communities in protecting key roosting sites, bat food sources and sustainably harvesting bats (and encouraging decreased consumption) are key goals in working towards bat (and habitat) conservation in Fiji.

Kim et al. (2017) investigated the socioeconomic factors affecting the sustainable use of natural resources in rural communities in Fiji. Key dynamics focused on included the communities trust in external partners (government and NGOs), individual participation in decision-making regarding natural resource management, motivations behind management practices and rules in the community (with respect to fishing), and whether fishing was a source of income and/or protein source. Combining these key factors along with the new understanding of the complex human-bat interactions and perceptions highlighted in this present study, future resource management, land protection and community engagement should have solid foundations.

Contrary to recent bat population surveys in Fiji (Palmeirim et al., 2005; Scanlon, Petit, & Bottroff, 2014), many participants perceived that bat population trends overall were increasing in recent years. However, comments from older participants indicated that the bat populations may have decreased as bats are no longer found hanging in large chains from roosting trees. Comments were also made that it is harder to find bats or catch bats now than it used to be. There are a number of possible explanations as to why more bats are being seen, and these include movement of bats into populated areas due to habitat encroachment and deforestation (Giles et al., 2018; Voigt & Kingston, 2016). This may have led to decreases in native food sources, meaning that bats are switching to agroforests or crops that are easier to access (Luskin, 2010). A population decrease was also noticed since the most recent category 5 cyclone (Cyclone Winston, 2016) at the time of the study. Other studies have monitored populations following large cyclonic storms and found the abundance and behaviour of bat species varied with the impact on primary forest, secondary forest, and species ecology; as well as short-term displacement vs long-term population counts (Gilbert et al., 1997; McConkey et al., 2004; Pierson et al., 1996; Scanlon et al., 2018; Shilton et al., 2008). Fijian bat populations were not formally monitored after this event but very high levels of bat consumption post Cyclone Winston were reported from villagers in south Taveuni. Perception of bat population trends is important as if they are perceived to be increasing in number then reducing activities that are detrimental to bat species such as hunting, deforestation, cave tourism may not be perceived as important.

With the majority of participants perceiving bats as good or both good and bad, this perspective could be reinforced and used as a focus for bat conservation. Reasons for bats being seen as good included their importance in the environment and their suitability as a food source. The role of bats as pollinators and seed dispersers in the environment was understood by some individuals or in some villages where previous community engagement, education and research had been conducted about bats. This shows that previous education efforts have increased the knowledge in this area specifically about bats however it did not necessarily translate to any proactive conservation efforts. Trewhella et al. (2005) and Hoffmaster et al. (2016) also highlight the importance of education about the role of bats in the environment and how bats can benefit people may increase the overall positive perception of bats.

Bats are often perceived negatively for either being directly harmful to humans, or indirectly through damage to fruit crops subsequently resulting in loss of income (Aziz et al., 2016; Kingston, 2016; Musila et al., 2018; K. Suwannarong et al., 2020). In this study, just over half of the participants reported bats can harm humans through biting or scratching. Even though people recognised that bats can cause harm, this did not appear to influence their interactions with bats such as catching, or intent to pick up and eat a sick bat if one was found. Similar behaviours were also reported in Ghana, where despite the risk of contracting Ebola Virus, bats were still being caught, sold and consumed (Lawson et al., 2019). The consumption of fruit crops by foraging bats was a main reason why people perceived bats to be negative. Income loss was not investigated in this study nor was it mentioned as a direct effect from the bats by the participants.

It is important to encourage positive perceptions when highlighting the benefit of bats and working towards conservation of a species, however bats can pose potential risk of disease to humans (Maurice et al., 2017). This study has highlighted an interesting conundrum for conservationists, where part of the positive perception of the Fijian bats is that they are seen as a “fresh and clean” food source. Conservationists might discourage consumption of the bats by educating people about the zoonotic disease risks associated with bat contact and consumption, however this risks tainting people’s perception of the bats and may lead to increased pressure on roosts and foraging habitat. The negative effect on bat conservation associated with a fear of zoonotic disease has been demonstrated in Australia in relation to Hendravirus, where bat roosts have been deliberately destroyed to reduce perceived disease risks around horse stables and paddocks (Edson et al., 2015;

Kung et al., 2015; Walsh et al., 2017). In Kenya, Bat roosts have also actively been disturbed or bats killed due to negative perceptions surrounding bats, retaliation to crop damage, or myths and beliefs about bats and disease (Musila et al., 2018).

Zoonotic diseases from bats may be spread via direct contact with saliva, blood, urine, faeces or birth products, or indirect routes through arthropod vectors (Kruse et al., 2004). This survey asked participants about direct contact with saliva, blood, urine and faeces, as well as identifying other opportunities for exposure – hunting, consumption, guano mining, and visiting roost sites. Some participants also reported other forms of contact such as medicine and jewellery. These routes have previously been reported (Palmeirim et al., 2005; Scanlon, Petit, & Bottroff, 2014) however never quantified or explored which is especially useful in determining whom is at risk of exposure to a zoonotic disease, if present, in bats in Fiji. This study identified that age and sex are predictors of contact with bats with older people and males more likely to have contact with bats. With regards to preparation of bat meat – older people are more likely prepare bat than younger, especially people aged between 40-49 and over 60 years of age.

Consumption of bat meat in Fijian villages appears to be common with more than 79% of participants reporting having eaten bat in the past. This has decreased to 51.5% of participants currently consuming or will consume bat meat in the near future. Age and gender are predictors of current bat consumption, with men more likely to eat bats than women as well as people aged over 24 years of age. These findings are similar to bat consumption in Ghana (Lawson et al., 2019) and Thailand (Kanokwan Suwannarong et al., 2020). This decrease in bat consumption is in line with a decrease in people currently hunting/catching bats. This is likely due to frequent reporting of bats getting harder to hunt, understanding of the importance of the bats in the environment and therefore not killing as many, legal protection over a cave population, and also of a general population drift of people moving away from the villages.

Unlike some countries (Kamins et al., 2011; Mickleburgh et al., 2009), bats are not readily sold in markets in Fiji, rather caught for personal or village consumption. Consumption of bat meat was generally reported as seasonal and associated with positive comments of being “tasty, clean and healthy” but it may also be an important source of protein for some villages. The demographics in this study were not comprehensive enough to draw conclusions on whether rural vs urban, or coastal vs inland inhabitants were more or less likely to consume bat meat. Understanding the traditional uses and on going importance of bats as bushmeat is important to navigate the sensitive topic of decreasing consumption to conserve bat populations (Mickleburgh et al., 2009; Rushton et al., 2005).

Globally, the use of bats for medicinal purposes is not uncommon. A review by Mildenstein et al. (2016) identified that countries in East Asia, North Africa, South Asia, South East Asia and sub-saharan Africa have been recorded to use bats for both food and medicine. In Fiji, medicinal use of bats has not been recorded as a common practice and prior to this study has only been mentioned once in published data (Scanlon, Petit, & Bottroff, 2014). Through questionnaires, it was found that while medicine is not often the primary use of bats, medicine or medicinal benefits from bats were perceived such as relief from muscle/back aches, treatment of high blood pressure and heart issues. The importance of understanding what bats are used for, and the means of contact that people have with them, is essential when developing education, conservation strategies, and to assess the risks people may have to exposure to zoonotic disease.

The main limitation in this study was sampling/participant bias. Participants were either nominated by a village chief (possibly a subsection of the village was therefore targeted), volunteered (and were more willing to elaborate on answers or provide additional information), or were the vendors in markets free to talk at the time rather than a pre-calculated subsection of the population. Participation was also limited to adults and therefore no conclusions can be made regarding the perceptions and interactions of bats and minors, or risk factors. Most interviews took place in villages close to bat roosting sites or market places with fruit and vegetable vendors, therefore there was already a potential bias towards bat interactions. It can be argued though that as this pilot study was designed to quantify these interactions, focusing time and resources on communities/populations more likely to be exposed to bats provided an in depth understanding. There were a few interviews where translation was required for >50% of the interview and it can not be confirmed how the questions were asked, or if respondents were lead to the answers. Other limitations included length of study period, personnel support physically collecting data, financial constraints, transport limitations, and permission delays. Despite limitations and challenges, this pilot study provides the first quantitative and qualitative study of interactions between people and bats in Fiji leading to the identification of risk factors for bat contact, consumption, and preparation, as well as highlighting areas for potential bat conservation interventions and measures.

The importance of understanding the level of knowledge about a focal species for conservation efforts is vital for ensuring that these efforts are efficient and effective (Carter et al., 2020; Castillo-Huitrón et al., 2020; Trewhella et al., 2005; Voigt & Kingston, 2016). Although participants were asked to comment on population trends, this study did not cover or monitor the populations of the six species present in Fiji. Baseline data about the distribution of the six species of bats in Fiji has been gathered by Palmeirim et al. (2005) and Scanlon, Petit and Bottroff (2014) however there is an opportunity for community engagement and citizen science for ongoing monitoring of population trends, activity and diet.

## 2.5 Conclusion

Through face-to-face questionnaires, this study identified complex human-bat relationships and interactions, identified that potential at risk groups for exposure to zoonotic disease from bats are present, and highlights areas for targeted education efforts towards bats and conservation. Overall, the perception of bats in Fiji by participants in this study are positive but the persistent use of bats as food creates a difficult conundrum for bat conservation. This positive attitude can be used for future education and conservation efforts but if zoonotic diseases are present in Fijian bats, it will be important to navigate how this is reported to the wider community to not create a negative idea surrounding bats as is the case in many countries. If Fijian bats carry zoonotic pathogens, this study has identified many potential routes of exposure of Fijian people to zoonotic disease. Highlighting how disease is spread, how to decrease possible exposure and as well as the benefits of bats to the community and environment are key messages to safeguard public health and to also improve bat conservation in Fiji.

# Chapter 3 A survey for selected zoonotic diseases in the pooled urine and faeces of Fijian bats

## 3.1 Background

Bats are widely implicated as a reservoir of many zoonotic diseases and a primary source of infectious disease outbreaks worldwide. In Australasia and the Pacific, bats have been found to shed a number of viruses with zoonotic potential, occasionally leading to epidemics e.g. Rhabdoviridae, Coronaviridae, Paramyxoviridae, Bunyaviridae, and Togaviridae (Mackenzie et al., 2003; Mackenzie et al., 2001; Wang & Cowled, 2015). Coronaviruses and coronavirus-like viruses (e.g. Severe Acute Respiratory Syndrome (SARS) and Middle Eastern Respiratory Syndrome (MERS)) have been isolated from bat guano (Annan et al., 2013; Dominguez et al., 2007; Ge et al., 2015; Gouilh et al., 2011; Memish et al., 2013). Paramyxoviruses are ubiquitous pathogens with a variety of host species however two zoonotic henipaviruses (Hendra virus and Nipah virus) have resulted in human fatalities. The viruses are believed to have spread from bats to horses and pigs respectively and then on to humans. Paramyxoviruses have been isolated from bat urine (Anderson & Marsh, 2015; Chua, 2003; Chua et al., 2002; Clayton et al., 2013).

Bats are also known to carry zoonotic bacteria such as *Leptospira* spp. and fungi such as *Histoplasma* spp. which can cause significant illness in humans and animals (Dietrich et al., 2015; Lyon et al., 2004). *Leptospira* spp. are spirochete bacteria that often replicate in the kidneys of mammals and are then excreted in urine (Lau et al., 2018). Rodents and domesticated livestock are commonly identified as an animal source of infection however *Leptospira* spp. have also been isolated from bat urine (Cox et al., 2005; Tulsiani et al., 2011). Fiji has one of the highest incidences of morbidity and mortality from leptospirosis recorded in the Pacific region and these rates are thought to be under reported (Lau et al., 2016).

*Histoplasma capsulatum* is the pathogenic fungi causing histoplasmosis – a systemic disease in humans often presenting with respiratory symptoms due to inhalation of the conidia. The dimorphic fungus is found in damp environments/soil enriched with bird and bat faeces throughout the Americas, Africa, Asia and Oceania (Linder & Kauffman, 2019). Recently human cases have been reported from both cave visitors (researchers and tourists) as well as researchers at cave entrances (Jülg et al., 2008; Lyon et al., 2004). In the available literature there are no reports of histoplasmosis in Fiji (Chakrabarti & Slavin, 2011; Monchy et al., 1998).

