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DRAFT REPORT

Absolute Population Densities of the Lizards of Ritidian Point, Guam National Wildlife Refuge

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Executive summary - In Feb.-Mar. 1997 we intensively sampled the lizards of Guam National Wildlife Refuge at Ritidian Point using a total removal methodology. In our application of this technique, two 10 x 10 m patches of forest were surrounded by a lizard-proof barrier (fence at ground level to contain terrestrial lizards and canopy separation to contain arboreal species) and all above-ground vegetation was minutely inspected for lizards as it was being removed. Both samples were collected in coastal forest, one in native 'strand' forest east of the headquarters area and the second in an abandoned 'coconut' plantation southwest of headquarters. These yielded the first absolute population density estimates for lizards in coastal forest on Guam. Concurrently, we sampled the lizards of the same forest types using adhesive trapping and visual surveys, techniques for estimating relative abundance that have been used extensively throughout the Pacific region. These can be compared to the densities discovered through absolute removals to assess the sampling biases of the more widely-used but unvalidated techniques.

The removal indicated that several species attain relatively high densities in coastal forest. For example, the Blue-tailed Skink (*Emoia caeruleocauda*) averaged 3850/ha and exceeded 5000/ha at the coconut site, and the Mourning Gecko (*Lepidodactylus lugubris*) averaged 2650/ha. Overall, about half of all lizards were skinks (lizards in the family Scincidae, primarily day-active terrestrial species) and the remainder were geckos (lizards in the family Gekkonidae, primarily nocturnal species found usually in trees).

Because this sampling yielded the first absolute density estimates for coastal forest in Guam, it cannot be readily compared to similar samples. However, in comparison to samples collected elsewhere in Guam (tangantangan forest of Northwest Field or ravine forest of Ordnance Annex), the number of lizards was relatively low (Ritidian area mean of 8000/ha compared to 12,200 and 12,100 for other native forest and tangantangan forest on Guam respectively). However, in comparison to those same forest types on Saipan, the overall lizard density was somewhat higher (Saipan totals were 5750 and 6700 for native and tangantangan forest respectively). Based on the few samples we have conducted to date, we suspect that higher overall lizard densities are associated with forests having greater light penetration (increases density of sun-loving species) and lower predator densities (ground lizards on Saipan seem to be reduced by high Musk

Shrew (*Suncus murinus*) densities and some arboreal species on Guam seem to be depressed by the Brown Treesnake (*Boiga irregularis*)).

In addition to quantifying the lizard fauna of Guam National Wildlife Refuge in unprecedented detail, providing evidence for the role of native forest in the sustenance of native wildlife, and providing data on the impact of the Brown Treesnake on Mariana lizards, the data obtained from this work will be utilized for comparisons with tropical lizard assemblages throughout the world, for detailed evaluation of the role of forest structure in the habitat requirements of lizards, and for validating other techniques which may be used for sampling lizards. Representative analyses along these lines are presented.

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What Is Known about Guam's Lizards

The identities of lizard species found on the main island of Guam are relatively well known, due to a succession of amateur and professional surveys increasing in tempo after World War II (WWII) and leading up to the recent activity associated with management of the Brown Treesnake (35+ lizard presentations, reports and publications; see citations in References). Fourteen species are recorded (Rodda et al. 1991), of which at least six are the result of recent (within last 500 years), probably human-aided, introductions (Pregill 1998). Although some information is available on the relative abundances of the various species (see References), several species are not readily distinguishable on the basis of sightings, the relative visibility or detectability of each species is not known, nor is it known if the detectability is constant among habitats. Finally, the precision of relative measures of abundance is not known for any technique used in this area. Thus, it has been possible to make only general statements about the abundances of lizards, and clear inferences about the influence of habitat and predator assemblages have not been possible.

