CHAPTER 24

The role of dung beetles in the sustainability of pasture and grasslands

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Abstract

Livestock pastureland is one of the most common production systems in the temperate and tropical areas of Mexico. The quantity of dung deposited into the soil by livestock causes a large amount of nitrogen to be released into the atmosphere and facilitates the development of flies and parasites harmful to humans. Dung beetles, through their feeding and reproductive behavior, are primarily responsible for nutrient reincorporation through the consumption and storage of dung in the soil. In this chapter, we evaluate the importance of dung beetles to the sustainable management of livestock pastureland in Veracruz, Mexico, and the risks on dung beetle community of the application of herbicides to pastures, and insecticide and antiparasitic use in the livestock. A more environmentally sound management strategy is suggested that includes taking landscape diversity into account in order to achieve the sustainable management of livestock pastureland in Veracruz.

Keywords: Dung beetles, ecosystem services, grasslands, anthelmintics, Veracruz, Mexico.

1 Introduction

The history of mankind is closely related to the modification of ecosystems and their transformation into simpler systems that can be used to greater advantage. Agro ecosystems are an example of such transformation, and can yield agricultural, livestock, and forestry products. Livestock production systems are distributed widely throughout the tropics.

Since the beginning of the colonization of the new world, and following the Spanish conquest in Mexico, livestock production has become a widespread form
of land use. The development and expansion of livestock production presents a complex problem that includes important aspects, such as the production of goods and services as well as cultural, social, and ecological impacts [1]. From an ecological point of view, analysis of this productive system is crucial if aspirations toward the balanced and sustainable management of soil, biodiversity, and natural resources are to be realized, and is necessary in order to address the lack of understanding with regard to the relationship between livestock and the wild fauna and flora [2].

The expansion of livestock production was due to the appropriation of ecosystems and natural formations on the part of these herbivores that have become adapted to savannas, scrublands, and forests in temperate, warm, moist, and dry climates. From shortly before the middle of the sixteenth century until the late nineteenth century, livestock did not cause significant damage to the original structure of the vegetation nor effect substantial changes in the specific composition of tropical ecosystems [2]. However, in the second half of the twentieth century, the drive toward livestock production, accompanied by a process of human colonization toward the humid tropics, created an increase demand for carrying capacity that led to the transformation of forests into pastures. This transformation of the original vegetation into open habitat, where grasses predominate over arboreal vegetation, also implies the modification of biogeochemical and nutrient cycles.

These disturbances have lead to the disappearance of native species, the invasion of exotic species, and have produced effects on soil fertility and structure. The presence and activity of livestock in these environments cause soil compaction and accumulation of dung on the surface which, if not reincorporated into the soil, causes severe environmental damage and economic losses [3]. In the 1990s, worldwide livestock production generated 12–30 million tonnes of nitrogen through the volatilization of ammonia (NH₃) excreted in livestock feces [4].

In the case of cattle production, which is the activity under consideration in this chapter, the grassland system comprises a series of three stages that interact among themselves: herbaceous growth, consumption by grazing animals (utilization), and conversion into animal products. Within this system, there is an inverted flow of nutrients to the soil via excretion and decomposition [5]. It is at this point that dung beetles should be considered an important element of livestock systems. Their actions and effects of soil and dung removal, among other environmental services, contribute to the maintenance of the soil physical structure and fertility and to the retention of water, nitrogen, and other nutrients [3].

Veracruz is one of the mega-diverse states of Mexico, where livestock production is a major economic activity [1], but it has generated the progressive replacement of forests with grasslands and fodder crops. This process has intensified over the last four decades. In the period 1980–1990, growth of livestock production was reported while forest areas decreased in regions such as El Totonacapan in the north and Los Tuxtlas in the south, affecting many animal and plant populations in these regions [1].

In this chapter, we analyze the role of dung beetles in livestock pasturelands, as well as the mechanisms they employ to exploit the dung deposited on pastureland
and the environmental services they provide. It also explores the effect of farming practices on populations of these insects in Mexico and evaluates the economic benefits generated by the producers of meat and milk in the state of Veracruz. Finally, a series of recommendations are proposed that include a model of sustainable management of cattle pasturelands in Mexico that reconciles an increase in livestock productivity with conservation of the environment, including dung beetles.

