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Abstract: India has a shortage of forage and feed for its estimated 535 million head of livestock. Nutrition is the most limiting factor for goats in India to fulfill their genetic potential. Most Indian goats are managed in extensive grazing systems and information about goat nutrition and management practices in India is scarce. Consequently, this study’s objective was to identify how goat management practices impact goat health and the environment in Western Odisha. A nine-month goat observation experiment took place in the Kandhamal District of Odisha to observe the current livestock system and browsing behavior of goats. The methods utilized for goat observations were novel and suggest how other researchers could approach future grazing systems research. Digestible dry matter intake of forages selected by goats in the available pasturage was low compared to similar studies. There was a high proportion of non-native, invasive species selected by goats. Livestock management practices in combination with other human interventions that are disturbing forest and pastureland ecology are degrading available lands for grazing. To improve the productivity of grazing livestock and the condition of common property resources, investment must be made by government.

ABOUT THE AUTHOR
Dr. D. J. Cherney’s research group is based in the Animal Science Department of Cornell University. Dr. Cherney is an animal nutritionist with a unique ability to evaluate challenges that livestock experience with forages across a wide range of production systems. The group’s research mainly focuses on identifying appropriate forage management to sustain high productivity while maintaining economic viability, environmental sustainability, and animal welfare. Several researchers have focused on improvements to forage utilization in developing countries by addressing potential improvements to laboratory or management systems to assess forage quality and ensure optimal consumption.

PUBLIC INTEREST STATEMENT
Nutrition is the most limiting factor for goats in India to fulfill their genetic potential from a national shortage of forage and feed for livestock. This study’s objective was to identify how goat management practices impact goat health and the environment in Western Odisha. A nine-month goat observation experiment took place in the Kandhamal District of Odisha to observe the current livestock system and browsing behavior of goats. The methods utilized for goat observations were novel and suggest how other researchers could approach future grazing systems research. Digestible dry matter intake of forages selected by goats in the available pasturage was low compared to similar studies. There was a high proportion of non-native, invasive species selected by goats. To improve the productivity of grazing livestock and the condition of common property resources, investment must be made by government departments to monitor land management practices and reestablish pastures with improved forages.
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**Subjects:** Agricultural Development; Agriculture and Food; Animal Ecology; Resource Management - Environmental Studies

**Keywords:** goat nutrition; land use; grazing management; pasture management

1. **Introduction**

India has one of the largest livestock populations in the world, and notably, most livestock feed requirements are met by crop residues and byproducts, gathered forages from uncultivated or cultivated lands, and grazing on common property resources or harvested fields (Dikshit & Birthal, 2010). Substantial estimated forage supply shortfalls are projected to worsen for the next several decades (Dikshit & Birthal, 2010; Roy & Singh, 2008). Current nutrient supply limitations prevent goats from fulfilling their genetic potential (Mandal et al., 2005). Birthal and Jha (2005) identified feed scarcity as the most limiting constraint to improvements in livestock productivity.

A shift toward small ruminants as the preferable livestock has stemmed from natural resource degradation in arid and semiarid regions and considerable growth in meat consumption (A. K. Singh, 2013). Annual domestic demand for small ruminant meat has increased from 0.6 million tons in 2011 to an estimated 1.275 million tons in 2030, which would result in a shortfall of 0.25 million tons (Hegde & Deo, 2015). Feeding India's livestock population is becoming increasingly more challenging given the widening forage supply gap and growing demand for animal source proteins. Goats mainly consume their feed from grazing lands, which are being degraded across India, including Odisha State. Odisha's Department of Fisheries and Animal Resources Development has stated that deterioration of common property resources is a major ecological concern (Government of Odisha, 2002, 2014). The total area of common property resources in Odisha has dropped from 8519 thousand ha in 1950–51 (55% of the state’s total geographic area) to 5108 thousand ha in 2010–2011 (33% of the state's total geographic area) (Raghunath & Mamata, 2013). Reductions in common property resources are likely caused by encroachments by rural households, over-exploitation, and government development programs that distribute land, which has been observed in other areas of Odisha (Raghunath & Mamata, 2013). Approaches to ameliorate grazing lands to meet the requirements of livestock are essential with current trends toward increasing demand for goat meat and simultaneous degradation of the lands where they graze.

Quantity and quality of feed intake by grazing animals is crucial for the identification of constraints to efficient production where nutrient intake is a main limitation (Ramirez, 1999). Finding accurate estimates of forage intake selections of browsing herbivores has historically been a fundamental methodological obstacle, and the complexity of the feeding environment increases the difficulty (Bonnet et al., 2015). Monitoring goat intake within a laboratory setting with metabolism crates is one method of obtaining reliable data, but this does not account for the complexities of the real-life farm scenario (Bonnet et al., 2015). Methodologies that can be used in the field are constructive for understanding the true application of research conclusions. The current study aimed to determine how goat management decisions impact animal health and ecological outcomes in Western Odisha, India by piloting a new method of goat observation to characterize forage selection by goats and to quantify selection quality.

2. **Materials and Methods**

2.1. **Site selection and project design**

Two project sites (villages) in the Tikabali Block of Kandhamal District, Odisha were selected to participate in the project. Breka is located at 84.3494E, 20.2072 N, and Budugudari is located at
84.3519E, 20.2333 N, with an elevation of 610 m above sea level (Figure 1). Village selection criteria included: (1) more than half of village households owning goats, (2) existing local infrastructure available to facilitate project logistics, and (3) willingness of farmers and local government officials to participate. Four households were randomly selected within each village from a sampling frame of households owning four or more adult female goats of reproductive age. Four females from each household (n = 32) were identified as likely to conceive during the project timeline and were selected as the major goats of interest, hereafter referred to as selected goats. All other adult goats, for a total of 90 enrolled goats (24 males and 66 females at the beginning of the project) from participating households were also enrolled for the measurement of other parameters such as weights. Animal procedures were reviewed and approved by the Cornell University Institutional Animal Care and Use Committee under the Animal Welfare Assurance (A3347-01) and Institutional Review Board approval was obtained (#1,603,006,254) from Cornell University.

The current eight-month longitudinal study started in May 2016 and ended in December 2016. The timeline was divided into three seasons: summer (May—June), rainy (July—September), and winter (October—December). Repeated-measures were collected seasonally. Temperatures in Kandhamal District’s hot, moist and sub-humid climate (Panigrahi et al., 2010) ranged from 23.4°C to 33.3°C, 22.1°C to 27.9 °C, and 15.5 °C to 28.1°C in summer,
rainy, and winter seasons, respectively. Average daily precipitation was 5.1 mm (SD ± 9.43), 10.4 mm (SD ± 14.6), and 0.81 mm (SD ± 3.13) in summer, rainy and winter seasons, respectively.

2.2. Data collection, management, and analysis

2.2.1. Goat health
The 90 enrolled adult goats (24 males and 66 females) were weighed monthly with a manual hanging scale (National Weighing & Instruments, Sydney, Australia). Adult body weights were analyzed in a mixed model with weight as the dependent variable, season and sex as fixed effects and goat nested in household and household as random effects. Body condition scores were evaluated monthly with the Langston University 9-point palpation and observation scale from 1 to 5 by 0.5-point increments (Detweiler et al., 2008). Body condition scores were analyzed in a mixed model with body condition score as the dependent variable, season, age, and sex as fixed effects and goat nested in household and household as random effects.

FAMACHA® (Van Wyk & Bath, 2002) scores were assessed monthly by judging the degree of anemia displayed in eye mucous membranes on a scale of one to five where one is optimal and five is highly anemic. FAMACHA® scores were analyzed in a mixed model with season and age as fixed effects, and goat nested within household and household as random effects. Fecal egg counts were recorded during rainy and winter seasons using McMaster’s slides (Zajac et al., 2014). Fecal egg counts were transformed to square roots and analyzed in a mixed model with season as a fixed effect, and goat nested in household and household as random effects. All goats were dewormed with a Levamisole dewormer (Fasnil) at the beginning and end of the rainy season. Goats were vaccinated against enterotoxaemia, peste des petits ruminants, and goat pox at the onset of the rainy season.

