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Article

Do Food Plants Provide Sufficient Sodium, Calcium, and Magnesium to Sika Deer in Japan? An Analysis using Global Plant Trait Data

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Simple Summary: Selective culling of female deer is effective in reducing overabundant sika deer (*Cervus nippon*) populations. Sodium (Na), calcium (Ca), and magnesium (Mg) can act as an attractant to selectively cull female sika deer due to the differences in mineral requirements. Here, we estimated whether food plants provide sika deer sufficient Na, Ca, and Mg, and compared the results between male and female. Our analysis demonstrated that sufficient Na and Ca is not always provided, especially when the intake is small or the deer large. Na deficiency was more intense for lactating females than males, whereas Ca deficiency was more intense for males. We suggest that Na and Ca could be useful for developing effective culling methods. Especially, Na could be useful for selective culling of female sika deer during lactating period.

Abstract: Deficient minerals in overabundant populations could act as an attractant to cull sika deer (*Cervus nippon*). Because selective culling of female deer is reported to be effective in reducing sika deer populations, it is particularly important to clarify the differences in mineral requirements between male and female. Here, using global plant trait data and a published list of sika deer food plants in Japan, we estimated whether food plants provide sika deer sufficient sodium (Na), calcium (Ca), and magnesium (Mg), and compared the results between male and female. An analysis of 191 food plant species suggested that food plants can provide sufficient Mg, whereas sufficient Na and Ca is not always provided, especially when the intake is small or the deer large. Na deficiency was more intense for lactating females than males, suggesting that Na can be an effective attractant for selectively culling female deer. In summary, this study demonstrated that sika deer in Japan might require extra Na and Ca sources in addition to food plants, and therefore these minerals could be useful for developing effective culling methods.

Keywords: *Cervus nippon*; mineral requirements; sodium; TRY Plant Traits Database

1. Introduction

Ungulate overpopulation is an important issue in the northern hemisphere [1], including northern America [2] and Europe [3]. Ungulate populations are regulated by bottom-up, top-down, and abiotic factors [4]. A lack of certain nutrients/elements may limit ungulate population growth, especially at a high population density.

Sodium (Na), calcium (Ca), and magnesium (Mg) may be limiting elements for ungulates at a high population density because livestock are often deficient in these elements, especially Na, which is supplemented artificially [5]. A mineral deficiency can also occur in nature based on the fact that various animals use salt licks [6–8]. Geophagy (i.e., eating soil) is common in ungulates [9–11], probably for mineral supplementation. Various species were reported to lick natural springs, presumably for obtaining minerals [12].

Ceacero et al. (2014) [13] reported that Iberian red deer (*Cervus elaphus*) feed on sea weeds, possibly to acquire minerals. The use of salt licks has often been attributed to a requirement for Na [8,9,14], which is important for maintaining osmotic pressure [15]. However, it may also be due to a requirement for other minerals, such as Ca, which is a major component of bones [16], and Mg, which has important roles in enzyme activity and bone development [17]. Several studies have argued that natural salt licks are important sources of Ca and Mg [18].

Sika deer (*Cervus nippon*) are native to eastern Asia and have been introduced into many parts of the world, such as Europe, North America, and New Zealand [19]. In some areas, the deer populations have increased enough that they cause serious browsing damage to natural and anthropogenic environments [19,20]. In Japan, especially, the sika deer population has increased dramatically in recent decades [21]. According to the Ministry of the Environment (2015), the distribution of sika deer expanded more than 2.5 times from 1978 to 2015 [22]. Since this substantial increase in the sika deer population and distribution and subsequent overbrowsing could lead to mineral deficiencies in sika deer, we considered that the deficient minerals in overabuntant populations act as an attractant to cull deer. Indeed, sika deer also lick salt [23]. In addition, sika deer are being culled in many parts of Japan to reduce overabundant populations, and the development of effective culling methods is desirable. Because selective culling of female deer is reported to be effective in reducing sika deer populations [24,25], it is particularly important to clarify the differences in mineral deficiency between male and female. However, no study has evaluated whether sika deer in Japan obtain sufficient minerals, such as Na, Ca, and Mg, through food plants by comparing the minerals provided by food plants and mineral requirements of sika deer. Mineral deficiencies between male and female deer have also not been compared. In this study, we evaluated whether food plants can provide sika deer sufficient Na, Ca, and Mg by comparing the minerals provided by food plants, calculated from leaf mineral contents, and mineral requirements of sika deer, simulated by several scenarios of daily dry matter intake (DMI), body weight (BW), and sex.

