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Contribution of dung beetles to cattle productivity in the tropics: A stochastic-dynamic modeling approach

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ABSTRACT

Dung beetles provide different services to agroecosystems. Previous economic assessment of this insect group highlights their importance in temperate zones using linear models or ecosystem services frameworks. This paper proposes a stochastic-dynamic model to simulate dung production and degradation in order to estimate the contribution of dung beetles to dual-purpose cattle production in the tropical grasslands of Veracruz, Mexico. The model allowed for estimation of sampling distributions of dung occurrence in the field, the coverage area, nitrogen burial, and maintenance of clean grasslands and their economic benefits. Contributions of dung beetles are expressed as 95% confidence intervals. Dung beetles removed from 56.2 to 116.9 depositions $ha^{-1} d^{-1}$ and the efficiency in dung removal was between 65 to 69%. At the grassland scale, dung beetles cleaned an area from 8.5 to 26.9 $m^2 ha^{-1} d^{-1}$. Nitrogen burial ranged from 32.2 to 136.2 kg $ha^{-1} y^{-1}$. The clean area maintained annually varied between 31 to 98% of the pastures. The annual benefit per animal unit ranged between US $149.1 to US$ 423.6 and at state level the benefit (US$ × 10E6) was between 140.6 and 455.8. The most important economic contribution was maintaining clean areas (71.4%), then by incorporating nitrogen as fertilizer (28.3%), and last in milk and meat benefits (< 1%). The model allowed for the representation of the natural variability of some key factors involved in dung processing by beetles related to dual-purpose cattle production.

1. Introduction

Dung beetles perform different roles in natural and agricultural systems by participating in seed dispersal, nutrient cycling, and parasite reduction (Nichols et al., 2008). Some of these activities benefit humans and are considered as ecosystem services (Millenium Ecosystem Assessment, 2005). The benefits provided by dung beetles depends on the species richness and abundance in a given area (Manning et al., 2016), but some human activities affect their populations, such as the use of some parasiticides which can reduce dung beetle populations (Beynon et al., 2012). Dung burial by coprophagous beetles has long been recognized as a positive activity in agricultural production (Boyd and Banzhaf, 2007). In the United States, the economic value of dung beetles was calculated first by Fincher (1981), and then by Losey and Vaughan (2006); its economic contribution was estimated at US$ 380 million, composed of different services. A recent paper reported the economic benefits of dung beetles in the United Kingdom (Beynon et al., 2015), where their estimated contribution was almost US$ 560 million per year. In addition to the reduction in costs by dung beetle activities, there are costs incurred when restoring dung burial services, related to research activities and programs aimed at introducing these insects into areas where they are not present, for example in Australia (Edwards, 2007).

The value of dung beetle activity has been estimated by computing the difference between the costs of services when the beetles are present and when they are absent (Losey and Vaughan, 2006), that is, equating beetle activities to alternate services for generating benefits. The difference is computed for each of the services the beetles provide and the total is the sum of all savings. This method has also been applied to compute the economic value of biological control agents (Cullen et al., 2008). The approach is based on point estimates, which generate unique values, but the natural variability of the different processes is not taken into account. In contrast, stochastic models simulate the input variables as observations sampled from probability

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distributions, and then processing them in the required sequence to obtain a distribution of the response variable (Burmaster and Anderson, 1994). Therefore, this approach allows representing and measuring the natural variability of the target process (Atanassov and Dimov, 2008). Stochastic simulation has been employed to evaluate the economic impact of non-native nocive species in Southeast Asia (Nghiem et al., 2013), fault tree analysis of spittlebug occurrence (García-García et al., 2006), and microbiological risk assessment (Peleg et al., 2007). Likewise, dung production and decay is a dynamic, complex process (Laing et al., 2003; Hirooka, 2010), and is a key element for modeling the contribution of dung beetles to cattle productivity; hence the necessity to consider both the inherent variability and the dynamics of the processes involved.

While the previous studies of dung beetle economic contributions help to recognize their importance, these works have been carried out in temperate zones with certain cattle breeds and using deterministic, *ad-hoc* models or frameworks. Therefore, dung beetle contribution may be different with other cattle types or production systems like those implemented in tropical regions (Slade et al., 2016). The state of Veracruz, Mexico, contributed 464,980 tons of meat and 706,981 m^3 of milk in 2013, ranking it in first and sixth place, respectively (SIAP, 2015a). The state has a cattle population of about 3.7 million head, and ranch area near to 3.7 million ha, covering > 50% of state land (SIAP, 2015b). Unlike other production systems in central and northern states of Mexico, most of the cattle are managed on grasslands and pastures, and few are confined. Cattle are dual-purpose, producing milk and meat, a common practice in tropical cattle production systems (Vilaboa and Díaz, 2009). In addition, their productivity is low due to inefficient management practices and race adaptability (Vilaboa et al., 2009). Dung beetles are important components of cattle production systems in Veracruz; nearly 60 species contribute to the degradation of dung produced by cattle, horses and other vertebrates in pastures and forests (Halffter and Edmonds, 1982), and communities between 11 to 15 species are present in the tropical grasslands most of the year (Montes de Oca, 2001; Flota-Bañuelos et al., 2012; Martínez and Suárez, 2012). Their effect on dung degradation fluctuates during the year, with the highest decomposition rates occurring during the rainy season (Cruz et al., 2012). Due to the impact of dung beetle activity on agroecosystems, the relevance of cattle production in Veracruz, and the intrinsic variability of these factors, the purpose of this research was to assess the contribution of this insect group to cattle productivity using a stochastic-dynamic modeling approach.

