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ARTIGOS

Invasive rodents in French Guiana: an overview for *Mus musculus, Rattus norvegicus,* and *R. rattus* (Murinae: Muridae)

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Abstract: As the invasive murine rodents have too often been neglected in Neotropical faunal inventories, a synthesis on the presence of the House mouse, the Black rat, and the Norway rat was ascertained for French Guiana. We relied on preserved museum-specimens, on caught and released animals, on identified remains extracted from Barn owl (*Tyto alba*) pellets, and on bona-fide visual observations. The aggregated data allowed documenting the presence of at least one invasive Murinae in 31 localities throughout the country. Most observations and/or captures concern the northern coastal areas, where the vast majority of villages and cities are to be found. All three murines were found together in only two localities (Sinnamary; Cayenne) whereas globally the most frequent species was *Rattus rattus,* followed by *Mus musculus,* and finally *R. norvegicus.* Invasive murines were also found on five offshore islands, and the House mouse was caught in an isolated gold-mining camp in the center of the country. Biometric data are provided for characterizing some external and cranio-dental variables in *M. musculus* and *R. rattus.* Owl pellets materials indicate that both species of *Rattus* can be easily sorted by the crown-length non-overlapping values of their upper and/or lower molars.

Key-Words: Guyane; Invasive rodents; Distribution; Guianan Shield.

Resumo: Roedores invasores na Guiana Francesa: uma visão general *Mus musculus, Rattus norvegicus* e *R. rattus* (Murinae: Muridae). Considerando que os roedores muríneos têm sido muito frequentemente negligenciados nos inventários da fauna neotropical, uma síntese sobre a presença do camundongo, do rato-preto e da ratazana foi feita para a Guiana Francesa. Nós nos baseamos em espécimes preservados em museus, em animais capturados e posteriormente soltos, em fragmentos identificados oriundos de regurgitos da coruja suindara (*Tyto alba*) e em registros visuais de naturalistas experientes. Os dados em conjunto permitiram documentar a presença de, pelo menos, um Murinae invasor em 31 localidades ao longo do país. A maioria das observações e/ou capturas ocorreu em áreas costeiras do norte, onde a grande maioria das vilas e cidades se localizam. Todas as três espécies de muríneos foram encontradas juntas apenas em duas localidades (Sinnamary e Cayenne), enquanto globalmente a espécie mais frequente foi *Rattus rattus,* seguida de *Mus musculus,* e finalmente *R. norvegicus.* Os muríneos invasores foram também encontrados em cinco ilhas costeiras, além de que o camundongo foi capturado em um campo de mineração de ouro isolado no centro do país. Dados biométricos são disponibilizados caracterizando algumas variáveis externas e crânio-dentais de *M. musculus* e *R. rattus.* O material abundante nos regurgitos de coruja indica que ambas as espécies de *Rattus* podem ser facilmente reconhecidas através de valores não sobrepostos de comprimentos dos molares superiores ou inferiores.

Palavras-Chave: Guiana Francesa; Roedores invasores; Distribuição; Escudo das Guianas.

INTRODUCTION

Many species of plants, microbes, and animals have been introduced around the world. Species are considered "alien" or "invasive" when they are not native to an area, but become established and cause, or are likely to cause, economic or environmental harm or harm to human health. Such is the case for three species of murine rodents (Murinae: Muridae) in French Guiana – and throughout the Americas: the House mouse *Mus musculus* Linnaeus, 1758, the Black rat (or Roof rat) *Rattus rattus* (Linnaeus, 1758), and the Norway rat (or Brown rat) *Rattus norvegicus* (Berkenhout, 1769). These vertebrate species were introduced inadvertently, by early explorers of the New World who arrived with their ships infested with rats and mice, which as a result, have colonized much

of the Americas (Wittmer & Pitt, 2012). Some time after the discovery of the Guianas by the Spanish, *R. rattus* and *M. musculus* may have been introduced to French Guiana, first by ships entering the littoral areas of Cayenne and/or Saint-Laurent du Maroni. The introduction of *R. norvegicus* most likely is from a later date, probably around the second half of the 18th century (Husson, 1978).

As invasive species, murine rodents are particularly problematic because they have many characteristics that make them very effective invaders (Aplin *et al.,* 2011), as they have adapted to several life-styles: terrestrial, semi-aquatic, and arboreal. Several types of damage have been caused by rodent introductions throughout the Americas (Witmer & Pitt, 2012); the substantial and worldwide loss of human food, both crops in field and stored foodstuffs, has been documented in a few reviews (Meerburg *et al.,* 2009; Witmer & Singleton, 2011). In addition to consuming human foodstuffs, murine rodents also contaminate much more stored food through high levels of defecation and urination.