2. Materials and Methods

Dataset

A dataset of leaf nutrient contents of sika deer food plants in Japan was constructed using plant trait data from the TRY Plant Trait Database [26]. From TRY, we extracted the leaf Na, Ca, and Mg contents per leaf dry mass (Trait IDs 260, 252, and 257, respectively) for plant species previously documented as sika deer food in Japan [27]. The final dataset included 3179 values for 191 plant species (Table S1) from five original publications [28–32]. The leaf mineral content data were averaged for each species, and the averaged values were used for further analysis.

Analysis

Using the leaf mineral concentration data for sika deer food plants in Japan, we simulated whether each plant species could provide sufficient minerals for sika deer. We considered four sika deer body weight (BW) scenarios based on the BW range of sika deer in Japan (i.e., 30, 60, 90, and 120 kg) and four daily dry matter intake (DMI) scenarios considering a wider range than reported from feeding experiments (i.e., 0.5, 1.5, 3, and 4.5 kg) [33–35]. Unrealistic scenarios (BW 30 kg with DMI 3 or 4.5 kg; BW 60 kg with DMI 4.5 kg; and BW 120 kg with DMI 0.5 kg) were excluded from our analysis. Mineral contents provided by leaves, which were calculated by multiplying DMI and leaf mineral concentration, were compared with the mineral requirement of sika deer calculated as follows. The Na maintenance requirement was calculated based on the following equation for *Cervus* [16]:

$$Na\_req\_maintain = 9.0 / 1000 \times BW \text{ (g day}^{-1}\text{)} \quad \text{eq. 1}$$

, where *Na_req_maintain* is the Na requirement for maintenance and *BW* is body weight (kg). The Na requirement for males was calculated as *Na_req_maintain* plus the requirement for antlers, assuming that antler growth in sika deer requires 150 days, as follows [16]:

$$Na\_req\_male = Na\_req\_maintain + (0.005 \times 26 \times BW^{0.75}) / (0.98 \times 150) \text{ (g day}^{-1}\text{)} \quad \text{eq. 2.}$$

The equation for determining the Na requirement of females during lactation [16] was modified for sika deer as follows:

$$Na\_req\_female = Na\_req\_maintain + (0.0175 \times BW \times Na\_milk\_sika) / 0.98 \quad \text{eq. 3}$$

, where *Na_milk_sika* is the Na content in sika deer milk (1.00 g L^{-1}, [36]). We also calculated the Na requirement of female during non-lactating period (equal to *Na_req_maintain*) by omitting the term expressing the Na requirement for milk production from the equation. The above equations do not include the Na requirements for body growth, assuming that body growth is limited by a lack of food plants. The maintenance Mg requirement (*Mg_req_maintain*) was calculated based on the following equation for goats [16], because equations for goats were recommended to calculate values for cervids (equation for cervids were not available) [16]:

$$Mg\_req\_maintain = (0.0035 \times BW) / 0.20 \text{ (g day}^{-1}\text{)} \quad \text{eq. 4.}$$

Without considering Mg requirement for body growth, the Mg requirement for males was assumed to be equal to *Mg_req_maintain* [16]. The Mg requirement for lactating females was calculated using equations prepared for goats as recommended [16], but modified as follows:

$$Mg\_req\_female = Mg\_req\_maintain + (0.0175 \times BW \times Mg\_milk\_sika) / 0.20 \quad \text{eq. 5}$$

, where *Mg_milk_sika* is the Mg content of sika deer milk (0.0819 g L^{-1}, [36]). Mg requirement for gestation was not taken into consideration, because this was not included equations for Na and Ca. Thus, Mg requirement of female during non-lactating period was considered equal to Mg requirement of male. The maintenance Ca requirement (*Ca_req_maintain*) was calculated based on the following equation for *Cervus* [16]:

$$Ca\_req\_maintain = (0.025 \times BW + 0.25 \times DMI) / 0.34 \text{ (g day}^{-1}\text{)} \quad \text{eq. 6.}$$