What Is Known about Densities of Lizards in the Marianas in General

Although no absolute population density estimates have been published for lizards in the Marianas, we have collected some statistics for Saipan (Rodda and Fritts 1997) and Guam (Rodda and Fritts 1996, Rodda et al. in prep.), some of which have been noted in Campbell (1996). These support the general impression

of many herpetologists that lizards are relatively abundant on remote islands such as Guam, which are depauperate (species poor) compared to mainland faunas. However, the Guam data cannot be considered representative of Pacific Islands, as Guam is home to an extraordinary abundance of Brown Treesnakes (*Boiga irregularis*), a well-known lizard predator (Rodda and Fritts 1992, Rodda et al. 1998). Although there is no island that is exactly like Guam while lacking snakes, the large snake-free southern Mariana islands are the most similar in terms of their lizard faunas. However, of these, Rota differs from Guam in that it experienced much less loss of native habitat due to warfare and agriculture, whereas Tinian has suffered more. In addition, Rota has not yet experienced the major disruptions caused by the introductions of *Suncus murinus*, a shrew, and *Carlia fusca*, an exotic skink that has seemingly replaced the native skinks in many sites in the Marianas. Saipan, like Guam, has both the shrew and *Carlia*.

Although Guam has not had its vegetation mapped, as best we can tell, the proportion of native forest on Guam is surely greater than that of Saipan, which has been documented to be about 4% native forest by Falanruw et al. (1989). Engbring and Ramsey (1984) judged that 23% of northern Guam was "primary limestone forest" based on aerial photos of unspecified date. Although Saipan forests were more extensively converted to agricultural land uses prior to WWII, Saipan is probably as similar to Guam as an island can be found in terms of lizard community ecology.

What this Study Adds to Knowledge of Mariana Lizards

Details of Guam's native forest herpetofauna. - The measurements provided by this study allow, for the first time, unequivocal comparisons among habitats and species.

Understanding the role of native forest. - Because these measurements allow one to unequivocally compare habitats, it is possible to assess the role of native forests in the sustenance of Guam's native lizards.

Tools for evaluating other survey techniques. - Absolute population density estimates can be compared to the relative estimates we collected, but also to those made by others previously and subsequently. We can thereby determine the relative detectability of different species and begin to collect needed data on the precision and stability of these detectability estimates.

MATERIALS AND METHODS

We used a total removal methodology to obtain our absolute population density estimates. Our use of this method differed from some previous uses in that we not only progressively removed all animals from the study plots, but we also removed all aboveground vegetation, which greatly facilitated the detection of animals. However, in order for this method to give an unbiased estimate of the population density, we had to insure that the animals were taken from a precisely known amount of forest. To accomplish this, we first isolated the patch of forest, insuring that no animals could enter or leave during the removal. Thus, there were two major components to this work: isolation of the forest plot, and removal of all animals and plants. In addition, we obtained relative lizard population density estimates for each of the plots prior to removal. After completion of the removal sampling, we removed the barrier and returned downed vegetation to the plot to facilitate regrowth of the sampled plots. These four steps are described in greater detail below.

Isolation of the Forest Plot

Equipment used. - A wide variety of forestry tools are useful for this work (appendix). For the coconut trees, we used climbing spikes; for all climbing we utilized safety ropes and other precautions (Dial and Tobin 1994). A crew of 3-4 persons is desirable for the various phases of plot isolation (see below), but a larger crew is preferred for the removal phase, as this can require considerable effort. In principle, it should be possible to leave the barrier in place for whatever

time is required to inspect all vegetation thoroughly. However, in practice, one wishes to minimize the time span, as the longer the barrier is relied upon, the greater is the risk of immigration or emigration. As the forest at Ritidian was the densest we have sampled (5-6.5 metric tons of vegetation per plot), the time required for removal was also greater than previously experienced. Using a crew of about eight persons, we completed removal in 3-4 d for each Ritidian plot (Table 1). Using the sixteen removal plots sampled to date, the number of person-h required for removal is correlated with the wet mass of vegetation removed (r^2 = 0.68; est. removal effort = 0.0178*(veg. mass) + 36.4 person-h).

Table 1. Characteristics of the Ritidian study sites. Note that latitude and longitude are given in decimal degrees and that elevation is in m.

