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Seasonal variation in population location of the Galapagos tortoise, geochelone elephantopus vandenburghi, on Volcan Alcedo, Isabela Island, Galapagos archipelago

Kent R. Beaman

ABSTRACT

Seasonal Variation in Population Location

of the Galápagos Tortoise,

Geochelone elephantopus vandenburghi,

on Volcán Alcedo, Isabela Island, Galápagos Archipelago

by

Kent R. Beaman

Twenty tortoises, 10 adult males and 10 adult females, were tagged with radio transmitters. Numbers were painted on each carapace to aid in visual sighting. The tortoises were released, and their movement was monitored over a one year period.

The percent recovery of tagged tortoises along with the numbers of non-tagged tortoises counted in sections of the study area, were used to determine tortoise population movement and location.

Weather data were collected and observations were made concerning the vegetation. These observations were compared with those from previous studies to see what impact seasonal climatic conditions and food availability had on tortoise movement.

Population movement does occur on Volcán Alcedo. This movement is dependent on seasonal weather patterns and food availability.

LOMA LINDA UNIVERSITY

Graduate School

SEASONAL VARIATION IN POPULATION LOCATION OF THE GALÁPAGOS TORTOISE, *GEOCHELONE ELEPHANTOPUS VANDENBURGHI*, ON VOLCÁN ALCEDO, ISABELA ISLAND, GALÁPAGOS ARCHIPELAGO

by

Kent R. Beaman

A Thesis submitted in Partial Fulfillment of the Requirements for the Degree Master of Arts in Biology

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DECEMBER 1985

Each person whose signature appears below certifies that this thesis in his opinion is adequate, in scope and quality, as a thesis for the degree Master of Arts.

Lester E. Harris, Jr., Chairman

Lester E. Harris, Jr., Professor of Biology

Elmer A. Widmer

Elmer A. Widmer, Professor of Environmental Health

Gary L. Bradley, Associate Professor of Biology

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I. INTRODUCTION

Throughout the world there are many species of animals whose present day existence is dependent upon man's attempts to insure their survival. One such example is the giant tortoise endemic to the Galápagos Islands. Due to the early work of Darwin (1859) and the uniqueness of the Galápagos fauna, additional exploration and study have been focused on these islands.

During the 17th and 18th centuries, giant tortoise populations were heavily exploited by pirates, whalers, and fur-sealers who used the tortoise as a source of food during their long sea voyages. Further exploitation occurred when colonists and oil seekers arrived in the 1800's. In the 1900's scientific expeditions visited the islands to collect tortoises for scientific study. During this span of time over 100,000 tortoises were removed from the islands (Townsend, 1925).

Today, only 11 of the original 15 geographical races of giant tortoise, *Geochelone elephantopus*, remain. Of these, seven were threatened with extinction due to depleted population numbers and competition with introduced animals. Through the combined conservation and management efforts of the Charles Darwin Research Station and Galápagos National Park Service, these remaining seven populations of the giant tortoise have stabilized and some are returning to their former abundance (MacFarland et al., 1974a and 1974b).

The giant tortoise is still considered a threatened species and information concerning it's natural history is of significance (Honeggar, 1975). Early accounts of the giant tortoise were primarily descriptive emphasizing taxonomy. These include the first attempts at describing the various subspecies of giant tortoise within the genus Testudo = Geochelone (Harlan, 1827 and 1835; Jackson, 1837; Gunther, 1875; Rothschild, 1901 and 1902; and Van Denburgh, 1907 and 1914).

More recent studies have focused on conservation (Smith, 1972 and 1976; MacFarland et al., 1974a and 1974b; MacFarland and Reeder, 1975), captive propagation and management (Throp, 1975; Bacon, 1980; and Reynolds, 1982), and natural history (Carpenter, 1963; Dawson, 1966; MacFarland and Reeder, 1974; Rodhouse et al., 1975; Marlow and Patton, 1981; Fritts, 1983; Fowler, 1983; and Schafer, 1983).

Early observers of tortoise migration commented on movements to and from the nesting areas. Baur (1889) noted that:

> "As the females were found in low sandy bottoms, and all without exception were full of eggs, of which generally from ten to fourteen were hard, it is presumable that they came down from the mountains for the express purpose of laying. This opinion seems strengthened by the circumstance of there being no male tortoises among them, the few we found having been taken a considerable distance up the mountain."

Other references simply described the trails of the giant tortoise, often showing evidence of extensive use such as traversing between the highlands and the coast during the nesting period (Beck, 1902; Carpenter, 1963).

The most descriptive account of tortoise movement was reported by Heller (1903), who wrote:

> "All three of the species we observed make seasonal vertical migrations. Soon after the rainy season they descend the mountains to the grass covered flats at their bases to feed and deposit their eggs in the light soil. These migrations are most marked in the dry regions, as at Tagus Cove, Albemarle (Isabela)[1], but even at Iguana Cove on the same island where there is an abundance of moisture at lower elevations a nearly complete migration takes place. On Duncan Island the tortoises scatter out so in the dry season that their movements can scarcely be called a vertical migration. In their seasonal pilgramages they follow well established trails used perhaps for generations. These trails radiate from the higher plateaus as a center and usually follow the floors of the canyons to the flats below. Some of the trails are of considerable length, requiring several days of persistent effort on the part of the tortoise to cover them."

The literature suggests that the giant tortoise frequently moves in a vague pattern, but several unanswered questions remain. What are the factors responsible for tortoise migration? Does this movement occur seasonally? It is the purpose of this research project, to study these movement patterns as well as the ecological factors associated with them.

The experimental design aimed to determine the following: 1) the extent of tortoise movement as revealed

1. Isabela is the officially recognized Spanish name for the island.

through the use of radio telemetry and 2) the effect of climatic and other ecological changes on tortoise movement. By comparing these data with that of others, who have studied the same population, it is hoped that a better understanding of tortoise migration may be accomplished.

