Terrestrial Small Mammals (Soricidae and Muridae) from the Gamba Complex of Protected Areas, Gabon: Species Composition and Comparison of Sampling Techniques

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1 Introduction

The Guineo-Congolian region encompasses 2.8 million km^2 of lowland rainforest stretching from the coastal regions of West Africa to eastern Democratic Republic of Congo (White 2001). The altitude is less than 1000 m except for a few higher peaks, and the rainfall averages 1600-2000 mm per year. The region is renowned for both its plant and animal diversity, with an estimated 8000 species of plants (80% endemic, White 1983) and 270 species of lowland mammals belonging to 120 genera (Grubb 2001, White 2001). Gabon, in the heart of the Guineo-Congolian region, has some 80% of its original tropical moist forest remaining, which is the highest of all West, Central, and East African rainforest countries (Naughton-Treves and Weber 2001).

Although there have been repeated surveys of large mammals in the region (Whitesides *et al.* 1988, White 1994, Happold 1996, Muchaal and Ngandjui 1999, Hart 2001, Ray 2001, Turkalo and Fay 2001, Boddicker this volume, Lahm and Tezi this volume), only in recent years have terrestrial small mammal communities received the same attention. Surveys in northeastern Gabon (Duplantier 1982, 1989; Brosset 1988, Goodman *et al.* 2001), central Gabon (Barrière and Colyn 1997, Nicolas and Colyn 1999), the Central African Republic (Ray and Hutterer 1995, Morvan *et al.* 1999, Barrière *et al.* 2000, Malcolm and Ray 2000), the Democratic Republic of Congo (Dieterlen 1986, Barrière and Colyn 1997, Gubista 1999, Nicolas and Colyn 1999, Dudu *et al.* in press), Cameroon (Barrière and Colyn 1997, Nicolas and Colyn 1999) and Equatorial Guinea (Lasso *et al.* 1996) have demonstrated a diverse small mammal community. The southern section of Gabon, including the Gamba Complex of Protected Areas, was surveyed recently by Nicolas and Barrière (2001), Goodman and Hutterer (2004), Nicolas *et al.* (2004), Primus *et al.* (this volume), and by Rodriguez *et al.* (this volume).

In this paper, we document species of terrestrial insectivores (Soricidae) and rodents (Muridae) weighing less than 100 g that occur in the Gamba Complex, compare faunal composition between coastal and inland sites, and test the success of different sampling protocols. In addition, we discuss our findings in the context of other mammal surveys conducted in lowland rainforests of Central Africa.

2 Study Area

The Gamba Complex in southern Gabon comprises the Ndogo and Ngové lagoons and their drainages and encompasses over 11,000 km^2 of coastal and inland rainforest. The major habitat types within the Complex include coastal scrub forest, mangrove forest, savannah, seasonally flooded forest, and upland forest. The Complex is the focus of conservation efforts due to its abundance of large mammal species including elephant (*Loxodonta cyclotis)*, buffalo (*Syncerus caffer nana*), hippopotamus (*Hippopotamus amphibius*), gorilla (*Gorilla gorilla gorilla)*, and chimpanzee (*Pan troglodytes troglodytes*).

All small mammal trapping was centered around four focal areas: the recently-named Loango National Park, the township of Gamba, and the Shell Gabon oil

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Table 1. Details of surveys within the Gamba Complex, Gabon. The trapping effort was relatively similar among sites, with the exception of surveys at Gamba which were 2/3 that of the other sites. The area surveyed at each location was calculated by placing a 1 km buffer around each survey site.

