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Taxonomic identity of invasive rabbits in Cuba: first record of Eastern Cottontail, *Sylvilagus floridanus* (Mammalia: Lagomorpha)

Carlos A. Mancina[1*], **Efrén García Tió**[2], **Rafael Borroto-Páez**[3], **Héctor M. Díaz**[1] and **Fernando A. Cervantes**[4]

1 Instituto de Ecología y Sistemática, Carretera de Varona km. 3 ½ Capdevila, Boyeros, C.P. 10800, La Habana, Cuba
2 Federación Cubana de Caza Deportiva. Calle 7ma # 21808. Playa, C.P. 12200, La Habana, Cuba
3 Sociedad Cubana de Zoología
4 Instituto de Biología, Universidad Nacional Autónoma de México. A.P 70-153, C.P. 04510, DF, México
* Corresponding author. E-mail: mancina@ecologia.cu

Abstract: In islands of the West Indian zoogeographical region, rabbits are not native, and wild populations are the result of introductions. *Oryctolagus cuniculus* is the only lagomorph listed among the introduced mammals of the Cuban archipelago. We analyzed specimens of wild rabbits and we report the occurrence of *Sylvilagus floridanus* for the first time in Cuba. Capture data suggest that their distribution is currently limited to the west-central region of the island. However, the niche models showed high climatic suitability throughout the majority of Cuba, suggesting a high expansion probability.

Key words: Eastern Cottontail, introduced mammal, new record, niche modeling, *Oryctolagus cuniculus*, West Indies

In Cuba, as in other islands of the West Indian zoogeographical region (*sensu* Hershkovitz 1958), rabbits are not native, and wild populations are the result of introduction for hunting and cuniculture (Long 2003). The origin of wild rabbit populations in Cuba is uncertain, but their introduction likely dates to the first years of Spanish colonization. Rodríguez-Ferrer (1876) wrote that domesticated forms of *Oryctolagus cuniculus* Linnaeus, 1758 were imported to Cuba from France, Spain and the U.S.A., probably in the early nineteenth century or just before. However, he suggested that these introduced rabbits failed to establish enduring wild populations in Cuba due to low availability of food and the wet climate. Moreover, Varona (1974) mentioned that wild European rabbits could have been imported from the Canary Islands to Cuba about 1880s. However, based on the currently available information it is not possible to verify the exact origin or introduction date.

The European rabbit, *O. cuniculus,* has been introduced to more than 800 islands worldwide resulting populations in the wild (Long 2003). Perhaps because of the widespread proliferation of *O. cuniculus* throughout the world, Cuban wild rabbit populations are assumed to comprise only this species. In fact, *O. cuniculus*is the only lagomorph listed among the introduced mammals of the Cuban archipelago and in official documents that detail legal regulations and hunting guides (Varona 1974; González et al. 1994; Chamizo 2004; Anonymous 2008; Borroto-Páez 2009). However, we are unaware of any biological study on wild rabbits in Cuba that might verify this presumed species identification. As a result, we analyzed specimens of wild rabbits hunted from several localities in Cuba. Surprisingly, all specimens were identified as *Sylvilagus floridanus* Allen, 1890.

In this paper, we therefore report the occurrence of *S. floridanus* and scientifically document, for the first time, this genus and species in Cuba. Additionally, we modeled the environmental niche of *S. floridanus* in its native range and projected the model to the Cuban archipelago in order to estimate the potential distribution in this species throughout the Cuban archipelago. Climate is an important predictor of the establishment success of invasive species (Bomford et al. 2009), and ecological niche modeling has been demonstrated to be effective for assessing the potential distributions of introduced or invasive species (Jeschke and Strayer 2008; Taylor et al. 2012). The climatic suitability maps would provide assistance for management and prioritizing areas for surveillance of this invasive species in Cuba.

We examined 17 adult wild rabbit skulls collected, between May 2012 and June 2014, from localities in western (Pinar del Río and Artemisa provinces) and central (Matanzas and Villa Clara provinces) Cuba.