II. MATERIALS AND METHODS

A. Study Area

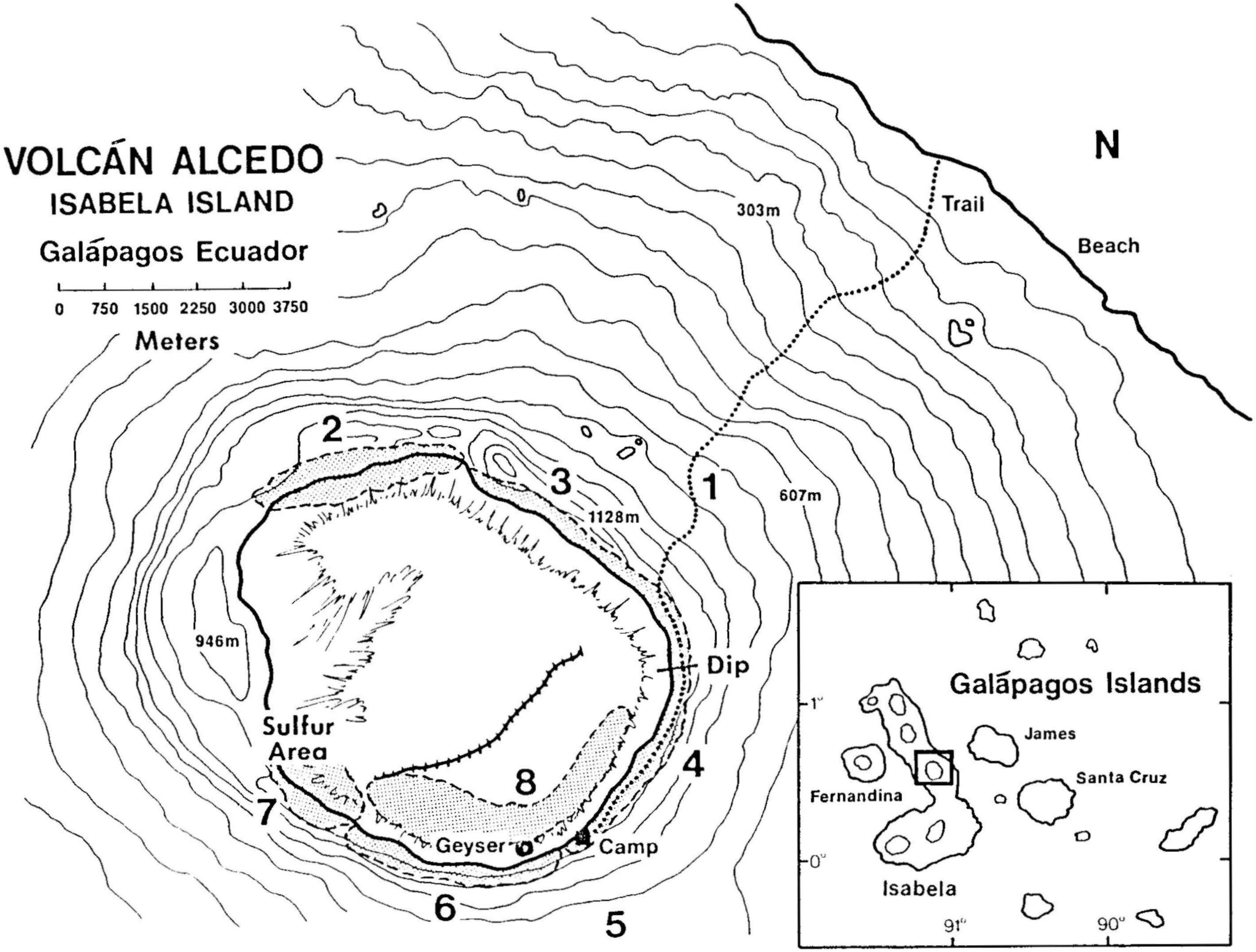
The Galápagos Archipelago is a group of islands that lie approximately 960 km off the west coast of Ecuador (Fig 1 inset). These islands straddle the equator. They are scattered over a 1,036,000 sq km area. The land area of the islands is roughly 7,856 sq km (Thornton, 1971).

Isabela is the largest island within the group. Stretching 134 km in length and with a total land area of 4,670 sq km, its total area is more than all the other islands combined (Wiggins and Porter, 1971). Isabela Island is composed of six large volcanos, each of which rise above 1,067 m in elevation. These volcanos are of the shield type with extremely wide craters compared with their overall height. Extensive lava flows cover their flanks and serve to connect them together in a long chain (Thornton, 1971).

Each volcano supports its own population of the giant tortoise. The Volcán Alcedo population (*Geochelone elephantopus vandenburghi*) has an estimated number of 3,000-5,000 tortoises. It is the largest population of the giant tortoise in the Galápagos Islands (MacFarland et al., 1974a).

In the tortoise migration study the Alcedo population was chosen for two reasons: 1) the large population size, and 2) accessibility of the study site.

Figure 1. Map of the Volcán Alcedo study site (adapted from Servicio Parque Nacional Galápagos. 1980. Guide to the Visitor Sites of Parque Nacional Galápagos). Inset shows the major islands within the Galápagos Archipelago, with the location of Volcán Alcedo shown in the square.


VOLCÁN ALCEDO
ISABELA ISLAND
Galápagos Ecuador
0 750 1500 2250 3000 3750
Meters
N
Trail
Beach
0
303m
607m
1128m
946m
1
2
3
4
5
6
7
8
Dip
Sulfur Area
Geyser
Camp
Galápagos Islands
1°
0°
91°
90°
James
Santa Cruz
Fernandina
Isabela

Volcán Alcedo is the most centrally located volcano on Isabela Island. It rises to an elevation of 1,177 m with a crater diameter of 10 km. It is the largest crater on the island. The crater depth approaches 305 m and the inner walls are almost vertical.

Some geological features include a "bench rim" located about 120 m above the floor, which extends almost completely around the inner wall of the crater. A large fault is visible extending east to west along the floor. This divides the floor into two sections one 3.5 m higher than the other. Volcán Alcedo is not active except for a fumarole (geyser) located just inside the south rim and a steam venting sulfur area along the west end of the crater (Fig 1)(Banfield et al., 1956).

To make the tracking of the tortoises easier the crater was divided into eight sections (Fig 1).

B. Climate

Although the Galápagos Islands are situated on the equator their climate is quite different from other tropical islands. The presence of the cold Humboldt current coming up the west coast of South America from Antarctica and then sweeping out to the islands is a major contributing factor to the type of climatic conditions found in the islands.

Two "seasons" occur in Galápagos i.e., from June through December and from January through May. When the Humboldt current is present the islands experience a cool season marked by fog, heavy overcast skies and with cool air temperatures seldom above 25 C. Precipitation levels are low during this time (less than 2.03 cm/month) but a heavy mist covers the highlands. Locally this mist is referred to as garúa and this time of year is known as the "garúa season" (Thornton, 1971; Wiggins and Porter, 1971).

The months of January through May are much warmer with temperatures reaching 33 C. This period has higher levels of precipitation due to the presence of the El Niño current. The El Niño causes the sea temperatures to rise thus increasing the amount of rainfall on land 2.5 to 15.2 cm/month. The El Niño seems to fluctuate from year to year. Every few years (4 to 6 on the average) a "large scale" El Niño passes through the islands, bringing catastrophic disruption of the local marine environment and torrential rainfall over the land areas. During other years the rainfall can be intermittent, while some years are quite dry. This time of year is known locally as the "rainy season" (Rasmusson, 1985; Thornton, 1971).