2 Dung beetles

Dung beetles are insects that belong to the order Coleoptera. The group consists of species of the subfamilies Scarabaeinae, Geotrupinae, and Aphodiinae that feed on the feces of large herbivores throughout their larval and adult lives. The greatest diversity of dung beetles is found in temperate and tropical zones [6,7]. In Mexico, the dominant group in tropical and temperate zones is Scarabaeinae. Geotrupinae is found mainly in montane areas while Aphodiinae is common in temperate zones, but also found in the tropics. These beetles, commonly called ‘roda cacas’, ‘vaqueros’, or ‘toritos’, are most active during the rainy season (late May to September), when they are frequently observed in or next to the pats of dung.

Adults feed on the microorganisms present in dung, while the larvae feed on the fibers contained within it [8]. Thus, the dung is comprehensively utilized by this group of insects, contributing to the reincorporation of nutrients into ecosystems, to seed dispersal, to the control of parasites, and to the displacement and mixing of soil particles, a process known as bioturbation [3].

Adults locate the food source by smell, which is detected in flight by the antennae. Once located, the beetles land close to or directly upon it. Food can be consumed in situ, or a portion may be transported above or below ground for subsequent consumption elsewhere food relocation [8]. Dung beetles are divided, according to particular food relocation strategy, into tunnelers or paracoprids, rollers or telocoprids, and dwellers or endocoprids [8,9] (Fig. 1).

As the name implies, ‘tunneler’ beetles dig tunnels that may be straight or branched, below or beside the dung source, in which they accumulate the food for consumption. In the case of the ‘rollers’, small portions of food are separated and formed into balls that are then rolled to a certain location to be consumed by the adult roller. ‘Dweller’ beetles feed directly on the dung and do not relocate the food.

Following emergence as adults, there is a feeding period that takes place prior to the reproductive stage. The duration of this period varies in different species.

During nesting, it is very common to observe the activity of dung beetles in the pats of dung (Fig. 2) and it is then that breeding pairs are formed.

Depending on the subfamily to which the species belongs, the females lay their eggs in brood masses or in brood balls (Geotrupinae and Scarabaeinae), or they may be deposited within or near the food (Aphodiinae) [8,10].

The different ways in which the species nest have different impacts on various ecological processes, including nutrient cycling, bioturbation, secondary burial of
Figure 1: Dung beetle food relocation strategies. E, endocoprid; P, paracoprid, T. telocoprid, d, dung. (Source: modified by Huerta and Cruz from [6, 8]).

Figure 2: Dung beetle dung recycling activity: d, dung; s, soil removed.

seeds, and suppression of pathogens and parasites. Tunnelers favor bioturbation, while rollers favor the dispersal of seeds. Both tunnelers and rollers contribute to nutrient recycling, but at different depths of the soil profile. Other factors that influence the quantity of dung removed are the type and moisture content of the soil [11], and the quality of dung [12].

3 Dung beetles in pastureland areas

Deforestation and forest fragmentation lead to changes in the patterns of abundance, biomass, and diversity of beetles in which the open areas and pastures
contain fewer species than the forests [13–17]. Thus, the process of livestock production has caused a change in the beetle communities and, in the case of the tropical grasslands of Mexico and Central America, has led to a homogenization of the structure and composition of these communities [18].

Of the more than 400 species of Scarabaeidae of Mexico [19], around 20% are found in pastures and livestock grazing areas using cattle dung as their main source of food and for reproduction. The number of species and taxonomic composition vary depending on the altitude and region of the country. Numerous studies of dung beetles at different locations in the country show that dung beetles associated with open areas of pasture and grassland form an assembly of well-defined structure [14, 20–26].

For tropical and subtropical regions, the assembly consists of 8 to 14 species of Scarabaeinae with the majority (85%) being tunnelers and the remaining being rollers. On inclusion of the Aphodiinae species, between 7 and 12, more species may be considered: these are small (less than 5 mm) and exhibit endocoprid habits.

In temperate regions, the number of species varies between 3 and 8 species of Scarabaeinae, and between 1 and 3 species of Geotrupinae that are tunnelers, and 12 species of Aphodiinae that are dwellers. In cold regions, the dung beetle assembly is substantially reduced to two or three species of Geotrupinae, one or perhaps two species of Scarabaeinae and about eight species of Aphodiinae.

