# RECOVERY PLAN

# O'AHU TREE SNAILS

## OF THE

# GENUS ACHATINELLA

U.S. Department of the Interior
Fish and Wildlife Service
Region One, Portland, Oregon
April, 1993

RECOVERY PLAN FOR THE O'AHU TREE SNAILS

OF THE GENUS ACHATINELLA

Published by
U.S. Fish and Wildlife Service
Portland, Oregon

Approved: Marvin L. Plenert

Regional Director
Title

June 30, 1992
Date

THIS IS THE COMPLETED RECOVERY PLAN FOR HAWAI'I'S ENDANGERED TREE SNAILS IN THE GENUS ACHATINELLA. IT DELINEATES REASONABLE ACTIONS THAT ARE BELIEVED TO BE REQUIRED TO RECOVER AND/OR PROTECT THE SPECIES. OBJECTIVES WILL BE ATTAINED AND ANY NECESSARY FUNDS MADE AVAILABLE SUBJECT TO BUDGETARY AND OTHER CONSTRAINTS AFFECTING THE PARTIES INVOLVED, AS WELL AS THE NEED TO ADDRESS OTHER PRIORITIES. THIS RECOVERY PLAN DOES NOT NECESSARILY REPRESENT OFFICIAL POSITIONS OR APPROVALS OF THE COOPERATING AGENCIES, AND IT DOES NOT NECESSARILY REPRESENT THE VIEWS OF ALL INDIVIDUALS WHO PLAYED A ROLE IN PREPARING THIS PLAN. IT IS SUBJECT TO MODIFICATION AS DICTATED BY NEW FINDINGS, CHANGES IN SPECIES STATUS, AND COMPLETION OF TASKS DESCRIBED IN THE PLAN.

Literature Citation: U.S. Fish and Wildlife Service. 1992. Recovery Plan for the O'ahu Tree Snails of the Genus Achatinella. U.S. Fish and Wildlife Service, Portland, OR. 64 pp. + 64 pp. of Appendices + 5 figures.

ADDITIONAL COPIES MAY BE PURCHASED FROM:

Fish and Wildlife Reference Service
5430 Grosvenor Lane, Suite 110
Bethesda, Maryland 20814
301/492-6403
or
1-800-582-3421

The fee for the Plan varies depending on the number of pages of the Plan.

## ACKNOWLEDGEMENTS

The recovery plan for the O'ahu tree snails of the genus Achatinella was prepared by Michael G. Hadfield, Stephen E. Miller, and Anne H. Carwile of the Kewalo Marine Laboratory, University of Hawai'i, 41 Ahui Street, Honolulu, Hawai'i 96822.

The authors gratefully acknowledge the many courtesies given by the staff of the Bishop Museum and The Nature Conservancy of Hawai'i. Without the records and collections of the Bishop Museum, the current status of the Achatinella species would have been impossible to determine. The compilations of The Nature Conservancy's Heritage Program shortened the work in many places. In addition, many individuals gave generously of their time and resources in helping to make the species records as up to date as possible; they are listed in Appendix II. Finally, among the many helpful critiques received from reviewers of the draft of this document, those of Dr. C. C. Christensen were exceptionally thorough and provocative. We have incorporated a number of his suggestions, especially in Part II.

## EXECUTIVE SUMMARY OF THE RECOVERY PLAN FOR O'AHU TREE SNAILS OF THE GENUS ACHATINELLA

**Current Species Status:** All 41 species in the genus *Achatinella* are federally listed as endangered. Sixteen species are now extinct, 5 species have not been seen in over 15 years, and 18 of the remaining 20 species are on the verge of extinction. Only *Achatinella mustelina* and perhaps *A. sowerbyana* are believed to exist in substantial numbers; however, their ranges are greatly reduced and recent observations show their numbers to be rapidly declining. Population levels and distributions are generally unknown due to the lack of recent comprehensive surveys.

**Habitat Requirements and Limiting Factors:** Members of the genus *Achatinella* are currently found in mountainous (above 400 m elevation) dry to wet forests and shrublands on the island of O'ahu, Hawai'i. They are arboreal, nocturnal, and feed by grazing fungus from the surface of native plant leaves. Although they are occasionally seen on exotic plants, it is unknown whether the fungal biota of these plants provides long-term support for healthy breeding populations. The most serious threats to the survival of Oahu tree snails are predation by the introduced carnivorous snail, *Euglandina rosea*, predation by rats and loss of habitat due to the spread of non-native vegetation into higher elevation forests.

**Recovery Objective:** The primary interim objective is to stabilize populations of tree snails found within essential habitat identified in Figures 2 through 5 and initiate captive propagation of same.

**Recovery Criteria:** No downlisting or delisting goal can be set at this time. However, the O'ahu tree snails may be considered for down listing once all remaining populations have been located and stabilized.

**Actions Needed:**

1. Initiate captive propagation by removing individuals from presently known populations.
2. Locate additional habitat/populations of Achatinella spp. within historic range and initiate captive propagation of same.
3. Secure essential habitat.
4. Assess and manage current threats to the continued existence of tree snails.
5. Conduct research on ecology of Achatinella spp.
6. Begin reestablishment of snail colonies.

**Total Estimated Cost of Recovery ($1,000):**

| Year | Need 1 | Need 2 | Need 3 | Need 4 | Need 5 | Need 6 | Total |
|---|---|---|---|---|---|---|---|
| 1992 | 59.5 | 45 | 0 | 187.5 | 40 | 0 | 332 |
| 1993 | 59.5 | 45 | 17 | 187 | 40 | 0 | 348.5 |
| 1994 | 34.5 | 45 | 17 | 187 | 40 | 0 | 323.5 |
| 1995 | 34.5 | 5 | 0 | 142 | 40 | 0 | 221.5 |
| 1996 | 32.5 | 5 | 0 | 142 | 40 | 0 | 219.5 |
| 1997 | 32.5 | 5 | 0 | 142 | 40 | 0 | 219.5 |
| 1998 | 15 | 0 | 0 | 142 | 40 | 5 | 202 |
| 1999 | 15 | 0 | 0 | 142 | 40 | 5 | 202 |
| 2000 | 15 | 0 | 0 | 142 | 40 | 19 | 216 |
| 2001 | 15 | 0 | 0 | 142 | 40 | 14 | 211 |
| 2002 | 15 | 0 | 0 | 122 | 0 | 14 | 151 |
| 2003 | 15 | 0 | 0 | 122 | 0 | 14 | 151 |
| 2004 | 15 | 0 | 0 | 122 | 0 | 14 | 151 |
| 2005 | 15 | 0 | 0 | 122 | 0 | 14 | 151 |
| ----- | ------ | ------ | ------ | ------ | ------ | ------ | ----- |
| Total | 373 | 150 | 34 | 2043.5 | 400 | 99 | 3099.5 |

**Date of Recovery:** 2005 - Interim Goal

## TABLE OF CONTENTS

## LIST OF TABLES



## LIST OF FIGURES

# RECOVERY PLAN FOR THE O'AHU TREE SNAILS OF THE GENUS *ACHATINELLA*

## I. INTRODUCTION

### BRIEF OVERVIEW

Hawai'i's tree snails, once so abundant, colorful and variable that they attracted world wide attention among naturalists, are mostly extinct today. The tree snails are mentioned in Hawaiian folklore and songs, and their shells were used in leis and other ornaments (Bryan, 1935). The variety of shapes, colors and patterns of the shells of the species of *Achatinella* intrigued evolutionary biologists, malacologists and amateur collectors alike. The genus is endemic to O'ahu, and the subfamily Achatinellinae is endemic to the Hawai'ian Islands. All species of *Achatinella* live in trees and bushes, feeding on fungi scraped from the surfaces of the leaves and trunks. Adult snails are hermaphroditic and can live for many years. The young are born alive. Because growth rate and fecundity are naturally very low, *Achatinella* species are especially vulnerable to loss of individuals through collection, predation or other disturbances.

Historically, destruction of native forest habitat and the introduction of predators such as rats are probable major reasons for reductions in species' range and abundance. More recently, predation by the introduced carnivorous snail *Euglandina rosea*, predation by rats, and habitat loss due to the spread of non-native vegetation into higher elevation forests have decimated populations of *Achatinella* (Hadfield, 1986). In some cases, excessive collection of snails for their shells has probably contributed to declines. Other unknown factors, such as introduced diseases, may be affecting snails as well. Where once the snails were common in most of the native forests of the Ko'olau and Wai'anae Ranges of O'ahu, today they are restricted to remnant native forests on the high ridges of both ranges.

The entire genus of Achatinella, consisting of 41 species, was placed on the U. S. Fish and Wildlife Service (USFWS) Endangered Species List on January 13, 1981; critical habitat was not designated (USFWS 1981). In 1984 the genus was listed as one of the world's twelve most endangered animals (Anon, 1985). The endangered species declaration listed 22 of the 41 species as "probably extinct." Based on the current review, it is concluded that 16 species are extinct (no living specimens have been observed for more than 25 years); another 5 species have not been seen for over 15 years. Of the remaining 20 species for which there is some recent evidence of survival, 18 have been seen only in small numbers and in very restricted areas and are on the verge of extinction. Only Achatinella mustelina and perhaps A. sowerbyana exist in substantial numbers today, but their ranges are greatly reduced, and recent observations show their numbers to be rapidly declining.

## TAXONOMY

The first Hawai'ian Achatinella shell to reach Europe was acquired as part of a shell lei by George Dixon, a British ship captain in 1786; the new species was named Helix apexfulva. Many of the species now in the genus Achatinella were originally described in other genera, among them Helix Linnaeus 1758, Turbo Linnaeus 1758, Achatina Lamark 1799, and Monodonta Lamark 1799. The genus Achatinella was erected in 1828 by Swainson and, at that time, included seven species. By 1888 the genus had accumulated 227 described species and 900 varieties, indicating the intense collecting and taxonomic interest that the snails had attracted in the mid-19th century (Pilsbry and Cooke, 1912-1914, Christensen, 1985).

Classification of genera and subordinate groups in the sub-family Achatinellinae is based entirely on characteristics of the shell, including shape, color, and color pattern. Zimmermann

(1948) commented that "no two authorities seem to be in entire agreement as to what constitutes a genus, species, subspecies, variety, or color form in this group. It is truly a complex of complexes" (p.101).

In a comprehensive monograph published in 1912-1914, Pilsbry and Cooke revised the subfamily Achatinellinae and reduced the number of *Achatinella* species to 41 (Table 1). They recognized three subgenera: *Achatinella*, sensu strictu, Swainson 1828; *Bulimella* Pfeiffer 1854; and *Achatinellastrum* Pfeiffer 1854. Within the subgenera, Pilsbry and Cooke also erected eleven taxonomic series, each of which is a group of species with many similarities and gradations of shell shape and color.

In 1942 Welch synonymized the 6 species in Pilsbry and Cooke's "series of *A. apexfulva*" plus *A. valida* into a single species, *A. apexfulva*. Welch (1954, 1958) further combined the 3 species in the "series of *A. bulimoides*" to one, *A. bulimoides*. The similarity of the species within a series led to the suggestion that each series could represent a single species (Christensen, 1985).If this trend were continued, the number of species in the genus *Achatinella* would be reduced to 12-16 (Christensen, 1985). We retain Pilsbry and Cooke's nomenclature throughout this report because it is the nomenclature used in the federal listing of *Achatinella* as an endangered genus.

Collecting Hawaiian snails was a popular activity, especially in the late eighteen hundreds. Several private collections approached 100,000 specimens each, and many of these collections were donated or sold to museums. In addition to the land snails collected by its staff, the Bishop Museum in Honolulu has the collections of Spalding (108,000 shells), J. Emerson (51,570 shells), Wilder (48,291 shells), Thwing (38,688 shells), A. Emerson (20,700 shells), Tracy (10,000 shells), Davis (5,000 shells), and others. John T. Gulick's collection of 44,500 shells was divided into 20 sets which were sold or donated to a number of institutions, including the Australian Museum and the University of Missouri (Clench 1959). Large collections of Hawaiian land shells are also held in The Natural History Museum in London, The Field Museum of Natural History in Chicago, The Academy of Natural Sciences of Philadelphia, and the Museum of Comparative Zoology at Harvard University.

In the heyday of collecting, individual species of Achatinella were referred to by common names which are not in use today. For example, *A. bellula* were known as "Pauoa pinks" and *A. juddii* were "Wahiawa grays". Collectively, members of the genus are commonly known as O'ahu tree snails, little agate shells, kahuli, pupu kuahiwi, and pupu kanioe.

## DESCRIPTION

Adult snails of the genus *Achatinella* have relatively large shells, 17 to 24 mm in length. The shells are oblong to ovate and have a more or less glossy surface. Both dextral and sinistral shell coiling occurs, although some species are restricted to one form or the other. The adult shell has 5 to 7 whorls, and the umbilicus is closed or has only a minute opening. The lip is simple in some species but becomes thickened at maturity in others. The columella bears a strong spiral lamella. Shells are often strikingly colored with spiral bands or streaks in the direction of the growth lines (Pilsbry and Cooke, 1912-1914). Taxonomic affinities, species descriptions and synonymies for the 41 *Achatinella* species are presented in Appendix I.

TABLE 1. CLASSIFICATION OF ACHATINELLA SPECIES.

The following classification is from Cooke and Kondo (1960) except for the "series" designations which are from Pilsbry and Cooke (1912-1914). Nineteen species are considered extant (*) on the Federal List of Endangered Species. Of the twenty-two species listed as extinct, it is possible that one or more persists in small, isolated populations. Table 2 gives an updated assessment of the number of extant species of Achatinella based on the data collected for this report.

Phylum Mollusca
- Class Gastropoda
  - Subclass Pulmonata
    - Order Stylommatophora
      - Suborder Orthurethra
        - Family Achatinellidae (with 6 subfamilies)
          - Subfamily Achatinellinae (with 4 genera)
            - Tribe Achatinellini
              - Genus Achatinella
                - Subgenera Bulimella, Achatinellastrum, Achatinella

Subgenus Bulimella Pfeiffer:

Series of Achatinella viridans 1

A. viridans Mighels, 1845
A. abbreviata Reeve, 1850
A. taeniolata Pfeiffer, 1846 *

Series of Achatinella byronii 3

A. byronii (Wood, 1828) *
A. lila Pilsbry, 1914 *
A. pulcherrima Swainson, 1828 *
A. decipiens Newcomb, 1854 *

Series of Achatinella bulimoides 1

A. bulimoides Swainson, 1828 *
A. rosea Swainson, 1828
A. elegans Newcomb, 1854

Series of Achatinella fuscobasis 6

A. fuscobasis (E. A. Smith, 1873) *
A. pupukanioe Pilsbry & Cooke,1914*
A. sowerbyana Pfeiffer, 1855 *

TABLE 1 continued. CLASSIFICATION OF ACHATINELLA SPECIES.

Subgenus Achatinellastrum Pfeiffer:

Series of *Achatinella vulpina*

A. vulpina (Ferussac, 1824)
A. phaeozona Gulick, 1856
A. buddii Newcomb, 1853
A. fulgens Newcomb, 1853 *
A. stewartii (Green, 1827)

Series of *Achatinella casta*

A. casta Newcomb, 1853
A. bellula E. A. Smith, 1873 *
A. juncea Gulick, 1856

Series of *Achatinella papyracea*

A. papyracea Gulick, 1856

Series of *Achatinella livida*

A. livida Swainson, 1828
A. juddii Baldwin, 1895
A. curta Newcomb, 1853 *
A. dimorpha Gulick, 1858
A. caesia Gulick, 1858

Wai'anae Range Species: Intermediate between the *A. papyracea* and *A. livida* series.

A. spaldingi Pilsbry & Cooke, 1914
A. lehuiensis E. A. Smith, 1873
A. thaanumi Pilsbry & Cooke, 1914

Subgenus Achatinella Swainson:

Series of *Achatinella lorata*

A. lorata Ferussac, 1824 *

TABLE 1 concluded. CLASSIFICATION OF ACHATINELLA SPECIES.

Series of Achatinella apexfulva

A. apexfulva, (Dixon, 1789) *
A. cestus Newcomb, 1853
A. vittata Reeve, 1850
A. turgida Newcomb, 1853 *
A. leucorraphe (Gulick, 1873) *
A. swiftii Newcomb, 1853 *

Series of Achatinella decora

A. decora (Ferussac, 1821)
A. valida Pfeiffer, 1855
A. mustelina Mighels, 1845 *
A. concavospira Pfeiffer, 1859 *

## HISTORIC RANGE AND POPULATION STATUS

Species of the genus Achatinella are found only on the island of O'ahu in the Hawaiian Islands. These species once occurred from near sea level along the windward coast (as indicated by fossilized shells), through the uppermost reaches of the Ko'olau and Wai'anae Mountains and across the central plain (Pilsbry and Cooke, 1912-1914; Emerson, Ms., undated, post-1900). However, most forests below 305 m elevation were cleared for agriculture by early Polynesians and later by European settlers. Pilsbry and Cooke (1912-1914; p. xlix) wrote:

> "That there has been a change from more humid to dryer climate in many districts of all the islands, if not known by historic evidence would be demonstrated by the restriction of most land snails to higher levels than formerly occupied. Sixty years ago the Achatinella was found in abundance at half the elevations now inhabited by them. Still earlier forest shells lived within a few feet of the present sea level, as the Kailua and

Kahuku deposits show. ...it is obvious that the Pleistocene forests extended nearly or quite to the sea on the northern and western coasts of both O'ahu and Moloka'i. The changes within the last century are held to be due to deforestation by cattle, which by destroying the underbrush cause the desiccation of the forest humus, and prevent reproduction of the native trees."

Thus by 1900 the vegetation and microclimate necessary to sustain tree snail populations were absent from low elevation areas. Since 1900, populations of snails have been found only at elevations above 305 m in shrublands, forests and bogs.

The historic ranges of all 41 Achatinella species are mapped in Appendix IV. The species' ranges presented in Pilsbry and Cooke (1912-1914) are considered here as "historic" for all except A. mustelina. For this later species, the distribution presented by Welch (1938) is taken as "historic." These range maps form a baseline from which further reductions in species ranges can be assessed. The Achatinella species had ranges varying from 3 to 150 $km^2$. Snail populations were most abundant in higher elevation ravines and the upper areas of ridges. Lack of forest on steep slopes restricted population ranges, especially on the windward (northeast) cliffs of the Ko'olau Range. Color varieties within a species or population were sometimes limited to a single tree.

The abundance of the historic populations of Achatinella species is difficult to accurately access. Most, if not all, early shell collectors were not concerned with documenting basic biological information such as distribution, abundance, habitat type or basic life history. Hadfield (1986) extensively surveyed the published literature on Hawai'ian tree snail abundance, and the following synopsis is drawn from that work. J. T. Gulick, collecting in the early 1850's, was reported to have taken in excess of 1,000 shells on a single day's outing in the northern Ko'olaus. In the southern Ko'olaus at Sugarloaf over 4,000 specimens were collected by participants in an 1853 Punahou School picnic! A similar outing yielded over 2,000 specimens comprising fourteen species of Achatinella. Cooke (1903) reported collecting 3,000 Achatinella multizonata (=A. bellula) from an area extending for about one mile on the northwestern side of Nuuanu Valley. These snails came from a number of semi-isolated populations within the described zone, suggesting fairly high local densities. Emerson characterized A. viridans on the midridge of Palolo Valley as so abundant that they "...hung in clusters on the hoe vines" (Ms., undated, post-1900). The collecting tallies from the Wai'anae Range were also impressive. For example, Baldwin (working in the late 1800's) gathered over 2,000 shells in four days from the eastern valleys of the Wai'anae Range. Thus it appears that historic colonies of achatinellas were widespread and densely populated.

## CURRENT RANGE AND POPULATION STATUS

Any attempt at assessing the current range and abundance of the 41 species of Achatinella is tentative at best, due to the continuing rapid reduction in their numbers and ranges as a result of predation and loss of habitat, and to the lack of recent comprehensive surveys, especially in the northern Ko'olau Range. The data used to estimate the status of populations and their current ranges have been obtained from field notes and interviews with individuals who have hiked the Ko'olau and Wai'anae Mountains and whose identifications of tree snail species are considered to be reliable. These individuals are acknowledged in Appendix II. Table 2 lists the year, the location, and the source of the most recent sighting for each Achatinella species. The locations are, in most cases, the names of ridges, peaks, or trails in the Ko'olau or Wai'anae Ranges. This table also codes each species on a scale from 1, relatively abundant, to 6, almost certainly extinct, as determined from modern field notes and interviews. The maps in Appendix IV show species' ranges based on field observations made since 1974. While compiling these data, it became apparent that many localities where tree snails were known to exist historically have not been surveyed in many years. Consequently, the current range and population status of many *Achatinella* species will remain uncertain until extensive and systematic surveys are done. Figure 1 shows each species' approximate current range, based on recent citings (1974 to 1989), as indicated in Appendix IV by dotted lines.

All of the surviving species of *Achatinella* have experienced enormous reductions in range and abundance (Appendix IV). In the southern Ko'olau Range, numerous areas where snails were once abundant are now completely devoid of *Achatinella* spp. One example of such a reduction is the area around Ka'au Crater at the head of Palolo Valley. Historically this area was rich in snails and was extensively collected; live populations of *Achatinella fulgens* and *A. abbreviata* were seen there as late as 1961 (Kondo, field notes, Appendix II). By 1966, surveyors of this area were unable to locate any live snails (Christensen, field notes, Appendix II). This pattern has been documented numerous times along the ridges of the Ko'olau and Wai'anae Ranges. These recent declines were almost always preceded and accompanied by the spread of the predatory snail *Euglandina rosea* into the tree snail habitats. For the species seen since 1973, reductions in their ranges have been in excess of 95% in the Ko'olau Mountains and 75% in the Wai'anae Mountains (Appendix IV).

With the exception of the work by M. G. Hadfield and his colleagues S. E. Miller, A. H. Carwile, and B. S. Mountain, tree snail abundances have not been quantitatively or systematically assessed, either historically or recently. Information gathered from recent field notes and interviews with numerous biologists and naturalists (Appendix II) indicate that the number of live snails seen on a given survey or hike ranges from 2 or 3 snails to more than 100 (only reported for *Achatinella mustelina*). Often no snails are seen. For most written reports, it is unclear if snail sightings were for one or more trees, and whether the trees were isolated or part of a larger expanse of intact native vegetation.

Based on all currently available information, snail abundances can be qualitatively assessed as follows; Achatinella mustelina, a species restricted to the Wai'anae Range, is currently the most abundant of the Hawaiian tree snails. The number of snails in a single bush or tree can range from 2 to 40. Achatinella sowerbyana, from the northern Ko'olau Mountains, is the next most abundant species with 1 to 20 snails per tree at the heart of its current range. For other extant species of Achatinella (Table 2), usually only two or three snails are found in a single bush or tree. For all species, bushes or trees containing snails are often isolated and widely scattered.

Although Achatinella is restricted to the island of O'ahu, several introductions to the forests of Kauai have been attempted (Christensen, 1985). A. bellula, introduced around 1892, has not been seen since 1911. A. vulpina, introduced around 1903-1907 was seen as late as 1973. The current status of these populations is unknown.

TABLE 2. CURRENT STATUS OF ACHATINELLA SPECIES.

Status Codes:
- 1 = extant with occasional moderate local density.
- 2 = extant but uncommon; range very restricted.
- 3 = probably extant; very few snails seen recently.
- 4 = possibly extant; not seen after 1973.
- 5 = probably extinct; not seen after 1963.
- 6 = almost certainly extinct.

| Status | Species | Last Record | Location | Source |
|---|---|---|---|---|
| (5) | *A. abbreviata* | 1963 | Waialaenui-Palolo | Kondo[1] |
| | | 1961 | Ka'au Crater | Kondo[1] |
| (2) | *A. apexfulva* | 1985 | Poamoho Trail | Chung[2] |
| | | 1979 | Peahinaia Trail | Chung[2] |
| (3) | *A. bellula* | 1981 | Above Pahoa Flats | Chung[1,2] |
| | | 1975 | Nuuanu-Kalihi Ridge | Chung[1,2] |
| (6) | *A. buddii* | uncommon by 1900 | | Pilsbry and Cooke, 1912-1914 |
| (3) | *A. bulimoides* | 1985 | Poamoho Trail | Chung[2] |
| (3) | *A. byronii* | ca.1976 | Manana Trail | Hart* |
| | | 1960 | Wahiawa Trail | Kondo[1] |
| (6) | *A. caesia* | rare by 1900 | | Pilsbry and Cooke 1912-1914 |
| (6) | *A. casta* | no current information | | |
| (4) | *A. cestus* | 1966 | Hawai'iloa Ridge | Christensen[1] |
| (2) | *A. concavospira* | 1988 | Pu'u Kaua | Chung[1,2] |
| | | 1980 | Kanehoa Trail | Chung[1,2] |
| (2) | *A. curta* | 1989 | Peahinaia Trail | Miller *et al.*[3] |
| | | 1986 | Kawailoa Trail | Chung[2] |

TABLE 2, continued.

| Status | Species | Last Record | Location | Source |
|---|---|---|---|---|
| (2) | A. decipiens | 1990 | Schofield-Waikane Trail | Hadfield et al.[4] |
| | | 1989 | Puu Kaaumakua Area | Hadfield et al.[4] |
| | | 1986 | Poamoho Trail | Chung[2] |
| | | 1974 | Waikane Trail | Gagne et al., 1975 |
| (6) | A. decora | uncommon by 1900 | | Pilsbry and Cooke, 1912-1914 |
| (4) | A. dimorpha | 1967 | Pupukea trail | Christensen[1] |
| | | 1967 | Paumaulu-Kaunala | Christensen[1] |
| (5) | A. elegans | 1952 | Ma'akua-Papali | Kondo[1] |
| | | 1952 | Punaiki-Makao | Kondo[1] |
| (2) | A. fulgens | 1989 | Pia Valley | Miller et al.[3] |
| | | 1988 | Kului Gulch | Chung[2] |
| (2) | A. fuscobasis | 1991 | Konahuanui | Hadfield et al.[1] |
| (2) | A. fuscobasis | 1989 | Konahuanui | Miller et al.[3] |
| | | 1980 | Wilwilinui Ridge | Chung[1,2] |
| (5) | A. juddii | 1958 | Pu'u Uau | Kondo[1] |
| (5) | A. juncea | no current information | | |
| (6) | A. lehuiensis | 1922 | Haleauau Valley | Pilsbry and Cooke, 1921 |
| (2) | A. leucorraphe | 1989 | Schofield-Waikane Trail | Miller et al.[3] |
| (2) | A. lila | 1987 | Poamoho | Chung[2] |
| | | 1979 | Kipapa Trail | Lepson[2] |
| | | 1976 | Manana Trail | Chung[2] |
| | | 1974 | Waikane Trail Summit | Western[1] |
| (3) | A. livida | 1981 | Laie Trail-Summit | Mountain et. al., 1981** |

TABLE 2, continued.

| Status | Species | Last Record | Location | Source |
|---|---|---|---|---|
| (3) | *A. lorata* | 1979 | Tantalus-Pauoa Flats | Christensen[2] |
| (1) | *A. mustelina* | 1991 | Pahole | Hadfield *et al.*[5] |
| | | 1990 | Ka'ala Natural Area Reserve | Hadfield *et al.*[5] |
| | | 1989 | Palikea | Hadfield *et al.*[1] |
| | | 1989 | Pahole | Hadfield *et al.*[1] |
| | | 1988 | Mokuleia | Smith[2] |
| | | 1987 | Ka'ala area | Chung[1] |
| | | 1986 | Kanehoa | Chung[1] |
| | | 1984 | Makua Valley | Christensen and Hadfield, 1984 |
| (6) | *A. papyracea* | <1945 | | |
| (3) | *A. phaeozona* | 1974 | Ka'alakei valley | Higashino* |
| (3) | *A. pulcherrima* | 1974 | Helemano | Chung[2] |
| (3) | *A. pupukanioe* | 1980 | Aiea Ridge Trail | Galloway[1,2] |
| | | 1976 | Manana Trail | Chung[1,2] |
| (5) | *A. rosea* | 1949 | Pu'u Peahinaia | Kondo[1] |
| (1) | *A. sowerbyana* | 1989 | Peahinaia | Miller *et al.*[3] |
| | | 1988 | Poamoho Trail | Shank[2] |
| (6) | *A. spaldingi* | 1938 | Pukaloa | Christensen, 1983 |
| (5) | *A. stewartii* | 1961 | Tantalus | Kondo[1] |
| | | 1960 | Manoa Cliffs Trail | Kondo[1] |
| (4) | *A. swiftii* | 1970's | ? | Hart, 1979 |
| (4) | *A. taeniolata* | 1966 | Hawai'iloa Ridge | Christensen[1] |
| | | 1966 | Kuliouou | Christensen[1] |
| (6) | *A. thaanumi* | rare since 1900 | | Pilsbry and Cooke, 1912-1914 |
| (3) | *A. turgida* | 1974 | Manana | Gagne *et. al.*, 1975 |

TABLE 2, concluded.

| Status | Species | Last Record | Location | Source |
|---|---|---|---|---|
| (5) | *A. valida* | 1951 | Kaunala-Oio | Kondo[1] |
| (3) | *A. viridans* | 1979 | Above Wailupe | Chung[2] |
| | | 1979 | Wiliwilinui Ridge | Chung[1,2] |
| | | 1976 | Above Kulepiamoa | Chung[2] |
| (6) | *A. vittata* | 1953 | Nuuanu Valley | Kondo[1] |
| (4) | *A. vulpina* | 1965 | Tantalus | Christensen[1] |
| | | 1962 | Halawa valley | Kondo[1] |

* personal communication to D. Chung.
** species identification tentative.
1 data from field notes.
2 data from interviews.
3 data from surveys supported by a grant to M. G. Hadfield from the World Wildlife Fund.
4 data from surveys supported by the U.S. Fish and Wildlife Service.
5 data from surveys supported by funds from the Hawaii Department of Forestry and Wildlife.

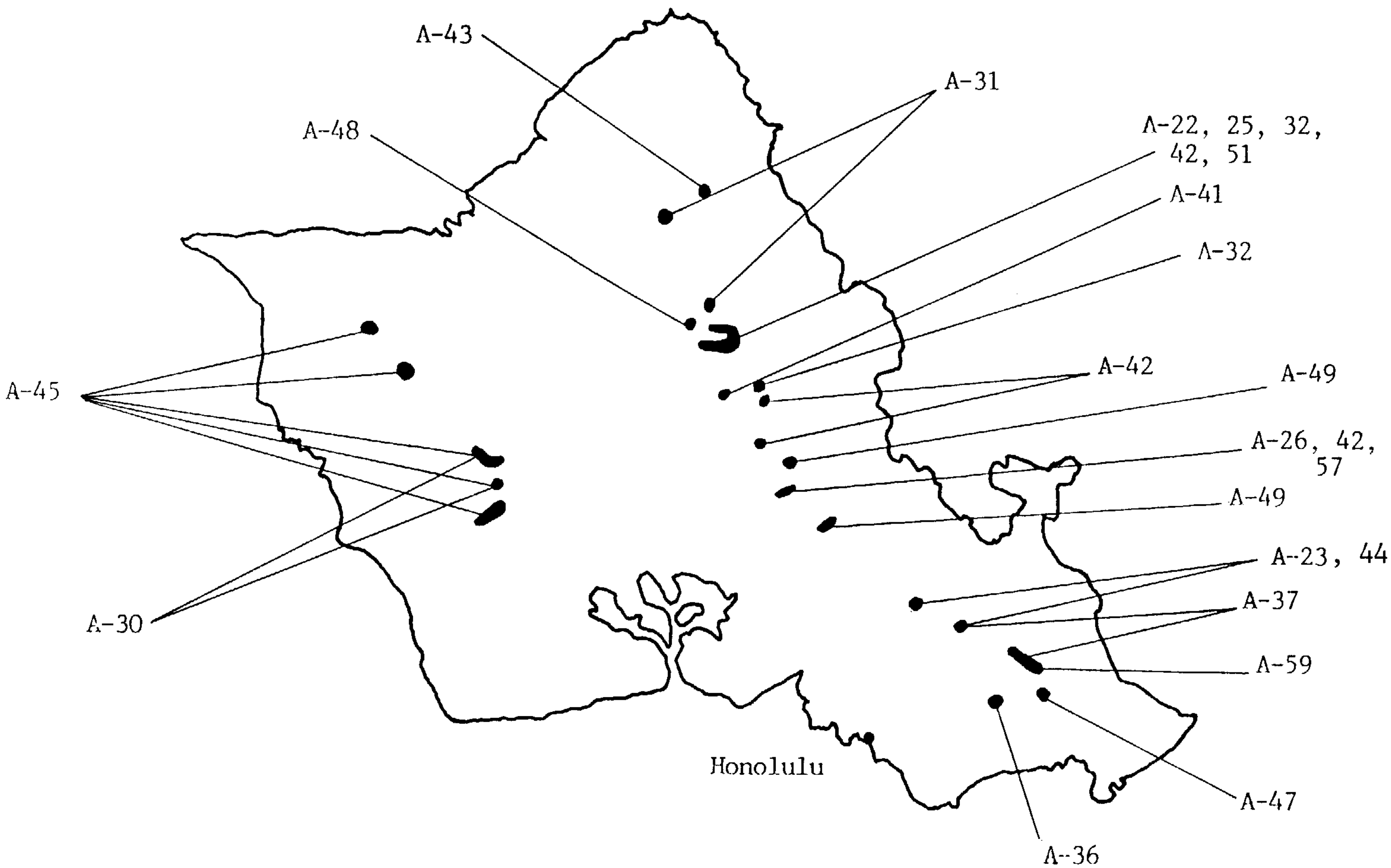



Figure 1.' Distribution of tree snail species on O'ahu (number refers to appendix range map).

