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Demography and welfare status of free-roaming dogs in Yangmingshan National Park, Taiwan

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ABSTRACT

Free-roaming dogs (*Canis familiaris*) cause threats to native wildlife and public health and raise concerns for their welfare. Understanding the demography of free-roaming dog populations is essential for developing an effective management plan. An evaluation of their welfare status would be beneficial to earn public support for the management plan. In this study, we estimated the population size, survivorship, and health of a free-roaming dog population in Yangmingshan National Park (YMSNP), Taiwan, during 2016–2018. YMSNP is a rural area with human settlements but also a protected area of conservation concern. We identified 191, 176, 216 individuals at our sampling sites in 2016, 2017, and 2018, respectively. Using a photographic capture-recapture method and extrapolation, we estimated that there were 786–979 dogs in the park during this 3-year period. The annual apparent survival rate of identified dogs was 16.7% for 2016–2017 and 23.9% for 2017–2018. The dogs had a high rate of lameness and dermatosis of 5.1–8.8% and 14.2–18.1%, respectively. Thirty-five blood samples showed that 34.3% of the dogs were anemic, 37.1% showed abnormal white blood cell counts, and 68.6% exhibited abnormal platelet counts. These results suggested that the dogs were at high density with low survivorship and in poor health, and new individuals entered the population continuously. Interventions to manage this dog population and to improve their welfare must be carried out. Our study provides an example for monitoring and managing a free-roaming dog population in a rural, conservation area in Southeast Asia.

1. Introduction

Dogs (*Canis familiaris*) have been domesticated by humans for thousands of years, and they have become the most common pets in the world (Larson et al., 2012), with an estimated 700–987 million individuals (Hughes and Macdonald, 2013; Gompper, 2014). However, a high proportion of dogs are free-roaming, which means that they are not confined in a proscribed area by owners or are strays (Matter and Daniels, 2000; Hughes and Macdonald, 2013). Free-roaming dogs usually have high mortality, low reproductive success, and a poor quality of life due to chronic disease and malnutrition (Boitani et al., 1995). Because of the close relationship between dogs and humans, their welfare is of general concern to the public.

Free-roaming dogs not only raise issues regarding their welfare, but they also create serious threats to public health and to natural ecosystems. For example, the dog is one of the most important reservoirs and vectors of human rabies, which causes around 55,000 human deaths per year (Knobel et al., 2005). Furthermore, dogs are exotic carnivores, which cause considerable damage to native wildlife through predation, competition, disease transmission, and hybridization (Vanak and Gompper, 2009; Doherty et al., 2017). At least 188 endangered wildlife species are under threat due to dogs (Doherty et al., 2017). Therefore, effective management of dog populations is essential for animal welfare, public health, and conservation.

To manage an animal population, demographic data are usually required. Published data on dog demography are available for many regions of the world (Gompper, 2014). However, most of the previous studies used mail surveys or telephone interviews (Downes et al., 2009) and focused on owned dogs, which resulted in sampling bias against unowned dogs (Ratsitorahina et al., 2009). Although some studies had carried out field surveys to estimate the abundance of free-roaming dog populations, many of them had low validity due to limitations of their

Abbreviations: YMSNP, Yangmingshan National Park

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research methods (Belo et al., 2015) (e.g. lack of consideration in heterogeneities of detection or capture probabilities). Furthermore, managing a dog population is challenging due to public perception (Young et al., 2011). In many countries, people are highly sympathetic to stray dogs because of cultural or religious beliefs, and they may disagree with intense management methods such as capture and removal. Under this scenario, earning public support is necessary before executing any management plan. We suggest that providing evidence of the poor welfare status of free-roaming dogs would improve people's acceptance of management plans.

The number of owned dogs in Taiwan was estimated to be 1,777,000 (Council of Agriculture, 2017). A high proportion of dog owners, especially in rural areas, allow their dogs to move about freely outdoors (Hsu et al., 2003). In addition, the population size of stray dogs was estimated as 128,000 (Council of Agriculture, 2015). Free-roaming dogs in Taiwan have attacked endangered species such as Chinese pangolin (*Manis pentadactyla*; Wang et al., 2011), and the may have infected native carnivores with canine distemper (Chen et al., 2008). There is also a program to prevent rabies since the reemergence of animal rabies in southern Taiwan in 2013 (Huang et al., 2015). Moreover, animal welfare of dogs receives a great deal of attention in Taiwanese society. Evidence for this is that the Animal Protection Law has been revised seven times in the past ten years (2009–2019) to improve responsible ownership and animal welfare. The law stipulates that pet dogs should be registered and should be neutered, although the achieving rates are not clear. Euthanasia is prohibited for dogs, unless the dog has a severe injury, an incurable disease, or a notifiable infectious disease.