The climatic conditions on Volcán Alcedo are characteristic of that seen throughout the islands. Varying conditions however, can be observed in different areas of the crater. For the most part the north and west rims, in addition to the middle floor, are dry. The only moisture received in these areas comes from either the heavy rain or the garúa which is quite sporadic. Air temperatures are higher because these areas are usually clear and rarely covered with clouds. Temperatures of 28 to 33 C are predominant. On the south and east rims the weather is much different. The prevailing winds are out of the southeast allowing clouds to build up over these sections of the rim. The cloud cover allows for a higher percipitation level and cooler air temperatures i.e., 16 to 22.4 C.

Temperature and relative humidity data were collected using a Taylor Sling Psychrometer. Observations on cloud cover and moisture levels were recorded and water ponds on the southeast rims measured for area and depths. These data are presented in Appendix A-F along with weather data collected by Fowler (1983).

C. Vegetation

Due to the variable climatic conditions found on Volcán Alcedo, the vegetation found there is quite diverse. Since the giant tortoise is dependent upon the surrounding vegetation for its survival, a discussion of this part of the environment is important. Observations of the Alcedo plant community were made during each study trip. This data correlates with Hamann (1981).

NORTH/WEST SECTION: From an altitude of 100-390 m the common woody species included *Bursera graveolens*, *Zanthoxylum fagara*, *Tournefortia psilostachya*, *T. pubescens*, *Croton* *scouteri*, *Cordia leucophlyctis*, *Waltheria ovata*, and *Alternanthera echinocephala*. At the 100 m level *Pisonia floribunda* was encountered, while at 390 m *Psidium galapageium* was common. The herb layer in this area was well developed and composed of many species. Above the 390 m level *Scalesia microcephala*, *Z. fagara*, and *P. galapageium* were quite conspicuous.

The vegetation began to change with increasing altitude. At 600 m the landscape was a scattered woody area with a closed ground cover. *S. microcephala*, *Z. fagara*, and *Baccharis gnidiifola* were the dominant plant species in this fairly zerophytic, but evergreen vegetation. *S. microcephala* continued to be the dominant plant species to the rim of the crater. The lower parts of this evergreen scrub community contained *Lippia rosmarinifolia*, which gradually replaced *P. floribunda* and *T. pubescens* with an increase in altitude. *Pennisetum pauperum* and *Ipomea alba* appeared at the 700 m level and became more common at the higher altitudes.

The rim vegetation consisted of *S. microcephala* and *Tournefortia rufo-sericea* with a closed herb layer dominated by *Paspalum galapageium*. Inside the north rim the crater was densely vegetated with *S. microcephala*, *Darwiniothamnus tenuifolius*, *Z. fagara*, *T. rufo-sericea*, *C. leucophlyctis*, *I. alba*, and *P. pauperum*. The *S. microcephala* and *D. tenuifolius* were often found in very dense stands.

EAST SECTION: The vegetation complex of the eastern part of the crater was a microphyllous evergreen scrub, and is similar in composition to that of the north rim (e.g. Z. fagara and T. rufo-sericea, with S. microcephala less dominant.

This part of the rim had an increased amount of epiphytes and the evergreen steppe changed to a dense evergreen scrub. Psychotria rufipes was the dominant plant in the area, with a very dense herb layer composed of and often dominated by ferns such as Polypodium phyllitides, P. dispersum, Adiantum concinnum, Doryopteris pedata, and Rhumora adiantiformus. The more common epiphytes included Tillandsia insularis, Peperomia galapagensis, Lycopodium passerinoides, L. dichotomum, Polypodium lanceolatum, and Epidendrum spicatum.

The impact of the large tortoise population was evidenced along the rim area where large meadows were present. Tortoise activity and trails were quite noticeable in these areas. These meadows were similar to those found in other parts of the archipelago, containing such common species as P. galapageium, Cuphaea carthagenesis, Lobelia xalapensis, Mecardonia dianthera, Lindernia anagallidea, Cyperus brevifolis, and Borreria laevis.

SOUTH SECTION: The inner slopes above the steam vent were covered with an evergreen low forest dominated by S.

microcephala and *C. scouteri*. *Cyathea weatherbyana* was common on the steep cliff sides. Tangled masses of *I. alba* were growing on the rocky parts, and was also a common climber in the *Scalesia-Croton* forest. Some otherwise rare plants were noted in this area: *Canna lambertii*, *Polystichum gelidum*, *Hypolepis hostilis*, *Polygonum hydropiperoides*, *Ponthieva maculata*, and *Elaphoglossum engelii*.

The outside rim above the steam vent had a dense, species-rich vegetation. Dense clusters of *C. weatherbyana* were common, along with *T. rufo-sericea*, *S. microcephala*, *P. rufipes*, and *I. alba*. Woody plants like *S. microcephala* and *Acnistus ellipticus* were less common in this area. Most of the woody plants present were heavily draped with epiphytes both vascular and bryophytic. The herb layer was well developed and dominated by ferns.

FLOOR SECTION: The floor area is an evergreen low forest dominated by *S. microcephala* and *C. scouteri*. It changes into a deciduous forest scrub where *B. graveolens* and *P. floribunda* are common at lower elevations on the floor. The ground vegetation and herb layer are sparse to non-existent in this area due to low moisture levels and the presence of vast lava fields.

NOTE: A detailed description of the plants mentioned in this section can be found in: *Flora of the Galápagos Islands* by I.R. Wiggins and D.M. Porter (1971).

