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Original Research Article

Home Range Characteristics of a Released Milu (*Elaphurus davidianus*) Population during Different Periods and Effects of Water Submersion in Dongting Lake Wetland, China

Running Title: Home Range of Milu Population in Donting Lake Wetland

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**Novelty statement:** To explore activity rhythm of released milu population, we estimated their home range size, and contacted with water body of Dongting Lake. Milu is the flagship species for China which died out in the last century, individuals were reintroduced from England, and milu mostly live in natural reserves, the objects in our study are the first population which are released to wild where is away from their former habitat. Focusing on the released milu population is significant for them, it is beneficial to management the rewild population, and helpful for their development.

**Abstract**

To understand home range (HR) characteristics and the distribution of a released milu population at Dongting Lake, we estimated HR size using the minimum convex polygon and kernel density estimator methods from location data. A maximum flooded time index (MSTI) was calculated and overlaid with seasonal HR data to explore the effects of seasonal floods on the distribution pattern. Results showed that: (1) Contemporaneous HR sizes of females were larger than the male individual during the rut; (2) Males and females individuals cohabitated in spring and their HR sizes were large, the population dispersed during summer with HR sizes decreasing, and the HR sizes in winter were largest; (3) Home range of milu population change significantly between dry period and wet period. The milu individuals were released during dry periods and their habitat was identical and large, then the population dispersed during the wet season and some individual HR sizes shrank distinctly; (4) the rut and parturition periods were sequential but somewhat short, and HR sizes during the parturition period were more preponderant than that in the rut; (5) female milu prefer to live in areas that were flooded for 40%–50% of year based on MSTI. In general, the HR distribution and size of the milu population changed with the changing periods, including different seasons, dry period and wet period etc. Available space, food resources, and shelter were influenced by water level variation in Dongting Lake, so we speculate water level were the main factor affecting the distribution and HR size of milu directly or indirectly.

**Keywords:** Père David’s deer; Home range; Maximum flooded time index; Dongting Lake

Introduction

Patterns of spatial utilisation and population distribution reveal significant information regarding animal biology and behaviour (Sarkar *et al*., 2016). Home range (HR) is defined as the area utilised during an animal’s normal daily activities, such as food gathering, mating, and caring for young (Burt, 1943). The HR provides a clear definition of the timeframe involved during a given HR analysis (Seaman, 1996; Hansteen *et al*., 1997). Shape, size, and structure of the HR and the relationship between HR and the environment are key components of animal ecology (Kaczensky *et al*., 2010). Mammals appear to have larger HR sizes when they live in less productive habitats or where food resources are distributed unevenly (Rautio *et al*., 2013). Furthermore, an understanding of how animals use their HR is important for managing wildlife (Kernohan, 2001; Willems and Hill, 2009).

Milu (*Elaphurus davidianus*, also called the Père David’s deer) is endemic to China, is Yangtze River drainage (Yang *et al*., 2016). Milu is a typical species that was reintroduced from Europe to China in the 1980s, nearly a century after its extirpation due to natural factors and human disturbances (Ding, 2018). There are three milu breeding and protective organizations, including Beijing Milu Park, Jiangsu Dafeng Milu National Nature Reserve (DMNNR), and Hubei Shishou Milu National Nature Reserve. Milu prefer the habitat where food is abundant, near the water, and far away from human activity (He *et al*., 2007). Research has investigated plants which milu eat, and proved that squishy plants are chosen by them (Liang and Li, 1991). Milu populations now mainly live in captive or free range situations, and have become more adapted to human activities than when they lived in the wild prior to their extirpation (Jiang *et al*., 2001). During breeding season, male individuals compete for the qualification of mating, all male milu can be classified into three ranks as King, Challenger and Bachelor (Liu, 2014). With the development of a large captive milu population, some issues have appeared, such as environmental degradation, resource scarcity, and inbreeding, thus, the recovery of the wild milu population has been slow (Zhang *et al*., 2011). A previous study on the mitochondrial DNA control regions in milu verified low genetic diversity (Meng *et al*., 2014).

Therefore, 16 milu individuals from DMNNR were selected for release in the Dongting Lake wetland. This was the first implementation of an ex-site conservation in China. A total of 11 individuals were fitted with satellite tracking equipment (Wang *et al*., 2019), the collars were equipped on them after they were narcotized transitorily. This project was guided by Chinese Forestry and Grassland Administration, and implemented by Hunan Provincial Government and Hunan Wild Animal Rescue and Breeding Center with approval. To the best of our knowledge, the present study is the first to explore descriptive HR characteristics of a long-distance rewild milu population using satellite transmitters. The aim of this paper is to supervise released milu population, and is beneficial for management by the Dongting Lake National Nature Reserve.

