SHORT COMMUNICATIONS

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Introduction and Establishment of Raccoon Rabies on Islands: Jekyll Island, Georgia, USA as a Case Study

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ABSTRACT: The introduction of rabies virus (RABV) to barrier islands, which are often popular tourist destinations with resource-rich habitats and connectivity and proximity to the mainland, is especially concerning because it can easily become endemic due to factors like dense rabies-vector populations (e.g., raccoons [*Procyon lotor*]), high inter- and intraspecies contact rates, and anthropogenic activities such as supplemental feeding of feral cats (*Felis catus*). In January 2013, a neurologic raccoon found on the Jekyll Island (JI), Georgia, US causeway tested positive for rabies. Mortality investigations of 29 raccoons have been conducted between December 2012–May 2017. The two most common diagnoses were RABV (n=11) and canine distemper virus (CDV; n=8). Parvoviral enteritis was diagnosed in four raccoons but no coinfections were diagnosed. There was no apparent seasonality for rabies cases, but all CDV cases occurred in spring-fall. Most (64%) rabies submissions came from residential or recreational use areas located near feral cat feeding stations. Jekyll Island is a popular destination where tourists engage in numerous outdoor activities which facilitate human-wildlife interactions. Concerns regarding public and animal health highlight the importance of rabies surveillance, prevention, and control on islands. This is the first report of rabies on JI and emphasizes the importance of disease investigations because the assumption that neurologic raccoons have CDV, an endemic pathogen, can miss the establishment of novel pathogens such as RABV.

Key words: Epizootic, infectious disease, island biogeography, *Procyon lotor*, public health, urban wildlife, zoonoses.

Rabies has a near 100% fatality rate and is now considered enzootic in most eastern US populations of the raccoon (*Procyon lotor*), the main terrestrial host in this region (Rupprecht et al. 2000). Historically enzootic in Florida, rabies was introduced to West Virginia through raccoon translocations (Nettles et al. 1979). Thereafter, rabies spread throughout the eastern US, and the highest number of rabies diagnoses occurred in Georgia (n=297), North Carolina (n=385), and Virginia (n=506) in 2013 (Dyer et al. 2014). Most rabies epidemiologic data come from mainland populations while the introduction and establishment on barrier islands remains poorly described.

Large islands (e.g., Australia and Japan) have a long history of rabies prevention or control and eradication efforts (Rupprecht et al. 2000). Although Australia is currently free of terrestrial rabies, the risk of the spread of the virus from Southeast Asia engendered a strict quarantine preparedness plan (Sparkes et al. 2015). In contrast to large, isolated islands, small barrier islands with roadway connection to the mainland and diverse land-use practices, such as Jekyll Island (JI), Georgia, US (31°4′12″N, 81°25′13″W), are more vulnerable to the introduction of rabies because of high densities of susceptible hosts such as raccoons (Parsons et al. 2013). High raccoon densities on islands may be facilitated by anthropogenic food sources and resource-rich habitats and, because raccoons are highly adaptable, islands with a mixture of development and ample marshland can support the

TABLE 1. Raccoons (*Procyon lotor*) from Jekyll Island, Georgia, USA presenting with neurologic or physical signs when submitted to the Southeastern Cooperative Wildlife Disease Study for investigation of mortalities (2012–17).