Site	Dates surveyed	Trap nights	# insectivorous species (Soricidae)*	# rodent species (Muridae)*	1 km Buffers Area sampled (km^2)	1 km Buffers Species/km^2
Rabi	2/19 -3/14/02	3666	9	12	15.7	1.34
Toucan	5/29- 6/13/02**	3495	8	10	12.1	1.49
Loango	10/25-11/9/02***	3501	6	5	14.3	0.77
Gamba	11/13-11/28/02	2097	4	4	8.7	0.92
Total		**12759**	**9**	**12**	**50.8**	

* does not include incidental captures, i.e. *Chlorotalpa, Potamogale, Graphiurus*, or the large murid *Cricetomys*
** one site surveyed: 2/28- 3/6/02.
*** first pitfall surveyed: 9/27- 10/3/02.

concessions in Rabi and Toucan (see map page xxxii). Both the Loango and Gamba sampling areas were within five km of the coast, and the remaining sites were > 20 km from the coast. Each of these locations was sampled during 2002 (Table 1). All areas, except for Loango National Park, had a system of roads that was used to access study sites. The location of all survey sites was marked with a GPS and each survey line was selectively placed into one of the habitat classes discussed above. The area sampled at each focal area, based on 1-km buffers placed around each trapping site, was estimated at 8.7-15.7 km^2 (Table 1).

3 Methods

3.1 Trapping protocol and data analysis

Surveys were conducted for terrestrial small mammals at each study site using combinations of pitfalls, live- and snap-traps. Two types of survey protocols were used: one with pitfall arrays and one without. A survey with pitfalls consisted of three 100-meter pitfall lines placed > 30 m apart. Each line contained eleven 20-L buckets sunk to ground level and positioned 10 m apart, with a 0.5 m high fence of plastic sheeting connecting the buckets. Each pitfall line was in place for seven nights and checked daily (see Burger *et al.* this volume, and Pauwels *et al.* this volume for details of sampling methods). Three traplines, each containing 26 Sherman live-traps, were placed in the vicinity of the pitfall lines. The 10 x 6 x 6 cm traps where placed at five-meter intervals, with > 30 m between traplines. The traps were baited with a mixture of peanut butter and oats or manioc. The traps were checked daily and rebaited as necessary. On each line, the live-traps were replaced after three nights with snap-traps (museum specials and Victor rat traps) for a total of six nights at a location. A second protocol involved the same arrangement of live- and snap-traps without the pitfall lines. The trapping effort at each site was the total of bucket-nights (number of buckets x number of nights) and trap-nights (number of traps x number of nights). The Government of Gabon authorized the research and the use of some specimens as vouchers. All other specimens were released.

3.2 Vouchers and species identifications

Specimens were prepared either as standard museum skins with associated skulls and skeletons, as fluid preserved specimens, or as full skeletons. Tissue samples were saved from all specimens. Each specimen was identified with a unique number that linked all tissue samples with the skin/fluid and skeleton from an individual. Specimens have been deposited in the Smithsonian National Museum of Natural History (USNM), the Gabon Biodiversity Program in Gamba, and the tissue samples at the Natural Science Research Laboratory at Texas Tech University. The fieldwork was conducted by CO, WM, and SG. Insectivore species were determined by PB and rodent species were determined by CO and MC.

Taxonomy of small mammals in the region is challenging due to the limited number of specimens and the existence of phenotypically similar species. Recent work with the shrews (Family Soricidae) has led to taxonomic revisions (Quérouil *et al.* 2001, Quérouil *et al.* in press) and the naming of new species (Hutterer *et al.* 2001). Of particular concern are the three following *Crocidura* complexes: *hilde-*

Table 2. Insectivore (Soricidae) and rodent (Muridae) species found in the Gamba Complex, Gabon. The four study locations are listed for the presence of the species (X). Individuals captured during other activities are indicated as incidental (I).