The Ca requirement for males was calculated as *Ca_req_maintain* plus the Ca requirement for antlers as [16]:

$$Ca\_req\_male = Ca\_req\_maintain + (0.05 \times BW) / 0.39 \text{ (g day}^{-1}\text{)} \quad \text{eq. 7.}$$

The Ca requirement for lactating females was calculated as *Ca_req_maintain* plus the Ca requirement for lactation [16] with a minor modification:

$$Ca\_req\_female = Ca\_req\_maintain + (0.0175 \times BW \times Ca\_milk\_sika) / 0.39 \quad \text{eq. 8}$$

, where *Ca_milk_sika* is the Ca content of sika deer milk (1.62 g L^{-1}, [36]). The Ca requirements for body growth were also not included. Ca requirement of female during non-lactating period (equal to *Ca_req_maintain*) was also calculated by omitting the term expressing the Ca requirement for milk production from the equation.

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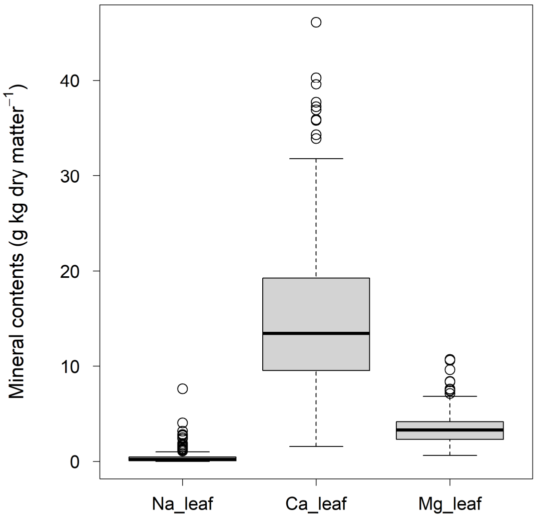

Figure 1. Boxplot of the distribution of leaf mineral contents of sika deer food plants. Na_leaf, Ca_leaf, and Mg_leaf are the Na, Ca, and Mg contents per leaf dry mass, respectively.

3. Results

The sika deer food plant dataset used for this analysis showed large variance (Fig. 1). The average leaf contents of Na, Ca, and Mg were 0.47 ± 0.82, 15.3 ± 8.4, and 3.5 ± 1.8 (g element kg-1 dry matter ± standard deviation), respectively.

Our analysis showed that the Na requirements were rarely achieved by food plants, especially under the scenarios with a smaller DMI and larger BW (Fig. 2). In most of the 12 scenarios, less than 50% of the food plant species provided sufficient Na (Fig. 2a, c, d, f–h, j–l). The results also indicated that a Na deficiency would be more intense for lactating females than males (Fig. 2), as the Na requirement for females was more than double that of males (Fig. 2). Our finding that Na requirements often exceed the provision by food plants contrasted to that for Mg; the leaf Mg contents were higher than required in most of the food plants in our analysis, except for the scenarios with combinations of large BW and small DMI (Fig. 3c, f), indicating that Mg deficiency is less likely. The fulfillment of the Ca requirement depended largely on the scenario (Fig. 4). A lower DMI resulted in insufficient Ca provision in a large portion of the food plant species, especially for greater BWs (Fig. 4a, c, g, f, j), whereas Ca requirements were met in a large portion of the food plant species when the DMI was ≥ 3 kg (Fig. 4). Ca requirement for males was larger than that of females (Fig. 4). The sika deer food plant dataset used for this analysis showed large variance (Fig. 1). The average leaf contents of Na, Ca, and Mg were 0.47 ± 0.82, 15.3 ± 8.4, and 3.5 ± 1.8 (g element kg^{-1} dry matter ± standard deviation), respectively.