In Mexico, the conversion of large tracts of forest to grassland has also favored the expansion of two invasive species that have successfully colonized the grasslands, pastures, and grazing areas of practically the whole country: Euoniticellus intermedius and Digitonthophagus gazella. These invasive species of dung beetles have integrated themselves into the native beetle communities of grassland and pastures [22, 27–31].

4 The function of dung beetles

The effectiveness of soil removal and facilitation of the disintegration of dung depend on the composition of beetle assemblies present in the pasture or grassland. The size, strategy, and speed of dung relocation, as well as the nesting type and form of each species allow the definition of functional groups with different effects on the dung, from a gradual and partial disintegration to a complete and rapid removal from the soil surface [32]. The time of activity of the species (day/dusk/night) in relation to the availability of dung also influences the intensity and colonization of the dung by different species [28].

Dichotomius colonicus is a large tunneler species (average 26 mm in length) commonly found in grasslands and subtropical pastures. An individual of this species can bury up to 130 g (average 49 g) dry weight of compost and remove up to 1000 g (average 287 g) of soil [33]. According to Anduaga and Huerta [34], this and two slightly smaller (15–22 mm) species belonging to the genera Copris and Phanaeus are able to respectively reincorporate up to 135, 24.3 ± 8.5, and 12 ± 2.5 g (dry weight) of dung per pair during the nesting season. Taking into
account that there may be between 3 and 8 nests under each dung pat [35], the reincorporation of this material by dung beetles is considerable.

Tunneling species, and those of large size, are generally more efficient than the small endocoprid species at reincorporating dung into the soil, while the efficiency of the roller and medium-sized species is intermediate. It is also important to consider the abundance of the different species. Generally, the size of a beetle species is inversely related to its relative abundance within the dung pat: small species tend to have more individuals present than larger species. Both the size and abundance are related to the dung exploitation strategy. Larger species can take advantage of the resource better and more quickly by reaching the dung before others. However, large numbers of individuals of medium- and small-sized species may be grouped in some dung pats and not in others. The ephemeral and patchy nature of dung means an understanding of how a competitive resource such as dung is shared may be facilitated by an examination of the beetle relocation strategy, size, and time of arrival [36].

The forms and practices of livestock management have a major influence on how the beetles can carry out their activities as facilitators of decomposition and disintegration of dung on the surface of grassland and pastures. In general terms, three forms of livestock management are recognized in Mexico: extensive, semi-extensive, and intensive. Each of these is undertaken based on factors such as land availability, quantity and purpose (meat/milk) of livestock, and available technology, resources, and market. Extensive management of livestock is the most widespread form in Mexico, followed by semi-extensive management. Obviously, the carrying capacity of the productive system and the method of management will determine the amount of dung produced. An increase in livestock increases the amount of dung deposited on the ground, but when an excess remains without disintegration, a significant amount of usable area of pasture is lost. When livestock production is intensive, dung tends to accumulate and this slow disintegrating organic matter presents recycling problems. Without the activity of the beetles, dung can remain on the soil of the pasture for months to years, depending on environmental conditions. The dung deposited on the ground occupies a total area which can be considerable if the dung accumulates and directly or indirectly reduces pasture area [37].

In a case study of two farms in the temperate municipality of Xico, Veracruz, practicing different livestock management (1 extensive and the other semi-extensive), it was found that the composition of the assemblies was the same (16 species: 8 Scarabaeinae and 8 Aphodiinae), but the relative abundance of some of these differed between the two locations. Moreover, the average density of beetles collected in traps baited with cow dung was less where the management is semi-extensive than where it is extensive (Montes de Oca, unpublished data).

5 Environmental services provided by dung beetles

As previously stated, one of the major problems caused by intensive and extensive livestock production is the accumulation of dung if it is not reincorporated into the
soil, causing severe environmental damage and economic losses [3]. An important part of the nutrients consumed by vertebrates remains in their feces [4] and the efficiency with which these nutrients can be returned to the ecosystem has wide implications for its productivity (Fig. 3). The tunneling beetles, by transporting the dung below ground to their burrows, enrich the soil with nutrients to a greater depth than the roller beetles which usually make their nests in superficial excavations on the soil surface. Microorganisms, mainly bacteria in the dung, promote the release of compounds that enrich the soil; however, the behavior of the beetles also favors the process of nutrient release; it has been observed that individuals of several species of both tunneler and roller beetles, when making a food ball, cover it with their own excrement which in turn contains bacteria that can presumably alter the decomposition process and promote a process of fermentation of the dung [6].