Scientific name	Common name	Number captured	Mean adult weight (g)	Study locations			
				Rabi	Toucan	Loango	Gamba
Soricidae							
Crocidura batesi	Bates' shrew	11	10.3	X	X	X	I
Crocidura crenata	Long-footed shrew	31	8.1	X	X	X	I
Crocidura dolichura	Long-tailed musk shrew	10	7	X	X		I
Crocidura goliath	Goliath shrew	18	49	X	X	X	X
Crocidura grassei	Grassé's forest shrew	2	12	X		X	
Paracrocidura schoutedeni	Lesser large-headed shrew	7	8.1	X	X		
Suncus remyi	Remy's pygmy shrew	5	1.8	X	X		X
Sylvisorex johnstoni	Johnston's forest shrew	93	2.9	X	X	X	X
Sylvisorex ollula	Greater forest shrew	30	13.7	X	X	X	X
Muridae							
Deomys ferrugineus	Congo forest rat	9	53.3	X	X		
Grammomys poensis	Western rainforest Grammomys	6	52.2	X	X		I
Heimyscus fumosus	Smoky Heimyscus	18	20.6	X	X	X	
Hybomys univittatus	Peter's Hybomys	28	49.5	X	X		
Hylomyscus aeta	Beaded Hylomyscus	11	23.1	X	X	X	
Hylomyscus parvus	Lesser Hylomyscus	27	13.6	X	X	X	X
Hylomyscus stella	Stella Hylomyscus	138	17.5	X	X	X	X
Lophuromys nudicaudus	Fire-bellied brush-furred rat	7	35.5	X	X		
Malacomys longipes	Common Malacomys	27	88.2	X	X	X	X
Mus musculoides	Pygmy mouse	28	7.8	X	I		I
Praomys tullbergi	Tullberg's Praomys	80	30.7	X	X	X	X
Stochomys longicaudatus	Target rat	2	71.1	X			

gardeae (composed of *C. hildegardeae*, *C. denti* and *C. attila*), *poensis* (composed of *C. poensis*, *C. batesi*, and *C. nigrofusca*), and *olivieri* (composed of *C. olivieri*, *C. goliath* and *C. mutesae*), which are in urgent need of revision (Quérouil *et al.* in press).

The rodent species found within the Guineo-Congolian region present the same challenges with recent revisions of *Praomys* (Lecomte *et al.* 2002, Volobouev *et al.* 2002) and *Hylomyscus* (Quérouil 2001). There is much work to be done to clarify this diverse assemblage of species that overlap in distribution. A fuller inventory within the Gamba Complex would provide needed information for additional taxonomic study and contribute toward a clearer geographical understanding of these species complexes.

Several conventions were adopted in listing certain species names in the text and tables. The designation "cf." (as in *Crocidura* cf. *denti*) suggests that the specimen(s) best fit within the morphological variation described for the named species, but could, under further examination, represent a different species. "*Crocidura poensis* complex" is used to represent *C.* cf. *poensis* and *C. batesi*, while "*Praomys tullbergi* group" suggests the potential presence of both *P. tullbergi* and the recently-described *P. petteri* (Lecompte *et al.* 2001, Van der Straeten *et al.* 2003). Incidental captures included *Chlorotalpa leucorhina* (1), *Graphiurus* sp. (3), *Potamogale velox* (1 specimen caught by fish net in Rabi), and *Cricetomys emini* (2).

4 Results

A total of 588 individuals was captured during 12,759 trap-nights of effort. These individuals comprised at least 21 species of small mammals, divided between insectivores (9 species) and rodents (12 species, Table 2). A similar suite of species was found at each survey location, with individual species missing from sites rather than each site possessing a unique community. There was one obvious difference between locations: coastal sites contained only 60% of the species richness of the inland sites after adjusting for trapping effort (Fig. 1A). Murid rodents accounted for most of the increase in species richness at inland sites (Table 3). There was a positive correlation between species richness and the amount of area surveyed ($r = 0.67$).

Table 3A and B. A comparison of species composition and relative abundance (percent) for insectivores (A) and terrestrial rodent species (B) found in this study and in other regions of the Congo basin. Studies are listed in order of their proximity to this study. For species where abundances were not given, we have indicated their presence with an "X". Our incidental captures of *Cricetomys* are included in section B, since the species is reported in Malcolm and Ray's (2000) study.