The three murine invasive species are reservoirs for epidemic transmission of many zoonotic pathogens of public health importance, transmitting several diseases to humans and livestock (Meerburg *et al.,* 2009). Specifically, so far, the two following pathogens have been evidenced in French Guianan murines: lymphocytic choriomeningitis mammarenavirus (family Arenaviridae) in *M. musculus* (Lavergne *et al.,* 2016); and leptospirosis (spirochetes bacteria *Leptospira interrogans* serovar Copenhageni) in urban *R. norvegicus* (Duchassin *et al.,* 1965).

Norway rats are originally native to northern China (Musser & Carleton, 2005). Records show that the first sighting of *R. norvegicus* in the New World occurred in the 1770's as ship stowaways (Puckett *et al.,* 2016). The Norway rat is closely tied to human settlements, and is essentially terrestrial, with much burrowing activity near artificial watercourses (Corbet, 1991).

Rattus norvegicus is the cause of extensive economic damage to farms, food products, industries, and households. In relation to public health, this species is a reservoir for important zoonotic pathogens (Costa *et al.,* 2014) such as bacteria (*e.g., Leptospira interrogans*), viruses (*e.g.,* Seoul virus), and helminths (*e.g., Capillaria hepatica* Bancroft, 1893). Reproductive capacity of Norway rats can be very high in tropical urban areas, such as in the city of Salvador (Bahia state, Brazil) where Panti-May *et al.* (2016) examined 106 pregnant females and found a median number of 10 embryos. Furthermore, their study provided an estimate of ca. 37 days between two consecutive litters, and that throughout the whole year. Panti-May *et al.* (2016) compared their data with those from the temperate locality of Baltimore (Maryland, USA), and found that the Brown rats of Salvador have a much higher fecundity.

Rattus rattus is found on all continents of the earth. Although the species is believed to be native to India and possibly other Indo-Malayan countries, it has been introduced through human travel overseas to all continents (Aplin *et al.,* 2011). *R. rattus* are designed by several vernacular names: Ship rats, House rat, Black rat, and Roof rat. Whereas Norway rats seem limited to urban areas, the Black rats readily adapt to field and forest habitats in some tropical and semi-tropical areas (Wittmer & Pitt, 2012) causing damage to orchard, grain, and sugarcane crops. Because of their arboreal nature, Roof rat can prey on adult birds, nestlings, and eggs under some circumstances (Niethammer & Krapp, 1978).

Mus musculus may have originally been distributed from the Mediterranean region to southwestern China, but it has now been spread throughout the world by humans (Musser & Carleton, 2005) and generally lives in close association with humans – in houses, barns, granaries, etc. (Corbet, 1991). House mice cause many types of damage (Timm, 1994; Witmer & Jojola, 2006), and a major concern is the consumption and contamination of stored foods.

Despite the ecological and public health impacts of House mice and of Black and Norway rats in shantytowns worldwide, there is a paucity of data describing the population dynamics of invasive rats and mice in urban landscapes. Ecological studies evaluating murine demography have before all been limited to temperate urban environments of the Northern Hemisphere, but some studies in the Neotropics have recently appeared (Panti-May *et al.,* 2016).

Murine rodents are considered to be universal carriers of *Leptospira,* which are spirochaete bacteria which can induce leptospirosis – a systemic disease of humans and domestic animals (Costa *et al.,* 2014). Mice and rats harbor the spirochetes in their renal tubules and spread them to the surrounding environment through contaminated urine (Petrakovsky *et al.,* 2014). In the city of Cayenne (French Guiana) and its bordering slum communities, Duchassin *et al.* (1965) have caught and analyzed 152 *R. norvegicus* for a human-health study of leptospirosis; they found 51 rats positive for leptospirosis, of which 31 samples were confirmed through molecular identification. According to Epelboin *et al.* (2016), leptospirosis has a yearly prevalence of 5 to 40 human cases per 100'000 people in French Guiana – and its main reservoir is the Brown rat. Similar values were found in a Brown rat population from the Brazilian city of Salvador, where de Faria *et al.* (2008) noticed that 80% of 142 *R. norvegicus* were positive for the culture of *Leptospira interrogans,* and that 68% of the rats had a high titer in their serum for these pathogenic spirochetes.

Thus, the objectives of this work are to gather the different kinds of data (museum's specimens, bona fide observations, barn owl diet analysis) concerning the three species of invasive murine rodents at the geographic scale of French Guiana, in order to ascertain their distribution and their abundance relative to each other and to the native fauna of small rodents. We also take the opportunity of this new materials for presenting some reproductive and morphometric data characterizing these non-indigenous rodents, and these data will complement those known for an other Guianan country, namely Suriname (Husson, 1978). Regarding human health aspects, a better knowledge of the basic ecology of these pests is essential to formulate effective rodent control strategies.