These Cuban wild rabbit skulls were compared with skulls of the European rabbit (*O. cuniculus*) and other rabbit species deposited in the Field Museum of Natural History (Chicago, IL, USA) and the Mammal Collection from the Instituto de Biología (Universidad Nacional Autónoma de México); in addition, we used species keys (Hall 1981; Cervantes and Lorenzo 1997) for identification at the species level. Cranial measurements were taken following Diersing and Wilson (1980) using a digital caliper (error ± 0.01 mm). All measured skulls are deposited in the Collection of Mammals at the Instituto de Ecología y Sistemática, in Havana, Cuba.

Voucher specimens: Colección de Mamíferos del Instituto de Ecología y Sistemática, La Habana, Cuba (acronym: CZACC), CZACC 1.5551-1.5557 (7 specimens); material non-catalogued (10 specimens). Comparative material: *O. cuniculus* (Field Museum of Natural History: FMNH), FMNH 6455-6457; FMNH 90610-90609; FMNH 57229. *S. floridanus*, FMNH 73339; FMNH 7740-7742; FMNH 57168; FMNH 15949-15950; FMNH 198936-198941.

Because the ecology of wild rabbits in Cuba has not been previously studied, we also examined 42 adult rabbits in order to collect data pertaining to sex ratio, reproductive status, and body mass. These rabbits were collected between June 2013 and July 2014 from a rabbit population in northeastern Artemisa province. The study area, at 90 m above sea level (a.s.l.), is covered in small patches of secondary vegetation and agricultural fields (e.g., sugar cane).

The ecological niche was modeled with the MaxEnt software (Phillips et al. 2006). We used 2294 georeferenced presence points that constitute the distribution of *S. floridanus* in mainland America and 26 records from invaded range in Cuba. All georeferenced data of native range were obtained from the Global Biodiversity Information Facility (GBIF) database (http://data.gbif.org). To reduce the clusters of localities that might create bias in environmental space, we used localities that were at least 5 km apart. As predictors, we used the following at a spatial resolution of 30 minutes, altitude and uncorrelated bioclimatic layers (pairwise Pearson correlation with $r < 0.70$): maximum temperature of the warmest month, annual temperature range, mean temperature of wettest quarter, mean temperature of coldest quarter, annual precipitation, precipitation seasonality, precipitation of warmest quarter, and precipitation of coldest quarter (Hijmans et al. 2005).

We ran the Maxent models using the default setting (iterations 500, convergence threshold 0.00001, and regularization value1). The native *plus* invasive presence points were randomly partitioned into 1,740 (75%) training and 580 (25%) testing datasets with 10 subsample replicates to evaluate model performance. Model performance was evaluated by measuring the area under the Receiver Operating Characteristic (ROC) curve (AUC). AUC is a measure that ranges from 0.5 (random accuracy) to a maximum value of 1.0 (perfect discrimination) (Peterson et al. 2011). The "10 percentile training presence" threshold value was used to discriminate suitable from non-suitable habitat. This threshold may to reduce the overly extensive prediction when many calibration localities exist (Radosavljevic and Anderson, 2014). The ecological niche model generated for *S. floridanus* was then projected onto both the native range and the Cuban archipelago to assess the potential distribution, and the presence points in Cuba were plotted on the potential distribution map.

All analyzed specimens of the wild Cuban rabbit were distinguishable from *O. cuniculus* by their relatively smaller size and shorter ears. Whereas *O. cuniculus* typically exhibit a total body length greater than 490 mm and ear length greater than 80 mm, our specimens exhibited total body lengths (mean ± standard deviation) of 377.5 ± 35.3 mm and ear lengths (from notch) of 61.3 ± 2.4 mm. In addition to these differences in external characteristics, we also discovered distinct differences in skull morphology between wild Cuban rabbit specimens and *O. cuniculus* specimens. One major skull characteristic that allowed us to distinguish our specimens from *Oryctolagus* genus is the tip of the posterior extension of supraorbital process: whereas in our specimens this touched the braincase, this tip is free of the braincase in *Oryctolagus* (Figure 1).

