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(RESEARCH ARTICLE)

The impact of river and mountainous terrain on the spread of Formosan ferret-badger (*Melogale moschata subaurantiaca*) rabies in Taiwan

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Abstract

Since the initial epizootic of the Formosan ferret-badger (FFB) rabies outbroke in 2013, the enzootic area of the FFB rabies has always been limited to six counties and three cities in Taiwan. These six counties and three cities, from north to south, are Taichung City, Nantou County, Yunlin County, Chiayi County, Tainan City, Kaohsiung City, Hualien County, Taitung County, and Pingtung County. They are located south of the Daan River and the Heping River, the latter is on the east side of the Daan River. In January 2023, ten years after 2013, under the annual Surveillance Program for the Detection of the FFB rabies instituted by the Animal and Plant Health Inspection Agency (APHIA), Ministry of Agriculture, it was found that the FFB rabies virus had spread across the Daan River and entered Miaoli County, which is located in the north side of the Daan River. The previously naïve populations of FFBs in Miaoli County were infected; therefore, another initial massive epizootic of the FFB rabies cannot be ruled out in areas north of the Daan River and the Heping River in the future.

Keywords: Rabies; Epidemiology; Spread; Terrain

1. Introduction

The rabies virus (RABV) is the prototype virus of the Lyssavirus genus. The genus Lyssavirus is divided into 17 species accepted by the International Committee on the Taxonomy of Viruses (ICTV) [1]. The number of human deaths globally due to dog-mediated rabies is estimated to be 59 000 annually, accounting for more than 99% of all human rabies deaths [2]. The RABV is believed to be capable of infecting all mammals. Animal rabies viruses of the world exist in two epidemiological cycles: one is the urban cycle featured with dog-mediated rabies, and the other is the wildlife cycle (otherwise known as the sylvatic cycle) with rabies circulating in certain wildlife populations in forests.

RABV is typically transmitted through the saliva of the carriers by biting or scratching the victim. The major reservoir hosts of the rabies virus are terrestrial carnivores and bats [3]. In the urban cycle of rabies, dogs are the main reservoir hosts in the world. Common reservoir hosts in the wildlife cycle of rabies include foxes, bats, skunks, raccoons, raccoon dogs, mongooses, and ferret-badgers. Bat-mediated rabies is only found in the New World, and rabies has not been detected in bats of the Old World [4]. On July 17, 2013, under the Surveillance Programs for the Detection of Zoonotic Diseases in Wildlife instituted by the APHIA, RABV was found in FFBs [5, 6], which marked the first appearance of rabies in Taiwan since the World Health Organization (WHO) declared Taiwan rabies free in 1961 [5]. So far, the ferret-badger

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rabies has only occurred in Taiwan and China's Mainland [7]. There is no dog-mediated rabies in Taiwan, and the FFB is the only one rabies reservoir and no human rabies deaths have been associated with the FFB rabies in Taiwan.

Since 2013, the APHIA has implemented comprehensive and continuous Surveillance Programs for the Detection of Rabies in the whole country [5]. Data showed that until the end of 2022, the FFB rabies in Taiwan had been limited to these above-mentioned six counties and three cities. The possible reason is that the Daan and the Heping Rivers, on the north side of these six counties and three cities, which prevented the northward spread of the FFB rabies [5, 8]. However, in January 2023, cases of the FFB rabies were found on the northern side of the above-mentioned Daan River. This report details the monitoring process and discusses its possible causes.

2. Material and methods

In Surveillance Programs for the Detection of Rabies of the APHIA, animal samples include live and dead animals. Live animals were captured using the animal capture web and/or the single-door box trap. Dead animal samples were mainly gathered from animals found dead including roadkill as well as animals that unfortunately died after being treated for injuries. Dead animal samples were gathered/collected with the assistance of law enforcement officials of municipal/prefectural competent authorities for veterinarians, wildlife conservationists/researchers, and *the active engagement of the general public*. These samples were sent to the local competent authorities for the veterinary scanning surveillance.