## LIFE HISTORY

Members of the genus Achatinella are arboreal, nocturnal, and feed by grazing fungus from the surface of leaves (Henshaw, in Pilsbry and Cooke, 1912-1914; personal observations). According to older reports the snails occurred on a wide variety of introduced as well as native plants; however, modern observers report the snails primarily on native vegetation. Achatinellas are still occasionally seen on non-native plants, but it is not known if the fungal biota of these plants provides long-term support for healthy breeding populations.

Individuals of Achatinella species are hermaphroditic, but are assumed to be self-sterile. Adult snails almost invariably contain a single embryo in the uterus, and embryos are present at all times of year (Henshaw, in Pilsbry and Cooke, 1912-1914; Neal, 1928; Hadfield and Mountain, 1980). Young snails are born live at a relatively large size, and coexist with the adults. Data on growth, population size, and age distribution are lacking for most species of Achatinella. The most extensively studied species is A. mustelina from the Wai'anae mountains. Hadfield and his colleagues have studied the demography and life history of this species since 1972 (Hadfield and Mountain, 1980; Hadfield, 1986; Hadfield et. al., unpublished) and have found Achatinella mustelina to be about 4.5 mm. at birth. Lifespan is estimated to be at least 11 years. At sexual maturity, shell growth stops and a thickened lip or callus develops on the shell aperture; this occurs at about 7 years of age. Adult sizes range from 16.7 to 20.4 mm. The number of young produced by an adult snail is estimated at 1 to 4 per year. Severns (1981) described the growth of A. lila in captivity. The snails were 3 mm at birth and grew to a maximum size of 17 mm in an estimated 5.7 years.

During the day achatinelline snails seal themselves to leaves or trunks; at night they move about to graze. Movement of A. mustelina between trees is limited, and individually marked snails are often recovered month after month in the same bush or tree (Hadfield and Mountain, 1980; Hadfield, 1986). Only after a strong wind storm are snails found scattered into neighboring trees (Hadfield *et. al*., unpublished). Earlier authors had commented also on the lack of movement in *Achatinella* (e.g. Pilsbry and Cooke, 1912-1914; Kondo, field notes, Appendix II).

Little is known about the specific habitat requirements of *Achatinella* species. Pilsbry and Cooke (1912-1914) reported that of the variety of plant species known to support tree snail populations, not all harbor snails in any specific area. Similar observations have been made by recent field observers (Appendix II). It is unclear if this incomplete utilization of available habitat is an artifact of recent disturbances or a result of natural, tree-to-tree variation in habitat quality.

## HABITAT DESCRIPTION

Species of the genus *Achatinella* are currently found in mountainous (above 400 m elevation) dry to wet forests and shrublands on the island of O'ahu, Hawai'i. Above elevations of about 500 m native vegetation predominates. At lower elevations, including windward coastal areas and the central O'ahu plain, forests were cleared for agricultural and commercial use or were heavily invaded by exotic vegetation by 1900. These latter areas are no longer capable of supporting populations of achatinelline tree snails. The following information pertains to areas where tree snail populations have been seen in the last 80 years.

**Terrain.** Habitats for tree snails occur in both the Ko'olau and Wai'anae Mountains on O'ahu. The Ko'olau Range extends 60 km from southeast to northwest along the eastern half of the island. The windward (northeast) slope of the range is characterized by steep cliffs (pali) and short ridges less than 5-6 km long. Leeward ridges as long as 18 km parallel one another to the southwest and west alternating with steep-sided stream valleys.

In areas where tree snails persist, the central ridge varies between 670 and 950 m elevation.

The Wai'anae Range runs from southeast to northwest in a 32 km arc along the western coast of O'ahu. The steep pali of this range are to leeward (western slope); both windward and leeward ridges are less than 5 km in length. The central ridge varies between 800 and 950 m elevation in the areas inhabited by tree snails. Peak elevations occur at Pu'u Kanehoa (832 m) in the central part of the range and at Ka'ala (1230 m) in the north.

**Climate.** Tradewinds dominate the weather of the Hawai'ian Islands for most of the year (Blumenstock and Price, 1976). As these winds rise up and over the Ko'olau pali there is orographic cloud formation leading to frequent light to moderate showers on the summit and windward slopes. Annual rainfall greatly depends on the frequency and intensity of two to six major storm systems each winter (October through March). Severe droughts occur when the low pressure storm systems fail to reach the islands. Drought conditions can substantially affect the survival of juvenile snails (Hadfield et. al., unpublished). Storm-generated winds can gust up to 100-120 km/hr and may be important in dispersing tree snails to nearby trees (Hadfield et. al., unpublished).

Rainfall patterns differ dramatically within and between the two mountain ranges. Rainfall is heaviest (750 cm/yr) in the central Ko'olaus between Pu'u Ka'inapua'a (695 m) and Pu'u Pauoa (775 m). In the southern Ko'olaus the maximum rainfall (375 cm/yr) falls on the ridge between Pu'u Konahuanui (950 m) and Pu'u Lanipo (670 m). Precipitation declines with elevation along the Ko'olau Range to 190 cm/yr at about 305 m elevation. The Wai'anae Range lies in the rain shadow of the Ko'olau Range. Maximum rainfall (235 cm/yr) occurs at Ka'ala (1230 m). North of Ka'ala rainfall decreases with elevation to about 100 cm/yr at 305 m. Along the main ridge of the central and southern Wai'anaes rainfall is 100 cm/yr and 75 cm/yr, respectively. At higher elevations (generally above 700 m) in both mountain ranges fog drip within clouded areas can contribute up to 40% of the available moisture (Blumenstock and Price, 1976).

Mean monthly temperatures at elevations below 1220 m elevation vary 2-4 °C/yr, and increase 0.5-3.0 °C for each 305 m decrease in elevation (Blumenstock and Price, 1976). On the slopes of Mauna Loa on the island of Hawaii, winter temperatures average about 19.5 °C at 305 m, 16.0 °C at 900 m and 14.4 °C at 1200 m; during the summer months temperatures are around 22.3 °C at 305 m, 19.1 °C at 900 m, and 17.7 °C at 1200 m.

**Vegetation.** Hawaiian tree snails occur on a variety of native plant species found in dry, mesic, and wet forests. On O'ahu the lowest areas where snail populations may be found are remnant lowland dry forests in the Wai'anae Range. The mesic forests of the Ko'olau and upper Wai'anae Ranges retain many native plant species, but are highly disturbed by invading foreign species such as strawberry guava (*Psidium cattleianum*), silk oak (*Grevillea robusta*), christmas berry (*Schinus terebinthifolius*), *Lantana camara*, and *Clidemia hirta*. Wet forests in the Ko'olau Range have the greatest diversity of native plant species on O'ahu but still suffer from invasions of competing exotic vegetation, rooting and seed dispersal by pigs. Bogs do not constitute a major tree-snail habitat on O'ahu. Historic and current records indicate that the Ka'ala bog (Wai'anae Range) has never been a habitat for *Achatinella* species. The Ka'au Crater in the southern Ko'olaus once supported several species of *Achatinella* (Kondo, field notes, Appendix II), but recent surveys in this area indicate that these snails are locally extinct.

Snails generally avoid trees with pubescent leaves (Pilsbry and Cooke, 1912-1914). Cooke (1903) reported on the frequency of occurrence of a variety of plants and the utilization of these plants by *Achatinella multizonata* (=*A. bellula*) in Nuuanu Valley. Cooke's data suggest that snails show little preference among the plants (Table 3). Table 4 presents an incomplete listing of plant species inhabited by tree snails, as obtained from interviews and field notes of numerous biologists and naturalists (Appendix II) as well as published papers.

Table 5 provides a list of sensitive plant species that are or may be found in each of the four essential habitat areas identified in Figures 2 through 5. Any management regimes contemplated in the essential habitat areas should take into account the presence of listed, proposed and candidate species of plants, vertebrates and invertebrates. Given the lack of information on the status of native invertebrates on O'ahu, surveys will need to be done in the four essential habitat areas before management regimes that may affect such invertebrates are initiated.

TABLE 3. OCCURRENCE OF ACHATINELLA MULTIZONATA (=A. BELLULA) ON VEGETATION IN NUUANU VALLEY (COOKE 1903).

| Scientific name | Percent occurrence of the plant | Percent of snails |
|---|---|---|
| Metrosideros polymorpha | 53.3 | 54.6 |
| Psidium guajava | 29.8 | 26.7 |
| Psychotria sp. | 9.8 | 14.2 |
| Hedyotis sp. | 2.3 | 1.2 |
| Paederia foetida (=P. scandens) | 1.7 | 1.2 |
| other plants | 3.1 | 2.1 |

TABLE 4. PARTIAL LIST OF VEGETATION UPON WHICH ACHATINELLA SPECIES HAVE BEEN REPORTED.

| Scientific name | Common or Hawaiian name | Native or introduced |
| --- | --- | --- |
| Acacia koa | koa | native |
| Aleurites moluccana | kukui | introduced, prehistoric |
| Antidesma spp. | hame | native |
| Musa paradisiaca | banana, mai'a | introduced |
| Bidens spp. | ko'oko'olau | native |
| Bobea elatior | ahakea | native |
| Broussaisia arguta | puahanui | native |
| Coprosma spp. | pilo | native |
| Cordyline fruticosa | ti or ki | introduced, prehistoric |
| Diospyros spp. | lama | native |
| Dubautia spp. | many names | native |
| Freycinetia arborea | 'ie'ie | native |
| Hedyotis spp. | many names | native |
| Lantana camara | lakana | introduced |
| lobeliads | many names | native |
| Metrosideros polymorpha | 'ohi'a-lehua | native |
| Nestegis sandwicensis | olopua or pua | native |
| Pelea spp. | mokihana | native |
| Perrottetia sandwicensis | olomea | native |
| Pisonia umbellifera | papala kepau | native |
| Psidium spp. | guava | introduced |
| Psychotria spp. | kopiko | native |
| Paederia scandens | maile pilau | native |
| Sapindus oahuensis | a'ulu | native |
| Xylosma hawaiiense | maua | native |

TABLE 5. FEDERALLY SENSITIVE (E=Endangered; P=Proposed; C=Candidate (Category 1) PLANT SPECIES PRESENT IN THE FOUR ESSENTIAL HABITAT AREAS.

| | Ko'olau | | Wai'anae | |
|---|---|---|---|---|
| | North | South | North | South |
| (E) Abutilon sandwicense | | | x | x |
| (P) Alectryon macrococcus var. m. | | | x | x |
| (E) Alsinidendron obovatum | | | x | |
| (E) Alsinidendron trinerve | | | x | |
| (C) Bonamia menziesii | | | x | x |
| (C) Cyanea grimesiana ssp. obatae | | | | x |
| (E) Cyanea pinnatifida | | | | x |
| (E) Cyanea superba ssp. superba | | | x | |
| (P) Cyrtandra polyantha | | x | | |
| (E) Diellia falcata | | | x | x |
| (C) Diellia unisora | | | | x |
| (E) Dubautia herbstobatae | | | x | |
| (C) Flueggea neowawraea | | | x | x |
| (E) Gouania meyenii | | | x | |
| (C) Gouania vitifolia | | | x | |
| (E) Hedyotis degeneri var. coprosmifolia | | | x | |
| (E) Hedyotis parvula | | | x | |
| (P) Hesperomannia arborescens | x | x | | |
| (E) Hesperomannia arbuscula | | | x | x |
| (C) Hibiscus brackenridgei ssp. b. | | | x | |
| (C) Hibiscus brackenridgei ssp. mokuleiana | | x | | |
| (E) Lipochaeta lobata var. leptophylla | | | | x |
| (E) Lipochaeta tenuifolia | | | x | |
| (E) Lobelia niihauensis | | | x | x |
| (P) Lobelia oahuensis | x | x | | |
| (P) Lycopodium nutans | x | | | |
| (P) Melicope lydgatei | x | | | |
| (P) Melicope pallida | | | | x |
| (E) Neraudia angulata var. a. | | | | x |
| (E) Neraudia angulata var. dentata | | | x | |
| (E) Nototrichium humile | | | x | x |
| (E) Phyllostegia mollis | | | | x |
| (C) Plantago princeps var. anomala | | | x | x |
| (C) Plantago princeps var. longibrachiata | x | | | |
| (P) Rollandia crispa | x | | | |
| (E) Sanicula mariversa | | | x | |
| (E) Schiedea kaalae | | | x | x |
| (E) Silene perlmanii | | | | x |

| TABLE 5, Concluded | Ko'olau North | Ko'olau South | Wai'anae North | Wai'anae South |
|---|---|---|---|---|
| (P) Solanum sandwicense | | | | x |
| (P) Stenogyne kanehoana | | | | x |
| (E) Tetramolopium filiforme var. f. | | | x | |
| (E) Tetramolopium lepidotum ssp. l. | | | | x |
| (P) Tetraplasandra gymnocarpa | x | x | | x |
| (E) Urera kaalae | | | | x |
| (E) Viola chamissoniana ssp. c. | | | | x |

## REASONS FOR DECLINE AND CURRENT THREATS

The decline and disappearance of the species of Achatinella are the result of many factors acting over an extended period of time (Frick 1856; Baldwin 1887; Pilsbry and Cooke 1912-1914; Bryan 1935; Cooke 1941; Kondo 1970, 1980; Hart 1975, 1978, 1979; Hadfield and Mountain 1981); they have recently been reviewed by Christensen (1985) and Hadfield (1986). Low reproductive rates and limited dispersal abilities make them very sensitive to loss of habitat, shell collecting, and predation, all known to have contributed to the extinction of populations, varieties, and species (Hadfield, 1986).

Habitat Destruction. Removal of forests and introduction of invasive vegetation began with the prehistoric arrival of the Polynesians and accelerated after the arrival of Europeans in 1778. Lower elevation lands now used for pasture, agriculture, or housing once supported native forests occupied by achatinellid snails (Pilsbry and Cooke, 1912-1914; Emerson, Ms., undated, post-1900). Forests not cleared for agriculture were invaded by feral cattle, horses, goats and pigs (Baldwin, 1887). The grazing activities of these mammals reduced the forest understory, prevented recovery by native plants, and aided the invasion of exotic plants by spreading their seeds and clearing areas for the seeds to set. At the present time, goats and pigs remain a serious threat to the native forests. Human activities such as hunting, hiking, military maneuvers, clearing for illegal marijuana patches, and construction of helicopter landing sites. Roads and trails also contribute to the spread of exotic vegetation. Logging has significantly altered native forests; where reforestation was attempted, non-native species unsuitable as snail habitat, such as eucalyptus, ironwood, and Norfolk pine were often planted. Forest fires have a particularly catastrophic effect on snail populations. Fires not only directly kill the snails, but in the wake of a fire, non-native plants quickly spread into and dominate burned-over areas. Alteration of forest understory has led to changes in moisture and humidity which further inhibit the recovery of native forests to suitable habitat for tree snails (Pilsbry and Cooke, 1912-1914).

**Predation**: The carnivorous snail Euglandina rosea and the European rat Rattus rattus are the two demonstrated predators on extant populations of Hawaiian tree snails. Other possible predators are the terrestrial flatworm Geoplana septemlineata, which has been reported to feed on snails (Mead, 1979), the terrestrial snail Oxychilus alliarius (Severns, 1984), the Norway rat Rattus norvegicus, and the polynesian rat Rattus exulans. Parasitism and disease, though not documented in Achatinella, may also contribute to the decline of snail populations (Hadfield, 1986).

Euglandina rosea was introduced to Hawai'i between 1955 and 1956 by the Hawai'i State Department of Agriculture in an effort to control the African snail, Achatina fulica. Euglandina rosea is a voracious predator on other terrestrial and arboreal snails and is responsible for the extinction of all eight species of the tree snail genus Partula on the island of Moorea in French Polynesia (Clarke and Murray, 1984; Murray et. al., 1988). Euglandina rosea follows mucous trails of other gastropods (Cook,

1985) and will climb trees and bushes to capture its prey. Already by 1958 Euglandina was found in Makiki Heights with dead Achatinella (Kondo, field notes, Appendix II). Since its introduction, E. rosea has spread to low and high elevations throughout the Ko'olau and Wai'anae Ranges and has been the cause of the local extinction of many populations of Achatinella (field notes of Hadfield, Kondo, Christensen, and Chung, Appendix II). An example of the impact of Euglandina rosea follows.

A population of Achatinella mustelina occupying a 5 by 5 m quadrate at an elevation of 730 m on Kanehoa Ridge in the central Wai'anae Range was intensively studied by mark-recapture methods from 1974 to 1976 (Hadfield and Mountain, 1980). Among other demographic parameters determined, the population of A. mustelina was estimated at 215 snails in the quadrate. Furthermore, the population was stable during the regular mark-recapture censusing, with a low level of mortality due to rat predation. Between 1972 and 1976 Euglandina rosea was observed at successively higher elevations along Kanehoa Ridge; they were observed at 300 m in 1974 and near 700 m in 1977. In August 1979, shells of E. rosea were abundant at the study site, and an intensive search of the quadrate failed to locate a single living individual of A. mustelina or any other terrestrial or arboreal snail species, many of which had previously been observed in the area. A broader search of the area around the study site showed that the invasion of once rich habitat by E. rosea had led to the total disappearance of the native snail fauna.

Rattus rattus became widespread on O'ahu in the 1870's (Atkinson 1977; Perkins, 1899). In 1887 Baldwin noted that it was not uncommon to find large numbers of shells around the lairs of rats and mice. Kondo mentions in his field notes from the 1950's (Appendix II) that Achatinella shells damaged by rats were common beneath the snail trees at many locations. The best documented example of the impact of rats on tree snails comes from an unpublished report (Hadfield, 1988) to the U. S. Fish and Wildlife Service and the Hawai'i State Division of Forestry and Wildlife.

The study site at which the rat invasion occurred had been surveyed once a month for 4 1/2 years prior to the invasion. On the basis of shells recovered on the ground at each visit, Hadfield and his colleagues estimated that about 10% of the shells of *Achatinella mustelina* had been broken by rats (Hadfield, 1986). Between January and April 1988, rats invaded this well-studied site and killed about half of the snails in the population. The rats selectively preyed on larger snails, eliminating about 76% of the reproductive adults and 72% of snails over 15 mm in length. Only 16% of the snails under 15 mm long were killed by rats. Even if no other disturbances occur at this site, the population of *A. mustelina* will take years to recover from this sudden and catastrophic surge in rat-caused mortality.

**Collecting**: Historically, collecting was probably responsible for a decline in ranges and abundance of some species of *Achatinella* (Hadfield, 1986). In the mid- to late 1800's "land shell fever" hit the island, and hundreds of thousands of snails were collected for their shells (Alexander, 1953; Kay, 1970; Emerson, Ms., undated, post-1900). By 1914 several species had declined drastically and were considered rare (Pilsbry and Cooke, 1912-1914). Though collecting abated by about 1940, most *Achatinella* species were already severely decimated. Today, collecting even two or three adult snails can remove a large percentage of the reproductive population in a bush or tree, thereby driving that population closer to extinction. Collecting of tree snails must now be viewed as a threat to the further survival of the species.

## CONSERVATION EFFORTS

**Endangered Status.** The entire genus *Achatinella* was placed on the U.S. Endangered Species list in 1981 (USFWS 1981). Critical habitat was not designated. The genus *Achatinella* was placed on the Hawai'i State Endangered Species List in 1981. In 1988, the Hawai'i State Division of Forestry and Wildlife formulated the "Threatened and Endangered Species Plan for Wildlife, Plants and Invertebrates" (1988); this plan recommended specific actions to deal with the problems of protecting threatened and endangered species and set priorities for action. Proposed actions include the establishment of snail sanctuaries, elimination of snail predators, and the development of propagation programs for *Achatinella*; however, all these proposals were given low priority for implementation at the time of writing.

**Habitat Protection.** Populations of *Achatinella mustelina* exist within the boundaries of the State Pahole and Ka'ala Natural Areas Reserves (Appendix II). Most other known extant populations of *Achatinella* spp. occur in forests regulated by the Hawai'i State Department of Land and Natural Resources, the United States Department of Defense, or private owners such as Campbell Estate. In 1990, The Nature Conservancy leased a 3,692-acre tract from Campbell Estate at Palikea in the Wai'anae Mountains. This reserve was established in part to protect populations of *A. mustelina*. Virtually all of the lands managed by the State are zoned conservation.

**Determination of Range and Present Population Status.** Most of the recent data on species' ranges for *Achatinella* have come from private individuals who have an interest in native Hawaiian biota (Appendix II and Table 2). Systematic field surveys of the status of *Achatinella* have been limited to the work outlined in Table 6. Extensive valley and ridge surveys have been conducted as part of environmental impact studies in North Halawa Valley (Hadfield, 1981), the Kahuku area (Hadfield, 1981), high elevation sites between Laie and Wahiawa (Mountain *et. al.*, 1981a, 1981b), and Makua Valley (Christensen and Hadfield, 1984). In 1988, a World Wildlife Fund grant was awarded to M. G. Hadfield to carry out a series of twelve 1-day surveying trips into selected areas of the Ko'olau and Wai'anae Mountains. The purpose of these surveys is to assess the abundances and ranges of populations of Achatinella and, where possible, to identify populations for later life-history studies. These surveys were completed in 1989.

The Nature Conservancy's Hawai'i Heritage Program is in the process of collecting recent (post 1945) geographical and abundance data on all species of Achatinella. This program is ongoing and will be a useful depository for distributional information.

**TABLE 6. RECENT SYSTEMATIC SURVEYS FOR ACHATINELLA SPECIES CONDUCTED BY M. G. HADFIELD AND HIS COLLEAGUES.**

| Location (maximum elevation) | Year | Species | Number Seen |
|---|---|---|---|
| Multi-day Surveys | | | |
| Kahuku (6 days; 183 m) | 1981 | no snails seen | -- |
| Laie-Wahiawa* (3 days; 700 m) | 1981 | A. livida | 1 |
| | | A. sowerbyana | 12 |
| N. Halawa Valley (12 days; 550 m) | 1981 | no snails seen | -- |
| Makua Valley (8 days; 700 m) | 1984 | A. mustelina | 256 |
| Peahinaia** (2 days; 610 m) | 1989 | A. curta | 3 |
| | | A. sowerbyana | 5 |
| Puu Ka'aumakua[1] (2 days; 800 m) | 1989 | A. decipiens | 7 |
| Pahole NARS[2] (12 days; 500-1300 m) | 1990 | A. mustelina | >300 |
| N. of Schofield-Waikane Trail[1] (2 days; 650 m) | 1990 | A. decipiens | 5 |
| Mt. Ka'ala NARS[2] (3 days; 1230 m) | 1990 | A. mustelina | >50 |
| 1-day Surveys(maximum elevation) | | | |
| Kawailoa Trail (610 m) | 1983 | no snails seen | -- |
| Kului Gulch (350 m) | 1983 | A. fulgens | 6 |
| Pahole NAR area (700 m) | 1983 | A. mustelina | 51 |

TABLE 6, concluded.

| Location | Year | Species | Number Seen |
|---|---|---|---|
| Peahinaia Trail (550 m) | 1983 | A. curta | 6 |
| | | A. sowerbyana | 4 |
| Poamoho Trail (670 m) | 1983 | A. apexfulva | 3 |
| | | A. sowerbyana | 12 |
| Ka'au Crater area** (560 m) | 1988 | no snails seen | -- |
| Manana Trail** (520 m) | 1988 | no snails seen | -- |
| Palikea Ridge** (915 m) | 1988 | A. mustelina | 37 |
| Waimano Trail** (500 m) | 1988 | no snails seen | -- |
| N. Halawa Trail** (670 m) | 1989 | no snails seen | -- |
| Hawai'iloa Ridge** (730 m) | 1989 | no snails seen | -- |
| Konahuanui** (960 m) | 1989 | A. fuscobasis | 6 |
| Pia Valley in Niu** (460 m) | 1989 | A. fulgens | 1 |
| Schofield-Waikane Trail** (550 m) | 1989 | A. leucorraphe | 1 |
| | | A. sowerbyana | 1 |
| Waikane Trail summit[1] (850 m) | 1989 | A. decipiens | 5 |
| N. of Kipapa Trail[1] (800-900 m) | 1989 | no snails seen | -- |
| Peahinaia ridge and s.[1] (800 m) | 1990 | no snails seen | -- |
| Konahuanui (960 m) | 1991 | A. fuscobasis | 11 |

* Selected sites above 380 m between Laie Trail and Schofield-Waikane Trail (Mountain et. al., 1981a, 1981b).
** Supported by a grant to M. G. Hadfield from the World Wildlife Fund.
[1] Supported by the U.S. Fish and Wildlife Service.
[2] Supported by funds from the Hawaii Department of Forestry and Wildlife.

**Research on Life History and Habitat Requirements**: The life histories of two Achatinella species have been studied recently using mark-recapture methods (Hadfield and Mountain, 1980; Hadfield, 1986; Hadfield et. al., unpublished). Growth rates, population sizes, fecundities, mortalities, and life spans for three populations of Achatinella mustelina from the northern, southern, and central Wai'anae Mountains were studied. Similar, but much less extensive data have been collected for a small population of A. sowerbyana in the central Ko'olau Mountains (Hadfield et. al., unpublished). To date, these studies represent the only comprehensive and systematic work on the biology of achatinelline snails. The methodology developed in these studies can be used to study other species of Achatinella.

**Captive Propagation.** Apart from a 3-month study by Severns (1981) with specimens of Achatinella lila, the work of M. G. Hadfield and his colleagues at the University of Hawai'i is the most complete and long term effort at captive propagation of Hawaiian tree snails. This work began in 1986 with two achatinelline species from Moloka'i, Partulina proxima and P. redfieldii. Considerable effort has been invested in improving the propagation methods (Appendix III). If conditions are not optimal, premature birth may significantly increase juvenile mortality; low growth rates and small size at sexual maturity can also result from inadequate propagation conditions (Carwile, Hadfield and Miller, unpublished). Innovations in captive propagation methods have improved survivorship of snails in the laboratory. Studies on captive propagation of Achatinella spp. are currently being carried out by Michael Hadfield and his colleagues at the University of Hawaii. They have maintained specimens of Achatinella decipiens, A. mustelina and A. fuscobasis for periods of 8 to 18 months. As of October 1991, 10 adult A. mustelina have produced 25 healthy offspring, and establishment of a new field population using these progeny is currently being considered.

**Predator Control.** Hadfield (1988) reported a large increase in mortality in a population of A. mustelina due to rat predation. In May 1988, David Smith of the Natural Areas Reserves management group, Hawai'i Division of Forestry and Wildlife, placed rat-poison bait boxes at the site where the predation had occurred.

The poisoned bait rapidly and continuously disappeared from the boxes after their installation. No additional rat predation was observed in September 1988, or February 1989 (Hadfield et. al., unpublished data).

Recently, efforts were begun to control predators around a population of A. mustelina near Pu'u Palikea in the southern Wai'anae Mountains. In May 1988, two live Euglandina rosea were found together with many freshly killed A. mustelina on the ground beneath bushes containing live A. mustelina. M. G. Hadfield and S. E. Miller of the University of Hawaii developed an interim management plan for this population which is being implemented together with The Nature Conservancy and The Estate of James Campbell (owners of the property). Trained volunteers from The Nature Conservancy are monitoring rat-bait stations and searching for Euglandina around the snail trees; Hadfield and Miller are using mark-recapture methods to assess the stability of the population of A. mustelina.

## II. RECOVERY

### OBJECTIVES

The primary objectives of this recovery plan are to initiate captive propagation of all extant Oahu tree snail species, secure the four essential habitat areas identified in Figures 2 through 5 and stabilize the populations of tree snails found within those areas.

The status of most Hawaiian tree snails is so poorly known that no downlisting or delisting objective can be established at this time. Eventually, through the development of populations in nature that are robust and free of the twin threats of predation and habitat destruction, steps should be taken to downlist the Hawaiian tree snails (or individual species) to Threatened.

NARRATIVE

1. Continue and expand captive propagation efforts.

Captive propagation may be the only way to prevent the extinction of certain species of tree snails. During the spring of 1990, Hadfield and his colleagues found numerous, scattered populations of Achatinella species that consisted of fewer than 10 snails, often including 1 or 2 adults. In many of these situations, the predatory snail Euglandina rosea was present and obviously rapidly destroying the populations. Because of the threat of E. rosea predation and the fear that low numbers of adults have reduced breeding efficiency, Hadfield and his colleagues removed snails of three Achatinella species to the lab between March 1990 and January 1991. One of these, A. fuscobasis, now appears to exist only at the peak of Konahuanui, and Euglandina rosea is found there, in the very bushes occupied by the Achatinella. There is no doubt that time is running out for many populations, and probably species of Achatinella. Only immediate collection and captive propagation can save them until such time as newly discovered predator-control programs can make natural habitats safe for them again.

Hadfield and his colleagues at the University of Hawaii have maintained specimens of Achatinella decipiens, A. mustelina and A. fuscobasis for periods of 8 to 18 months, using the methods described in Appendix III. As stated in the Introduction section of this plan (Part 1), as of October 1991, 10 adult A. mustelina have produced 25 offspring that may be used in the establishment of a new field population.

11. Study captive propagation methods.

Additional data for successful captive propagation of large numbers of achatinelline snails must be obtained. More trials with small environmental chambers need to be made. If the exceedingly slow growth rates measured for achatinelline snails in the field are due even in part to scarcity of food, then it is probable that growth rates can be increased and generation times shortened by supplying large amounts of "natural" foods to snails in captivity. Thus far, Hadfield and his co-workers have found that the growth rates of snails are accelerated in the laboratory, up to 4 fold. This will be an important step in building populations large enough to attempt reintroduction.

111. Develop methods for cultivation of native fungal foods for snails.

Further research on the cultivation of black molds specific to native Hawaiian trees, the usual food of Achatinella spp., is an essential part of captive culture. While Hadfield and co-workers (unpublished) have succeeded in starting cultures of black molds from native trees, they have found these molds to be very difficult to maintain and sub-culture. Other methods should be tried in a broad, experimentally based approach to growing one or more species of fungus obtained from native trees that are frequently inhabited by the achatinelline species, such as Metrosideros polymorpha and Antidesma spp. In the interim, snail diets can be augmented with the readily cultured sooty molds that are common on cultivated trees in Hawaiian yards and gardens; current work has shown that Partulina spp. readily eat sooty molds.

112. Experiment with parameters, such as day length, to accelerate growth/maturation.

Achatinelline snails are typically nocturnal. Except on very dark and rainy days, the snails stay sealed against a leaf or trunk during daylight hours and feed only at night. Snails can possibly be encouraged to eat more, and thus grow faster, by putting them in environmental chambers where dark periods are considerably longer than normal. Studies on day length should be conducted as controlled experiments to watch for potential detrimental affects of altered day length. Laboratory studies on the effects of other parameters on growth and maturation should be initiated as knowledge of such parameters is gained through research on the ecology of these little-known species.

12. Establish and maintain facilities for captive propagation.

For purposes of propagation of large numbers of individuals of Achatinella of several species, much larger habitats must be provided. Spacious, green-house enclosures ("snail houses") are needed where large, planted native trees and bushes can be maintained under ambient daylight conditions. By carefully monitoring meteorological conditions at field sites prior to collecting snails for captive propagation, the "snail houses" can be set up with climatic regimes that mimic those in the field; parameters to be controlled include temperature (fluctuating daily and seasonally), standing humidity, and rainfall (frequency and duration).

Snails of different species, but taken from similar elevations and habitats, can be propagated together in the same snail house as long as the species are isolated from each other in order to prevent interspecific hybridization. By eliminating sources of predation and hopefully disease, these enclosures can make a major contribution to both preserving species and building sufficient numbers to reestablish populations in areas where they are about to be, or already are, extinct.

13. Remove snails from field populations for captive propagation.

Once adequate "snail houses" have been built and tested, *Achatinella* species should be removed from native populations for the purpose of captive propagation. Populations of achatinelline snails from which individuals may be removed will fall into one of two categories: (1) relatively robust, but geographically restricted, populations of species that were once much more widespread; and (2) very small populations of snails (less than 20) living in habitats of very restricted area or under conditions where the snails' survival is highly unlikely due to predators, habitat loss, or other factors. Steps to be followed subsequent to finding a population of an *Achatinella* species will vary depending on which of these two categories best describes it. For populations in the first category, relatively small numbers (perhaps 10-20) of snails could be removed and placed in the environmental chambers to serve as a source for establishing new populations in areas deemed suitable (see below). Populations in the second category may represent the only remaining members of a species. Such populations may be so small and/or threatened that their persistence in nature is highly doubtful. If the population cannot be managed in the wild, they should be removed *in toto* and brought to the snail enclosures. Hopefully, by removing these residual snails to optimal habitats, free of predators and other unrecognized detrimental factors, the snails can not only be conserved, but propagated into numbers that can eventually be reintroduced to suitable field sites. These might or might not be the original sites from which the snails were removed. It is unlikely that any species other than *Achatinella mustelina* and *A. sowerbyana* currently occur in populations in the first category.

2. **Locate and evaluate additional populations of Achatinella spp. within four essential habitat areas.**

There is no doubt that many of the described species of Achatinella no longer exist. However, for some of these species there is uncertainty due to the lack of recent comprehensive field surveys. Furthermore, for species which are known to persist, the extent of their current ranges and the status of their populations are unknown. Table 7 identifies the four essential habitat areas in which the extant species of Achatinella are known to exist.