There are six species of bats in Fiji - *Pteropus tonganus tonganus* (Pacific flying-fox), *Pteropus samoensis nawaiensis* (Samoan flying-fox), *Notopteris macdonaldi* (Fijian blossom-bat), *Mirimiri acrodont* (Fijian monkey-faced bat) *Chaerephon bregullae* (Fijian free-tailed/mastiff bat) and *Emballonura semicaudata semicaudata* (Pacific sheath-tailed bat) (Palmeirim et al., 2005). The distribution and conservation status of bats in Fiji has sporadically been documented over the past 40 years. Due to human encroachment and agricultural development of primary forest, there is potentially an increase in interactions between humans and bats. In Fiji, reported interactions between humans and bats include hunting and consumption of bats as food, mining of bat guano, cave tourism and human-wildlife conflicts around farming (Flannery, 1995; Mickleburgh et al., 2009; Palmeirim et al., 2007; Scanlon, Petit, & Bottroff, 2014).

To date there has been no disease investigations focusing on or including bats in Fiji. A single study in 1971 investigating arboviruses found antibodies to Murray Valley Fever in 44/84 bats sera sampled (Maguire et al., 1971). In this study, I aimed to investigate the presence or absence of selected potential zoonotic pathogens (*Leptospira*, *Histoplasma, Paramyxovirus* and *Coronavirus*) in urine and guano of Fijian bats.

## 3.2 Materials and Methods

### *3.2.1 Ethics and approval*

This study was approved by the Fijian Ministry of Education, Heritage and Arts (MOEHA), and included letters of support from the Ministry of iTaukei Affairs, Ministry of Health, Department of Environment, University of South Pacific (USP) and NatureFiji-MareqetiViti (NFMV). MOEHA also reviewed and approved Human and Animal Ethics (RA 35/18).

Permission for access to individual collection sites was granted by the landowner, caretaker or village chief where applicable.

### *3.2.2 Urine and guano collection*

Site selection was guided by previous studies identifying where roosting sites were (Figure 7) as well as input from collaborators USP and NFMV. Time, site accessibility, weather and financial availability also influenced the final locations.

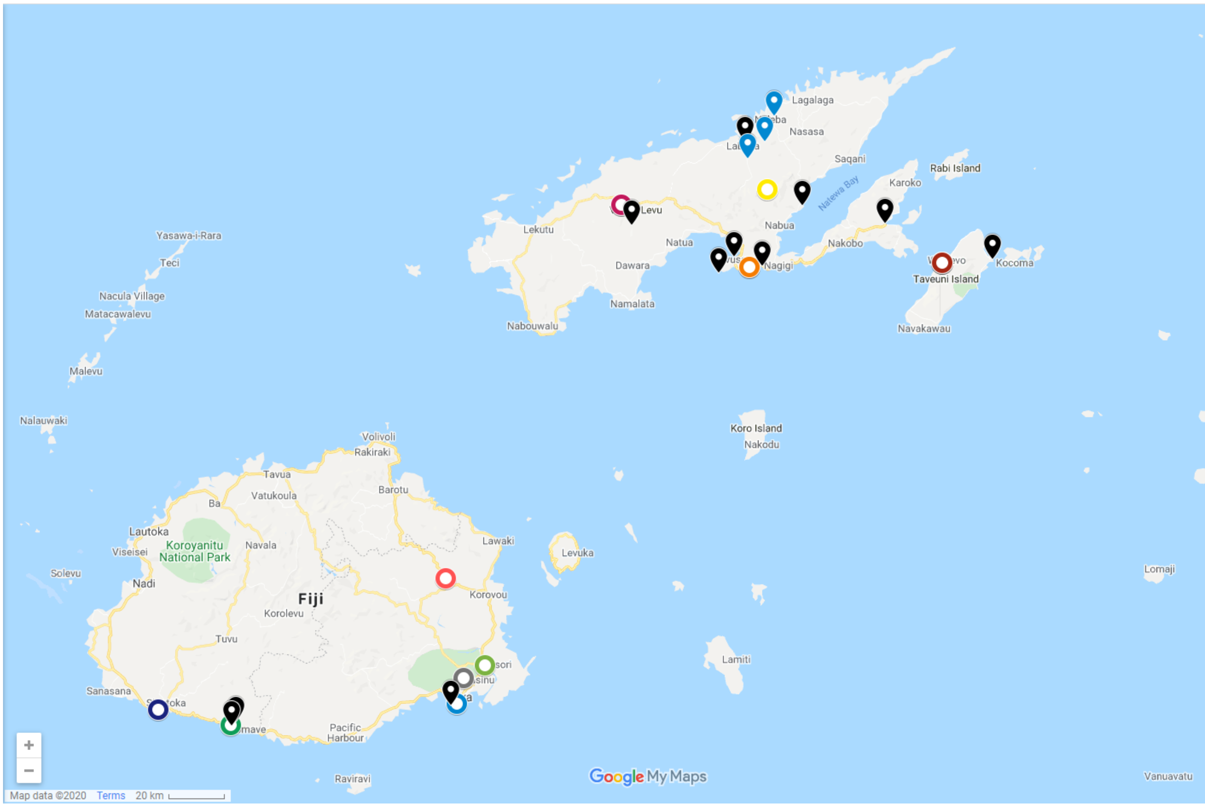


*Figure 7: Visited roost sites across Viti Levu, Vanua Levu and Taveuni: Coloured circles - urine and faecal sample collection sites (colour correlates to name of site – see Table 5), Black pins – abandoned roost sites*

*Table 5: Bat roosting sites sampled by location (coloured to match Fig.), species visually identified (ID'd) (PFF – Pacific flying fox, FBB – Fijian blossom bat, FFTB – Fijian free-tailed bat), Estimated bat population count based on photos of the sites and counts at the time of collection, and the number of urine and faecal samples collected*

| **Location** | | **Bat Sp. Visually ID'd** | **Estimated pop. Count** | **No. urine samples** | **No. faecal samples** |
|---|---|---|---|---|---|
| Viti Levu | Arboreal 1 | PFF | 40-60 | 11 | 11 |
| | Arboreal 2 | PFF | 20 | 2 | 9 |
| | Arboreal 3 | PFF | 80-100 | 1 | 9 |
| | Arboreal 4 | PFF | 150-200 | 11 | 11 |
| | Arboreal 5 | PFF | 150-200 | 11 | 11 |
| | Cave | FBB | Not counted | 12 | 12 |
| Vanua Levu | Arboreal 1 | PFF | 100-120 | 3 | 8 |
| | Arboreal 2 | PFF | 250-300 | 8 | 9 |
| | Cave | FFTB | Not counted | 10 | 10 |
| Taveuni | Arboreal | PFF | 400-500 | 9 | 8 |
| **10 sites** | | **3 spp.** | | **78** | **98** |

Fieldwork and samples were collected from late August to early October, 2018, with a total of 15 sampling nights. A total of 175 samples were collected across ten sites – six on Viti Levu, three on Vanua Levu and one on Taveuni (Table 5). A further 17 sites were visited where roosts had previously been identified/reported/recorded but they were abandoned or the bats had moved further away where access was limited – four sites on Viti Levu, ten sites on Vanua Levu and three sites on Taveuni (marked as black pins Figure 7).

Tree roosts of *P. tonganus* accounted for eight of the sites sampled, and six were visited prior to sampling to plan the timing of collection and access to ensure disturbance was minimised and maximise samples collected. It was not possible to visit the other two sites prior due to access and timing of travel to and from the locations. Thick plastic sheets measuring between 2m x 2m up to 4m x 2m were laid underneath the area of the roost tree with the highest density of roosting bats within an hour of sunset. If sheets could not be laid on the ground due to slope or undergrowth, they were tied as taut as possible to trees. Each sheet was sprayed with 70% ethanol and air dried. Occasionally a sheet would be reused after being washed, air dried in full sun, sprayed with ethanol and air dried, and repeated. This would only occur once per sheet if required (due to remote location or availability of materials).

Faecal and urine samples were collected one to two hours after sunrise. Samples were collected into 5mL cryovials prefilled with 2mL RNAlater® (Ambion™). Sample volume did not surpass the 2mL volume of RNAlater® to ensure a minimum dilution of 50:50. Urine samples were collected using a 3mL disposable plastic pipette if enough of a droplet was available otherwise sterile cotton tip swabs were soaked in urine then placed into the collection vial. Faecal samples were collected using sterile cotton tip swabs.

Personal protective equipment consisting of disposable gloves, face masks and glasses were worn during sample collection.

Manufacturer guidelines for sample storage in RNAlater were followed where possible (Life Technologies Corporation, 2011). Samples were stored at room temperature (ranging 22°C to 30°C) until access to a refrigerator was possible (2-8°C) which was a maximum of 9 days (Vanua Levu Cave). Storage at 25°C for up to 7 days has minimal sample degradation where sample degradation may occur after 14 days (per. Manufacturer guidelines). In the case of samples from Taveuni Arboreal, these samples were refrigerated within 4 days of collecting for a period of 48hrs however they were then back at room temperature for 9 days until access to a refrigerator was possible again. If possible, refrigerated samples were placed on ice during transport between locations. All samples were then imported into New Zealand to the MEpiLab, Hopkirk facility, Massey University under Biosecurity Authority/Clearance Certificate B/2018/323072, permit number 2018067387.

### *3.2.3 Laboratory analysis*

#### *3.2.3.1 Leptospira spp.*

After centrifugation (16000xg for 3 minutes), deoxyribonucleic acid (DNA) from 1mL of pelleted urine was extracted using a QIAamp DNA Mini Kit following manufacturer instructions. DNA was stored at -80˚C immediately following extraction until analysis. Conventional polymerase chain reaction (PCR) was carried out in 20 µL volumes using

5x HOT FIREPol PCR MasterMix (Solis BioDyne), and 1 μL of each (inner) primer (10mM) was combined with 2 μL extracted DNA, see Table 6 for conditions and primer sequences.

*3.2.3.2 Histoplasma*

DNA from approximately 200 mg faeces was extracted with a Zymo Quick-DNA™ Fecal/Soil Microbe Miniprep Kit following the manufacturer instructions. DNA was stored at -80˚C immediately following extraction until analysis. Semi nested and nested PCR was carried out in 20 μL volumes using 5x HOT FIREPol PCR MasterMix (Solis BioDyne), 1 μL each (inner) primer (10mM) was combined with 2 μL template (extracted DNA or PCR product from outer primers). In the case of internal transcribed spacer (ITS) primers, outer PCR product was diluted 1:20 before amplification with inner primer sets (Table 6).

*3.2.3.3 Paramyxovirus*

Ribonucleic acid (RNA) from urine was extracted with Roche High Pure Viral Nucleic Acid Kit. Briefly, 200 μL urine in RNAlater sample was added to 0.5 mL phosphate-buffered saline (PBS) and incubated for 1 hour at 4˚C. Following centrifugation (6,000xg for 5min) 450 μL of supernatant was filtered through a 0.45μM syringe filter resulting in a 200μL sample for extraction following the manufacturer instructions. RNA was stored at -80˚C immediately following extraction until analysis. Reverse transcription (RT) PCR was performed in 25μL volumes with Superscript™ III two-step RT-PCR system with platinum™ taq DNA polymerase kit using 11μL of DNAse treated (Invitrogen DNA-free™ DNA Removal Kit) sample and 1μL each (outer) primer (10mM). RT-PCR conditions are summarized in Table 6. For amplification of the inner PCR products, 4μL of 5x HOT FIREPol PCR MasterMix (Solis BioDyne) was combined with 1μL each (inner) primer (10mM) and 2μL product from the RT-PCR in a 20μL reaction volume and the same PCR conditions were used.

*3.2.3.4 Coronavirus*

RNA from approximately 200mg faeces was extracted with Roche High Pure Viral Nucleic Acid Kit as described for paramyxovirus (above) following kit instructions. RNA was stored at -80˚C immediately following extraction until analysis. Nested RT PCR was performed as described for paramyxovirus (above) with the primers and conditions outlined in Table 6.

*3.2.3.5 Host DNA*

To confirm the presence of host species in the samples, extracted DNA from faeces was tested by Cytochrome c oxidase I (COX1) gene PCR using LCO1490 and HCO2198 primers (Folmer et al., 1994).

*3.2.3.6 PCR validation*

In the absence of suitable positive control material, DNA was synthesized with binding sites for the primers used in Coronavirus, Paramyxovirus and Histoplasma amplifications (Table 6). Using the NEB PCR Cloning Kit from New England BioLabs and TOPO TA Cloning Kit from Invitrogen copies of the synthetically generated DNA were cloned and then quantified by QuBit. Samples were serially diluted and amplified using primers in Table 6 to determine limit of detection and sensitivity of PCR tests. *Leptospira* positive controls were available from *Leptospira* cultures previously extracted in the MEpiLab.

*3.2.3.7 Sequence and phylogenetic analysis*

All PCR products were visualised by gel electrophoresis on 1% agarose gels run at 70V for 60 minutes (BioRad Gel Doc). Successful PCR products were cleaned up by gel excision and sequenced in both forward and reverse orientation at Massey Genome services using Applied Biosystems Inc. ABI 3730 capillary instrumentation.