Burial of the dung by the beetles helps to reduce the loss of N, leading to improved soil fertility by facilitating its absorption by plants [38, 39], and a reduction in the emission of N to the atmosphere. Recent studies have estimated the impacts of the activity of dung beetles on soil fertility [40, 41]. One of the mechanisms by which dung beetles affect the nitrogen cycle is by accelerating mineralization rates. The processes of both volatilization and mineralization of N are mediated by bacteria and by the feeding and breeding activities of dung beetles, which in turn modify the fauna of microorganisms in the dung. Aerobic conditions in dung and high levels of carbon and nitrogen in the upper soil layers are

Figure 3: Economic losses averted by the environmental services provided by dung beetles following dung relocation.
stimulated by the activity of dung beetles, promoting bacterial growth, including that of bacteria responsible for the mineralization of N [39,42,43]. However, the manner in which dung beetle feces influences the prevention of N loss through NH$_3$ volatilization is unknown [39], and further studies are required to fully understand this process (see Nichols et al. [3]).

Dung beetles not only contribute to soil fertility with incorporation of N, high concentrations of amino acids have also been reported on the surface of the nest balls that may have accumulated following the fixation of gaseous nitrogen carried out by microorganisms in the digestive tracts of dung beetle larvae [44].

Several authors have reported an increase of nutrients (P, K, N, Ca, and Mg) in soils exposed to the activity of dung beetles and in experimental mounds of dung [45–48]. It was also found that dung beetle activity caused an increase in pH and cation exchange capacity of the soil, but had little effect on humus content [45].

Tunnels may be very shallow and simple (a single tunnel or a few with some branching) for small species such as those of the genera Onthophagus, Canthidium, and Ateuchus among others, or may be deep and complex such as those of Phanaeus, Copris and Dichotomius [8,35]. Bang et al. [40] evaluated the impact of three species of tunneler beetles (Copris ochus, C. tripartitus, and Onthophagus lenzii) on the permeability of soil below the dung pat and found that only the largest (Copris ochus) had an increased effect on permeability at depths below 10 cm. Roller beetles, transporting a small ball of dung a few centimeters to several meters away from the food source and burying it superficially in order to nest, can be assumed to contribute less to the fertility and bioturbation of the soil than tunneler, but no studies have been conducted to confirm this.

Several studies have shown an increase in primary productivity as a result of dung beetle activity: the dung mixed by them below the soil causes a significant increase in height and biomass, as well as protein and nitrogen content, of plants [40, 46, 47, 50, 51]. In a study of natural vegetation, Borghesio [52] found that the presence of dung beetles significantly increased the net primary productivity (NPP) of plants compared with sites with dung but without beetles and control sites without dung (see Nichols et al. [3]).

Dung beetles that live in tropical forests are also involved in dispersal of the seeds present in the feces of frugivorous mammals [53, 54]. During the storage of food in burrows by the tunnelers, or when the rollers transport a ball to the nest, the seeds of various species of forest trees are also transported. This system of dispersal and post-dispersal by the dung beetles, known as diplodochy, often confers greater advantages to the seeds [55, 56]. Diplodochy has been studied in forest dung beetles that disperse small seeds [53]. Burial of the food by the dung beetles reduces the risk of predation of seeds, carried out mainly by rodents [57], but very little is known regarding diplodochy in livestock production systems [3]. While there are reports of the dispersal of invasive plants by livestock [58, 59], it is unknown whether dung beetles in areas of pasture are involved in the germination and establishment of invasive and other plants [3].
Dung beetles contribute, through their feeding and nesting behaviors, to the control of flies, pathogens, and parasitic nematodes. Research on pests and pest control by dung beetles has been carried out in pasture areas, due to their close association with human populations. In studies in Australia [60,61], a significant decrease was reported in the emergence of nematodes in livestock dung manipulated by *Digitonthophagus gazella*, whereas dung with no beetles was found to contain 50 times more helminth larvae. Fincher [62] conducted an experiment in which the population of dung beetles in grazing livestock in southeastern United States was increased 5-fold, resulting in an almost 15-fold reduction in the quantity of the endoparasite *Ostertagia ostertagi*, compared with dung devoid of beetles. The presence in dung of up to nine times more endoparasites (Ostertagia and Cooperia) in pastures without dung beetles compared with dung in pastures with dung beetles reveals the important role played by this group of insects in the control of parasites. Dung beetles are also involved in the reduction of the fungus *Pilobolus sporangia* which is dispersed by nematodes in the grasslands [63].