21. Conduct surveys.

Comprehensive field surveys should be undertaken in the four essential habitat areas identified in Figures 2 through 5 and shown in Table 7. Subsequent to surveys, all populations identified should be studied to determine their importance to the continued existence of any species or subspecies.

**TABLE 7. DISTRIBUTION OF TREE SNAIL SPECIES BY ESSENTIAL HABITAT UNITS.**

| | Wai'anae Mountains | | Ko'olau Range | |
|---|---|---|---|---|
| | Northern | Southern | Northern | Southern |
| Achatinella mustelina | A-45 | A-45 | | |
| A. concavospira | | A-30 | | |
| A. apexfluva | | | A-22 | |
| A. bulimoides | | | A-25 | |
| A. byronii | | | A-26 | |
| A. curta | | | A-31 | |
| A. decipiens | | | A-32 | |
| A. leucorraphe | | | A-41 | |
| A. lila | | | A-42 | |
| A. livida | | | A-43 | |
| A. pulcherrima | | | A-48 | |
| A. pupukanloe | | | A-49 | |
| A. sowerbyana | | | A-51 | |
| A. turgida | | | A-57 | |
| A. bellula | | | | A-23 |
| A. fulgens | | | | A-36 |
| A. fuscobasis | | | | A-37 |
| A. phaeozona | | | | A-47 |
| A. viridans | | | | A-59 |

211. Northern Ko'olau range.

The region of O'ahu where intensive surveys are most urgently needed lies in the northern half of the Ko'olau Range, shown in Figure 2. Beginning at about Kipapa Stream and extending northward, each ridge running from both windward and leeward sides of the range should be ascended by survey teams. The teams should be trained to locate and identify achatinelline snails. Furthermore, each team should include at least one member who is familiar with native Hawaiian plants. By identifying appropriate trees, shrubs or vines, the survey team can focus its search for tree snails on the most likely habitats. The surveys should extend well down onto the sides of ridges, using ropes for security where necessary, and into high elevation gullies. Many of the tree species favored by achatinelline snails (e.g. *Antidesma* spp.) are especially abundant on very steep slopes.

Most (but not all) of the known remaining populations of *Achatinella* spp. occur near the highest elevations in the Ko'olau Range. Thus, the surveys must include regions that are accessible only from the central ridge of the range. From that ridge, short, precipitously ending side ridges, both to leeward and windward, should be systematically searched. Recent information from scattered sources indicates that these relatively inaccessible high elevation sites are the most probable places to find relict populations of species of *Achatinella* that once inhabited the northern Ko'olau Range (see maps, Appendix IV).

212. Southern Ko'olau range.

Intensive surveys, using the same methods detailed in Task 211, must also be conducted in the areas delineated in Figure 3.

213. Northern Wai'anae range.

Intensive surveys, using the same methods detailed in Task 211, must be conducted in the areas delineated in Figure 4.

214. Southern Wai'anae range.

Intensive surveys, using the same methods detailed in Task 211, must be conducted in the areas delineated in Figure 5.

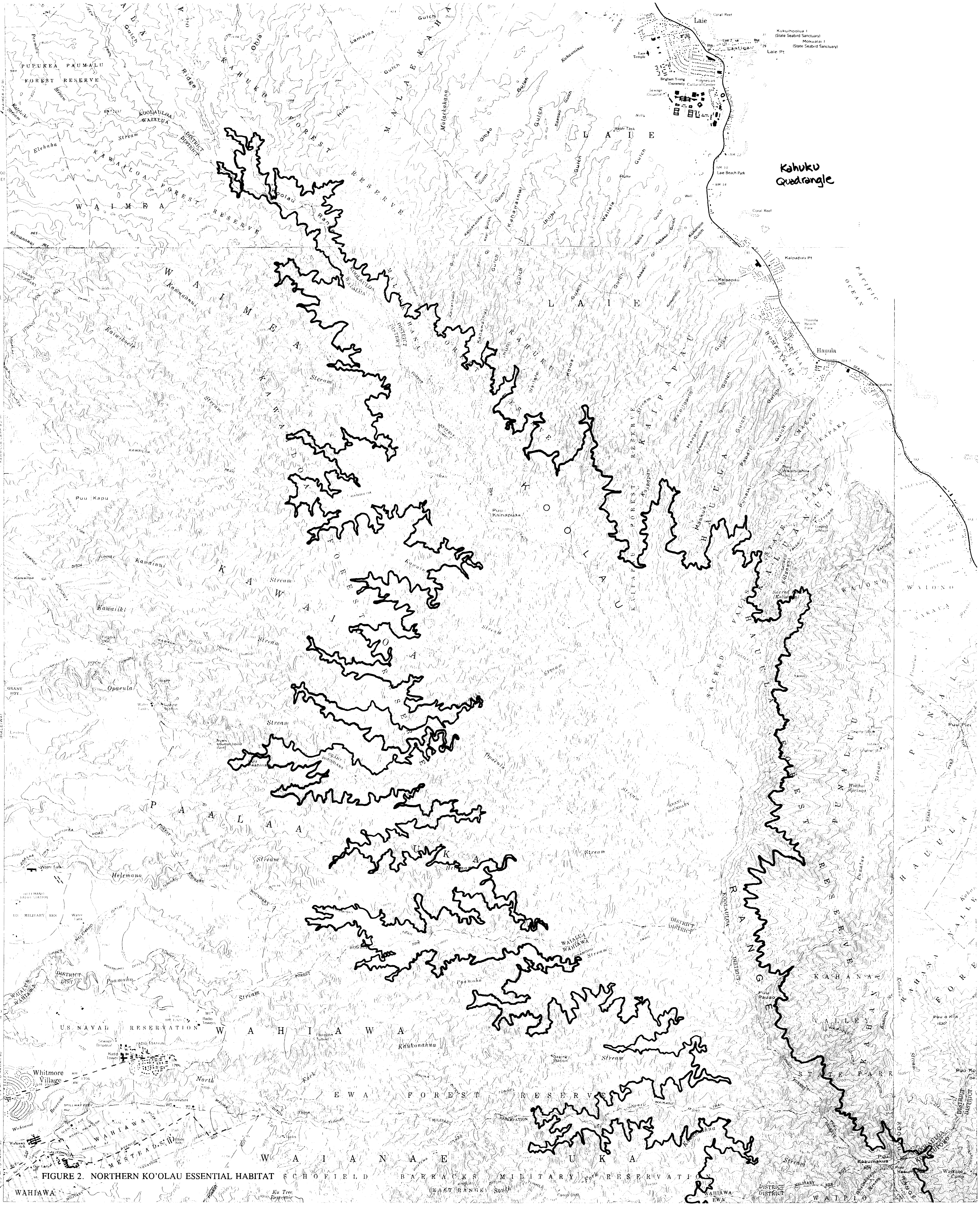



FIGURE 2. NORTHERN KO'OLAU ESSENTIAL HABITAT

WAIPAHU QUADRANGLE
HAWAII—HONOLULU CO.
ISLAND OF OAHU
7.5 MINUTE SERIES (TOPOGRAPHIC)

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

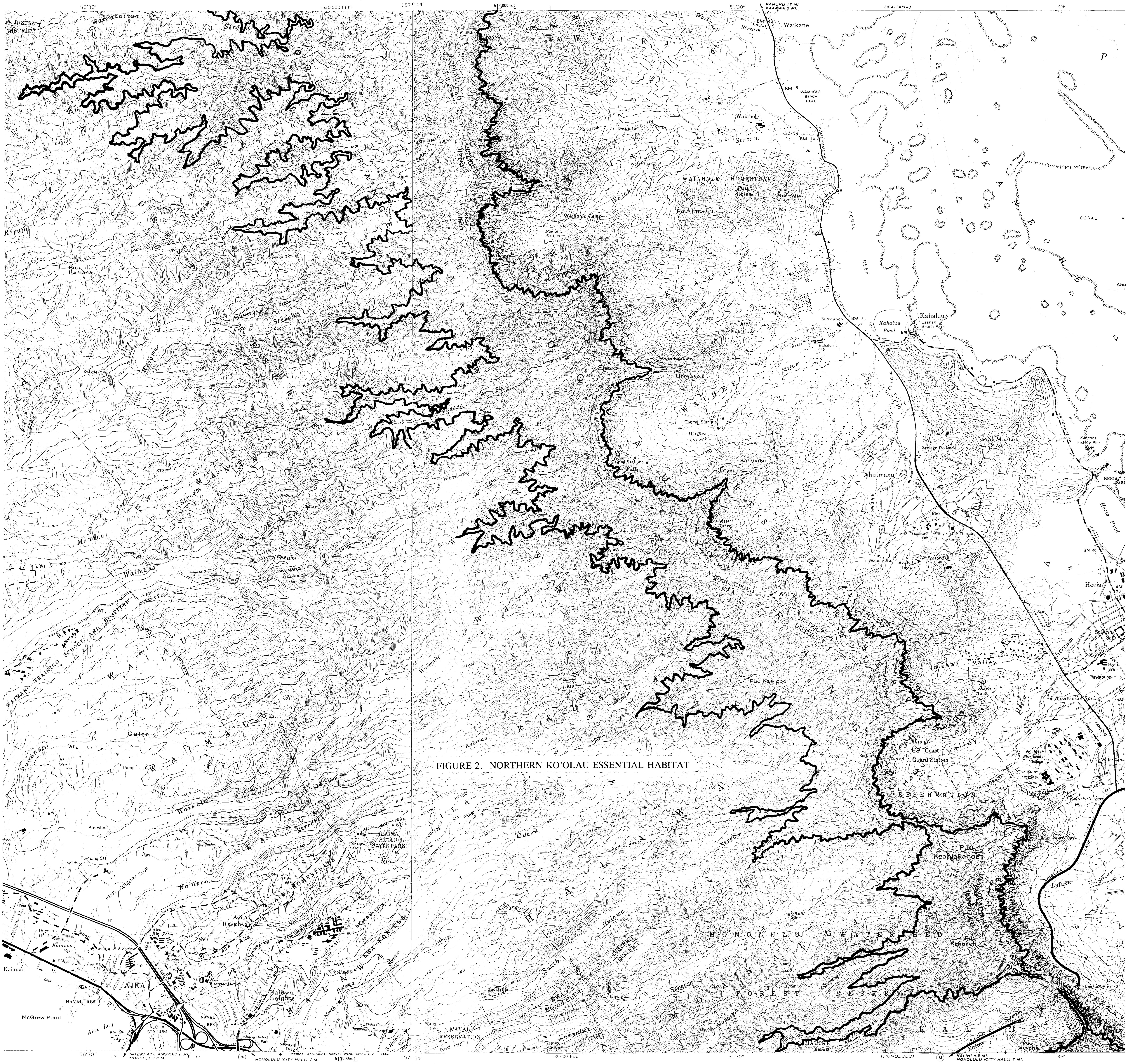



FIGURE 2. NORTHERN KO'OLAU ESSENTIAL HABITAT

ROAD CLASSIFICATION
Heavy duty — Light duty
Medium duty — Unimproved dirt
Interstate Route — State Route

HAWAIIAN ISLANDS
QUADRANGLE LOCATION

Map of the Island of Oahu, scale 1:62 500, 1954, is available

WAIPAHU, HAWAII
N2122.5—W15754/7.5
1983

Mapped, edited, and published by the Geological Survey
Revised in cooperation with Hawaii Dept. of Transportation

Control by USGS and NOS/NOAA

Topography by photogrammetric methods from aerial photographs taken 1954. Field checked 1968. Revised from aerial photographs taken 1978. Limited field check 1981. Map edited 1983

Selected hydrographic data compiled from NOS/NOAA chart 4134 (1964)
This information is not intended for navigational purposes

Projection and 10,000-foot grid ticks: Hawaii coordinate system, zone 3 (transverse Mercator) Clarke spheroid 1866. Old Hawaiian Datum 1000-meter Universal Transverse Mercator grid ticks, zone 4, shown in blue. International spheroid. To place on the predicted North American Datum 1983 move the projection lines 354 meters north and 284 meters west as shown by dashed corner ticks

Red tint indicates areas in which only landmark buildings are shown

There may be private inholdings within the boundaries of the National or State reservations shown on this map

APPROXIMATE MEAN
DECLINATION 1983

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 20-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL
DEPTH CURVES AND SOUNDINGS IN FEET—DATUM IS MEAN LOWER LOW WATER
SHORELINE SHOWN REPRESENTS THE APPROXIMATE LINE OF MEAN HIGH WATER
THE RELATIONSHIP BETWEEN THE TWO DATUMS IS VARIABLE
THE AVERAGE RANGE OF TIDE IS APPROXIMATELY 1 FOOT

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

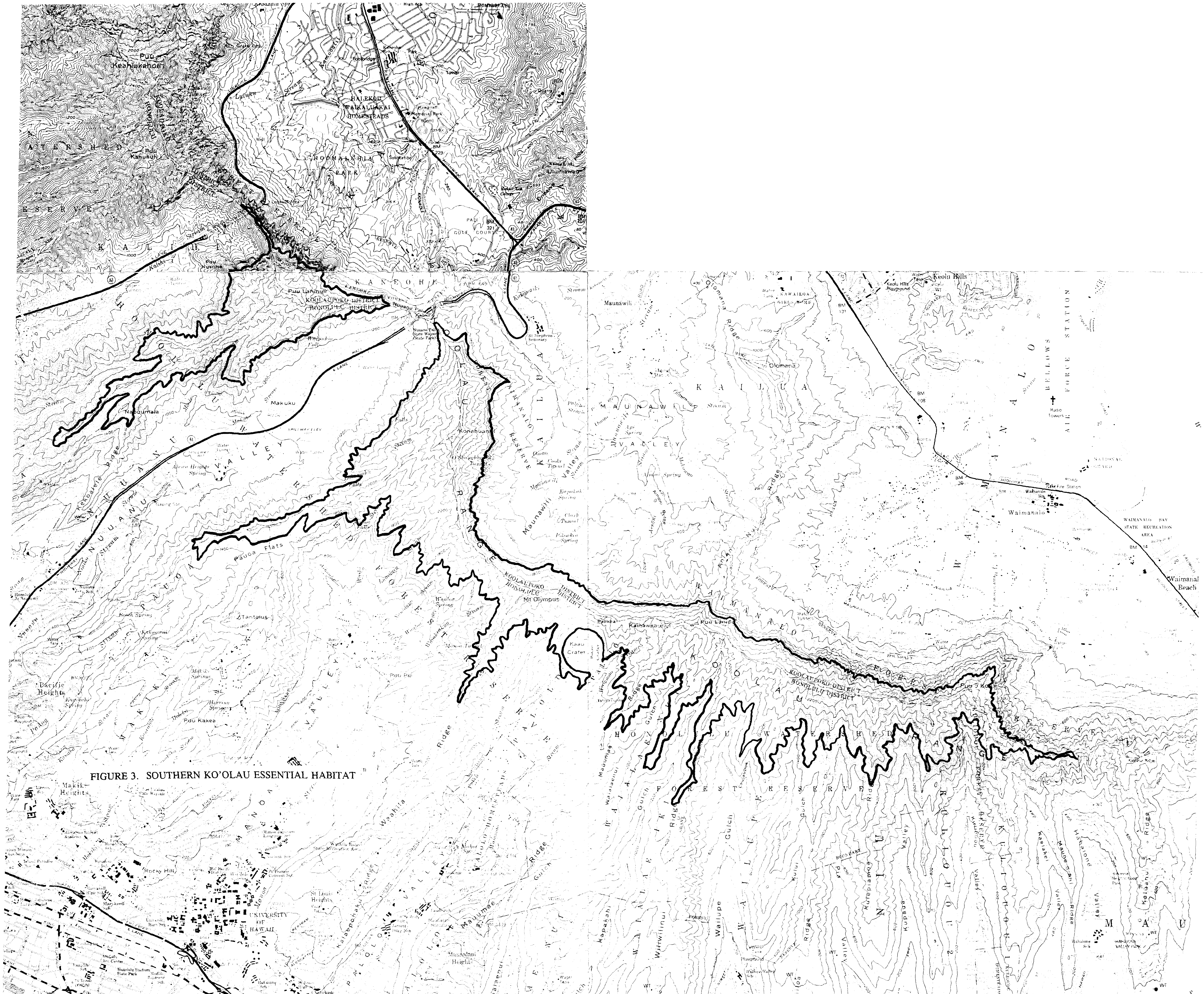



FIGURE 3. SOUTHERN KO'OLAU ESSENTIAL HABITAT

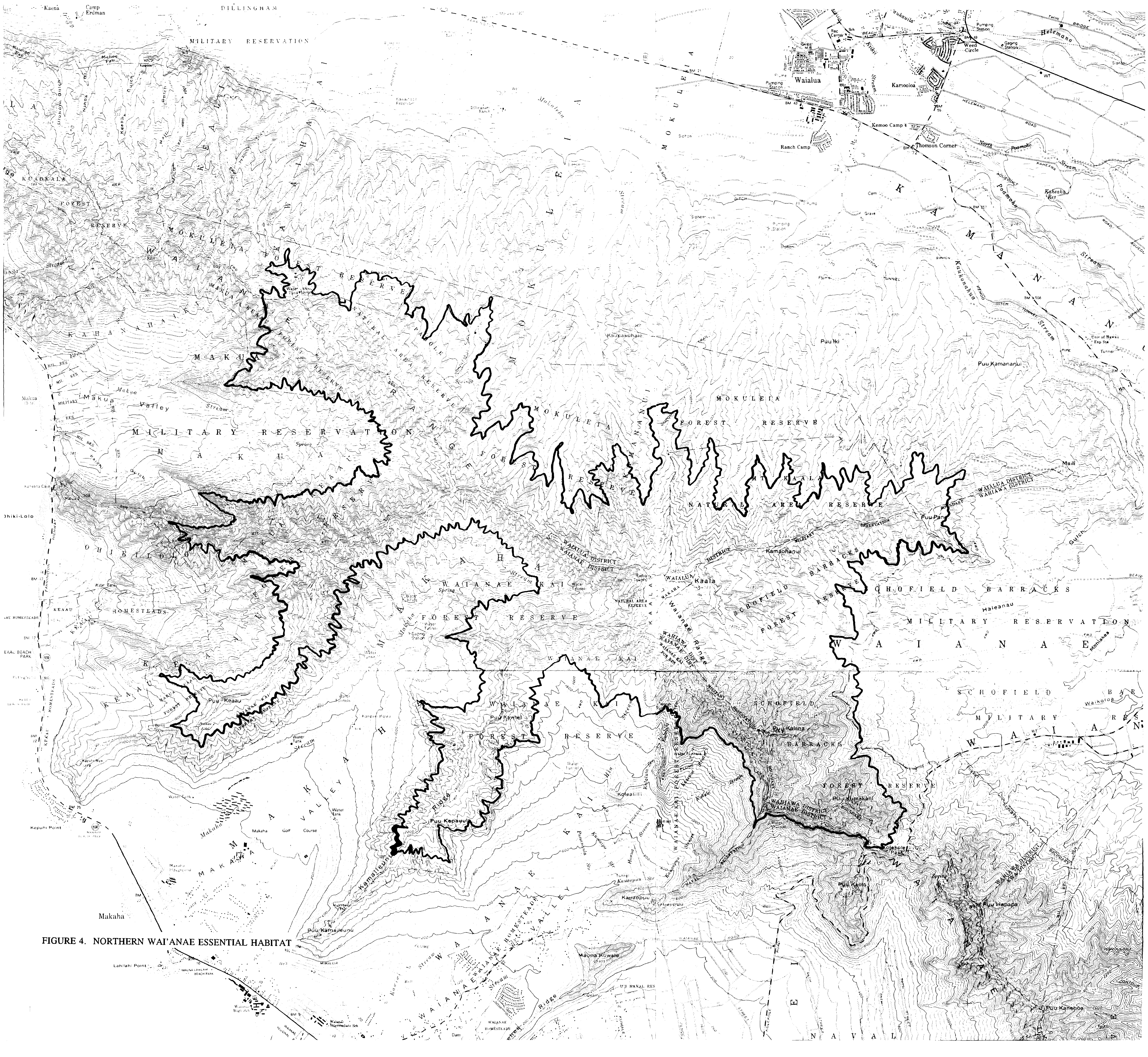



FIGURE 4. NORTHERN WAI'ANAE ESSENTIAL HABITAT

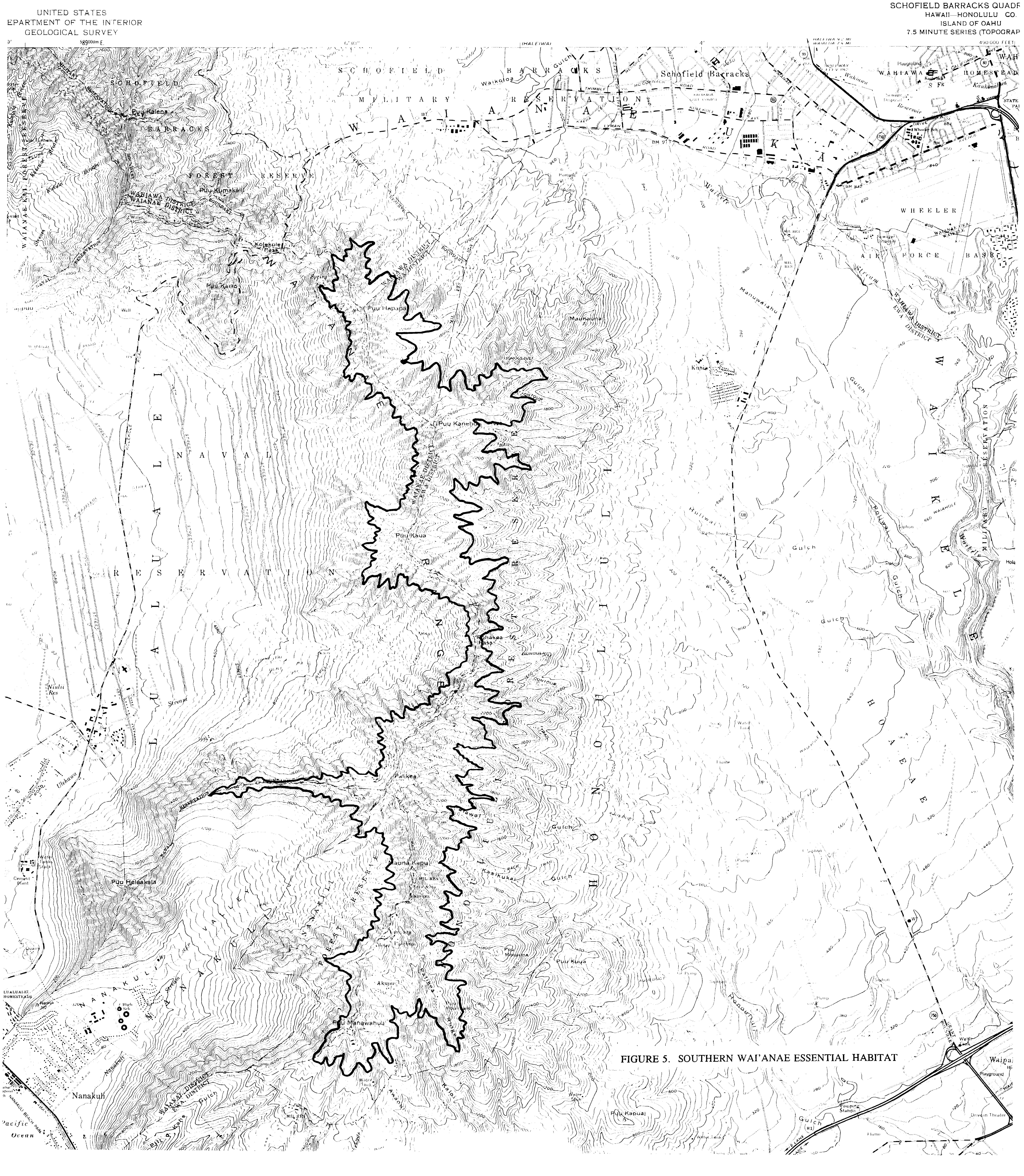



FIGURE 5. SOUTHERN WAI'ANAE ESSENTIAL HABITAT

22. Map geographical area occupied by each population.

When a population is found: (1) the species should be identified by comparing photographs (or perhaps dead, ground shells) with museum specimens, (2) the geographic extent of the population should be determined and mapped by careful examination of all vegetation in the vicinity of the population, and (3) it should be determined who currently is responsible for the land where the population lies. (If the land is in any other category than one restricted for conservation purposes, steps should be taken to place it in such a category.)

3. **Assess and manage current threats to the continued existence of tree snails.**

Factors in each habitat that tend to reduce the viability of populations should be sought. The presence of known and potential predators should be especially determined.

31. Conduct research on methods to eliminate predators.

The predatory snail, *Euglandina rosea*, and rats are probably two of the greatest threats to the viability of *Achatinella* species.

311. Assess impact of predatory snails.

Determine significance of impact of predatory snails on continuing survival of *Achatinella* spp.

312. Conduct research on methods to eliminate introduced predatory snails.

Very little is known about controlling the predatory snail. At present there are no known chemical or biological agents available to extirpate introduced predatory snails such as *Euglandina rosea*; research aimed at gaining such information should be initiated. Because they are predators, they will not respond to traditional "snail and slug bait" which is formulated to attract herbivorous gastropods. These sorts of toxins should be avoided in areas with endemic snails.

313. Assess impact of rats.

Determine significance of impact of rats on continuing survival of *Achatinella* spp.

314. Assess impact of alien vertebrates responsible for habitat destruction.

Determine significance of impact of alien vertebrates responsible for habitat destruction on continuing survival of *Achatinella* spp.

315. Conduct research on other potential threats.

Ground-living predators, *Geoplana septemlineata* (a flatworm) and *Oxychilus alliarius* (a gastropod) may be affecting tree snails. Further studies should be undertaken to determine the extent to which these predators affect populations of *Achatinella* species, and research should be carried out to determine ways to control the predators in the field. The historical disappearance of populations of *Achatinella* species without apparent external cause suggests that lethal pathogens may sometimes be responsible. There is no information on this topic for the achatinellines, nor for snails in general. The possibility should be investigated if such disappearances are noticed in the course of the recovery efforts. Recently dead snails found during intense field investigations would provide a good source of material to search for the presence of pathogenic bacteria, viruses or fungi.

32. Manage currently known occupied Achatinella spp. habitat.

All sites where *Achatinella* spp. are known to currently exist need to be secured and managed. Table 8 shows the ownership of such sites.

321. Develop a cooperative agreement to secure essential tree snail habitat on O'ahu that is managed by the Hawaii Department of Land and Natural Resources.

A cooperative agreement between the Fish and Wildlife Service (Service) and the Hawaii Department of Land and Natural Resources (DLNR) needs to be developed to secure the 12 DLNR Forest Reserves, 2 State Parks and 2 Natural Areas that are included within the essential habitats in the four preserves (Table 8).

322. <u>Develop a cooperative agreement to secure essential tree snail habitat on O'ahu that is managed by the U.S. Navy</u>.

A cooperative agreement between the Service, the U.S. Navy and DLNR needs to be developed to secure Navy lands that are included within essential habitats in the Northern Wai'anae and Southern Wai'anae Mountain Preserves (Table 8).

323. <u>Develop a cooperative agreement to secure essential tree snail habitat on O'ahu that is managed by the U.S. Army</u>.

A cooperative agreement between the Service, the U.S. Army and DLNR needs to be developed to secure Schofield Barracks Forest Reserve Lands and Makua Military Reservation lands that are included within essential habitats in the Northern Wai'anae Mountains Preserve, Southern Wai'anae Mountains Preserve, and the Northern Ko'olau Preserve (Table 8).

324. <u>Develop a cooperative agreement to secure essential tree snail habitat on O'ahu that is managed by the U.S. Coast Guard</u>.

A cooperative agreement between the Service, the U.S. Coast Guard and DLNR needs to be developed to secure Haiku Valley Reservation lands that are included within essential habitat in the Northern Ko'olau Preserve (Table 8).

325. <u>Develop a cooperative agreement to secure essential tree snail habitat on O'ahu that is managed by the city of Honolulu</u>.

A cooperative agreement between the Service, the city of Honolulu and DLNR needs to be developed to secure Honolulu Watershed Forest Reserve lands that are included within essential habitats in the Southern Wai'anae Mountains Preserve, Northern Ko'olau range Preserve, and Southern Ko'olau range Preserve (Table 8).

TABLE 8. LIST OF MANAGEMENT UNITS THAT MAKE UP THE TREE SNAIL ESSENTIAL HABITAT.

| Unit Name | Wai'anae Mountains Northern | Wai'anae Mountains Southern | Ko'olau Range Northern | Ko'olau Range Southern |
|---|---|---|---|---|
| **Department of Land & Natural Resources** | | | | |
| Ewa Forest Reserve | | | x | |
| Hauula Forest Res. | | | x | |
| Kahana Valley State Park | | | x | |
| Kaipapau Forest Res. | | | x | |
| Kawailoa Forest Res. | | | x | |
| Kuaokala Forest Res. | x | | | |
| Kahuku Forest Res. | | | x | |
| Kaneohe Forest Res. | | | x | x |
| Kuliouou Forest Res. | | | | x |
| Mokuleia Forest Res. | x | | | |
| Mt. Kaala Natural Area | x | | | |
| Nanakuli Forest Res. | | x | | |
| Pahole Natural Area Res. | x | | | |
| Sacred Falls State Park | | | x | |
| Waiahole Forest Reserve | | | x | |
| Waimanalo Forest Reserve | | | | x |
| **U.S. Navy** | | | | |
| Makua Keeau Forest Res. | x | | | |
| Naval Reservation (Waianae District) | | x | | |
| **U.S. Army** | | | | |
| Schofield Barracks Forest Reserve | x | x | x | |
| Makua Military Reserv. | x | | | |
| **U.S. Coast Guard** | | | | |
| Haiku Valley Reservation | | | x | |
| **City of Honolulu** | | | | |
| Honolulu Watershed Forest Reserve | | x | x | x |

326. <u>Manage currently known occupied snail habitat in Northern Ko'olau range</u>.

Probably the most important candidate area for protection lies in the northern half of the Ko'olau Range; this preserve should include all lands lying above the 490-meter contour in the area north of the ridge (south of Kaukonahua Stream) that intersects the central ridge of the Ko'olau Range at Pu'u Ka'aumakua. This area is pictured in Figure 2. The described area includes all known and potential residual ranges for twelve species of <u>Achatinella</u>: <u>A</u>. <u>apexfulva</u>, <u>A</u>. <u>bulimoides</u>, <u>A</u>. <u>byronii</u>, <u>A</u>. <u>curta</u>, <u>A</u>. <u>decipiens</u>, <u>A</u>. <u>leucorraphe</u>, <u>A</u>. <u>lila</u>, <u>A</u>. <u>livida</u>, <u>A</u>. <u>pulcherrima</u>, <u>A</u>. <u>pupukanloe</u>, <u>A</u>. <u>sowerbyana</u> and <u>A</u>. <u>turgida</u> (see Table 7).

3261. <u>Manage predatory snail</u>.

Based on findings in Task 312, implement appropriate control measures.

3262. <u>Manage predatory rats</u>.

Much more is known about the control of rats compared to the control of predatory snails. Rat traps or poison-bait stations should be placed and maintained until rats are no longer a problem in selected areas.

3263. <u>Manage alien vertebrates responsible for habitat destruction</u>.

Elimination or control of feral ungulates such as goats and pigs should improve habitat for tree snails. A decrease in the pig populations in snail habitat would assist in the control of exotic plants.

3264. <u>Remove alien plants responsible for major habitat degradation</u>.

Invasion of snail habitat by exotic vegetation can be a serious problem. While there are numerous reports of achatinelline snails being observed on <u>Lantana</u>, bananas and other exotic vegetation, more recent observations indicate that exotic vegetation usually does not sustain populations of tree snails in places where they had previously been abundant. An exception is seen in a few high valleys of the southeastern

Ko'olaus where Achatinella fulgens occurs high on the trunks of large guava trees. Except for such sites, exotic vegetation should generally be controlled in tree snail habitat. If this leads to extensive loss of cover, appropriate native vegetation should be planted as the alien species are removed. Plant control in many areas needs to target only a few major species, including Clidemia hirta, Lantana camara, and Psidium spp. Clidemia hirta is undoubtedly the major plant problem at the moment on Oahu. The Hawaii Department of Land and Natural Resources received approval for release of the fungus (Colletotrichum gloeosporioides) to control Clidemia hirta under the weed biological control program. It has since been disseminated statewide and is proving very successful.

3265. Monitor population.

Monitor population semi-annually or annually, as necessary, to determine if it is increasing or decreasing, and if management of predators is successful.

327. Manage currently known occupied snail habitat in Southern Ko'olau range.

This area, delineated in Figure 3, includes all known and potential residual ranges for five species of Achatinella: A. bellula, A. fulgens, A. fuscobasis, A. phaeozona and A. viridans (see Table 7).

3271. Manage predatory snail.

See narrative of task 3261.

3272. Manage predatory rats.

See narrative of task 3262.

3273. Manage alien vertebrates responsible for habitat destruction.

See narrative of task 3263.

3274. Remove alien plants responsible for major habitat degradation.

See narrative of task 3264.

3275. Monitor population.

See narrative of task 3265.

328. Manage currently known occupied snail habitat in Northern Wai'anae range.

Major portions of the remaining habitat of *Achatinella mustelina* lie within the boundaries of the two Hawai'i State Natural Areas Reserves at Pahole and Ka'ala. However, there are important snail populations left out of these preserves, along the main ridge of the Wai'anae Range and extending down on both sides. Most of the land belongs to DLNR with a small chunk being managed by the Navy and another by the Army (Table 8). The most appropriate action would be to develop cooperative agreements to protect and manage this essential habitat area for tree snails (tasks 321, 322 and 323).