Materials and Methods

**Study site**

The Dongting Lake wetland (28°30′–30°20′ N, 111°40′–113°10′ E) is located in the middle reaches of the Yangtze River region, China, and is a component of larger important international wetlands (Li *et al*., 2013; Liang *et al*., 2015; Wang *et al*., 2017). Dongting Lake shows seasonal variation in rainfall (Zhang *et al*., 2016). During the wet season (from May to October), Dongting Lake reaches its highest water level and expands to a large water surface area, whereas the area becomes lake bottom–land periodically during the dry season (from November to April of the next year) (Lai *et al*., 2013). There are six types of landscapes in the wetland, including open water, mudflats, *Carex* marshes, reed marshes, polar forests, and other areas (Guan *et al*., 2016). The Dongting was recognized as the key region for numerous migratory water-bird for overwintering (Cao *et al*., 2008). There was no large sarcophagous animals, but some ungulates occasionally appear which owned by herdsmen. The study survey determined that nearly 90% of the local people depend on Dongting Lake (Cao *et al*., 2010), and numerous residents live beside the Lake. In general, considering the climate, resources, and environmental conditions, the Dongting Lake wetland contains an ideal habitat for milu populations, where an exclusive natural wild milu population has been established since 1998 due to heavy flooding (Yang *et al*., 2002; Yang *et al*., 2007).

**Period partition and home range (HR) size estimation**

In the present study, the location data of 11 milu individuals were collected from March 4, 2016, to July 29, 2017, covering more than one year. During the whole experiment process, we all concerned about animal welfare. Approving body and any reference numbers of milu individuals and other details were supplied relating to ethical approvals: The Animal Ethics Committee, Central South University of Forestry and Technology provided full approval for this study. To more clearly understand the HR characteristics of the milu population, we divided the location data into different periods based on usual seasonal change, water level characteristic in Dongting Lake, and physiological situation of the Père David’s deer.

Displaying the satellite tracking data on the map, and the single male individual habitat was divided into two apparent periods with one data collection period being from March 4, 2016, to May 23, 2016, and the other from May 23, 2016, to June 26, 2016. Based on the data collected from the male milu, the study estimated the HRs of female milu whose habitats overlapped with the male milu during the above two periods (Fig. S1). There were ten females with associated location data. Based on seasonal transformation, the periods were divided into spring (March to May), summer (June to August), autumn (September to November), and winter (December to February the following year) (Fig. S2). Considering water levels, the wet period (May to October) and dry period (November to April the following year) were separated (Fig. S3).

Because of our interest in the HR characteristics of female milu during specific physiological periods, we also examined the parturition period (April and May) and the rut period (June and July) (Fig. S4).

When the location data of individuals included the entire month in each period, then the period was usable. For example, there was location data for one individual existed in March, April, and May, therefore, the spring period was chosen, if there were data just in one or two month, it could not be used.

HR sizes were estimated using "Home range Tools (HRT)" in ArcGIS 10.2. According to previous studies, we chose both the minimum convex polygon (MCP) (Reinecke *et al*., 2014; Flanagan *et al*., 2016; Plotz *et al*., 2016) and kernel density estimator (KDE) (Kitts-morgan *et al*., 2015; Fleming *et al*., 2016) methods. After the location data from each individual were imported into ArcGIS 10.2, the HR size was estimated using levels of 95% and 50% for MCP and KDE, respectively.

**Water surface variation monitoring**

The water surface area of Dongting Lake fluctuates regularly, which greatly affects the habitat. Terra/MODIS data were selected to monitor variations in the water surface area of Dongting Lake. Based on the visible light and near-infrared band remote-sensing imagery, the water body area was extracted from other land cover types. MOD09Q1 was MODIS image which update every 8-day, and all MOD09Q1 data during 2016 and 2017 have been downloaded from LAADS DAAC (<http://ladsweb.modaps.eosdis.nasa.gov/>) (Huang *et al*., 2012). Images with obscuring cloud cover were omitted from the study, yielding 34 images from 2016 and 25 images from 2017. These 59 images were re-projected to the commonly used projection of the Universal Transverse Mercator (WGS84) using a nearest neighbour re-sampling method with the MODIS Reprojection Tool. To eliminate the influence of water plants, sediment, soil moisture content, and clouds, the water body extraction steps in the study, including the three rules listed below, relied on band1, band2, and NDVI of the MODIS data.

(1) If NDVI ≤ 0.1, the pixel could be identified as a water body. The NDVI value is influenced by climate and landscapes, but 0 could not be used as a threshold value to extract water because there are many water plants in Dongting Lake from April to September. Referring to previous study regarding threshold ranges from −0.1 to 0.3 (Tan, 2002), we selected 0.1 as the threshold based on our visual opinion by comparing with original image.