The aim of our research was to study the demographics and welfare status of free-roaming dogs in Yangmingshan National Park (YMSNP), Taiwan. YMSNP demonstrates both a typical rural area of Taiwan and a protected area of conservation concern. To estimate population size and survivorship, we conducted route censuses and used a photographic capture-recapture method during the summer for three years. Although free-roaming dogs include owned but unconfined dogs and stray dogs, we did not distinguish these types due to technical difficulty in the field. To evaluate the health of dogs, we recorded the appearance of dermatosis and lameness during the route censuses. In addition, we captured stray dogs to collect blood samples to carry out complete blood counts. The information gained in our study is essential for planning programs to manage free-roaming dogs and to improve their welfare.

2. Material and methods

2.1. Study area

Yangmingshan National Park (25.18 °N and 121.55 °E) is located in northern Taiwan and surrounded by the Taipei–New Taipei metropolitan area, where 7 million people reside (Fig. 1). This mountainous national park encompasses an area of 113 km^2 with elevations that range from 56 m to 1120 m. The area has a humid subtropical climate. This national park aims to conserve lower-elevation ecosystems of Taiwan, which include threatened wildlife species such as Chinese pangolin, small Indian civet (*Viverricula indica*), masked palm civet (*Paguma larvata*), Formosan macaque (*Macaca cyclopis*), sambar (*Rusa unicolor*), and Reeves's muntjac (*Muntiacus reevesi*). Natural vegetation covers > 90% of the park's surface, and human settlements and agricultural lands account for < 10% (Hsu et al., 2008). Villages and human settlements existed before the establishment of the national park in 1985, which are distributed in several parts of the national park and which contain approximately 12,000 people (Ministry of the Interior, 2013). There are 19 million person-time tourists who visit this park each year (Ministry of the Interior, 2013).

2.2. Route census and photographic capture-recapture method

We conducted route surveys at 6 sites (Site A–F) within YMSNP (Fig. 1; Table 1) during July and August 2016–2018. The six sites cover environmental types that include recreation areas, villages, and major roads (Table 1). One or two researchers walked or rode a motorcycle slowly along the six routes once a week on randomly chosen days with good weather. A single survey for one route took approximately 2–3 h between 5:00–8:00 or 16:00–19:00, when free-roaming dogs were most active (Lin et al., 2000). We identified every dog encountered by recording its physical characteristics such as coat color and pattern, fur length, age (adult, juvenile, or pup), sex (when possible), facial features, tameness, and physical conditions that included dermatosis and lameness. We photographed the dogs with a camera for later reference.

We conducted five surveys for each site every year. We then applied a photographic capture-recapture method to estimate the population size for each year. The capture-recapture method assumed that the population was closed (i.e., that no immigration, emigration, births, or deaths occurred during the sampling period). Therefore, we completed the surveys for each site within 1.5 months to be consistent with the assumption of a closed population during that short interval. No individual was observed to travel between sampling sites during the 1.5-month period. Although female dogs gave birth occasionally during the sampling periods, we did not include the pups in our capture-recapture model because pups usually have a very low survival rate and are easily captured by rangers at YMSNP.

We established a capture history for every identified dog from the replicated surveys and used the software program CARE-4 (Yang and Chao, 2006) to estimate population size. We combined data from Sites A–E to estimate the overall population size and the detection probability. We analyzed data from Site F separately due to the extremely high population size. We tested four candidate models, which differed in their assumed sources of variation in detection probability. The M_0 model (i.e., a null model) assumed no variation in detection probability between individuals or over time. The M_t model was a time variation model that assumed that capture probabilities changed over time. The M_h model was a heterogeneity model that assumed capture probabilities differed among individuals due to age, sex, etc. In this study, we assumed that heterogeneity occurred among sampling sites. Finally, the M_{th} model was a combination of the M_t and M_h models. We did not consider the M_b model and its related models, where an animal's behavior changes after being "captured", because we presumed that our survey disturbed the animals very little. All datasets passed the examination for population closure. We used Akaike's Information Criterion (AIC) to select the best model. We considered models that had a $\Delta AIC < 2$ equally fit, then averaged the competitive models following Burnham and Anderson (2002).