The comparative analysis of external and skull characteristics allowed us to further identify our specimens to the species level as *S. floridanus*, as the specimens were distinguishable from other potential congeners according to the diagnostic criteria described by Hall (1981) and Cervantes and Lorenzo (1997). In particular, the pelage of *S. floridanus* was usually reddish-brown on the upper parts and white on the venter and tail, and the nuchal patch was present but not very pronounced in most individuals (Figure 2). Furthermore, the mean body mass was 1078.1 ± 86.2 g for adult males and 1221.5 ± 297.5 g for adult females, which is comparable with North American populations of *S. floridanus* (e.g., Chapman et al. 1980; Bond et al. 2004). Because of the wide continental distribution of *S. floridanus*, their external and cranial characteristics vary highly among localities. However, the cranial measurements from Cuban specimens (Table 1) are within the observed range of most subspecies of *S. floridanus*in both west-central Mexico (Diersing and Wilson 1980) and east-central U.S.A (Chapman et al. 1980).

Ecological data from the samples obtained from Artemisa province suggest a 1:1 sex ratio (21 males and 21 females), which conforms to the sex ratio documented for this species in North American populations (Bond et al. 2004). We observed pregnancy between March

Figure 1. Views of the skull and mandible of *Sylvilagus floridanus* (**A**; adult female, CZACC-5553) from Cuba compared with *Oryctolagus cuniculus* (**B**). The arrows indicate the tip of the posterior extension of the supraorbital process, which touches the braincase in *Sylvilagus* but remains free of the braincase in *Oryctolagus*.

Figure 2. Dorsal, ventral, and lateral views of the skin of *Sylvilagus floridanus*, adult male CZACC 1.5557. Collected in Artemisa province, Cuba.

Table 1. Cranial measurements (mean ± standard deviation, in mm) of specimens of *Sylvilagus floridanus* from Cuba. For measurement definitions see Diersing and Wilson (1980).

Variables	Males (*n* = 8)	Females (*n* = 9)
Greatest skull length	73.9 ± 1.73	73.28 ± 2.18
Basilar length	58.9 ± 0.72	58.8 ± 2.21
Zygomatic breadth	34.3 ± 0.28	34.53 ± 0.61
Braincase breadth	24.5 ± 0.87	24.14 ± 0.74
Interorbital breadth	18.67 ± 0.51	18.06 ± 0.69
Palatal length	29.33 ± 1.11	30.44 ± 1.46
Bullar length	11.7 ± 0.95	11.34 ± 0.83
Mastoid width	24.7 ± 0.17	23.98 ± 1.29
Height of braincase	28.67 ± 1.4	29.68 ± 1.54
Maxillary toothrow	11.73 ± 0.97	11.98 ± 0.7
Diameter of external auditory meatus	3.97 ± 0.12	3.98 ± 0.54
Mandible total length	52.1 ± 0.9	51.66 ± 1.43
Mandibular toothrow	12.33 ± 1.53	12.1 ± 0.23

and July with two and three embryos in each female. This litter size is less than previously reported in some continental populations (e.g., Ecke 1955). However, both breeding season and litter size likely vary among populations (Bond et al. 2004), as Barkalow (1962) suggested that cottontails in northern latitudes produce larger litters than in southern latitudes.

Anecdotal data of harvested cottontails in Cuba suggest that their distribution is limited to the west-central region of the island. However, wild rabbits are apparently more abundant on the Habana-Matanzas Plain and have not been captured nor sighted further east than Sancti Spíritus province in central Cuba. Based on our occurrence data, these rabbits are most typically found at sites of low altitude (< 250 m a.s.l.), where annual temperature ranges from 23.5–25.5°C and annual precipitation between ranges from 1200–1600 mm. Generally, the rabbits are associated with crop fields, grasslands, and scrublands. Although anecdotal, these observations conform to expectations presented by Betolino et al. (2011a), in which distribution models based on landscape attributes found that the presence of introduced *S. floridanus* in northwestern Italy is favored by crops and meadows with high ecotones extension and wide hydrographic networks associated with riverside vegetation.

Our own predictive models had high AUC values (0.805 ± 0.009 for training and 0.789 ± 0.012 for test), indicating reasonable model performance. The models showed high climatic suitability for *S. floridanus* throughout the majority of Cuba, with 88,707 km^2 (ca. 87% of the island) considered suitable for Eastern Cottontails (Figure 3). The models predicted that only relatively small areas in Camagüey province, as well as the highlands in the most eastern region of Cuba, do not present suitable environments for this species.