2.2.2. Environmental impacts
Each of the 32 selected goats was observed for one full day in each season (summer, rainy, and winter) during grazing. Four goats were followed per day for a total of eight days per season. Trained staff members followed goats and recorded whether the goat was eating, standing, lying down, or ruminating at 15-min intervals using the Open Data Kit tablet software (www.opendatakit.org) for the nine prominent hours of grazing in the day. If a goat was visibly chewing its cud, then it was marked as ruminating; otherwise, it was marked as standing or lying down if none of the other activities applied. If the goat was consuming vegetation, the selected plant was photographed and a sample was collected.

All collected plants were identified locally or they were pressed between newspaper and cardboard (Lacey et al., 2001) for later identification. Plants were classified into five lifeform classes: trees, shrubs (and subshrubs), shrub/trees, herbs, and graminoids (grasses and grass-like) according to USDA definitions (United States Department of Agriculture, 2005). Grass and grass-like species were left unidentified because of the difficulty of identifying the precise species a goat selected in a mixed stand, and the challenge botanists experienced to identify grasses. Plant species were identified by botanists at the Regional Plant Resource Center in Bhubaneswar, Odisha, and scientific nomenclature of species was followed according to Khuroo et al. (2012) and online databases such as The Annual Checklist of World Plants (http://www.catalogueoflife.org/) and International Plant Names Index (http://www.ipni.org).

Alien plant species were identified as invasive, naturalized, or invasive (N/I), naturalized (Nt), casual or naturalized (C/N), casual or cultivated according to Khuroo et al. (2012). “N/I” refers to naturalized alien species with insufficient evidence to be recognized as invasive, but has the potential to be invasive soon. “C/N” refers to casual alien species with insufficient evidence to be termed as naturalized, but with potential to become naturalized soon.
Species consumed more than five times during a season were collected for laboratory analysis. Forage samples were oven-dried to a constant weight at 60°C and dry matter (DM) concentration was recorded. Samples were shipped to the International Livestock Research Institute in Hyderabad, India for analysis by near infrared reflectance spectroscopy. Samples were analyzed for predicted metabolizable energy (ME), neutral detergent fiber (NDF), acid detergent fiber (ADF), crude protein (CP), and in vitro organic matter digestibility (IVOMD). Metabolizable energy was calculated as ME (MJ/kg DM) = 2.20 + 0.136 Gp + 0.057 CP, where Gp is the net gas production (ml) from a 200 mg dry sample after a 24 h incubation and correction for daily variation in activity of rumen liquor using the Hohenheim standard (Makkar, 2004). Gas production at 24 hours was used to predict in vitro digestible organic matter concentrations with the equation IVOMD = 15.38 + (0.8453*Gp) + (0.595*CP on a dry matter basis for %) + (0.181*Ash %) (Menke & Steingass, 1988). A diet for each goat was created based on its daily selections. If a plant was not sampled for nutritional analysis because it was not selected frequently enough, an average was applied based on the other plants that were collected in its lifeform class and season. Researchers applied the National Research Council's (National Research Council, 2007) parameters for goats to determine if diets met nutritional requirements, assuming standard book values for dry matter intake.

The 32 selected goats were fitted with GPS collars (Garmin Etrex 30, Olathe, Kansas, U.S.) (Figure 2) in each season and continued with their regular grazing practices, and location coordinates were recorded at 10-s intervals. GPS collars did not appear to impact grazing behaviors, and goats were accustomed to wearing heavy bells around their necks. Data were downloaded daily to record grazing locations, and distance walked horizontally and vertically. Because goats tended to live in close proximity to their owners and herders, the presence of nearby observers was not distracting to their grazing habits. A mixed model was used to analyze the distance walked per day with season as a fixed effect and goat nested within household and household as random effects. An ANOVA model was used to analyze differences between the type of forage (i.e., grass, herb, shrub, shrub/tree, or tree) selected and season. QGIS (QGIS Development Team 3.0.1-Girona), QGIS Geographic Information System, Open Source Geospatial Foundation Project (http://qgis.osgeo.org) software was used to develop maps of grazing routes and grids totaling the time spent in specific areas of grazing lands.

2.2.3. Focus groups
Focus groups were held in the two participating villages at the initiation of the project and at the end of each season in addition to four focus groups conducted in nearby villages for a total of 12 focus groups. Focus groups averaged 10 participants (SD = 4.64) per meeting, and men and women were represented at all meetings with a slightly stronger representation by male participants. Focus group topics centered on land management practices regarding grazing habits and land changes over time. An interview was conducted with personnel at the Forest Department in the district capital of Phulbani regarding monitoring practices and the scenario of forest ecosystems in the Kandhamal District.

2.2.4. Statistical analyses
R (version 3.4.2, 2017, R Foundation for Statistical Computing, Vienna, Austria) was used for all statistical analyses. All analyses were considered statistically significant if P ≤ 0.05. For model establishment, all covariates and interactions of interest were first included and then selected backwards with removal at P > 0.1.

3. Results
Two of the eight participating households were considered Scheduled Caste and six were Scheduled Tribes of the Khond tribe, as defined by the Government of India (2011a). The main sources of livelihood were cultivation, wage labor, livestock, and collection of non-timber forest products. A single major cropping season was bounded by rainfall, lack of irrigation, and unmanaged livestock. Livestock owners would only monitor livestock during the rainy season, which made it difficult for farmers to cultivate in the remainder of the year because crops would be damaged by unattended livestock. Most farmers cultivated rice as the staple crop with supplementary food crops of maize and vegetables. Mean household land ownership was 1.20 ha (SD ± 0.79). Goats were raised for the meat market. Mean herd size was 12 goats (SD ± 3.20), and all
goats were non-descript breeds. Outside of grazing, goat management labor was fulfilled by family members, besides shared-labor agreements maintained for grazing purposes. Seven of eight households reported the adult female as main caretaker in summer, and care shifted to the elder female in the rainy season in five of the eight households. Care was more evenly spread
across family members in the winter with 5/8 households reporting that adult male and female primarily cared for goats. In shared-labor agreements, goat farmers would rotate days to herd goats from several goat-owning households, which enabled labor investment elsewhere. In the village of Budugudari, goats were actively herded the entire year for fear of wild dogs attacking goats. In Breko, goats were herded during cultivation season (June—December), but were left unattended when fields were fallow (January—May).

Goat shelters had thatched roofs with brick or mud walls or goats were kept in rooms within farmers’ homes without raised platforms to prevent goat contact with feces. Common water sources for goats were puddles or streams that were found while grazing. Goats did not have access to free water in the home, but a water bucket was offered once per goat in the evening.

3.1. Goat health
The mean CP for commonly selected forages (Table 1) was 16% (SD ± 6.21) and mean ME was 8.17 MJ/kg (SD ± 1.49). NDF averaged 45.69% (SD ± 11.61) and ADF averaged 25.09% (SD ± 8.58). Mean IVOMD was 55.77% (SD ± 9.69).

All goat diets were sufficient in CP when compared to National Research Council standards for the type of physiological status (i.e., pregnant, lactating, or maintenance only) (National Research Council, 2007) (Table 2). Requirements for concentration of metabolizable energy were unmet on 60 of the 96 goat-days foraged.

Adult body weights (Table 3) did not vary between the rainy and winter seasons (P = 0.5607), but did vary between the other season comparisons for both male and female goats (P < 0.0001). Female weights were 16.4 kg (SE ± 1.22), 17.6 kg (SE ± 1.21), and 17.7 kg (SE ± 1.21) in the summer, rainy, and winter seasons, respectively. Weights averaged 13.4 kg (SE ± 1.59), 14.5 kg (SE ± 1.58), and 14.6 kg (SE ± 1.58) for male goats during summer, rainy, and winter seasons, respectively. Body conditions scores (Table 3) varied based on season (P < 0.0001), though the comparison between rainy and summer seasons was less pronounced (P = 0.02). Body condition scores for female goats averaged 1.50 (SE ± 0.04), 1.41 (SE ± 0.04), and 1.23 (SE ± 0.04) and for males averaged 1.63 (SE ± 0.05), 1.54 (SE ± 0.05), and 1.36 (SE ± 0.04) for the summer, rainy, and winter seasons, respectively. Body condition scores were not variable between the rainy and summer seasons, but they were different between the other season comparisons (P < 0.0001).

During the eight-month timeline, 20 of the 32 selected female goats were pregnant and one gave birth to stillborn twins that likely died from dystocia. Females produced 16 singles and nine pairs of twins (34 kids total). Eleven kids of the 34 total kids did not survive until the end of the project, nine of which were twins.