Parasites, flies, and pathogens could be controlled through chemicals produced by the dung beetles. These beetles have glands in different parts of the body that are related to their behavior [64,65]. Tunneller beetles have very few cuticular exocrine glands in their bodies, while roller beetles, which are more exposed by their behavior of transporting food over the soil surface, have a wide variety of these glands in different parts of the body [64]. The glands may be synthesizing various substances related to the services provided by these beetles, but this process is poorly understood [65].

In *Canthon cyanellus cyanellus*, a roller beetle of the American forests that not only feeds on carrion but also consumes livestock dung, Bellés and Favila [66] found that food balls rolled by the males repel the larvae of flies of the genus *Calliphora*. The male *Canthon c. cyanellus* produces 4-methoxyphenylacetic acid in its abdominal glands. This compound inhibits the growth of the entomopathogenic fungus *Fusarium* and also that of phytopathogenic bacteria [67].

### 6 Dung beetles and chemicals used in livestock production areas

Herd productivity depends on the veterinary management of the livestock, pest control, dung, and pasture. However, the farming practices used for the management and control of the livestock–pasture ecosystem can have serious ecological consequences as a result of the chemical products commonly used. Residues of herbicides, insecticides, and antiparasitics produce imbalance in the environment that affects the soil fauna, especially the dung beetles [68].

The use of herbicides in Mexico has become very common. In the case of livestock grazing pastures, weeds were at one time removed manually by laborers and an annual burning of pastures, but around 20 years ago this practice was replaced by the use of herbicides, which unfortunately tend to be indiscriminate. The toxic...
effect of herbicides on the surrounding environment, soil, water, and human population is poorly understood.

2, 4-Dichlorophenoxyacetic acid (2,4-D) is the active ingredient in the herbicides most commonly used in Veracruz and probably all over Mexico. The residues of this substance, known since the Vietnam War, remain in the soil for more than 50 years [69] and their effects on invertebrates and vertebrates, including humans, are mutagenic, causing cancer, sterility, and sometimes death. In humans, 2, 4-D, has been linked to leukemia in children of mothers exposed to the chemical before birth [70]. Farmers exposed to these molecules exhibited abnormalities in spermatogenesis, skin, and an increased risk of gastric cancer [71, 72]. It also has neurotoxic, immunosuppressive, and hepatotoxic effects [73]. Dung beetles of livestock pastures can be totally eliminated by the use of this chemical [74, 75].

Herbicide residues have been found in the soil [76], water [77], and in vegetable juices [78]. Its toxicity has also been observed in some aquatic plants and animals [79] and in aquatic bacterial communities [80].

Insecticides are applied monthly to cattle, especially in warmer seasons, to control flies and ticks. The most commonly used are the organophosphates, which are also the most toxic, followed by the pyrethroids and finally other less harmful compounds.

Organophosphate insecticides are those most widely used and have high residual power. They degrade in the soil after 4–6 weeks and reach the water where they persist for a longer period of time. They pollute the water and are highly toxic to aquatic organisms and humans, in whom they cause carcinogenesis, reproductive toxicity, and neurotoxicity [81]. The pyrethroids are less toxic and degrade rapidly in air and light [82] although they can cause genetic damage. This has been demonstrated in *Anopheles funestus*, the mosquito vector of malaria in humans, with which duplication of genes with resistance to pyrethroid insecticides has been associated, representing an obstacle to their control [83].

The most commonly used antiparasitics in Veracruz, and perhaps in pastureland areas throughout Mexico, are those that contain ivermectin, fenbendazole, and albendazole [74, 75, 84]. The existence of residues has been demonstrated in different livestock organs and products for human consumption, such as milk and cheese [85–87], in human plasma [88]; and in edible fruits and vegetables [89].

Ivermectin is the product most harmful to the fauna of soil and dung, because it persists within the body of the animal and in the environment after being evacuated in feces [90, 91]. Ivermectin residues, and other anthelmintics that have been administered to cattle over a period of time, have adverse effects on the diptera and dung beetles that are so necessary to the livestock pastures [92–94].