D. Instrumentation

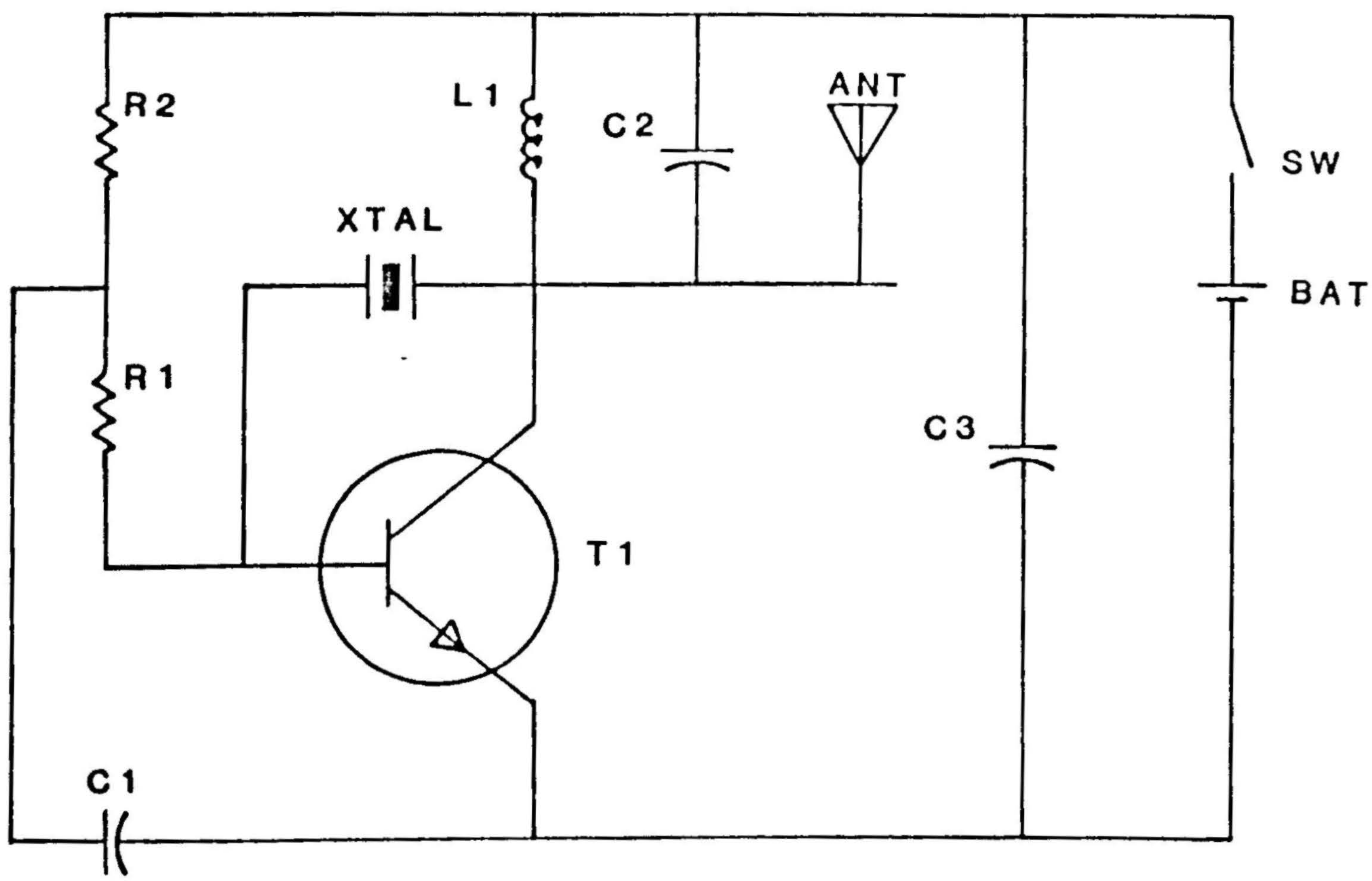
1. Transmitter Design

Initially a single stage transmitter, designed by Cochran and Lord (1963) and modified by Winter et al. (1978), was selected for its simplicity and low current drain (Fig 2). The design was further modified as follows: 1) to yield a pulsed-signal 0.25 sec in length at a rate of 31 min^{-1} and 2) by substituting a ferrite core toroid coil (with 22 turns of #24 copper wire) for the straight ferrite coil antenna. These changes were made to minimize the effect of the magnetic fields and capacitances generated by the position of the transmitter components on the printed circuit board.

The transmitter components were attached with silver solder to a 4.5 x 5.0 cm phenolic printed circuit board with a 1/8 wavelength silver wound steel guitar string used as an antenna. A 3 volt 3800 mah #LO28 lithium battery pack fabricated by Wildlife Materials Inc. (R. R. 1 Carbondale, IL 62901) was used to power the transmitter. The transmitter drew 1.6 ma current. With a 3800 mah battery the expected battery life was three months, nine days. Each transmitter was then covered with a coat of spar varnish and potted in G. E. silicone rubber to a depth of 1.0 cm.

This first transmitter weighed 57.2 g which is well within the transportation weight limits for an average size

Figure 2. Circuit diagram for a 27 Mhz transmitter used on Galápagos tortoises. XTAL, cut to desired x-band frequency (HC25 holder). T1, silicon transistor (2N3904). R1, 1K. R2, 390K. C1, electrolytic capacitor, 4.7 uf. C2, 7-75 pf. C3, 0.001 uf. Battery 3.4 V, 3800 mah, lithium (type L028). L1, 22 turns of #24 enameled copper wire on a ferrite core toroid coil form 1.5 cm in diameter. SW, miniature Radio Shack sliding switch.


R2
L1
C2
ANT
SW
XTAL
BAT
R1
C3
T1
C1

tortoise (68.0 to 226.8 kg). A juvenile tortoise weighing 2 kg can easily carry a transmitter of 36 g.

These initial transmitters did not stand up to the stress put on them by the tortoises consequently the internal components were exposed and ruined. A second transmitter utilizing the same circuit but using a different means of protection was then built.

The loop antenna, 5.5 cm in diameter, consisted of 3 turns of #24 copper wire soldered to the tuning capacitor terminals and positioned 2 cm above the other tranmitter components. Internal components were covered with 3 coats of spar varnish and potted in epoxy. A 6 volt 7K67 Duracell battery was inserted on the top of the transmitter and potted in place. The increased battery voltage doubled the range of the transmitter from 0.8 to 1.6 km. The transmitter was encased in a 5.7 cm PVC pipe cap for protection.

2. Tracking Equipment

Transmitter tracking equipment consisted of two modified Radio Shack TRC-208, 5 watt, six channel recievers. A printed circuit board containing 16 crystals and a rotary-crystal selection switch were added to each reciever. Twenty x-band channels were used to correspond with each transmitter.

The circuit board and switch were enclosed in a 6.35 x 6.35 cm grounded metal circuit box attached to the front of the reciever. Hand capacitance problems made it necessary to exchange the box for a plastic container which was sealed over the circuit board and switch with G. E. silicone adhesive.

A hand held directional loop antenna designed after Cochran (1966) was added to each reciever to help locate the signals given off by each transmitter. The antenna was 68.58 cm in diameter, but in the field proved to large and unwieldly in the dense vegetation. A 45.72 cm antenna was designed, constructed and used on succeeding trips to the study area.

E. Field Applications

1. Transmitter Attachment

Carapace sections from skeletal material were studied to find the best location point for the transmitter. The location of the attachment hole is critical because the bone, though 3 cm in thickness, is mostly air space and extremely thin, 1.0 to 2.5 mm at the outer edges of the carapace. The site selected was in the thickest bone region, 3 cm from the anterior edge of the second marginal scute, as recommended by Rouhe (1983). The transmitter was attached with a 6.5 mm x 6.35 cm stainless steel bolt.

2. Field Monitoring Techniques

It was hypothesized prior to the initial field study that radio tagged tortoises would permit optimal locating during their foraging migration. Twenty transmitters were then built with the intent of monitoring the migration patterns of 10 adult male and 10 adult female tortoises.