A Insectivores (Soricidae)

Species	This study	Monts Doudou, Gabon[1]	Monts Doudou, Gabon[2]	Minkebe, Gabon[3]	Makoukou, Gabon[4]	Equatorial Guinea[5]	Ngotto Forest, CAR[6]
Sylvisorex ollula	14.5	10.1	9.7	17.2	5.1	11.6	9.3
Sylvisorex johnstoni	44.9	30.4	41	6.9	15.2	30.8	25
Crocidura poensis complex	5.3	10.1	10.9	3.5	50	3.8	13.3
Paracrocidura schoutedeni	3.4	X	13.5	13.8		15.4	17.6
Crocidura goliath	8.7	1.3	5	17.2	1.9	3.8	0.08
Crocidura crenata	15	16.4	6.2	10.3	7.6		8.1
Crocidura dolichura	4.8	2.5	3.6	3.5	8.9	3.8	8.4
Crocidura grassei	1	X	9.1	6.9	3.1	3.8	0.08
Suncus remyi	2.4	1.3	1	3.5	5.1		3.6
Crocidura cf. *mutesae*							0.3
Crocidura cf. *nigrofusca*							0.08
Crocidura cf. *denti*							0.9
Crocidura hildegardeae							0.08
Crocidura ludia							0.6
Congosorex verheyeni							1.8
Crocidura olivieri				13.8	3.1	27	9.4
Crocidura maurisca				3.5			
Sylvisorex konganensis							0.8
Total	**207**	**79**	**503**	**29**	**158**	**26**	**1350**

B Terrestrial rodents (Muridae)

Species	This study	Monts Doudou, Gabon[1]	Makoukou, Gabon[2]	Central African Republic[3]	Democratic Republic of Congo[4]	Democratic Republic of Congo[5]
Cricetomys emini	0.5			2.2		
Deomys ferrugineus	2.3	2.7	11.1	3.9	6.8	4.4
Grammomys poensis	1.5	0.2	0.4	2.8	0.4	
Heimyscus fumosus	4.7	10.6	11.5	3.5		
Hybomys univittatus	7.3	17.6	3.1	10		21.1
Hylomyscus aeta	2.9	0.5		9.7		
Hylomyscus parvus	7	0.3	2.6			
Hylomyscus alleni-stella group	36	40.2	58.1	33.3	14.5	40
Lophuromys nudicaudus	1.8	0.9		0.4		
Praomys tullbergi group	20.9	21.5	12	32.6		
Stochomys longicaudatus	0.5	0.1	0.5	1.6	4.9	
Malacomys longipes	7	5.4			13	1.1
Mus musculoides	7.3				0.9	5.6
Lemniscomys striatus					1.2	
Oenomys hypoxanthus					2.1	2.2
Lophuromys flavopunctatus					7.8	2.2
Praomys jacksoni					22.2	23.3
Lophuromys sikapusi			0.7			
Hybomys lunaris					24.9	
Lophuromys luteogaster					0.9	
Colomys goslingi					0.4	
Total	**381**	**1155**	**549**	**1163**	**3541**	**90**

[1] Nicolas et al. 2004, [2] Duplantier 1989, [3] Malcolm and Ray 2000, [4] Dieterlen 1986, [5] Gubista 1999, [6] Barrière *et al.* 2000

Examination of the species accumulation curves for each location indicates that sampling intensity was sufficient to characterize the small mammal community (Fig. 1A-B). Pitfall lines and traps did not sample the small mammal community equally (Fig. 2). Although there was no significant difference for rodents, there were significantly more insectivores captured in pitfalls than in traps. This difference might be due partially to the smaller size range of insectivores, but a general linear model of capture rates showed weight was not a significant determinant ($F = 1.01$, d.f. = 1, 111, $P = 0.32$). Trap type ($F = 8.25$, d.f. = 1, 111, $P = 0.005$) and the interaction between trap type and animal taxonomy (partial $F = 19.65$, d.f. = 1, 111, $P < 0.001$) explained the greatest amount of variability in capture frequency.