Sequences were assembled in Geneious using denovo assembly to align forward and reverse readings. Consensus sequences were generated and used for phylogenetic analyses. Additional *Leptospira* glmU sequences were sourced from the NCBI database and aligned with our study sequences using MAFFT software. A phylogenetic tree was generated using PHYML 3.0 (Guindon et al., 2010), with parameters determined by

Smart Model Selection (SMS) (Lefort et al., 2017) and branch support using aLRT SH-like method (Anisimova & Gascuel, 2006). Tree annotations and edits were produced in Evolview v3 (Subramanian et al., 2019) (Figure 8).

*Table 6: Summary of PCR for each pathogen tested (Coronavirus, Paramyxovirus, Histoplasma and Leptospira) as well as host bat DNA*

| Pathogen | PCR Type | Locus | Amplicon size | Primer Sequences | PCR conditions | Reference |
|---|---|---|---|---|---|---|
| Coronavirus | RT Nested | RNA-dependent RNA polymerase (RdRp) | 400 | COR-F1: CGT TGG IAC WAA YBT VCC WYT ICA RBT RGG | RT 45°C for 30 min, 94°C for 2 mins followed by PCR 95°C for 15 min; 15 cycles at 95°C for 30 s, 65°C for 30 s (−1°C/cycle), and 72°C for 45 s; 35 cycles at 94°C for 30 s, 50°C for 30 s, and 72°C for 45 s; and 1 cycle at 72°C for 5 min. | (Quan et al., 2010) |
| | | | | COR-R1: GGT CAT KAT AGC RTC AVM ASW WGC NAC NAC ATG | | |
| | | | | COR-F2: GGC WCC WCC HGG NGA RCA ATT | | |
| | | | | COR-R2: GGW AWC CCC AYT GYT GWA YRT C | | |
| | | | | | | |
| Paramyxovirus | RT Semi nested | RNA polymerase L gene | 650 | PAR-F1: GAA GGI TAT TGT CAI AAR NTN TGG AC | RT 45°C for 30 min, 94°C for 2 mins followed by PCR 94°C for 15 min and then 40 cycles at 94°C for 15 s, 48°C for 30 s, 72°C for 30 s, and a final extension at 72°C for 7 min. | (Tong et al., 2008) |
| | | | | PAR-R: GCT GAA GTT ACI GGI TCI CCD ATR TTN C | | |
| | | | | PAR-F2: GTT GCT TCA ATG GTT CAR GGN GAY AA | | |
| | | | | PAR-R: GCT GAA GTT ACI GGI TCI CCD ATR TTN C | | |
| | | | | | | |
| Histoplasma (1) | Conventional Semi Nested | H antigen gene | 439 | HC2: GCGGGGTTGGCTCTGCTCT | 95°C for 15 min; 35 cycles of 94°C for 1 min, 59°C for 1 min, and 72°C for 1 min; and a final extension at 72°C for 10 min. | (Bracca et al., 2003) |
| | | | | HC3: TTGGAAACCCCGGGCTTG | | |
| | | | 330 | HC2: GCGGGGTTGGCTCTGCTCT | | |
| | | | | HC1: TCATAGTAGGCTGTTCACCCCCG | | |
| | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Histoplasma (2) | Conventional Nested | Internal transcribed spacer region | 600 | ITS-1: TCCGTAGTAACCTGCGG | 95°C for 15 min; 40 cycles of 95°C for 1 min, 55°C for 1 min, and 72°C for 1 min; and a final extension at 72°C for 10 min. | (Reid & Schafer, 1999) |
| | | | | ITS-4: TCCTCCGCTTATTGATATGC | | |
| | | | 400 | HC-1: GGAGCCTCTGACCGGGAC | | |
| | | | | HC-2: GCACGTCCCACCGGTCAG | | |
| | | | | | | |
| *Leptospira* | Conventional PCR | glmU | 600 | glmU_DW_F: CCCGTATGAAAACGGATCAGCC | 94°C for 5 min; 5 cycles of 94°C for 30s, 50°C for 40s, and 72°C for 1 min; 50 cycles of 94°C for 30s, 55°C for 40s, and 72°C for 1 min; and a final extension at 72°C for 10 min. | Unpublished |
| | | | | glmU_DW_R: ATTCTCCCTGAGCGTTTTGATTTC | | |
| | | | | | | |
| | | | | | | |
| Host (bat) | Conventional PCR | Cytochrome c oxidase subunit 1 (COI) | 658 | LCO-1490F: GGTCAACAAATCATAAAGATATTGG | 95°C for 15 min; 35 cycles of 95°C for 1 min, 43°C for 1 min, and 72°C for 1 min; and a final extension at 72°C for 10 min | (Folmer et al., 1994) |
| | | | | HCO-2198R: TAAACTTCAGGGTGACCAAAAAATCA | | |

## 3.3 Results

The results of sampling pooled urine samples and faecal samples from Fijian bats is summarised in Table 7. No positive samples were detected for *Paramyxovirus*, *Coronavirus* or *Histoplasma* spp.

*Table 7 Results of PCR findings for each location, pooled urine and faecal samples, the bats visually and DNA detected at each site (PFF - Pacific Flying Fox, FBB - Fijian Blossom Bat, FFTB - Fijian Free-tailed Bat), and the Leptospira positive samples.*

| **Location** | **Bat Sp. Visually ID'd** | **Bat Sp. DNA present** | **No. urine samples** | **No. faecal samples** | **Lepto +ve urine samples** |
|---|---|---|---|---|---|
| Viti Levu Arboreal 1 | PFF | PFF | 11 | 11 | 2 |
| Viti Levu Arboreal 2 | PFF | | 2 | 9 | 0 |
| Viti Levu Arboreal 3 | PFF | | 1 | 9 | 0 |
| Viti Levu Arboreal 4 | PFF | PFF | 11 | 11 | 4 |
| Viti Levu Arboreal 5 | PFF | | 11 | 11 | 7 |
| Viti Levu Cave | FBB | | 12 | 12 | 9 |
| Vanua Levu Arboreal 1 | PFF | PFF | 3 | 8 | 3 |
| Vanua Levu Arboreal 2 | PFF | PFF | 8 | 9 | 7 |
| Vanua Levu Cave | FFTB | | 10 | 10 | 0 |
| Taveuni Arboreal | PFF | PFF | 9 | 8 | 6 |
| **10 sites** | **3 sp.** | | **78** | **98** | **38** |

### *3.3.1 Leptospira sp.*

Almost half of the 78 pooled urine samples (48.7%, 38/78) were PCR positive for *Leptospira* sp. The positive *Leptospira* samples were from 7 of the 10 sites and host DNA from the Pacific flying fox (*P. tonganus*) was detected at five of these sites (Taveuni Arboreal, Vanua Levu Arboreal 1, Vanua Levu Arboreal 2, Viti Levu Arboreal 1 and Viti Levu Arboreal 4). One of the sites (Viti Levu Cave) is home to a colony of *N. macdonaldi* however host DNA was not isolated in these samples. A different bat species DNA was detected at Vanua Levu Cave. The closest BLAST (Basic Local Alignment Search Tool) match for the 570 bp (base pairs) obtained was to *Chaerephon plicatus*, at 95.6% similarity. This may represent Fijian free-tailed/mastiff bat *Chaerephon bregullae*, which is not represented in the NCBI sequence database. No *Leptospira* positive samples were found at Vanua Levu Cave and no host DNA could be found at the remaining sites.

The positive samples were phylogenetically distinct with all 35 sequenced samples having no strong (88.8 – 96.8%) matches with known alleles. Phylogenies based on the glmU gene showed clustering with *L. borgpetersenii*, *L. kirshneri*, and *L. interrogans* (Figure 8).

### *3.3.2 Paramyxovirus, Coronavirus and Histoplasma*

All urine samples were PCR negative for paramyxoviruses, coronaviruses and *Histoplasma*. The DNA from the faecal samples were run twice with 2 different primers for *Histoplasma* and both runs were negative.

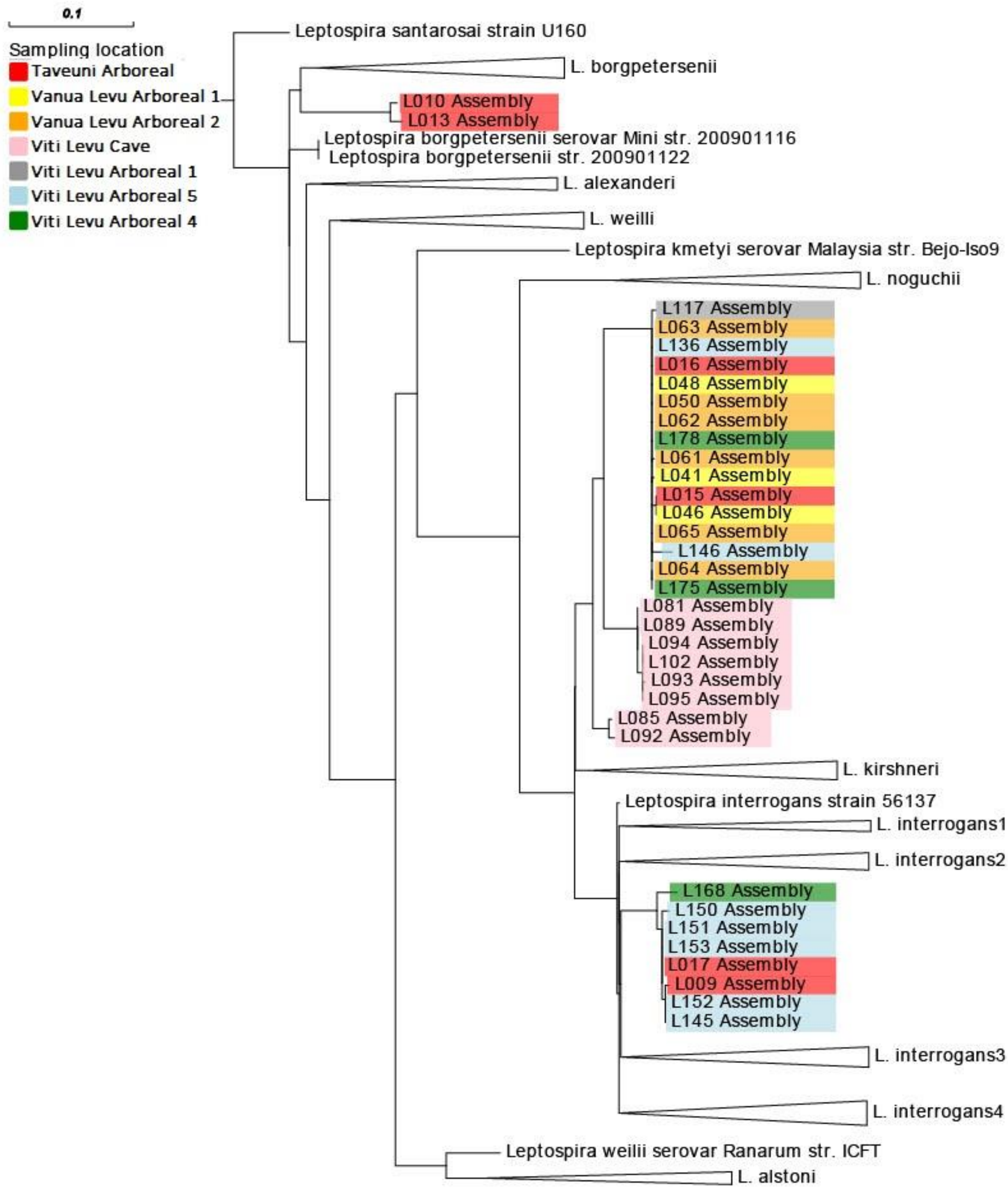


*Figure 8: Phylogenetic tree of Leptospira sp. generated using PHYML 3.0 with the sequenced samples identified by location collected*

## 3.4 Discussion

This study is the first to report the isolated of *Leptospira* spp. from bats in Fiji. *Leptospira* DNA was detected via PCR in urine from *P. tonganus* and in urine collected under a roost of *N. macdonaldi*. Pooled urine samples were positive from seven sites both arboreal and cave roosts. The species isolated represent new serovars which have not yet been reported. Further sampling and analysis (e.g. culture) will be necessary to confirm and formally identify these new serovars. Host DNA was not confirmed in the samples from Viti Levu Cave where *N. macdonaldi* roosts however this species was visually identified. This is the first recording of potentially zoonotic bacteria isolated from bats in Fiji.