Month and year	Age	Reason for submission	Diagnosis[a]	Diagnostic method[b]
December 2012	Adult	Unknown	Parvoviral enteritis	IHC
January 2013	Adult	Physical signs	Unknown	Necropsy
January 2013	Adult	Neurologic signs	Rabies	FA
April 2013	Unknown	Neurologic signs	Unknown	Necropsy
April 2014	Adult	Neurologic signs	CDV	FA
April 2014	Adult	Neurologic signs	CDV	FA
May 2014	Adult	Neurologic signs	CDV	FA
May 2014	Adult	Found dead	Parvoviral enteritis	IHC
May 2014	Adult	Found dead	CDV	IHC
June 2014	Unknown	Neurologic signs	Renal failure	IHC
July 2014	Adult	Neurologic signs	CDV	FA
July 2014	Unknown	Found dead	CDV	IHC
July 2014	Juvenile	Neurologic signs	CDV	FA
October 2014	Adult	Neurologic signs	CDV	PCR
November 2014	Unknown	Neurologic signs	Rabies	FA
March 2015	Adult	Physical and neurologic signs	Rabies (RRVV)	FA and IHC
April 2015	Adult	Neurologic signs	Gastric foreign body (fishhook)	Necropsy
May 2015	Adult	Physical and neurologic signs	Rabies (RRVV)	FA and IHC
July 2015	Adult	Neurologic signs	Rabies (RRVV)	FA and IHC
July 2015	Juvenile	Found dead	Emaciation/starvation	Necropsy
July 2015	Adult	Physical and neurologic signs	Rabies (RRVV)	FA and IHC
October 2015	Adult	Physical and neurologic signs	Rabies (RRVV)	FA
October 2015	Adult	Physical and neurologic signs	Rabies (RRVV)	FA
November 2016	Juvenile	Found dead	Parvoviral enteritis[c]	IHC and PCR
December 2016	Adult	Found dead	Parvoviral enteritis[c]	IHC and PCR
January 2017	Adult	Physical and neurologic signs	Rabies (RRVV)	FA
February 2017	Adult	Physical and neurologic signs	Rabies (RRVV)	FA
March 2017	Adult	Physical and neurologic signs	Rabies (RRVV)	FA
May 2017	Neonate	Physical signs	Trauma	Necropsy

[a] CDV = canine distemper virus; rabies = rabies virus; rabies (RRVV) = raccoon rabies virus variant.

[b] IHC = immunohistochemistry; FA = fluorescent antibody test.

[c] Identified as canine parvovirus 2a variant.

highest densities, potentially increasing the risk of contact with domestic animals and people. Finally, bridges or causeways can facilitate raccoon movement from endemic areas on the mainland to barrier islands. Rabies surveillance is essential to allow for effective and economic application of control measures on islands to prevent exposure of humans or other animals (Elser et al. 2016).

Rabies in wildlife, though widespread in the region, had not been documented on JI. From December 2012–April 2013, the JI Authority responded to reports of raccoons with neurologic signs (Table 1). One raccoon was found while it was suffering a seizure on the 11-km causeway, the only route connecting JI to the mainland. The raccoon was humanely euthanized and transported to the Georgia Sea Turtle Center for a necropsy. Brain tissue was submitted to the University of Georgia (Athens, Georgia) for direct fluorescent antibody (FA) testing for canine distemper virus (CDV) and rabies virus (RABV). It was positive for RABV but negative for CDV. We do not know if this raccoon was dispersing from the mainland or if it became infected on the island. At about the same time, three other sick raccoons were also euthanized and submitted for mortality investigation, but they proved to be negative for RABV and CDV by FA of brain tissue, so additional testing was performed. One raccoon had grossly enlarged mesenteric lymph nodes and was diagnosed with parvoviral enteritis by immunohistochemical staining of histologic lesions that included massive epithelial necrosis of the small intestine and cecum and a loss of crypts, villous erosion, and thick mats of superficial bacteria. The cause of neurologic signs in the other two raccoons was not determined.