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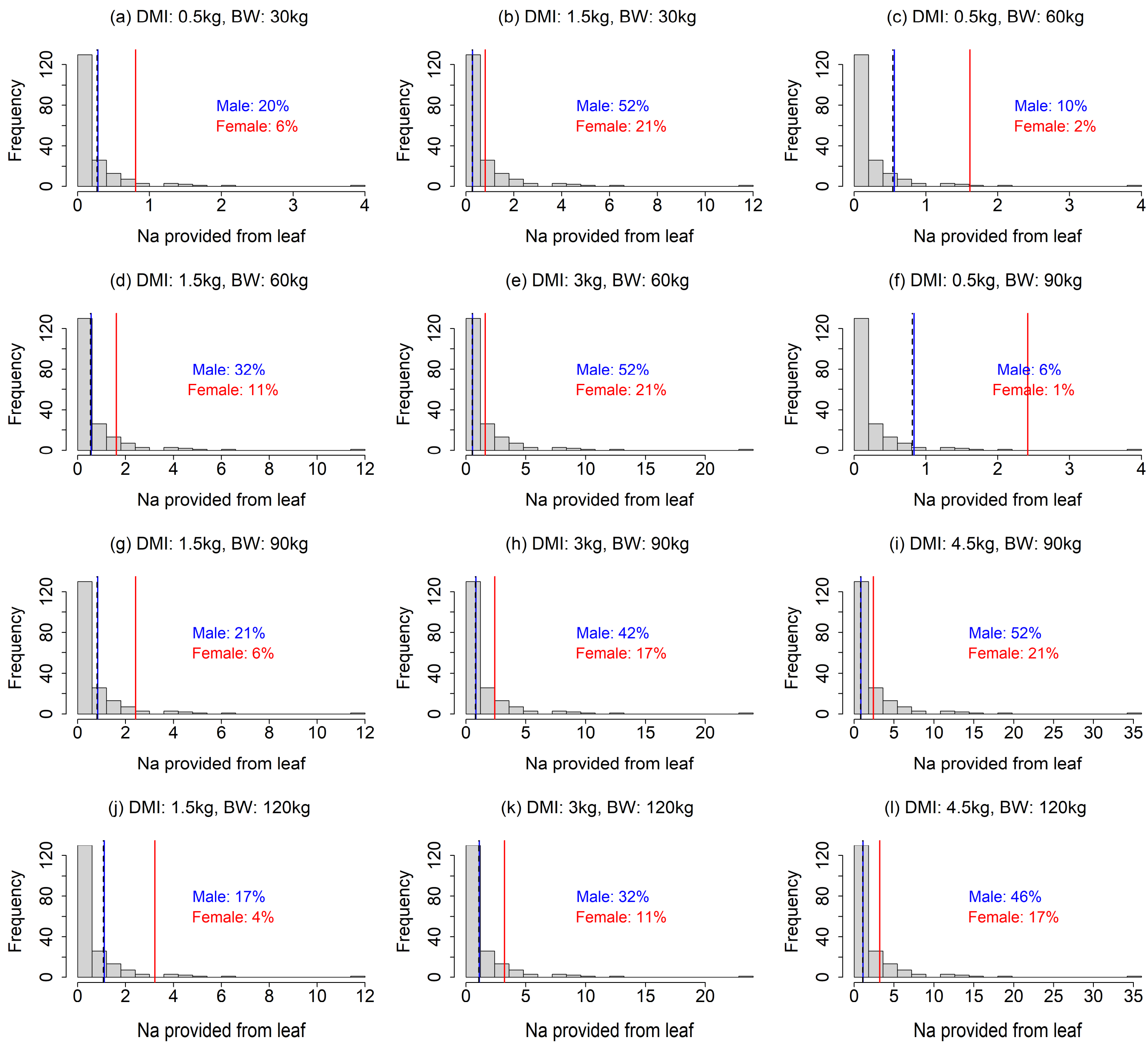

Figure 2. Comparison of Na provision by food plants and the Na requirement of sika deer under 12 scenarios (four dry matter intake levels × four body weights excluding unrealistic scenarios). The histogram indicates the distribution of Na provision calculated from the leaves of food plant species. The solid lines indicate the Na requirements of male (blue) and female (red) sika deer. Dashed line indicates Na requirement of female during non-lactating period, which equal to Na maintenance requirement for both male and female. In the figures, the percentage is the proportion of food plant species that meet the Na requirements.