(2) If the DNband2＜1,400, the pixel could be identified as a water body. The band2 of MOD09Q1 is a near-infrared band in which the characteristics of plants and soil are opposite to those of water bodies. When the threshold is between 1,000 and 1,400 (Huang *et al*., 2012) water bodies can be distinguished from other landscape, such as build-up and bare soil. As in rule (1), 1,400 was selected as the threshold with the help of visual assessment.

(3) To eliminate the influence of clouds, based on rules (1) and rule (2), if DNband1＞2,000, and DNband2＞2,000, then the pixel could be identified as non-water body.

The value of water bodies and non-water bodies was defined as 1 and 0, respectively; then, the images were combined based on the period partition and estimated maximum flooded time index (MSTI) of each period using the band calculator in ArcGIS 10.2 software.

**Overlay analysis of HR and water variation**

Considering the seasonality of water surface variations of Dongting Lake, the MSTI was estimated based on seasons, making use of images from March 2016 to February 2017. The study did not distinguish individuals during the analysis process, but combined milu location data based on their habitats during different seasons, and estimated HR sizes using the 95%MCP method for visualized observation, respectively. These estimates were coupled with a MSTI map over the year long period. To analyse the utilisation of MSTI by the milu population of Dongting Lake, MSTI was divided into 10 levels (0−10%, 10%−20%, 20%−30%, 30%−40%, 40%−50%, 50%−60%, 60%−70%, 70%−80%, 80%−90%, and 90%−100%), then calculated the HRs utilization proportion of each above level for each different seasonal. The overlay analysis was performed using ArcGIS 10.2. Fig. 1 shows the workflow diagram of the present study.

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**Fig. 1:** Water extraction andseasonal home-range overlaying analysis procedures. Notes: HR represents home range, KDE represents kernel density estimator method, MCP represents minimum convex polygon method, MSTI represents maximum flooded time index

Results

**Summary of location data**

Location data were collected from individual via the milu, matching tracker IDs (Table 1). The study collected 52,815 location data points in total, and the mean quantity for each animal was approximately 4,000. The majority of the trackers did not provide the location data of milu individuals in 2017, except for Milu02 and Milu04. Milu16 was the only male individual in the studied population, whose location data were collected from March 4 to June 26, 2016, and from September 8 to 26, 2016.

**Table 1:** Location data of milu individuals

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Milu ID** | **Tracker ID** | **Sex** | **Location data quantity** | **Time span** |
| Milu01 | HNRC001 | Female | 4481 | 2016/3/4–2016/8/14 |
| Milu02 | HNRC002 | Female | 5653 | 2016/3/4–2017/7/29 |
| Milu03 | HNRC003 | Female | 4516 | 2016/3/4–2016/9/15 |
| Milu04 | HNRC004 | Female | 6142 | 2016/3/4–2017/7/29 |
| Milu05 | HNRC005 | Female | 5124 | 2016/3/4–2017/3/15 |
| Milu08 | HNRC008 | Female | 4688 | 2016/3/4–2017/3/17 |
| Milu09 | HNRC009 | Female | 2976 | 2016/3/4–2016/5/26 |
| Milu14 | HNRC014 | Female | 3633 | 2016/3/4–2016/7/20 |
| Milu15 | HNRC015 | Female | 4189 | 2016/3/4–2016/8/30 |
| Milu16 | HNRC016 | Male | 4641 | 2016/3/4–2016/6/262016/9/8–2016/9/27 |
| Milu17 | HNRC017 | Female | 6772 | 2016/3/4–2017/5/5 |

**Sex differences in milu HR**

There were two distinct habitats utilised by the male milu from March 4 to May 23, and from May 23 to June 26, which was driven by the increasing water level (Fig. S1). Several female individuals range overlapped with the male milu in these two habitats. Comparing the milu of different sexes, the HR sizes were dissimilar. The results showed that (1) there were ten female individuals living with the male milu in habitat 1, the male HR size was smaller than that of the females, and only the HR size of Milu05 was smaller than that of the male determined by both the 50%MCP and 50%KDE methods; and (2) four individual females lived with the male in habitat 2 over time. During the study period, the HR size of the male seemed to approximate that of the female milu, or was slightly larger than the females except for Milu09, determined by the 95%KDE method (Table 2).