In an informal interview of Cuban hunters in the preparation of this paper, we determined that four decades ago rabbit sighting were limited around the Habana-Matanzas Plain. However, in the last twenty years rabbits have been hunted in localities in the Central region in Villa Clara and Sancti Spíritus provinces. Because of absence of geographic barriers as well as low diversity of native competitors or predators, the models suggest a high expansion probability of this invasive species. As occurred in northwestern Italy (Bertolino et al. 2011b), this rabbit could continue to expand its distribution range on Cuba.

The specimens analyzed in this study were obtained from localities that cover the most part of area of occupancy known of Cuban wild rabbits. Because all specimens were positively identified as *S. floridanus*, the current existence of feral populations of the European rabbit (*O. cuniculus*) in Cuba is currently unknown. However, European rabbits are very commonly found in captivity throughout Cuba, and it is therefore possible, and perhaps even certainly, that *O. cuniculus* has been either accidentally or deliberately released by farmers. In fact, some hunters report that in certain localities two distinguishable types of rabbits occur in the wild. In addition, a specimen identified as *O. cuniculus* (MCZ-41256), collected in southeast of Havana province, is deposited in the Museum of Comparative Zoology, Harvard University; although details of the habitat where it was collected are unknown.

The arrival of the Eastern Cottontail rabbit to Cuba likely occurred through intentional introductions from the U.S.A. for hunting purposes. This species is the most important game animal in the U.S.A. (Chapman et al. 1982) and was the subject of massive introductions and translocations within the U.S.A.during the first half of the twentieth century (Chapman and Morgan 1973; Hall 1981). In the early twentieth century, the intentional introduction of non-native species was a common practice in Cuba, and a government program to enrich Cuban fauna was responsible for introducing numerous species from the U.S.A. (Gómez de la Maza 1932). Although we have not yet found reports specifically documenting the introduction of *S. floridanus* in Cuban hunting bulletins, gray literature, or other publications, likely this species could have been imported and released around Havana, and we are currently in the process of researching this historical issue. To date, exists only a single report of *Sylvilagus* genus elsewhere in the West Indies (Dominican Republic; Ministerio de Medio Ambiente y Recursos Naturales 2012), but their specific status is unknown.

As for other islands of the West Indies, Cuba has a depauperate native mammal fauna (Borroto-Páez and Mancina 2011). This zoogeographic subregion has been the subject of many mammal introductions (Massetti 2011; Borroto-Páez and Woods 2012). The ecological impacts of many invasive species on these islands have