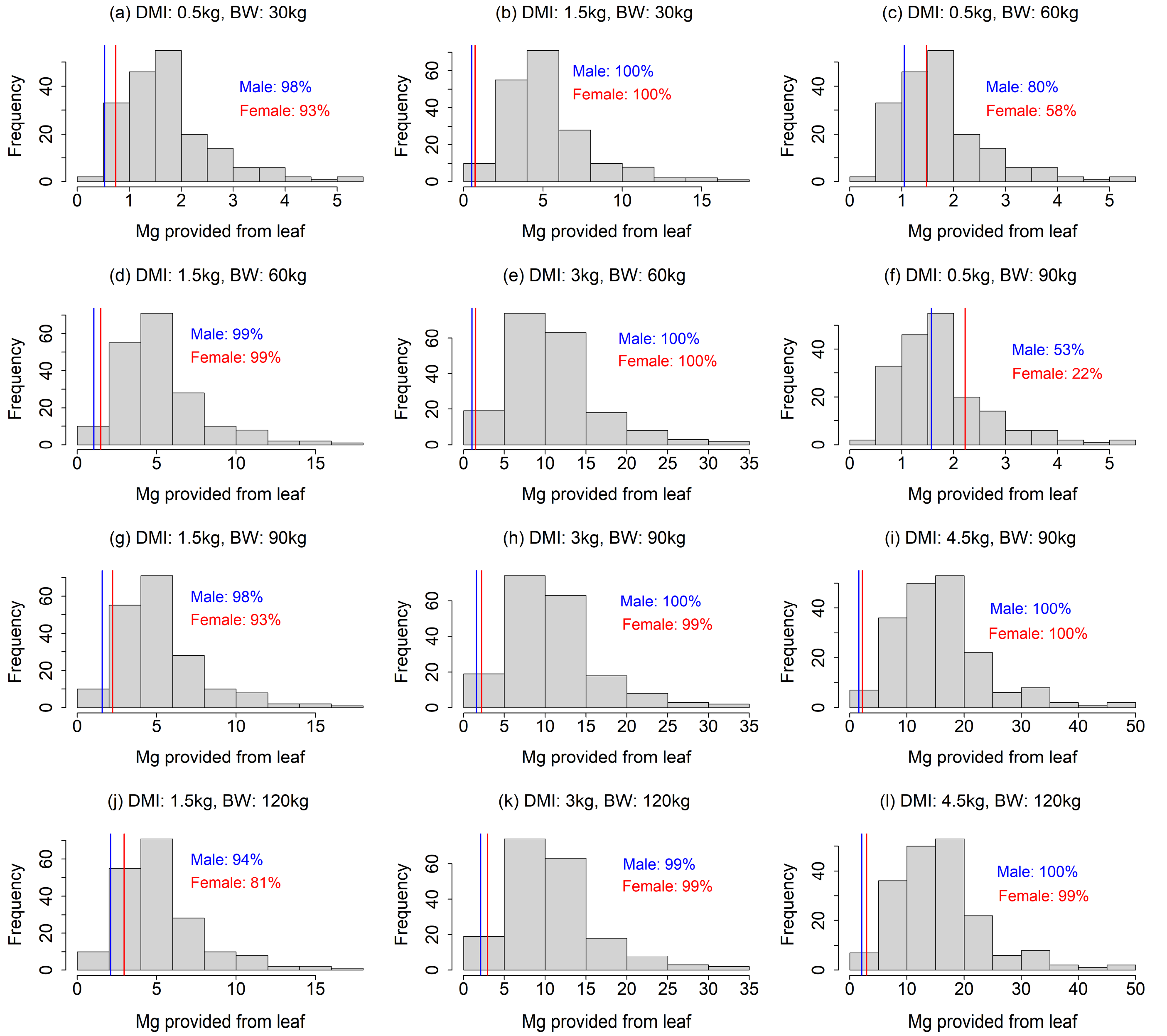

Figure 3. Comparison of Mg provision by food plants and the Mg requirement of sika deer under 12 scenarios (four dry matter intake levels × four body weights excluding unrealistic scenarios). The histogram indicates the distribution of Mg provision calculated from the leaves of food plant species. The solid lines indicate the Mg requirements of male (blue) and female (red) sika deer. Mg requirement of female during non-lactating period is equal to Mg requirement of male. In the figures, the percentage is the proportion of food plant species that meet the Mg requirements.