We divided the estimated population sizes by the size of sampling areas to estimate population densities. We defined the sampling area as the area within 100 m in either sides of the survey route. Previous studies showed that the home range size of sedentary dogs was 2.5–5.3 ha (Meek, 1999; Durr and Ward, 2014). If we assume a home range is a circle, the radius would be 89–130 m. We chose a distance of 100 m, which was slightly lower than the median value, because terrain in most areas of YMSNP was rugged. Thus, the sampling area for Sites A–E was 4.66 km^2, and it was 0.31 km^2 for Site F (Table 1).

We calculated total population size of free-roaming dogs in YMSNP by multiplying the estimated population density of Sites A–E by the area of potential habitat except Site F, plus the population size of Site F. Because free-roaming dogs mainly inhabit the paved road system and nearby areas (Chuang, 2004), we defined the potential habitat of dogs in the national park as the area within 100 m from road system. The total length of the road system throughout YMSNP was 231.6 km, and thus the area of potential habitat of dogs was 28.1 km^2, not including Site F.

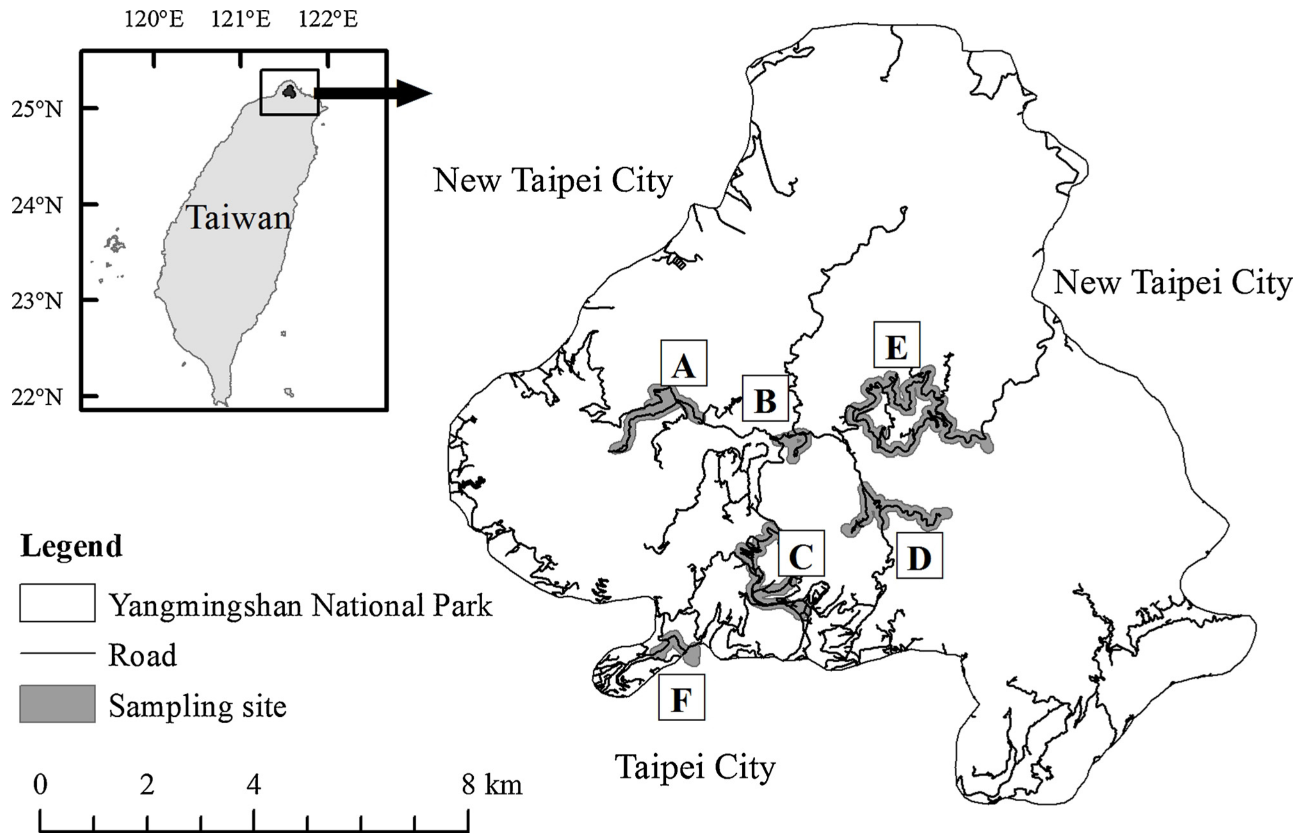

Fig. 1. Map of six sampling sites for population size estimation of free-roaming dogs in Yangmingshan National Park, Taiwan, during 2016–2018.