**Table 2:** HR sizes of individual milu by sex (km2). Notes: “H1” denotes habitat 1, “H2” denotes habitat 2, and the distributions are shown in Fig. S1

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Period** | **Habitat** | **HR ID** | **Sex** | **95%MCP** | **50%MCP** | **95%KDE** | **50%KDE** |
| 20160304—20160523 | H1 | Milu16 | Male | 9.33 | 2.84 | 14.48 | 2.96 |
| Milu01 | Female | 17.63 | 4.26 | 19.78 | 4.36 |
| Milu02 | Female | 17.93 | 5.72 | 21.11 | 5.29 |
| Milu03 | Female | 18.41 | 6.07 | 20.37 | 5.28 |
| Milu04 | Female | 16.64 | 4.90 | 20.20 | 4.86 |
| Milu05 | Female | 16.78 | 2.01 | 15.47 | 2.50 |
| Milu08 | Female | 17.82 | 6.48 | 24.38 | 6.63 |
| Milu09 | Female | 16.22 | 7.62 | 25.04 | 6.37 |
| Milu14 | Female | 17.81 | 8.30 | 27.57 | 6.68 |
| Milu15 | Female | 15.97 | 5.81 | 20.63 | 4.60 |
| Milu17 | Female | 12.87 | 7.11 | 18.69 | 4.84 |
| Mean of female |  | 16.81±1.60 | 5.83±1.81 | 21.32±3.47 | 5.14±1.26 |
| 20160523—20160626 | H2 | Milu16 | Male | 0.59 | 0.30 | 0.81 | 0.22 |
| Milu04 | Female | 0.60 | 0.29 | 0.71 | 0.22 |
| Milu08 | Female | 0.60 | 0.28 | 0.75 | 0.21 |
| Milu09 | Female | 0.63 | 0.14 | 1.19 | 0.29 |
| Milu15 | Female | 0.64 | 0.29 | 0.75 | 0.21 |
| Mean of female |  | 0.62±0.02 | 0.25±0.07 | 0.85±0.23 | 0.23±0.04 |

**HR variations during different seasons**

Based on the data collection periods, the spring period existed both in 2016 and 2017, and the milu population changed their habitats over time. Large differences in HR sizes for different individuals existed during each season. HRs in winter were larger than in other seasons, whereas HR sizes during summer were smallest (Table 3, Fig. S2). In different seasons, habitat utilisation by milu was unequal. Primarily, all individuals lived together during the spring of 2016, but during the spring in 2017, only three individuals provided data, and they lived alone. Space utilization showed great discrepancy, with the HR size of Milu17 during spring of 2017 being vast, reaching 146.12km2 using the 95%KDE method, which was considerably larger than the HR sizes for the other milu. The milu population dispersed and became separated into two groups during the summer of 2016, and the population that lived at habitat 2 (Su-H2) during the summer utilised a smallest HR. Five individuals which offered data lived at three habitats respectively during autumn, the form of groups was unaltered also in winter.

**Table 3:** Milu home range size during different seasons (km2). Notes: In the list “Habitats”, the abbreviation of the preceding two letters represents respective seasons, the number “17” after the HR ID in list 3 represents the year date e.g. “Milu02-Sp17” represents the HR of Milu02 during the spring of 2017. The habitat distributions are shown in Fig. S2