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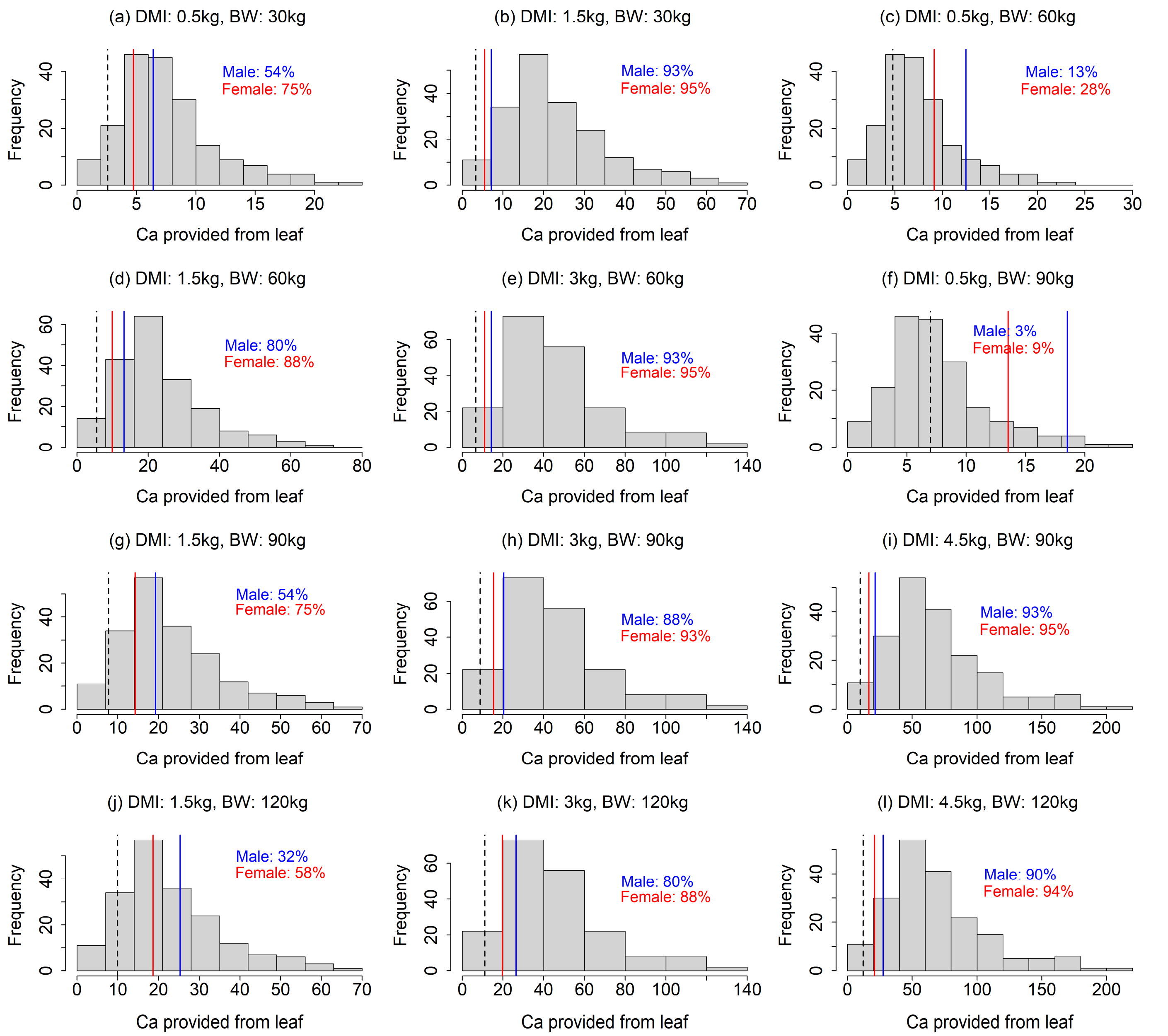