3281. Manage predatory snail.

See narrative of task #3261.

3282. Manage predatory rats.

See narrative of task #3262.

3283. Manage alien vertebrates responsible for habitat destructions.

See narrative of task #3263.

3284. Remove alien plants responsible for habitat destruction.

See narrative of task #3264.

3285. Monitor population.

See narrative of task #3265.

329. Manage currently known occupied snail habitat in Southern Wai'anae range.

There are remnant populations of *Achatinella mustelina* in the higher elevations of the southern half of the Wai'anae Range that are unique in color form and shell shape. A preserve that connected all elevations above 610 m, from Mauna Kapu in the south to Pu'u Hapapa in the north, would help protect these remnant, isolated snail populations. The preserve would form a very narrow band, especially as lands to the west of the ridge lie on the sheer leeward cliffs of the Wai'anae Range. In addition to A. mustelina, this preserve would include the residual range of A. concavospira, the other surviving achatinelline snail of the Wai'anaes.

3291. Manage predatory snail.

See narrative of task #3261.

3292. Manage predatory rats.

See narrative of task #3262.

3293. Manage alien vertebrates responsible for habitat destructions.

See narrative of task #3263.

3294. Remove alien plants responsible for habitat destruction.

See narrative of task #3264.

3295. Monitor population.

See narrative of task #3265.

4. **Conduct research on ecology of Achatinella spp.**

41. Determine demographic parameters.

For each population of tree snails found to be essential to the continued existence of any species or sub-species of *Achatinella*, demographic studies should be initiated. These studies should use the mark-recapture methods (see Hadfield and Mountain, 1980) to assess for each population: (1) the number of snails present and its stability over time; (2) the size- and age-frequency distributions of snails in the population (age-frequency analyses can only be done when size-specific growth rates have been obtained); (3) age-specific mortality; (4) annual fecundity; and (5) specific causes of mortality. During these studies, as many other aspects of the biology of each species should be recorded as possible. Much more information on food sources, tree-to-tree movement, plant specificity as a function of location and elevation, and distribution relative to climate will greatly enhance understanding of the snails and increase prospects for successful captive culture and reintroduction.

42. Identify habitat needed by Achatinella species.

From the data provided here and information available through various local agencies (e.g. The Nature Conservancy's Heritage Program), the major remaining portions of the historical range of Achatinella species can be determined now. Reserves for the tree snails should generally include areas of O'ahu at elevations greater than 450 m that are covered entirely or mostly with native vegetation. There are at least four areas of O'ahu that are so critical to the survival of one or more species of Achatinella that they should be considered for special protection (Northern Ko'olau, Southern Ko'olau, Northern Wai'anae and Southern Wai'anae), shown in Figures 2 through 5.

5. **Reestablish snail colonies.**

Because of slow maturation and low reproduction rates, the production of large numbers of snails to reintroduce into field habitats is a long-term project. This must be realized at the outset of captive propagation efforts: the fewer animals in any propagation group brought to the "snail house", the longer the time before reintroduction can begin. Decades may be required.

51. Identify reintroduction sites.

Once sufficient snail numbers (40-50) of any given species have been produced in the captive enclosures, reintroduction to native habitats can be considered. Before reintroduction, suitable sites must be identified. Criteria for suitable sites should be: (1) that the area once harbored the species under consideration; (2) that appropriate vegetation to support a snail population is present; (3) that climatic conditions at the site are comparable to those under which the snails have been maintained in captivity; and (4) that predators or potential predators can be managed in the area. Potential sites should be selected which are in remote areas, not subject to frequent human disturbance, and mostly free of exotic vegetation (e.g. Lantana, Clidemia, guava).

52. Reintroduce snails to field sites.

When habitats for reintroduction have been selected and investigated, snails should be placed together in relatively dense aggregations. At least 20 snails in a relatively small tree (3-4 m tall and 2-3 m in diameter) is a minimal goal. The tree should be of an appropriate native species and selected carefully for apparent vigor and shading.

Snails should be liberated into the tree at a time when the climate is cool and frequent rainfall is likely, probably in winter months. Field workers should remain in the area for a week or even longer to monitor the snails' activities and return them to the original tree should they begin to scatter too widely. It may take some time to establish snails in a tree. Often, snails quickly leave a tree into which they have been transplanted, while others left in their "home tree" or even removed and returned to the same tree are repeatedly observed in that tree over long periods of time (Hadfield and Mountain, 1981; Hadfield and Miller, 1989; Hadfield et. al., unpublished).

53. Monitor reestablished colonies.

Before placing captive-reared snails in the field, the snails should be individually marked so that their growth and individual migratory patterns can be followed in the months and perhaps even years after they are released. Introduced populations should be monitored to determine their growth or decline.

## LITERATURE CITED

Anonymous. 1985. I.U.C.N. points to plight of the world's threatened plants and animals, parks and reserves. Oryx 12:69-71.

Alexander, M. C. 1953. Dr. Baldwin of Lahina. Stanford University Press, Berkeley, California. 359 pp.

Atkinson, I. A. E. 1977. A reassessment of the factors, particularly *Rattus rattus* L., that influenced the decline of endemic forest birds in the Hawaiian Islands. Pacific Science 31:109-133.

Baldwin, D. D. 1887. The land shells of the Hawaiian Islands. Hawaiian Almanac and Annual 1887:55-63.

Blumenstock, D. I. and S. Price. 1976. Climates of the states: Hawaii. In: E. A. Kay, ed., *A Natural History of the Hawaiian Islands*. pp. 155-204.

Bryan, E. H. 1935. Hawaiian nature notes. Honolulu Star-bulletin, Ltd, Honolulu Hawai'i. pp. 208-213.

Caum, E. L. 1928. Check list of Hawaiian land and fresh-water Mollusca. B. P. Bishop Museum Bull. 56:1-79.

Christensen, C. C. 1983. An archival survey of the endangered Oahu tree snail (Genus *Achatinella*) on U. S. Army Support command, Hawaii, Installations. Unpublished report. Prepared for the Department of the Army, Corps of Engineers, Pacific Ocean Division, Honolulu, Hawaii. iii + 22 pp., appendices A1-A11.

Christensen, C. C., and M. G. Hadfield. 1984. Field survey of endangered Oahu tree snails (Genus *Achatinella*) on the Makua Military Reservation, Oahu, Hawaii. Unpublished report prepared for the U.S. Army Corps of Engineers, Pacific Ocean Division. 20 pp.

Christensen, C. C. 1985. Endangered species information system species workbook. Part I - Species Distribution; Part II - Species Biology. Unpublished report prepared for the U. S. Department of Interior, Fish and Wildlife Service, Office of endangered Species. 70 pp.

Clarke, B., J. Murray and M. S. Johnson. 1984. The extinction of endemic species by a program of biological control. Pacific Science 38:97-104.

Clench, W. J. 1959. John T. Gulick's Hawaiian land shells. Nautilus 72:95-98.

Cook, A. 1985. Functional aspects of trail following by the carnivorous snail Euglandina rosea. Malacologia 26:173-181.

Cooke, Jr., C. M. 1903. Distribution and variation of Achatinella multizonata from Nuuanu Valley. Occasional Papers of the B. P Bishop Museum 2:65-76.

Cooke, Jr., C. M. 1941. Hawaiian Land Shells. Paradise of the Pacific 53:20-25.

Cooke, Jr., C. M. and Y. Kondo. 1960. Revision of Tornatellinidae and Achatinellidae (Gastropoda, Pulmonata). B. P. Bishop Museum Bull. 221:1-303.

Emerson, O. P. (Ms., undated, post-1900). The gay Achatinellidae and their habits. B. P. Bishop Museum, 24 pp.

Frick, D. 1856. Notes on Hawaiian terrestrial conchology. Sandwich Islands Monthly Magazine 1:137-140.

Gagne, B.H., E.A. Kay and P.S. Langford. 1975. A survey of Achatinella on Oahu, Hawaii: September to December 1974. Unpublished report prepared for the U.S. Department of Interior, U.S. Fish and Wildlife Service. 5 pp., 1 figure, 3 tables + appendix.

Hadfield, M. G. and B. S. Mountain. 1980. A field study of a vanishing species, Achatinella mustelina (Gastropoda, Pulmonata), in the Waianae Mountains of Oahu. Pacific Science 34:345-358.

Hadfield, M. G. 1981. A survey of Kahuku Windfarms Wind Turbine Sites for Gastropods and Small Mammals. Unpublished report prepared for Ecotrophics. 10 pp.

Hadfield, M. G. 1981. A survey of North Halawa Valley for endangered snails of the genus Achatinella. Unpublished report. 11 pp.

Hadfield, M. G. 1986. Extinction in Hawaiian achatinelline snails. Malacologia 27:67-81.

Hadfield, M. G. 1988. Report on research activities on the Hawaiian tree snails with specific reference to predation by rats. Unpublished report to the State of Hawai'i Department of Land and Natural Resources, Division of Forestry and Wildlife and the U. S. Department of the Interior, Fish and Wildlife Service. 4 pp.

Hadfield, M. G. and S. E. Miller. 1989. Demographic studies on Hawai'i's endangered tree snails: _Partulina proxima_. Pacific Science 43:1-16.

Hart, A. D. 1975. Living jewels imperiled. Defenders 50:482-486.

Hart, A. D. 1978. The onslaught against Hawaii's tree snails. Natural History 87:46-57.

Hart, A. D. 1979. A survival status report on the endemic Hawaiian tree snail genus _Achatinella_ (Swainson) from O'ahu. Unpublished report prepared for the U. S. Department of Interior, Fish and Wildlife Service, Office of Endangered Species. 25 pp.

Hawaii, Department of Land and Natural Resources. 1988. Threatened and endangered species plan for wildlife, plants and invertebrates, Honolulu, Hawaii. 56 pp.

Kay, E. A. 1970. A tribute to Hawai'i's missionaries: shell collectors and conchologists. Hawaiian Shell News 18:1-7.

Kondo, Y. 1970. Extinct land molluscan species. Unpublished report prepared for the Colloquium on Endangered Species of Hawaii. 8 pp.

Kondo, Y. 1980. Endangered land snails, Pacific. Unpublished report prepared for the International Union for the Conservation of Nature. 15 pp.

Mead, A. 1979. Economic malacology with particular reference to _Achatina fulica_. In: Fretter, V. and J. Peake, eds., _Pulmonates_, 2B. Academic Press, London. 150 pp.

Mountain, B. A., P. Galloway and H. Snyder. 1981a. Investigation of the occurrence of _Achatinella_ at various sites along the proposed electrical transmission lines between Laie and Wahiawa. A partial report. Unpublished report prepared for Ecotrophics. 12 pp.

Mountain, B. A., P. Galloway and H. Snyder. 1981b. Investigation of the occurrence of _Achatinella_ at various sites along the proposed electrical transmission lines between Laie and Wahiawa. Partial report II. Unpublished report prepared for Ecotrophics. 6 pp + 5 maps.

Murray, J., E. Murray and M. S. Johnson. 1988. The extinction of _Partula_ on Moorea. Pacific Science 42:150-153.

Neal, M. C. 1928. Anatomical studies of Achatinellidae. B. P. Bishop Museum, Bulletin No. 47:34-49.

Perkins, R. C. L. 1899. Introduction. In. Sharp, D., ed., Fauna Hawaiiensis. Cambridge University Press, Cambridge. 1:xv-ccxxviii.

Pilsbry, H. A. and C. M. Cooke, Jr. 1912-1914. Achatinellidae. Manual of Conchology, 2nd ser., Vol. 21. lviii + 428 pp., 63 plates.

Pilsbry, H. A. and C. M. Cooke, Jr. 1921. A new Achatinella from Oahu. Nautilus 34:109-110.

Severns, M. 1981. Growth rate determination of Achatinella lila, a Hawaiian tree snail. The Nautilus 95:140-144.

Severns, M. 1984. Another threat to Hawaii's endemics. Hawaiian Shell News 32:1 and 9.

Thwing, E. W. 1907. Reprint of the original descriptions of the genus Achatinella. B. P. Bishop Museum Occasional Papers 3: i-xi, 1-196, 3 plates.

U.S. Fish and Wildlife Services. 1981. Endangered and threatened wildlife and plants; listing the Hawaiian (Oahu) tree snails of the genus Achatinella as endangered species. Prepared by the U. S. Department of Interior, Fish and Wildlife Service. Federal Register 46:3178-3182.

Welch, D. A. 1938. Distribution and variation of Achatinella mustelina Mighels in the Waianae Mountains, Oahu. B. P. Bishop Museum Bulletin 152. 164 pp., 13 plates.

Welch, D. A. 1942. Distribution and variation of the Hawaiian tree snail Achatinella apexfulva Dixon in the Koolau Range, Oahu. Smithsonian Miscellaneous Collections 103:1-236.

Welch, D. A. 1954. Distribution and variation of the Hawaiian tree snail Achatinella bulimoides Swainson on the leeward and northern slope of the Ko'olau Range, Oahu. Proceedings of the Academy of Natural Sciences of Philadelphia 106:63-107.

Welch, D. A. 1958. Distribution and variation of the Hawaiian tree snail Achatinella bulimoides Swainson on the windward slope of the Koolau Range, Oahu. Proceedings of the Academy of Natural Sciences of Philadelphia 110:123-212.

Zimmerman, E. C. 1948. Insects of Hawaii, Vol. 1. University of Hawaii Press, Honolulu, Hawai'i. xx + 206 pp.

# III. IMPLEMENTATION SCHEDULE

The Implementation Schedule that follows outlines actions and estimated costs for the Achatinella recovery program, as set forth in this recovery plan. It is a guide for meeting the objectives discussed in Part II of this Plan. This schedule indicates task priority, task numbers, task descriptions, duration of tasks, the agencies responsible for committing funds, and lastly, estimated costs. The agencies responsible for committing funds are not, necessarily, the entities that will actually carry out the tasks. When more than one agency is listed as the responsible party, an asterisk is used to identify the lead entity.

The actions identified in the implementation schedule, when accomplished, should protect habitat for the species and hopefully stabilize populations. Monetary needs for all parties involved are identified to reach this point. Further research is needed to determine what actions are needed to achieve recovery of the species. A complete estimate of the cost of recovery is not available until such studies are conducted.

Priorities in Column 1 of the following implementation schedule are assigned as follows:

**Priority 1** - An action that must be taken to prevent extinction or to prevent the species from declining irreversibly in the foreseeable future.

**Priority 2** - An action that must be taken to prevent a significant decline in species population/habitat quality, or some other significant negative impact short of extinction.

**Priority 3** - All other actions necessary to meet the recovery objectives.

**Key to Acronyms Used in Implementation Schedule**

| | | |
|---|---|---|
| FWE | - | Fish & Wildlife Service, Fish & Wildlife Enhancement, Honolulu, HI |
| DLNR | - | Hawaii Department of Land & Natural Resources |
| USA | - | U.S. Army |
| USN | - | U.S. Navy |
| USCG | - | U.S. Coast Guard |
| HONO | - | City and County of Honolulu |
| C | - | Continual, task will be implemented on an annual basis once it is begun. |

Total Cost = Projected cost of task from start to task completion.

RECOVERY PLAN IMPLEMENTATION SCHEDULE FOR OAHU TREE SNAIL

| PRIOR-ITY # | TASK # | TASK DESCRIPTION | TASK DURA-TION (YRS) | RESPONSIBLE PARTY | TOTAL COST | FY 1992 | FY 1993 | FY 1994 | FY 1995 | FY 1996 | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 111 | Develop methods for cultivation of native fungal foods. | 6 | FWE | 45 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | Ongoing. UH has carried out this effort since 1986. FWE now granting UH funds to continue |
| 1 | 112 | Experiment with day length to accelerate growth. | 4 | FWE | 8 | 2 | 2 | 2 | 2 | | Ongoing. |
| 1 | 12 | Establish & maintain facilities for captive propagation | 15 | FWE | 260 | 40 | 40 | 15 | 15 | 15 | Two snail houses constructed in 1991. To be placed at Lyon Arboretum in 1992. |
| 1 | 13 | Remove snails from field populations for captive propogation | 6 | FWE | 60 | 10 | 10 | 10 | 10 | 10 | |
| | NEED 1 (Initiate Captive Propagation) | | | | 373 | 59.5 | 59.5 | 34.5 | 34.5 | 32.5 | |
| | | Conduct surveys: | | | | | | | | | |
| 1 | 211 | Northern Ko'olau range. | 3 | DLNR*<br>FWE | 24<br>6 | 8<br>2 | 8<br>2 | 8<br>2 | | | |
| 1 | 212 | Southern Ko'olau range. | 3 | DLNR*<br>FWE | 24<br>6 | 8<br>2 | 8<br>2 | 8<br>2 | | | |
| 1 | 213 | Northern Wai'anae range. | 3 | DLNR*<br>FWE | 24<br>6 | 8<br>2 | 8<br>2 | 8<br>2 | | | |
| 1 | 214 | Southern Wai'anae range. | 3 | FWE*<br>DLNR | 24<br>6 | 8<br>2 | 8<br>2 | 8<br>2 | | | |
| 1 | 22 | Map geographical area occupied by each population. | 6 | FWE*<br>DLNR | 24<br>6 | 4<br>1 | 4<br>1 | 4<br>1 | 4<br>1 | 4<br>1 | |
| | NEED 2 (Locate Additional Habitat/Populations) | | | | 150 | 45 | 45 | 45 | 5 | 5 | |

RECOVERY PLAN IMPLEMENTATION SCHEDULE FOR OAHU TREE SNAIL

| PRIORITY # | TASK # | TASK DESCRIPTION | TASK DURATION (YRS) | RESPONSIBLE PARTY | TOTAL COST | FY 1992 | FY 1993 | FY 1994 | FY 1995 | FY 1996 | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3273 | Manage alien vertebrates. | C | DLNR* | 28 | 2 | 2 | 2 | 2 | 2 | |
| | | | | FWE | 14 | 1 | 1 | 1 | 1 | 1 | |
| | | | | HONO | 3.5 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | |
| 1 | 3274 | Remove alien plants. | C | DLNR* | 28 | 2 | 2 | 2 | 2 | 2 | |
| | | | | FWE | 14 | 1 | 1 | 1 | 1 | 1 | |
| | | | | HONO | 3.5 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | |
| 1 | 3275 | Monitor population. | C | FWE* | 28 | 2 | 2 | 2 | 2 | 2 | |
| | | | | DLNR | 14 | 1 | 1 | 1 | 1 | 1 | |
| | | Conduct management tasks - Northern Wai'anae range: | | | | | | | | | |
| 1 | 3281 | Manage predatory snail. | C | DLNR* | 98 | 7 | 7 | 7 | 7 | 7 | |
| | | | | FWE | 42 | 3 | 3 | 3 | 3 | 3 | |
| | | | | USN | 14 | 1 | 1 | 1 | 1 | 1 | |
| | | | | USA | 28 | 2 | 2 | 2 | 2 | 2 | |
| 1 | 3282 | Manage predatory rats. | C | DLNR* | 42 | 3 | 3 | 3 | 3 | 3 | |
| | | | | FWE | 28 | 2 | 2 | 2 | 2 | 2 | |
| | | | | USN | 3.5 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | |
| | | | | USA | 7 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | |
| 1 | 3283 | Manage alien vertebrates. | C | DLNR* | 42 | 3 | 3 | 3 | 3 | 3 | |
| | | | | FWE | 28 | 2 | 2 | 2 | 2 | 2 | |
| | | | | USN | 3.5 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | |
| | | | | USA | 7 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | |
| 1 | 3284 | Remove alien plants. | C | DLNR* | 42 | 3 | 3 | 3 | 3 | 3 | |
| | | | | FWE | 28 | 2 | 2 | 2 | 2 | 2 | |
| | | | | USN | 3.5 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | |
| | | | | USA | 7 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | |
| 1 | 3285 | Monitor population. | C | FWE* | 42 | 3 | 3 | 3 | 3 | 3 | |
| | | | | DLNR | 28 | 2 | 2 | 2 | 2 | 2 | |
| | | Conduct management tasks - Southern Wai'anae range: | | | | | | | | | |
| 1 | 3291 | Manage predatory snail. | C | DLNR | 14 | 1 | 1 | 1 | 1 | 1 | |
| | | | | FWE* | 42 | 3 | 3 | 3 | 3 | 3 | |
| | | | | USN | 14 | 1 | 1 | 1 | 1 | 1 | |
| | | | | USA | 14 | 1 | 1 | 1 | 1 | 1 | |
| | | | | HONO | 14 | 1 | 1 | 1 | 1 | 1 | |

RECOVERY PLAN IMPLEMENTATION SCHEDULE FOR OAHU TREE SNAIL

| PRIORITY # | TASK # | TASK DESCRIPTION | TASK DURATION (YRS) | RESPONSIBLE PARTY | TOTAL COST | FY 1992 | FY 1993 | FY 1994 | FY 1995 | FY 1996 | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Secure currently occupied sites: | | | | | | | | | |
| 1 | 321 | Develop cooperative agreement to secure essential habitat on lands managed by DLNR. | 2 | FWE*<br>DLNR | 4<br>2 | | 2<br>1 | 2<br>1 | | | |
| 1 | 322 | Develop cooperative agreement to secure essential habitat on lands managed by USN. | 2 | FWE*<br>USN<br>DLNR | 4<br>2<br>1 | | 2<br>1<br>0.5 | 2<br>1<br>0.5 | | | |
| 1 | 323 | Develop cooperative agreement to secure essential habitat on lands managed by USA. | 2 | FWE*<br>USA<br>DLNR | 4<br>2<br>1 | | 2<br>1<br>0.5 | 2<br>1<br>0.5 | | | |
| 1 | 324 | Develop cooperative agreement to secure essential habitat on lands managed by USCG. | 2 | FWE*<br>USCG<br>DLNR | 4<br>2<br>1 | | 2<br>1<br>0.5 | 2<br>1<br>0.5 | | | |
| 1 | 325 | Develop cooperative agreement to secure essential habitat on lands managed by HONO. | 2 | FWS*<br>HONO<br>DLNR | 4<br>2<br>1 | | 2<br>1<br>0.5 | 2<br>1<br>0.5 | | | |
| | NEED 3 (Secure Essential Habitat) | | | | 34 | 0 | 17 | 17 | 0 | 0 | |
| 1 | 311 | Assess impact of predatory snails. | 3 | FWE*<br>DLNR | 30<br>15 | 10<br>5 | 10<br>5 | 10<br>5 | | | |
| 1 | 312 | Conduct research on methods to eliminate predatory snails. | 10 | FWE | 100 | 10 | 10 | 10 | 10 | 10 | |
| 1 | 313 | Assess impact of predatory rats. | 3 | FWE*<br>DLNR | 30<br>15 | 10<br>5 | 10<br>5 | 10<br>5 | | | |
| 1 | 314 | Assess impact of alien vertebrates responsible for habitat destruction. | 3 | FWE*<br>DLNR | 30<br>15 | 10<br>5 | 10<br>5 | 10<br>5 | | | |

RECOVERY PLAN IMPLEMENTATION SCHEDULE FOR OAHU TREE SNAIL

| PRIORITY # | TASK # | TASK DESCRIPTION | TASK DURATION (YRS) | RESPONSIBLE PARTY | TOTAL COST | FY 1992 | FY 1993 | FY 1994 | FY 1995 | FY 1996 | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 315 | Conduct research on other potential threats. | 10 | FWE* | 80 | 8 | 8 | 8 | 8 | 8 | |
| | | | | DLNR | 20 | 2 | 2 | 2 | 2 | 2 | |
| | | Conduct management tasks - Northern Ko'olau range: | | | | | | | | | |
| 1 | 3261 | Manage predatory snail. | C | DLNR* | 140 | 10 | 10 | 10 | 10 | 10 | |
| | | | | FWE | 70 | 5 | 5 | 5 | 5 | 5 | |
| | | | | USA | 14 | 1 | 1 | 1 | 1 | 1 | |
| | | | | USCG | 14 | 1 | 1 | 1 | 1 | 1 | |
| | | | | HONO | 14 | 1 | 1 | 1 | 1 | 1 | |
| 1 | 3262 | Manage predatory rats. | C | DLNR* | 70 | 5 | 5 | 5 | 5 | 5 | |
| | | | | FWE | 28 | 2 | 2 | 2 | 2 | 2 | |
| | | | | USA | 7 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | |
| | | | | USCG | 7 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | |
| | | | | HONO | 7 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | |
| 1 | 3263 | Manage alien vertebrates. | C | DLNR* | 70 | 5 | 5 | 5 | 5 | 5 | |
| | | | | FWE | 28 | 2 | 2 | 2 | 2 | 2 | |
| | | | | USA | 7 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | |
| | | | | USCG | 7 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | |
| | | | | HONO | 7 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | |
| 1 | 3264 | Remove alien plants. | C | DLNR* | 70 | 5 | 5 | 5 | 5 | 5 | |
| | | | | FWE | 28 | 2 | 2 | 2 | 2 | 2 | |
| | | | | USA | 7 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | |
| | | | | USCG | 7 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | |
| | | | | HONO | 7 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | |
| 1 | 3265 | Monitor population. | C | FWS* | 70 | 5 | 5 | 5 | 5 | 5 | |
| | | | | DLNR | 28 | 2 | 2 | 2 | 2 | 2 | |
| | | Conduct management tasks - Southern Ko'olau range: | | | | | | | | | |
| 1 | 3271 | Manage predatory snail. | C | DLNR* | 70 | 5 | 5 | 5 | 5 | 5 | |
| | | | | FWE | 28 | 2 | 2 | 2 | 2 | 2 | |
| | | | | HONO | 7.5 | 1 | 0.5 | 0.5 | 0.5 | 0.5 | |
| 1 | 3272 | Manage predatory rats. | C | DLNR* | 28 | 2 | 2 | 2 | 2 | 2 | |
| | | | | FWE | 14 | 1 | 1 | 1 | 1 | 1 | |
| | | | | HONO | 3.5 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | |

RECOVERY PLAN IMPLEMENTATION SCHEDULE FOR OAHU TREE SNAIL

| PRIORITY # | TASK # | TASK DESCRIPTION | TASK DURATION (YRS) | RESPONSIBLE PARTY | TOTAL COST | FY 1992 | FY 1993 | FY 1994 | FY 1995 | FY 1996 | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3292 | Manage predatory rats. | C | DLNR | 3.5 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | |
| | | | | FWE* | 14 | 1 | 1 | 1 | 1 | 1 | |
| | | | | USN | 3.5 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | |
| | | | | USA | 3.5 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | |
| | | | | HONO | 3.5 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | |
| 1 | 3293 | Manage alien vertebrates. | C | DLNR | 3.5 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | |
| | | | | FWE* | 14 | 1 | 1 | 1 | 1 | 1 | |
| | | | | USN | 3.5 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | |
| | | | | USA | 3.5 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | |
| | | | | HONO | 3.5 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | |
| 1 | 3294 | Remove alien plants. | C | DLNR | 3.5 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | |
| | | | | FWE* | 14 | 1 | 1 | 1 | 1 | 1 | |
| | | | | USN | 3.5 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | |
| | | | | USA | 3.5 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | |
| | | | | HONO | 3.5 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | |
| 1 | 3295 | Monitor population. | C | FWE* | 28 | 2 | 2 | 2 | 2 | 2 | |
| | | | | DLNR | 14 | 1 | 1 | 1 | 1 | 1 | |
| | NEED 4 (Manage Threats) | | | | 2043.5 | 187.5 | 187 | 187 | 142 | 142 | |
| 2 | 41 | Determine demographic parameters. | 10 | FWE | 200 | 20 | 20 | 20 | 20 | 20 | |
| 2 | 42 | Identify habitat needed. | 10 | FWE | 200 | 20 | 20 | 20 | 20 | 20 | |
| | NEED 5 (Ecol. Research) | | | | 400 | 40 | 40 | 40 | 40 | 40 | |
| 3 | 51 | Identify reintroduction sites. | 5 | FWE | 15 | | | | | | |
| 3 | 52 | Reintroduce snails to field sites. | 10 | FWE* | 48 | | | | | | |
| | | | | DLNR | 12 | | | | | | |
| 3 | 53 | Monitor reestablished colonies. | C | FWE* | 12 | | | | | | |
| | | | | DLNR | 12 | | | | | | |
| | NEED 6 (Reestablish Colonies) | | | | 99 | 0 | 0 | 0 | 0 | 0 | |

RECOVERY PLAN IMPLEMENTATION SCHEDULE FOR OAHU TREE SNAIL

| PRIOR-ITY # | TASK # | TASK DESCRIPTION | TASK DURA-TION (YRS) | RESPONSIBLE PARTY | TOTAL COST | FY 1992 | FY 1993 | FY 1994 | FY 1995 | FY 1996 | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TOTAL COST | | | 3099.5 | 332 | 348.5 | 323.5 | 221.5 | 219.5 | |

## APPENDIX I. SPECIES DESCRIPTIONS.

**Classification and descriptions of the forty-one Achatinella species.**

The following classification, species descriptions and commentary are from Pilsbry and Cooke (1912-1914; also see Thwing, 1907 and Caum, 1928). A modern treatment of classification would probably consider each "series" to represent a single species (see pp. 6-12, above). There are three recognized subgenera within the genus Achatinella.

**Genus Achatinella Swainson, 1828:**
The dextral or sinistral shell is imperforate or minutely perforate, oblong, ovate or globose-conic; smooth or longitudinally corrugated, with only weak traces of spiral sculpture. Shell color is in spiral bands or streaks in the direction of the growth lines. The lip is simple or thickened within and sometimes slightly expanding. The columella bears a strong callous fold. Type Achatinella apexfulva (Dixon).

**Subgenus Bulimella Pfeiffer 1854:**
Shell shape is oblong-conic or ovate. The spire is obtuse, rounded or convexly-conic near the apex. The outer lip is thickened by a strong callous rib within the aperture (except in A. abbreviata and A. lila). Type Achatinella byroni Newcomb.

**Series of Achatinella byronii:**
The shell is oblong-conic, often with streaks or bands of dark green, and often roughly striate or corrugated; mainly dextral.

**A. byronii (Wood, 1828):**
The dextral or sinistral shell is imperforate and pyramidal-conic; solid and glossy with an obtuse apex. Shell color varies, but is typically green and light greenish-yellow in oblique streaks on the last two whorls, with a faint green peripheral band and a dark chestnut band bordering the suture below. The preceding whorl is yellow with a chestnut band and the three embryonic whorls are pinkish gray. The aperture is white and the lip is bordered with dark brown. Faint spiral striae sculpture the embryonic whorls, and later whorls are convex and irregularly wrinkled in the direction of growth-lines. The whorls are convex and the last is often very obtusely angular at the periphery. The aperture is strongly oblique and the lip thickened within by a strong rib near the margin. The columellar fold is moderate, and white or

tinted. Length 20.0 mm, diameter 11.0 mm, 6.5 whorls.

Synonyms: A. melanostoma Newcomb; A. limbata Gulick; A. ruguosa Newcomb; Bulimella rugosa Lyons; Helix byronii Wood; Helicteres byronensis (Gray).

**A. lila Pilsbry, 1914:**
The shell is sinistral, ovate-conic, thin but strong, nearly smooth, brilliantly glossy. The embryonic whorls are burnt sienna brown (weathering to whitish in adult shells), or sometimes there is a light median zone. The last whorl has either a uniform blackish chestnut, or a chestnut peripheral band and baso-columellar patch on a yellow ground, or like the last but with a green band midway between periphery and suture, or with sutural and peripheral bands and a baso-columellar patch of yellow on a chestnut ground. There are also a few specimens more or less intermediate between these patterns. The aperture is moderately oblique, and colored white or faintly lilac within. The peristome is acute, and slightly or not thickened within. The columellar fold is strong, and is colored purple or white. Length 17.0 mm, diameter 11.0 mm, 5 1/2 whorls.

**A. pulcherrima Swainson, 1828:**
The dextral shell is ovate oblong, subcylindrical and slender. Some specimens are more ventricose than other. The color is white or yellow with none to several broad bands of chestnut. The margin of the lip is brown. The ground color is a deep and rich chestnut, with from one to three bands of orange, yellow, fulvous or white. The marginal groove to the suture is very close and distinct in all. Pilsbry considered this to be a subspecies of A. byronii. Length 20.0 mm, diameter 11.2 mm, 6 whorls.

Synonyms: A. lorata Ferussac, Reeve; A. melanostoma Newcomb; A. multicolor Pfeiffer; A. mahogani Gulick; Bulimella pulcherrima Lyons.

**A. decipiens Newcomb, 1854:**
The rough sinistral (eastern range) or smooth dextral (western range) shell is conically-elongate, solid, slightly rounded, and margined above. The aperture elongately-ovate and the lip is sub-reflected. The columella is short, obliquely twisted and has an expanded callus. The suture is slightly impressed with numerous longitudinal, oblique striae. Shell color is white with yellow transverse bands, or yellow with white transverse lines and longitudinal chestnut colored stripes. Cooke considered this to be a subspecies of *A. byronii*. Length 20.5 mm, diameter 9.0 mm, 6 whorls.

Synonyms: *A. corrugata* Gulick; *A. torrida* Gulick; *A. planospira* Pfeiffer.

**Series of Achatinella viridans:**
Considered to be a subdivision of the *A. byronii* Series for the exclusively dextral species of the southeastern end of the Ko'olau Range. Frequently with bright green color.

**A. viridans Mighels, 1845:**
The dextral shell is elongate-conic, imperforate with convex whorls and a slightly impressed line below the suture. The color is green with light streaks intermixed. The aperture is subovate and stained with a pink color just within the margin. The lip is slightly thickened. Length 19.2 mm, diameter 12.0 mm, 5 whorls.