Table 1
Basic information and number of individuals identified for six sampling sites where population size was estimated for free-roaming dogs in Yangmingshan National Park, Taiwan.

Site	Place name	Major environmental type	Length (km)	Area size (ha)	Number of identified individuals		
					2016	2017	2018
Site A	Datun Nature Park and Erziping Recreation Area	Recreation area	4.5	69	23	15	17
Site B	Xiaoyoukeng Recreation Area	Recreation area, Major road	1.6	47	17	5	15
Site C	Yangming Park and Hushan village	Village, Park, Major road	5.7	92	40	48	54
Site D	Lengshuikeng Recreation Area	Recreation area	4.3	75	20	17	17
Site E	Macao	Major road	11.4	183	21	29	34
Site F	Longfenggu and Liuhuanggu	Recreation area, Village	1.7	31	70	62	79
Total			29.3	497	191	176	216

2.3. Evaluation of dog health

To evaluate the status of free-roaming dogs, we applied four indices: 1) lameness rate, 2) dermatosis rate, 3) survivorship, and 4) complete blood cell count. In general, lameness is the inability to use one or more limbs in a normal manner, which would suggest the presence of foot wounds or other painful disease. To show the severity of lameness in YMNP, we defined lameness as the loss of a paw or an entire foot. We classified dogs with apparent skin lesions as having dermatosis. The lameness rate and dermatosis rate were percentages calculated by taking the number of dogs with lameness or dermatosis and dividing by the number of all identified dogs in the route census. To evaluate survivorship, we calculated annual apparent survival rate and two-year apparent survival rate as the proportion of individuals that survived for two or three consecutive years (Lebreton et al., 1992; Bart et al., 1998).

The rangers of YMSNP routinely captured and removed stray dogs by cage traps or by hand. We took blood samples from the captured dogs before they were placed in shelters. According to their appearance (e.g., without collar) and a scan of a microchip, we could confirm that these individuals were unowned. Blood was collected from the cephalic vein with a 23 G needle and 5 ml syringe (5 cc/ml Syringe, with 23 G x 1/1/4 inch needle, TERUMO®, Japan). Blood samples were placed into tubes (BD Microtainer® tube with k2EDTA, Becton, Dickinson and Company, USA) coated with ethylenediaminetetraacetic acid (EDTA) for hematology. Complete blood cell counts were conducted using an autoanalyzer (Exigo BM800, Boule Medical AB, Sweden) < 4 h after blood was collected. Parameters analyzed included hemoglobin (Hb), hematocrit (HCT), RBC count, mean corpuscular volume (MCV), mean corpuscular hemoglobulin (MCH), mean corpuscular hemoglobulin concentration (MCHC), white blood cell (WBC) count, and platelet count. Tested values of adults were compared with reference values at the clinical pathology lab of National Taiwan University Veterinary Teaching Hospital (NTUVTH); tested values from pups were compared with reference values from pups at the age of eight weeks (Brenten et al., 2016; von Dehn, 2014)

Table 2
Population size estimation of free roaming dogs using a photographic capture-recapture method at six sampling sites in Yangmingshan National Park, Taiwan, during 2016–2018. The Akaike's Information Criterion (AIC), AIC difference (ΔAIC), AIC weight (w_i; weight of evidence in favor of a given model), estimated abundance, and 95% confidence interval values for the best-fitting models (with ΔAIC < 2) are included.

Year	Site	Best-fitting model	AIC	ΔAIC	w_i	Estimated abundance	95% confidence interval	Estimated density (dog/km^2)	95% confidence interval
2016	A to E	M_h	732.72	0	0.54	150.9	136.2–179.8		
		M_{th}	733.01	0.29	0.46	150.2	135.8–178.8		
		Model average				150.6	136.0–179.3	32	29–38
	F	M_t	−83.64	0	1	70.6	70.0–77.0	228	226–248
2017	A to E	M_h	781.05	0	0.61	120.0	116.4–129.3		
		M_{th}	781.97	0.92	0.39	119.9	116.3–129.1		
		Model average				120.0	116.3–129.2	26	25–28
	F	M_t	8.73	0	1	62.4	62.0–68.8	201	200–222
2018	A to E	M_{th}	921.20	0	1	144.7	140.4–154.5	31	30–33
	F	M_t	−17.25	0	1	84.1	80.8–93.2	271	261–301

3. Results

3.1. Population status

During route surveys in 2016–2018, we encountered free-roaming dogs 1388 times. From those records, we identified 191 individuals in 2016, 176 in 2017, and 216 in 2018 (Table 1). Age of the dogs was skewed toward adult age groups (> 1 year old; 92.1% for 2016, 96.0% for 2017, and 92.1% for 2018). Sex ratio of the dogs varied during the three years; we observed more males during 2016–2017 but more females in 2018 (Table S1).