MATERIALS AND METHODS

We used different sources of data for drawing the general picture of the three invasive Murinae in French Guiana.

a) Specimens caught and preserved by scientists and various collectors, including specimens caught, ear-biopsied for molecular typing, and then released or discarded after euthanasy. Abbreviations for institutions housing specimens are: MHNG = Museum d'Histoire Naturelle de la ville de Genève (Geneva); MNHN = Museum National d'Histoire Naturelle (Paris); ISEM-V = Institut des Sciences de l'Evolution de Montpellier, Montpellier University (Montpellier).
b) Observations from well-trained amateur naturalists, sometimes accompanied by photographs; although observations were haphazardly acquired (*i.e.,* not the product of systematic surveys or focused searches), most are accompanied by a sufficiently detailed description of the animal(s) such that identifications could be made with confidence.
c) Skulls extracted from owl pellets (mostly: *Tyto alba,* but also *Pulsatrix perspicillata*), and whose identification followed Baglan & Catzeflis (2016). All bone fragments and skulls used in this study are preserved at the author's affiliation laboratory. Batches of owl pellets containing remains of murine rodents together with other small vertebrates come from four localities (from west to east): Awala-Yalimapo (506 birds and mammals extracted and identified); Sinnamary (646); Macouria (27); and Cayenne (49).

Standard external measurements (Head and Body Length; Tail Length; Hind Foot Length without claws; Ear Length) were those recorded by the collectors. Only subadult and adults were considered, *i.e.,* animals with all three molars fully erupted (Niethammer & Krapp, 1978). Cranial and dental measurements were taken as described by Voss *et al.* (2001: 73-75). As samples of wild-caught murines had never been studied before in the Guianas, I tested for sexual dimorphism in a few external and cranio-dental characters for *Rattus rattus* and *Mus musculus.* The retained variables are Head and Body Length; Tail Length; Hind Foot length (without claws); Ear length; Weight; Condylo-Incisive Length; Zygomatic Breadth; Length of Nasals; Length of Upper Molars; Cranial Depth (vertical distance from ventral margin of bulla to top of cranium). Statistical analysis and comparisons used parametric (t-tests) and non-parametric (Mann-Whitney tests) tests available in the software PAST (PAleontological STatistics: Hammer *et al.,* 2011).

Most specimens of Murinae caught in French Guiana were from anecdotal samplings (*i.e.,* not the product of systematic surveys or focused searches), with two exceptions (Cacao; Trois-Paletuviers). There, traps (Sherman and/or wire mesh cages) were set with the main aim of sampling *R. rattus* (in an agricultural estate at Cacao: 04°34'28"N; 52°27'11"W) or *M. musculus* (in a small village at Trois-Paletuviers: 04°04'00"N; 51°39'40"W). At Cacao, sampling efforts amounted to 1136 trap-nights for 15 nights (5 to 10 traps/night) between 2007 and 2012; at Trois-Palétuviers, sampling amounted to 871 trap-nights during part of June and July 2013 (80 to 100 traps/night).

RESULTS

Our database has 184 records of murines in French Guiana: 163 caught individuals (see Appendix-1) and 21 observations. The most frequent species is *R. rattus* (n = 92 data), followed by *M. musculus* (n = 83), and finally *R. norvegicus* (n = 9).

The analysis of owl-pellets materials from 4 localities yields 51 *R. norvegicus,* 38 *R. rattus,* and 6 *M. musculus.* Results are presented by decreasing frequency of each taxon.

a) Black rats (*Rattus rattus*) – *R. rattus* has been caught in 17 localities, ranging from Awala-Yalimapo in the north-west littoral to Saut Maripa (municipality of Saint-Georges de l'Oyapock) in the north-east (Figure 1 and Appendix-2).

A series of 22 full grown (sub-adults and older) animals caught in a small-scale farming estate near Cacao (municipality of Roura) will serve to document some external and skull metrics (Table 1). Mann-Whitney and t-tests each indicate no support ($p > 0.10$) for sexual dimorphism in French Guianan Black rats, and this conforms with what is known in Europe (Niethammer

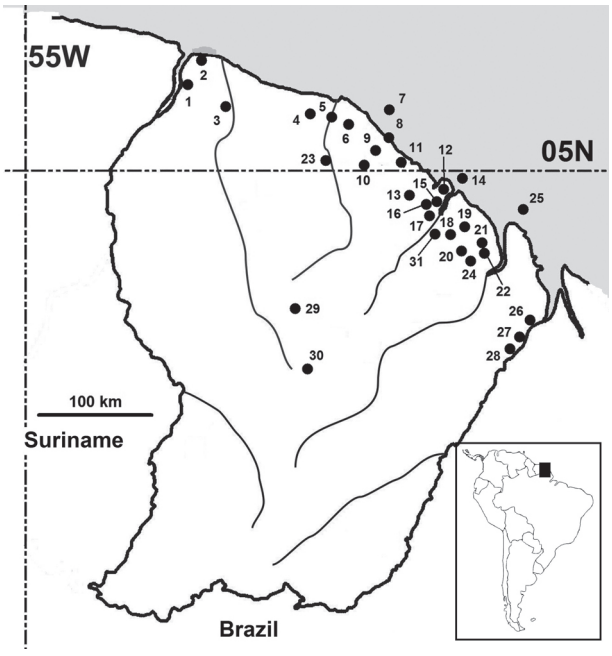

Figure 1: map of French Guiana with 31 localities where invasive murines have been evidenced through caught specimens and/or bona-fide visual observations and/or cranial remains from owl pellets. Appendix-2 lists all localities numbered 1 to 31, with details on the presence of each murine species in every locality.