Recorded at 15-min intervals, the goat activities during the daily nine-hour principal grazing period (Table 4) indicate that goats spent the majority of their time grazing when compared to walking, ruminating, lying down or standing.

Fecal egg counts averaged 835 eggs per gram (SD ± 726) of feces. Five out of 63 goats had greater than 2000 helminth eggs, and 19 of 63 sampled goats had more than 1000 helminth eggs, which is the threshold for deworming lactating females or young animals (Fernandez, 2012). Fecal egg counts were greater in the rainy season (Table 5). FAMACHA® scores from the rainy and winter seasons had a mean of 4, and 464 goats of 487 sampled goats during rainy and winter seasons scored greater than 2, which is the recommended threshold for deworming. Differences among seasons were not detected in FAMACHA® scores (Table 5).
| Species                        | Forage type | n | DM¹ | CP² | NDF³ | ADF⁴ | IVOMD⁵ | Predicted ME⁶ |
|-------------------------------|-------------|---|-----|-----|------|------|--------|---------------|
| Ailanthus excelsa Roxb.       | Tree        | 1 | 36.7| 17.6| 19.5 | 18.1 | 57.5   | 7.96         |
| Artocarpus heterophyllus Lam. | Tree        | 2 | 39.5 ± 3.0³ | 12.2 ± 0.21 | 25.0 ± 2.98 | 4.26 ± 2.39 | 84.9 ± 3.01 | 13.8 ± 0.27 |
| Atylosia scarabaceoides (L.) Benth. | Shrub     | 2 | 41.6 ± 1.79 | 12.5 ± 0.07 | 48.2 ± 2.25 | 27.2 ± 3.05 | 48.7 ± 0.79 | 6.92 ± 0.15 |
| Azadirachta indica A. Juss.   | Tree        | 2 | 34.8 ± 0.40 | 22.0 ± 0.22 | 29.2 ± 0.88 | 12.2 ± 2.68 | 66.9 ± 1.14 | 9.38 ± 0.13 |
| Casearia tomentosa Roxb.      | Tree        | 2 | 29.5 ± 3.40 | 16.2 ± 3.32 | 43.5 ± 7.88 | 23.7 ± 4.11 | 62.3 ± 5.13 | 9.22 ± 0.53 |
| Cassia tora L.                | Herb        | 1 | 19.0 | 18.1 | 41.5 | 22.9 | 62.3 | 8.93         |
| Celosia argentea L.           | Shrub       | 1 | 26.1 | 11.1 | 60.7 | 35.9 | 46.8 | 6.87         |
| Chromolaena odorata (L.) R.M. King & H.Rob. | Shrub | 4 | 27.4 ± 4.68 | 20.8 ± 4.28 | 39.1 ± 2.57 | 22.6 ± 0.96 | 56.9 ± 2.87 | 7.93 ± 0.49 |
| Cipadessa baccifera (Roth) Miq. | Shrub    | 2 | 32.1 ± 6.34 | 24.2 ± 0.82 | 21.2 ± 3.02 | 5.30 ± 2.80 | 71.6 ± 4.07 | 9.99 ± 0.51 |
| Clerodendrum infortunatum L.  | Shrub/tree  | 2 | 18.0 ± 2.81 | 26.8 ± 0.09 | 43.9 ± 1.11 | 24.4 ± 1.18 | 63.9 ± 2.37 | 9.16 ± 0.42 |
| Cynodon dactylon (L.) Pers.   | Grass       | 3 | 30.8 ± 9.64 | 15.0 ± 4.70 | 57.2 ± 2.73 | 32.7 ± 3.06 | 54.0 ± 3.05 | 7.43 ± 0.37 |
| Dalbergia lanceolata L. f. subsp. paniculata (Roxb.) Thoth. | Tree     | 1 | 52.2 | 24.3 | 42.9 | 24.3 | 58.0 | 7.98         |

(Continued)
| Species                                      | Forage type | n  | DM | CP  | NDF | ADF | IVOMD | Predicted ME |
|----------------------------------------------|-------------|----|-----|-----|-----|-----|-------|--------------|
| *Dendrocalamus strictus* (Roxb.) Nees.     | Grass       | 1  | 47.1| 22.1| 63.8| 31.8| 53.8  | 7.69         |
| *Desmodium triflorum* (L.) DC.              | Herb        | 2  | 38.1±2.04| 12.5±2.92| 39.9±6.53| 36.5±3.49| 45.6±2.76| 5.89±0.65     |
| *Diospyros melanoxylon* Roxb.               | Tree        | 2  | 32.7±0.08| 5.74   | 69.0±3.08| 37.6±0.73| 35.1±2.06| 6.27±0.04     |
| *Evolvulus nummularius* (L.)                | Herb        | 1  | 36.4| 19.1| 30.3| 32.9| 52.4  | 6.51         |
| *Ficus virens* Aiton                        | Tree        | 2  | 27.2±6.56| 16.9±0.59| 55.0±1.71| 30.6±0.78| 51.0±2.03| 7.55±0.40     |
| *Halanthera pubescens* (Wall.) G.Don        | Shrub/tree  | 4  | 29.2±9.82| 15.1±0.85| 35.1±9.07| 17.7±4.52| 57.9±1.04| 8.44±0.20     |
| *Kydia calycina* Roxb.                      | Tree        | 1  | 41.8| 18.8| 57.5| 21.1| 51.3  | 7.81         |
| *Lantana camara* L.                         | Shrub       | 4  | 25.6±4.60| 18.9±1.02| 43.3±5.65| 23.4±3.21| 62.0±1.02| 9.21±0.15     |
| *Madhuca longifolia* var. Latifolia (Roxb.)| Tree        | 3  | 45.5±1.17| 6.76±1.18| 57.6±5.48| 27.0±2.61| 39.8±1.42| 6.29±0.22     |
| *Mangifera indica* L.                       | Tree        | 2  | 46.8±1.06| 8.92±1.79| 42.1±1.16| 36.3±0.29| 40.5±0.03| 5.95±0.09     |
| *Mimosa pudica* L.                          | Herb        | 4  | 28.6±4.80| 26.1±3.18| 44.2±2.55| 24.4±4.57| 57.3±0.97| 7.99±0.31     |
| *Mitracarpus hirtus* (L.) DC.               | Shrub       | 1  | 30.2| 14.6| 30.4| 18.9| 61.9  | 9.06         |
| *Phoenix acaulis* Roxb.                     | Shrub       | 1  | 46.2| 8.49 | 58.14| 34.20| 51.53 | 7.38         |
| *Shorea robusta* Gaertn. (flower)           | Tree        | 1  | 82.9| 7.66 | 44.0 | 21.0 | 51.7  | 7.51         |
| *Shorea robusta* Gaertn. (leaf)             | Tree        | 3  | 32.5±5.33| 11.4±1.20| 54.9±1.42| 24.0±1.35| 52.9±0.66| 8.67±0.21     |

(Continued)
| Species                  | Forage type | n  | DM\(^1\) | CP\(^2\)  | NDF\(^3\) | ADF\(^4\) | IVOMD\(^5\) | Predicted ME\(^6\) |
|-------------------------|-------------|----|-----------|-----------|-----------|-----------|-------------|-------------------|
| Sida acuta Burm. f.     | Herb        | 2  | 36.2 ± 2.19 | 16.7 ± 1.01 | 51.8 ± 1.24 | 27.6 ± 1.71 | 56.9 ± 2.91 | 8.34 ± 0.59 |
| Tamarindus indica L.    | Tree        | 1  | 29.6       | 13.1      | 48.8      | 28.4      | 67.4        | 10.1             |
| Tephrosia purpurea Pers.| Shrub       | 2  | 22.3 ± 3.37 | 26.5 ± 1.21 | 37.1 ± 3.31 | 21.6 ± 0.56 | 65.6 ± 0.26 | 9.07 ± 0.0    |
| Vitex negundo L.        | Shrub       | 4  | 30.3 ± 4.86 | 14.7 ± 3.41 | 42.6 ± 2.58 | 28.6 ± 2.65 | 49.1 ± 2.63 | 7.25 ± 0.31 |
| Wendlandia tinctoria (Roxb.) DC. | Tree | 2  | 38.3 ± 5.88 | 8.79 ± 0.50 | 48.9 ± 0.14 | 21.6 ± 0.11 | 49.3 ± 0.54 | 7.95 ± 0.12 |
| Woodfordia fruticosa (L.) Kurz | Shrub | 3  | 41.2 ± 3.83 | 8.83 ± 0.74 | 47.5 ± 1.52 | 24.6 ± 1.16 | 48.3 ± 1.82 | 7.78 ± 0.15 |
| Ziziphus mauritiana Lam. | Tree        | 4  | 38.6 ± 6.24 | 18.3 ± 2.04 | 49.2 ± 4.41 | 23.5 ± 7.27 | 56.4 ± 4.15 | 8.29 ± 0.59 |
| Ziziphus oenopolia (L.) Mill. | Shrub        | 3  | 39.0 ± 3.13 | 18.7 ± 2.00 | 37.0 ± 6.91 | 18.2 ± 2.10 | 60.4 ± 3.22 | 8.75 ± 0.28 |
| Mixed grasses           | Grass       | 5  | 31.1 ± 10.1 | 15.3 ± 7.94 | 57.1 ± 4.66 | 33.4 ± 4.42 | 54.2 ± 3.66 | 7.59 ± 0.44 |