The trapping protocol called for three days of live-traps followed by three days of snap-traps. This was done both at sites that contained pitfalls and at sites with only traps. In both sets of trapping sites, the number of new species captured increased with the transfer from live to snap-traps (Fig. 3).

The Soricidae captured in the Gamba Complex range in size from the tiny *Suncus remyi* (1.8 g) to the large *Crocidura goliath* (73.3 g). *Crocidura* is the

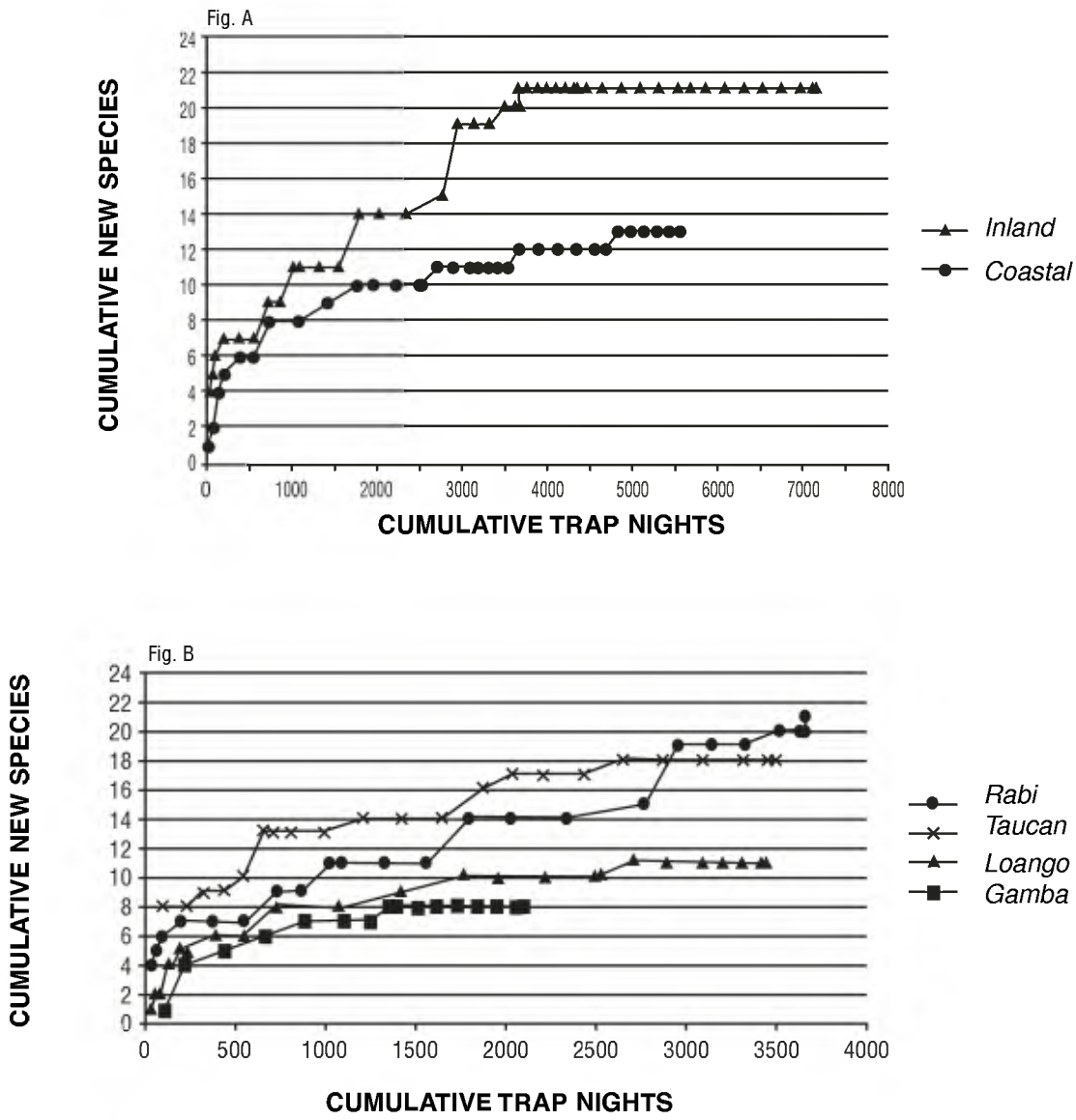

Figure 1. Species accumulation curves for a summary of inland and coastal survey locations (A) and for the four study locations (B).