Synonyms: *A radiata* Pfeiffer; *A. subvirens* Newcomb; *A. rutila* Newcomb; *A. macrostoma* Pfeiffer.

**A. abbreviata Reeve, 1850:**
The dextral shell is ovate and somewhat ventricose with convex whorls margined round the upper shell. The spire is rather short and obtuse at the apex. The columella is callous and twisted. Olive-yellow, with a black-brown line at the sutures; the lower part of the last whorl is very dark green and the apex is black. Length 19.0 mm, diameter 10.0 mm, 6 whorls.

Synonyms: *A. bacca* Reeve; *A. nivosa* Newcomb; *A. clementina* Pfeiffer.

**A. taeniolata Pfeiffer, 1846:**
The dextral shell is ovate-oblong, spiro-conic, solid, striatulate; more obsolete toward the apex and with slightly convex whorls. Shell colors are glossy white ornamented with varying brown bands. The white columella is strongly toothed above and the margin is dilated, reflexed and appressed. The white aperture is irregularly semioval; the peristome is narrowly thickened outside, and strongly lipped within. Length 20.0 mm, diameter 11.0 mm, 6 whorls. This is a subspecies of *A. viridans* as there is a complete intergradation between them.

Synonyms: *A. rubiginosa* Newcomb.

**Series of Achatinella bulimoides:**
The large, dextral or sinistral shell is smooth, ovate, and capacious; never marked with green.

**A. bulimoides Swainson. 1828:**
The dextral or sinistral shell is ovate-oblong and subventricose. Similar in form to *A. livida*, but the spire is less thickened and more pointed at the apex. The color is whitish with chestnut bands, and the apex is pale brown. The ground-color, in some specimens, is pale chestnut or ferruginous, banded with darker shades. Other specimens are pure white. The aperture is white. The suture is scarcely if at all margined by a groove. Length 21.3 mm, diameter 11.8 mm, 6 1/4 whorls.

Synonyms: *A. spadicea* Gulick; *A. obliqua* Gulick; *A. oomorpha* Gulick; *A. ovata* Newcomb; *A. candida* Pfeiffer; *A. vidua* Pfeiffer; *A. wheatleyi* Newcomb; *A. elegans wheatleyana* Newcomb; *A. fricki* Pfeiffer; *A. rotunda* (Gulick); *A. glabra* Newcomb; *Bulimella glabra* Newcomb.

**A. rosea Swainson, 1828:**
This species is a variety of *Achatinella bulimoides*. The sinistral shell is a pale, rose color, with two obsolete white bands. The margin of the lip and columella are of a deeper rose-color, and the aperture white. It should be observed that the subsutural groove is very distinct. Length 22.3 mm, diameter 13.5 mm, 6 1/3 whorls.

**A. elegans Newcomb, 1854:**
The dextral or sinistral shell is conically-elongate,

solid, plano-convex and margined above with the suture well impressed. The aperture is subovate and the white lip is expanded, subreflected, somewhat contracted in its center and thickened within. The short columella is flat and lightly toothed. The glossy shell color is alternating light and dark-brown, arranged in longitudinal lines or broad patches. Sometimes with a white sutural band and a white band on the body-whorl. Length 23.1 mm, diameter 10.3 mm, 6 whorls.

Synonyms: A. spadicea Gulick; A. wheatleyi Nob.; A. vidua Pfeiffer.

**Series of Achatinella fuscobasis:**
The smooth shell is ovate-conic and never marked with green. Most specimens are sinistral. Species are almost entirely confined to the high ridges and peaks.

**A. fuscobasis (E.A. Smith, 1873):**
The sinistral shell is ovate, with slightly convex whorls and the suture distinctly margined. The color is glossy white with the last whorl yellowish and ornamented with a median zone and base of brown. The aperture is white and the brown peristome is thick. The columellar fold is strong. Length 16.0 mm, diameter 10.0 mm, 6 whorls.

Synonyms: A. fuscobasis Smith; A. luteostoma Baldwin; A. lyonsiana Baldwin; Bulimella fuscobasis Smith; B. rosea Hartman.

**A. pupukanioe Pilsbry & Cooke, 1914:**
The dextral shell is conic and solid. The glossy color is a uniform white, or ivory yellow with a white sutural line, or either of these tints with a burnt sienna band immediately above a wider and darker band. The suture is margined. The lip is not expanded and has a brownish edge; the internal rib is white, or sometimes the whole lip is pale-pink. The white columellar fold is rather strong and abrupt. Length 16.3 mm, diameter 9.7 mm, 6 whorls.

**A. sowerbyana Pfeiffer, 1855:**
The sinistral or dextral shell is imperforate, conic-oblong and solid. The spire is slightly convexly-conic and the apex subacute. The suture is margined and the whorls are slightly convex. The glossy color is tawny buff and slightly streaked with a deeper shade. The

aperture is oblique and white within. The strong columellar fold is superior, twisted, and roseate. The peristome is rose-lipped with the outer margin shortly expanded and columellar margin dilated and adnate. Length 18.0 mm, diameter 9.0 mm, 6 whorls.

Synonyms: A. oviformis Newcomb; A. multicolor Pfeiffer; Bulimella sowerbiana Pfeiffer.

**Subgenus Achatinellastrum Pfeiffer 1854:**
The shell is imperforate, ovate-conic or oblong-conic and smooth. The embryonic whorls are not flattened. The outer lip is thin or only slightly thickened within the apex but not expanded. These are the most generally distributed of the Achatinella species and show a prolific area of intergrading color patterns. Type Achatinella producta Reeve.

**Series of Achatinella vulpina:**
Usually rather large and moderately strong shells, conspicuously colored, green, yellow or chestnut, generally streaked or banded, rarely white.

**A. vulpina (Ferussac, 1824):**
The dextral or sinistral shell is ovate-conic and colored glossy yellow, green, olive or chestnut; often banded with green or chestnut. Extremely variable color pattern. Length 19.0 mm, diameter 10.0 mm, 6 1/4 whorls.

Synonyms: A. castanea Reeve; A. adusta Reeve; A. ernestina Baldwin; A. olivacea Reeve; A. prasinus Reeve; A. virens Gulick; A. cucumis Gulick; A. analoga Gulick; A. longispira Smith; A. colorata Gulick; A. colorata Reeve; A. consanguinea Smith; A. ustulata Newcomb; A. tricolor Smith; A. prasinus Reeve; A. diluta Smith; A. ernestina Baldwin; Helix vulpina Ferussac.

**A. phaeozona Gulick, 1856:**
The sinistral shell is scarcely perforate, oblong-ovate, and solid. The apex is subacute and the spire convexly conical. The suture is marginate and moderately impressed. Shell color is glossy white with one to six black or chestnut bands varying in width. The whorls are moderately convex. The strong

central columellar fold is white with a dilated, adnate or sometimes slightly detached margin. The aperture is slightly oblique and lunately rounded. The peristome is acute and well thickened within. Seems to intergrade with A. fulgens and may be grouped with A. buddii. Length 22.0 mm, diameter 12.7 mm, 7 whorls.

**A. buddii Newcomb, 1853:**
The sinistral shell is conically ovate and solid. Whorls are convex and slightly margined above. The suture is moderately impressed and banded with white.

The aperture is ovate and the lip acute and thickened within. The columella is short with a terminal plication. Color yellowish (or cinnamon), slate or fawn; columella and aperture white. Differs from A. fulgens only in color. Length 20.5 mm, diameter 11.5 mm, 6 whorls.

Synonyms: A. fuscozona Smith.

**A. fulgens Newcomb, 1853:**
The sinistral (rarely dextral) shell is elongately conic with flatly convex whorls. The suture is slightly impressed and the aperture is ovate. The short, white columella is tuberculated and the simple lip is ribbed within and colored chestnut-brown. A broad white sutural fascia cuts the center of the last whorl. The apex is white. Length 23.1 mm, diameter 10.3 mm, 6 whorls.

Synonyms: A. liliacea Pfeiffer; A. lilaceum Pfeiffer; A. vulpina Ferussac; A. crassidentata Pfeiffer; A. plumata Gulick; A. diversa Gulick; A. varia Gulick; A. trilineata Gulick; A. augusta Smith; A. angusta Smith; A. versipellis Gulick; A. fuscolineata Smith; A. ampla Newcomb; A. solitaria Newcomb; Achatinellastrum versipilis Gulick.

**A. stewartii (Green, 1827):**
The dextral or sinistral shell is oblong-turrate, solid and lightly marked with lines of growth and very faint spiral striae. Whorls are convex. The glossy color is variable, but the typical pattern is citron yellow fading to white at the summit, with a black or deep brown band bordering the suture below on the last

3 to 3 1/2 whorls, and a black crescent bounding the columella. The aperture white and the columella some shade of violet. The outer lip simple or thickened within and the columellar fold is strong. Length 22.0 mm, diameter 11.3 mm, 6 1/2 whorls.

Synonyms: A. fuscozona Gulick; A. pulcherrima Reeve; A. venulata Newcomb; A. byronii Gray; A. johnsoni Newcomb; A. aplustre Newcomb; A. producta Reeve; A. bilineata Reeve; A. venulata Newcomb; A. hybrida Newcomb; A. dunkeri Cuming; A. vulpina Ferussac; Achatina stewartii Green.

**Series of Achatinella casta:**
Shells are small, whitish, yellow or chestnut, usually banded and never green.

**A. casta Newcomb, 1853:**
The dextral or sinistral shell is conically elongate and solid. Whorls are rounded and margined above. The aperture is sub-ovate and rather small. The simple lip is thickened within and the short columella has a strong plaited brownish tooth. The glossy color is white or yellow with extremely variable transverse bands of black, brown, pink or white, variously arranged. Length 16.7 mm, diameter 8.3 mm, 6 whorls.

Synonyms: A. cuneus Pfeiffer; A. concolor E. A. Smith; A. pygmaea E. A. Smith; A. ligata E. A. Smith; Eburnella casta Newcomb.

**A. bellula E. A. Smith, 1873:**
The dextral shell is long, subconic, imperforate and very lightly striate with growth lines. The glossy color is dilute chestnut (the spire paler) streaked darker, encircled with a few obsolete lines of a somewhat chestnut color, and a nearly black zone (sometimes wanting) below the periphery. Whorls are slightly convex and the suture is lightly bordered with chestnut. The aperture is short and white inside. The margin of the peristome is thin, but slightly thickened within. The columellar fold is strong and colored purple. Length 20.0 mm, diameter 10.0 mm, 6 1/2 whorls.

Synonyms: A. bellulae Smith; A. multizonata Baldwin.

**A. juncea Gulick, 1856:**
The sinistral shell is imperforate, elongately and accuminately ovate, thin, and finely striated. The color is glossy snow white. The apex is somewhat acute and the spire convexly turreted. The margined suture is well impressed and the whorls are convex. The white columella has a light twisted fold near the body whorl. The oblique, oval aperture is white within and the peristome is moderately thickened. The external margin is slightly expanded anteriorly; arcuate and acute. The narrow columellar margin is adnate and the parietal margin is thin. Length 16.0 mm, diameter 8.0 mm, 6 whorls.

**Series of Achatinella papyracea:**
Capacious, ovate, thin shells, the embryonic whorls not marked with an ocher band.

**A. papyracea Gulick, 1856:**
The sinistral shell is ovate-conic, imperforate, thin and finely striated. The polished color is a light gray, or of leaden ash, with obscure brown spiral lines. The apex is subacute and the spire is convexly conical. The marginate suture is impressed and whorls are moderately convex. The white columellar fold is central, slightly developed and not strongly twisted. The oblique, sinuately oval aperture is white or gray within and the peristome is scarcely thickened with an unreflected external margin; arcuate and acute. The narrow columellar margin is adnate and the parietal margin is wanting. Length 16.5 mm, diameter 9.7 mm, 5 1/2 whorls.

**Series of Achatinella livida:**
Rather small, stout, ovate or short shells, dull green, yellow or white; often with a few bands, or sometimes streaked. The embryonic shell often has an ocher band.

**A. juddii Baldwin, 1895:**
The dextral shell is imperforate, solid, pyramidally conical and covered with very delicate incremental lines; the nuclear whorls smooth. The apex is obtuse. Color is a shiny light gray, shading into light chestnut on the apical whorls with two black lines, one below and one at the periphery. Between the lines a white band revolves on the suture to the very tip of the apex. Whorls are margined above and slightly convex. The suture is lightly impressed. An oblique,

oval aperture is white to light gray within. The acute peristome is slightly thickened within and a little expanded. The white columellar margin is very slightly reflected, with the color of the exterior dark lines reappearing on the inner edge. The white columella terminates in a moderately developed flexuous fold. Length, 15.0 mm, diameter 9.5 mm, 6 whorls.

**A. livida Swainson, 1828:**
The dextral or sinistral shell is small, ovate and obtuse; with a thickened spire. The suture has a deep fulvous line. The color is a livid brown or grayish with no banding, to a livid purple which lies in longitudinal shades and gradually changes on the spiral whorls to white. The suture is marked by a line of deep orange brown. The aperture is white, tinged with purple. Length 17.0 mm, diameter 9.0 mm, 6 whorls.

Synonyms: *A. viridans* Mighels; *A. emersoni* Newcomb; *A. reevei* C. B. Adams; *A. recta* Newcomb; *A. glauca* Gulick; *A. herbacea* Gulick; *Eburnella livida* Swainson.

**A. curta Newcomb, 1853:**
Specimens are rare and extremely limited within their range. The sinistral or dextral shell is conical, with rounded whorls that are margined above, the last very ventricose. The aperture is ovate and the simple lip is slightly thickened within. The short columella has an abrupt, callous termination. The suture is only slightly impressed. Shell color is a polished yellow or chestnut with a plain or with a black sutural band, rarely with two or more on the last whorl. The columella is white or light brown. The round whorls and obese appearance of this shell are strikingly characteristic. Length 21.4 mm, diameter 10.3 mm, 5 whorls.

Synonyms: *A. rhodoraphe* E. A. Smith; *A. undulata* Newcomb; *A. delta* Gulick.

**A. dimorpha Gulick, 1858:**
The sinistral or dextral shell is imperforate, turreted, solid, and striated. The apex is rather obtuse and the spire turreted. The marginate suture is moderately impressed. Whorls are convex and shiny white or yellow with a brown sutural band. The columellar fold is central, white or rose, and moderately developed. The aperture is truncately

ellipsoidal and white within; the peristome is slightly thickened within, with an external, unreflected margin; arcuate and acute. The columellar margin is dilated and adnate; the parietal margin wanting. Length 18.0 mm, diameter 9.4 mm, 6 whorls.

Synonyms: A. albescens Gulick; A. zonata Gulick; A. contracta Gulick.

**A. caesia Gulick, 1858:**
Specimens were rare in the 1850's. The sinistral shell is imperforate, ovate-conic, solid and striated. The apex is somewhat acute and the spire is convexly conic. The marginate suture is moderately impressed. The shining shell is so streaked with white and fawn brown as to have a gray appearance. Whorls are convex. The moderately developed columellar fold is central and white. The white aperture is sinuately oval, white and the peristome is slightly thickened within with the external margin unreflected, arcuate, acute, and edged with brown. The columellar margin is dilated and adnate and the parietal margin wanting. Length 18.3 mm, diameter 10.7 mm, 6 1/2 whorls.

Synonyms: A. concidens Gulick; A. formosa Gulick; A. cognata Gulick; A. scitula Gulick; A. cervina Gulick.

**Wai'anae Range Species:**
Intermediate between the A. papyracea and A. livida Series. All are extremely rare and each species is known from a single colony all of which are on the north slope of the Wai'anae Range.

**A. spaldingi Pilsbry & Cooke, 1914:**
The sinistral shell is imperforate, ovate-conic, ventricose and quite thin. The color is white with slightly interrupted or spotted tawny bands and lines. There is usually a group of bands near the columella, and a space without bands at and below the periphery. The suture is edged with a band or line of the white ground; the apex a trifle dusky. The shell surface is not very glossy, or often dull in old shells, somewhat roughened by growth wrinkles and irregularly scattered impressions. Whorls are convex and joined by an impressed suture. The aperture is white and showing the bands weakly within. The outer lip not expanded; thin and acute. The columellar fold is whitish, spiral, and small. Length 16.5 mm, diameter 11.1 mm, 5 1/2 whorls.

**A. lehuiensis E. A. Smith, 1873:**
The sinistral shell is ovate-conic and very finely striated with growth and transverse lines. The glossy color is white, encircled with a purple-brown streaked zone and two brown zones, one above, the other below the periphery. The suture is submarginate. Whorls are convex. The aperture is white and the peristome is thin. The columellar fold is strong and rose colored. Length 17.0 mm, diameter 10.0 mm, 5 1/2 whorls.

**A. thaanumi Pilsbry & Cooke, 1914:**
Described from only two specimens. The sinistral shell is perforate, ovate-conic, and thin but moderately strong. The shell is marked with fine growth-lines and nearly obsolete spiral striae. The spire is conic with nearly straight outlines and a minute apex. The suture is very narrowly margined in one, but not in the other specimen. The glossy white shell is encircled by two chocolate bands, one above, the other below the periphery. There is no subsutural band or columellar dark patch. Embryonic whorls are white, becoming blue-gray at the tip. The aperture has a white lining, showing the bands faintly, but at the thin edge they become vivid, the acute peristome being elsewhere white. It is slightly thickened within. The columellar fold strong and white. Length 19.1 mm, diameter 11.6 mm, 6 whorls.

**Subgenus Achatinella sensu strictu Swainson 1828:**
The shell is globose-conic or ovate-conic, imperforate or minutely perforate and solid. The embryonic whorls are flattened. The aperture is quite oblique and the outer lip is well thickened but expanded very little if at all. There is a strong collumelar fold. Type *Achatinella apexfulva*.

**Series of Achatinella lorata**

**A. lorata Ferussac, 1824:**
The dextral shell is ovate-conic with an acute summit; striate. Glossy white with an epidermal color; epidermis uniform or ornamented with bands. Whorls regularly increasing and the suture margined. The white aperture is ovate. The columella is arcuate and prominent. The umbilical cleft is not distinct. Length 17.5 mm, diameter 11.0 mm, 5 1/2 whorls.

Synonyms: *A. hanleyana* Pfeiffer; *A. ventrosa* Pfeiffer; *A. nobilis* Pfeiffer; *A. alba* Nuttall; *A. pallida* Nuttall; *A. pulchella* Pfeiffer; *Helix lorata* Ferussac; *Achatina lorata* Ferussac.

Series of Achatinella apexfulva

**A. apexfulva, (Dixon, 1789):**
The dextral or sinistral shell is imperforate, ovate-piriform and solid. The spire is concave. The glossy color begins with Naples yellow on the almost flat embryonic whorls which gradually become elongate or drawn out. Following whorls are blackish carob brown to chestnut, sometimes with some whitish streaks and spiral lines. The narrow suture is light-edged. The lip is flesh or salmon and the columellar fold is nearly white. The aperture is bluish white within and the lip is moderately thickened. Length 19.0 mm, diameter 12.5 mm, 6 whorls.

Synonyms: *A. lugubris* Chemnitz; *A. pica* Swainson; *A. vespertina* Baldwin; *A. apicata* var. *alba* Sykes; *A. apicata* Newcomb; *A. swiftii* var. Newcomb; *A. aptycha* Pfeiffer; *Helix Apex Fulva* Dixon; *Turbo Apex Fulva* Dixon; *T. lugubris* Chemnitz; *Monodonta seminigra* Lamarck; *Bulimus seminiger* Mke.; *Apex gulickii* Smith; *A. lilaceus* Gulick.

**A. cestus Newcomb, 1853:**
The sinistral or dextral shell is solid, ventricose and pointed at the summit. The whorls are rounded, corded above with the last one tumid. The aperture is subovate and the short columella is strongly tuberculate. The lip is slightly expanded and thickened within. The apex is black and the second and third whorls are white. The three last whorls are white, yellowish or black or mixed, with a white cincture traversing the sutures and cutting the body whorl below the center. A broader band is sometimes present the white cincture. Sometimes with blotches or tessellations of black and white or longitudinal undulating lines of the same colors. The columella is chestnut and the lip is chestnut interrupted with white. Length 18.0 mm, diameter 10.3 mm, 6 whorls.

Synonyms: *A. forbesiana* Pfeiffer; *A. simulans* var. *cestus* Pfeiffer; *Bulimella forbsiana* Pfeiffer.

**A. vittata Reeve, 1850:**
"The dextral or sinistral shell is globosely conical and rather ventricose. Shell color is white, encircled with lines and fillets of pale brown. The

apex is black. The rounded whorls are broadly marginated around the upper part and the columella is callous but scarcely toothed. The lip is thickened. Very similar in shape and color to A. decora. Length 18.3 mm, diameter 11.3 mm, 6 whorls.

Synonyms: A. globosa Pfeiffer; A. simulans Reeve; Apex albofasciata Smith; Helix decora Ferussac; Achatina decora Ferussac.

**A. turgida Newcomb, 1853:**
The dextral or sinistral shell is smooth, ventricose and pointed at the apex; gradually enlarging for four turns and then enlarging very rapidly, for the last two turns which form most of the shell. The suture is slightly impressed, and beneath it revolves a linear depression. The aperture is subovate. The columella is short and terminates in a strong conical tubercle projecting into the aperture. The simple outer lip is thickened within and slightly tinged with pink or brown. The tubercle is the same color but with white fauces. The glossy shell coloring is extremely various; the background is white, yellow or black, with or without longitudinal zigzag lines, transverse bands or blotches covering the surface. Length 18.0 mm, diameter 14 mm, 6 whorls.

Synonyms: A. cestus Newcomb, in part; A. ovum Pfeiffer; A. cookei Baldwin.

**A. leucorraphe (Gulick, 1873):**
The dextral or sinistral shell is short, ovate-conic and striated with growth (but scarcely with spiral) lines. The color is gray ornamented with irregularly interrupted dark cinereous streaks and a few indistinct, white, spiral lines. The suture is broadly margined with snow white. The apex is blackish and the first four whorls are white and nearly flat. The remaining whorls are convex. The small, white aperture is somewhat ear-shaped. The peristome is slightly dilated and thickened within and the columellar fold is large and rosy in color. Length 19.0 mm, diameter 12.0 mm, 6 1/2 whorls.

**A. swiftii Newcomb, 1853:**
The dextral or sinistral shell is ovate, ventricose, pointed at the apex and smooth, with slightly rounded whorls, the last of which is strongly inflated and distinctly margined above. The short columella

terminates in a tubercle. The first three whorls are glossy white. The lower whorls are white with numerous fine, black and white markings arranged longitudinally to the shell, giving it a grayish aspects. Fine, obsolete white lines traverse the shell transversely, and a white sutural line is traced on the last two whorls. Length 18.0 mm, diameter 12.8 mm, 6 whorls.

Synonyms: *A. dolium* Pfeiffer; *Apex albospira* Smith; *A. innotabilis* Smith; *A. neglectus* Smith; *A. versicolor* Gulick; *A. flavidus* Gulick; *A. coniformis* Gulick; *A. tuberans* Gulick; *A. polymorpha* Gulick.

**Series of Achatinella decora:**
*A. mustelina* and *A. concavospira* are the dominant species of the Wai'anae Range. These two species, *A. decora* and *A. valida* appear to be from the same Ko'olau ancestral stock. Up to historic times forest extended from the Ko'olau to the Wai'anae Mountains allowing snails from the two ranges to mingle.

**A. decora (Ferussac, 1821):**
The dextral or sinistral shell is perforate, solid, and ovate-conic with a weakly striate surface. The spire is straight or slightly concave. The suture is superficial, with the usual impressed line defining a margin that is bordered below by a white band. The aperture is bluish white within and the pale, flesh-colored lip is slightly expanded and well thickened within. The columellar fold is moderate and nearly white. Embryonic whorls are cream color (varying from almost white to light ochraceous buff) with the tip often a little darker. The first neanic whorl is often blotched with chocolate, or with a chocolate band, extending as far as the last whorl. The last whorl is variously marked including shells copiously streaked with chestnut, bay or blackish chocolate on an ochraceous buff ground with or without a light subperipheral band; lightly streaked shells with chestnut over an ochreceous buff, with dark bands below the white sutural band and at the periphery and around the columella, or otherwise placed; shells of a creamy ochraceous buff, not streaked, having a few narrow dark bands and a nearly white lip with a yellowish edge. Length 21.3 mm, diameter 13.0 mm, 6 1/3 whorls.

Synonyms: *A. perversa* Swainson; *A. quernea*

Frick; *Apex tumefactus* Gulick; *A. decorus* Ferrussac; *Helix decora* Ferussac; *Turbo lugubris sinistrorsus* Chemnitz.

**A. valida Pfeiffer, 1855:**
The dextral or sinistral shell is solid imperforate, ovate-conic, and smooth with an elevated, conic spire. The brown apex is acute and the margined suture is white. The first three whorls are flat and the following whorls are slightly convex; the last whorl is inflated and about two-fifths of the total length. The color is an ashy-brown, somewhat banded with a pale tint and streaked with black. The aperture is oblique and truncate-auriform. The columellar fold is nodiform and slightly twisted. The peristome is brown-bordered and the right margin is nearly unexpanded and somewhat straightened. The columellar margin is dilated and appressed. Length 21.5 mm, diameter 13.0 mm, 6 whorls.

Synonyms: *A. cinerosa* Pfeiffer; *Apex leucophaeus* Gulick; *A. leucozonus* Gulick.

**A. mustelina Mighels, 1845:**
The dextral or sinistral shell is perforate and elongately conical with the convex whorls margined above. The color is variable; often dark brown with a light revolving band at the suture convex or white with numerous transverse brown or black lines. The thickened lip is simple and acute. The short, stout columella is slightly twisted, with a callus nearly closing the umbilicus. the aperture is ovate and oblong. Length 25.6 mm, diameter 1.5 mm. 7 whorls.

Synonyms: *A. vestita* Mighels; *A. multilineata* Newcomb; *A. monarcha* Pfeiffer; *A. bicolor* 'Gulick' Pfeiffer; *A. sordida* Newcomb; *A. napus* Pfeiffer; *A. pulcherrima* var. *elongata* Newcomb; *Apex mustelina* Mighels; *Bulimella multilineata* Newcomb.

**A. concavospira Pfeiffer, 1859:**
The dextral shell is subperforate, ovate-turrate, solid and striatulate. The glossy, whitish, color is ornamented with bands and narrow streaks of coffee color. The spire is concavely turrite, and the apex is somewhat acute and white. The suture is strongly margined and the first three whorls are flat followed

by convex whorls with the last one rounded and about equal to two-fifths the total length. The columellar fold is superior, nodiform and white. The aperture is oblique and reversed auriform. The peristome is liver colored, with the right margin a little expanded and the columellar margin very much dilated, reflexed and adnate. Length 21.5 mm, diameter 11.3 mm, 7 whorls.

Synonyms: Apex turbiniformis Gulick

## APPENDIX II. UNPUBLISHED DATA SOURCES.

**Sources of field-note and interview information on current ranges and abundances of extant species of Achatinella*.**

---

Bernice P. Bishop Museum, Department of Zoology. Unpublished Collection Records.

Dr. Carl Christensen: Field Notes (1962 - 1967). Copies of these notes are in the Malacology collection of the B. P. Bishop Museum and at The Nature Conservancy.

Mr. Clifford Chun: Field Notes (1974). M. G. Hadfield has a copy.

Dr. Daniel Chung: Interview and Field Notes (1972 - 1988). The Nature Conservancy has a synopsis of his field notes.

Mr. Peter Galloway: Interview and Field Notes (1977 - 1981). M. G. Hadfield has a copy of the notes.

Dr. Michael G. Hadfield: Field Notes (1980 - 1989). University of Hawai'i, Kewalo Marine Laboratory, 41 Ahui Street, Honolulu, Hawai'i 96813.

Dr. Yoshio Kondo: Field Notes (1945 - 1967). The original notes are in the Malacology collection of the B. P. Bishop Museum.

Mr. Jaan Lepson: Interview. University of Hawai'i, Department of Zoology, 2538 The Mall, Honolulu, Hawai'i 96822.

Mr. Stephen E. Miller: Interview and Field Notes (1983 -1989). University of Hawai'i, Department of Zoology, 2538 The Mall, Honolulu, Hawai'i 96822.

The Nature Conservancy: Maps and Elemental Occurrence Records (information for 1945 - 1989). 1116 Smith Street, Suite 201, Honolulu, Hawai'i 96813.

Mr. John Obata: Interview.

Ms. Barbara Shank: Interview.

Mr. David Smith: Interview. Division of Forestry and Wildlife, NARS. Honolulu, Hawai'i.

---

* All interviews were conducted by M. G. Hadfield or A. H. Carwile in 1988.

## APPENDIX III. CAPTIVE PROPAGATION METHODS.

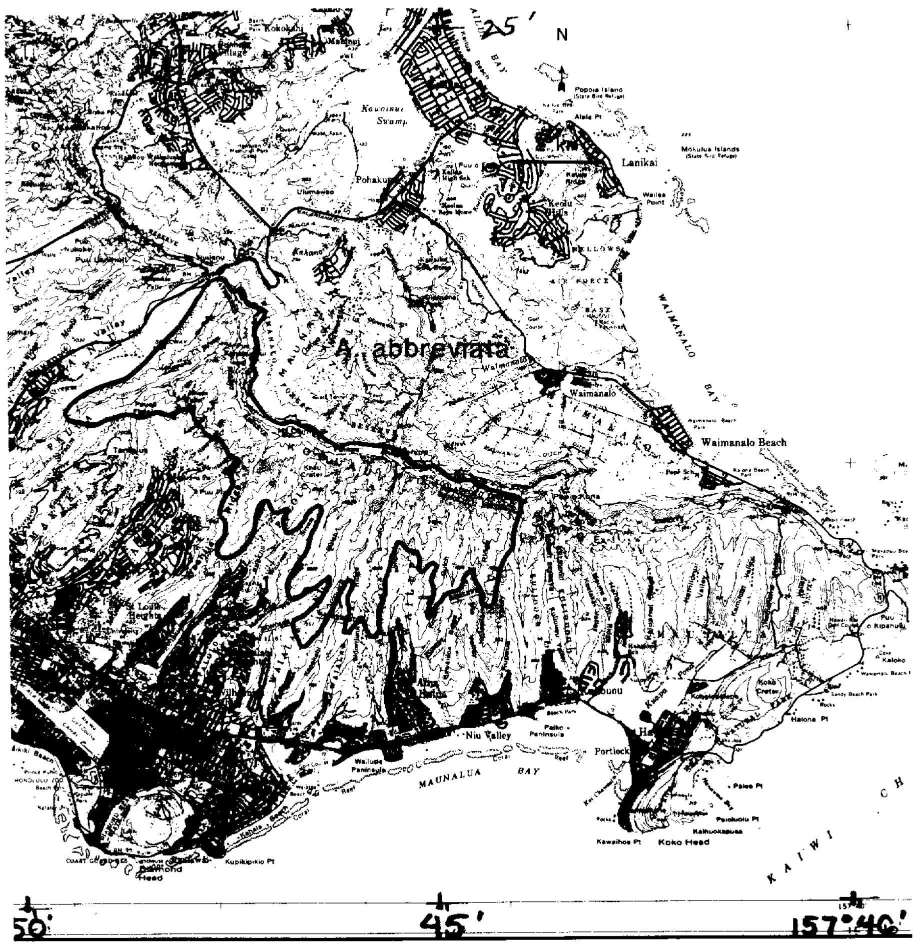
**Captive propagation methods for achatinelline snails (Hadfield *et. al.* unpublished data).**

The snails are maintained in commercially manufactured incubators with internal capacities of 16-21 $ft^3$. The incubators can be programmed for any desired light and temperature regime; they have been set to maintain 21-22 °C with a 12 hour daylight and a 12 hour dark period. Within the incubators, the snails are held in screened terraria to which are added fresh branches of o'hia-lehua leaves at about bi-weekly intervals. A timed sprinkler system sprays the area within each terrarium for four minutes three times per day, every eight hours. The terraria rest on screens which allow the water to escape during and after each spraying interval. Some of the water is trapped in tubs below the terraria, helping to maintain a relatively high humidity in each incubator. Fans, built into each incubator to circulate air and maintain a uniform temperature throughout, keep the environments within the terraria from becoming or remaining excessively moist. Thus climatic conditions in the terraria approximate those existing in some forested mountain areas of Hawai'i where tree snails have been observed.