Figure 4. Comparison between Ca provision via food plants and the Ca requirement of sika deer under the 12 scenarios (four dry matter intake levels × four body weights excluding unrealistic scenarios). The histogram is the distribution of Ca provision calculated from leaves of food plant species. The solid lines indicate the Ca requirements of male (blue) and female (red) sika deer. Dashed line indicates Ca requirement of female during non-lactating period, which equal to Na maintenance requirement for both male and female. In the figures, the percentage is the proportion of food plant species that met the Ca requirements.

4. Discussion

Our results suggest that food plants in Japan are unlikely to provide sufficient Na, which agrees with the traditional view that Na is the main deficient mineral leading to the use of salt licks [8,9,14]. By comparing several salt solutions as attractants experimentally, Fraser and Reardon (1980) demonstrated that Na, but not K, Ca, or Mg, attracted moose (*Alces alces*) and white-tailed deer (*Odocoileus virginianus*), indicating that Na was the primary attractant at their study site [6]. Sika deer were also reported to be attracted by Na [14,23,37]. The larger Na deficiency for lactating females than males (Fig. 2) is consistent with reports that female sika deer were attracted by salt, especially during pregnancy or lactation [14,23].

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This study suggests the importance of Ca as a potentially limiting element of sika deer in Japan. Although natural salt licks have been attributed to Na acquisition, several authors have reported that Ca could also be a salt lick attractant [18]. Kitahara et al. (2005) reported that sika deer in Hokkaido, Japan, may be Ca-deficient [38]. Tsujii and Tokumoto (1997) reported that several natural salt licks in Japan d

id not have high Na contents [39], but they had tended to have high Ca, Fe, Mg, and Mn contents. Miyazaki and Kohara (2017) reported that sika deer licked an antifreeze containing calcium chloride ($CaCl_2$) as the main component, proposing that antifreezes accelerate the overpopulation of sika deer in Japan by providing Ca [40]. Our simulation supported the hypothesis that sika deer in Japan are potentially deficient in Ca, demonstrating that Ca requirements may not be met by food plants, at least in certain situations (Fig. 4).

Our finding might be beneficial for efficiently culling sika deer using minerals as attractants. Culling is one of the important management tools for overabundant sika deer populations [24,41], and suitable attractants have been verified to increase culling efficiency [42,43]. We suggest that Na can be an effective attractant for selectively culling female deer, which has been reported to be effective in reducing sika deer populations [24,25], especially during lactating period (Fig. 2). We also suggest that Ca could be a potential attractant for sika deer (Fig. 4), as well as Na, which has been used as an effective attractant for hunting sika deer [23]. However, since Ca deficiency is stronger in male deer, Ca may not be an effective attractant for selective culling of female. Given the different mineral requirement patterns observed for male and female (Fig. 2 and 4) and potential seasonal changes in the effects of minerals to attract male and female [14], combination of multiple mineral usage depending on seasons might be more effective for sika deer culling.

In summary, our results indicate that food plants are unlikely to always provide sufficient Na and Ca, especially under current conditions in Japan, where sika deer overpopulation has intensified herbivorous pressure and the choice of food plant species is often limited. Furthermore, we suggested that Na can be an effective attractant for selectively culling female deer, whereas Ca could be an attractant for male deer. Nevertheless, this study has several limitations. First, the data were obtained from a global database, not in Japan. Since plant mineral contents are affected by soil conditions, data collection in Japan is required in the future. Second, the equations used to calculate the Na, Ca, and Mg requirements were not constructed for sika deer, although a minor modification was made for sika deer (see Materials and Methods). Equations for sika deer are required for a more robust estimation. Despite those limitations, this study demonstrates that sika deer in Japan might require extra Ca and Na sources in addition to food plants, and therefore these minerals could be useful for developing effective culling methods.

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Conflicts of Interest: The authors declare no conflict of interest.

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