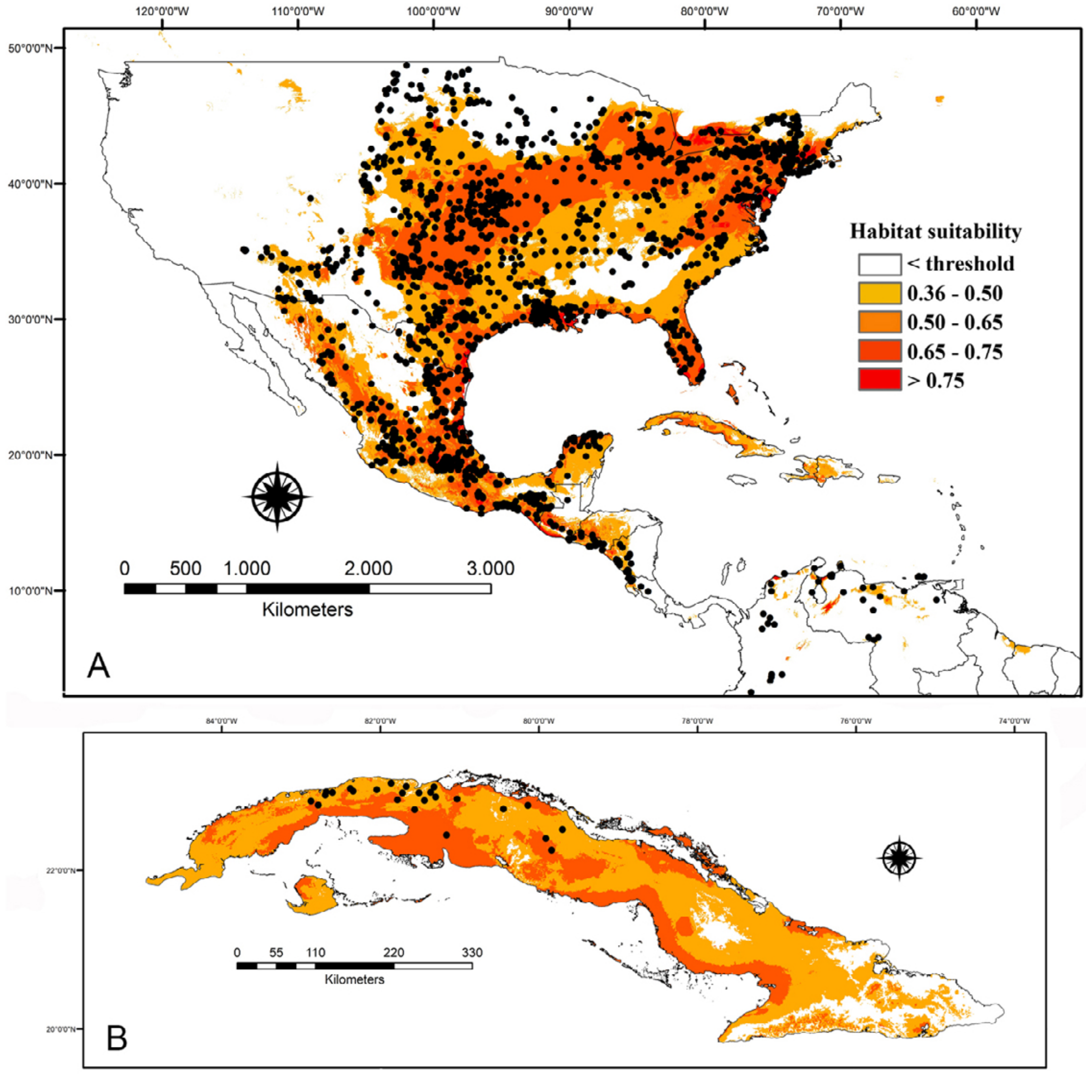

Figure 3. Ecological niche model for *Sylvilagus floridanus* based on presence records from native range in United States to northern South America and records from the invaded range in Cuba (A). The environmentally suitable area (orange gradient) was based on "10th percentile training presence" threshold; points represent occurrence records from GBIF. Projection of the model of predicted suitability to the Cuban archipelago (B); points represent localities where the species have been captured or sighted.

not been deeply evaluated, and the effects attributed to most species are based on limited or circumstantial data. In Cuba, there is no available evidence of rabbit-induced damage on native plants, although it is known that rabbits consume some commercial crops and sugar cane seedlings. However, as in other countries, rabbits can affect plant communities by over-grazing or by dispersing seeds of invasive plants (Bell et al. 1999; Fernandez and Saiz 2007). Moreover, *S. floridanus* hosts parasites and is a possible vector of diseases that can be transmitted to native fauna and humans (e.g., Jacobson et al. 1978; Cooney et al. 2005). This species can be a carrier of myxomatosis, which is lethal to rabbits (*O. cuniculus*) used for food production, as well as the West Nile Virus, an agent of significant human and veterinary disease (Tiawsirisup et al. 2005). For example, the introduction of *S. floridanus* to Italy also resulted in the introduction of several species of protozoan intestinal parasites of North American origin (Bertolino et al. 2010).

Due to the extensive home range, high reproductive rates as well as capacity to use a wide diversity of habitats (Chapman et al. 1980; Chapman and Ceballos 1990), rabbit populations should be controlled and monitored by Cuban conservation and health authorities. Of special concern is the possibility of the species' expansion or introduction to protected areas and offshore cays in the Cuban archipelago. There the ecological impacts might severe, affecting the integrity of autochthonous vegetation and forest regeneration, beside could compete with some species of endemic and endangered rodents (hutias). This study therefore makes an important contribution to updating the invasive species threat to the Cuban archipelago and the possible expansion of *S. floridanus*. We emphasize the need for additional study of this species in order to identify its geographic scope, life-history, and potential ecological and health impacts, for the purpose of science-based management and risk-reduction.

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