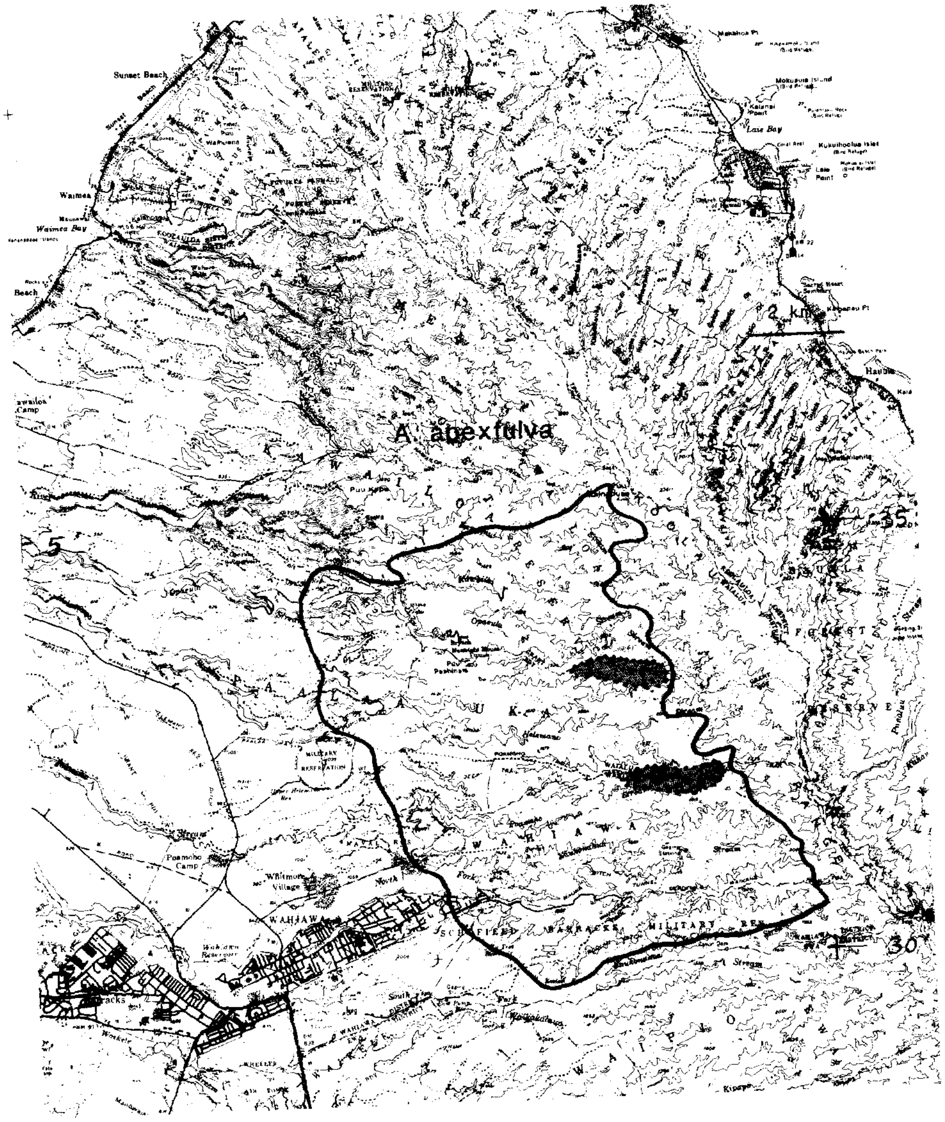
The captive snails feed on fungi that grow naturally on the leaves of o'hia that are periodically replaced in the terraria. In addition, a thin paste of corn starch in water is occasionally spread on the firm surfaces of the terraria, and cultures of sooty mold, grown on laboratory agar, are routinely introduced to the snails' habitats. Both the corn starch and the mold are consumed by the snails. Calcium is supplied to the snails as pieces of cuttlebone placed on the floors of the terraria.

## APPENDIX IV. SPECIES' RANGE MAPS.

Range maps of the the 41 species of Achatinella. Bold lines enclose historic ranges, as described in Pilsbry and Cooke (1912-1914) or Welch (1938). The dotted lines enclose areas of recent (1974 to 1989) citings as documented by survey field notes and interviews (Appendix II and Tables 2 and 5).

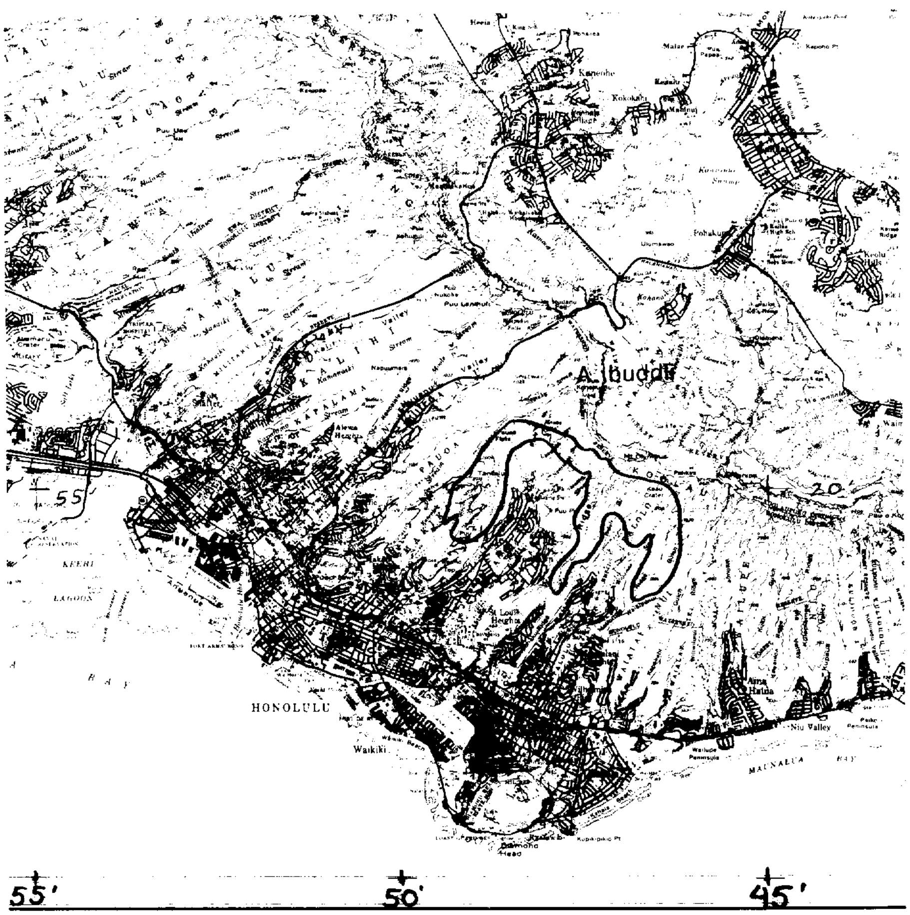



ACHATINELLA ABBREVIATA RANGE MAP

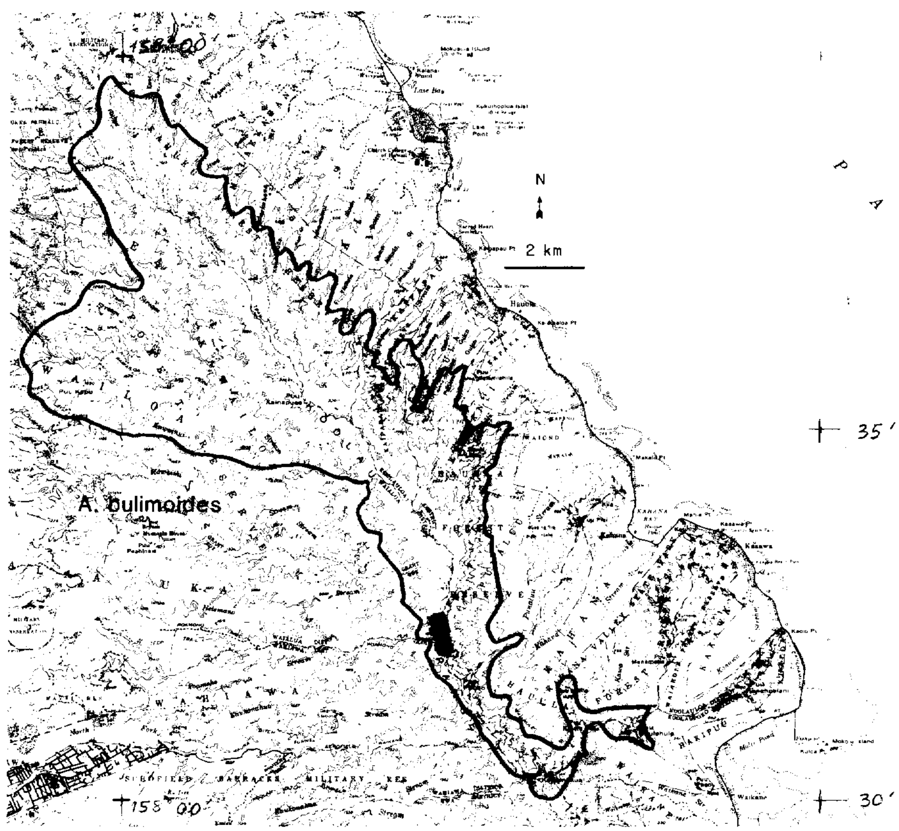



ACHATINELLA APEXFULVA RANGE MAP

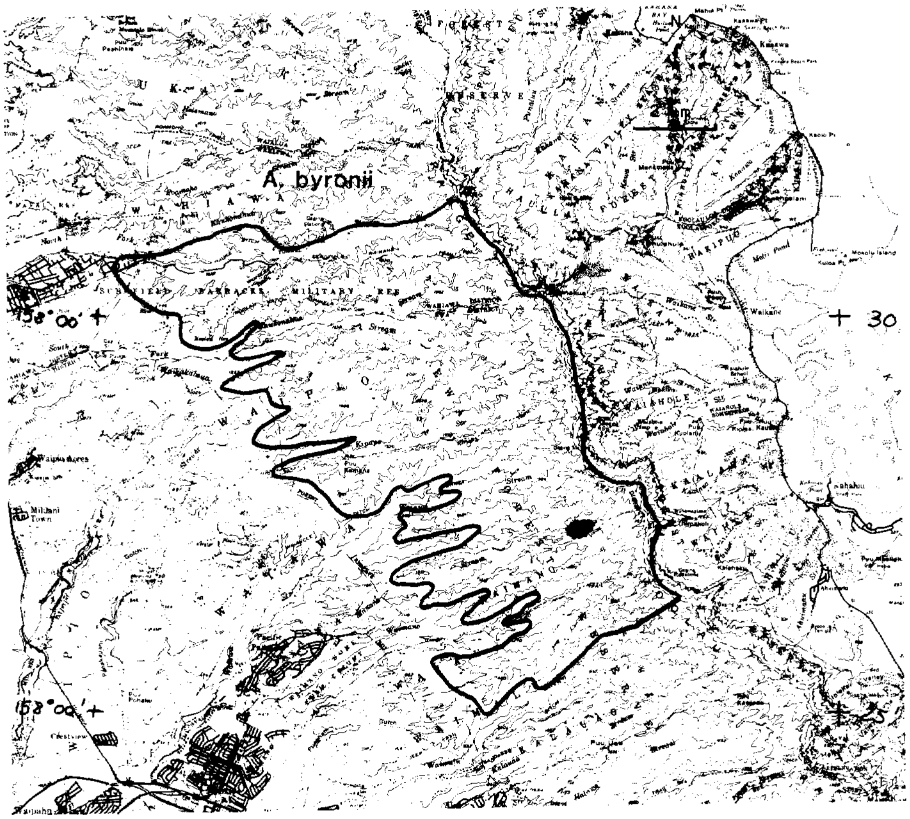

ACHATINELLA BELLULA RANGE MAP




ACHATINELLA BUDDII RANGE MAP

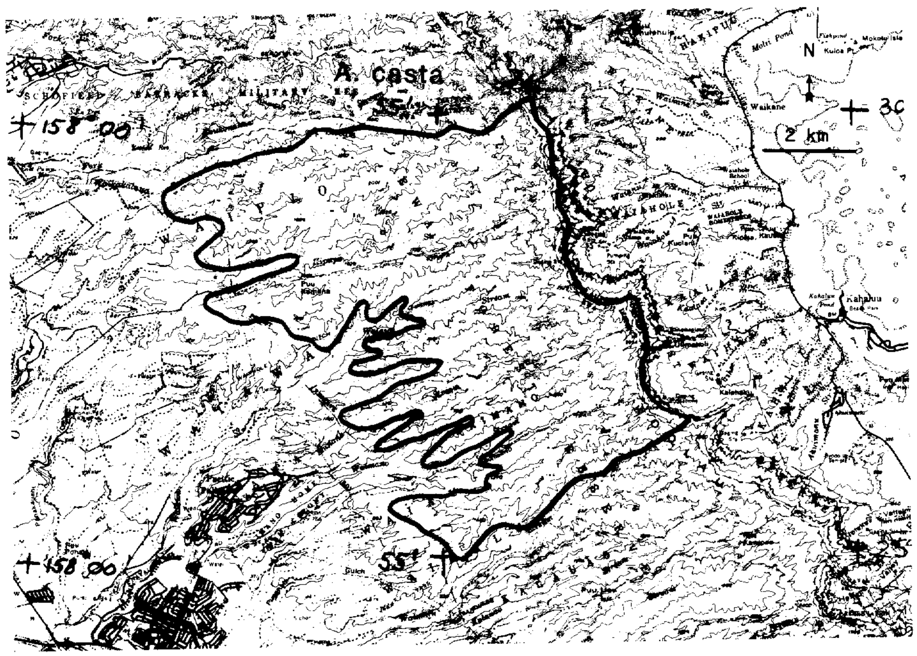



ACHATINELLA BULIMOIDES RANGE MAP

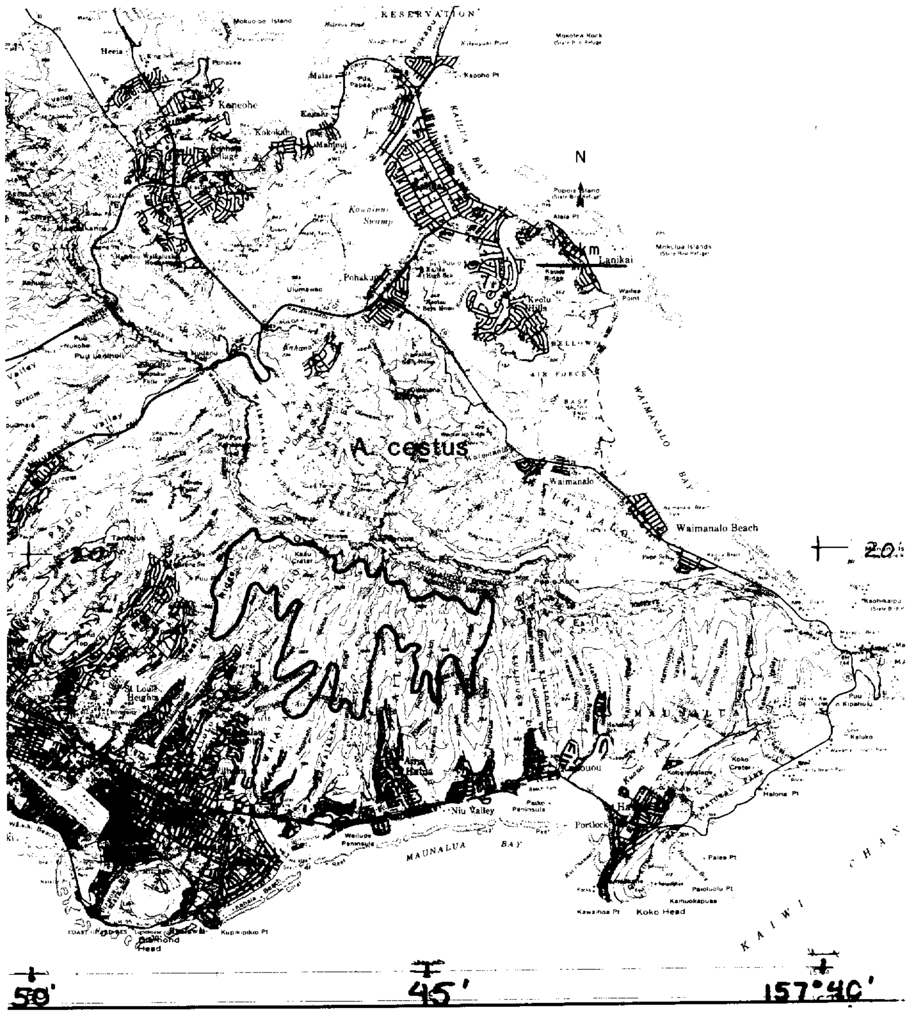



ACHATINELLA BYRONII RANGE MAP

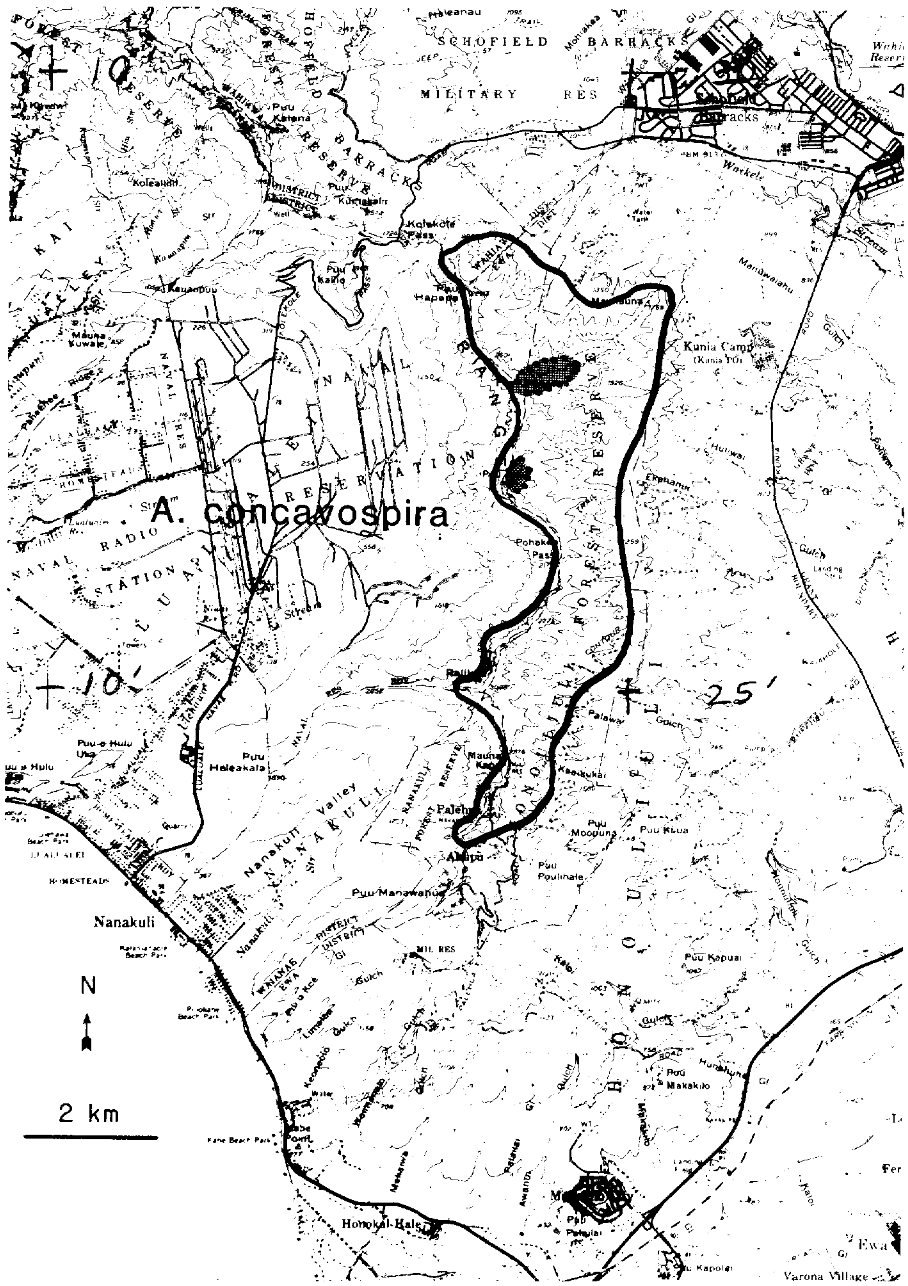

ACHATINELLA CAESIA RANGE MAP



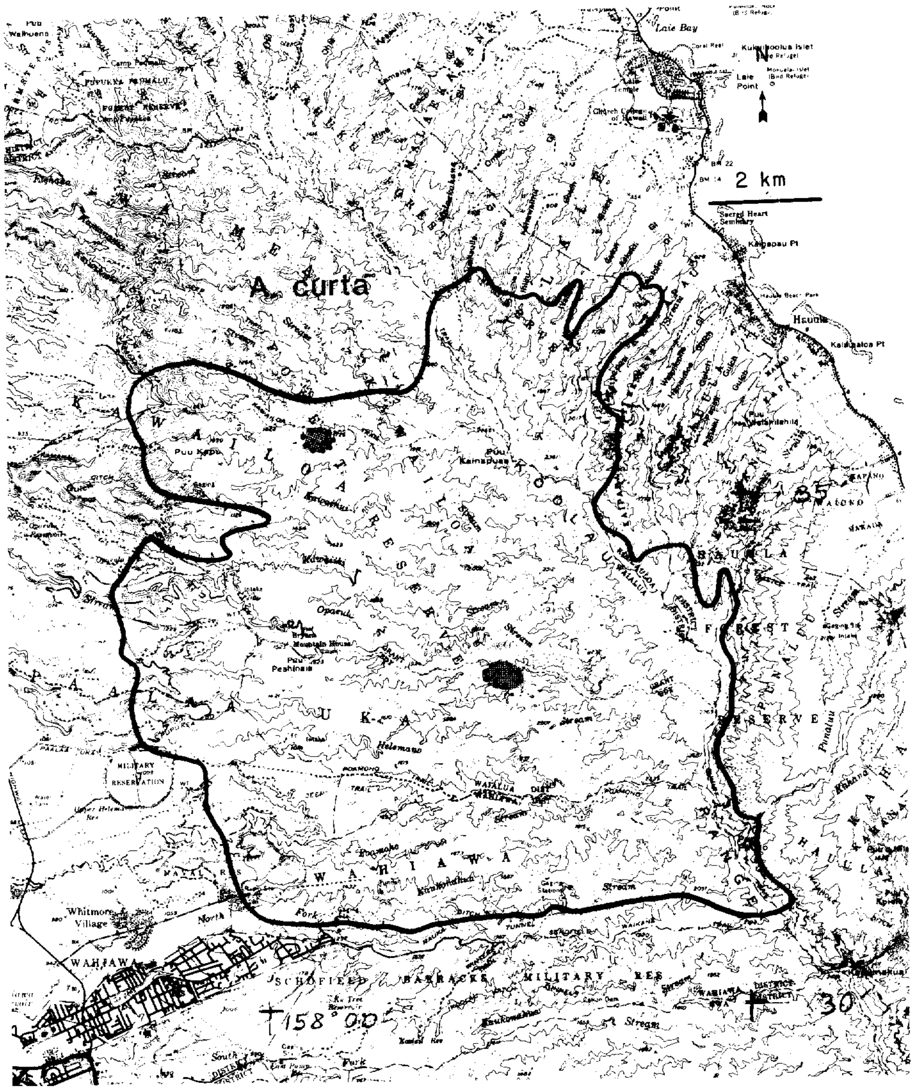

ACHATINELLA CASTA RANGE MAP



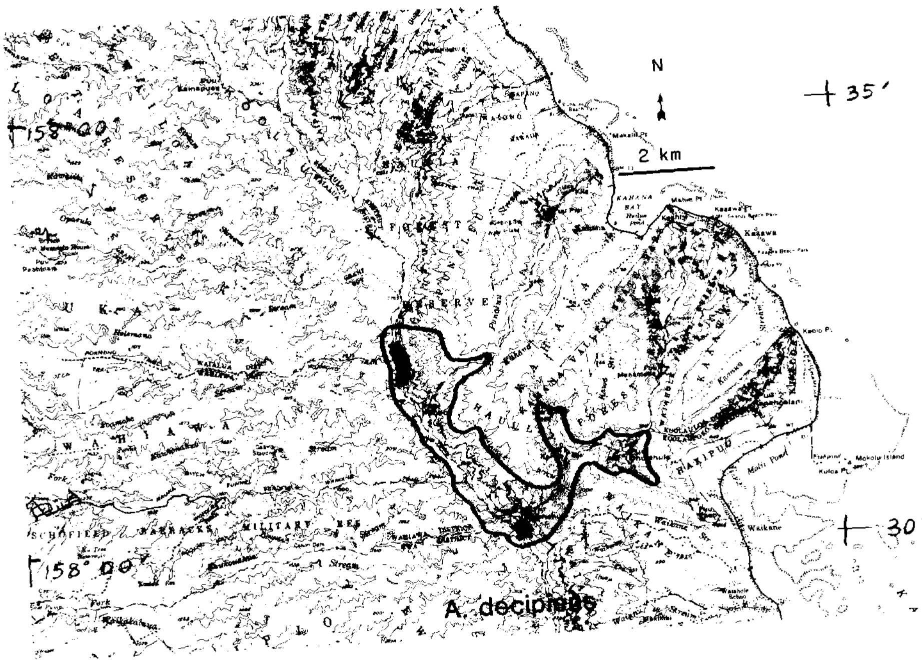

ACHATINELLA CESTUS RANGE MAP



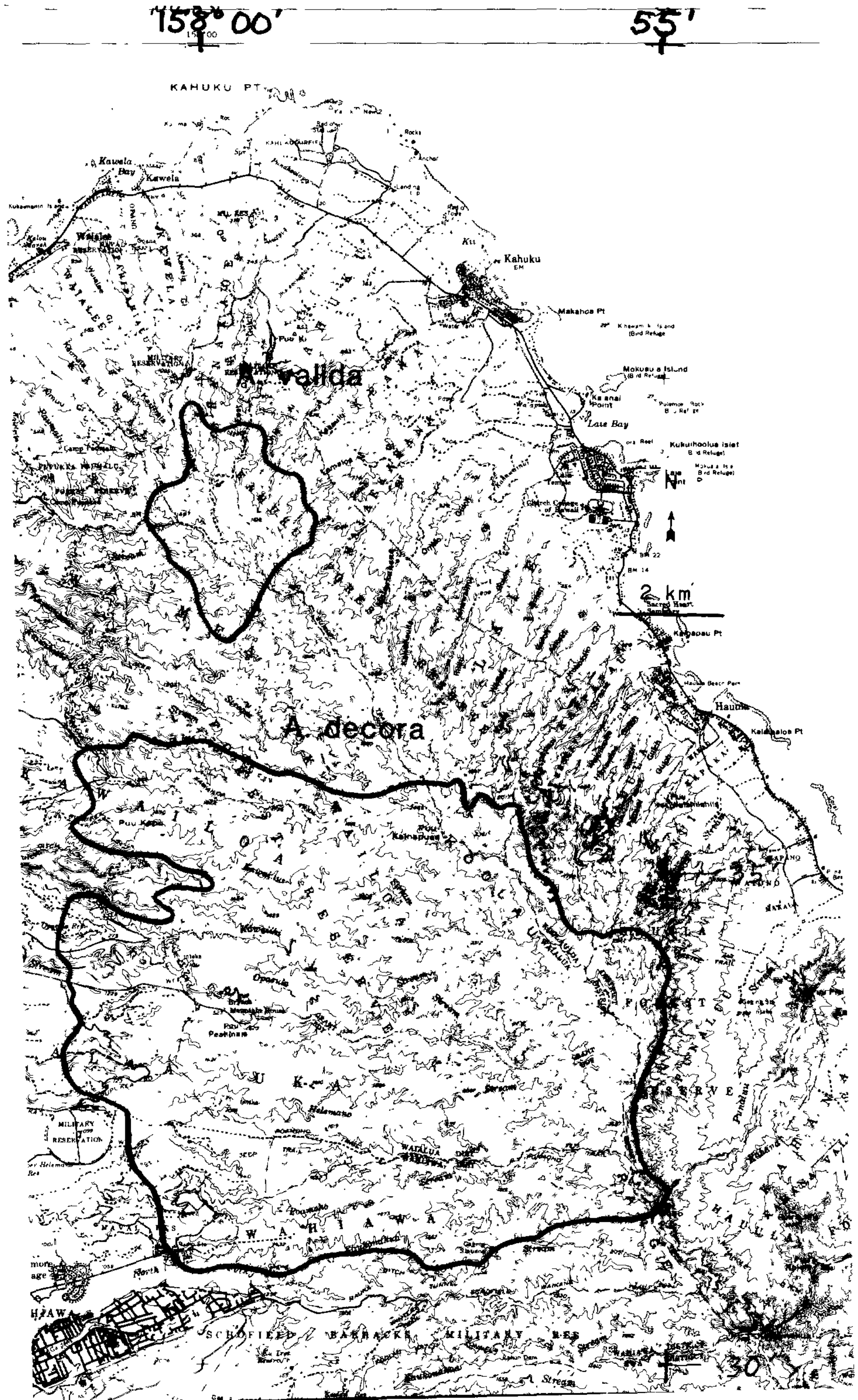

ACHATINELLA CONCAVOSPIRA RANGE MAP



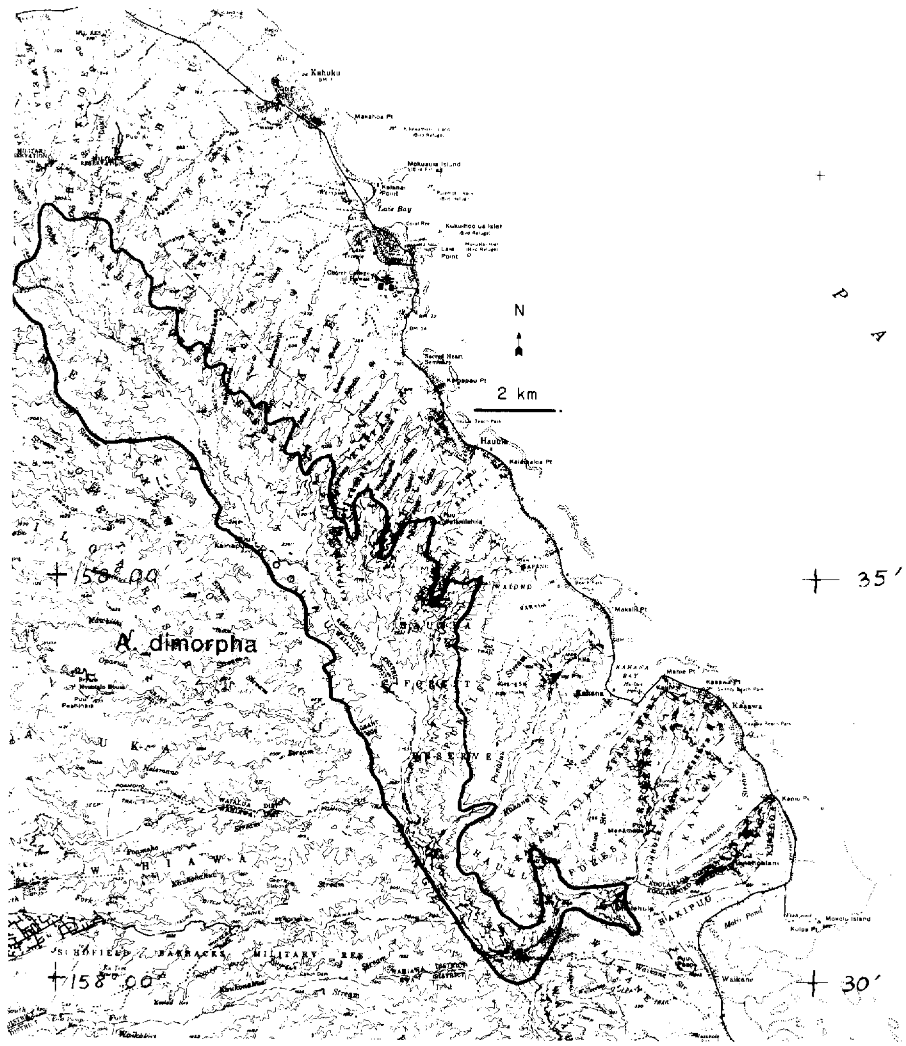

ACHATINELLA CURTA RANGE MAP



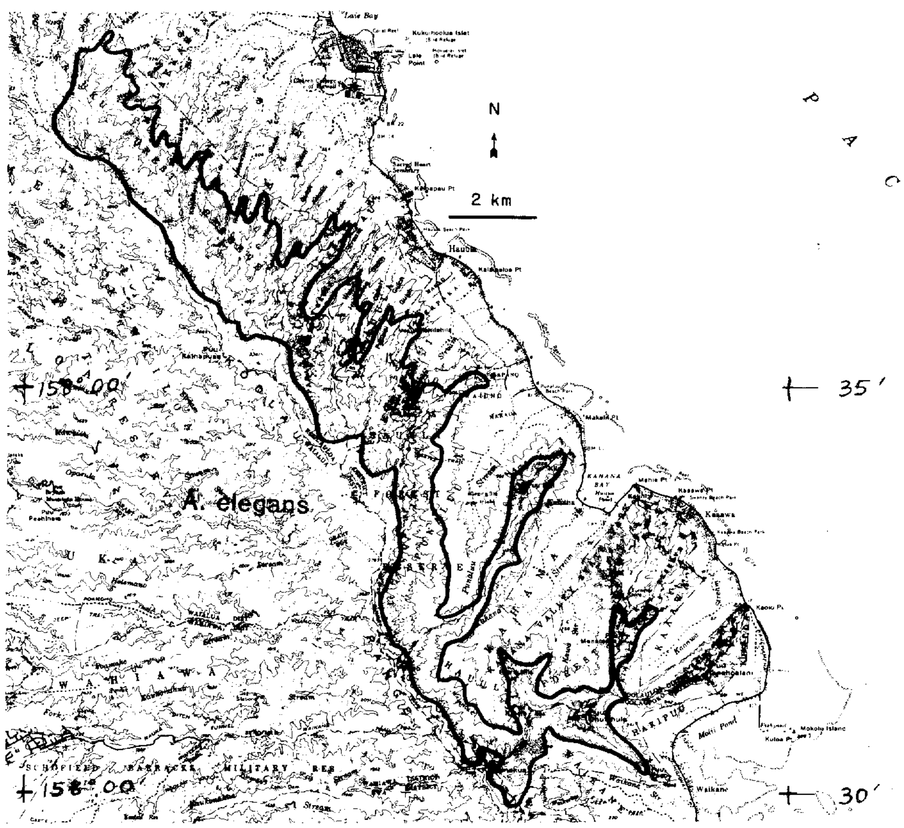

ACHATINELLA DECIPIENS RANGE MAP


158° 00'
55'
KAHUKU PT
Kahuku
A. valida
Laie Bay
2 km
A. decora
SCHOFIELD BARRACKS MILITARY RES