For Sites A–E, the M_h model ranked as the best-fitting model in 2016 and 2017, and the M_{th} model was best-fitting in 2018 (Table S2). However, the M_{th} model also competed with the M_h model in 2016 and 2017. We thus obtained the best approximate results by the model averaging approach (Table 2). Therefore, the capture-recapture method estimated a population size of 150.6 (density: 32 dog/km^2) in 2016, 120.0 (density: 26 dog/km^2) in 2017, and 144.7 (density: 31 dog/km^2) in 2018 (Table 2). For Site F, the M_t model was best-fitting in all three years (Table S2). The capture-recapture method estimated a population size of 70.6 (density: 228 dog/km^2) in 2016, 62.4 (density: 201 dog/km^2) in 2017, and 84.1 (density: 271 dog/km^2) in 2018 (Table 2).The estimated total population sizes of free-roaming dogs in YMSNP was 979 (95% CI: 891–1152) in 2016, 786 (95% CI: 764–842) in 2017, and 957 (95% CI: 931–1017) in 2018.

3.2. Survivorship and health of free-roaming dogs

Annual apparent survival rate was 16.7% from 2016 to 2017 and 23.9% from 2017 to 2018. Two-year apparent survival rate was 11.5% from 2016 to 2018. The lameness rates were 5.2%, 5.1%, and 8.8%, and the dermatosis rates were 16.2%, 14.2%, and 18.1% during 2016, 2017, and 2018, respectively (Fig. 2).

We collected blood samples from 35 dogs, which included 15 males and 20 females; 20 were adults and 15 were pups around eight weeks old. One individual was missing a right front paw. Five individuals had ticks. Thirteen dogs had abnormal hemoglobin concentrations (28.6% decreased and 8.6% increased), 13 dogs had abnormal hematocrit values (34.3% decreased and 2.9% increased), and 13 dogs had abnormal RBC counts (28.6% decreased and 8.6% increased). In addition, 13 dogs (37.1%) exhibited abnormal WBC counts, and 24 dogs (68.6%) demonstrated abnormal platelet counts (Table 3).

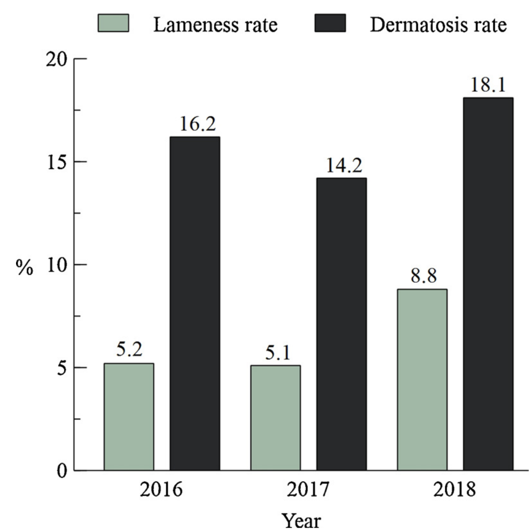

Fig. 2. Proportions of individuals with lameness and dermatosis in a free-roaming dog population in Yangmingshan National Park, Taiwan, during 2016–2018.

4. Discussion

The best-fitting capture-recapture models method were M_h, M_t, or M_{th}, which indicated that the capture probabilities varied among sites, occasions, or both. Different environments of the sites would affect detection ability, and dogs' habits may also have varied among sites. For example, sites with higher proportions of owned dogs or with more food subsidies from caretakers likely had higher capture probability. Moreover, although we carried out field surveys during specific time periods and good weather, dog activity was still likely influenced by time, temperature, tourist activity, or other unexpected factors. Therefore, the capture probabilities changed among survey occasions.