Lau et al (2016), identified the 6 most common (86.7% of reactive tests) serovars from microscopic agglutination test (MAT) of human clinical or suspect clinical cases in Fiji were *Leptospira interrogans* serovars Pohnpei (serogroup Australis), Australis (serogroup Australis), Canicola (serogroup Canicola), Copenhageni (serogroup Interohaemorrhagiae), Hardjo (serogroup Sejroe), and *Leptospira borgpetersenii* serovar Ballum (serogroup Ballum). Pohnpei was the predominant serovar. In the initial panel of 21 serovars tested, 1.2% of 198 randomly selected samples from Lau's study were seropositive to *Leptospira kirshneri* serovar Cynopteri. *L.kirshneri* was not included in the final panel of 6 that the remaining samples were tested against in Lau's study, however it is one of the serovars that 24 of samples in this study clustered near. It is possible that the new serovars isolated in this study are potentially zoonotic however further sampling and analysis from both human cases and bat reservoirs would be needed to confirm this.

Leptospirosis is a nationally notifiable disease in Fiji (MoHMS Fiji, 2016). In 2015, a multisector meeting with relevant stakeholders present was held in Fiji to discuss a strategy for Leptospirosis. The priorities for the five year strategy outlined in Reid et al. (2017): 1) Improved clinical management of leptospirosis, 2) Improved surveillance for leptospirosis, 3) Enhanced communication to minimise risk and improve health seeking behaviours, and 4) Strengthening coordination and governance structures. Of the 4 strategies listed, the positive Leptospira results in this study provide additional information for both the surveillance of the causative agent and the identification of a potential risk of exposure, and therefore should be added to communication around minimising risk.

Current interactions between bats and people in Fiji include hunting for consumption, guano mining and cave tourism. If the *Leptospira* spp. isolated in this study are found to be a causative agent in human cases, awareness to communities where people have direct contact with bat urine would be necessary. Recommendations may include, but not limited to, increased hygiene awareness and practices, decrease direct contact with bats, and appropriate use of PPE.

While my study did not detect molecular evidence of coronaviruses, paramyxoviruses or *Histoplasma* in the pooled samples, it cannot be concluded that the populations are free from these pathogens. I am unable to calculate the likely confidence range of my results due to the limited/lack of knowledge of the Fijian bats' distribution and population size. My samples were also pooled below roosts and therefore it is unknown how many individuals were sampled. It is likely only a relatively small number of individuals at each site were sampled in this study.

Coronaviruses and paramyxoviruses are also both intermittently shed, adding to the need for care when interpreting these negative results (Drexler et al., 2011; Field et al., 2011). Increased physiological stress, such as parturition and lactation, can increase the excretion of viruses such as coronaviruses and paramyxoviruses (Drexler et al., 2011; Plowright et al., 2008). Scanlon et al. (2014) recorded year round reproduction in *N. macdonali* and *P. samoensis nawaiensis*, pregnancy of *C. bregullae* in November, and *P. tonganus* annual maternity camps in July-September. Sampling in this study took place between August to October. Sampling period was also determined by season to decrease the likelihood of rain contaminating or diluting the samples during the wet season (November to April). Other possible limitations of the samples/analyses could include degradation of nucleic acids in tropical conditions during the time from excretion to collection into RNAlater, and false negative tests.

Further testing including a broader array of techniques/analyses such as directly sampling the bats, serology, if applicable tissue sampling. Indirect sampling should be continued with a larger sample size as well as time and spatial distribution. For example, for a pool size of 10, a minimum of 34 pools must be tested to provide 95% probability of detecting a prevalence of 0.05, assuming a test sensitivity of 0.9 and specificity of 1 for all pool sizes (https://epitools.ausvet.com.au/onestagefreedom). Or, if a random sample of 320 units is taken from a population of 4000 and 0 or fewer reactors are found, the probability that the population is diseased at a prevalence of 0.01 is 0.0497. This assumes test sensitivity of 0.9 and specificity of 1 (https://epitools.ausvet.com.au/onestagefreedom).

The complex relationships between pathogen traits, host/vector traits, and environmental factors influences the prevalence of pathogens (Dearing et al., 2015). Population diversity appears to be inversely related to disease prevalence (Johnson et al., 2013; Keesing et al., 2006). Population structure, social complexity, dispersal and host immunity may also influence pathogen spread and maintenance (Hayman et al., 2018; Ryan et al., 2013). In Fiji, further studies would be necessary to understand species diversity, population counts and intra- and interspecies interactions to understand if these factors influence disease prevalence in this country.

Fragmented landscapes can affect the distribution and persistence of pathogens, such as vector-borne pathogens (Millins et al., 2018). Sampling locations in Fiji were on the three largest islands and it is known that some species are capable of travel far from roosting sites, or inter-island flight (Palmeirim et al., 2005). It is possible that cave populations are fragmented due to the decrease in the distribution of cave populations observed (Malotaux, 2012). This may contribute to population infection and maintenance of pathogens (Thrall & Burdon, 1999)

Host DNA of *P. tonganus* was identified in five out of 8 sites where the species was visualised. *P. samoensis* has been recorded to roost solitarily or in low numbers including roosting with *P. tonganus* groups. It is possible that individuals were roosting among the groups sampled but were not visualised. A single Fijian blossom bat (*N. macdonaldi*) was caught during tarp setting by the guides in Viti Levu Cave however no samples were taken directly from the individual as per permits/ethics. A direct sample could have provided a known DNA sample. This is the same for the Fijian free-tailed/mastiff bat at Vanua Levu Cave. Lack of detection of host DNA in the remaining samples could be due to low concentration of DNA, lack of appropriate primers available, or degeneration of sample prior to being collected.

Communities were open to the research being conducted however ease of access, up to date knowledge on roost locations, sampling timing, and sample storage in remote locations all presented logistical challenges for this study.

Bat populations in Fiji have been declining but there has only been limited monitoring due to accessibility and the expanse of the island nation (Palmeirim et al., 2005; Scanlon, Petit, & Bottroff, 2014). Some sites that were visited during this current study, based on reports by Flannery (1995), Palmeirim et al. (2005) and Scanlon, Petit and Bottroff (2014), no longer had bats present. At the time of the study, category 5 Cyclone Winston had hit Fiji 2.5 years prior. There are some reports that population fragmentation from larger to smaller roosting colonies after cyclones take months to years to return to previous sites and numbers (Gilbert et al., 1997; McConkey et al., 2004; Pierson et al., 1996; Russell et al., 2016). As well as roost and food disruption, after cyclones bats may be more vulnerable to human predation and consumption. Current predictions for climate change include increased frequency and severity of severe weather events like cyclones in the Pacific (Duvat et al., 2021). During the study, local villages commented on the change in bat location attributing it to drought, deforestation for farming, and consumption of bats in the villages.

Cave tourism in Fiji is not as big as other countries (Furey & Racey, 2016; Malotaux, 2012) however two caves that were studied during this survey were visited regularly by tourists (Viti Levu cave) and local residents (both caves). This does increase the risk of contact of people with bat urine and faeces. Isolating *Leptospira* from urine in Viti Levu cave should be shared with local communities to ensure appropriate hygiene measures are in place when accessing the cave as well as discouraging touching any surfaces in the cave or cave entrance.

## 3.5 Conclusion

This study identified new genetically diverse *Leptospira* sp. in pooled urine samples from roosts home to *P. tonganus* and *N. macdonaldi*. These new serovars may have zoonotic potential however further investigation is needed to culture the bacteria, and screen for the new serovars in human cases. Given the endemic nature of human leptospirosis and it is a nationally notifiable disease in Fiji, these findings provide updated information for the Ministry of Health as bats may be a potential animal source of infection. Although samples were negative for coronaviruses, paramyxoviruses and *Histoplasma*, a broader study of larger sample size, population dynamics and numbers, reproductive biology as well as a longitudinal study would be necessary to conclude absence of disease.

# Chapter 4 General Discussion

Wildlife conservation is essential for global ecosystems (Mills, 2007). Methods of implementing, managing, and evaluating conservation efforts are evolving and constantly being reviewed. Key focuses for study include understanding human-wildlife interactions, threats facing wildlife, human perceptions, as well as community engagement and education (König et al., 2020; MacPhail & Colla, 2020; Trewhella et al., 2005; Wiles & Brooke, 2009). Bats play an essential role globally and are considered a keystone species (Cox et al., 1991; Hutson et al., 2001; Scanlon, Petit, Tuiwawa, et al., 2014; Scanlon & Petit, 2015). As five of the six species of bats in Fiji are listed as threatened to critically endangered, it is essential to investigate human-bat interactions explore the potential for community engagement and education about bat conservation. This pilot study aimed to understand the perceptions of Fijian people about bats, and to clarify and quantify human-bat interactions.

Understanding community demographics, perceptions and values provides necessary insight that can aid project design and setting realistic goals for a conservation project (Carter et al., 2020; Mogomotsi et al., 2020). To understand these topics in Fiji, a face-to-face survey was conducted in communities close to known bat roosts across the three main islands. Bats were perceived as good, or both good and bad, by the majority of participants. Reasons for positive perceptions included their suitability as a food source and their importance in the environment. Harnessing the positive perceptions and attitudes towards bats could lead to improved conservation and education efforts in Fiji. Knowledge of the role of bats in the environment appeared to be more thorough in communities where previous bat research was undertaken. This demonstrates the importance of education during research projects as well as the lasting positive perceptions this has had on the people in those communities.

This study did not investigate the perception and interactions of Fijian youths and bats. Education of school children is a key focus for many conservation programs (Bhattacharjee et al., 2018; Trewhella et al., 2005; Voigt & Kingston, 2016). In Australia, teaching aids have been written to link into the curriculum for school children (Sammel, 2020). Similar teaching aids could be developed and encouraged to be taught as part of the Fijian education curriculum. In 2018 Dr Sophie Petit wrote a book titled “Vakaruru and the Bananas” set in Fiji which is designed for primary school children. The book is about the importance of bats, their role in the environment and how killing them for consumption will negatively impact this. It is reported that the book has been distributed to all primary schools in Fiji (https://www.aucklandzoo.co.nz/news/were-helping-to-spread-awareness-for-fijis-endangered-bats; https://www.abc.net.au/radio-australia/programs/pacificbeat/conservation-groups-attempt-to-save-fijis-bats-from-extinction/11703182). This book offers a great starting platform to engage school children in environmental awareness. Further sociological studies that involve youths (<18 years of age) would be necessary to gain understanding of human-bat interactions, human-bat perceptions, and overall wildlife and environmental values of youths. Longitudinal studies and research into the most effective ways to change people's behaviour in regard to bat interactions to promote bat and environmental conservation would be an important focus not only for Fiji, the Pacific and the worldwide community.

In contrast to previous bat population studies in Fiji, many participants of this pilot study perceived the overall bat population to be increasing based on more local bat sightings. Local experiences may be more longitudinal than individual research projects can allow for, however there were a lot of comments made regarding the decrease in numbers seen after Cyclone Winston (2016). Current predictions for climate change include increased frequency and severity of cyclones in the Pacific, making ongoing population monitoring vital (Duvat et al., 2021). Citizen science and population counts are relied on for many studies, monitoring programs and databases worldwide (Hacker et al., 2020; MacPhail & Colla, 2020). In Fiji there may be the potential to encourage bat observations by Fijians with the provision of appropriate education topics such as roost count methods, formal record keeping, and monitoring tools.

Bats were not commonly believed to cause illness in people however harm in the form of biting or scratching was reported by 55.6% of participants. This perception is likely due to the absence of any reported zoonotic disease outbreak in Fiji with bats as the source. The disease investigation of pooled urine and faecal samples collected in this pilot study uncovered one of the four potentially zoonotic pathogens investigated– *Leptospira* sp. In Fiji, Leptospirosis is a nationally notifiable disease. It is unclear from this study if the novel species/serovars isolated are indeed zoonotic, or a causative agent in human leptospirosis cases. This potential public health issue requires further investigation. If it is found to be potentially zoonotic, the perception regarding harm from bats may change, along with the positive attitudes towards bats.

Zoonotic diseases from bats may be spread via direct contact with bodily fluids or indirect routes through intermediate hosts. In Fiji, interactions between people and bats that were identified in this study included hunting, preparation for consumption, consumption, guano mining, visiting roosting sites and medicinal uses. It was identified that age and sex are predictors of contact with bats, with older people and males more likely to have contact with bats. Older people were more likely to prepare bats for consumption than their younger counterparts, especially people aged between 40-49 years, and over 60 years. Age and gender are also predictors of current bat consumption with men more likely than women and people aged over 24 years of age. It is unclear if this age distribution is due to younger people changing their attitudes towards bats, or if it reflects the delineation of roles in communities. Quantifying human-bat interactions in Fiji provides useful data to design targeted education and bat conservation programs. These demographics should also be classed as higher risk groups to bat and bat product exposure and contact, therefore higher risk to exposure of zoonotic pathogens if present in Fiji.