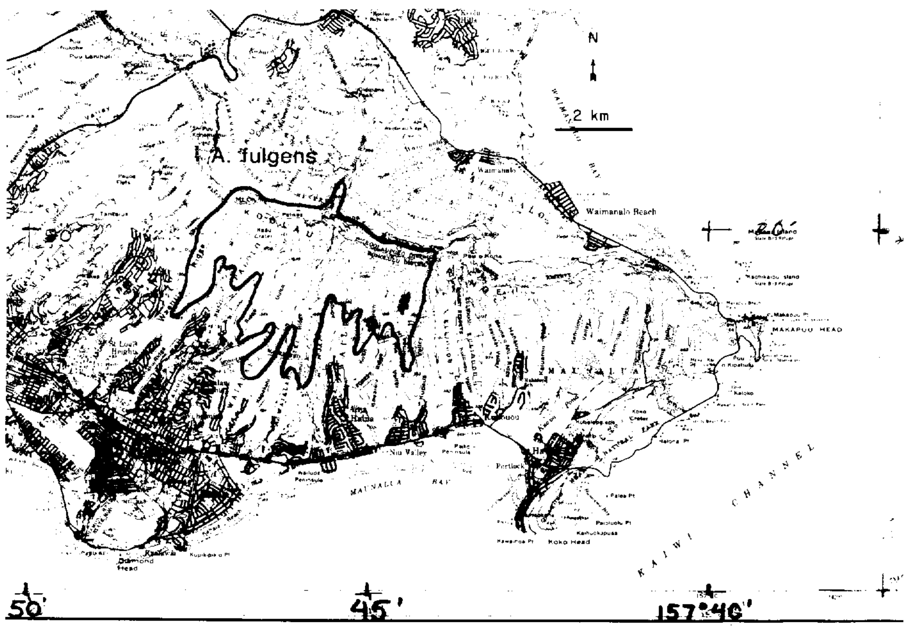
MAP



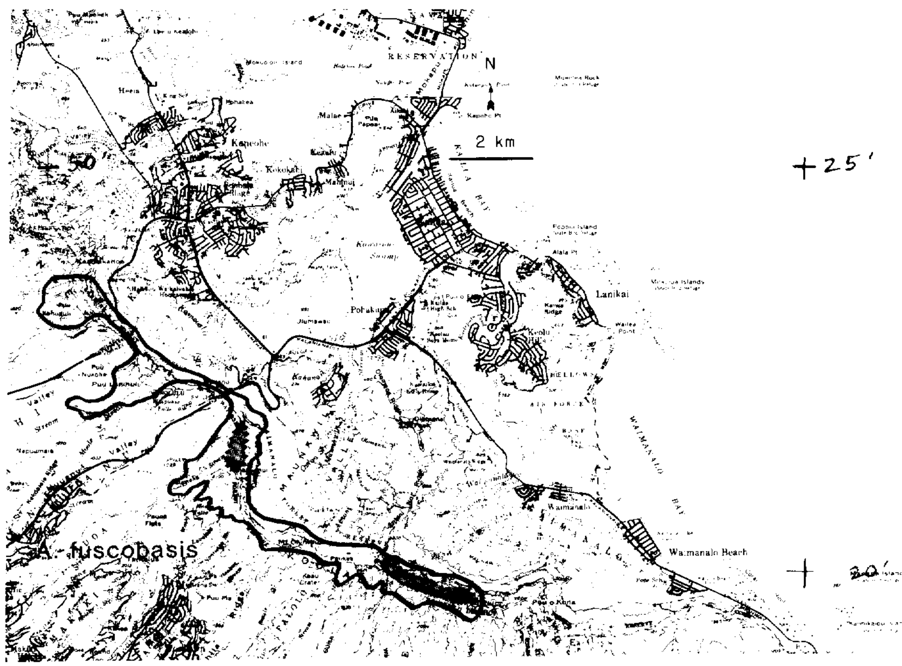

ACHATINELLA DIMORPHA RANGE MAP



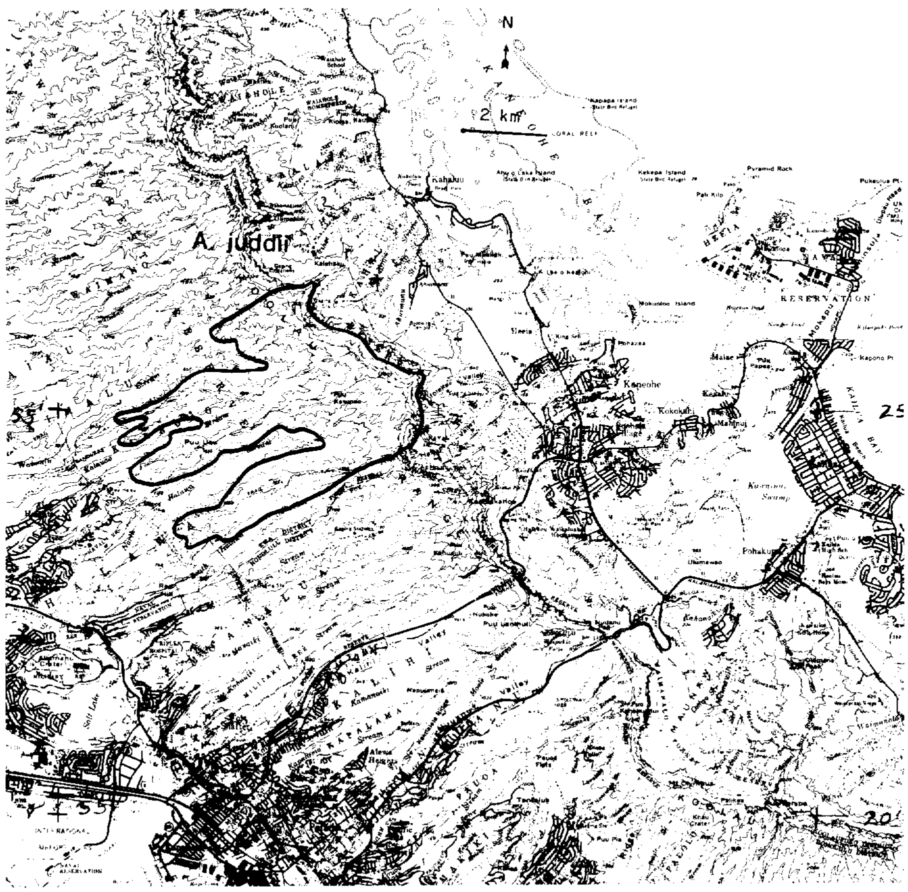

ACHATINELLA ELEGANS RANGE MAP



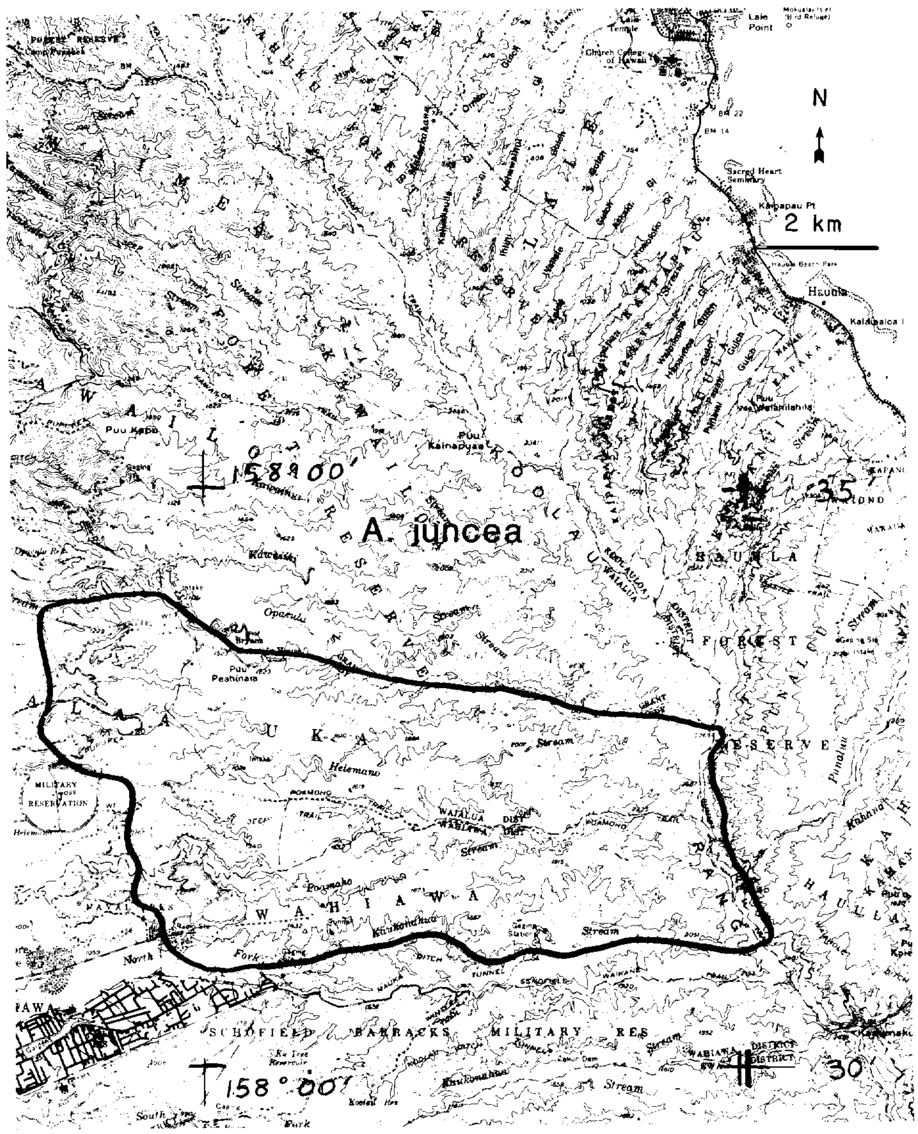

ACHATINELLA FULGENS RANGE MAP



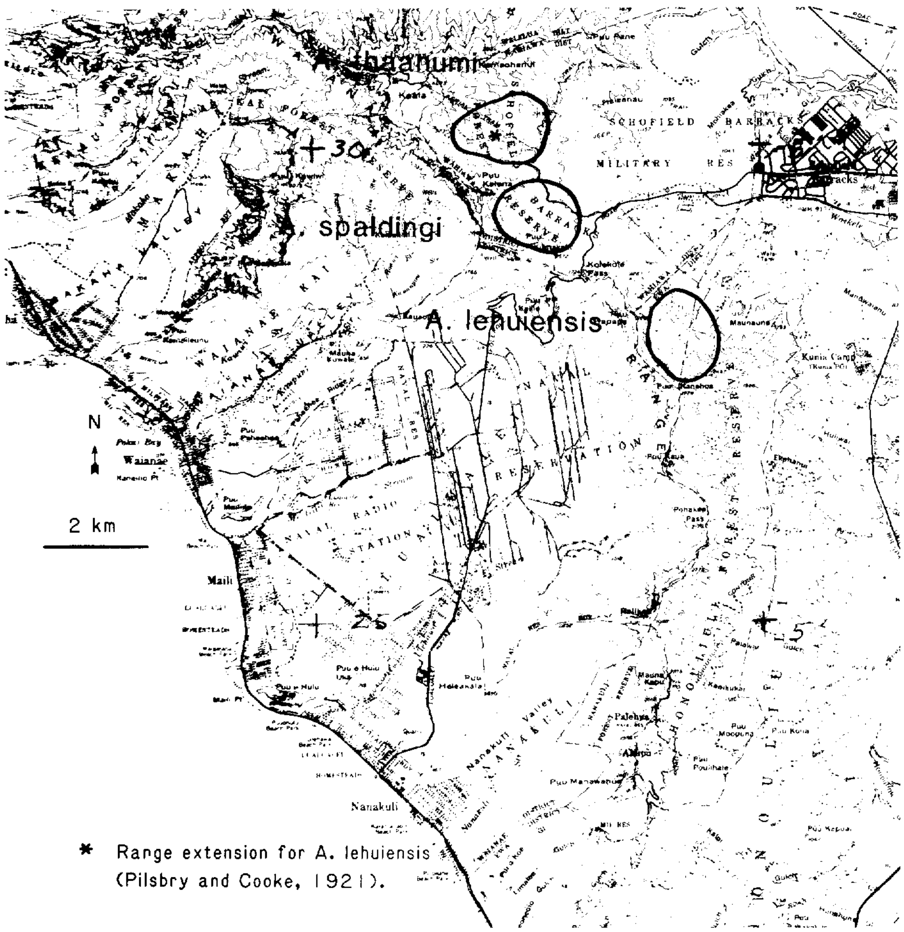

ACHATINELLA FUSCOBASIS RANGE MAP



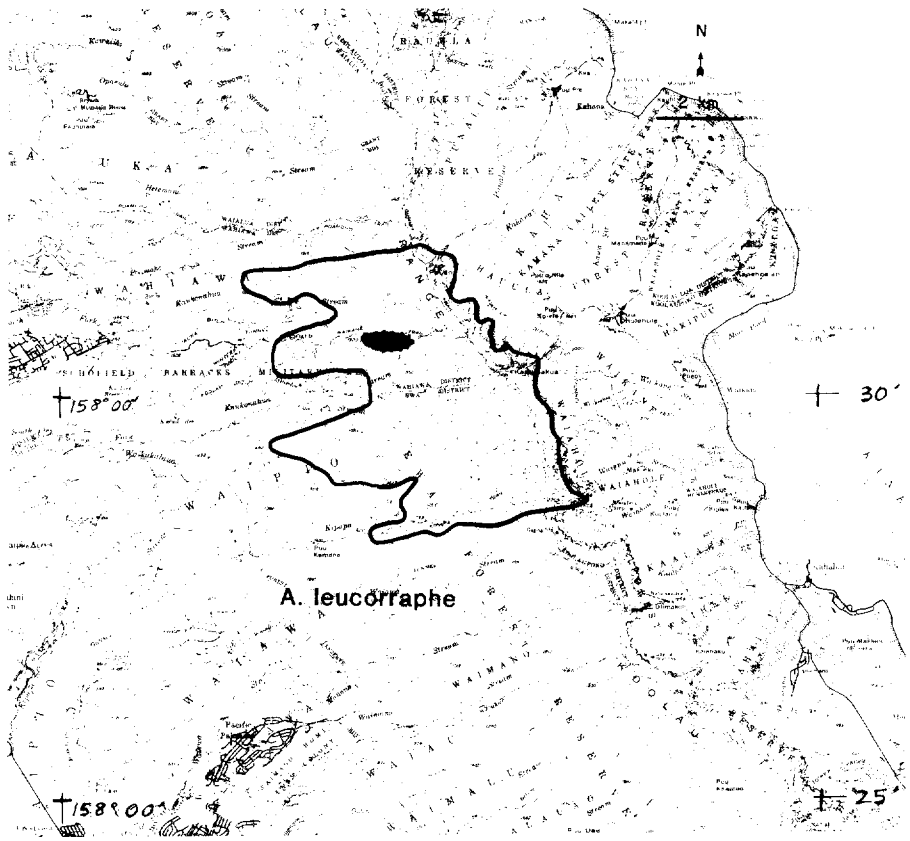

ACHATINELLA JUDDII RANGE MAP



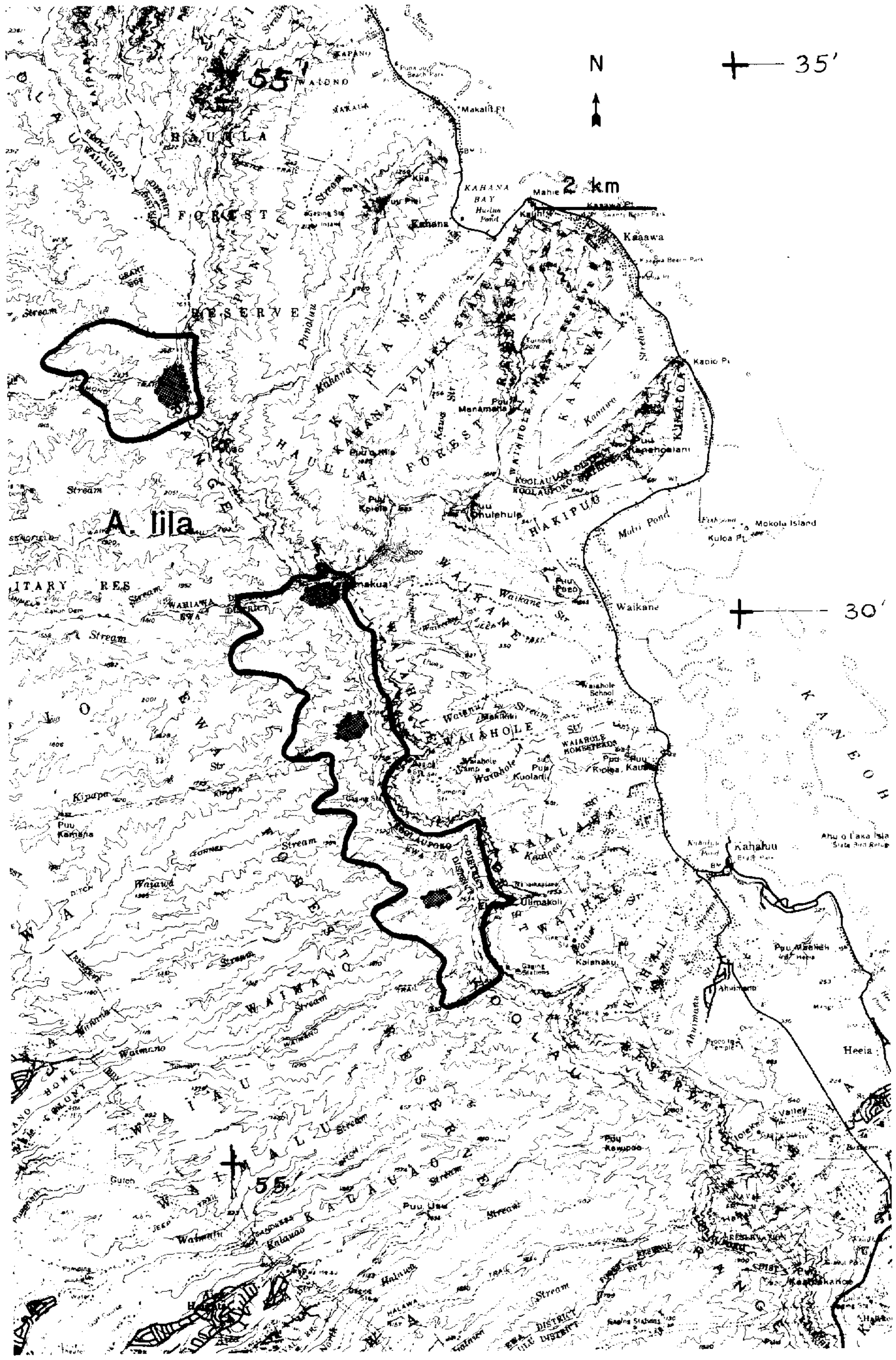

ACHATINELLA JUNCEA RANGE MAP



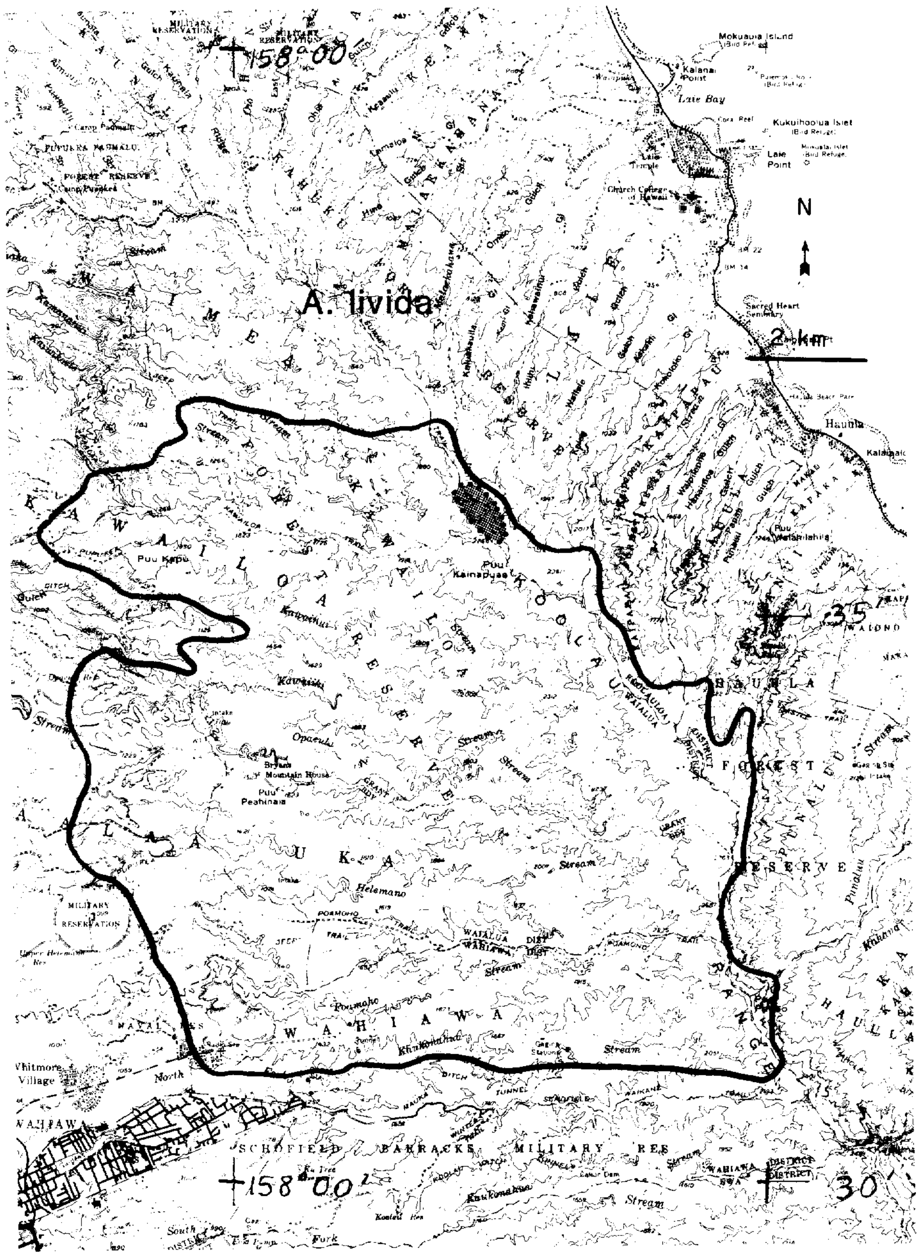

ACHATINELLA LEHUIENSIS RANGE MAP



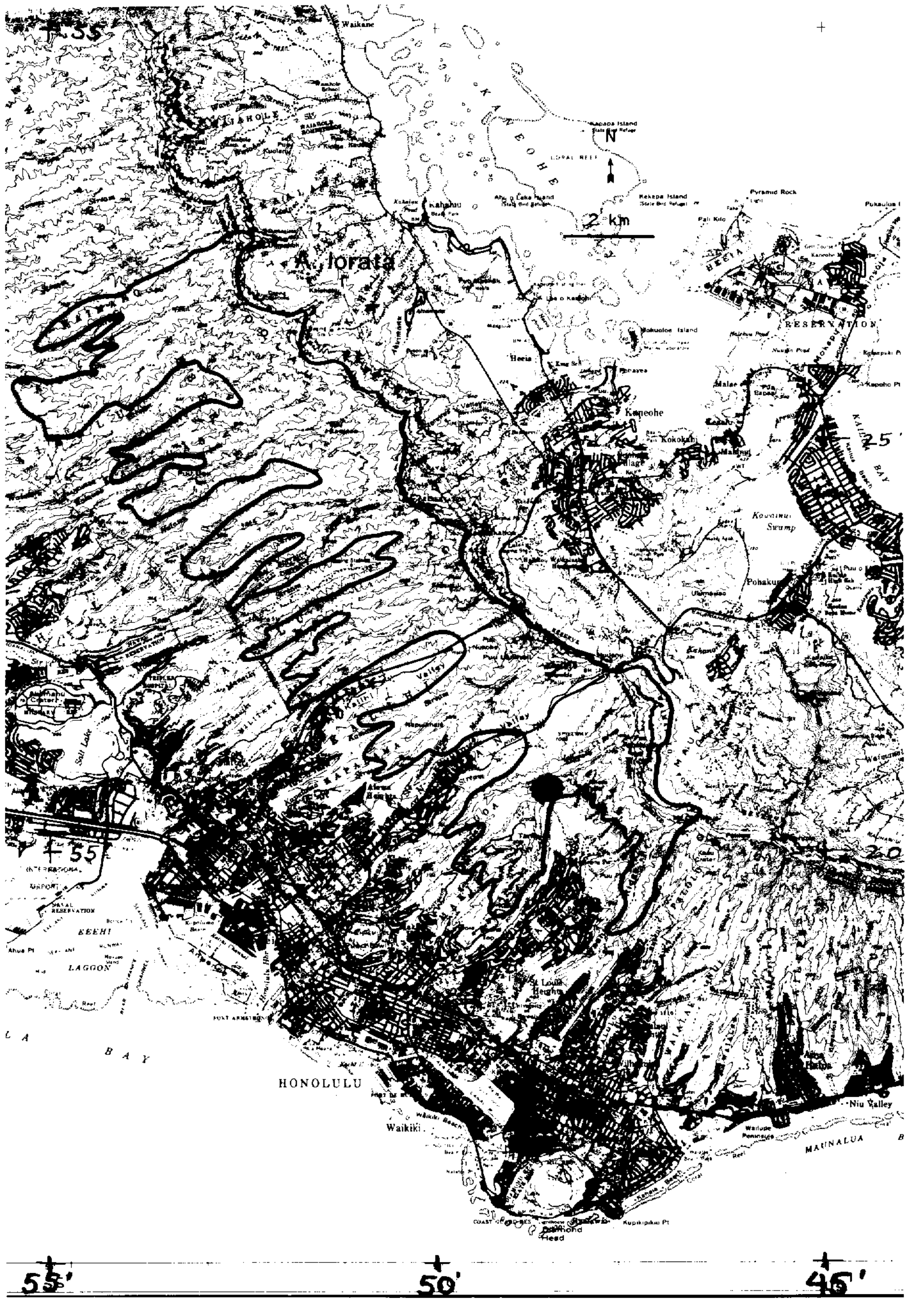

ACHATINELLA LEUCORRAPHE RANGE MAP



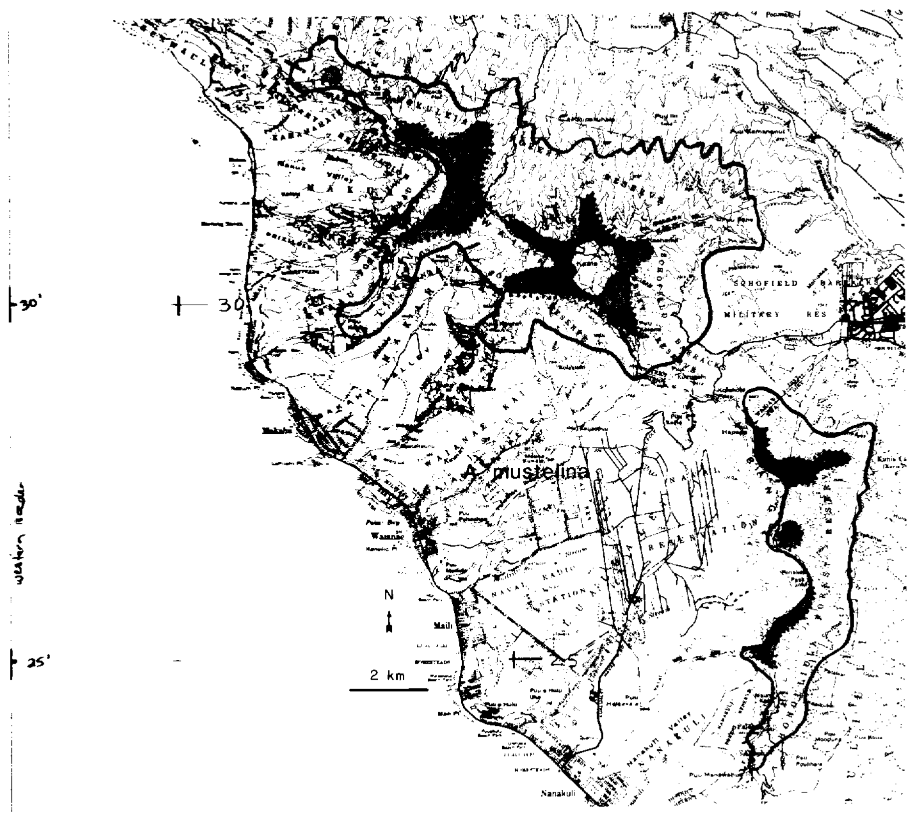

ACHATINELLA LILA RANGE MAP



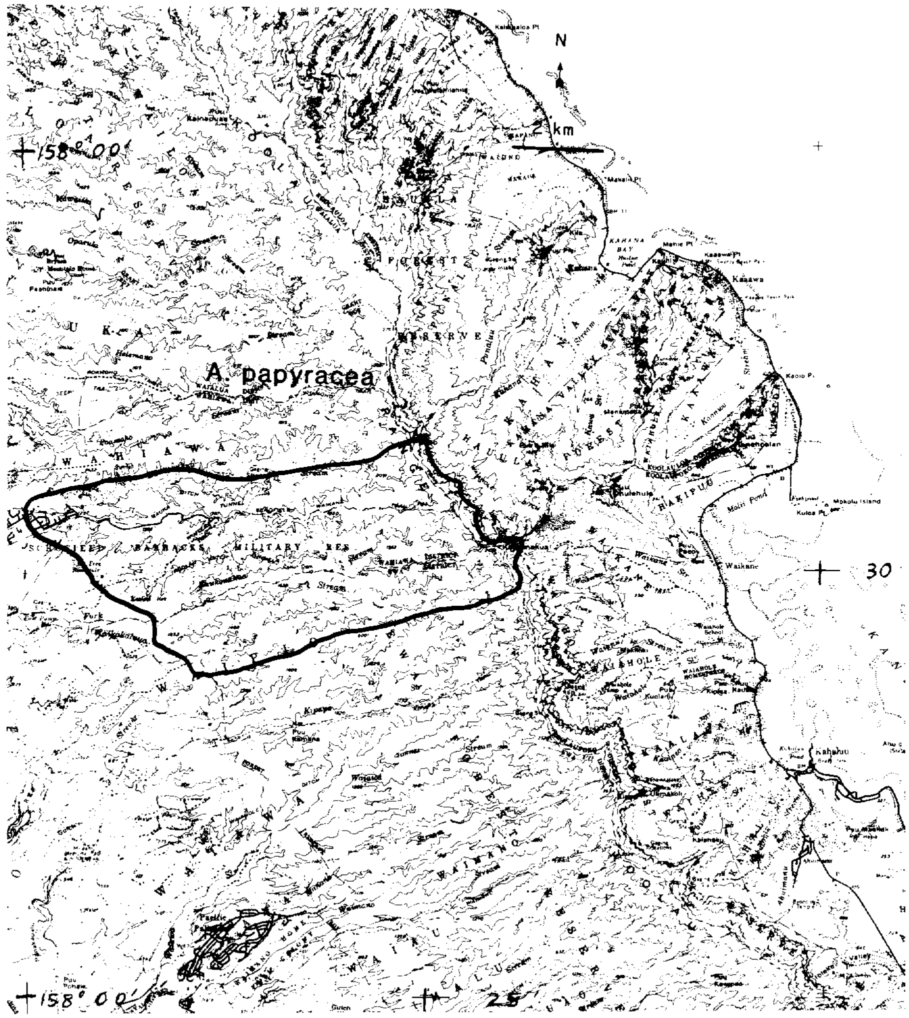

ACHATINELLA LIVIDA RANGE MAP



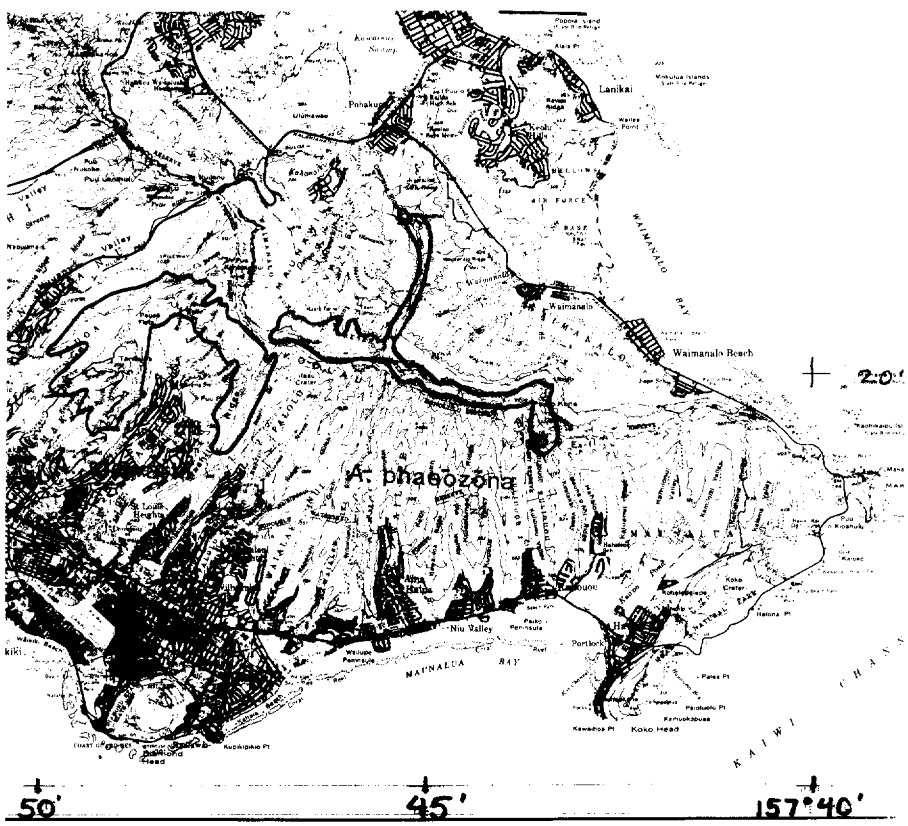

ACHATINELLA LORATA RANGE MAP



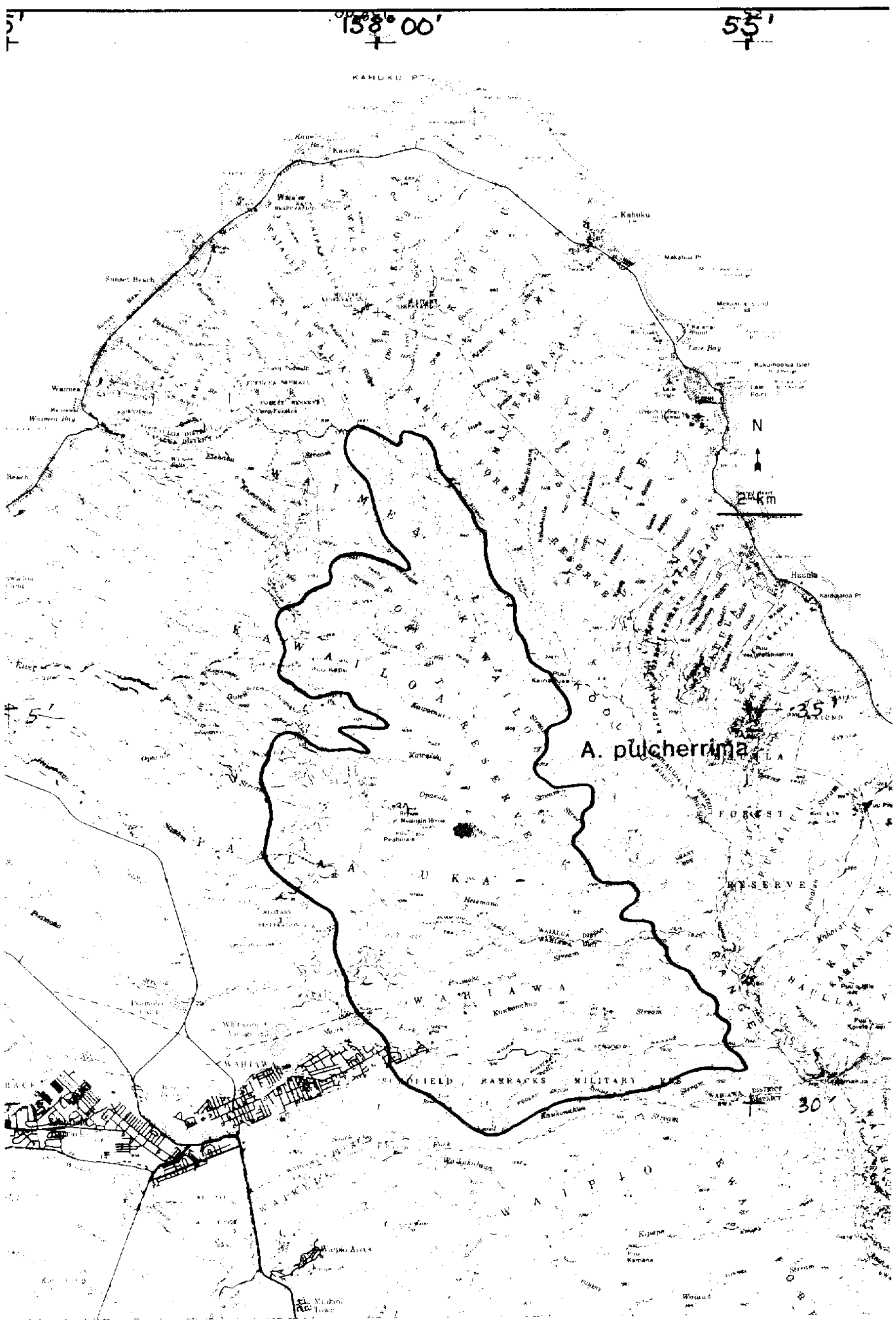

ACHATINELLA MUSTELINA RANGE MAP



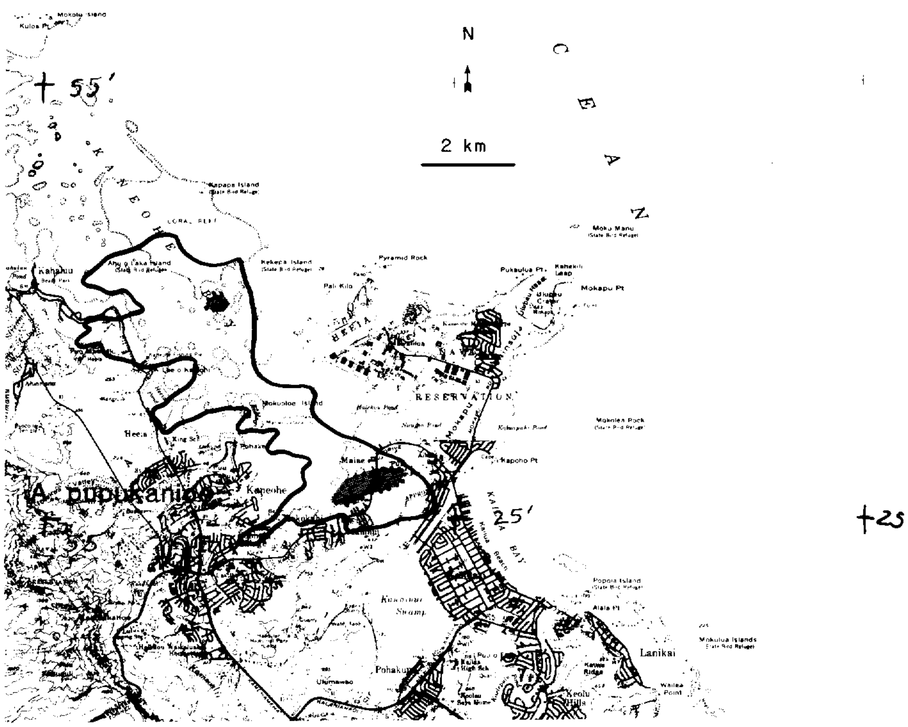

ACHATINELLA PAPYRACEA RANGE MAP



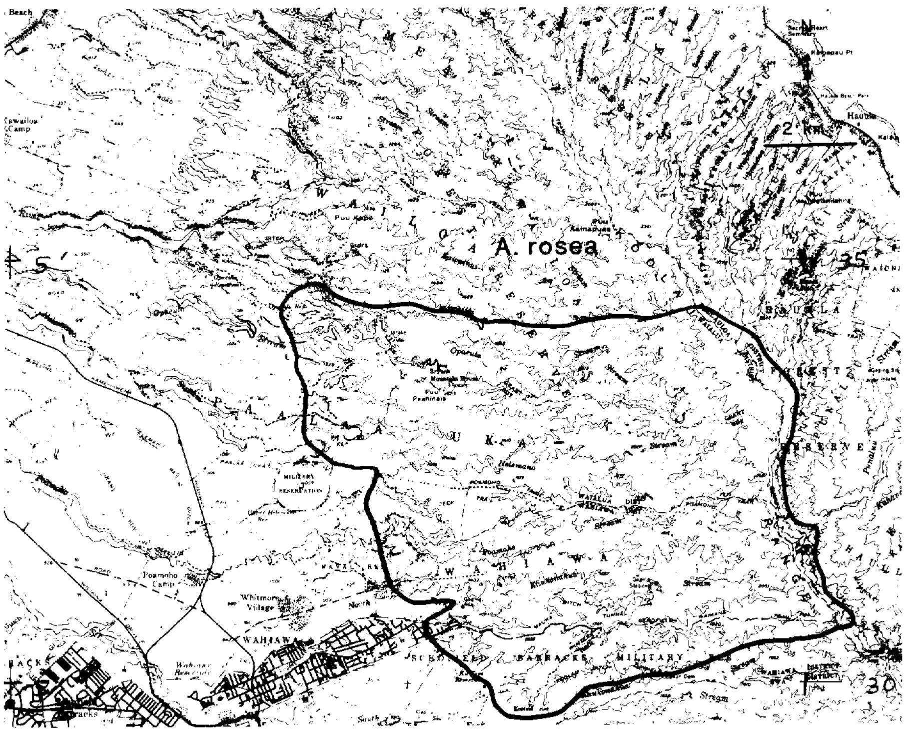

ACHATINELLA PHAEOZONA RANGE MAP



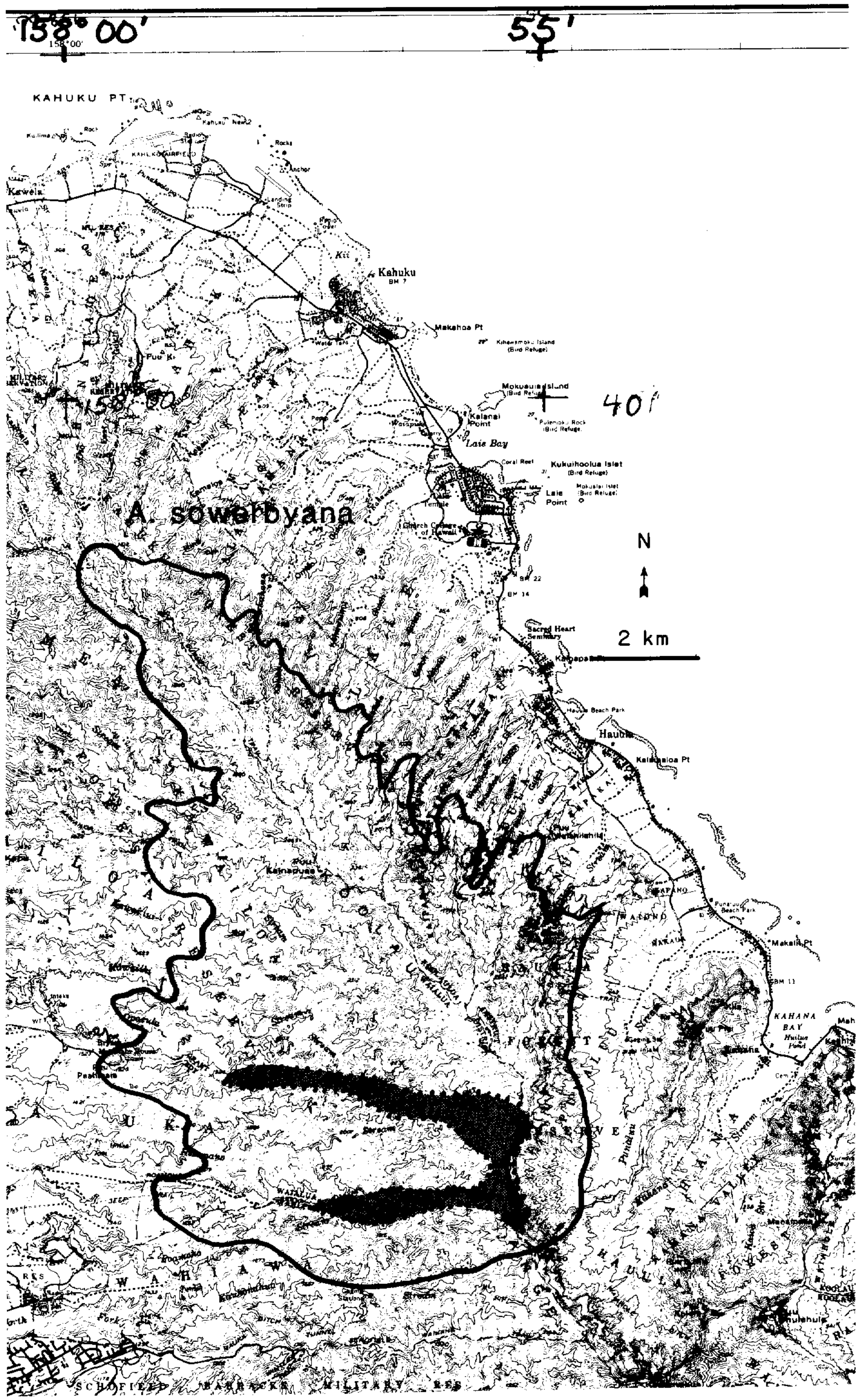

ACHATINELLA PULCHERRIMA RANGE MAP




ACHATINELLA PUPUKANIOE RANGE MAP




ACHATINELLA ROSEA RANGE MAP



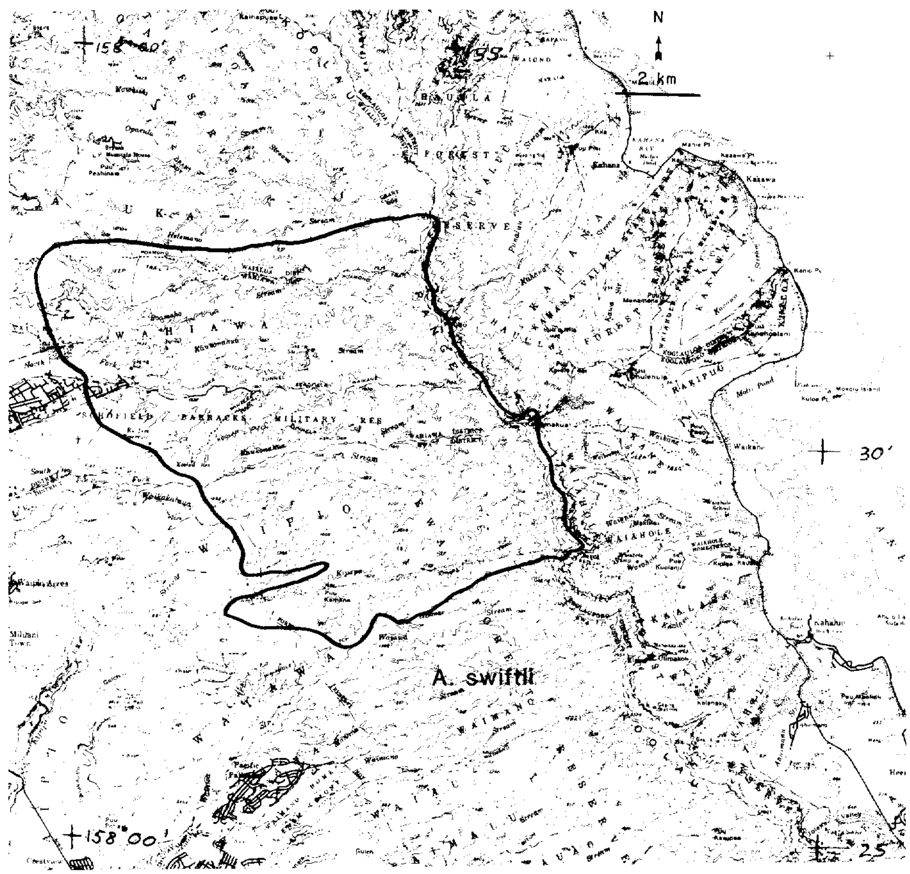

ACHATINELLA SOWERBYANA RANGE MAP

ACHATINELLA SPALDINGI RANGE MAP

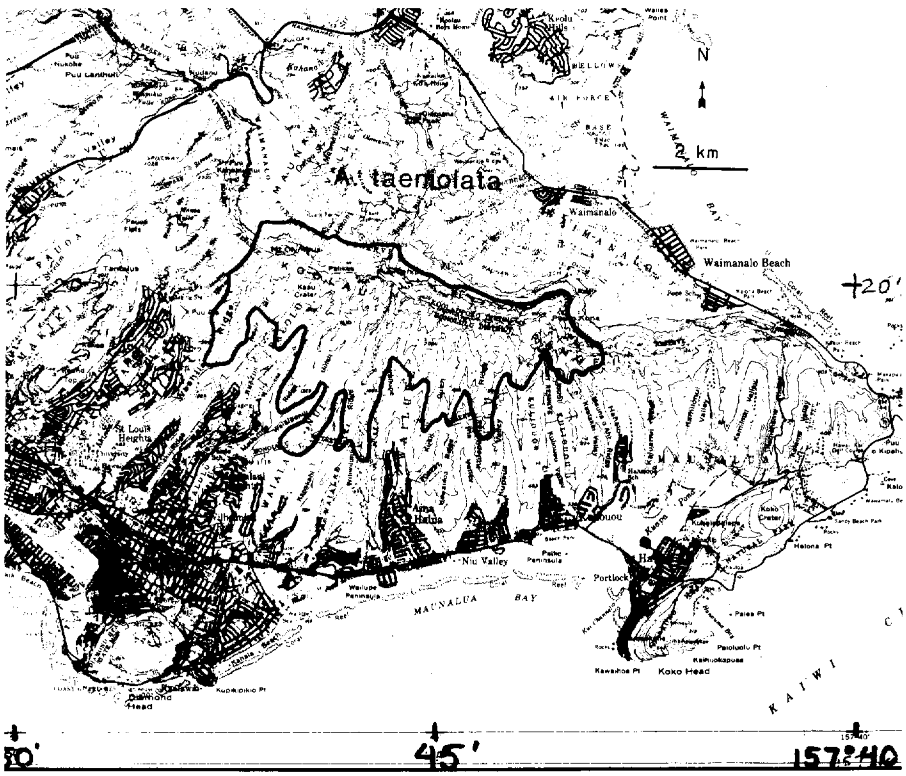
(see A. lehuiensis map)

ACHATINELLA STEWARTII RANGE MAP

(see A. phaeozona map)



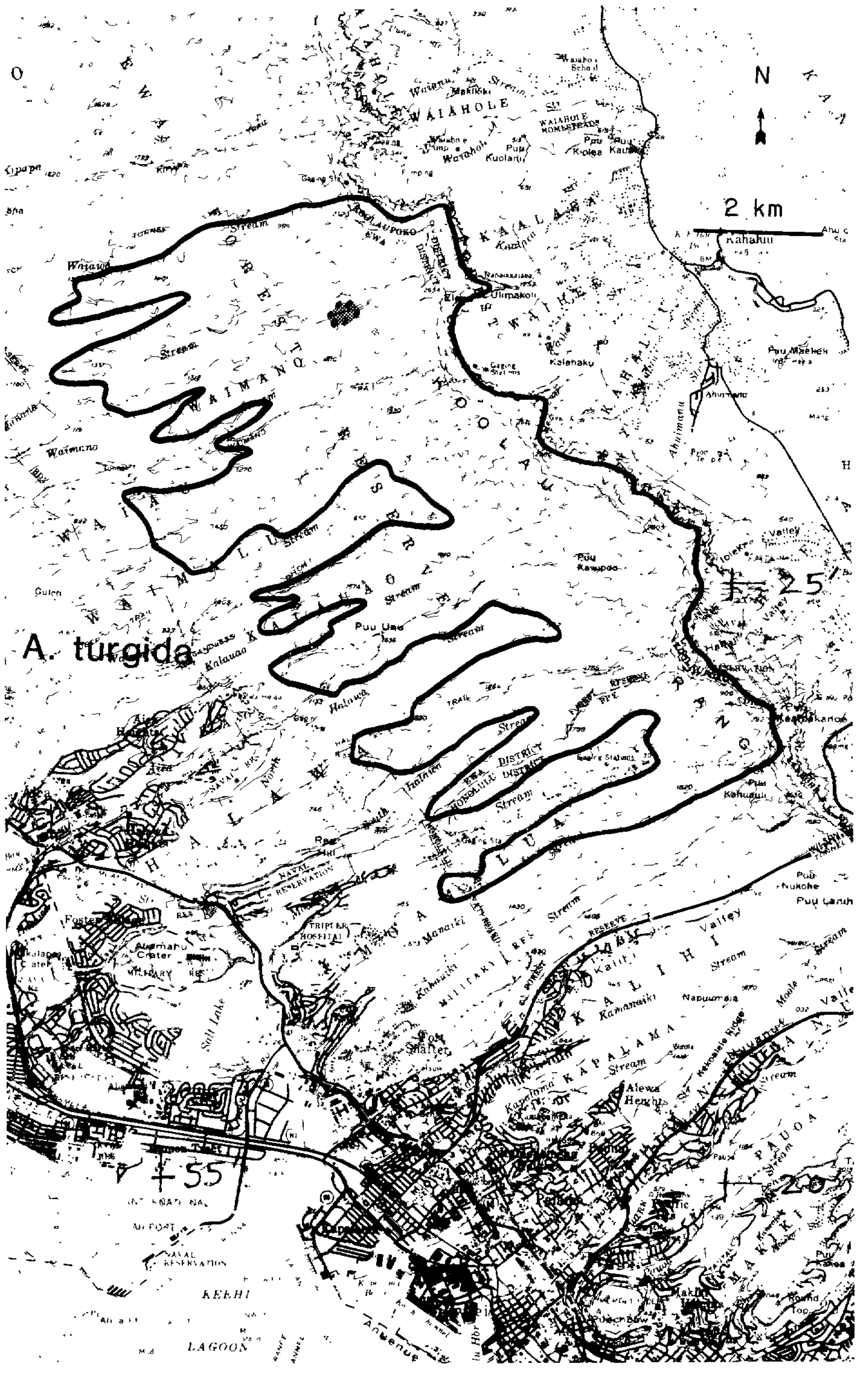

ACHATINELLA SWIFTII RANGE MAP




ACHATINELLA TAENIOLATA RANGE MAP