Our study reports on a large free-roaming dog population with as many as 786–979 individuals that existed in YMSNP. The human-dog ratio was approximately 5:1 in Taiwan (Tung et al., 2010), and 21% of owners in Taiwan allowed their dogs access to the outdoors (Hsu et al., 2003). Using the number of humans that live in YMSNP and the above parameters, we estimated that there were approximately 504 owned dogs that were free-roaming in YMSNP. This suggested that owned dogs accounted for 51–64% of the free-roaming dog population, while stray dogs accounted for 36–49%. In other countries, stray dogs usually contribute to < 10% of a free-roaming dog population in both rural and urban areas (Morters et al., 2014a). Stray dogs in YMSNP mainly originated from abandonment, immigration from the nearby city, and the accompanying reproduction (Lin and Shieh, 1999; Hsu et al., 2003). A large amount of food subsidies from caretakers widespread throughout YMSNP may have supported the survival and reproduction of these dogs. Longfenggu and Liuhuanggu (i.e., Site F), where the highest density of dogs occurred, is close to urban areas and has a large amount of feeding activities.

Dogs may attack wildlife and disturb wildlife by causing increased vigilance (Parsons et al., 2016), reduced food intake (Vanak and Gompper, 2009), lowered reproductive success (Weston and Elgar, 2007), or a change in habitat use (Zapata-Ríos and Branch, 2016). In

Table 3
Complete blood count results for 35 stray dogs from Yangmingshan National Park, Taiwan, during 2016–2018.

				Analyte							
Age	ID	Sex	Ectoparasite	Hb(g/dl)	HCT(%)	RBC(106/ul)	MCV(fl)	MCH(pg)	MCHC(g/dl)	WBC(/ul)	Pla(103/uL)
Adult	YM105001	M		13.8	39.6	5.89	67.3	23.5	34.9	11100	24[a]
	YM105002	M		13.6	38.3	6.04	63.4	22.5	35.5	17400	175[a]
	YM106001	M		15.3	41	6.73	60.9	22.8	37.4	8800	184[a]
	YM106002	M		8.8[a]	25[a]	4.25[a]	59[a]	20.8	35.2	12300	370
	YM106003	F		14.7	39	6.16	63.2	23.9	37.7	16900	348
	YM106010	F		10.2[a]	29.2[a]	4.41[a]	66.2	23.1	35	19200[b]	313
	YM106012	F		15.6	42.7	7.35	58[a]	21.1	36.5	27600[b]	297
	YM106013	F		19.7	56.9	8.34	67.4	23.4	34.6	10100	170[a]
	YM106014	F		15.9	43.5	7.18	60.5	22.1	36.6	10100	302
	YM107001	M		16.8	45.3	7.23	62.6	23.3	37.2	4900[a]	104[a]
	YM107002	M	Tick	11[a]	31.2[a]	5.41[a]	57.7[a]	20.4	35.3	18900	154[a]
	YM107003	F	Tick	8.7[a]	25.4[a]	3.7[a]	68.5	23.5	34.3	6900	195[a]
	YM107004	F		10.5[a]	31.4[a]	4.28[a]	73.2[b]	24.4	33.4	11100	31[a]
	YM107005	F	Tick	13.6	38.6	6.02	64.1	22.7	35.3	10300	127[a]
	YM107010	M	Tick	16.5	45.1	7.56	59.6[a]	21.7	36.5	11200	65[a]
	YM107011	M		12.6	34.4[a]	5.65	60.9	22.4	36.8	9200	213
	YM107013	F	Tick	11[a]	29.8[a]	4.56[a]	65.2	24.1	36.9	8600	89[a]
	YM107014	F		16.3	46.3	7.22	64	22.6	35.3	11200	86[a]
	YM107015	F		14	39.6	6.12	64.7	22.9	35.4	11300	190[a]
	YM107016	F		14.9	41.6	6.79	61.2	21.9	35.8	8700	95[a]
	Reference[c]			12-18	37-55	5.5-8.5	60-72	19.5-25.5	32.0-38.5	6000-17000	200-500
Pup	YM105003	M		12.6[b]	35.1	5.86	60.1[a]	21.6	35.9[b]	11700	465
	YM105004	M		10	29.6[a]	4.47	66.4	22.3	33.7[b]	8600[a]	20[a]
	YM105005	M		12.7[b]	36.7	5.97[b]	61.5[a]	21.3	34.6[b]	8700[a]	434
	YM105006	F		12.4	35.5	5.6	63.4	22.2	35.1[b]	10400[a]	411
	YM105007	M		9.1[a]	27.3[a]	3.93[a]	69.5	23.1	33.3	5600[a]	60[a]
	YM105008	F		10.2	30.7	4.53	67.7	22.6	33.3	5500[a]	212[a]
	YM106008	F		6.6[a]	18.7[a]	2.78[a]	67.1	23.6[b]	35.2[b]	11200[a]	21[a]
	YM106009	M		12.5	35.7	5.51	64.8	22.8	35.1[b]	19700[b]	192[a]
	YM106011	F		8.9[a]	26.5[a]	3.77[a]	70.3	23.3	33.4	11200[a]	220[a]
	YM106015	F		14.7[b]	39.9[b]	6.97[b]	57.2[a]	21.2	37[b]	15600	551[b]
	YM106016	F		12	33.7	6.14[b]	54.9[a]	19.6[a]	35.7[b]	13500	612[b]
	YM107006	F		10.5	29.6	4.45	66.6	23.6[b]	35.5[b]	7600[a]	432
	YM107007	F		10.5	29.4	4.48	65.6	23.5[b]	35.8[b]	15000	463
	YM107008	M		10.6	29.5	4.5	65.6	23.7[b]	36.1[b]	12400	255[a]
	YM107012	M		6.6[a]	19.9[a]	2.9[a]	68.8	22.9	33.3	5900[a]	87[a]
	Reference[d]			9.4-12.5	29.0-39.0	4.44-5.9	64.2-72	20.8-23.4	32.1-33.6	11800-17300	241-476