\(^1\)Forage samples taken in duplicate were averaged with standard deviations shown.
\(^2\)DM = dry matter
\(^3\)CP = crude protein
\(^4\)NDF = neutral detergent fiber
\(^5\)ADF = acid detergent fiber
\(^6\)IVOMD = in vitro organic matter digestibility
\(^6\)Predicted ME = predicted metabolizable energy
Table 2. Nutritional composition of mean individual goat daily selections

|          | Season    |               | All seasons |               |               |               |
|----------|-----------|---------------|-------------|---------------|---------------|---------------|
|          |           | Mean | SD   | Mean | SD   | Mean | SD   | Mean | SD   | Mean | SD   | %               | %               |
| DM       | Summer    | 40.2 | 4.41 | 27.1 | 2.58 | 37.3 | 2.05 | 34.9 | 6.46 |       |       |                 |                 |
| CP       | Rainy     | 20.9 | 2.09 | 16.3 | 1.56 | 14.6 | 2.21 | 17.3 | 3.32 |       |       |                 |                 |
| ME       | Winter    | 7.95 | 0.16 | 7.99 | 0.41 | 7.78 | 0.31 | 7.91 | 0.32 |       |       |                 |                 |
| NDF      | All       | 50.9 | 3.23 | 49.9 | 4.58 | 48.7 | 3.52 | 49.8 | 3.89 |       |       |                 |                 |
| ADF      |           | 27.4 | 1.74 | 27.9 | 3.24 | 27.8 | 3.13 | 27.7 | 2.77 |       |       |                 |                 |
| IVOMD    |           | 55.7 | 1.09 | 55.6 | 1.75 | 53.3 | 1.83 | 54.8 | 1.93 |       |       |                 |                 |

Table 3. All adult goats’ mean weights, ages, and body condition scores with standard deviations

|                  | n  | Mean body weight | Mean age | Mean body condition score |
|------------------|----|------------------|----------|--------------------------|
|                  | kg | days             |          |                          |
| Adult females (> one year) | 45 | 20.2 ± 5.56 | 1063 ± 492 | 1.3 ± 0.35 |
| Adult males (> one year)     | 18 | 16.3 ± 6.53 | 507 ± 277  | 1.5 ± 0.40  |

Table 4. Activities within three seasons of 32 goats over the daily nine-hour principal grazing period

|          | Summer | Rainy | Winter | p-value |
|----------|--------|-------|--------|---------|
| Grazing  |        |       |        | 0.4855† |
| Walking  | 554    | 560   | 523    | 46.4    | < 0.0001 |
| Ruminating | 135  | 143   | 140    | 12.4    | < 0.0001 |
| Lying down | 123  | 139   | 128    | 11.4    | 0.5973  |
| Standing | 136    | 210   | 272    | 24.1    | < 0.0001 |

Table 5. Predicted means of fecal egg counts and FAMACHA© scores within seasons

| Analysis   | Predicted mean of rainy season | Predicted mean of winter season | p-value |
|------------|--------------------------------|---------------------------------|---------|
| Fecal egg count* | 840 (566–1168)† | 497 (290–759) | 0.0411  |
| FAMACHA©** | 3.61 ± 0.10†† | 3.54 ± 0.08 | 0.4335  |

†Chi Square test result comparing activities across seasons.

*Confidence intervals presented because of square root transformation.
††Standard errors presented for FAMACHA© scores.
*Mixed model with square root of fecal egg count as the dependent variable; season as a fixed effect; goat nested within household and household as random effects.
**Mixed model with FAMACHA© score as the dependent variable; season and age as fixed effects; goat nested within household and household as random effects.
3.2. Environmental impacts
The proportion of native and alien species from the identified species were 531/902 and 377/902, respectively (Table 6). Two hundred and fifty of 902 identified species were invasive, 54/902 were N/I, 22/902 were Nt, 43/902 were C/N, and 8/902 were cultivated.

Table 6. Forage species selected more than five times by selected goats totaled for each season

| Species                          | # of selections per season | Alien or native species | Forage type |
|----------------------------------|----------------------------|-------------------------|-------------|
|                                  | Summer | Rainy | Winter |                        |             |
| Artocarpus heterophyllus Lam.    | 2      | 11    | 0      | Native                  | Tree        |
| Atylosia scarabaeoides (L.) Benth.| 0      | 0     | 10     | Native                  | Shrub       |
| Azadirachta indica A. Juss.      | 1      | 3     | 1      | Nt                      | Tree        |
| Benkara malabarica (Lam.) Tirveng| 0      | 3     | 5      | Native                  | Tree        |
| Buchanania lanzan Spreng.        | 1      | 5     | 1      | Native                  | Tree        |
| Casearia tomentosa Roxb.         | 2      | 10    | 5      | Native                  | Tree        |
| Cassia toba L.                   | 0      | 11    | 2      | Invasive                | Herb        |
| Chromolaena odorata (L.) R.M. King & H.Rob. | 24 | 17 | 17 | Invasive                | Shrub       |
| Cipadessa baccifera (Roth) Miq.  | 4      | 12    | 6      | Native                  | Shrub       |
| Clerodendrum infortunatum L.     | 1      | 8     | 4      | Native                  | Shrub/Tree  |
| Dabergia lanceolana L. f. subsp. paniculata (Roxb.) Thoth. | 0 | 3 | 4 | Native | Tree |
| Dendrocalamus strictus (Roxb.) Nees. | 10 | 2 | 0 | Nt | Grass |
| Desmodium triflorum (L.) DC.     | 0      | 3     | 34     | N/I                     | Herb        |
| Diospyros melanoxylon Roxb.      | 0      | 5     | 1      | Native                  | Tree        |
| Evolvulus nummularius (L.) L.    | 0      | 1     | 10     | Invasive                | Herb        |
| Ficus benjamina L.               | 0      | 4     | 1      | Native                  | Tree        |
| Ficus virens Aiton               | 0      | 0     | 6      | Native                  | Tree        |
| Hemidesmus indicus (L.) R. Br.   | 2      | 4     | 0      | Native                  | Shrub       |

(Continued)
There was a total of 48 selections in all three seasons for unknown trees and shrubs, and the remaining selections were forages that were selected less than five times within a season. Comparisons made among all categories of native and alien species did not show any differences between the nutritional composition parameters of CP, ME, NDF, ADF, or IVOMD when using an ANOVA with each nutritional component as the dependent variable and the category of native vs. alien species as the independent variable. Means and standard deviations of each nutritional composition parameter is shown in Table 7.

Six-hundred and seventy-eight of the total 1625 identified of goat selections over the study period were grasses, followed by 365 tree selections, 305 of shrubs, 210 of herbs, and 67 from shrub/trees. There were no observed differences (P ≤ 0.05) between the type of forage selected and season. Several selected species overlapped between seasons. Grasses were more commonly selected in the rainy and summer seasons compared to the winter season (Figure 3). Though

### Table 6. (Continued)

| Species                                      | # of selections per season | Alien or native species | Forage type |
|----------------------------------------------|----------------------------|-------------------------|-------------|
| Holarrhena pubescens (Wall.) G.Don           |                            |                         |             |
| Lantana camara L.                            |                            |                         |             |
| Madhuca longifolia var. latifolia (Roxb.) A.Chev. |                            |                         |             |
| Mangifera indica L.                          |                            |                         |             |
| Mimoso pudica L.                             |                            |                         |             |
| Mitracarpus hirtus (L.) DC.                   |                            |                         |             |
| Phoenix acaulis Roxb.                        |                            |                         |             |
| Shorea robusta Gaertn.                       |                            |                         |             |
| Syzygium cumini (L.) Skeels                  |                            |                         |             |
| Tamarindus indica L.                         |                            |                         |             |
| Vitex negundo L.                             |                            |                         |             |
| Woodfordia fruticosa (L.) Kurz               |                            |                         |             |
| Ziziphus mauritiana Lam.                     |                            |                         |             |
| Ziziphus oenopolia (L.) Mill.                |                            |                         |             |
| Mixed grasses                                |                            |                         |             |
| Total                                       | 503                        | 492                     | 409         |

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grasses were not individually identified, it was observed that *Cynodon dactylon* (L.) Pers. represented the majority of grasses in mixed stands.