While bat meat consumption was reported to be on the decline by participants, consumption is still common, with seasonal hunting favoured. Bats are caught primarily for personal or village consumption which contrasts with other countries. It is therefore possible that as bats do not provide an important income through hunting and bushmeat, hunting practices may be more sustainable than other countries (Mildenstein et al., 2016; Nielsen et al., 2017; Wilson & Graham, 1992). Bat meat was perceived to be healthy, clean and tasty, and was the main reason bats were perceived as positive/good. Hunting, meat preparation and consumption all expose the individual to bat bodily fluids, and therefore pose a potential risk to human health. Other pacific nations (Wiles & Brooke, 2009) have regulated bat hunting, however complete bans are rare and may be difficult to impose. There are currently no broad regulations controlling the hunting of bats in Fiji. Encouraging adequate hygiene, PPE, and minimising regularity/number of bats hunted and consumed, may decrease exposure and infection risk for people. Decreasing hunting and consumption would also have a positive impact on bat populations locally (Mildenstein et al., 2016).

Participant selection for this study was influenced by a combination of study design, fieldwork timeframe, research personnel numbers, financial constraints, transport limitations and permission delays. The participants were biased in the context they were all located in villages or communities close to known bat roosting sites, the village chiefs often nominated who would participate, as well as a number self-nominating or volunteering. The bias of location of participants has gathered a more in-depth knowledge of human-bat interactions as well as identifying key at risk groups for bat contact which may not have been identified if a large proportion of participants were located away from roosting sites, e.g. larger cities. The bias is unlikely to negatively impact the results with respect to highlighting key perceptions and trends of bats, the breadth of bat interactions, and identifying at risk groups. All of this information is essential in contributing towards current public health knowledge, and future education and bat conservation efforts.

This study is the first to specifically investigate potential zoonotic diseases in Fiji. *Leptospira* DNA was detected via PCR in pooled urine samples from *P. tonganus* on the three main islands (Viti Levu, Vanua Levu and Taveuni). Although host DNA was not recovered, samples from a cave roost of *N. macdonaldi* were also positive for *Leptospira* DNA. All 35 of the 78 positive samples sequenced were phylogenetically distinct. Clustering occurred with *L. borgpetersenii*, *L kirshneri* and *L. interrogans*. *L. kirshneri* serovar Cynopteri is associated with human leptospirosis in Fiji (Lau) however further sample collection and analysis would be necessary to confirm if any of the *Leptospira* spp. isolated in this study are implicated in human diseases and therefore zoonotic.

While my study did not detect any molecular evidence of coronaviruses, paramyxoviruses or *Histoplasma* in the pooled urine and faecal samples, it cannot be concluded that the bat population is free from these pathogens. With the current limited knowledge of Fijian bat distribution and population size, it is not possible to calculate the likely confidence range of my results. As samples were pooled, it is unknown how many individuals were sampled and it is likely only a small number. Pathogen presence is influenced by the complex relationships between host/vector traits, pathogen traits, and environmental factors (Dearing et al., 2015). Pathogen traits such as intermittent shedding of coronaviruses and paramyxoviruses need to be considered when interpreting this study's once off negative results. The collection period was short and each site was sampled once (with the exception of two sites due to weather). Further testing including a broader array of techniques/analyses such as directly sampling bats, serology, and if applicable, tissue sampling. Indirect sampling should be continued with a larger sample size, and time and spatial distribution.

## Conclusions

My results have demonstrated a network of dynamic interactions between people and bats in Fiji, and several potential routes for zoonotic disease transfer between bats and people. The detection of *Leptospira* spp. in the Fijian bats confirms the potential for the bats to be a public health risk to the Fijian people, and contradicts the widely held view discovered in this study that bats are a clean and healthy food source. Developed with a One Health focus, this pilot study provides baseline data for current disease status and up to date advice regarding public health information, guidelines and education.

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# Appendices

## *Appendix 1: Free and Prior Informed Consent Fijian Bat Research*

### Free and Prior Informed Consent

**Fijian bats: interactions with people and disease surveillance focusing on zoonotic pathogens**

**Date of interviews/questionnaires:** 9 August 2018 – 11 October 2018

**Primary researcher:** Jessica McCutchan

**Project information**

As part of the Masters of Veterinary Science in Wildlife and Zoo Animal Health, Jessica McCutchan is conducting a research project focusing on Fijian bats. A questionnaire has been prepared to identify interactions between people and bats. Bat urine and faeces will be collected for analysis at the laboratory.

**Project aims**

1. To document the interactions between people (both local and tourist population) and bats through a survey
2. Survey Fijian bats for the presence of several important pathogens that can be carried by bats worldwide by testing urine and faeces at a laboratory in New Zealand

The sites for survey and sample collection will be decided after consultation with local experts as well as village spokes-people and chiefs. No handling of animals is required.

**Invitation to participate in the project**

You are invited to participate in this project by providing information regarding interaction/contact between bats and people throughout Fiji by answering the pre-approved questionnaire. Your answers to the questionnaire will be voice recorded (no video) and also written down at the time. It will be conducted by the principle researcher (Jessica), with the assistance of local guides and translators as required. The questionnaire was written in English and has been translated into Fijian.

**Risks:** There is no risk to you. This study is not designed to discourage interactions/contact with bats or change any practices with bats. This study has been designed to pose minimal risk and disturbance to the bats as there will only be indirect interactions with live animals.

**Benefits to taking part in the study:** Information provided through questionnaires will:

- Greatly improve the knowledge and education around the interactions between people and bats
- Identify areas to improve future conservation of the bat species
- Identify if there is any risk of exposure to zoonotic pathogens
- May help update advice regarding public health implications

**Confidentiality:** Your involvement is entirely voluntary. Any information provided will be handled in confidence. You will remain personally anonymous in any report or publication. For the previously mentioned aims and benefits, the findings of the project will be published. Confidentiality will be maintained as no personal information will be published and each questionnaire will be assigned a number for statistical analysis. Once published, the hard copies of the questionnaires and voice recordings of the interviews will be destroyed. You can withdraw your involvement in the project at any time until publication by contacting Jessica McCutchan.

**Consent:** If you consent to participating in this study please complete the attached consent form and return to the primary researcher.

**Approval to conduct research**

Locally, this project has the endorsement of Ministry of Education, Ministry of ITaukei Affairs, University of South Pacific and NatureFiji. The Ministry of Health, Biosecurity Authority Fiji and Department of Environment have also been consulted. Animal and Human ethics have been approved.

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### Free and Prior Informed Consent

**Fijian bats: interactions with people and disease surveillance focusing on zoonotic pathogens**

**Contacts for queries or problems**

If you have any questions, comments or concerns about the questionnaire or the rest of the project please contact myself (Jessica) or my supervisors.

**Primary Researcher:**

- Jessica McCutchan j.mccutchan@massey.ac.nz ; +6797147277 (Fiji); +642102739236 (New Zealand)

Supervisors:

- Professor Brett Gartrell B.Gartrell@massey.ac.nz ; and
- Dr David Hayman D.T.S.Hayman@massey.ac.nz

### Free and Prior Informed Consent

**Fijian bats: interactions with people and disease surveillance focusing on zoonotic pathogens**

**Certificate of consent**

The details of the above "Fijian bats: interactions with people and disease surveillance focusing on zoonotic pathogens" project has been explained to me and the questions that I have asked have been answered to my satisfaction.

Confidentiality of the information, and the process involved in retrieving, sending and storing data and interview transcripts have been fully explained and I agree to the process.

I give my full and informed consent to be involved in this project in accordance with the terms outlined on the attached Participant Information Sheet.

**Name:** ______________________________

**Village:** ______________ **Mataqali:** ______________ **Yavusa:** ______________

**Position:** ______________________________

**Date:** _____ / _____ / ________

**Signature:** ______________________________

*Upon providing the full details of the nature of the research, the respondent above has expressed his/her full and informed consent to be involved in the project*

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*Appendix 2: Questionnaire - Fijian bats: interactions with people and disease surveillance focusing on zoonotic pathogens - English*

## Fijian bats: interactions with people and disease surveillance focusing on zoonotic pathogens

### QUESTIONNAIRE

**Subject details** *Questions 1 – 7*

*Please note your name and address is only recorded in case we require further information from you while in your region. It is not recorded next to your responses in the research database or disclosed to third parties.*

1. Name: ________________________________________________
   (optional)
2. Address:_______________________________________________
   (optional)
3. Region:
   _______________________________________________________
4. Age:
   a. 18-24
   b. 25-30
   c. 30-39
   d. 40-49
   e. 50-59
   f. 60+
   g. Not specified
5. Gender:
   a. Male
   b. Female
   c. Other

**6.** Role in the community (if applicable):
_________________________

_________________________

**7.** Education:
______________________

**Perception of bats** *Questions 8 - 19*

*Please answer the following questions with your own personal experiences in mind. Please feel free to add any extra comments with your answer to the questions. Please state if you do not wish to answer the question asked. With your permission the following interview will be recorded with a voice recorder. The recording will not be made public. It is only for record keeping and to assist with ensuring the answers are recorded correctly.*

8. Do you see bats near where you live or work?
   a. Yes
   b. No
9. How many species or types of bats do you see?
   ________________________________
   Comments ______________________________
10. What do you think bats eat?
    a. Fruit
    b. Seed
    c. Plants
    d. Insects
    e. Other ________________
11. What have you seen bats eat?
    a. Fruit
    b. Seed
    c. Plants
    d. Insects
    e. Other ________________
12. At what times do you see bats being active (eg. flight, eating, vocalising)?
    a. Dawn/sunrise
    b. Morning
    c. Afternoon
    d. Dusk/sunset
    e. Night
    f. Other ________________
13. In your experience, have the number of bats you have observed –
    a. Decreased?
    b. Increased?
    c. OR Stayed the same? - G*o to question 15*
14. Why do you think the numbers of bats have changed?
    a. Increased - ______________________________
    b. Decreased - ______________________________
15. In your opinion, are the bats -
    a. Good - Why? ______________________________
    b. Bad - Why? ______________________________
    c. Both – Why (unless answered both above)? ______________________________
    d. Neither good nor bad. ______________________________
16. What role do bats play in the wider environment? ______________________________
17. Do the bats influence your day to day life?
    a. Yes – How? ______________________________
    b. No
18. Can bats harm humans?
    a. Yes – How? ______________________________
    b. No – Why? ______________________________
19. Who/which people do you think eats bats? Eg. Poor, wealthy, urban, rural, status, everyone?
    ______________________________

## **Interactions with bats** *Questions 20 - 36*

*The following questions are to identify the different interactions between people and bats by asking you about your personal experiences both past and present. There may be some questions that are repeated from the previous section. There will also be some questions about the different uses of bats. Please feel free to add any extra comments with your answer to the questions. Please state if you do not wish to answer the question asked.*

20. Are there any bats roosting near where you live, commute or work?
    a. No - *Go to question 22.*
    b. Yes
21. Where do they roost/sleep?
    a. Arboreal (sleep in trees)?
    b. Caves?
    c. Man-made infrastructure (eg. houses, bridges)?
    d. Other ____________________________
22. Have you ever been in contact with blood, saliva, urine or faeces from a bat?
    a. No
    b. Yes ______________________________
23. Have you ever been injured by a bat? (eg. Scratched or bitten?)
    a. No
    b. Yes ______________________________
24. In the **PAST** have you eaten bat meat?
    a. No - *Go to question 25.*
    b. Yes
    c. How many/much? ______________________________
    d. How often?
       d.i. Daily
       d.ii. Weekly
       d.iii. Monthly
       d.iv. Every 3 months
       d.v. Every 6 months
       d.vi. Once a year
       d.vii. Other___________________
    e. Where did you source the products from?
       e.i. Self-caught
       e.ii. Village caught
       e.iii. Market
       e.iv. Other ____________
    f. How were they prepared? ______________________________
25. Do you **CURRENTLY** eat bat meat?
    a. No - *Go to question 26.*
    b. Yes
    c. How many/much? ______________________________
    d. How often?
       d.i. Daily
       d.ii. Weekly
       d.iii. Monthly
       d.iv. Every 3 months
       d.v. Every 6 months
       d.vi. Once a year
       d.vii. Other____________________
    e. Where did you source the products from?
       e.i. Self-caught
       e.ii. Village caught
       e.iii. Market
       e.iv. Other __________________
    f. How are they prepared? ______________________________

26. In the **PAST** have you used bats for anything **__other than__** meat?
    a. No - *Go to question 27.*
    b. Yes – please specify
    ____________________________
    c. How many/much?
    ____________________________
    d. How often?
        d.i. Daily
        d.ii. Weekly
        d.iii. Monthly
        d.iv. Every 3 months
        d.v. Every 6 months
        d.vi. Once a year
        d.vii. Other__________
    e. Where did you source the products from?
        e.i. Self-caught
        e.ii. Village caught
        e.iii. Market
        e.iv. Other __________
    f. How were they prepared?
    ____________________________

27. Do you **CURRENTLY** use bats for anything **__other than__** meat?
    a. No - *Go to question 28.*
    b. Yes – please specify
    _________________
    c. How many/much?
    ____________________________
    d. How often?
        d.i. Daily
        d.ii. Weekly
        d.iii. Monthly
        d.iv. Every 3 months
        d.v. Every 6 months
        d.vi. Once a year
        d.vii. Other__________
    e. Where did you source the products from?
        e.i. Self-caught
        e.ii. Village caught
        e.iii. Market
        e.iv. Other
        ______________
    f. How were they prepared?
    ____________________________

28. Have you personally caught bats in the **PAST**?
    a. No - *Go to question 29.*
    b. Yes Year of last catch
    ____________________________
    c. Did you actively hunt (and how) OR find them by chance?____________________
    d. How many?
    _________________________
    e. How often?
        e.i. Daily
        e.ii. Weekly
        e.iii. Monthly
        e.iv. Every 3 months
        e.v. Every 6 months
        e.vi. Once a year
        e.vii. Other__________
    f. Purpose?
        f.i. Consumption
        f.ii. Income
        f.iii. Gift
        f.iv. Other _________

29. Do you **CURRENTLY** catch bats?
    a. No - *Go to question 30.*
    b. Yes

c. Are these actively hunted (and how) OR find them by chance?_________________

d. How many?