7 Economic value of ecosystem services provided by dung beetles in the State of Veracruz, Mexico

The value of the biodiversity in ecosystems is linked to the value of ecological services provided by the organisms that make up each environment [95].
The valuation of these services has been carried out mainly in relation to those of carbon and water capture, and aesthetic appeal. The valuation of biodiversity has shown the least growth, and an increased willingness to pay to preserve it has only been observed in rich northern countries [96]. In tropical and subtropical countries, adjustments must be made to the techniques of valuation of services, such as biodiversity, that have less priority because of the lack of perception of risk, unlike, for example, the use and management of water [97].

In the United States, the cost of the loss of the cleaning service dung beetles provide in livestock pastures was already estimated [41]. The analysis began by considering that the activity of these beetles causes a 19% reduction in the time it takes to degrade dung. This proportion is interpreted as the saving generated by the action of the beetles reducing the problems caused by the accumulation of dung. In this way, they established that 120 million US dollars are saved by pasture cleaning, 60 million dollars by preventing the loss of nitrogen from the dung, and 200 million dollars through pest control in livestock that do not receive chemicals, such as antiparasitics and insecticides, that could alter the service provided by the beetles, so these figures are very conservative.

The value of the ecosystem services provided by dung beetles to livestock pastures in Mexico and the impact of their loss on Mexican livestock productivity are unknown.

The theoretical cost for the state of Veracruz of loss of the pasture cleaning services of the beetles, as well as the nitrogen lost through volatilization and the control of livestock pests, is detailed below (M. Cruz, unpublished data).

The value of the pasture cleaning service provided by the dung beetles ($C_p$) depends on the total number of livestock in Veracruz ($C_t$), as well as the proportion of these livestock under the extensive management model ($P_r$). The proportion of cattle that did not receive antiparasitic substances, and those under organic farming management ($P_o$), must also be considered.

There are 4,527,000 heads of cattle in Veracruz [98], of which 90.14% are free grazing. Of the total, 93.45% are vaccinated and 92.83% are deparasitized [99]. We can assume that the difference (0.62%) between the vaccinated and deparasitized livestock of the total cattle count could correspond to livestock under organic management, because as a rule these are not treated with chemical substances, except for formally required vaccinations. Thus, this proportion of livestock produces dung that does not harm the beetles (Table 1).

Moreover, taking into account the increase in the process of degradation of dung carried out by dung beetles free from the negative influence of antiparasitic chemicals, an annual average reduction of 47.17% in the time of dung degradation due to coprophagic fauna was found in the Rancho San Román in the municipality of Medellín, Veracruz (M. Cruz unpublished data). This percentage is also considered as the reduction in the time that contamination by dung renders the grass is unavailable or unpalatable to the livestock. Livestock are known to reject a certain area surrounding each dung pat, thus further reducing the grass surface available for grazing [100].
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Table 1: Determination of the number of heads of livestock producing dung available to the dung beetles of Veracruz.

<table>
<thead>
<tr>
<th>$C_p$</th>
<th>$C_t \times P_r \times P_{nt}$ where</th>
</tr>
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<tbody>
<tr>
<td>$C_p$</td>
<td>count of heads of livestock producing dung</td>
</tr>
<tr>
<td>$C_t$</td>
<td>total count of heads of livestock in Veracruz*</td>
</tr>
<tr>
<td>$P_r$</td>
<td>proportion of livestock bred on ranches or in pastures**</td>
</tr>
<tr>
<td>$P_{nt}$</td>
<td>proportion of livestock untreated with antiparasitics (organic)**</td>
</tr>
</tbody>
</table>

| $C_p$ | 25,300 |
| $C_t$ | 4,527,000 |
| $P_r$ | 0.9014 |
| $P_{nt}$ | 0.0062 |

*Veracruz State Government [98] ** INEGI [99].

The value of pasture cleaning ($V_{rf}$) is defined first by the loss of meat production caused indirectly by the refusal to eat near the contaminated grass; and second, by the saving of nitrogen in the dung that is prevented from volatilization.

In both cases, the value ($V_r$), whether of beef or nitrogen saved, is calculated in kilograms.