Predicted means of kilometers walked per day in each season were 5.83 (SE ± 0.24), 6.35 (SE ± 0.24), and 6.54 (SE ± 0.24) for summer, rainy, and winter seasons, respectively; with differences between the summer and winter seasons (*P* = 0.0174) from a mixed model with distance walked per day with season as a fixed effect and goat nested within household and household as random effects. No differences were observed between villages.

Average maximum elevation reached while grazing was 631 meters (SD ± 86.1) and the average minimum elevation was 582 meters (SD ± 54.5). Figures 4 and 5 display the GPS tracks taken by 16 goats in each season within each village, and Figure 4 panel D and Figure 5 panel D report the combined GPS tracks of the same 16 goats across all three seasons with each village. Goats spent more time closer to their villages during summer season when fields were fallow and tended to disperse further away from the villages during rainy and winter seasons when fields were under cultivation.

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### Table 7. Nutritional composition means and standard deviations of alien and native species

| Species                    | n  | DM    | CP     | ME     | NDF   | ADF   | IVOMD  |
|----------------------------|----|-------|--------|--------|-------|-------|--------|
| Native                     | 21 | 39.2 ± 12.7 | 14.5 ± 6.11 | 8.15 ± 1.65 | 45.6 ± 12.8 | 23.7 ± 8.51 | 54.6 ± 10.9 |
| Invasive                   | 7  | 28.5 ± 6.19 | 18.7 ± 4.48 | 7.97 ± 1.00 | 44.4 ± 9.63 | 27.1 ± 5.32 | 56.4 ± 5.41 |
| Naturalized or invasive    | 3  | 30.2 ± 7.89 | 17.9 ± 7.52 | 8.01 ± 1.83 | 35.8 ± 4.88 | 25.7 ± 9.50 | 57.7 ± 10.6 |
| Naturalized                | 2  | 41.0 ± 8.68 | 22.0 ± 0.07 | 8.53 ± 1.19 | 46.5 ± 24.4 | 22.0 ± 13.9 | 60.4 ± 9.25 |
| Casual or naturalized      | 2  | 30.0 ± 0.51 | 13.9 ± 1.12 | 8.66 ± 1.99 | 45.7 ± 4.36 | 28.5 ± 0.14 | 58.2 ± 12.9 |

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Figure 3. Number of selections made for each forage type within seasons.
Figure 4. Budugudari village tracks from 16 goats in summer season (A), rainy season (B), winter season (C), and all three seasons combined (D). Map is set at latitude and longitude (84.363546E, 20.238235 N) and (84.348967E, 20.223568 N), approximately 2.5 km².

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Percent of goat hours spent in specific grid squares was calculated from Figures 4 and 5 and is aggregated in Table 8. Goats utilized a larger area in Breka compared to Budugdari in all three.
seasons, which resulted from the fact that most goats in Budugudari were herded together, whereas there were a number of separate herding groups in Breka.

All households reported forage shortfalls during April; seven households, three households, and one household of the eight total households reported forage shortfalls in May, June, and March, respectively. All participating households and nearby village representatives observed noticeable reductions in the forest size over recent years because of tree cutting or intentionally set forest fires. Because firewood was the primary fuel source for households, there was a high demand for firewood that farmers acknowledged was detrimental to the forest, but they believed that they had no other choice. Reductions in pasturelands outside of the forest were due to conversion to cultivation. One participant reported that quantity of vegetation previously consumed by a goat in an hour now required 2-h due to the loss of available vegetation. Personal communication with the Kandhamal District Divisional Forest Officer informed researchers that the Forest Department does not systematically monitor forest lands for over-grazing or mismanagement from livestock owners (personal communication, September 9, 2016).

Grazing routes were chosen by the day’s herder without a planned, rotational stocking system in both villages. Some herders discussed routes with the previous day’s herder and went to a different area, or they would visually seek out patches of taller vegetation. Management of goats within the forest was a challenge for older individuals, and only younger herders would allow goats to browse within the forest for fear of losing animals. Grazing routes varied seasonally based on avoidance of fields covered with crops during times of cultivation. During seasons when fields were fallow (December—June), goats could forage openly without restriction.

4. Discussion

4.1. Forage species selected
Goats selected more grasses in the summer and rainy seasons than during winter (Figure 3), which was likely related to the new growth that resulted from the monsoon rains that caused a variety of new shrubs and trees to become available in winter. Proportion of grasses in the diet was higher (678 of 1625 total selections) than expected and could be related to the non-availability of preferred browse species. Similar seasonal consumption of grasses was reported in Mexico and Brazil by goats browsing rangelands (Pfister & Malechek, 1986; Ramirez, 1999).

Of the 36 plants identified among the “world’s worst invasive species,” two were selected more than five times (Chromolaena odorata (L.) R.M.King & H.Rob. and Lantana camara L.) (Table 6), and one
species (*Leucaena leucocephala* (Lam.) de Wit) was selected twice (Khuroo et al., 2012). *Lantana camara* L., a commonly selected plant in all three seasons, is a major weed shrub across India that has invaded most pasturelands (13.2 million ha) (S. P. Singh, 1996). It is estimated that damage to pastureland caused by *Lantana camara* L. is USD 924 million per year because the weed is toxic to cattle and clean-up is costly (Pimentel et al., 2001). Goats are relatively resistant to poisoning from *Lantana camara* L. and do not suffer the same effects as sheep and cattle (Stiegelmeier et al., 2013). Invasive species management benefits a large number of stakeholders by improving protection of human, animal, and plant health, and the resulting enhancements to productivity in agriculture and forestry (Marbuah et al., 2014). Incidence and dispersal of invasive plant species is often symptomatic of underlying land management problems that need to be corrected before control of invasive species can be realized (Masters & Sheley, 2001). In our local context, disturbance to forest and rangeland ecosystems through human interventions has made niches available for opportunistic alien species to fill, and a long-term control plan of invasive plants should consider land management practices such as reducing land disturbance and reseeding with desirable plant species (Masters & Sheley, 2001).

Goats provide a valuable ecosystem service by browsing the *Lantana camara* L. noxious weed and other invasive plants. Prescriptive grazing with livestock is not a new concept, and was published in U.S. research as far back as the 1930s (Mosley, 1996), but has gained interest and application in the last few decades (Pearson & Ortega, 2009). Goats’ preference for woody browse species makes them an ideal candidate for control of invasive browse plants compared to sheep that prefer grass species (Walker et al., 1994). Though techniques such as herbicides may be more effective than prescriptive grazing with livestock (Pearson & Ortega, 2009), goats are a tool that farmers currently have available for the control of less-desirable species in grazing lands at a lower cost. Grazing must be short and targeted to successfully reduce biomass, flowering, and seed production, and multiple years of targeting specific species is most effective (Pearson & Ortega, 2009). Nutritional quality of the alien species in the current study was comparable to the nutritional components of native species in terms of CP, ME, NDF, ADF, and IVOMD (Table 7). Therefore, this could be a win-win scenario for goats to target invasive species because they will not experience a decline in diet quality while they are used as tool to combat alien species that can be detrimental to forest plant species diversity.

### 4.2. Method discussion
Methods to evaluate grazing in laboratory settings are appropriate when the scientific question is to understand a specific process in isolation from other processes that occur in natural systems. However, the complexity in natural systems requires “field-model” approaches (Bonnet et al., 2015). Benefits of the method proposed and applied in the current study are that the method is non-invasive, can be used in a variety of settings, and is low-cost relative to alternatives. We took a representative sub-sample of all activities and plant selections from goats during their main grazing hours by recording at 15-min intervals without requiring staff to take a full sample of all grazing choices and behaviors. Livestock need to be social to maintain their normal grazing behaviors around observers for the current method to be effective.