_________________________

e. How often?

- e.i. Daily
- e.ii. Weekly
- e.iii. Monthly
- e.iv. Every 3 months
- e.v. Every 6 months
- e.vi. Once a year
- e.vii. Other__________

f. Purpose?

- f.i. Consumption
- f.ii. Income
- f.iii. Gift
- f.iv. Other

_____________

30. Do you prepare bats to be consumed for eating?

a. No - *Go to question 31*

b. Yes

c. How many? ________________

d. How often?

- d.i. Daily
- d.ii. Weekly
- d.iii. Monthly
- d.iv. Every 3 months
- d.v. Every 6 months
- d.vi. Once a year
- d.vii. Other___________

e. How are the bats prepared for eating?

_____________________________

## **Guano** *Questions 31 – 32*

31. Have you used/mined guano in the **PAST**?

a. No - *Go to question 32.*

b. Yes

c. How much? ___________

d. How often?

- d.i. Daily
- d.ii. Weekly
- d.iii. Monthly
- d.iv. Every 3 months
- d.v. Every 6 months
- d.vi. Once a year
- d.vii. Other___________

e. Source?

- e.i. Self-mined
- e.ii. Purchased
- e.iii. Other

_______________

f. Purpose?

- f.i. Personal use
- f.ii. Income
- f.iii. Gift
- f.iv. Other

______________

32. Do you **CURRENTLY** use/mine guano?

a. Yes

b. No - *Go to question 33.*

c. How much? ___________

d. How often?

- d.i. Daily
- d.ii. Weekly
- d.iii. Monthly
- d.iv. Every 3 months
- d.v. Every 6 months

d.vi. Once a year

d.vii. Other__________

e. Source?

e.i. Self-mined

e.ii. Purchased

e.iii. Other __________

Purpose?

e.iv. Personal use

e.v. Income

e.vi. Gift

e.vii. Other __________

## **Roosting sites** *Questions 33 - 36*

33. Do you visit roosting sites?

a. Yes

b. No - *Go to question 34.*

c. Where is the roosting site? eg. Tree, cave, building ____________________________

d. Purpose? ____________________

e. How often?

e.i. Daily

e.ii. Weekly

e.iii. Monthly

e.iv. Every 3 months

e.v. Every 6 months

e.vi. Once a year

e.vii. Other__________

34. If you see an injured or sick bat – what do you do?

a. Leave it alone

b. Move it

c. Care for it

d. Kill it

e. Sell it

f. Eat it

g. Other ____________________________

35. Do you have any other interactions with bats? Yes or No

a. Please specify ______________________________ ______________________________

36. Are there any further comments you would like to add?

__________________________________
__________________________________
__________________________________
__________________________________
__________________________________
__________________________________
__________________________________

Thank you 😊

*Appendix 3: Questionnaire - Fijian Bats: interactions with people and disease surveillance focusing on zoonotic pathogens - Fijian*

## Fijian bats: interactions with people and disease surveillance focusing on zoonotic pathogens

**QUESTIONNAIRE**

**Ai Vakatataro ni vakadidike ni Beka(bats) I Viti**

**Subject details** *Questions 1 – 7*

*Please note your name and address is only recorded in case we require further information from you while in your region. It is not recorded next to your responses in the research database or disclosed to third parties.*

**Nomu I Tukutuku**

1. Yacamu (optional) ______________________________

2. Nomu I Tikotiko (optional) ______________________________

3. Nomu yasana (region) ______________________________

4. Nomu Yabaki :
   a. 18-24
   b. 25-29
   c. 30-39
   d. 40-49
   e. 50-59
   f. 60+
   g. Not specified

5. Toqa ga e dua:
   a. Tagane
   b. Yalewa

6. Na nomu I tutu vakavanua ena nomu I tikotiko se koro ______________________________

7. Vakatagedegede ni Vuli (education) ______________________________

**<u>Ai vakatakilakila ni Beka</u>** Questions 8 - 19

*Sa kerei mo ni qai sauma na taro me veidonui kei na nomuni kila ka me baleta na beka. Kevaka ko ni kila tale e so na I tukutuku me baleta na manumanu oqo, mo ni qai vakalewena e na vanua ko ni kila ni rawa ni vakacurumi kina. E na nomuni veivakadonui, na veitaro oqo ena katoni koto ena dua na monalivaliva lailai (voice recorder). Na veitalanoa e katoni, ena sega ni vakayagataki e na dua tani tale na ka. E na vakayagataki ga me ka ni vuli kei na vakadidike me baleti ira na beka, ka me vakadinadinataka ni veitarogi oqo e a yaco.*

8. Ni kemuni dau raica na beka, e na vanua o ni cakacaka se vaka I tikotiko kina?
   a. Io
   b. Sega
   c.
9. E vica kece na kena veimataqali ni manumanu oqo na beka o ni dau raica?

   ______________________________

   Comments: ____________________

10. Na cava o ni nanuma na kakana cava soti era dau kania na beka?
    a. Vua ni kau (fruits)
    b. Sore ni kau (seeds)
    c. Vu ni kau (plants)
    d. Manumanu lalai (insects)
    e. E so tale na ka? __________

11. Na cava o ni dau raica ni rad au kania na manumanu qo na beka?
    a. Vua ni kau (fruits)
    b. Sore ni kau (seeds)
    c. Vu ni kau (Plants)
    d. Manumanu lalai (insects)
    e. E so tale n aka ? _________

12. E na gauna cava soti oni dau raica vakalevu kina na beka? (gauna era veivukayaki, kana, vakavosavosa kina)
    a. Gauna ni cadra na siga (sunrise)
    b. Matakalailai (morning)
    c. Siga levu (afternoon)
    d. Yakavi/dromu na siga (sunset)
    e. Bogi (night)
    f. So tale na gauna? ________

13. E na nomu rai se kila ka, O ni nanuma na I wiliwili ni Beka e sa –
    a. Sa lailai tiko mai (decreasing)
    b. Sa levu tiko mai (increasing)
    c. Sega ni dua na veisau (toki sara ki na I kavitu (*15*) ni taro)

14. Na cava na nomu rai se nanuma e na vuku ni veisau ni wiliwili ni beka?
    a. Vakalevu tiko mai -

       ________________________

    b. Vakalailai tiko mai -

       ________________________

15. E na nomu rai, o ira na beka e:
    a. Vinaka? Baleta (vakamacala)

       ________________________

    b. Ca ? Baleta (Vakamacala)

       ________________________

    c. Vinaka ka ca talega (Kevaka ke a sega ni vakaleweni na taro e cake)

       ________________________

    d. Sega ni vinaka ka sega ni ca talega

       ________________________

16. Na cava o ni nanuma e nodra I tavi na beka e na veivanua?

    ______________________________

17. O ni nanuma ni o ira na beka era solia dua na vakacegu se vukea dua na tiki ni nomu bula e vei siga?
    a. Io – Vakamacalataka?

       ________________________

    b. Sega

       ________________________

18. O ni kila ni rawa beka vei ira na Beka me vakamavoataka na tamata?
    a. Io – Vakamacalataka?

       ________________________

    b. Sega, Vakamacalataka

       ________________________

19. Ocei ko ni nanuma era dau kania na Beka?

    ______________________________

    ______________________________

## <u>Veikilai kei na veitaratara kei ira na Beka</u>

*Na veitaro ena muri mai ke e baleta na nomu veikilai, kila ka kei na veitaratara (Interactions) vata kei ira na manumanu qo na beka, ena tarogi tiko na nomuni dau toboka se na cava oni dau cakava kevaka oni sa toboka rawa e dua na beka, se na kena laukana. E so na taro e sa vakayagataki oti mai cake, kevaka e so na nomuni nanuma se sau ni taro e a sega ni tarogi ena veitaro sa oti, mo ni qai vakatakila toka ena veivanua lala e toka e ra. Kevaka oni sa vakalewena oti se sauma oti na veitaro I cake, ka koni sa sega ni rawa ni qai sauma tale na veitaro e ra oqo, ni qai tukuna cake mai.*

20. Ko ni kila ke tiko e so na beka ena vanua o ni vakatikotiko kina se na nomuni vanua ni cakacaka?
    a. Sega - *Lade sara kina I katolu (22) ni taro*
    b. Io

21. Na vanua cava soti era dau moce se vakacegu kina?
    a. Veivunikau
    b. Loma ni qaravatu
    c. E na ruku ni Wavu, vale lala?
    d. So tale na vanua?

       ________________

22. Sa bau turuvi kemuni oti na dra (Blood), weli (saliva), suasua (Urine) se valelailai (faeces) ni Beka?
    a. Sega
    b. Io

       ________________________

23. Sa bau vakamavoa taki kemuni oti na beka? (Kadrumi, laukati, etc)
    a. Sega
    b. Io

       ________________________

24. Ko ni a dau kana beka I liu?
    a. Sega - *Toki ki nai kaono (25) ni taro*
    b. Io
    c. E vica kece na kena levu oni sa kania oti?

       ________________________

    d. Dau va vica na nomu dau kania na beka?
       i. Vei siga
       ii. Vei Macawa
       iii. Vei Vula
       iv. Vei tolu na vula
       v. Vei ono na vula
       vi. Vei dua na yabaki

vii. So tale na gauna? __________

e. O ni a kauta/toboka mai vei na manumanu oqo?
    i. Toboka vakai-kemuni ga
    ii. Toboka vakalewe levu/lewe ni koro
    iii. Kauta/volia mai na makete?
    iv. So tale na vanua o ni a kauta mai kina ? ________________

f. O ni a vakarautaka vakacava na kena caka/kana? _________________________

25. O ni se dau kania voliga na beka ena gauna oqo ?
    a. Sega - *Toki ki na I kavitu (26) ni taro*
    b. Io
    c. E vica kece na kena levu oni sa kania oti? _________________________
    d. Dau va vica na nomu dau kania na beka?
        i. Vei siga
        ii. Vei Macawa
        iii. Vei Vula
        iv. Vei tolu na vula
        v. Vei ono na vula
        vi. Vei dua na yabaki
        vii. So tale na gauna? __
    e. O ni a kauta/toboka mai vei na manumanu oqo?
        i. Toboka vakai-kemuni ga
        ii. Toboka vakalewe levu/lewe ni koro
        iii. Kauta/volia mai na makete?
        iv. So tale na vanua o ni a kauta mai kina ? ________________
    f. O ni a vakarautaka vakacava na kena caka/kana? _________________________

26. E na gauna I LIU, ko ni a dau vakayagataka na manumanu qo na Beka e na so tale na ka, duidui mai na kena e laukana?
    a. Sega - *lade kina I kawalu(27) ni taro*
    b. Io. Rawa ni ko vakamacalataka nomu sau ni taro. _________________________
    c. E vica kece na kena levu oni sa vakayagataka oti? _________________________
    d. Dau va vica na nomu dau kania na beka?
        i. Vei siga
        ii. Vei Macawa
        iii. Vei Vula
        iv. Vei tolu na vula
        v. Vei ono na vula
        vi. Vei dua na yabaki
        vii. So tale na gauna? __________
    e. O ni a kauta/toboka mai vei na manumanu oqo?
        i. Toboka vakai-kemuni ga
        ii. Toboka vakalewe levu/lewe ni koro
        iii. Kauta/volia mai na makete?
        iv. So tale na vanua o ni a kauta mai kina ? _______________

f. O ni a vakarautaka vakacava na kena caka/kana?