Table 1: External and skull measurements (in mm; weight in g) for 22 subadults and/or adult specimens of *Rattus rattus* from Cacao (municipality of Roura). Mann-Whitney and t-tests each indicate no support (p > 0.10) for sexual dimorphism. Abbreviations: HBL = Head and Body Length; TL = Tail Length; HF = Hind Foot length (without claws); Ea = Ear length; We: Weight; CIL = Condylo-Incisive Length; ZB = Zygomatic Breadth; LN = Length of Nasals; LM = Length of Upper Molars; CD = Cranial Depth (vertical distance from ventral margin of bulla to top of cranium). N = sample size.

Females	**HBL**	**LT**	**HF**	**Ear**	**We**	**CIL**	**ZB**	**LM**	**LN**	**CD**
Mean	165.7	209.8	32.7	23.8	121.8	36.7	18.8	6.1	13.5	13.7
min	133.0	177.0	30.0	22.0	60.0	31.6	17.6	5.8	12.3	13.0
max	191.0	237.0	35.0	28.0	190.0	40.9	20.0	6.6	15.0	14.8
N	11	11	11	11	11	11	7	11	7	7
Males	**HBL**	**LT**	**HF**	**Ear**	**We**	**CIL**	**ZB**	**LM**	**LN**	**CD**
Mean	165.6	196.8	32.6	23.1	106.0	35.7	18.5	6.1	13.4	13.9
min	133.0	172.0	30.0	21.0	48.0	31.0	17.0	5.9	11.2	12.7
max	198.0	217.0	35.0	25.0	170.0	40.5	20.3	6.4	15.4	15.0
N	11	11	11	11	11	11	7	11	9	9

Table 2: External and skull measurements (in mm; weight in g) for 22 subadults and/or adult specimens of *Mus musculus* from three localities (see text). Mann-Whitney and t-tests each indicate that females are larger (p < 0.05) than males for three variables: HBL, CIL, and LN. Abbreviations as for Table 1.

Females	**HBL**	**LT**	**HF**	**Ear**	**We**	**CIL**	**ZB**	**LM**	**LN**	**CD**
Mean	84.2	82.8	16.3	13.8	15.4	19.7	10.8	3.0	7.7	7.4
min	76.0	76.0	15.0	13.0	11.0	18.5	10.4	2.9	7.1	7.0
max	95.5	91.0	17.0	14.5	19.0	20.8	11.4	3.4	8.3	7.8
N	12	12	12	12	10	11	10	12	6	6
Males	**HBL**	**LT**	**HF**	**Ear**	**We**	**CIL**	**ZB**	**LM**	**LN**	**CD**
Mean	75.9	82.4	16.6	13.3	12.7	19.0	10.4	3.0	7.0	7.1
min	69.0	75.0	15.5	12.0	10.0	17.6	9.8	2.8	6.4	6.8
max	80.0	91.0	18.0	14.0	14.5	20.1	10.9	3.5	7.6	7.5
N	10	9	10	10	8	10	10	10	9	7

Table 3: Dental measurements (length of molars at crown) in sympatric *R. norvegicus* (above) and *R. rattus* (below) skull remains extracted from owl pellets (localities of Cayenne and Sinnamary). Mann-Whitney and t-tests each indicate that *R. norvegicus* is larger (p < 0.001) than *R. rattus* for all 6 variables. Abbreviations: M1, M2, M3 for upper molars; m1, m2, m3 for lower molars; SD = Standard-Deviation; N = sample size.

	M1M3	**M1M2**	**M1**	**m1m3**	**m1m2**	**m1**
Rattus norvegicus						
Mean	6.95	5.38	3.32	7.07	5.17	3.06
SD	0.14	0.11	0.08	0.25	0.11	0.07
min	6.7	5.2	3.2	6.7	5.0	3.0
max	7.2	5.6	3.5	7.5	5.5	3.2
N	16	19	19	9	18	17
Rattus rattus						
Mean	6.00	4.61	2.88	6.25	4.59	2.70
SD	0.31	0.28	0.13	0.27	0.19	0.13
min	5.6	4.0	2.6	5.8	4.3	2.5
max	6.5	5.2	3.1	6.7	4.9	2.9
N	16	20	18	11	18	16

Table 4: Rodents species caught in four localities where an invasive Murinae has been found in sympatry with indigenous species. Sampling-effort = traps × nights.