The method characterized the forage selections and quantified the quality of commonly selected forages of goats. Methodologies could be appended to also evaluate dry matter intake such as the use of fecal markers (Raleigh et al., 1980) or microhistological analyses (Alipayo et al., 1992).

### 4.3. Comparisons of goat health and diets
Most daily diets, assuming required daily dry matter intakes, were deficient in digestible feed components. There was no apparent pattern related to goat physiological status (early gestation, maintenance only, etc.) to determine nutritional status. Observed minor loss in body condition scores and gain in weight during the project timeline for female goats imply that goats could meet maintenance requirements. Higher ME diets would allow goats to improve body condition and gain more weight. Over half of the female goats sustained pregnancies, but a high incidence of pre-
weaning kid mortality (11 of 34 kids) implies that diets were not sufficient in digestible feed components to sustain lactation.

Crude protein concentrations were higher than for forage diets on other Indian rangelands (Bhatta et al., 2002). Excessive CP in the diet, particularly in proportion to available digestible dry matter, is deaminated to ammonia by rumen microbes, which costs the animal additional nutrients in the conversion to urea in the liver. Metabolic cost associated with the absorption and detoxification of ammonia to urea uses nutrients that could be available for milk production or improvements to animal production (Muller, 2003). Percent of NDF and ADF in diets (Table 2) and within individual forages (Table 1) were similar to other literature on Indian rangelands, though ADF values in the current study were somewhat lower (Bhatta et al., 2002).

Female goat ages and weights were both greater than males because females usually stay in the production system until they are no longer reproductively active; whereas males were sold between one and three years old (Table 3). Both male and female goats tended to marginally increase in weight over the three seasons as vegetation became more prevalent with the precipitation in the rainy season. We observed marginal decreases in the body condition over the three seasons in both male and female goats, which is contradictory to expectations because the increase in available forages would expectedly improve body conditions. Loss of body condition could be related to partitioning nutrients toward growth, pregnancy, or lactation instead of augmenting body reserves.

Activities recorded during the goats’ principal nine-hour grazing period demonstrate that goats spend comparable amounts of time grazing and lying in all three seasons (Table 4). Percent of time spent grazing was similar to those observed in other studies (Animut et al., 2005; Kronberg & Malechek, 1997). Time spent walking and standing was greater during the rainy and winter seasons, which is logical because goats could graze on land near the village during the summer season when fields were fallow, but they walked further during rainy and winter seasons when fields were under cultivation. Records of time spent ruminating would have been more accurately logged as non-exclusive because goats might have been standing or lying down while they were also ruminating. Goats were also more likely to ruminate in the evening hours when activities were not recorded because they did not have feed available outside of grazing hours and concentrated on feed intake during the day, especially given the energy limitations of the diet. Therefore, rates of rumination were likely higher than values shown.

4.4. Parasite analyses

Increased levels of eggs in feces during the rainy season compared to the winter season (Table 5) are consistent with results from other studies referenced by Kumar et al. (2013). FAMACHA© scores for nearly all goats were above the recommended threshold for deworming, which implies that most goats were anemic. Odisha’s Animal Husbandry Department and local veterinarians advised that all goats be dewormed at the beginning and end of the rainy season (May and September) (Government of Odisha, 2014). Because deworming is not a common practice in the field, this method would be effective short-term. The continued use of broad-spectrum dewormers such as levamisole, benzimidazole, and ivermectin, however, will cause an increase in gastrointestinal parasite resistance to dewormers (Kumar et al., 2013; Van Wyk & Bath, 2002). Thus, an integrated approach with selective deworming is recommended to reduce internal parasites without causing resistance (Torres-Acosta & Hoste, 2008). FAMACHA© scores should be used in combination with fecal egg counts and other health indicators like weight loss and diarrhea to deworm specific animals that require treatment (Fernandez, 2012).

Regular use of the same grazing routes, as observed in the current study, exacerbates the spread of internal parasites. Animals reinfect themselves on contaminated forages. Rotational stocking based on the infective larval-stage of parasites and potentially rotating different livestock species could help to reduce the parasite load of animals, but recommendations should be tested locally to understand the life-cycle of prevalent parasites (Torres-Acosta & Hoste, 2008;
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Waller, 2006). Goat housing in target villages should be updated with raised platforms for goats to avoid continuous contact with fecal matter. Stalls are not usually the primary site of parasite infection compared with contaminated water or forages, but goats residing in unsanitary conditions are more susceptible to internal parasite infections. Proper ventilation, reduced stocking densities, and access to clean areas free from fecal matter will help to reduce parasite loads (Kumar et al., 2013).

4.5. Grazing routes
Goats tended to graze in the same areas continuously and were not systematically rotated to allow pasture resting time. In summer season, goats tended to congregate around their owner’s houses because farmers would not herd goats when fields were fallow, which led to overgrazing nearby areas. During cultivation season (June—December), goats would be herded so that they did not damage crops, which is visualized in Figure 5 with the more expansive tracks covered by goats in rainy and winter seasons and the area covered in rainy and winter seasons compared to summer season in Breka (Table 8). Because goats were actively managed in Budugudari during summer season, there is less of a discrepancy in the area covered compared to the other seasons (Table 8), but goats could graze in the fallow cultivated fields closer to the village, which is why they grazed in cultivated areas in Figure 4 panel A. In Figure 4 panels B and C, one can see that goats are herded away from cultivated fields and moved further away from the village for grazing. A possible improvement that could be attempted in the future would be more actively using rotational grazing where grazing areas are either divided with fencing or animal movements are managed by a herder.

4.6. System resiliency
Kandhamal District is at risk for episodic weather conditions and is subject to frequent droughts, floods, and cyclones. Drought is prevalent in the region of Western Odisha and complete crop failures are common (Mallick & Ghosh, 2007). Shifting weather patterns are causing large-scale migration because cultivation and wage labor income are impacted (Mallick & Ghosh, 2007). Case studies from Rajasthan and Andhra Pradesh demonstrated resiliency via community-based approaches to sustainable management of common lands (e.g., improved productivity of pasture lands) as a key pathway to overcome potential traps relating to the “tragedy of the commons” (V&A Programme, 2009). Efforts to maintain the quality of forest and pasture lands through soil and water conservation will help land areas cope with unpredictable weather incidents, and along with the rearing of livestock, can help reduce migration of farmers from rural to urban areas (Turner, 2004).

4.7. Land management & extension services
Forest and pastureland degradation continues to be a critical issue across India and within Odisha. While the Forest Survey of India reported an increase in overall forest cover in India since 2015 (Forest Survey of India, 2017), growth in coverage of plantations was greater than the loss of natural forests (Houghton, 2005). The Forest Survey of India defines forest cover as “all tree stands with canopy density over 10% having an extent of more than one hectare … irrespective of its origin, species, ownership, land use or legal status” (Forest Survey of India, 2017). Plantations do not provide the same ecosystem services as natural forests in terms of species diversity, carbon storage, or the ability to withstand stress (Reddy et al., 2016). Across India, pastures were reduced from an estimated 70 million ha in 1947 to about 38 million ha in 1997, and many remaining pastures are already degraded or in the process of degradation (Government of India, 2011b). Odisha’s natural forests areas were reduced by about 30,000 km² between 1930 and 2013, with a decelerated reduction rate of about 153 km² between 2005 and 2013 (Reddy et al., 2016). Reports of exact figures of grazing lands are lacking because livestock graze on multiple categories of land such as permanent pastures, temporary pastures, wastelands (which constitute another arguable group of land classes) (Sreedevi et al., 2007), but there is agreement in the fact that land available for grazing has decreased and is becoming increasingly degraded in Odisha (Government of Odisha, 2002, 2014). Because goats largely depend on pasturelands for their feed, the widespread deterioration in quantity and quality of pastureland and resulting decline in forage mass
across Odisha appears to be the most significant constraint to goat husbandry (R. K. P. Singh, 2013).

Furthermore, goats have been identified as a major cause of ecological degradation and desertification from overgrazing and human interventions, such as shifting cultivation and pressure from human population growth are the main drivers of ecological deterioration (N. P. Singh, 2008). A designated Indian government task force evaluated the effects of goat rearing in ecologically fragile zones in 1987 and did not find evidence that goats posed a threat. They further indicated that given compliance with recommended carrying capacity that small ruminants are more economical and less harmful than larger livestock. When properly managed, goats can be a tool for regeneration of vegetation through dispersal of seeds and manure, weed control, and resulting forest fire prevention (N. P. Singh, 2008). However, heavy grazing intensities can reduce the vigor of grazed plants, distort plant growth patterns, compact grazing lands, and alter their biodiversity (Sreedevi et al., 2007).