Site	Latitude	Longitude	Elev.	BarrierDate	FirstDay	LastDay	PersHrs	Veg (kg)
strand (HHOL)	N 13.651	E 144.864	2	23-Feb-97	24-Feb-97	26-Feb-97	113	5118
coconut(DPIG)	N 13.648	E 144.853	3	02-Mar-97	03-Mar-97	06-Mar-97	133	6329

Site selection. - Site selection was constrained by the availability of suitable habitat, and the requirement that forest patches be more or less level and composed of soils that were deep enough to allow the emplacement of aluminum flashing fencing buried to a depth sufficient to preclude the passage of lizards. Furthermore, we did not want our study to compromise any important

archeological or other resources in the area, so it was several times necessary to move or reject prospective sites containing human artifacts.

While we endeavored to locate 10 x 10 m plots in each case, the occasional intervention of a large boulder or inappropriate soil caused us in some cases to choose alternate layouts that nonetheless constituted an area of 100 m^2, for example 8.3 x 12 m. In addition, we sometimes deviated from straight line boundaries in order to minimize the amount of vegetation that would have to be removed to achieve canopy separation. However, we insured that deviations to the inside of the nominal boundary were exactly balanced by equivalent deviations to the exterior of the straight line perimeter.

Vegetation sampling. - We characterized the vegetation of each plot in six ways: ground cover by percent cover of major structural types (e.g., graminoids v. vines, etc.); tree cover by number of stems, tree basal area, canopy height, and canopy coverage; and total fresh biomass of removed vegetation. Ground cover was sampled at 20 equidistantly placed points covering the entire 10 x 10 m plot. At each sampling point, a 20 x 50 cm Daubenmire frame [a 20 x 50 cm frame conspicuously marked to denote patches of 1, 5, 10, 20, 40, 50, and 60% of the total area] was placed (oriented parallel to the nearest boundary) and the percent cover estimated within the frame for each of ten major vegetation types. The average coverage by each of the ten types was the basis for the values reported here: litter coverage, grass coverage, herb coverage, and ground cover diversity (Shannon-Weiner Index; Pielou 1970).

Trees were defined as those with stems exceeding 1.0 cm dia at breast height; large trees were those exceeding 10.0 cm dia at breast height. For these, we report: number of stems, cross sectional area at breast height (estimated by measuring dbh with calipers and assuming that stems are circular in cross section), typical canopy height (i.e., excluding rare emergents), and canopy cover (estimated visually).

Ground separation/trenching. - It would be preferable to instantly emplace the barriers that preclude lizard immigration and emigration from a plot. However, it is inevitable that some lizards will leave a plot in response to the disturbance required to establish the barrier. Also, it is possible that the vegetation removed to provide canopy separation might inadvertently constitute a valued refugium and thereby concentrate lizards in the brush piles created. We attempted to avert these possibilities through a combination of carefully timed actions.

The first step was to remove enough low-lying vegetation to insure that lizards could not use the vegetation to bridge across the ground level barrier when it was later emplaced. The ground-level barrier was made from a fence of 508 mm wide (sold as "20 inch wide") aluminum flashing that was buried 50-100 mm into the ground. The lizards on Guam have only limited ability to leap upwards, but they can span distances of about 0.5 m when leaping downward. Thus to effect an unequivocal separation, we cleared a swath about 1 m wide to a height of about 2 m along the course in which the flashing fence would later be placed. In addition, in order to expedite the subsequent emplacement of the flashing, we used the occasion of ground clearing to excavate a furrow into which the flashing would

later be inserted. Furrow excavation inevitably revealed the presence of root obstacles. Such roots were severed to allow the later burial of the bottom of the flashing. In addition, we placed rebar supports at places where the flashing would bend sharply. Flashing would have to bend in a horizontal plane at the corners of the enclosure, and flashing would have to bend in a vertical plane at especially high and low places. Generally we used 3-4 supports per 10 m side. Additional rebar supports were later positioned where each roll of flashing ended or began, but these spots were not easily ascertained in advance. We used rebar for the supports, but any sharpened metal post would do. The preferred length of the bar depends on the hardness of the soil or substrate; the diameter is not critical. We used rebar pieces that were mostly about 0.9 m long. The bottom end of the rebar should be sharpened symmetrically, so that it does not tend to veer as it is being driven. The rebar was pounded vertically into the ground at the bottom of the trench such that the top of the bar was level or below the height of the flashing whenever possible. As a safety measure, it was sometimes desirable to place gaudy flagging on isolated rebar posts; this was not needed once the flashing connected and covered the rebar posts.