Capture method using the animal capture web: FFBs are nocturnal animals that often forage on agricultural land, dry river beds and estate roads at the edges of forests from 7:00 PM to 4:00 AM. To capture them, they visited the above-mentioned areas where FFBs were frequently seen. They scanned the areas using thermal imaging cameras. Then they captured FFBs using the animal capture web. FFBs run slowly. Adult FFBs weigh no more than 2 kg, and juvenile FFBs weigh around 800 mg. Therefore, they are easy to catch. FFBs could be found within a distance of 70-100 m using a thermal imaging camera. People should wear long-sleeved leather gloves while capturing FFBs. They must have received rabies pre-exposure prophylaxis (PrEP).

Capture method using the single-door box trap: FFBs were live-captured in traps baited with bananas, oranges, chickens, and sardines. The single-door box trap was deployed at 7:00 PM and checked at 4:00 AM the next day. In Surveillance Programs for the Detection of Rabies of the APHIA, all animal samples (or heads only) were sent to the national Veterinary Research Institute (VRI) for rabies diagnosis. They were diagnosed using the direct fluorescent antibody (DFA) test. This test is based on the standard operating procedure in Chapter 3.1.18 of "Manual of Diagnostic Tests and Vaccines for Terrestrial Animals 2022" of the World Organization for Animal Health (WOAH) [9]. In January 2023, five FFBs were sampled and sent to the VRI for rabies diagnosis.

Animal Health Research Institute (AHRI, the old name of VRI) paired with the Nancy Laboratory (Nancy Laboratory for Rabies and Wildlife, the European Union Reference for Rabies of the WOAH) for rabies diagnosis. The WOAH twinning project for rabies-associated laboratory techniques between Nancy Laboratory and VRI (formerly AHRI), was achieved on November 7, 2022. [10].

3. Results

The species and the number of all wild carnivores sampled in Miaoli County from January 2013 to December 2022 were shown in Table 1. Based on the data in Table 1, 671 wild carnivores were sampled in Miaoli County from 2013 to December 2022. These included 475 FFBs and 196 wild carnivores of four other species. All of them were negative for rabies infection. During the routine surveillance work in January 2023 under the Surveillance Programs for the Detection of Rabies of the APHIA, five FFBs were sampled. The GPS coordinates, administrative areas, rabies test results, and other associated data of the five FFB samples collected were listed in Table 2 and Figure 1. Table 2 showed that 3 out of the 5 wild FFB samples were positive for rabies infection. Figure 1 showed that the three positive FFB samples (red arrows) were located in the mountainous area on the north side of the Daan River.

Table 1 The number of Confirmed Rabies Cases and Number of Tested Animals by Species: Miaoli, Taiwan, 2013–2022

Years	Ferret-badger	Masked palm civet	Crab-eating mongoose	Small Indian civet	Leopard cat	Subtotal
2013	0/147	0/8	0/1	0/1	0	0/157
2014	0/15	0/1	0/1	0	0	0/17
2015	0/19	0/7	0	0	0	0/26
2016	0/16	0/3	0	0	0/1	0/20
2017	0/28	0/4	0	0	0/2	0/34
2018	0/33	0/5	0/3	0	0/1	0/42
2019	0/27	0/9	0/6	0	0/11	0/53
2020	0/107	0/32	0/8	0	0/15	0/162
2021	0/46	0/23	0	0	0/15	0/84
2022	0/37	0/20	0/4	0/1	0/14	0/76
Total	0/475	0/112	0/23	0/2	0/59	0/671

Note: Number of positives/tested. Masked palm civet (Paguma larvata taivana); Crab-eating mongoose (Herpestes urva formosanus); *small Indian civet* (Viverricula indica); leopard cat (Prionailurus bengalensis chinensis).

Table 2 Rabies Surveillance Information for FFBs in Miaoli County of Taiwan, January 2013

Serial no.	Catch date	County	Township	Rabies status*	E Longitude; N Latitude
1	01-Jan-2023	Miaoli	Zhuolan	Not rabid	(120.8563; 24.3021)
2	02-Jan-2023	Miaoli	Zhuolan	Rabid	(120.8737; 24.3165)
3	04-Jan-2023	Miaoli	Zhuolan	Not rabid	(120.8563; 24.3021)
4	08-Jan-2023	Miaoli	Zhuolan	Rabid	(120.8712; 24.2984)
5	18-Jan-2023	Miaoli	Taian	Rabid	(120.9636; 24.3866)

* Direct fluorescent antibody (DFA) test.