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Habitats** | **HR ID** | **95%MCP** | **50%MCP** | **95%KDE** | **50%KDE** |
| Spring | Sp-H1 | Milu01-Sp | 17.81 | 5.15 | 21.08 | 4.71 |
| Milu02-Sp | 17.81 | 6.84 | 20.80 | 5.44 |
| Milu03-Sp | 18.35 | 6.95 | 17.49 | 4.41 |
| Milu04-Sp | 23.49 | 6.05 | 29.42 | 6.45 |
| Milu05-Sp | 16.37 | 3.33 | 15.33 | 2.65 |
| Milu08-Sp | 24.68 | 8.39 | 35.58 | 8.78 |
| Milu09-Sp | 17.44 | 8.11 | 25.48 | 5.96 |
| Milu14-Sp | 17.92 | 8.72 | 23.17 | 5.94 |
| Milu15-Sp | 22.63 | 7.70 | 29.50 | 6.11 |
| Milu17-Sp | 13.10 | 6.80 | 18.51 | 4.80 |
|  | Mean value | 18.96±3.56 | 6.80±1.64 | 23.64±6.34 | 5.53±1.59 |
| Sp-H2 | Milu02-Sp17 | 2.76 | 0.87 | 4.62 | 1.16 |
| Sp-H3 | Milu04-Sp17 | 28.41 | 9.50 | 37.70 | 8.63 |
| Sp-H4 | Milu17-Sp17 | 57.49 | 29.78 | 146.12 | 44.28 |
| Summer | Su-H1 | Milu01-Su | 2.72 | 0.41 | 4.18 | 0.85 |
|  |  | Milu02-Su | 2.57 | 0.40 | 4.14 | 0.77 |
|  |  | Milu03-Su | 2.82 | 0.51 | 4.14 | 0.78 |
|  |  | Milu05-Su | 2.78 | 0.51 | 4.10 | 0.79 |
|  |  | Milu17-Su | 2.78 | 0.57 | 4.03 | 0.82 |
|  |  | Mean value | 2.73±0.10 | 0.48±0.07 | 4.12±0.06 | 0.80±0.03 |
|  | Su-H2 | Milu04-Su | 0.79 | 0.37 | 0.89 | 0.23 |
|  | Milu08-Su | 0.75 | 0.34 | 0.88 | 0.24 |
|  | Milu15-Su | 0.83 | 0.36 | 0.89 | 0.21 |
|  |  | Mean value | 0.79±0.04 | 0.36±0.02 | 0.89±0.01 | 0.23±0.02 |
| Autumn | Au-H1 | Milu02-Au | 5.19 | 0.60 | 7.87 | 0.94 |
| Au-H2 | Milu04-Au | 15.11 | 1.32 | 29.38 | 3.95 |
| Milu08-Au | 15.04 | 1.24 | 45.45 | 7.93 |
|  | Mean value | 15.08±0.05 | 1.28±0.06 | 37.42±11.36 | 5.94±2.81 |
| Au-H3 | Milu05-Au | 64.40 | 9.56 | 64.70 | 13.18 |
| Milu17-Au | 67.52 | 10.01 | 67.01 | 13.74 |
|  |  | Mean value | 65.96±2.21 | 9.79±0.32 | 65.86±1.63 | 13.46±0.40 |
| Winter | Wi-H1 | Milu02-Wi | 4.22 | 0.69 | 6.64 | 1.48 |
| Wi-H2 | Milu04-Wi | 35.80 | 12.82 | 55.45 | 12.67 |
| Milu08-Wi | 49.71 | 14.70 | 72.05 | 17.15 |
|  | Mean value | 42.76±9.84 | 13.76±1.33 | 63.75±11.74 | 14.91±3.17 |
| Wi-H3 | Milu05-Wi | 52.20 | 10.60 | 57.91 | 10.38 |
| Milu17-Wi | 51.66 | 15.94 | 73.44 | 14.53 |
|  |  | Mean value | 51.93±0.38 | 13.27±3.78 | 65.68±10.98 | 12.46±2.93 |

**HR variation during different water periods**

There were two main habitats utilised by the milu population during the wet period (Table 4 and Fig. S3). Milu02 and Milu04 provided data corresponding with the wet period in 2017. Milu04 moved to a third habitat in 2017, however Milu02 stayed at the same habitat where it had lived during 2016. The size of the HRs of individuals fluctuated, with the level in habitat 1 during the wet period (Wet-H1) being higher than that of habitat 2 (Wet-H2). Maximum acreage during the wet period was 44.92 km2 using the 95%KDE method for Milu02 in 2017. During dry periods, HRs size when milu lived at habitat 3 (Dry-H3) were much larger than they lived at habitat 2 (Dry-H2) and habitat 1 (Dry-H1). During dry periods, all individuals lived together in 2016, but four milu moved to new during dry period in 2017. The size of the HRs during the dry period in habitat 1 (Dry-H1) was approximately equal, however, an increase of space utilisation occurred in habitat 2 (Dry-H2), and especially in habitat 3 (Dry-H3). The HR size of Milu17 reached 287.71 km2 in habitat 3 (Dry-H3) during the dry period.

**Table 4:** Home range size of milu during different water periods (km2). Notes: The number “17” after the HR ID in list 3 represents the year data, e.g. “Milu02-Wet17” represents the HR of Milu02 during the wet period in 2017, and so on. The habitat distributions are shown in Fig. S3