Five rules were followed to minimize the influence of this trenching/clearing activity on the lizards: 1) activity occurred during the day to minimize disturbance of nocturnal geckos, 2) no motorized tools were used (in our experience, chainsaws in particular induce flight in lizards), 3) brush removed at this stage was dispersed rather than being piled, so that lizards would not be attracted to potential brushpile refugia, 4) half of the removed vegetation was

placed within the plot and the other half was place outside, to limit any bias this vegetation might have on lizard movements, and 5) this activity was scheduled to occur 48 h prior to initiation of vegetation removal, so that any terrestrial lizards disturbed by the activity would have plenty of time to regain their normal home range prior to isolation. On the other hand, heliophilic (sun-loving) lizards may be attracted to the light gap created by vegetation removal, so it is best to otherwise minimize the time which might permit heliophilic lizards to move into the area.

Canopy separation. - Canopy separation inevitably has an adverse effect on arboreal species. Most arboreal species on Guam are also nocturnal. Generally, unless physically disturbed, nocturnal species will not move away from an area of disturbance until nightfall following the disturbance. However, the terrestrial species disturbed by canopy separation are likely to move away immediately, but normally return to their home ranges if given sufficient daylight hours without a disturbance. Therefore, we always separated the canopy as early as possible in the day on which the barrier would be placed after nightfall. In this way, nocturnal species would have no opportunity to vacate the plot if they were disturbed by canopy separation, and diurnal species would have at least half a day to return to their terrestrial haunts after we had left the area.

Canopy separation is straightforward in principle; a gap of at least 1 m must be achieved between all aboveground vegetation. This measurement must accommodate tree movements induced by wind. If possible, it is desirable to create the gap in the foliage directly over the line on which the ground level barrier will later be placed (to minimize the ability of lizards to immigrate or emigrate by

jumping from a leaning tree to the other side of the barrier), and in forests composed of trees with vertical trunks this can be achieved. However, forests of the Marianas often have trees that have partially fallen in response to typhoon winds. We attempted to minimize inclusion of such trees when choosing a site, but not all could be avoided. The problem is illustrated in Fig. 1.