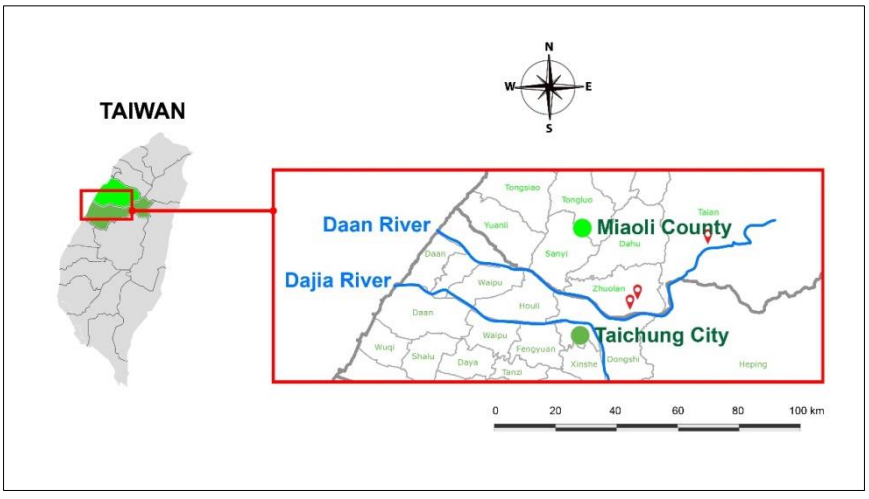

Figure 1 The location of three rabid FFBs (red arrows) in the Zhuolan and Taian ~~of~~ townships in Miaoli County sampled in January 2023. Three rabid FFBs in red arrows were shown in the northern mountainous areas of the Daan River.

4. Discussion

Rabies surveillance is the key parameter to assess the rabies situation within the country. The success of planning, implementing, improving performance, and evaluating any eradication program of rabies is dependent on rabies surveillance. After a decades-long program of dog vaccination and dog population management, Dog-mediated Rabies Virus Variants (DMRVV) have been eliminated in the United States. Maintaining this DMRVV-free status requires strict quarantine of imported dogs and continuous implementation of the domestic rabies diagnosis and surveillance system [11, 12]. The Surveillance Programs of Rabies of the APHIA found positive cases of the FFB rabies in the mountainous area on the north side of the Daan River, illustrating the importance of rabies surveillance.

Emerging Infectious Diseases (EIDs) in wildlife populations and concomitant threats to humans and livestock have always attracted public concern [13]. Such EIDs are usually caused by invading pathogen populations into areas inhabited by susceptible host populations. The landscape structure of areas affects the distribution, abundance and movements of hosts, and vectors and pathogen populations. Therefore, the landscape structure inherently influences localized interactions between infectious and susceptible individuals [14]. Previous studies of fox rabies in Europe indicated that "Large rivers, lakes and high mountain chains functioned as obstacles to the spread of rabies [15]", which illustrated the landscape structure of areas, like the Daan River and Heping River, was possible to function as obstacles to the northward spread of the FFB rabies [5, 8].

Common carnivores in Taiwan include FFBs, masked palm civets, crab-eating mongooses, small Indian civets, yellow-throated martens (*Martes flavigula chrysospila*), and Siberian weasels (*Mustela sibirica*). Among these five common carnivores, FFBs inhabited all elevations throughout Taiwan. Masked palm civets and crab-eating mongooses mainly inhabited mid-to-low elevations. Yellow-throated martens and Siberian weasels mainly inhabited mid-to-high elevations [16, 17]. Based on the surveillance records of the APHIA from 2013 to December 2021, the FFB accounted for 62.9% (2,563 of 4,072) of all sampled carnivores [18]. It could be related to the wide distribution of the FFB's habitats, which also seemed to explain why Table 1 showed that the FFB also had accounted for 70.8% (475 of 671), occupying the largest proportion among the carnivores from 2013 to 2022 in Miaoli County.

Previous studies of red foxes (*Vulpes vulpes*) have shown that areas of high-quality habitats support high population densities of red foxes. When the Arctic variant of the rabies virus in red foxes infected the naïve red fox populations that had never been infected by rabies, the initial epizootic would cause the greatest depression in the red fox population [19]. Following an initial epizootic of rabies, a series of successively smaller epizootics would increase frequency over time [20, 21]. The infectivity of the rabies virus variant to the reservoir host is much stronger than that to the novel host. Transmission of rabies virus is primarily among conspecific, with cross-species transmission to other mammals usually depending upon direct interactions with individuals of the reservoir host species [22]. The above statements showed that the FFB was the primary target of the Surveillance Programs of Rabies in Taiwan, although other wild carnivores were also very important.