During the first study trip (September 1983) the transmitters were attached to 10 male and 10 female tortoises from the southeast rim of the volcano (Fig 1 Section 4). These tortoises were arbitrarily picked, physically restrained, and tagged. After each transmitter was in place, an identification number was painted with yellow paint on the upper part of the carapace to aid in visual sighting. The transmitters were tested and the tortoises were released.

On 18 December five more tortoises, adjacent to the geyser area, were tagged with numbers (Section 8). This was done to monitor any tortoise movement in and out of this specific area.

III. RESULTS

A. Tagged Tortoises

1. September 1983

The tortoises tagged with transmitters were monitored and released on 7 September in Section 4 of the study area (Fig 1). Attempts to relocate them with the receivers on 9 September resulted in the identification of all but three: Nos. 8, 13, and 15. Numbers 3, 18, and 19 were resighted in the same area where they had been marked (Section 4) (Table 1).

On 10 September on the hike back to the coast, Nos. 2, 6, 11-13, 18 and 19 were observed on the southeast rim near where they had been tagged (Section 4).

2. December 1983

The initial hike across the rim to the main camp was uneventful. Tortoise No. 12 was visually located in Section 4 where it had been tagged. The protective covering on the transmitters was damaged, thus exposing the internal components and ruining them. It was then decided to locate all other tortoises by visual sightings (Table 1).

On 11 December Nos. 12 and 17 were seen on the rim and numbers 7 and 14 along the east flank just below the rim (Section 4).

Hiking along the rim to the east on 14 December, No. 12 was observed where it had been seen earlier (Section 4). The vegetation was still quite plentiful from the "Dip" to just before the sulfur beds. The water ponds were dry except for some mud left by the moisture that collected during the evenings (Compare with data in Appendix F).

Along the east flank on 17 December No. 4 was located about 0.21 km below the rim (Section 5). Number 5 was located just below the rim and No. 12 had moved some distance below the rim on the outer flank. Back on the rim on 19 December, Nos. 17 and 14 were located in the middle part of the rim (Section 4) and No. 12 was seen down along the flank (Section 5).

Returning to the geyser area on 21 December, Nos. 22 and 24 were still around the geyser. Number 22 had moved up from where it had been tagged to the east and was around the geyser area and No. 25 was by a large pond area near where it had been tagged. Numbers 21 and 23 were not relocated.

3. <u>June 1984</u>

Numbers 1 and 16 were relocated on 19 June going east along the rim (Section 4).

On 22 June No. 20 was observed in a pond area just past the camp to the east and No. 16 was seen on the rim (Section 4). When water ponds are available, tortoises congregate in these low depression area. A tour group hiking up from the

TABLE 1

Summary data and percentages of tortoises relocated after the initial tagging.

DATE	NUMBER OF TORTOISES RECOVERED	PERCENT
Sept. 9, 1983	17/20	85%
Sept. 10, 1983	7/20	35%
Dec. 1983*	5/20	25%
Jun. 1984*	5/20	25%

*The tortoises relocated on each of these trips were different numbers, giving a total of 10 tortoises relocated during the last two trips. These 10 tortoises were also part of the total number of tortoises recovered on the September trip. Two tortoises out of the original 20 were not relocated.

beach reported that they had seen Nos. 11, 13, and 16 all on the rim (Section 4).

On 23 June No. 20 was located further up the rim to the east, while No. 2 was approximately 1.6 km from camp (Section 4) on 24 June. The same tour group came across No. 24 down near the geyser.

Of the five tortoises marked adjacent to the geyser (Section 8), three were relocated three days after being marked. Only one tortoise was relocated in this area six months later during the June trip. Two tortoises were never relocated.

B. Non-tagged Tortoises

The majority of non-tagged tortoises counted during the three study trips were seen on the southeast sections of the volcano (Sections 3-8).

The total number of tortoises counted during each trip were not significantly different. However, the number of tortoises counted in each section were quite different, indicating that the tortoises prefer certain areas of the volcano over others (Table 2, Fig 3 and 4).