   ________________________

27. E na gauna OQO, Ko ni se vakayagataka voliga na beka me kani so tale na ka, duidui mai na kena e laukana?
    a. Sega - *Lade ki na I kaciwa(28) ni taro*
    b. Io - vakamacalataka ______
    c. E vica kece na kena levu oni sa toboka oti?

       ________________________

    d. Dau va vica na nomu dau toboka na beka?
       i. Vei siga
       ii. Vei Macawa
       iii. Vei Vula
       iv. Vei tolu na vula
       v. Vei ono na vula
       vi. Vei dua na yabaki
       vii. So tale na gauna?

            _________
    e. O ni a kauta/toboka mai vei na manumanu oqo?
       i. Toboka vakai-kemuni ga
       ii. Toboka vakalewe levu/lewe ni koro
       iii. Kauta/volia mai na makete?
       iv. So tale na vanua o ni a kauta mai kina ?

            ________________
    f. O ni a vakarautaka vakacava na kena caka/kana?

       ________________________

28. O ni a dau tobo Beka vakai iko ena gauna I liu?
    a. Sega - *Lade ki nai katini (29) ni taro*
    b. Io - yabaki ko ni a sa toboka oti kina e dua?

       _______________________
    c. Ko nia dau toboki ira ena veigauna se e na gauna ga o raici ira kina?

       ________________________
    d. E vica kece ko ni a dau toboka ena dua na gauna?

       ________________________
    e. O ni dau toboka ena vei:
       i. Siga
       ii. Macawa
       iii. Vula
       iv. Tolu na macawa
       v. Ono na macawa
       vi. Dua na yabaki
       vii. So tale na gauna?

            __________________
    f. Ke na I naki?
       i. Me laukana?
       ii. Me I vurevure ni Lavo
       iii. Me kani soli se loloma
       iv. So tale na kena yakayagataki?

            __________________

29. O ni se tobo beka tikoga e na gauna oqo?
    a. Sega - *Lade ki na I katinikadua(30) ni taro*
    b. Io
    c. Ko nia dau toboki ira ena veigauna se e na gauna ga o raici ira kina?

       ________________________

d. E vica kece ko ni a dau toboka ena dua na gauna?

___________________________

e. O ni dau toboka ena vei:
    i. Siga
    ii. Macawa
    iii. Vula
    iv. Tolu na macawa
    v. Ono na macawa
    vi. Dua na yabaki
    vii. So tale na gauna?

    ____________________

f. Ke na I naki?
    i. Me laukana?
    ii. Me I vurevure ni Lavo
    iii. Me kani soli se loloma
    iv. So tale na kena yakayagataki?

    ____________________

30. Ni koni dau vakarautaka na Beka me ka ni laukana?
    a. Sega - *Lade ki na I katinikarua(31) ni taro*
    b. Io
    c. E vica kece ko ni dau vakarautaka?

    ___________________________

    d. O ni dau vakarautaka ena vei:
        i. Siga
        ii. Macawa
        iii. Vula
        iv. Tolu na macawa
        v. Ono na macawa
        vi. Dua na yabaki
        vii. So tale na gauna?

        ____________________

    e. Oni dau cakava vakacava na kena vakarautaki?

    ___________________________

31. O ni sa bau vakayagataka na nodra valelailai se de ni beka ena gauna I liu?
    a. Sega - *Lade ki na I katinikatolu (32) ni taro*
    b. Io
    c. Dau vakacava na kena I vakarau oni dau vakayagataka?

    ________________

    d. O ni dau vakayagataka ena vei:
        i. Siga
        ii. Macawa
        iii. Vula
        iv. Tolu na macawa
        v. Ono na macawa
        vi. Dua na yabaki
        vii. So tale na gauna?

        ____________________

    e. Vanua e kau mai kina?
        i. O ni kauta se vakarautaka vakai kemuni ga.
        ii. O ni volia mai
        iii. So tale na vanua o ni kauta main a nodra vale-lailai se de ni beka.?

        ____________________

    f. Na kena vakayagataki?
        i. Nomu I vakayagataka ena vukumu ga (personal use)
        ii. Me I vurevure ni I lavo
        iii. Me ka ni soli se I loloma.
        iv. So tale na kena I vakayagataki koni kila

        ____________________

32. O ni se dau vakayagataka voliga na nodra vale-lailai se na de ni beka ena gauna oqo?
    a. Io
    b. Sega - *Lade ki na I katinikava (33) ni taro*
    c. Dau vakacava na kena I vakarau oni dau vakayagataka?

       ________________

    d. O ni dau vakayagataka ena vei:
        i. Siga
        ii. Macawa
        iii. Vula
        iv. Tolu na macawa
        v. Ono na macawa
        vi. Dua na yabaki
        vii. So tale na gauna?

             __________

    e. Vanua e kau mai kina?
        i. O ni kauta se vakarautaka vakai kemuni ga.
        ii. O ni volia mai
        iii. So tale na vanua o ni kauta main a nodra vale-lailai se de ni beka.?

             ____________________

    f. Na kena vakayagataki?
        i. Nomu I vakayagataka ena vukumu ga (personal use)
        ii. Me I vurevure ni I lavo
        iii. Me ka ni soli se I loloma.
        iv. So tale na kena I vakayagataki koni kila

             ____________________

33. O ni dau lakova se sikova na nodra I vunivuni na beka?
    a. Io
    b. Sega - *Lade ki na I katinikalima(34) ni taro.*
    c. Era dau vuni se vakacegu vakalevu I na vanua cava o ira na beka oqo. (qaravatu, vu-ni-kau, ruku ni wavu, etc)

       __________________________

    d. Na cava na vuni nomuni dau sikova kina na nodra vanua ni vakavakacegu?

       _____________________

        i. O ni dau sikova ena vei:
           Siga
        ii. Macawa
        iii. Vula
        iv. Tolu na macawa
        v. Ono na macawa
        vi. Dua na yabaki
        vii. So tale na gauna?

             ____________________

34. Kevaka o ni raica e dua na beka e mavoa tu se tauvimate – na cava o ni na cakava?
    a. Laiva vakadua
    b. Vakayavalata
    c. Qarava me vinaka na manumanu
    d. Vakamatea
    e. Volitaka
    f. Vakayagataka me laukana
    g. So tale na ka.

       ______________________

35. E so tale na ka o ni dau cakava kei ira na manumanu qo, na Beka?
Io se sega
Kerekere vakamacalataka mada.
________________________________
________________________________

36. Kevaka e so tale na I tukutuku me baleti ira na manumanu qo na beka, e a sega ni tarogi, se a vakalutumi ena gauna ni veitarogi qo, qai kerea moni vakamacalataka mada mai.
________________________________
________________________________
________________________________
________________________________
________________________________
________________________________
________________________________

Vinaka vakalevu, na nomuni taura tiko na nomuni gauna mo ni vakalewena e dua na ka ni vakadidike lailai oqo, au sa nuitaka na nomuni veitokoni kei na nomuni yalodina ena veisaumi taro.

*Appendix 4: Detailed results of the logistic regression model for past and current bat consumption, contact with bats, and preparation of bats for consumption*

**Current bat eating model**

logit_eat <- glm(Eat_bat ~ Age + Gender,data=jess_data,family="binomial")

summary(logit_eat)

Call:

glm(formula = Eat_bat ~ Age + Gender, family = "binomial", data = jess_data)

Deviance Residuals:

| Min | 1Q | Median | 3Q | Max |
|---|---|---|---|---|
| -1.6486 | -1.0585 | 0.7707 | 1.0612 | 1.7576 |

Coefficients

| | Estimate | Standard Error | Z value | p-value |
|---|---|---|---|---|
| (Intercept) | 1.3045 | 0.4378 | 2.980 | 0.00289 ** |
| Age 25-29 | 1.0182 | 0.5404 | 1.884 | 0.05954 . |
| Age 30-39 | 0.5534 | 0.5038 | 1.098 | 0.27199 |
| Age 40-49 | 1.5840 | 0.5535 | 2.862 | 0.00421 ** |
| Age 50-59 | 1.1912 | 0.5635 | 2.114 | 0.03450 * |
| Age 60+ | 1.4967 | 0.5778 | 2.590 | 0.00959 ** |
| GenderM | 0.7824 | 0.3067 | 2.551 | 0.01075 * |

---

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

Null deviance: 272.97 on 196 degrees of freedom

Residual deviance: 251.47 on 190 degrees of freedom

(12 observations deleted due to missingness)

AIC: 265.47

Number of Fisher Scoring iterations: 4

logit_eat_i <- glm(Eat_bat ~ Age * Gender,data=jess_data,family="binomial")

summary(logit_eat_i)

Call:

glm(formula = Eat_bat ~ Age * Gender, family = "binomial", data = jess_data)

Deviance Residuals:

| Min | 1Q | Median | 3Q | Max |
|---|---|---|---|---|
| -1.6651 | -1.1213 | 0.7585 | 1.0302 | 2.3548 |

Coefficients

| | Estimate | Standard Error | Z value | p-value |
|---|---|---|---|---|
| (Intercept) | -2.708 | 1.033 | -2.622 | 0.00874 ** |
| Age 25-29 | 2.575 | 1.155 | 2.229 | 0.02584 * |
| Age 30-39 | 1.710 | 1.123 | 1.522 | 0.12809 |
| Age 40-49 | 3.807 | 1.183 | 3.217 | 0.00129 ** |
| Age 50-59 | 2.197 | 1.265 | 1.737 | 0.08238 . |
| Age 60+ | 3.401 | 1.252 | 2.717 | 0.00658 ** |
| GenderM | 2.842 | 1.155 | 2.460 | 0.01390 * |
| Age 25-29:GenderM | -2.351 | 1.358 | -1.731 | 0.08345 . |
| Age 30-39:GenderM | -1.555 | 1.313 | -1.184 | 0.23624 |
| Age 40-49:GenderM | -3.689 | 1.386 | -2.661 | 0.00779 ** |
| Age 50-59:GenderM | -1.483 | 1.451 | -1.022 | 0.30667 |
| Age 60+:GenderM | -2.842 | 1.444 | -1.968 | 0.04905 * |

---

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

Null deviance: 272.97 on 196 degrees of freedom

Residual deviance: 240.26 on 185 degrees of freedom

(12 observations deleted due to missingness)

AIC: 264.26

Number of Fisher Scoring iterations: 5

AIC(logit_eat,logit_eat_i)

| | df | AIC |
|---|---|---|
| logit_eat | 7 | 265.4748 |
| logit_eat_i | 12 | 264.2594 |

**Past bat eating model**

```
logit_eat_past <- glm(Past_eat_bat ~ Age + Gender,data=jess_data,family="binomial")

summary(logit_eat_past)

Call:

glm(formula = Past_eat_bat ~ Age + Gender, family = "binomial", data = jess_data)


Deviance Residuals:

     Min        1Q    Median        3Q       Max
 -2.3239    0.2107    0.5231    0.7953    1.0157
```

Coefficients

| | Estimate | Standard Error | Z value | p-value |
|---|---|---|---|---|
| (Intercept) | 0.57503 | 0.44293 | 1.298 | 0.19420 |
| Age 25-29 | -0.18192 | 0.58713 | -0.310 | 0.75668 |
| Age 30-39 | 0.17961 | 0.55157 | 0.326 | 0.74471 |
| Age 40-49 | 0.41406 | 0.62761 | 0.660 | 0.50943 |
| Age 50-59 | -0.03042 | 0.64201 | -0.047 | 0.96221 |
| Age 60+ | 2.05572 | 1.10967 | 1.853 | 0.06395 . |
| GenderM | 1.16547 | 0.38654 | 3.015 | 0.00257 ** |

```
---

Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 201.51  on 196  degrees of freedom

Residual deviance: 183.38  on 190  degrees of freedom

  (12 observations deleted due to missingness)

AIC: 197.38

Number of Fisher Scoring iterations: 6
```

logit_eat_past_i <- glm(Past_eat_bat ~ Age * Gender,data=jess_data,family="binomial")

summary(logit_eat_past_i)

Call:

glm(formula = Past_eat_bat ~ Age * Gender, family = "binomial", data = jess_data)

Deviance Residuals:

| Min | 1Q | Median | 3Q | Max |
|---|---|---|---|---|
| -2.09629 | 0.00013 | 0.53498 | 0.73248 | 1.04885 |