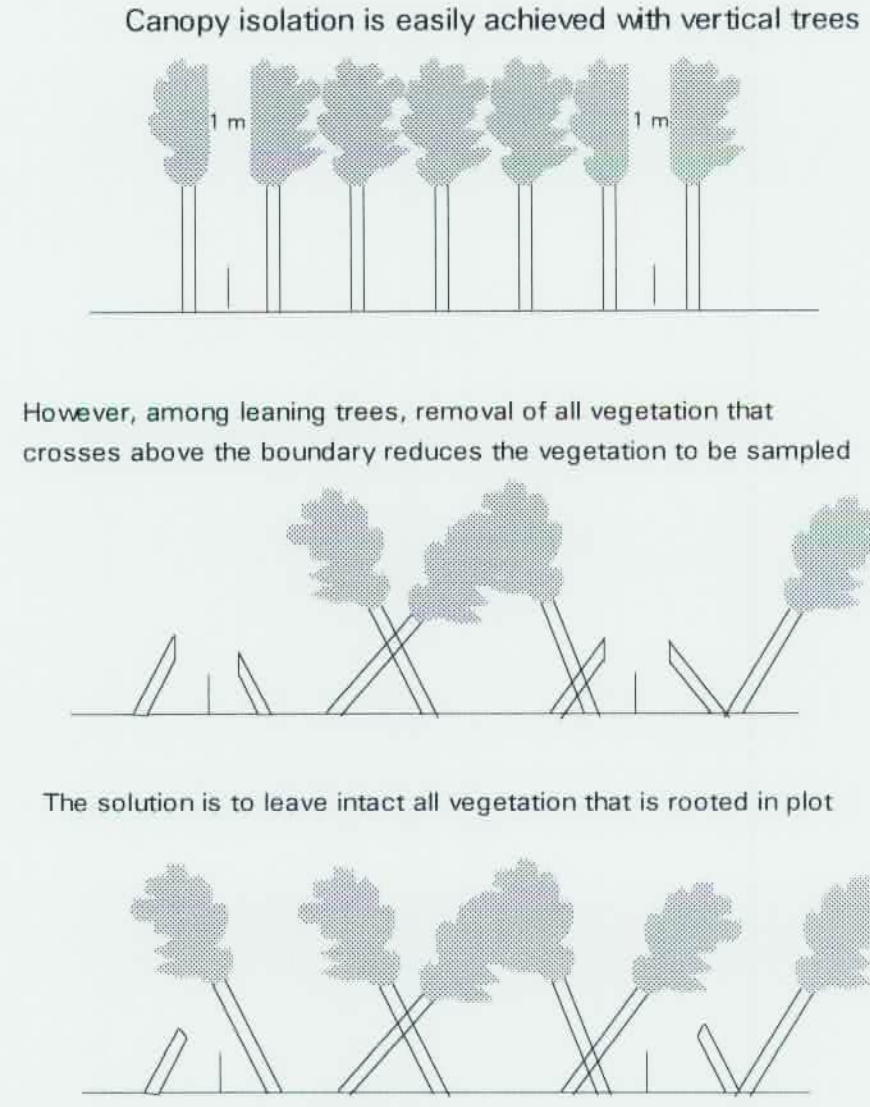


Fig. 1. In general, trees rooted in a plot should be left undamaged by canopy separation, to insure sampling of a full measure of forest volume (equivalent to 10 x 10 x 10 m, though not usually in a cubic shape).

separation, to insure sampling of a full measure of forest volume (equivalent to 10 x 10 x 10 m, though not usually in a cubic shape).

Wherever a cut is made in a tree, all limbs, branches, and leaves distal to the cut fall to the ground. If all stems that pass above the perimeter line are cut, the total amount of aboveground vegetation formerly within the plot will be reduced by the amount of leaning vegetation that entered the plots "airspace" from trunks rooted outside of the plot (Fig. 1). Furthermore, strict boundary cutting creates excessively large light gaps (altering the lizard habitat). The solution is to generally leave intact all stems that arise from trees rooted within the plot, regardless of whether they pass to the outside of the barrier above ground level. This insures that the aboveground vegetation that is sampled is quantitatively representative of what would be found in the airspace of an arbitrary 10 x 10 m column of forest.

Installation of barrier. - We installed the aluminum flashing barrier in the first hours of darkness on the night immediately preceding removal of lizards. This insured that nocturnal species would be trapped within the sampled plot (because they are loath to crawl out of the trees while humans are disturbing the area). The diurnal species were also trapped because they had already cloistered themselves in their nighttime refugia by the time we began barrier installation. Given that the trench to receive the barrier had already been cleared, it took only 1-2 h to install the fence.

Rebar supports were added as needed during the installation of the fence. All supports can be placed during fence erection, but the pounding needed for their

emplacement may create additional disturbance, which we preferred to reduce by preplacing rebar supports at all of the predictable locations (the rebar needed for finishing or beginning a roll of flashing cannot easily be predicted). The rebar was connected to the aluminum flashing with two short pieces of tie wire, which were twisted together on the outside of the barrier and were themselves covered with smooth tape. The rebar and the upper half of the fence were thoroughly sprayed with lithium automotive grease to present a chemical and mechanical barrier to climbing geckos (none of the lizards could climb clean and unblemished aluminum flashing, but geckos are capable of climbing soiled flashing and even skinks can climb irregularities created by poorly placed or damaged tape). Finally, the edges of any limbs or branches that passed near the barrier and might have inspired a lizard to jump were protected with a sticky trap. Details of all these procedures follow.