1. The first case relates to the amount of meat gained by the reduction in contaminated surface area of pasture. According to Anderson et al. [101], 7.63 kg of meat per year per head of cattle may be lost ($L_{nb}$), through the effect of grass contaminated by dung. But if 47.17% is saved by the pasture cleaning of the beetles, then only 3.6 kg ($L_b$) per head is lost (M. Cruz, unpublished data). Using the formula applied by Losey and Vaughan [41], the value of the meat lost when there is no beetle activity, minus the percentage saved when there is beetle activity, would represent approximately 3.34 million pesos saved by the activity of dung beetles in Veracruz (Table 2).

2. In the case of nitrogen saving, it is known that 2% of cattle dung is nitrogen but, of this amount, 80% is lost by volatilization before burial. If every cow produces around 27 kg of nitrogen per year [38], the volatilization loss would be 21.6 kg of nitrogen in the absence of the beetles ($L_{nb}$). Assuming that this volatilization is reduced by 47.17% when the beetles are active, this amount is estimated to be only 11.4 kg of nitrogen lost per head per year ($L_b$). The estimated value of 0.44 US dollars for a kilogram of nitrogen [102] would ultimately save nearly 1.47 million pesos in saved nitrogen (Table 3).

The activity of dung beetles helps to eliminate internal parasites of cattle; therefore, it is important to consider the economic value of this factor and the estimated value for the losses caused by these parasites when the beetles are absent. According to the company ‘Salud Animal de Latinoamérica’, the economic losses caused by pests vary from 200 to 2000 pesos per head of livestock. If we consider the average loss to be 1100 pesos per head per season [103], and we multiply this value by the number of heads of cattle under extensive management and receiving antiparasitics in Veracruz, we calculate a cost of 5000 million pesos a year for deparasitizing cattle. Assuming that the beetles contribute by reducing 47.17% of
The costs associated with parasites in the cattle that do not receive antiparasitics (0.62%), we can calculate that these cattle represent 0.29% of the total population (0.0062 × 0.4717 = 0.0029), and the cost of 5000 million pesos is incurred by the 99.71% of the total population that does receive antiparasitics. Without the service provided by the beetles, this percentage would be 100% and would incur a total cost of 5014.5 million pesos per season, meaning that the presence of the beetles reduces these costs by 14.5 million pesos.

In cattle, some livestock losses are caused by flies, especially the ‘horn fly’ *Haematobia irritans*, which can reduce animal weight by up to 339 g/day, or 123 kg/head/year depending on the density of flies per animal [104]. If this value is multiplied by the number of heads of livestock in Veracruz, it would result in the loss of 560 million kg of weight which, according to the value of a kilo of meat (32.75 pesos), would be equivalent to 18,344 million pesos a year for Veracruz alone.

Considering the extensive and organic meat-producing livestock separately, this population account for 3.47 million kg of meat per year at a value of 113 million pesos.

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### Table 2: Approximate value in kilograms of meat gained due to the grass cleaning action of the dung beetles in the State of Veracruz.

\[
V_{rf} = V_c \times C_{P} (L_{nb} - L_{b}) \text{ where}
\]
\[
V_{rf} = \text{value of reduction in contaminated forage} = \$3,339,157.2
\]
\[
V_c = \text{value of livestock production gained (in kg of meat)} = \$32.75
\]
\[
C_{P} = \text{heads of livestock producing dung} = 25,300
\]
\[
L_{nb} = \text{Losses of meat per animal (kg/head/year), in the absence of beetle activity} = 7.63
\]
\[
L_{b} = \text{Losses of meat per animal (kg/head/year), at current level of beetle activity} = 3.6
\]

*Veracruz State Government [98] ** Anderson *et al.* [101].

### Table 3: Value of the grass cleaning service in kilograms of nitrogen saved.

\[
V_{rf} = V_c \times C_{P} (L_{nb} - L_{b}) \text{ where:}
\]
\[
V_{rf} = \text{value of reduction in contaminated forage} = \$1,476,103.2
\]
\[
V_c = \text{value of nitrogen saved (per kg)} = 0.44 \text{ USD}** = \$5.72
\]
\[
C_{P} = \text{heads of livestock producing dung} = 25,300
\]
\[
L_{nb} = \text{Losses of nitrogen per animal (kg/head/year), in the absence of beetle activity} = 21.6
\]
\[
L_{b} = \text{Losses of nitrogen per animal (kg/head/year) at current level of beetle activity} = 11.4
\]

*McEwan [102] ** assuming the US dollar = 13 pesos.
This proportion of the population that benefits from the services of the beetles corresponds to 99.71% of the total livestock population. If it were 100%, the loss would be 3.48 million kilos of meat with a value of 114 million pesos a year in the absence of beetles. The savings in this situation would be one million pesos a year for Veracruz (Table 4).