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Habitat** | **HR ID** | **95%MCP** | **50%MCP** | **95%KDE** | **50%KDE** |
| Wet Period | Wet-H1 | Milu01-Wet | 5.23 | 1.33 | 10.50 | 2.18 |
|  | Milu02-Wet | 14.14 | 0.43 | 6.50 | 1.09 |
|  |  | Milu03-Wet | 7.72 | 0.56 | 7.55 | 1.35 |
|  |  | Milu05-Wet | 15.74 | 0.59 | 9.95 | 1.07 |
|  |  | Milu14-Wet | 7.63 | 2.04 | 11.10 | 2.39 |
|  |  | Milu17-Wet | 16.28 | 1.04 | 11.95 | 1.11 |
|  |  | Milu02-Wet17 | 16.09 | 4.16 | 44.92 | 10.22 |
|  |  | Mean value | 11.83±4.77 | 1.45±1.32 | 14.64±13.49 | 2.77±3.33 |
|  | Wet-H2 | Milu04-Wet | 8.00 | 1.96 | 10.92 | 1.59 |
|  |  | Milu08-Wet | 8.59 | 0.88 | 9.96 | 1.43 |
|  |  | Milu09-Wet | 3.39 | 0.34 | 4.58 | 0.65 |
|  |  | Milu15-Wet | 3.32 | 0.44 | 4.46 | 0.85 |
|  |  | Mean value | 5.83±2.86 | 0.91±0.74 | 7.48±3.44 | 1.13±0.45 |
|  | Wet-H3 | Milu04-Wet17 | 8.31 | 2.09 | 16.28 | 3.09 |
| Dry Period | Dry-H1 | Milu01-Dry | 15.10 | 2.33 | 15.24 | 3.02 |
| Milu02-Dry | 12.31 | 2.73 | 17.16 | 3.65 |
| Milu03-Dry | 11.39 | 3.46 | 13.40 | 3.13 |
| Milu04-Dry | 11.06 | 2.17 | 15.66 | 3.13 |
| Milu05-Dry | 12.59 | 1.16 | 13.54 | 1.60 |
| Milu08-Dry | 13.37 | 4.02 | 19.35 | 4.57 |
| Milu09-Dry | 15.20 | 4.40 | 17.77 | 4.21 |
| Milu14-Dry | 14.94 | 4.26 | 18.89 | 4.11 |
| Milu15-Dry | 15.01 | 2.39 | 15.95 | 3.13 |
| Milu17-Dry | 11.38 | 4.16 | 16.65 | 3.67 |
| Milu02-Dry17 | 6.50 | 1.18 | 8.13 | 1.79 |
|  | Mean value | 12.62±2.60 | 2.93±1.20 | 15.61±3.13 | 3.27±0.93 |
| Dry-H2 | Milu04-Dry17 | 68.59 | 28.45 | 100.09 | 23.83 |
| Milu08-Dry17 | 71.94 | 16.96 | 85.66 | 18.05 |
|  | Mean value | 70.27±2.37 | 22.71±8.12 | 92.88±10.20 | 20.94±4.09 |
| Dry-H3 | Milu05-Dry17 | 108.99 | 39.12 | 280.33 | 59.47 |
| Milu17-Dry17 | 166.95 | 52.18 | 287.71 | 78.60 |
|  |  | Mean value | 137.97±40.98 | 45.65±9.23 | 284.02±5.22 | 69.04±13.53 |

**HR size during the parturition and rut periods**

The parturition and rut periods were two continuous periods (Table 5). In 2016, ten individuals were living together in habitat 1 (Par-H1) during the parturition period. The population was separated into two groups from the parturition period to the rut period, and their HR sizes reduced (Fig. S4). The HR of Milu08 was prominent, totalling 41.93 km2 during the parturition period from the 95%KDE method. Comparing habitat 1 (Rut-H1) and habitat 2 (Rut-H2) during the rut period, the milu population use lesser space in habitat 2 (Rut-H2). Three individuals lived in habitat 2 (Rut-H2), and their respective HRs were all less than 1 km2.

**Table 5:** Milu home range sizes during the parturition and rut periods (km2). Notes: “Par” in list 2 denotes the parturition period; the number “17” after the HR ID in list 3 represents the year data, such as in the listing "Milu02-Par17" represents the home range of Milu02 during the parturition period in 2017, and so on. The habitat distributions are shown in Fig. S4