Better monitoring of grazing intensities requires investment in the quality of agricultural services and outreach for livestock systems, which can facilitate productivity gains. A designated agency, (e.g., Forest Department, Department of Agriculture, Animal Husbandry Department or a specific sub-group) could be tasked with regulation of stocking rates and practices, particularly in areas where livestock could further degrade natural ecosystems (Singh et al., 2006). During the project, farmers requested and received a fodder cultivation workshop, demonstrating demand for information to improve management practices. Farmers made multiple requests to the Animal Husbandry Department to continue future dissemination of information about livestock feed in the future, but researchers observed that existing extension networks were ill-equipped to handle these requests.

National policies that promote management of common property resources and grazing lands have been proposed (Government of India, 2011b), but have yet to be realized and implemented at the local level. Policies should systematically value the functions of grasslands and pasturelands that provide feed for livestock to ensure their long-term productivity. Departments of Animal Husbandry and Agriculture have focused attention on cultivation of fodder with the Accelerated Fodder Development Programme (AFDP), which could reduce pressure on common property resources through increased availability of other feed resources. However, there has not been a designated program to develop fodder or preserve vegetation on common property resources (Government of India, 2011b). The Kandhamal District Divisional Forest Officer communicated that there is no systematic monitoring of forest lands for stocking density or overgrazing at the local level (personal communication, September 9, 2016). Information regarding forest degradation or mismanagement of land came from the Forest Survey of India’s satellite data rather than locally collected information. Monitoring at the local level would allow for the effects of degradation through over-grazing to be mitigated before they become irreparable.

Approaches to address challenges associated with extensive livestock systems are two-fold: pasturelands must be improved and grazing management must be properly implemented. To increase the productivity of pasturelands, low-yielding annual grasses could be replaced with high-yielding perennial grasses in conjunction with legumes to assist with microbial nitrogen fixation (Indian Council of Agricultural Research, 2006). When selecting a species to seed, desired qualities are: high nutritive value, palatable, productive, adapted to local soils and climate (Trivedi, 2002). As discussed previously, rotational stocking of livestock would allow forage enough time to regrow so that animals do not overgraze. Creating mutualistic relationships between livestock and plantations or orchards through silvopastoral or hortipastoral systems is a way to produce high-quality forages from wastelands or other marginalize lands. Trees, grasses, and legumes can be cultivated on the same plot to provide farmers with crops for sale like mangoes or timber while also providing livestock with proper supplementation from planned fodder crops. Agroforestry technologies like silvopasture or hortipasture provide opportunities to remediate degraded land
and also provide forages to meet the growing demands of livestock (Indian Council of Agricultural Research, 2006).

More research is required about grazing land degradation and tools for regeneration both at the macro-level and at the local level for specific climatic regions. Several studies have been conducted about carrying capacity of grazing lands, but they are fragmented and difficult to apply in other location settings. A more systematic approach to research of grazing lands would be helpful for policymakers (Government of India, 2011b).

5. Conclusions
Goat diets from free-range pasturelands in Western Odisha were insufficient in digestible feed components on 60 of the 96 days where goats were observed during the current eight-month study. Goats tended to graze in the same areas repeatedly without planned rotational stocking. The combination of deforestation and unplanned grazing are contributing to a decline in the quality of grazing lands available for livestock. Goats encountered several alien and invasive species that indicate a deficiency in management of forest and pasturelands. Organized interventions to improve the quality of forest and pasturelands must be undertaken either by the government through animal husbandry extension networks or the Forest Department or from the community level to avoid the continued deterioration of available lands for grazing.

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References
Alipayo, D., Valdez, R., Holechek, J. L., & Cordenas, M. (1992). Evaluation of microhistological analysis for determining ruminant diet botanical composition. Journal of Range Management, 45(2), 148–152. https://doi.org/10.2307/4002773
Animut, G., Goetsch, A. L., Aiken, G. E., Puchala, R., Detweiler, G., Krehbiel, C. R., Merkel, R. C., Sahlu, T., Dawson, L. J., Johnson, Z. B., & Gipson, T. A. (2003). Grazing behavior and energy expenditure by sheep and goats co-grazing grass/forb pastures at three stocking rates. Small Ruminant Research, 59(2–3), 191–201. https://doi.org/10.1016/s0745-7840.2005.05.014
Bhatia, R., Shinde, A. K., Sankhyan, S. K., & Verma, D. L. (2002). Nutrition of range goats in a shrubland of western India. Asian-Australasian Journal of Animal Sciences, 15(12), 1719–1724. https://doi.org/10.5713/ajas.2002.1719
Birthal, P. S., & Jha, A. K. (2005). Economic losses due to various constraints in dairy production in India. Indian Journal of Animal Sciences, 75(12), 1470–1475. https://www.researchgate.net/profile/Pratap_Birthal2/publication/295400150_Economic_losses_due_to_various_constraints_in_dairy_production_in_India/links/583661740b0ae3f3e331c5582/Economic-losses-due-to-various-constraints-in-dairy-production-in-India.pdf
Bonnet, O. J. F., Meuret, M., Tischler, M. R., Cezimbra, I. M., Azambuja, J. C. R., & Carvalho, P. C. F. (2015). Continuous bite monitoring: A method to assess the foraging dynamics of herbivores in natural grazing conditions. Animal Production Science, 55(3), 339–349. https://doi.org/10.1071/AN14540
Detweiler, G., Gipson, T., Merkel, R. C., Goetsch, A., & Sahlu, T. (2008). Body condition scores in goats (Vol. Proc. 23rd). Goat Field Day, Langston University.
Dikshit, A. K., & Birthal, P. S. (2010). India’s livestock feed demand: Estimates and projections. Agricultural Economics Review, 23, 15–28. https://core.ac.uk/download/pdf/6397003.pdf
Fernandez, D. (2012). Fecal egg counting for sheep and goat producers. Cooperative Extension Program, University of Arkansas at Pine Bluff.
Forest Survey of India. (2017). State of the forest report - forest cover. Forest Survey of India (Ministry of Environment & Forests).

Government of India. (2011a). Census of India 2011: Instruction manual for householding and housing census. Office of the Registrar General & Census Commissioner.

Government of India. (2011b). Report of the Sub Group III on Fodder and Pasture Management.

Government of Odisha. (2002). Orissa state livestock sector policy. Government of Orissa: Department of Fisheries and Animal Resources Development.

Government of Odisha. (2014). Perspective plan - animal resources development sector 2010-2020.

Government of Orissa: Department of Fisheries and Animal Resources Development.

Hegde, N. G., & Deo, A. D. (2015). Goat value chain development for empowering rural women in India. Indian Journal of Animal Sciences, 85(9), 1-00. https://www.researchgate.net/publication/286124879_Goat_value_chain_development_for_em-powering_rural_women_in_India

Houghton, R. A. (2005). Tropical deforestation as a source of greenhouse gas emissions. In P. Moutinho & S. Schwartzman. (Eds.), Tropical deforestation and climate change. IPAM - Instituto de Pesquisa Ambiental da Amazônia (pp. 13-21). http://www.edf.org/page.cfm?tagID=477&s=2801%5Cvhome/napoletoni/Dropbox/sndre/alphair/Moutinho2005a.pdf

Indian Council of Agricultural Research. (2006). Forage crops and grasses. In Handbook of Agriculture (5th ed., pp. 1353-1417). New Delhi.

Khuroo, M. S., Malik, A. H., Weber, E., Rashid, I., & Dar, G. H. (2012). Alien flora of India: Taxonomic composition, invasion status and biogeographic affiliations. Biological Invasions, 14(1), 99-113. https://doi.org/10.1007/s10530-011-9981-2

Kronberg, S. L., & Malechek, J. C. (1997). Relationships between nutrition and foraging behavior of free-ranging sheep and goats. Journal of Animal Science, 75(7), 1756-1763. https://doi.org/10.2527/1997.7571756x

Kumar, N., Rao, T. K. S., Varghese, A., & Rathor, V. S. (2013). Internal parasite management in grazing livestock. Journal of Parasitic Diseases, 37(2), 151-157. https://doi.org/10.1007/s12639-012-0215-z

Lacey, J., Short, S., & Mosley, J. (2001). How to collect, press, and mount plants. http://store.msuextension.org/Publications/AgAndNaturalResources/MT1983159AG.pdf

Makkar, H. P. S. (2004). Recent advances in the in vitro gas method for evaluation of nutritional quality of feed resources. In Assessing quality and safety of animal foods (160th ed., pp. 55-88). Food and Agriculture Organization of the United Nations.