There are eight steps, that were done in the following order: 1) insert flashing in ground, 2) emplace any needed rebar supports, 3) tamp earth to hold bottom of flashing, 4) tie rebar to flashing, 5) tape all seams and rugosities, 6) spray lithium grease on completed fence, 7) if necessary wet soil at base of fence and retamp for better seal, and 8) place sticky traps.

1) The aluminum flashing was rolled out by one or two persons while one or two more forced it into the trench and backfilled soil. We found that it was vastly preferable to have the fence follow a subtly sinuous path rather than run in a straight line. Sinuosity in the fence line enables it to conform to the inevitable



Fig. 2. Sinuosity in the line of the barrier fence makes it easier for the flashing to conform to the inevitable irregularities in the height of the ground. At places where the ground is concave, the top edge of the flashing becomes more sinuous (side-to-side) than does the bottom, which exhibits little side-to-side sinuosity in the concavity; above convexities, the converse occurs.

irregularities in the ground's height without the necessity for seaming the flashing or creating sharp curves which lizards could climb (Fig. 2).

2) Sharpened rebar was driven into the ground on the outside of the fence as needed. Rebar supports were not strictly necessary, but were of considerable help in protecting the fence from being uprooted by people who accidently tripped over the fence while entering or leaving.

3) The tamping of soil can be difficult if the soil is dry. We have found that wetting the soil helps, but it is important not to wet the soil on the first tamping, because it is very difficult to wet the soil right next to the flashing without getting the flashing wet, and wet flashing cannot be greased. Also, we found it best to finalize tamping only after the fence was in its final position.

4) To tie the flashing to the rebar it was necessary to punch two small holes (about 2 cm apart, pushing from the inside to the outside of the enclosure), one on

either side of the rebar. Holes punched from the outside to the inside of the enclosure tended to create a rough spot on the inside, potentially enabling a climbing lizard to gain purchase and escape; therefore, this was avoided. One pair of holes was punched 5-10 cm below the top of the rebar, the other at the base of the flashing. The 20 cm long tie wire was doubled into a U shape and pushed through the flashing from the inside. After twisting the two ends tightly together, the excess was cut off, and the protruding remainder folded down against the rebar.

5) After smoothing the tie wire against the inside, a 5 x 5 cm patch of aluminum tape (such as is sold at hardware stores for patching holey car bodies or mufflers) was placed over the inside ties. When carefully rubbed down, this tape presented an extremely smooth surface. Aluminum tape was also used to close the seam at the ends of flashing pieces. However, aluminum tape is expensive and it does not accommodate irregular surfaces. Therefore, for the outside we used duct tape, which covered the ties, rebar, and the ends of flashing rolls.

6) We sprayed white lithium grease on all tape and rough surfaces, as well as the top 15 cm of the fence (both inside and out).

7) As mentioned above, we poured water along the base of the fence (inside and out), if the soil was too dry to pack well, and gave a final tamping.

8) To minimize immigration/emigration by jumping lizards, we put sticky traps on all surfaces near enough to the barrier to tempt a lizard. These were attached to trees using a stapling gun. They were placed at vulnerable points both inside and outside of the plot.

Lizard Assemblage Composition

Our lizard density estimates can be expressed either as number/ha (Table 3) or biomass/ha (Table 4, Fig. 4). As each plot was exactly 0.01 ha in size, actual numbers captured in each plot can be deduced by dividing the reported densities by 100/ha. We did not encounter large numbers of juveniles of any species in the Ritidian removal plots; therefore, the biomasses reflect a fairly normal species size in all cases. Because different sites have different mixes of large and small species, we prefer to use biomass (kg/ha) rather than density (individuals/ha) when comparing sites or species. For comparison to other sites, the aggregate biomass of lizards at Ritidian (11.9 kg/ha) was the lowest of the averages we have recorded using removal techniques: 15.3 kg/ha (Ordnance Annex), 23.8 kg/ha (NW Field with snakes), 53.5 kg/ha (NW Field without snakes), 14.2 kg/ha (Saipan native forest), and 14.5 kg/ha (Saipan tangantangan forest).