Adding the estimated savings produced by dung beetles in the cattle pastures of Veracruz, a sum in excess of 20 million pesos per year is estimated (Table 4). It is very likely that this figure would be higher if it included the contributions of other types of dung or noncattle livestock or even of those that receive only temporary chemical treatments although these data would be very difficult to evaluate.

With the results presented here from official and estimated information of various sources, we can see that a significant monetary cost exists for the environmental services provided by dung beetles.

8 Conclusions and recommendations

An understanding of the interrelationship between livestock, fauna, flora, and the environmental conditions for livestock development is critical to achieving balanced and sustainable management of productive systems. In turn, this must be compatible with the interests of conservation of soil, vegetation, and animal diversity in order to reduce or cushion impacts on the environment.

The search for appropriate mechanisms to sustain this relationship must be carried out in order to maintain or modify existing forms of management in Mexican livestock production. Currently, there are no studies regarding the processes ongoing in the livestock pastures of Mexico, nor even in those of Veracruz, despite this being a state where half of the surface area of approximately 36,000 km² is dedicated to livestock production, and which has a cattle population of almost 3,000,000 head of cattle, ranking first and fifth in the country for meat and milk production, respectively.
For this reason, research on the role played by dung beetles in processes of soil fertility, parasite suppression, and reduction of nitrogen loss to the atmosphere in the farming systems of Veracruz is necessary. In addition, further research is required in tropical forests, where dung beetles are capable of burying all mammalian feces deposited on the soil, within hours of deposition [105]. We do not know the effect of nutrient uptake and bioturbation in Veracruz livestock pastures by the tunneler dung beetle species that follow different patterns of nesting, nor whether the exotic dung beetles that have already established themselves in the pastures have negative effects on the native fauna of beetles in the different farming regions.

As described previously, one of the most common practices in farming is the use of various chemicals which have clear negative effects on the livestock system. Fertilizers can reach nearby rivers and lakes, and leaching of their residues causes considerable nutrient enrichment resulting in eutrophication of aquatic systems and rendering them toxic to wildlife and humans. It is noteworthy that while the beetles are very efficient in increasing plant productivity, efficiency studies of dung beetle reincorporation of nutrients are still required in both natural and modified environments.

As for the environmental services provided by dung beetles, studies regarding the economic value of those are incipient in Mexico and producing preliminary results; we therefore recommend a continued study in areas of high livestock production.

We also need to know the causes of the loss of this insect biodiversity and the economic values associated with these changes and with their role in the sustainable development of livestock production.

It is necessary that official government agencies are fully aware of these services and provide support in the studies to raise awareness in the farmers concerned in order to effect a favorable change in the management of their properties. This can allow them to add value to their products, now that the organic produce label is highly valued in international and domestic markets, while making sustainable use of the environment.

Another important aspect is the requirement in Mexico that the marketing and application of highly toxic chemicals, currently used in areas of intensive farming, is regulated and supervised or even prohibited. In Mexico to date, no ecotoxicological studies have been carried out on the effects of herbicide and pesticide pollution, nor of antiparasitics on populations and communities of dung beetles or other animals, including man. Furthermore, the degree of soil and water contamination by these substances has not been fully evaluated; we therefore propose the implementation of such studies. Regarding antiparasitics, examination of the effect on dung beetles began only recently.

It would be appropriate to the respective biological and chemical valuations in livestock production areas to try to establish agricultural management policies setting out a scheduled and balanced program of vermicides and herbicides in order to conserve and make sustainable use of these ecosystems.

The efficiency of livestock production systems must be associated with biodiversity conservation and the elimination or reduction of environmental pollution.
Furthermore, biodiversity conservation should not only be considered within protected areas, but also in managed ecosystems [106,107], among which livestock production systems are of great importance in the state of Veracruz. A matrix of vegetation in the landscape of grasslands of Veracruz is desirable, allowing for good production, but maintenance of the biodiversity of natural and managed systems found within the landscape. Livestock production systems that include an agricultural matrix that allows the transit and survival of species native to the region and those of the agroecosystem [108] can successfully integrate sustainable development and conservation.

References


The Role of Dung Beetles in the Sustainability