Locality	**Awala-Yalimapo**	**Angoulème (Mana)**	**Cacao**	**Kaw**
Sampling Effort	1899	3401	1136	1110
Individuals total	66	34	46	16
Didelphidae spp.	33	4	9	2
Holochilus sciureus	—	—	—	2
Hylaeamys megacephalus	—	—	3	—
Mesomys hispidus	2	—	2	—
Mus musculus	—	—	—	10
Nectomys rattus	—	—	—	1
Oecomys auyantepui	4	2	—	—
Oligoryzomys delicatus	—	—	—	1
Proechimys cuvieri	10	12	2	—
Proechimys guyannensis	9	7	—	—
Rattus rattus	1	9	27	—
Rhipidomys nitela	—	—	2	—
Zygodontomys brevicaudata	7	—	1	—

& Krapp, 1978) and elsewhere. Measurements from this study compare well with those provided by Husson (1978: tables 87 and 88) for Suriname.

Unpublished data by Colin Niel and Cecile Richard-Hansen indicate that on the island of Ilet la Mère (ca. 7 km offshore from Cayenne) the Black rats are the commonest caught non-volant terrestrial rodents. There, in September 2001, C. Niel and C. Richard-Hansen sampled 250 full-grown individuals, of which 130 females and 120 males (sex-ratio not different from equilibrium: Chi-square test); the only other animal caught was a four-eyed grey opossum (*Philander opossum* [Linne, 1758]) (C. Niel, *pers. comm.,* october 2001). Black rats are also known on two other islands: Ile du Diable (15 km offshore from Kourou) and Ilet le Pere (ca. 6 km offshore from Cayenne).

At Cacao, traps were set in one small lodge and in two nearby wooden shanty (for keeping agricultural tools and gear) dispersed through an agricultural estate mixing fruit trees (mainly rambutan: *Nephelium lappaceum;* orange: *Citrus × sinensis*) and traditional vegetables (lettuce, cuncumbers, Chinese cabbage). After a sampling effort of 1136 trap-nights interspersed between 2007 and 2012 (15 days per year), 46 non-volant small mammals have been caught, of which 27 Black rats (15 females, 12 males). The 27 *R. rattus* specimens represented two colour forms with regards to the ventral side: three had pure self-white belly (colour form *"frugivorus":* see Husson, 1978: 501), and 23 had a gray-blackish belly (colour forms *"alexandrinus"* and *"rattus":* Husson, 1978: 493-499); finally, one individual looked like an hybrid with a mixture of ventral hairs: some self-white and others gray-based.

Reproductive data for the Cacao sample include 4 pregnant females (with 3, 4, 9 and 12 embryos) and 2 other lactating females; there were four very young individuals (weights between 42 and 48 g, only two upper molars); and 4 males with well apparent scrotum (testes measuring 11-12 by 20-22 mm).

The Black rats have been evidenced in each of the four samples of owl pellets: *R. rattus* is the sole Murinae species at Awala-Yalimapo (13 rats out of 277 rodents) and at Macouria (1 rat out of 10 rodents). Elsewhere, Black rats have been found with the two other murines, with abundances ranging from 2% (out of 646 vertebrate preys at Sinnamary) to 29% (out of 49 preys at Cayenne).

b) *Mus musculus* – The House mouse has been caught in 16 localities, ranging from Saint-Jean du Maroni in the northwest to Trois-Paletuviers (municipality of Saint-Georges de l'Oyapock) in the north-east (Figure 1 and Appendix-2). *M. musculus* was observed in two additional localities: an inhabited house in the village of Awala-Yalimapo, and the warehouses and technical buildings of Petit-Saut hydroelectric dam (municipality of Sinnamary). Of interest is one isolated locality (Sophie: number 29 on Figure 1) in the center of French Guiana. Sophie is a small gold-mining camp (just a few wooden lodges), which was in full activity in the early 1960's, at the time (06 September 1962) when one specimen was collected by René Chauvancy and preserved as MNHN-1966-5. *M. musculus* has also been found onto Ile du Grand Connetable, an offshore island ca. 18 km from the mouth of Approuague river (municipality of Regina).

As part of an investigation program on the diversity of viruses hosted by rodents, 37 *M. musculus* were collected in different types of man-made environments (Lavergne *et al.,* 2016). Most of them (n = 20) came from a small Amerindian village (Trois Palétuviers) located along the Oyapock River at the Brazilian border (see below), while the others (n = 17) came from the urban and periurban areas of Cayenne including its neighboring cities. Two House mice caught in 2013 in a small residential house (municipality of Rémire-Monjoly) were harboring the lymphocytic choriomeningitis mammarenavirus (family Arenaviridae), as detailed in Lavergne *et al.* (2016).

At the small village of Trois Palétuviers, Sherman traps and wire-mesh traps were set in and below 11 traditional houses and their nearby outdoor kitchen, both at ground level and at some height onto the half-timbered beams. *M. musculus* was caught in 8 houses, always indoor, for a total of 20 individuals (10 females; 10 males) after a sampling-effort of 871 trap-nights during 10 consecutive days (28 June to 08 July, 2013).