Including the first rabies case, a total of 29 raccoons from JI that presented with neurologic signs or that died naturally were submitted for necropsy from December 2012–May 2017 (Table 1). Personnel from JI Authority actively survey for, and respond year-round to, reports of raccoons with neurologic signs. Most (64%) rabies submissions came from residential or recreational use areas in the middle and north sections of JI near feral cat (*Felis catus*) feeding stations (Fig. 1). In most cases (n=20), a gross necropsy with histopathology was done, and brain tissue was submitted for RABV and CDV testing via FA. For nine rabies-positive raccoons, further diagnostics were not performed. For most cases, RABV and CDV were the etiologies during two overlapping outbreaks. In 2014, 11 raccoons were submitted for mortality investigation, of which eight (73%) had CDV, one (9%) had rabies, one (9%) had parvoviral enteritis, and one (9%) was of undetermined etiology. In 2015, 6/8 (75%) raccoons submitted had microscopic lesions consistent with viral encephalitis and were confirmed to be positive for rabies through FA testing. Despite continued active surveillance, no additional sick raccoons were noted until November and December, 2016, when two raccoons were submitted within 2 wk of each other, both with parvoviral enteritis. These cases were followed by three raccoon submissions in the first quarter of 2017, all of which were positive for RABV. A total of 9/11 (82%) RABV samples submitted to the Centers for Disease Control and Prevention (Atlanta, Georgia) were typed as the raccoon rabies virus variant. Although parvovirus is a common cause of mortality among young raccoons in rehabilitation, it is rarely associated with disease in free-ranging raccoons (Allison et al. 2012). Nevertheless, four cases have been diagnosed from JI as of May 2017. A partial capsid protein-encoding gene sequence was obtained from intestinal samples from two cases using PCR with primers 555for and 555rev as described by Buonavoglia et al. (2001). Both cases were positive for the variant of canine parvovirus 2a reported from raccoons in the eastern US (Allison et al. 2012). In addition, rabies virus and parvoviral enteritis-positive cases have occurred at approximately 2-yr intervals.

The re-emergence of rabies in Taiwan after a 52-yr absence emphasizes the need for adaptive surveillance on islands (Wu et al. 2014). The emergence and sustained transmission of rabies on JI further highlights the importance of rabies surveillance on islands and the management of anthropogenic activities, such as inadvertent and purposeful supplemental feeding, which can lead to high raccoon densities and which has been associated with rabies transmission and spillover to other species (Riley et al. 1998). Raccoons on JI have an abundance of natural resources from salt marshes and anthropogenic food sources including picnic areas, campgrounds, and additional supplemental feeding at feral cat feeding stations. Feeding stations attract a variety of wildlife including raccoons that feed and regularly interact with feral cats during morning feeding times (Fig. 2). In addition to facilitating higher densities, feeding stations enable pathogen transmission by increasing both inter- and intraspecies contact rates (Weissinger et al. 2009). Mandatory cat vaccination against rabies in the US varies by state, and local governments often implement their own regulations (American Veterinary Medical Association 2017). In addition, rabies vaccination produces, at most, 3 yr of protection against infection (Brown et al. 2016).

High raccoon densities are a public health concern, particularly on islands like JI, be-