Coefficients

| | Estimate | Standard Error | Z value | p-value |
|---|---|---|---|---|
| (Intercept) | 0.5108 | 0.5164 | 0.989 | 0.323 |
| Age 25-29 | 0.1823 | 0.7528 | 0.242 | 0.809 |
| Age 30-39 | 0.2007 | 0.6513 | 0.308 | 0.758 |
| Age 40-49 | 0.9555 | 0.8228 | 1.161 | 0.245 |
| Age 50-59 | 0.5878 | 0.9661 | 0.608 | 0.543 |
| Age 60+ | 1.5685 | 1.1797 | 1.330 | 0.184 |
| GenderM | 1.3610 | 0.9185 | 1.482 | 0.138 |
| Age 25-29:GenderM | 0.8755 | 1.2126 | 0.722 | 0.470 |
| Age 30-39:GenderM | 16.8949 | 1423.3568 | 0.012 | 0.991 |
| Age 40-49:GenderM | 1.3610 | 1.2900 | 1.055 | 0.291 |
| Age 50-59:GenderM | 1.0733 | 1.3501 | 0.795 | 0.427 |
| Age 60+:GenderM | 15.1257 | 1537.4013 | 0.010 | 0.992 |

(Dispersion parameter for binomial family taken to be 1)

Null deviance: 201.51 on 196 degrees of freedom

Residual deviance: 172.20 on 185 degrees of freedom

(12 observations deleted due to missingness)

AIC: 196.2

Number of Fisher Scoring iterations: 17

AIC(logit_eat_past,logit_eat_past_i)

| | df | AIC |
|---|---|---|
| logit_eat_past | 7 | 197.3826 |
| logit_eat_past_i | 12 | 196.1991 |

**Contact with bats model**

logit_contact <- glm(Contact ~ Age + Gender,data=jess_data,family="binomial")

summary(logit_contact)

Call:

glm(formula = Contact ~ Age + Gender, family = "binomial", data = jess_data)

Deviance Residuals:

| Min | 1Q | Median | 3Q | Max |
|---|---|---|---|---|
| -2.1896 | -0.7863 | 0.4368 | 0.8725 | 1.9545 |

Coefficients

| | Estimate | Standard Error | Z value | p-value |
|---|---|---|---|---|
| (Intercept) | -1.7499 | 0.4711 | -3.714 | 0.000204 *** |
| Age 25-29 | 0.1810 | 0.5754 | 0.315 | 0.753071 |
| Age 30-39 | 0.7345 | 0.5317 | 1.381 | 0.167160 |
| Age 40-49 | 1.3160 | 0.5794 | 2.271 | 0.023121 * |
| Age 50-59 | 0.9426 | 0.5914 | 1.594 | 0.110980 |
| Age 60+ | 2.2667 | 0.6767 | 3.350 | 0.000809 *** |
| GenderM | 1.7848 | 0.3390 | 5.265 | 1.41e-07 *** |

---

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

Null deviance: 271.53 on 195 degrees of freedom

Residual deviance: 220.47 on 189 degrees of freedom

(13 observations deleted due to missingness)

AIC: 234.47

Number of Fisher Scoring iterations: 4

logit_contact_i <- glm(Contact ~ Age * Gender,data=jess_data,family="binomial")

summary(logit_contact_i)

Call:

glm(formula = Contact ~ Age * Gender, family = "binomial", data = jess_data)

Deviance Residuals:

| Min | 1Q | Median | 3Q | Max |
|---|---|---|---|---|
| -1.8930 | 0.6681 | 0.6039 | 0.9282 | 2.0393 |

Coefficients

| | Estimate | Standard Error | Z value | p-value |
|---|---|---|---|---|
| (Intercept) | -1.94591 | 0.75593 | -2.574 | 0.0100 * |
| Age 25-29 | 0.07411 | 1.07161 | 0.069 | 0.9449 |
| Age 30-39 | 0.55962 | 0.90632 | 0.617 | 0.5369 |
| Age 40-49 | 1.43508 | 0.91547 | 1.568 | 0.1170 |
| Age 50-59 | 1.94591 | 1.03510 | 1.880 | 0.0601 . |
| Age 60+ | 3.19867 | 1.10194 | 2.903 | 0.0037 ** |
| GenderM | 2.07944 | 0.91612 | 2.270 | 0.0232 * |
| Age 25-29:GenderM | 0.14904 | 1.28805 | 0.116 | 0.9079 |
| Age 30-39:GenderM | 0.47000 | 1.16266 | 0.404 | 0.6860 |
| Age 40-49:GenderM | -0.10228 | 1.23134 | -0.083 | 0.9338 |
| Age 50-59:GenderM | -1.46040 | 1.24862 | -1.170 | 0.2422 |
| Age 60+:GenderM | -1.72277 | 1.37191 | -1.256 | 0.2092 |

---

Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

Null deviance: 271.53  on 195  degrees of freedom

Residual deviance: 215.03  on 184  degrees of freedom

(13 observations deleted due to missingness)

AIC: 239.03

Number of Fisher Scoring iterations: 4

AIC(logit_contact,logit_contact_i)

| | df | AIC |
|---|---|---|
| logit_contact | 7 | 234.4723 |
| logit_contact_i | 12 | 239.0279 |

**Bat preparation for consumption model**

logit_prepare_i <- glm(Prepare_eat ~ Age * Gender,data=jess_data,family="binomial")

summary(logit_prepare_i)

Call:

glm(formula = Prepare_eat ~ Age * Gender, family = "binomial", data = jess_data)

Deviance Residuals:

| Min | 1Q | Median | 3Q | Max |
|---|---|---|---|---|
| -2.4043 | 0.9695 | 0.6444 | 0.8446 | 1.4432 |

Coefficients

| | Estimate | Standard Error | Z value | p-value |
|---|---|---|---|---|
| (Intercept) | -0.5108 | 0.5164 | -0.989 | 0.3226 |
| Age 25-29 | 0.3773 | 0.7311 | 0.516 | 0.6058 |
| Age 30-39 | 0.9808 | 0.6551 | 1.497 | 0.1343 |
| Age 40-49 | 1.9772 | 0.8228 | 2.403 | 0.0163 * |
| Age 50-59 | 0.2231 | 0.9220 | 0.242 | 0.8088 |
| Age 60+ | 2.5903 | 1.1797 | 2.196 | 0.0281 * |
| GenderM | 0.6444 | 0.7311 | 0.881 | 0.3781 |
| Age 25-29:GenderM | -1.1170 | 1.0295 | -1.085 | 0.2780 |
| Age 30-39:GenderM | 0.3326 | 1.0029 | 0.332 | 0.7402 |
| Age 40-49:GenderM | -1.0121 | 1.1305 | -0.895 | 0.3707 |
| Age 50-59:GenderM | 0.4906 | 1.1645 | 0.421 | 0.6735 |
| Age 60+:GenderM | 0.1094 | 1.6487 | 0.066 | 0.9471 |

---

Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

Null deviance: 254.29  on 195  degrees of freedom

Residual deviance: 221.23  on 184  degrees of freedom

(13 observations deleted due to missingness)

AIC: 245.23

Number of Fisher Scoring iterations: 5

```
logit_prepare <- glm(Prepare_eat ~ Age + Gender,data=jess_data,family="binomial")
summary(logit_prepare)
```

Call:

glm(formula = Prepare_eat ~ Age + Gender, family = "binomial", data = jess_data)

Deviance Residuals:

| Min | 1Q | Median | 3Q | Max |
|---|---|---|---|---|
| -2.3436 | -1.0979 | 0.6371 | 0.9048 | 1.4418 |

Coefficients

| | Estimate | Standard Error | Z value | p-value |
|---|---|---|---|---|
| (Intercept) | -0.3960 | 0.3977 | -0.996 | 0.31942 |
| Age 25-29 | -0.2070 | 0.5127 | -0.404 | 0.68647 |
| Age 30-39 | 1.0775 | 0.4849 | 2.222 | 0.02626 * |
| Age 40-49 | 1.4745 | 0.5622 | 2.623 | 0.00873 ** |
| Age 50-59 | 0.6245 | 0.5454 | 1.145 | 0.25220 |
| Age 60+ | 2.6630 | 0.8210 | 3.243 | 0.00118 ** |
| GenderM | 0.4130 | 0.3302 | 1.251 | 0.21100 |

---

Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

Null deviance: 254.29  on 195  degrees of freedom

Residual deviance: 225.07  on 189  degrees of freedom

(13 observations deleted due to missingness)

AIC: 239.07

Number of Fisher Scoring iterations: 5

AIC(logit_prepare,logit_prepare_i)

| | df | AIC |
|---|---|---|
| logit_prepare | 7 | 239.0651 |
| logit_prepare_i | 12 | 245.2323 |

*Table 8: Participant details - Gender, and age category*

| Participant details | Gender | | Age category (in years) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Male | Female | 18-24 | 25-29 | 30-39 | 40-49 | 50-59 | 60+ |
| **Total** | 108 | 90 | 31 | 33 | 47 | 32 | 28 | 27 |
| **Percentage** | 54.5 | 45.5 | 15.7 | 16.7 | 23.7 | 16.2 | 14.1 | 13.6 |

*Table 9: Participant details – education in years, where NA = No Answer*

| Participant details | Education (in years) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 13+ | NA |
| **Total** | 2 | 1 | 1 | 4 | 3 | 26 | 14 | 31 | 22 | 48 | 10 | 32 | 4 |
| **Percentage** | 1 | 0.5 | 0.5 | 2 | 1.5 | 13.1 | 7.1 | 15.7 | 11.1 | 24.2 | 5.1 | 16.2 | 2 |

*Table 10: Participant details - religion, where NA = No Answer*

| Participant details | Religion | | | | | | |
|---|---|---|---|---|---|---|---|
| | Methodist | Christian | Catholic | Other Christian | Hindu | No religion | NA |
| **Total** | 102 | 23 | 35 | 27 | 6 | 2 | 3 |
| **Percentage** | 51.5 | 11.6 | 17.7 | 13.6 | 3 | 1 | 1.5 |

*Table 11: Participant perceptions about the diet of bats and what they have been observed to eat*

| Question | What do you think bats eat? | | | | | | What have you seen bats eat? | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fruit | Seed | Plants/ Flowers | Insects | Other | NA | Fruit | Seed | Plants/ Flowers | Insects | Other | NA |
| **Number** | 194 | 6 | 27 | 14 | 8 | 2 | 195 | 3 | 14 | 9 | 5 | 1 |
| **Comments** | | 5/6* | 26/27* | 12/14* | 5/8*, 2/8**. Other = lizards, rats, nuts, dew/mist, ground fruit | No Answer | | 2/3* | 13/14* | 7/9* | 1/5*, 1/5**. Other = dew/mist, nuts | No Answer |
| | * also answered Fruit<br>** also answered Insects | | | | | | | | | | | |

*Table 12: Reported time of day for bat activity*

| Question | At what times do you see bats being active? | | | | | |
|---|---|---|---|---|---|---|
| | Dawn/ Sunrise | Morning | Afternoon | Dusk/ Sunset | Night | Other* |
| **Number** | 20 | 9 | 85* | 45* | 113 | 13 |
| **Comments** | 86 partipants answered 2 or more times of day that bats were active. Some answers varied depending on size/type of bat.<br>*Other: “during day go up and down in the trees above the mountain”; “if clouded weather will be out active at lunchtime”; “tan ones are seen at any time of day”; “if disturbed will see during the day”; “B. lulu anytime during the day”; “only see during a cyclone”. | | | | | |

*Table 13: Reported presence of bat roosts close to human activity*

| Question | Are there any bats roosting near where you live, commute or work? | | If YES, Where are the roosts? | | | |
|---|---|---|---|---|---|---|
| | Yes | No | Tree | Cave | Both tree and cave | NA |
| **Response** | 128 | 69 | 114 | 3 | 11 | 69 |
| **Percentage** | 65 | 35 | 89.1 | 2.3 | 8.6 | - |

Note: NA = Not applicable as no roosting reported

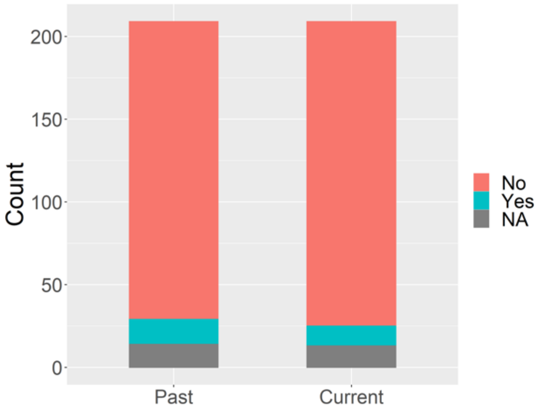


*Figure 9: Comparing past and present reported use of bat guano as fertiliser in Fiji*