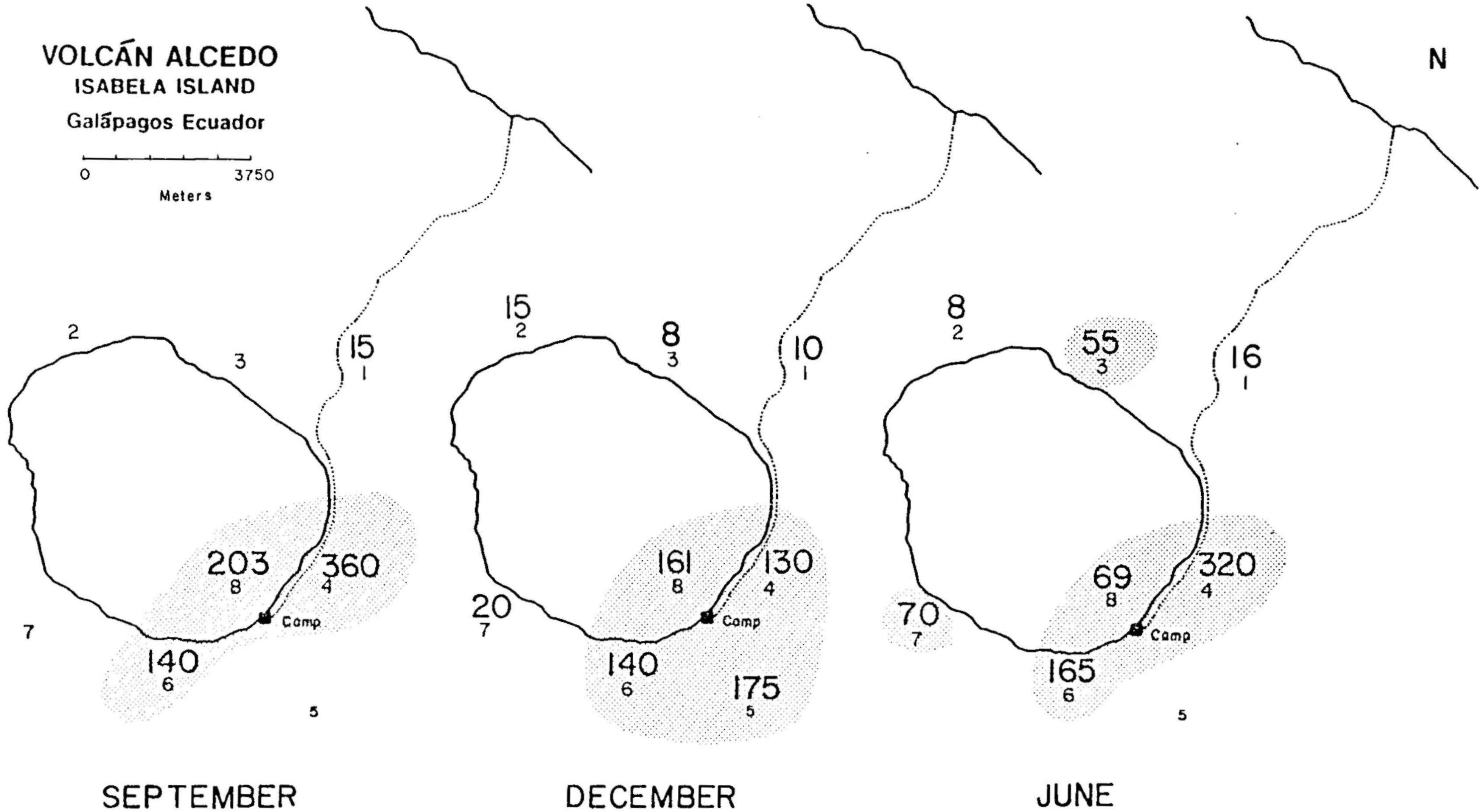
TABLE 2

Summary data on the number of non-tagged tortoises counted in each section of the study area during each of the three scheduled trips (see Fig 1).

	SECTIONS IN THE STUDY AREA							
DATE	1	2	3	4	5	6	7	8
Sept. 4, 1983	15	---	---	360	---	---	---	---
Sept. 8, 1983	--	---	---	---	---	---	---	203
Subtotal	15	---	---	360	---	---	---	203
Dec. 10, 1983	10	---	---	130	---	---	---	---
Dec. 12, 1983	--	---	---	---	75	---	---	108
Dec. 13, 1983	--	---	---	---	---	140	20	53
Dec. 15, 1983	--	---	---	---	100	---	---	---
Dec. 24, 1983	--	15	8	---	---	---	---	---
Subtotal	10	15	8	130	175	140	20	161
Jun. 16, 1984	2	---	---	---	---	---	---	---
Jun. 17, 1984	6	8	30	---	---	---	---	---
Jun. 19, 1984	--	---	---	95	---	---	---	---
Jun. 20, 1984	--	---	---	---	---	---	---	7
Jun. 21, 1984	--	---	---	---	---	165	70	62
Jun. 22, 1984	--	---	25	225	---	---	---	---
Subtotal	16	8	55	320	---	165	70	69
Total:	41	23	63	810	175	305	90	433

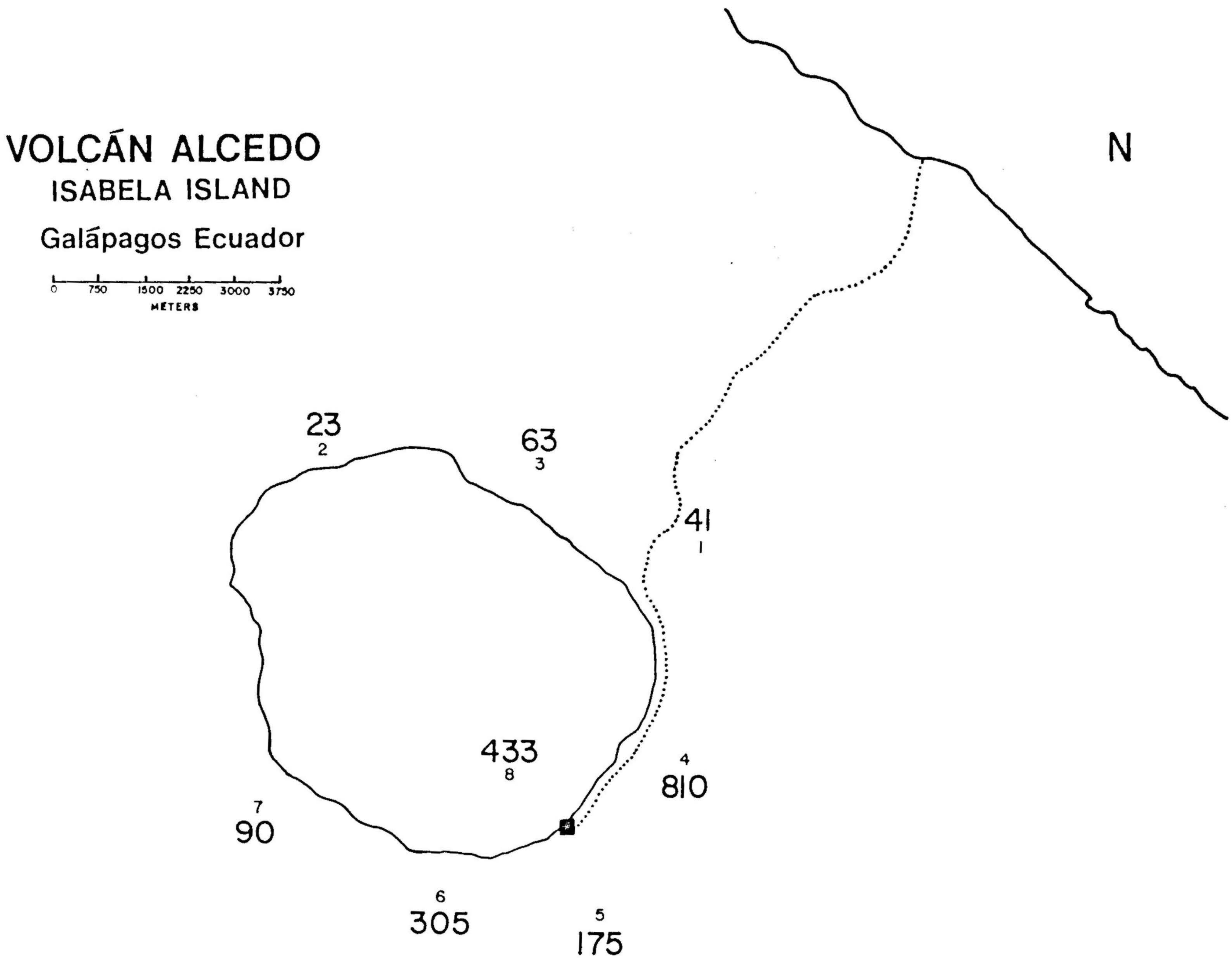
Note: Areas with blanks were not visited during those times.

Figure 3. Map showing tortoise distribution during the three study trips. Shaded areas show where the majority of the tortoise population is located. These areas are approximations and are not to scale. Areas without numbers were areas not visited during that time.