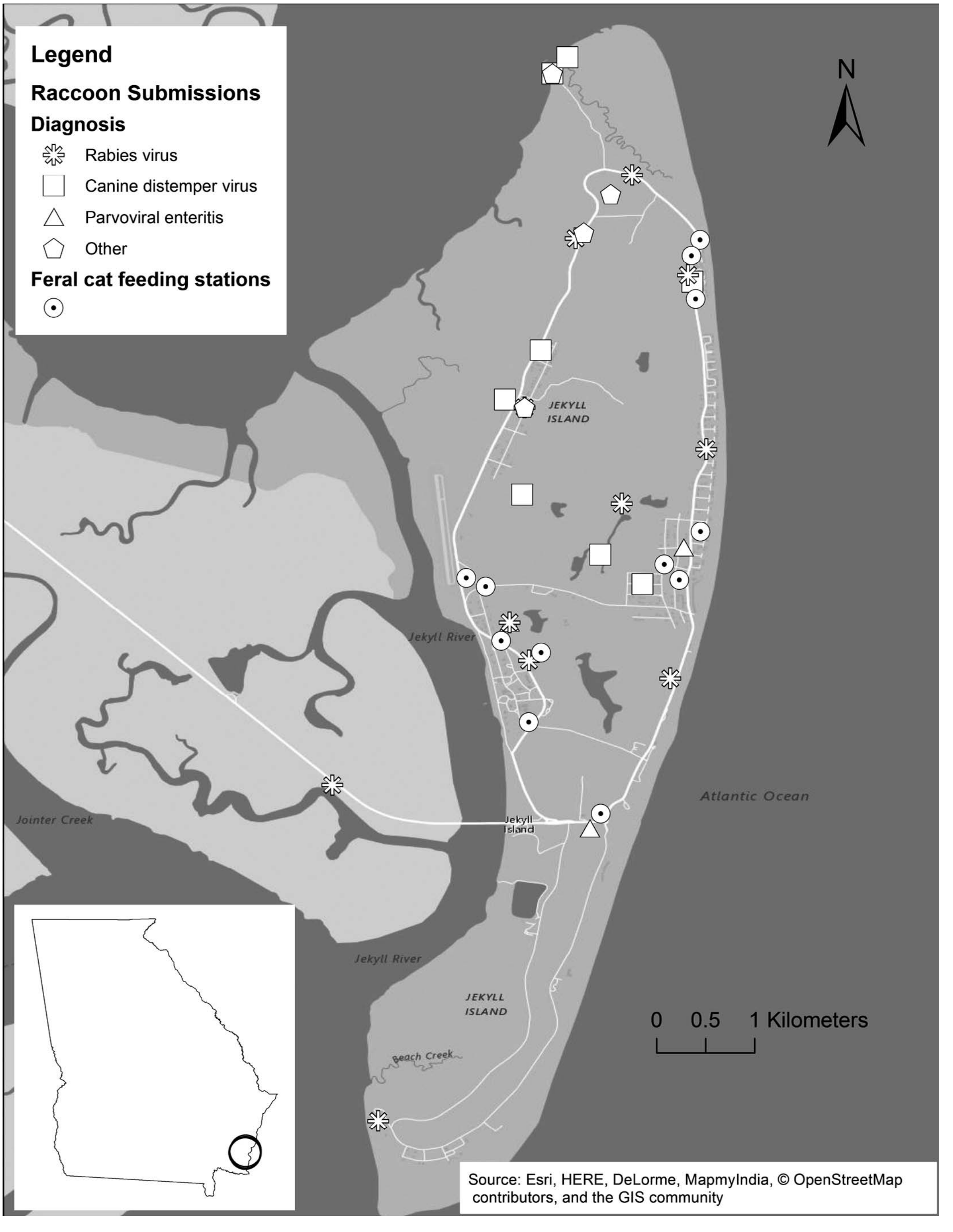

FIGURE 1. Locations of feral cat (*Felis catus*) feeding stations and sources of raccoon (*Procyon lotor*) rabies cases on Jekyll Island, Georgia, USA.

cause of the relative high probability there for close human-raccoon contact. Unlike other barrier islands in Georgia that are either completely protected natural areas (e.g., Cumberland Island) or almost entirely developed (e.g., St. Simon's Island), Jekyll Island is a state park with approximately two thirds of its area undeveloped (Jekyll Island Authority