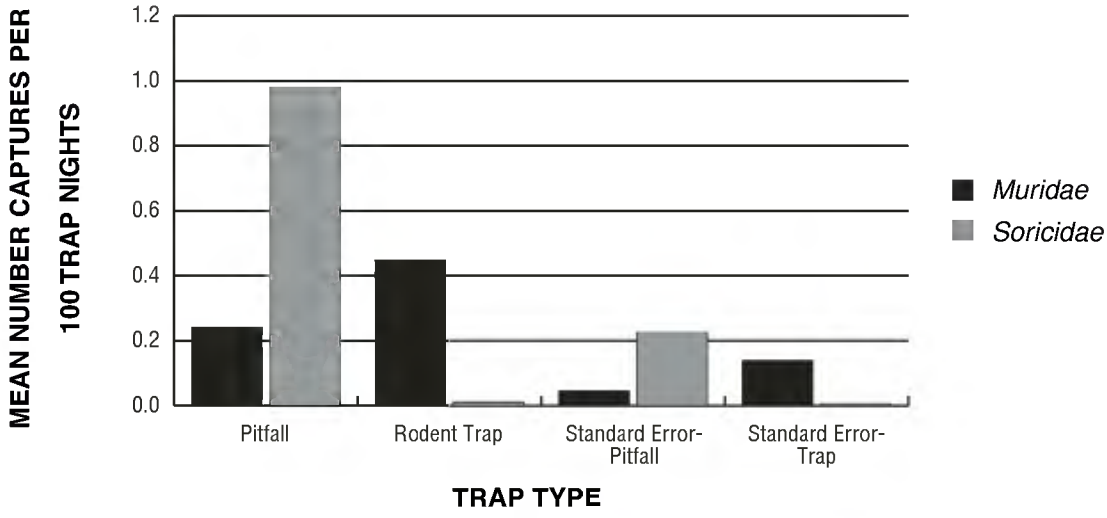

Figure 2. Mean number of individuals captured per 100 trap nights, grouped by Muridae and Soricidae, using pitfalls or rodent traps.

most successful genus of African shrews, and also the most widespread (Delany and Happold 1979). However, of the four soricid genera we observed in the Complex (i.e., *Crocidura, Paracrocidura, Sylvisorex,* and *Suncus*), the diminutive *Sylvisorex johnstoni* dominated the shrew community at each study location. *S. johnstoni* comprised 45% of all shrew captures, followed by *S. ollula* and *Crocidura crenata* (both about 15%; Table 3A).

Muridae is the largest family of rodents, with approximately 1,335 species (Nowak 1999). The murid rodents *Hylomyscus stella* and *Praomys tullbergi* were found at each study location (Table 2) and, comprised the majority of captures overall (36 and 21%, respectively; Table 3B). Several species were found only at the inland locations (i.e., *Lophuromys, Hybomys,* and *Deomys*). The coastal sites were each dominated by a single species; Loango National Park was dominated by *Praomys* (57% of rodent captures) and Gamba by *Malacomys* (55% of rodent captures). Our only captures of *Stochomys* were in secondary growth around oil production and human development at Rabi. The Muridae are typically frugivorous or omnivorous. An exception is the Congo forest rat, *Deomys ferrugineus*, the only insectivorous rodent captured (Happold 1996). The majority of the Muridae are terrestrial, with the exception of the arboreal *Grammomys poensis* and the three species of *Hylomyscus* captured in this study (Happold 1996). While the *Hylomyscus* are considered arboreal, *H. stella* in particular makes frequent use of the forest floor.