Previous studies also showed that the spread rate of the rabies epizootic significantly correlated with spatial heterogeneities, as shown below:

- Blocked by rivers: When there was a river in the spread direction of the epizootic, the river would block the path of the reservoir host and stagnated the spread of the epizootic. Rivers being vertical to the spread direction of the epizootic would have the greatest impact; The wider the river, the longer the epizootic spread remained stagnant [21].
- Blocked by habitats: The chief plant of the Adirondack Mountains in New York was coniferous forest, which raccoons dislike. There was no raccoon in the Adirondack Mountains. Therefore, the spread of raccoon-mediated rabies was stagnant when it reached the Adirondack Mountains. It took four years for the epizootic to slowly spread along the terrain inhabited by raccoons outside the Adirondack Mountains [23].
- Blocked by air-dropped oral vaccines: Air-dropped oral vaccines could protect reservoir hosts in vaccine-covered areas against rabies. Its effect was related to (1) the immune capacity of the vaccine, (2) the containment design of the air-dropped vaccine, and (3) topographic features [22].
- The spread rate of the FFB rabies: The average spread rate of fox-mediated rabies was 30 to 50 km/year in Europe and 20 to 80 km/year in Italy [24]. The spread rate of raccoon-mediated rabies in Connecticut and Pennsylvania was 30 to 48 km/year [25, 26, 27]. The spread rate of the FFB rabies in Hualien County was 10.69 km/year [28]. The reason the FFB rabies spreads at a lower rate than fox-mediated and raccoon-mediated rabies might be the FFB's smaller size (< 2 kg for an adult FFB), shorter legs, and slower speed of movement [29]. Another reason might be the topography of Hualien County. Hualien County is part of the Taitung Riff

Valley. The Taitung Riff Valley is squeezed like a 140-kilometer-long (84-mile) slim cigar between the Taitung Mountains and the Central Mountain Range. It is 2 kilometers wide in some places and never exceeds 7 kilometers at its broadest [30]. On its eastern side, the terrain is steep, and the height drops sharply to the Pacific Ocean. Such terrain made it difficult for FFBs to move around. In addition, the Central Mountain Range spans Taiwan's main island from north to south. It has many large rivers flowing eastward to the Pacific Ocean, such as the Siouguluan and the Hualien Rivers. These rivers are perpendicular to the direction of the northward spread of the FFB rabies in Hualien County. The flow of these rivers was fast, which could slow down the spread of the FFB rabies to the north.

In this study, the Figure 1 showed that the Miaoli County was located on the north side of Taichung City, with the Daan River as the main boundary between them. Table 1 indicated that from the initial epizootic outbreak in 2013 through the end of 2022, the enzootic area of the FFB rabies had been limited to south of the Daan River, implying that the Daan River blocked the northward spread of the FFB rabies. This reasoning was also in line with the WHO statement of rabies epidemiology that "Large rivers, lakes and high mountain chains functioned as obstacles to the spread (of rabies). Rivers were usually crossed (by rabies virus) where bridges were available (WHO, 2005)." Additionally, the annual report of Water Pollution Prevention of Taichung City of 2021 indicated that: "… the dry seasons for large rivers in Taichung City were from November to April the next year. In recent years, rainfall during the dry season had shown a trend of decreasing yearly. With much less rainfall especially during the dry season, the river flow decreased accordingly" [31].

5. Conclusion

It was reasonable that because of climate changed in recent years, Taichung City got less rainfall yearly, especially during the dry seasons. As a result, the FFB rabies spread across the Daan River during the dry season, and infected previously naïve FFBs in Miaoli County. That was a possible cause that the FFB rabies happened in Miaoli County, although more reasons might emerge in future researches.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare no conflict of interest.

Statement of ethical approval

The ethics approval was not required, for *a*ll *raw* data files were offered or downloaded *from APHIA or governmental websites*.

Statement of informed consent

An informed consent was taken from all the participants.

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