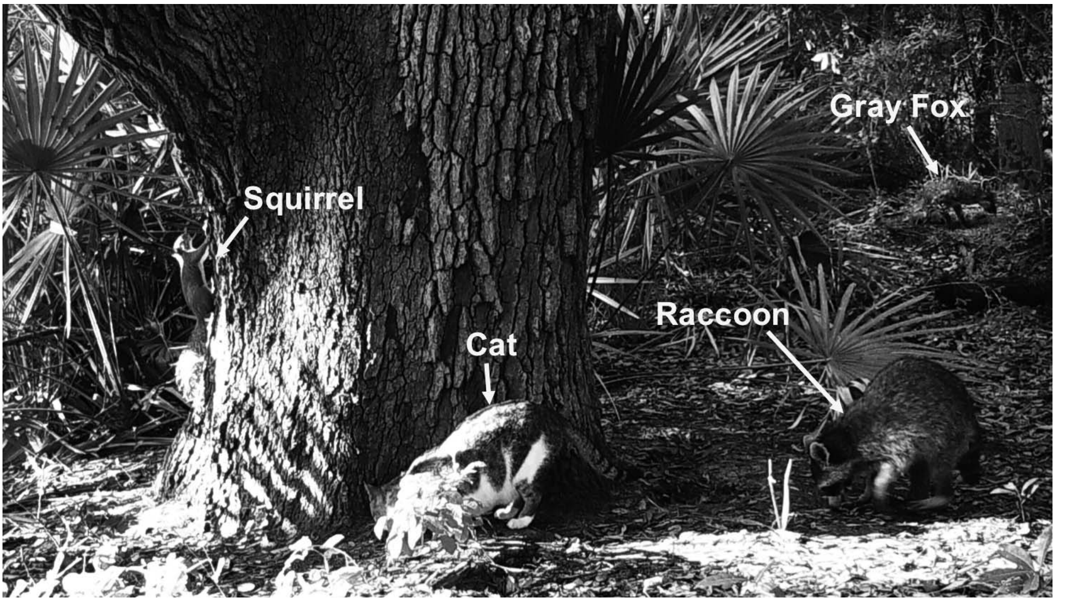

FIGURE 2. Camera trap image showing simultaneous use of a feral cat (*Felis catus*) feeding station on Jekyll Island, Georgia, USA by a cat, a gray squirrel (*Sciurus carolinensis*), a raccoon (*Procyon lotor*), and a gray fox (*Urocyon cinereoargenteus*).

2015). Over 500,000 annual visitors use the beaches, the 32 km of multiuse trails through maritime hardwood forests and marshes, and golf courses, and otherwise engage in outdoor activities that facilitate contact with wildlife, including raccoons. A particular concern is that when raccoons become habituated to humans, domestic, and peridomestic animals, and visit feral cat feeding stations near recreational and residential areas during daylight hours, potential public health risk foci are established (Gerhold and Jessup 2013).

This diagnostic investigation emphasized the importance of postmortem evaluation of raccoons with neurologic signs because clinical signs cannot be used to accurately differentiate between RABV, CDV, trauma, or other causes. Although coinfection with RABV and CDV was not found in this investigation, our data provide evidence for possible overlapping outbreaks and the potential for coinfections. Missed coinfections or misdiagnoses may prevent or delay implementation of appropriate public health measures. Because RABV, CDV, and parvovirus can infect various hosts and are easily transmitted, high raccoon densities or interactions at feral cat feeding stations could assist transmission, particularly through direct contact. Artificial increases in raccoon abundance can also have conservation implications because raccoons prey on protected fauna, such as sea turtle eggs, which may lead to recommendations for culling (Davis and Whiting 1977). However, raccoons play important ecologic roles (e.g., seed dispersal, predation of vertebrate and invertebrate species), and the potential consequences of their removal from these environments warrants careful consideration (Ratnaswamy and Warren 1998).

Barrier islands are unique, biodiverse, delicate ecosystems already struggling to balance substantial tourism impacts. The introduction of novel pathogens that pose significant concerns to public and animal health is of major importance. The recent confirmation of rabies on JI should be used to promote public awareness and education on the dangers of anthropogenic activities such as supplemental feeding at feral cat stations or by well-meaning citizens at campgrounds and picnic shelters. Our study showed that both

CDV and parvovirus infections also caused raccoon mortalities on JI. As both viruses can cause morbidity and mortality in numerous domestic and wild carnivore species, these findings should be communicated to the public to encourage annual pet vaccination. A plan to prevent further transmission of rabies on JI, as well as on other islands, should include surveillance of raccoons that are found dead or exhibit neurologic signs as well as identification of potential points of intense intra- and interspecies contact. Other more intensive strategies, such as an oral rabies vaccination program, may be considered. Further research to determine current raccoon population size, health, and individual home ranges may help determine potential pathogen transmission dynamics.

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