5 Discussion

The distribution of mammals is not consistent across the Congo Basin, with concentrations in mammal species richness that are not due to obvious physical or landscape barriers (Happold 1996). Two main theories are used to explain the distribution of mammalian species richness within the Guineo-Congolian region. First, the current distribution of mammals in the region may be due to contractions and expansions of the rainforest zone over evolutionary time. Glaciations in the northern hemisphere led to dry conditions in the tropics, so rainforests contracted to a few isolated refugia (Happold 1996). Interglacial periods led to expansions of the forest outwards from the refugia, and fauna from previously isolated refugia could become sympatric. This pattern of contraction and expansion may have assisted in speciation (Happold 1996) and several areas within the region have been identified as potential refugia of high species richness. Apart from scattered montane refuges, some argue for the existence of a major fluvial refuge in the Congo Basin (Colyn *et al.* 1991, Grubb 2001, Colyn and Deleporte 2002). Rivers are often barriers to ranges or mark vicariance of allotaxa within forest zones, especially for primates.

A second theory is that the high mammalian diversity in the Guineo-Congolian region reflects high plant species diversity (see Campbell *et al.* this volume). One hectare plots in the region can contain more than 100 tree species (Delany and Happold

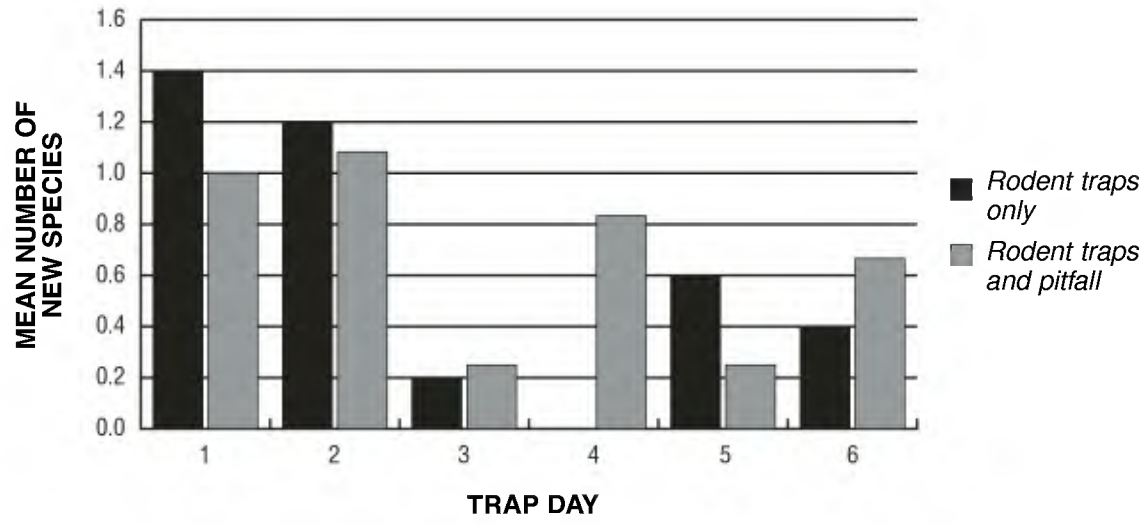

Figure 3. Mean number of new species captured for each day during a 6-day period from rodent traps. For the first 3 days, Sherman live-traps were used. During the remaining 3 days, the live-traps were replaced with snap-traps.

1979). The abundance and variety of vegetation, along with the vertical stratification of the forest, results in many niches that have been exploited by forest mammals (Delany and Happold 1979). Different species within a taxon use different strata of the rainforest or spend a different proportion of their time in each strata. The Makoukou area in northeastern Gabon recorded 124 species of mammals, with rodents composing about 25% of the total species (Happold 1996). Mammal species richness in the Guineo-Congolian rainforest is similar to that of rainforests in other parts of the world; for example Wilson (1983) recorded 137 mammal species for a rainforest in Costa Rica.