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Habitat** | **HR ID** | **95%MCP** | **50%MCP** | **95%KDE** | **50%KDE** |
| Parturition Period | Par-H1 | Milu01-Par | 13.72 | 6.50 | 19.00 | 4.29 |
| Milu02-Par | 16.39 | 6.09 | 23.27 | 5.66 |
|  | Milu03-Par | 16.75 | 5.82 | 22.00 | 5.50 |
|  | Milu04-Par | 23.98 | 10.90 | 39.81 | 10.05 |
|  | Milu05-Par | 12.47 | 4.40 | 14.05 | 3.00 |
|  | Milu08-Par | 24.16 | 9.80 | 41.63 | 10.84 |
|  | Milu09-Par | 20.91 | 6.64 | 33.94 | 6.45 |
|  | Milu14-Par | 17.27 | 10.54 | 30.87 | 7.42 |
|  | Milu15-Par | 16.08 | 7.24 | 26.30 | 5.73 |
|  | Milu17-Par | 16.63 | 3.90 | 19.37 | 4.11 |
|  |  | Mean value | 17.84±3.96 | 7.18±2.46 | 27.02±9.25 | 6.31±2.52 |
|  | Par-H2 | Milu02-Par17 | 2.71 | 0.75 | 4.96 | 1.25 |
|  | Par-H3 | Milu04-Par17 | 10.43 | 2.98 | 20.35 | 4.27 |
| Rut Period | Rut-H1 | Milu01-Rut | 2.03 | 0.50 | 3.23 | 0.66 |
| Milu02-Rut | 2.32 | 0.37 | 3.26 | 0.64 |
| Milu03-Rut | 2.26 | 0.52 | 3.32 | 0.65 |
| Milu05-Rut | 2.29 | 0.47 | 3.20 | 0.64 |
| Milu14-Rut | 1.89 | 0.49 | 3.20 | 0.68 |
| Milu17-Rut | 2.19 | 0.55 | 3.21 | 0.68 |
|  | Mean value | 2.16±0.17 | 0.48±0.06 | 3.24±0.05 | 0.66±0.02 |
| Rut-H2 | Milu04-Rut | 0.75 | 0.31 | 0.81 | 0.21 |
| Milu08-Rut | 0.72 | 0.29 | 0.83 | 0.21 |
| Milu15-Rut | 0.80 | 0.31 | 0.85 | 0.20 |
|  |  | Mean value | 0.76±0.04 | 0.30±0.01 | 0.83±0.02 | 0.21±0.01 |
|  | Rut-H3 | Milu02-Rut17 | 12.13 | 8.12 | 50.77 | 11.54 |
|  | Rut-H4 | Milu04-Rut17 | 5.37 | 2.05 | 17.74 | 3.95 |

**Maximum submersion time index of Dongting Lake**

Because of the seasonal change in water levels, the MSTI was higher in the inner lake and mainstream, and decreased gradually towards the lake edges. Compared with 2016 under the visual, the MSTI seem increased near the inner lake and mainstream in 2017. The MSTI changed inconspicuously at the two poles, and bottomland with low MSTI remained visually similar between 2016 and 2017 (Fig. 2).



**Fig. 2:** Average yearly max-submersion time index of Dongting Lake in 2016 and 2017

**Relationship of HR and water variation**

As Fig. 3 showed, there are more than one HRs in some seasons, and size of all HRs were different from each other. In 2016, the milu population lived together in spring, and then split into two groups in summer. Groups increased to three in autumn, and the habitats they used were wider, and somewhere was more than ten kilometres farther from where they were initially released. When the water surface covered most of the Dongting Lake area in summer, the milu left the Dongting Lake wetland and lived outside until water levels receded. The HR size increased and then decreased from spring to autumn, and the HRs in summer were the smallest of any season. Most of the HRs in the summer and part of the HR in the spring and autumn were outside of Dongting Lake. Some milu individuals travelled through the inner lake and moved towards the far southern edge of the lake, whereas others stayed near the inner lake during the autumn and winter. Compared with the HRs near the inner lake, the sizes of the southern HRs were larger than northern.



**Fig. 3:** Seasonal home range and max-submersion time index of Dongting Lake. The HRs were estimation using 95%MCP base on location data of all individuals in different seasons

The proportion of MSTI utilisation by HR during the seasons is shown in Table 6. Most MSTI levels were utilised as HRs except for Su-HR1 and Su-HR2. When the water surface extended during summer, milu moved outwards. Su-HR1 only made use of the marginal area when MSTI was low, and another HR used in summer, the Su-HR2, was outside of the Dongting Lake area. During other seasons, milu inhabited the area where MSTI ranged from 30% to 50%, making higher use of the area where MSTI was 40%–50% than where it was 30%–40%. When MSTI was close to 0% or 100%, milu rarely appeared in that area at any time of the year.

**Table 6:** Percentage of utilisation of each MSTI level of the home range during different seasons (%)

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **MSTI** | **Sp-HR1** | **Su-HR1** | **Su-HR2** | **Au-HR1** | **Au-HR2** | **Au-HR3** | **Wi-HR1** | **Wi-HR2** | **Wi-HR3** |
| 0~10% | 12.40 | 87.50 | - | 17.91 | 20.71 | 1.68 | 0 | 13.86 | 0.22 |
| 10%~20% | 6.40 | 12.50 | - | 8.96 | 8.59 | 0.84 | 0 | 5.01 | 11.42 |
| 20%~30% | 8.80 | 0 | - | 4.48 | 12.63 | 1.12 | 0 | 3.98 | 6.90 |
| 30%~40% | 23.20 | 0 | - | 28.36 | 27.27 | 13.69 | 23.19 | 13.57 | 32.11 |
| 40%~50% | 34.40 | 0 | - | 25.37 | 19.70 | 33.71 | 56.52 | 22.27 | 39.01 |
| 50%~60% | 9.20 | 0 | - | 13.43 | 9.09 | 5.59 | 8.70 | 6.93 | 4.09 |
| 60%~70% | 3.20 | 0 | - | 0 | 2.02 | 5.68 | 2.90 | 6.78 | 4.63 |
| 70%~80% | 2.00 | 0 | - | 1.49 | 0 | 4.93 | 7.25 | 3.69 | 1.62 |
| 80%~90% | 0.40 | 0 | - | 0 | 0 | 12.48 | 1.45 | 12.54 | 0 |
| 90%~100% | 0.00 | 0 | - | 0 | 0 | 20.30 | 0 | 11.36 | 0 |