We use 22 full-grown (all three upper molars functional) specimen of *M. musculus* (12 females; 10 males) for providing metrics variability (Table 2) in selected external and skull variables; these animals come from Cacao (five ind.), Kaw (seven), and Trois-Palétuviers (10). Mann-Whitney and t-tests each indicate that females are larger ($p < 0.05$) than males for three variables: Head and Body Length; Condylo-Incisive length; and length of Nasals. These observations conform to what is known elsewhere (Corbet & Harris, 1991). Measurements from this study compare well with those provided by Husson (1978: table 90) for Suriname.

Reproductive data concern 9 females with embryos (range 1 to 7, average 3.8 embryos/female) caught in June and July in the localities of Cacao and of Trois-Paletuviers.

House mice were rarely found in pellets: only 6 individuals out of 843 rodents: 5 *M. musculus* at Cayenne (out of 49 preys), and 1 single individual at Sinnamary, from a total of 646 vertebrates.

c) *Rattus norvegicus* – The Norway rat is known from only three localities: Sinnamary (from owl pellets), Cayenne (from specimens and owl-pellets), and Ile du Grand Connétable (from specimens and visual observations) (Figure 1 and Appendix-2).

Rattus norvegicus is the commonest murine found in owl pellets remains: 51 individuals were identified in the localities of Cayenne and Sinnamary, out of a total of 95 Murinae. Besides the qualitative characters depicted in classical treatises (Niethammer & Krapp 1978,

Corbet & Harris 1991) for recognizing each species of *Rattus* through their skull characteristics, the two rats also differ in crown-length of their upper and lower molars, as shown in Table 3 for materials originating from French Guianan owl pellets. Although our sample sizes are still rather small, it appears that there is almost no overlap in measurements between the two species, and this provides an easy way to identify each *Rattus* species in the course of rodent control experiments by health authorities.

d) Invasive Murinae and indigenous rodents – There are four localities where sampling in and nearby human settlements yielded *R. rattus* or *M. musculus* and other native rodents: at Awala-Yalimapo, a coastal Amerindian village of dispersed houses among fragments of highly degraded forest; at Angoulème, in an agricultural landscape of mainly pastures bordered by secondary forests; at Cacao, in an agricultural domain, bordered by secondary forests; and at Kaw, a village of concrete houses surrounded by large marshes and tiny fragments of secondary forests. Sampling used Sherman traps and wire-mesh traps set within a radius of 0.5 km, and Table 4 indicates the sampling-effort (traps × nights) and the numbers of the various species caught. Besides *R. rattus* or *Mus musculus,* there were between 3 (Angoulème; Kaw) and 5 (Awala; Cacao) species of native rodents. Table 4 thus lists 3 cases evidencing that *Proechimys* spp. and *R. rattus* can co-exist in French Guiana.

At Trois-Palétuviers, *Mus musculus* was the sole species caught in and near the traditional houses, whereas the nearest rodents (*Nectomys rattus* [Pelzeln, 1883]) were definitely outside the human settlements, in the secondary forests and grassy marshes bordering the village.

DISCUSSION

French Guiana is a French department located on the northeastern coast of the South American continent, where primary and/or mature secondary forests cover more than 90% of its territory (Gond *et al.,* 2011). Sampling non-volant small mammals within the large tracks of interior forests has never evidenced any invasive murine (Catzeflis *et al.,* 2014; Voss *et al.,* 2001) caught far away from a human settlement, and that situation is far better than in other tropical countries like Madagascar where Black rats have invaded the forests and jeopardized the populations of native nesomyine rodents (Goodman, 1995). Brito & Ojala-Barbour (2014) report one isolated *Rattus rattus* caught in pristine rainforest of Sangay National Park, in Ecuador. In neighbor Suriname, the same three invasive Murinae are present (Husson, 1978), with a similar distribution as in French Guiana: *Mus musculus* and *R. rattus* are more widely distributed than *R. norvegicus,* this latter being confined to large cities along the coast. In both countries, no official measures to control these pest species have so far been taken by authorities. Nevertheless, there are numerous Surinamese localities (Amerindian and/or Bush-Negroes settlements) of the interior of the country with known specimens of *R. rattus* (see pages 494 to 500 in Husson, 1978), whereas in French Guiana the few localities from the interior (such as Saül; Camopi; or Maripasoula) apparently do not host the Black rat.

In neighbor Brazilian state Amapá, few data are available regarding the three invasive murines: de Carvalho (1962) mentions one *R. rattus* specimen from the city of Oiapoque (right bank of Rio Oiapoque); the Environmental Assessment study (Ecotumucumaque, 2013) for the hydroelectric dam near Ferreira Gomes mentions that *R. norvegicus* was caught at the bridge over Rio Araguari (1 km west from the city of Ferreira Gomes). Elsewhere in Brazil, a study conducted in the slum communities (favelas) around the city of Salvador (state of Bahia) by Panti-May *et al.* (2016) indicates that *R. norvegicus* is the dominant species (90% out of 893 small non-volant mammals) in that urban environment, with the remaining being large opossums (9% *Didelphis aurita* [Wied-Neuwied, 1826]) and 1% of Black rats.