Table 3. Observed densities of lizards per hectare.

	strand	coconut	Mean
Geckos			
Gehyra mutilata	100	900	500
Hemidactylus frenatus	300	1000	650
Lepidodactylus lugubris	2300	3000	2650
Skinks			
Carlia fusca	400	300	350
Emoia caeruleocauda	2600	5100	3850
All lizards	5700	10300	8000

Table 4. Observed biomasses of lizards (kg) per hectare.

	strand	coconut	Mean
Geckos	3.41	8.34	5.88
Gehyra mutilata	0.15	2.34	1.25
Hemidactylus frenatus	0.64	2.52	1.58
Lepidodactylus lugubris	2.62	3.48	3.05
Skinks	4.8	7.32	6.06
Carlia fusca	0.90	1.00	0.95
Emoia caeruleocauda	3.90	6.32	5.11
All lizards	8.21	15.66	11.94

Table 4. Observed biomasses of lizards (kg) per hectare.

	strand	coconut	Mean
Geckos	3.41	8.34	**5.88**
Gehyra mutilata	0.15	2.34	**1.25**
Hemidactylus frenatus	0.64	2.52	**1.58**
Lepidodactylus lugubris	2.62	3.48	**3.05**
Skinks	4.8	7.32	**6.06**
Carlia fusca	0.90	1.00	**0.95**
Emoia caeruleocauda	3.90	6.32	**5.11**
All lizards	8.21	15.66	**11.94**

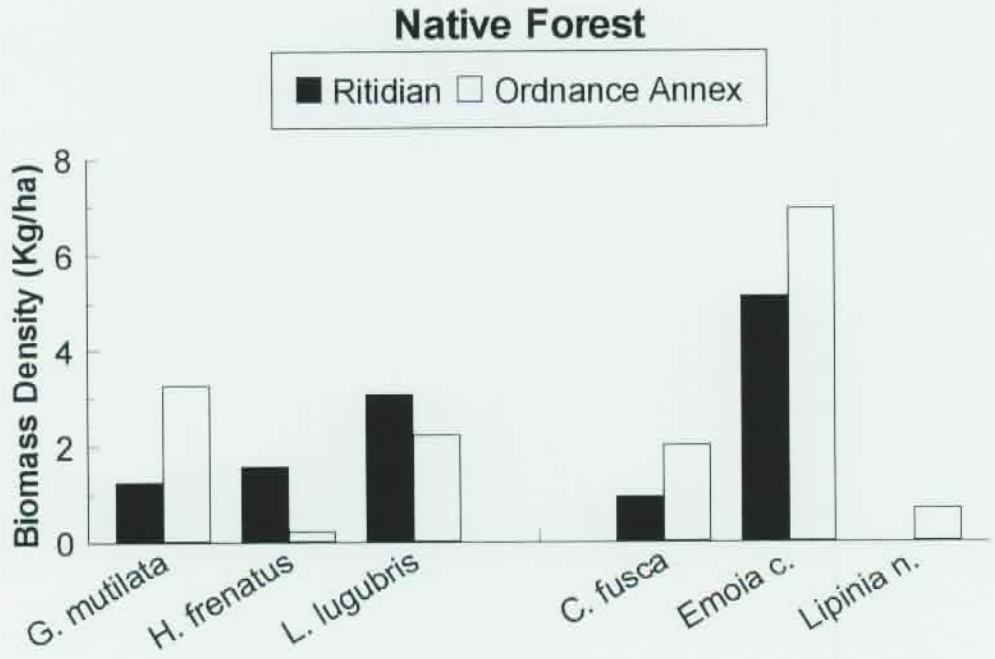


Fig. 4. Biomass density at Ritidian and Ordnance Annex.