[a] Lower than the reference value.
[b] Higher than the reference value.
[c] Reference value from National Taiwan University Veterinary Teaching Hospital.
[d] Reference value for pups at the age of eight weeks (Brenten et al., 2016; von Dehn, 2014).

protected areas in Central America and South America, the distributions and activity patterns of native wildlife were influenced by the occurrence of free-roaming dogs with a population density as low as 1–4 dogs/km^2 (Silva-Rodríguez and Sieving, 2012; Zapata-Ríos and Branch, 2016). In YMSNP, we estimated a dog population density of 26–32 dogs/km^2 along the road systems, which suggested a very high probability of threat to native wildlife. Because the YMSNP is a protected area for ecosystem conservation, the control and removal of free-roaming dogs must be adopted.

Dogs that are not well-cared for by humans usually have a short life expectancy (Morters et al., 2014b), which might be < 3 years (Beran, 1985; Kitala et al., 2001). In YMSNP, Lin and Shieh (1999) reported apparent survival rates of free-roaming dogs as 29% for adults and 7% for newborns through a 7-month period, and Chou and Chuang (2002) reported an apparent survival rate of 18% through a 7-month period. Although our study was not able to estimate the life expectancy of dogs, we found a very low annual apparent survival rate of 16.7–23.9%, which was consistent with previous studies. However, the estimated population sizes did not vary dramatically through the years (i.e., it decreased 20% in the second year and then increased to its original size in the third year). These results suggested that new individuals entered this population continuously. Therefore, management plans must consider the prevention of abandonment, immigration, and reproduction of dogs in this area.

In addition to low survivorship, our results also suggested that the dog population was in poor health. Skin conditions and lameness are welfare measures for stray dog populations (World Organisation for Animal Health, 2018). A study in a city of Mexico showed that 26% of captured stray dogs had skin lesions (Cortez-Aguirre et al., 2018). Another study in Bali in Indonesia showed 37.9% of dogs at a shelter had dermatosis, and various pathogens caused the dermatosis (Wiryana et al., 2014). Moreover, a survey of stray dogs in a city in Korea showed that ectoparasites were detected in 45.6% of the dogs (Chee et al., 2008). The dermatosis rate in our study was relatively lower than these other studies. However, we observed the dogs at a distance, so that small lesions might not have been visible and ectoparasites were undetectable. Although specific pathogens were not identified in this study, our data suggested that dogs with dermatosis were under risks of pathogenic infections. Furthermore, although a dog with a surgically amputated limb can live a high quality life if the amputation does not affect the dog's health (Barnard et al., 2014), stray dogs with missing limbs were probably not the result of surgical amputations, but were due to accidents that occurred in the park such as car collisions, animal traps, and fighting with other dogs. In a previous study in Mexico, only 1.5% of stray dogs were lame (Cortez-Aguirre et al., 2018). The high lameness rate in YMSNP suggested that this was a harsh environment for dogs.