In French Guiana, as in Suriname (Husson, 1978), the Black rats show a polymorphism of ventral colors, and the most frequent pelage type (23 out of 27 individuals from Cacao) is with gray-based ventral hairs. In Suriname, Husson (1978) lists 8 localities where both (white versus gray) color forms co-exist: 23 specimens with white belly as opposed to 45 animals with gray venter. For the two species (*R. rattus* and *M. musculus*) for which we have a small series of preserved individuals from French Guiana, the size (external and cranio-dental variables) of animals from French Guiana does not differ (data not shown) from what has been measured in Suriname by Husson (1978).

Black rats might live in sympatry with native rodents in rare occasions, as indicated on Table 4 for the localities Awala-Yalimapo, Angoulème, and Cacao. In Suriname, Husson (1978: 492) noted that *R. rattus* "in many localities [it] has replaced *Proechimys* as the house rat of the native settlements".

The two species of rats are found in sympatry in only two French Guianan localities (Sinnamary; Cayenne), but we caution that this should be considered very preliminary as there has been no adequate sampling in other coastal cities such as Saint-Laurent du Maroni or Kourou. In Suriname, Husson (1978) lists four localities where specimens of both species of *Rattus* have been collected.

Much remains to be learned from the three species of invasive murine rodents: a research priority is to sample for mice and rats in and near the localities of the interior: Camopi, Saul, Maripasoula. Amerindian settlements in the Maroni basin (villages such as Elaé, Cayodé, Taluhen) merit further inquiry, following the surveys made by Catzeflis (2012) at Trois-Sauts (upper Oyapok basin) who evidenced many species of indigenous rodents living in villages, but none invasive murine. Also

one should investigate for the presence of the Brown rat in the urban communities and near the man-made piers and jetties along the littoral: the harbors of Pariacabo at Kourou and of Port de l'Ouest at Saint-Laurent-du Maroni, as well as cities along major rivers such as Regina or Mana.

In conclusion, while invasive rodents will continue to pose challenges to land and resource managers as well as to human health authorities, they can be controlled or even eradicated with a well-planned and adequately-supported effort using rodenticides and other tools. With proper planning, non-target losses should be minimal if precautions are taken to avoid negative consequences to native rodents and other indigenous vertebrates. This paper has brought the first overview of the status of invasive murine rodents in French Guiana, showing that in some localities invasive and indigenous rodents might co-exist – but for how long?

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APPENDIX-1

Specimens examined

Specimens are organized by species, by municipality (administrative unit), by locality, and by institution housing the materials. Abbreviation: OP stands for skull extracted from owl pellet. ISEM = Institut des Sciences de l'Evolution de Montpellier (France), MHNG = Museum d'Histoire Naturelle de Genève (Switzerland), MNHN = Museum National d'Histoire Naturelle (Paris, France).

Mus musculus: Cayenne: city of Cayenne: MNHN 1981-1047, 1986-183, 1986-184, 1986-257, 1986-258; Kourou: Montagne des Singes: MNHN-2001-1574; Macouria: national road RN1 at pK-35: MHNG 1990.030, 1990.040, 1990.041; Regina: island of Grand Connétable: MNHN 2013-11, 2013-12; Rémire-Montjoly: downtown village MHNG-1974.058; prison near N5 road: MNHN-2001-1333; Roura: village of Cacao: MHNG 1975.066, 1975.067, 1975.076, 1975.083, 1979.062, 1979.065, 1979.067, 1975.078; village of Kaw: ISEM V-1916, V-1923; MHNG 1939.076 to 1939.083; bridge over Comté river MHNG-1972.029; lodge of Réserve Naturelle Trésor MHNG-1975.022; house at Savane Galion MNHN-1986-258bis; Saint-Georges de l'Oyapock: village of Trois-Palétuviers MHNG 2013-1939 to 2013-1951; Saint-Laurent du Maroni: Saint-Jean du Maroni MNHN-1904-419; Saül: village of Saül: MHNG-1885.065; MNHN 1986-178 to 1986-182; gold-mining camp Sophie MNHN 1966-5; Sinnamary: downtown village MNHN 2001-1575.

Rattus norvegicus: Cayenne: city of Cayenne (OP): ISEM V-2344 to V-2346; Roura: house at Savane Galion MNHN-1981-165; Regina: island of Grand Connétable:MHNG-1975.025; Sinnamary: downtown village (OP): ISEM V-3040.