2. Materials and methods

2.1. Description of the dung pat stochastic-dynamic model

The conceptual model of cattle deposition dynamics, as affected by dung beetle activity is presented in Fig. 1. It is assumed that under current management practices, a cattle population (*Ht*) is raised on a delimited pasture area (*At*), the height of the rectangle in Fig. 1. In tropical regions, cattle are maintained in the field throughout the year (Diaz-Rivera et al., 2011), thus, at any time, cattle are producing dung pats, which in turn are decomposing at a certain rate, and reach an equilibrium in the area covered. The presence of dung beetles accelerates dung decay compared to when no dung beetles occur in the field. Thus, the area covered with dung pats is smaller due to dung beetle decomposition activities (Cruz et al., 2012). In Fig. 1, the area covered with dung pats when beetles are active is *Ab*, while the area covered when beetles are not present is $Au = Ab + Ac$, thus *Ac* is the area cleaned by the dung beetles. The area covered by dung pats fluctuates during the year because of changes in the effectiveness of dung removal between the dry and rainy seasons (Cruz et al., 2012). The clean area supports a cattle population (*Hc*), which is a fraction (*Ac/At*) of population *Ht* and represents the direct contribution of dung beetles to productivity, expressed as the proportion of milk and meat production.

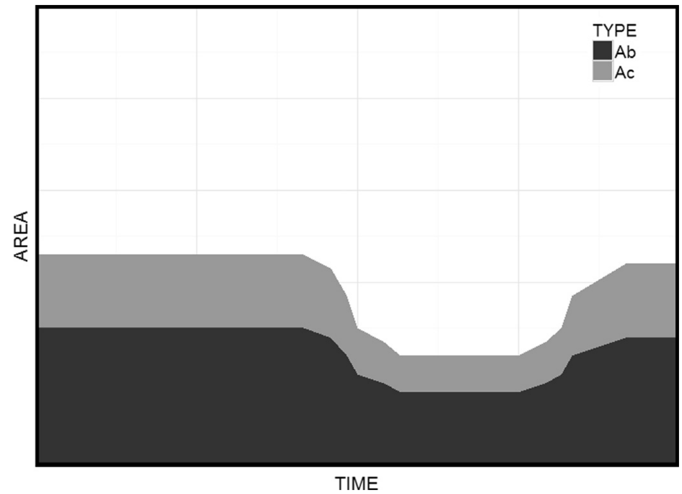

Fig. 1. Graphic representation of the dynamics of a grazing area covered by dung pats over time and the effect of dung beetles. The height of rectangle represents the total surface area (*At*) on which a given number of cattle (*Ht*) are managed; *Ac* is the area cleaned by dung beetles and *Ab* is the area which is always fouled because of the constant production of dung by cattle.

The indirect contribution of dung beetles is by the constant cleaning of the grazing area and by increasing the amount of nitrogen incorporated to the soil from burial activity. In this model, we assume that productivity derives basically from the grassland as the main forage source for cattle (van der Linden et al., 2015).

2.2. Stochastic-dynamic modeling approach

In this model, it is assumed that parasiticides are not applied to cattle because dung beetles are negatively affected by these products (Sommer and Bibby, 2002; Beynon et al., 2012). Therefore, *Ht* is the target cattle population not subject to parasiticide applications and it was computed as:

$$Ht = H*Pt \tag{1}$$

where *H* represents the total number of non-confined cattle existing in the state of Veracruz in a given year, and *Pt* is the proportion of cattle not subject to parasiticide applications. Moreover, *At* is the area occupied by the *Ht* population and is proportional to all of the grazing area in the state (*A*):

$$At = A*Pt \tag{2}$$

The dynamics of dung occurrence under field conditions is a complex process which basically depends on cattle deposition and decomposition rates. Dung pat occurrence under field conditions was modeled as a first order differential equation:

$$d\,(Ej)/dt = Kp*AU - rj*Ej \tag{3}$$

Eq. (3) represents the dynamics of dung pat abundance per day (*Ej*), as a function of total depositions minus dung removal, *j* indicates if dung beetles are present (*b*) or absent (*u*). *Kp* is the number of depositions per cow per day. Individual cattle were converted to animal units (*AU*), where one *AU* equates to a 450 kg cow (Teixeira et al., 2012); *AU* were used to standardize the different age classes of cattle. The term *rj* is a decomposition parameter of a first order exponential decay model, representing dung breakdown (Sommer and Bibby, 2002; Cruz et al., 2012). The value of *Ej* was solved from Eq. (3) for the steady state, that is, when $d(Ej)/dt = 0$, resulting in the following equation:

$$E_j = Kp*AU*{r_j}^{-1} \tag{4}$$

The degradation rates (*rj*) were estimated by fitting an exponential nonlinear regression model to data obtained from field-level experiments involving the activities of a community of dung beetle species for