Mallick, P. K., & Ghosh, A. K. (2007). Livestock status and opportunities in western Orissa - A case study. Pantnagar Journal of Research, 51(1), 119-121. https://www.cabdirect.org/cabdirect/abstract/20083156846

Mandal, A. B., Paul, S. S., Mandal, G. P., Kannan, A., & Pathak, N. N. (2005). Deriving nutrient requirements of growing Indian goats under tropical condition. Small Ruminant Research, 58(3), 201–217. https://doi.org/10.1016/j.smallrumres.2004.09.015

Marbuah, G., Gren, I., & Mckie, B. (2014). Economics of harmful invasive species: A review. Diversity, 6(3), 500-523. https://doi.org/10.3390/d6030500

Masters, R. A., & Shelley, R. L. (2001). Principles and practices for managing rangeland invasive plants. Journal of Rangeland Management, 54(5), 502–517. https://doi.org/10.2307/4003579

Menke, K. H., & Steingass, H. (1988). Estimation of the energetic feed value obtained from chemical analysis and in vitro gas production using rumen fluid. Animal Research and Development, 28, 7–55.

Mosley, J. C. (1996). Prescribed sheep grazing to suppress cheatgrass: A review. Sheep and Goat Research Journal, 12, 74–80.

Muller, L. (2003). Protein in pastures: Can it be too high? In Proceedings from Nutrition of dairy cows on pasture-based systems (pp. 71–74).

National Research Council. (2007). Nutrient requirements of small ruminants: Sheep, goats, cervids, and new world camelids. The National Academies Press. http://www.nap.edu/catalog/11654

Panigrahi, D., Mohanty, P. K., Acharya, M., & Senapati, P. C. (2018). Optimal utilisation of natural resources for agricultural sustainability in rainfed hill plateaus of Orissa. Agricultural Water Management, 97(7), 1006–1016. https://doi.org/10.1016/j.agwat.2010.02.005

Pearson, D., & Ortega, Y. (2009). Managing invasive plants in native pastures: Moving beyond weed control. In R. V. Kingely (Ed.), Weeds: Management, economic impacts and biology (pp. 1–21). Nova Science Publishers.

Pfister, J. A., & Malechek, J. C. (1986). The voluntary forage intake and nutrition of goats and sheep in the semi-arid tropics of northeastern Brazil. Journal of Animal Science, 63(4), 1078-1086. https://doi.org/10.2527/jas.1986.6341078x

Pimentel, D., McNair, S., Janeczko, J., Wightman, J., Simmonds, C., O’Connell, C., Wong, E., Russel, L., Zern, J., Aquino, T., & Tsomondo, T. (2001). Economic and environmental threats of alien plant, animal, and microbe invasions. Agriculture, Ecosystems & Environment, 84(1), 1–20. https://doi.org/10.1016/S0167-8809(00)00178-X

Raghunath, S., & Mamata, S. (2013). Contribution of common property resources for sustainable rural livelihoods in Orissa: Prospects and constraints. Journal Of Rural Development, 32(3), 245–261. http://search.ebscohost.com/login.aspx?direct=true&db=lah&AN=20133369682&site=ehost-live%5Cnhttp://www.nir.org.in/Journalruraldvevelopment.aspx%3CnCenmailsraghunic.sb@gmail.com%5Cf%20mamato_w@novusmail.com

Raleigh, J. R., Karchner, R. J., & Rittenhouse, L. R. (1980). Chronic oxide in range nutrition studies. Agricultural experiment station.. Oregon State University.

Ramirez, R. G. (1998). Feed resources and feeding techniques of small ruminants under extensive management conditions. Small Ruminant Research, 34(3), 215–230. https://doi.org/10.1016/S0921-4489(99)00075-9

Reddy, C. S., Jha, C. S., Dadhwal, V. K., Hari Krishna, P., Pasha, S. V., Satish, K. V., Dutta, K., Saranya, K. R. L., Rakesh, F., Rojashekar, G., & Diwakar, P. G. (2016). Quantification and monitoring of deforestation in India over eight decades (1930–2013). Biodiversity and Conservation, 25(1), 93–116. https://doi.org/10.1007/s10531-015-1033-2

Roy, M. M., & Singh, K. A. (2008). The fodder situation in rural India: Future outlook. International Forestry Review, 10(2), 217–234. https://doi.org/10.1505/ifor.10.2.217

Singh, A. K. (2013). Indian Grassland and fodder research institute vision 2030 (Vol. 53). Indian Grassland and Fodder Research Institute.
Singh, N. P. (2008). Rural needs: Free (range) grazing. International Forestry Review, 10(2), 235–244. http://openurl.ingenta.com/content/xref?genre=article&=1465-5489&volume=10&issue=2&page=235%5CnNTZ330%5Cnfile/c/OutputsandSettings/ Teufel/MyDocuments/Literature/RefmanArchive/ NT2330.pdf

Singh, P., Rohmani, A. R., Wangchuk, S., Mishra, C., Singh, K. D., Narain, P., … Chandawat, R. S. (2006). Report of the task force on grasslands and deserts. Government of India Planning Commission.

Singh, R. K. P. (2013). Livestock research and development priorities for Bihar and Odisha. IFPRI.

Singh, S. P. (1996). Biological control. In: 50 years of crop science research in India. In R. S. Paroda & K. L. Chadha (Eds.), 50 years of crop science research in India (pp. 88–116). Indian Council of Agricultural Research.

Sreedevi, T. K., Wani, S. P., Osman, M., & Tiwari, S. (2007). Rehabilitation of degraded lands in watersheds. In Best Bet options for integrated watershed management. Proceedings of the comprehensive assessment of watershed programs in India (pp. 205–220). ICRISAT, Stegelmeier, B. L., Field, R., Panter, K. E., Holl, J. O., Welch, K. D., Pfister, J. A.,… Cook, D. (2013). Selected poisonous plants affecting animal and human health. In W. Haschek, C. Rousseaux, & M. Wallig Eds., Haschek and Rousseaux’s handbook of toxicologic pathology (3rd ed., pp. 1259–1314). Academic Press. https://doi.org/10.1016/B978-0-12-415759-0.00040-6

Torres-Acosta, J. F. J., & Hoste, H. (2008). Alternative or improved methods to limit gastro-intestinal parasitism in grazing sheep and goats. Small Ruminant Research, 77(2–3), 159–173. https://doi.org/10.1016/j. smallrumres.2008.03.009

Trivedi, B. K. (2002). Grasses and legumes for tropical pastures. Indian Grassland and Fodder Research Institute.

Turner, R. L. (2004). Livestock production and the rural poor in Andhra Pradesh and Orissa states, India. Pro-Poor Livestock Policy Initiative. United States Department of Agriculture. (2005). Growth habits codes and definitions. https://plants.usda.gov/growth_habits_def.html

V&A Programme. (2009). Vulnerability and adaptation experiences from Rajasthan and Andhra Pradesh: Pasture land development.

Van Wyk, J. A., & Bath, G. F. (2002). The FAMACHA system for managing haemonchosis in sheep and goats by clinically identifying individual animals for treatment. Veterinary Research, 33(5), 509–529. https://doi.org/10.1051/vetres:2002036

Walker, J. W., Kronberg, S. L., Al-Rowaily, S. L., & West, N. E. (1994). Comparison of sheep and goat preferences for leafy spurge. Journal of Range Management, 47(6), 429. http://www.jstor.org/stable/4002992?origin=crossref

Waller, P. J. (2006). Sustainable nematode parasite control strategies for ruminant livestock by grazing management and biological control. Animal Feed Science and Technology, 126(3–4), 277–289. https://doi.org/10.1016/j.anifeedsci.2005.08.007

Zojac, A., Petersson, K., & Burdett, H. (2014). How to do the modified McMaster faecal egg counting procedure. https://web.uri.edu/sheepngoat/files/McMaster-Test_Final3.pdf