Rattus rattus: Mana: Angoulème along Mana river: ISEM V-1968, V-1976; MHNG-1939.084; MNHN 2004-325 to 2004-327; Awala-Yalimapo: downtown village: MNHN-2003-764, ISEM-V-2867; Cayenne: island Ile du Diable MNHN-2000-307; island Ilet la Mère MNHN 2001-2052 to 2001-2056; Macouria: bridge of Pont Larivot MNHN-2001-1388; Roura: agricultural domain near Cacao: MNHN 1994-114 to 1994-120; MHNG 1963.009, 1963.012, 1963.016, 1963.019, 1969.087, 1969.091, 1970.003, 1972.053 to 1972.062, 1975.030, 1975.042, 1975.052 to 1975.054, 1975.056 to 1975.058, 1975.069, 1975.077; bridge over Comté river MHNG-1975.029; downstream along River Mahury MNHN-1904-420; hen-roost farm along Nancibo road ISEM-V-1077, MHNG-1886.052, MNHN-2001-2235; Saint-Georges de l'Oyapock: downtown city MHNG-1954.057; Saut-Maripa along river Oyapock: MNHN 1981-399, 1981-400, 1981-410, 1981-411, 1981-602, 1982-104, 1982-603 to 1982-615; Saint-Laurent du Maroni: Saint-Jean du Maroni MNHN-1904-420; Sinnamary: Paracou MNHN-2001-1480; houses at Pointe Combi MHNG-1991.024.

APPENDIX-2

List of localities. List of 31 French Guianan localities with invasive murine rodents evidenced through either caught and preserved specimens (s), and/or owl pellets remains (p), and/or through bona-fide observations (o). For each locality numbered 1 to 31 as in Figure 1: administrative unit (municipality), name of location, geographic coordinates in degrees-minutes-seconds.

Locality number	*Mus musculus*	*Rattus norvegicus*	*Rattus rattus*	Municipality	Locality	Latitude	Longitude
1	s	—	—	Saint-Laurent du Maroni	Saint-Jean-du-Maroni	05°23’48”N	54°04’53”W
2	o	—	p; s	Awala-Yalimapo	Awala-Yalimapo: village	05°44’00”N	53°54’00”W
3	—	—	s	Mana	Angoulème	05°24’30”N	53°39’20”W
4	—	—	o; s	Sinnamary	Pripris de Yiyi	05°27’30”N	53°06’00”W
5	p; s	P	p; s	Sinnamary	Sinnamary village	05°23’00”N	52°57’00”W
6	—	—	s	Sinnamary	Paracou	05°16’31”N	52°55’25”W
7	—	—	s	Cayenne	Ile du Diable, island of	05°17’00”N	52°35’30”W
8	s	—	—	Kourou	Kourou: city	05°09’00”N	52°39’00”W
9	s	—	—	Kourou	Montagne des Singes	05°04’00”N	52°43’00”W
10	—	—	o	Kourou	pK-65 bridge over Crique Passoura	05°07’27”N	52°43’55”W
11	s	—	p; s	Macouria	Macouria: RN1 pK-35	05°00’28”N	52°28’11”W
12	o;p; s	p; s	p; s	Cayenne	Cayenne city and suburbs	04°56’35”N	52°19’35”W
13	—	—	o	Macouria	near the zoo of Montsinery	04°56’51”N	52°29’32”W
14	—	—	o	Cayenne	Ilet Le Père, island of	04°53’21”N	52°10’56”W
14	—	—	s	Cayenne	Ilet La Mère, island of	04°53’21”N	52°10’56”W
14	—	—	o	Cayenne	Ilets Dupont, islets of	04°53’21”N	52°10’56”W
15	—	—	s	Roura	Mahury river: mouth on left bank	04°51’15”N	52°15’54”W
16	—	—	s	Matoury	Matoury: la Chaumière	04°53’05”N	52°31’21”W
17	S	—	s	Rémire-Montjoly	Rémire-Montjoly	04°55’07”N	52°17’38”W
18	—	—	s	Roura	Piste Nancibo	04°40’00”N	52°30’00”W
19	S	—	s	Roura	La Comté: Pointe Maripa	04°40’47”N	52°20’35”W
20	S	—	s	Roura	Cacao	04°34’28”N	52°27’11”W
21	s	—	—	Roura	Reserve Trésor: isolated lodge	04°36’38”N	52°01’07”W
22	S	—	—	Roura	Kaw: village	04°33’00”N	52°09’00”W
23	O	—	—	Sinnamary	Petit Saut: buildings	05°03’00”N	53°03’00”W
24	—	—	O	Roura	Auberge des Orpailleurs: Orapu river	04°30’41”N	52°21’04”W
25	o; s	S	—	Régina	Connétable, island of	04°49’26”N	51°56’08”W
26	S	—	—	Saint Georges de l’Oyapock	Trois-Paletuviers: village	04°04’00”N	51°39’40”W
27	—	—	S	Saint Georges de l’Oyapock	Saint-Georges-Oyapock: city	03°53’48”N	51°48’07”W
28	—	—	S	Saint Georges de l’Oyapock	Saut Maripa, along river Oyapock	03°51’05”N	51°51’43”W
29	s	—	—	Saül	Sophie: mining camp	03°58’11”N	53°28’50’ ‘W
30	s	—	—	Saül	Saül: village	03°32’00”N	53°15’00”W
31	s	S	—	Roura	savane Le Galion	04°55’00”N	52°18’00”W