Complete blood counts objectively measured the degree of inflammation from infectious diseases, inflammatory insults, and the degree of anemia. Red blood cell counts reflect the body condition of stray dogs (Khan et al., 2011). When comparing the red blood cell counts from stray dogs in YMSNP to the reference values, 34.3% of stray dogs in YMSNP were anemic. In addition, 67.0% of anemic stray dogs in YMSNP had non-regenerative anemia, which suggested they had a chronic inflammatory state or nutritional deficiencies (Grimes and Fry, 2015). On the other hand, 26.7% of pups had elevated hematocrit, hemoglobin concentration, or RBC counts, which indicated they were dehydrated. Nevertheless, all 15 pups had a certain degree of hematologic abnormalities, meanwhile, those abnormalities appeared in 50.0% of adults. This provides further evidence that these dogs suffered from long-term illness or starvation in the wild. At an individual level, YM107001, a captured individual with a missing right front paw, had a lower white blood cell count compared with the reference range. The lower white blood cell count likely related to sustained and serious inflammation /infection in the injured leg that depleted white blood cells in the pool. There were five captured dogs with tick infections, and four of them were anemic, which might result from the tick infestation itself or from hemo-parasites that were vectored by ticks. For the three individuals with leukocytosis, there were no remarkable abnormalities noted upon physical examination. However, the elevated leukocytes indicated severe infection and an inflammation process, which highlighted the necessity of conducting a blood exam when objectively evaluating the health status of stray dogs. We recommend that a future study that directly compares the health conditions among stray dogs, owned but free-roaming dogs, and restricted dogs in the same area is necessary. Furthermore, biochemistry tests of blood samples and infectious diseases should be included in future studies for a more comprehensive examination of dog health.

Our study demonstrated that the national park contained a large free-roaming dog population with low survivorship and with poor health. Management actions must be started for the welfare of the dogs and for conservation of native wildlife. Possible management strategies for free-roaming dogs include capture and removal of unowned dogs, restricting dogs indoors by owners, and neutering (Soto and Palomares, 2015; Lessa et al., 2016; Zapata-Ríos and Branch, 2016; Doherty et al., 2017; Home et al., 2018).

First, capturing and transferring dogs to shelters would be an effective and efficient method to decrease the dog population. Adoption rate at dog shelters reached 69% in Taiwan (Council of Agriculture, 2018). The dogs placed in shelters would reduce high mortality risks in the wild, and they would have a chance to be adopted. In fact, the authorities at YMSNP removed stray dogs from the park in 1999, and the number of stray dogs decreased dramatically (Lin and Shieh, 1999). After that, the intensity of removal decreased, and the number of dogs recovered to a similar level as before (Chuang, 2004). Therefore, this method requires a long-term design or the population will rebound quickly (Beran and Frith, 1988). Second, education and advocating for responsible dog ownership is required, because owned dogs constituted part of the free-roaming dog population, and abandonment was a major source of stray dogs. Restricting owned dogs indoors and providing higher quality care would reduce the free-roaming behavior and improve their health. Finally, neutering is also necessary for the management of owned dogs, because unwanted pups are a major source of abandoned dogs (Fielding and Plumridge, 2005). However, a trap-neuter-release method is not appropriate for stray dogs in a national park because those dogs would still have a negative impact on native wildlife.

There were some limitations in this study. First, identification of age and sex is often difficult in the field. We thus could only provide a simple percentage of adults and pups rather than a more complete age structure. Although we found that sex ratio of the dog population likely had changed among years, we were not able to further discuss it because the sex of approximately 40% of the individuals was unavailable. Second, free-roaming dogs may concentrate in areas with higher food or/and shelter resources rather than being distributed evenly. Therefore, biases would occur when estimating the total population size by extrapolation. To reduce such biases, we selected sampling areas that covered major environment types of the study area (Table 1), and we dealt with data of Site F separately due to its obviously higher density. Finally, we evaluated the survivorship by using apparent survival rate rather than true survival rate, because we could not confirm that individuals that had disappeared were dead, had emigrated, or had been captured (Lebreton et al., 1992). However, home range size of free-roaming dogs were usually smaller than 1 km^2 (Durr and Ward, 2014), and we rarely observed individuals who roamed across more than one sampling area. Within the sampling areas, only 27 adult dogs were captured by the YMSNP rangers between July 2016 and August 2018 (Headquarters of YMSNP, unpublished data). Thus, we suggest that emigration and being captured are minor reasons for dog disappearance, but that death is major cause.

5. Conclusion

This study provides longitudinal demographic data of a free-roaming dog population at a rural area in Southeast Asia, and it highlights the dogs' poor health. We found that the population density of free-roaming dogs was high in YMSNP. Although survivorship were low during the three years of our study, population size did not decrease concomitantly because of frequent immigration and reproduction. Moreover, the high lameness rate, high dermatosis rate, and poor blood test values suggested that animal welfare of the dogs must be improved.

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