VOLCÁN ALCEDO
ISABELA ISLAND
Galápagos Ecuador
0
3750
Meters
N
2
3
15
1
203
8
360
4
Camp
7
140
6
5
SEPTEMBER
15
2
8
3
10
1
161
8
130
4
Camp
20
7
140
6
175
5
DECEMBER
8
2
55
3
16
1
69
8
320
4
70
7
Camp
165
6
5
JUNE

Figure 4. Map showing the total distribution of tortoises during the study.


VOLCÁN ALCEDO
ISABELA ISLAND
Galápagos Ecuador
0 750 1500 2250 3000 3750
METERS
N
23
2
63
3
41
1
433
8
4
810
7
90
6
305
5
175

IV. DISCUSSION

The observations made indicate that two types of movement patterns are present in the Alcedo population: 1) local movement of individual tortoises, and 2) widespread movement of the total population. This is consistent with reports of other tortoise studies on Volcan Alcedo (Fowler, 1983).

A. Local Tortoise Movement

Tortoise movement within a specific area on Volcān Alcedo is a daily occurrence. This activity begins in the early morning and it is during this time of day that most of the tortoise foraging behavior takes place.

Feeding is one of the most important activities engaged in by the tortoises. Tortoises on Alcedo are considered to be grazers and feed on grasses and other low lying vegetation. The feeding habits of the Galāpagos tortoise are discussed in detail by Fowler and Johnson (1985).

The availability of vegetation is determined by the amount of moisture present in an area. Because the prevailing winds are out of the south, the southeast sections of the volcano support the heaviest cloud cover and in turn receive the greatest amount of moisture (Table 3, Appendix A-E).

Because the southeast sections of the volcano receive the most moisture therefore having more vegetation, the majority of tortoise activity is centered along this part of the crater (Table 3). Activity can be observed on the rim, along the outer flanks, around the sulfur beds, around the geyser area, and along the southeast part of the floor (Table 2, Fig 3 and 4).

Tagged tortoises were recovered in the same area where they had been marked (Section 4). The tortoises had moved anywhere from 45.7 m to 0.40 km within the tagging area. Most of the tortoises stayed on the rim, but several were found down along the outer flanks. This data indicates that the tortoises have a preference for the southeast section of the volcano, due to the availability of both moisture and vegetation. Due to their daily foraging behavior, tortoise movement within a local area is quite evident.

Further evidence for local movement, can be seen in the daily movment of the tortoises between the rim and the geyser area. There are heavily used trails that support this fact along with personal observations of the movement. The tortoises marked around the geyser stayed in the area for a short time, while those that were not relocated had moved out of the area. This movement supports both the local and widspread movement hypothesis. During wet weather this movement increases dramatically.

Along the rim there are depression areas which fill with water during the rainy season. Heavy tortoise activity

TABLE 3

Summary data showing the relationship between climatic conditions/vegetation patterns to tortoise population location.

Section	Climate	Temperature C	Humidity	Vegetation	Tortoise #
4,5,6	Wet	18.7/17.5	92.5	Dense/Closed	1,290
1,7,3	Temperate	20.1/18.2	85.2	Intermediate	194
2	Dry	24.4/19.1	66.2	Sparse/Open	23*
8					433*

* Although both of these areas are dry, Section 8 is located on the southeast part of the volcano floor and inner slopes. This area recieves more moisture and supports a greater amount of vegetation.

Note: Dense/Sparse - % of cover, amount of vegetation etc.

Closed/Open - herb layer

See Wiggins and Porter, 1971 and Hamann, 1981 for more detail regarding the vegetation and plant communities.

on the rim was observed during this time too (Appendix F).

B. Widespread Tortoise Movement

Widespread movement of the Alcedo tortoise population is unlike that of large populations of birds or mammals i.e., the whole population doesn't move at the same time. This movement is heavily dependent on local tortoise movement within a given area.

By counting tortoises in these areas (Fig 1) and following the individual movement, the location of the total population can be determined (Table 2, Fig 3 and 4). This is supported by other population counts made on Alcedo by previous researchers (Castro, 1969; Cayot, 1983; Fowler, 1983).

Like the local movement, population shifts are dependent on the prevailing weather patterns. Areas receiving the most moisture, thus supporting more vegetation, are where the majority of the tortoise population will be at any given time. These areas include the southeast rim (Section 4 and 6) and the southeast flanks (Section 5).

After a particular wet year, movement to the floor (Section 8) also increases. Open areas on the floor fill with water creating large pools. Large numbers of tortoises can be observed in these pools during this time. These pools eventually dry up and the tortoises move to other areas (Moore, 1980; Fowler, 1983).

Widespread tortoise movement to the floor areas (Sections 3 and 8) also corresponds with the nesting period, June through September. This movement usually follows the rainy season, when the tortoises are attracted to the large pools of water down on the floor. When the water drys up large dirt areas are used by the female tortoises to lay their eggs. These areas also exist on the rim and outer flanks (Sections 4, 5, and 6), suggesting another reason for the majority of the tortoise population being found along this part of the volcano (MacFarland et al., 1974b; Fowler and Roe, 1984). Extensive trails in these areas, used year after year, suggest heavy use by the tortoises (DeRoy, 1984).

During the recent El Niño (1983-1984) which brought record levels of rainfall to the islands, widespread tortoise movement was quite dramatic. There was evidence that the populations (Santa Cruz and Alcedo) were spreading out over a much larger range compared with previous years (Cayot, 1983). On Volcán Alcedo tortoises were seen along the coast on the west side of the volcano which was quite unusual (DeRoy, 1984).

V. CONCLUSIONS

A. Considerable population movement does occur on Volcān Alcedo. This movement can be described as 1) local tortoise movement within a specific area, and 2) widespread tortoise movement i.e., population shifts from one area to another.

B. Population movement is dependent on two factors: 1) seasonal weather patterns, especially rainfall and 2) food availability.

C. Tortoise movement to and from the nesting areas corresponds to both the local and widespread movement patterns. (The nesting movement needs to be studied in more detail).

D. Remote sensing radio tracking of the tortoises to determine their movement patterns may be possible. However, additional experiments on equipment design and its placement for both reception and transmission are essential.