Small mammal surveys in the Gamba Complex were conducted using pitfalls, Sherman live-traps, and snap-traps. Pitfalls are an effective method of sampling terrestrial small mammals, especially shrews that are rarely taken in conventional traps (Williams and Braun 1983). The size of the pitfall bucket is critical in the capture of African soricids (Goodman *et al.* 2001, Goodman and Hutterer 2004), with larger pitfall buckets, as were used in this study, being more effective at capturing and retaining a wider variety of shrews. An examination of the mean number of rodents and shrews captured per 100 trap nights in either traps or pitfalls found distinct differences based on taxonomy (Fig. 2). Although more rodents were captured in traps than in pitfalls, the difference was not significant. Shrews were much more effectively sampled using a pitfall design, and the effect did not seem to depend on weight. Perhaps their limited vision and their feeding habits (i.e. attraction to insects that have fallen into the buckets) make them more susceptible to capture in pitfalls.

A second component of our protocol was to replace live-traps with snap traps after three days at a location. There is some indication that this change did increase the number of species captured. While we would expect that the number of new species captured should gradually decrease over the six days of trapping at a location, there was an increase in new species in days four through six (Fig. 3). Switching to snaps resulted in more species than we would expect if we used live-traps alone.

The species accumulation curves for our four survey locations revealed that our technique was effective for sampling the small mammal community (Fig. 1A-B). The most striking pattern was that the coastal sites had 60% of the species richness of the inland sites. Even when we account for differences in the amount of area surveyed, inland sites had a higher average richness than coastal sites (Table 1). The lower species richness in the coastal sites is mostly due to the absence of the rodents typical of inland forest communities, including *Hybomys* and *Deomys*. We did not find any rodents typical of the savanna, including *Lemniscomys striatus*, *Mastomys* sp., *Pelomys* sp., or *Lophuromys sikapusi*. Likewise we did not find any shrews that

inhabit the savanna or disturbed forest, specifically *Crocidura olivieri* and *C.* cf. *denti*. We were surprised to find a low species richness considering the diversity of habitats found in the coastal region (i.e. savanna, scrub forest, mangrove forest, and gallery forest). However, coastal forests in Gabon may be poorer than inland forests in terms of the diversity and abundance of fruiting plant species (Lahm, pers. comm.). Therefore the carrying capacity of the environment for frugivorous murid rodents may be lower than in inland forests. It is interesting to note that the common rodent species in the coastal region (i.e. *Praomys*, *Hylomyscus*, and *Malacomys*) are considered omnivorous (Kingdon 1997, Nowak 1999).

Overall, nine species of shrews and 12 species of rodents (Table 2) were found during our surveys in the Gamba Complex. Our results are comparable to other nearby studies (Table 3). Studies conducted further from the Gamba Complex revealed different species lists and abundances. The insectivore species recorded in our survey were very similar to those reported in other areas of Gabon, and *Sylvisorex johnstoni* also dominated the shrew community in the two studies in nearby Monts Doudou (Nicolas *et al.* 2004, Goodman and Hutterer 2004). The insectivore survey in the Central African Republic revealed 16 species in the Dzanga-Sangha forest (Ray and Hutterer 1995) and 18 species in the Ngotto forest (Barrière *et al.* 2000), and may represent a localized region for high insectivore diversity. However, we recorded an equal or greater number of rodent species than any of the other reported studies. There was high agreement with nearby communities, with other surveys in Gabon also being dominated by *Hylomyscus stella*.

The Gamba Complex has a rich small mammal fauna that is comparable to other areas of the Guineo-Congolian region. The diversity of habitat types near the coast was not correlated with increased species richness. Further studies are needed to determine if resources within coastal forests tend to be lower than those of inland forests, a hypothesis that seems to be supported by the plant community composition and structure (Campbell *et al.* this volume). At this time, we speculate that the lack of specialist rodents from coastal forests is indicative of fewer resources being available within this habitat.

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