Discussion

During the period when one individual male milu lived with the females, the HR of the male was smaller than that of the females. Regarding the behaviour of milu during rutting periods, the dominant male prefer to rest more than the other males and females (Ren *et al*., 2011). Because only one male milu provided GPS location data in the present study, it was highly possible that this was the dominant male; if not, it also faced competition from other male milu or challenged the dominant male voted by itself. Thus, the male milu tended to maintain its physical attributes by undertaking less daily activity.

With a change in season, the distribution and size of milu HRs changed from average to different. This phenomenon was apparent between spring and summer when milu entered their rutting period, and simultaneously water levels varied greatly. These were also differences between HRs during the rut and parturition periods. Water surface area of Dongting Lake was considered as the significant factor that influencing the distributions of milu (Yang *et al*., 2016). Water supplies in Dongting Lake are concentrated from June to September (Wang *et al*., 1998; Shi *et al*., 2012), thus the water level varied considerably during the summer or rut period. The milu population moved outward from the inner lake, and even moved outside the lake boundary. Without the pressure of the water body, human disturbance was probably the main external factor which influencing HR of milu. The milu population suffered greatly from human disturbance in the area and they only lived in the circumscribed area after they left the lake area. When the wet period passed, the milu population returned to the inner portion of the Dongting Lake wetland for searching favorite food and avoid human disturbance when water level reduced.

Food resources are one of the factors related to HRs (Damuth, 1981). Milu prefer to eat soft plants, however, they sometimes eat dry grass or branches when preferred food resources are unavailable (Wang and Wang, 2011). There is a great diversity of plants in the Dongting Lake wetland, with carex (*Carex brevicuspis*), reed (*Phragmites australis*), and poplars (*Populus euramericana*) being the main species (Yuan, 2008), therefore, Dongting Lake wetland is a suitable habitat for the milu population as it contains abundant food, water, and shelter. Other animal species are also abundant in Dongting Lake wetland, including birds and livestock, fortunately, there are no predators or contender species of milu in this region (Yang *et al*., 2005). Thus, when the milu population live in Dongting Lake, they are faced with low species competition and human disturbance. Food and water acquisition are the main energy demand factors for the deer. The water level may hinder milu foraging, thus, water influences the relationship of HR with food availability indirectly (Yang *et al*., 2016).

The present study combined the HRs with the MSTI of Dongting Lake, and showed that the hierarchy of MSTI was progressive. Areas with MSTI values of 30%–50% were well utilised by milu. Marshland is the main landscape of the area when the water surface shrinks. Some individuals converged with the natural wild milu population, hence, it is attractive to posit that communication with or the spoor of the congener population could cause the migration of an introduced enthetic population.

Conclusions

The aim of the present study was to explore the spatial utilisation of a milu population living in Dongting Lake wetland during different periods. According to the HR sizes during each period, spatial utilisation was related to water level. When water levels rose, milu changed habitat passively due to water surface extension. During such periods (summer, the wet period, and the rut period), HR sizes were smaller than those during the previous period, and most of the time the milu lived out of the lake boundary where human disturbance was common. Milu migrated back to the inner region of Dongting Lake until the water surface area receded, and they were more initiative of choice habitats. The areas where MSTI ranged from 30%–50% were primarily utilised areas that the milu preferred. Marshland is the main landscape in these areas which the milu could readily inhabit. Available food for milu was widely distributed. However, the searching process was impeded when water level increase (Yang *et al*., 2016). From the discussion, we think a lot of the relationship between water surface area with HR, and the distribution of the milu population, water level was likely to influenced the availability of space and food for milu population in Dongting Lake wetland.

**Supplementary Materials:**



**Fig. S1:** Habitat distributions of the individual male milu



**Fig. S2:** Seasonal habitat distributions of the milu population



**Fig. S3:** Habitat distribution of the milu population during different water periods



**Fig. S4:** Habitat distributions of the milu population during the rut and parturition periods

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