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VII. APPENDICES

APPENDIX A

Daily Air Temperatures (C) and Humidity (%)
Volcān Alcedo, Isabela Island, 1983/84

Location	Date	Max	Min	Relative Humidity
S. Rim	5Sept83	18.1	17.4	94.3
S. Rim	6Sept83	17.5	17.2	94.6
S. Rim	7Sept83	19.2	17.7	87.3
S. Rim	8Sept83	17.2	16.4	91.5
Floor	8Sept83	23.6	19.4	68.8
S. Rim	8Sept83	18.6	17.5	89.0
S. Rim	9Sept83	17.7	17.2	93.6
Beach	11Sept83	26.8	22.5	69.8
Beach	12Sept83	26.7	22.0	67.3
Beach	13Sept83	27.4	22.2	63.3
S. Rim	11Dec83	19.2	17.9	92.0
S. Rim	12Dec83	18.3	17.4	90.3
S. Rim	13Dec83	17.2	16.9	90.5
W. Rim	13Dec83	25.3	18.6	69.5
Floor	13Dec83	22.5	18.1	66.5
S. Rim	14Dec83	20.2	17.6	86.0
S. Rim	15Dec83	18.9	17.5	89.0
S. Flank	15Dec83	24.4	18.6	57.5
S. Rim	16Dec83	20.6	17.2	73.6
S. Rim	17Dec83	20.0	17.2	78.0
S. Rim	18Dec83	21.3	18.3	76.3
S. Rim	19Dec83	21.7	18.3	76.0
S. Rim	20Dec83	19.8	18.7	91.3
Floor	21Dec83	26.1	20.1	60.0
S. Rim	22Dec83	19.4	18.3	90.5
NE. Rim	23/24Dec83	18.9	18.3	94.6
E. Rim	16Jun84	17.8	17.2	94.0
E. Rim	17Jun84	20.9	18.9	83.6
E. Rim	18Jun84	21.8	18.3	72.6
E. Rim	19Jun84	21.1	18.9	81.0
S. Rim	19Jun84	20.0	17.2	76.0
S. Rim	20Jun84	19.7	18.6	89.5
S. Rim	21Jun84	17.5	17.2	95.0
S. Rim	22Jun84	17.4	17.4	97.0
S. Rim	23Jun84	18.5	18.3	96.3
S. Rim	24Jun84	16.1	15.6	93.0

APPENDIX B

Daily Air Temperatures (C)
Isabela Island, 1980

Location	Pto. Villamil		Santo Tomas		Alcedo	
Altitude	6 m		350 m		1100 m	
Date	Max	Min	Max	Min	Max	Min
January	26.4	24.3	27.8	18.6	20.6	15.0
February	29.6	26.5	29.2	19.0	24.2	15.1
March	27.6	24.0	31.4	19.4	26.5	16.1
April	27.6	24.2	30.1	20.1	26.3	17.0
May	26.1	24.0	26.5	19.4	25.0	16.7
June	25.3	23.3	25.0	17.3	----	----
July	24.1	21.1	23.0	16.4	21.9	12.0
August	23.9	19.4	23.2	16.2	26.7	11.4
September	23.7	19.0	23.4	16.0	----	----
October	23.1	19.6	23.2	16.5	24.5	13.0
November	23.1	20.0	24.1	16.5	23.7	12.1
December	23.1	20.8	25.0	16.8	23.3	13.1

Adapted from Fowler (1983).

APPENDIX C

Monthly Rainfall (mm), 1980

Location	CDRS	Pto. Villamil	Santo Tomas	Media Luna	Alcedo
Island	6 m	6 m	350 m	620 m	110 m
Altitude	St. Cruz	Isabela	Isabela	St. Cruz	Isabela
Date					
January	23.4	2.4	62.6	267.0	18.6
February	69.2	20.2	207.8	240.0	178.4
March	0	6.0	8.0	170.0	13.2
April	139.4	54.0	292.1	275.0	360.7
May	0	31.4	103.7	0	141.9
June	1.2	1.0	23.4	-----	-----
July	4.7	0	68.2	156.0	58.5
August	3.0	11.0	58.9	-----	0.8
September	3.6	5.3	60.4	-----	-----
October	5.8	2.9	102.0	108.0	0
November	4.5	5.8	56.4	-----	46.0
December	1.0	12.5	58.8	162.0	54.2

Adapted from Fowler (1983).

APPENDIX D

Monthly Frequency of Garúa Days
Rim Camp, Alcedo 1980

Date	Garúa/Rain Entire Day	Garúa/Sun	Sun Entire Day
January	3	2	0
February	5	9	0
March	3	5	3
April	3	11	0
May	8	2	0
July	7	6	0
August	0	6	3
October	1	5	1
November	6	14	2
December	11	5	0
Total	47	65	9
Percentage	38.8%	53.7%	7.4%

Adapted from Fowler (1983).

APPENDIX E

Cloud Cover and Moisture Data
V. Alcedo, 1983/84

Location	Date	Gaŕua/Rain	Cloud Cover	Clear
S. Rim	5Sept83	Morning	All Day	Occasional
S. Rim	6Sept83	Morning	All Day	-----
S. Rim	7Sept83	-----	Morning	All Day
S. Rim	8Sept83	Night	Afternoon	Morning
Floor	8Sept83	-----	Morning	Afternoon
S. Rim	9Sept83	Morning	All Day	Occasional
S. Rim	10Dec83	Evening	All Day	-----
S. Rim	11Dec83	Morning	Evening	All Day
Floor	11Dec83	-----	All Day	-----
S. Rim	12Dec83	Morning	All Day	Afternoon
S. Rim	13Dec83	Morning	Morning	Night
S. Rim	14Dec83	-----	All Day	Morning
S. Rim	15Dec83	Night/Morning	Scattered	All Day
S. Rim	16Dec83	-----	Scattered	All Day
S. Rim	17Dec83	-----	All Day	-----
S. Rim	18Dec83	-----	All Day	-----
Floor	18Dec83	-----	-----	All Day
S. Rim	19Dec83	Night	Afternoon	Morning
Floor	19Dec83	-----	Night	-----
S. Rim	20Dec83	Morning	Mid-day	Noon/Evening
Floor	20Dec83	-----	-----	Morning
S. Rim	21Dec83	Morning/Night	All Day	All Day
S. Rim	22Dec83	Morning/Night	Scattered	Warm/Sunny
S. Rim	23Dec83	Morning	All Day	-----
S. Rim	24Dec83	All Day	All Day	-----
S. Rim	16Jun84	-----	Morning	Afternoon
Floor	16Jun84	-----	-----	All Day
Flanks	17Jun84	-----	All Day	-----
S. Rim	17Jun84	-----	-----	All Day
Floor	17Jun84	-----	Morning	-----
S. Rim	18Jun84	-----	Afternoon	All Day
S. Rim	19Jun84	-----	Scattered	Night
S. Rim	20Jun84	-----	All Day	All Day
S. Rim	21Jun84	-----	All Day	All Day
S. Rim	22Jun84	All Day	All Day	-----
S. Rim	23Jun84	All Day	All Day	-----
S. Rim	24Jun84	Morning	Scattered	-----

APPENDIX F

Water Pond Data
S. Rim, 1983

	Length/Width (cm)	Depth (cm)
1.	163 x 152	9.7
2.	213 x 153	5.4
3.	154 x 153	7.5
4.	155 x 153	9.3
5.	154 x 120	9.8

These ponds were left over from the El Niño, and give some idea of the water availability on the rim area.