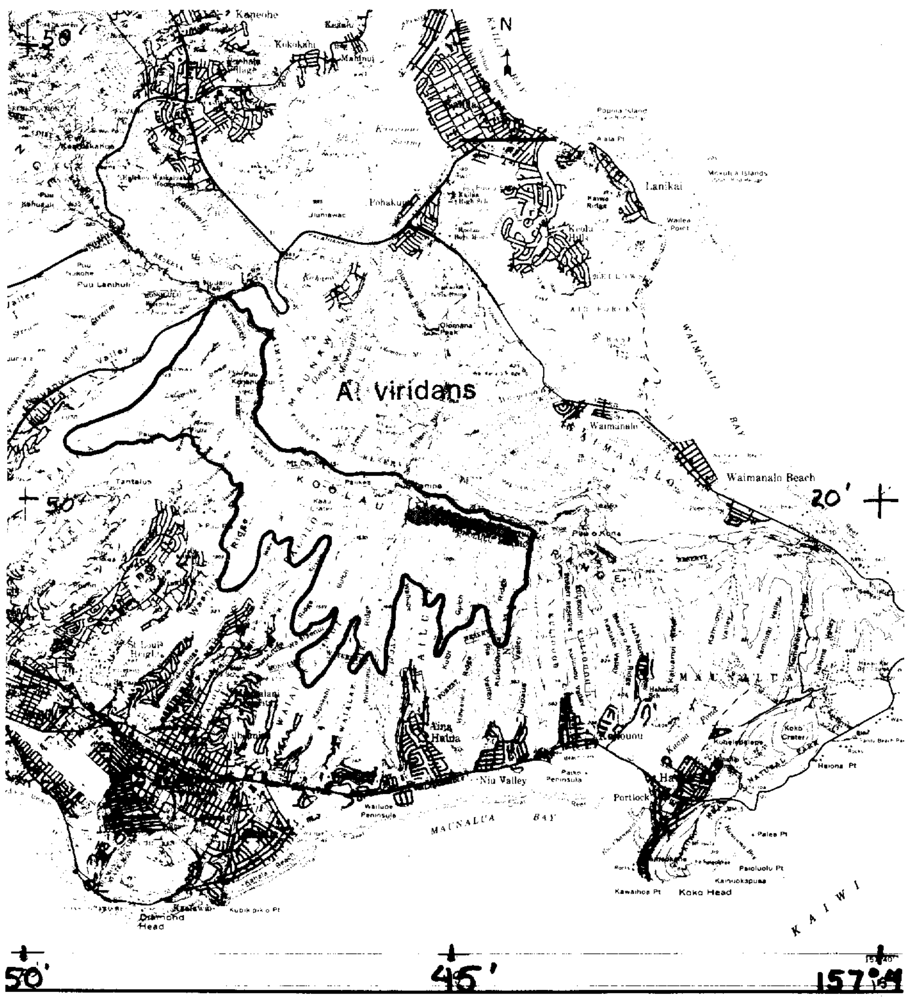
ACHATINELLA THAANUMI RANGE MAP

(see A. lehuiensis map)

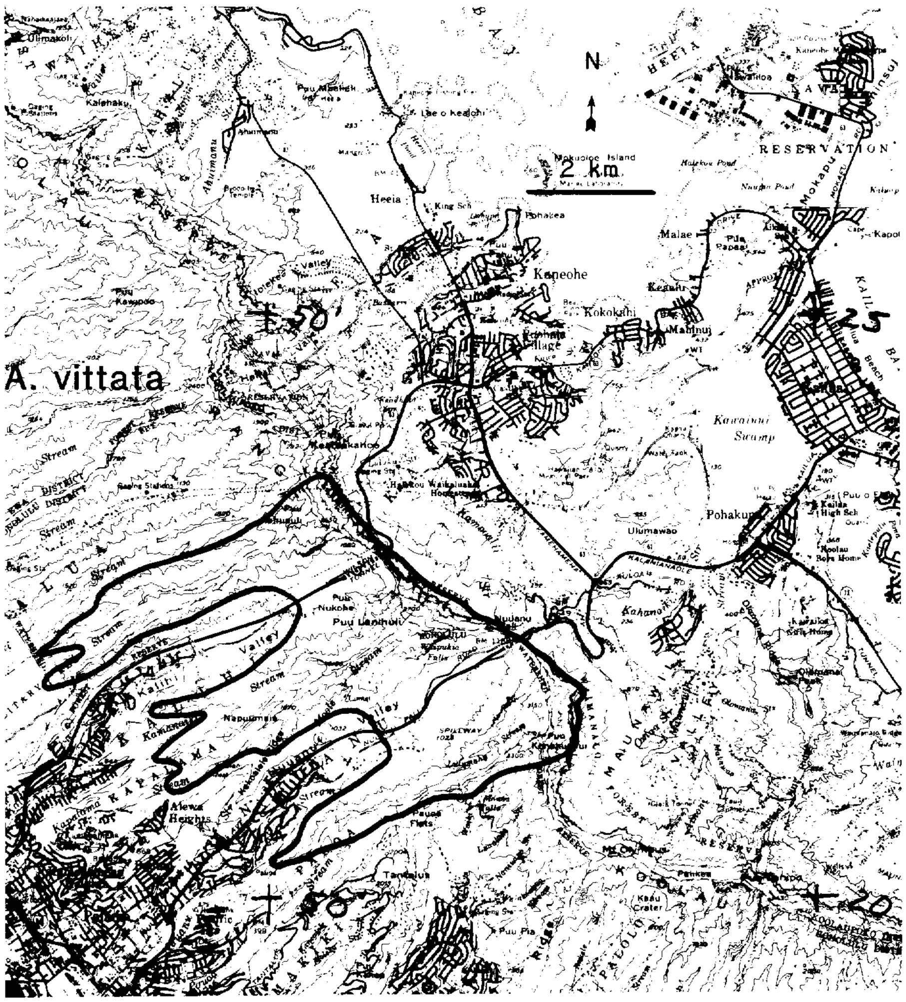



ACHATINELLA TURGIDA RANGE MAP

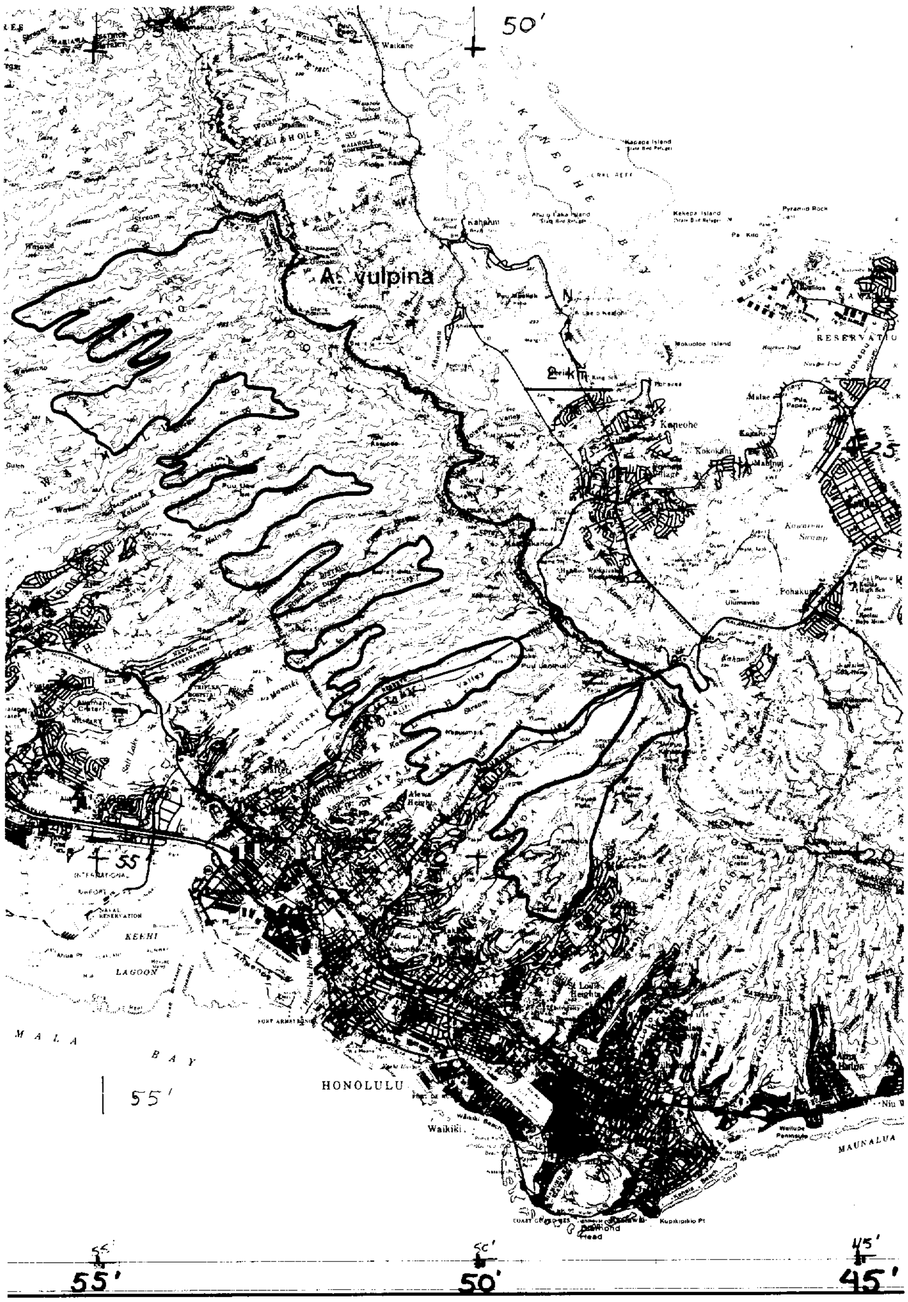
ACHATINELLA VALIDA RANGE MAP
(see *A. decora* map)




ACHATINELLA VIRIDANS RANGE MAP




ACHATINELLA VITTATA RANGE MAP




ACHATINELLA VULPINA RANGE MAP

APPENDIX V. INDIVIDUALS & AGENCIES CONTACTED DURING REVIEW

Dr. Alan Allison
Bishop Museum
P.O. Box 19000-A
Honolulu, HI 96817

* Michael G. Buck
Administrator
Department of Land and Natural Resources
Division of Forestry and Wildlife
Kalanimoku Bldg., Room 325
1151 Punchbowl Street
Honolulu, HI 96813

Dr. Carl Christensen
302 Holmes Hall
18 Everett Street
Cambridge, MA 02138

* Robert Cowey, Ph.D.
Curator of Malacology
Bernice P. Bishop Museum
P.O. Box 19000-A
Honolulu, HI 96817-0916

Environmental Protection Agency
Hazard Evaluation Division - EEB (TS769C)
401 M Street, S.W.
Washington, D.C. 20460

U.S. Fish and Wildlife Service
Regional Director, Region 8
Office of Research Support
18th & C Sts., N.W.
(725 ARLSQ)
Washington, D.C. 20240

* Dr. Michael G. Hadfield
Kewalo Marine Lab
41 Ahui Street
Honolulu, HI 96813

* Craig S. Harrison
3731 N. 6th Road
Arlington, VA 22203

* University of Hawaii
Department of Zoology
2538 The Mall
Honolulu, HI 96822
(Comments received From Dr. Leonard Freed)

* University of Hawaii
Department of General Science
Dean Hall 2
2450 Campus Road
Honolulu, HI 96822
(Comments received from Dr. Sheila Conant)

Mr. Lawrence Hirai
Directorate of Fac. Management
U.S. Army Support Command, HI
Environmental Mgmt. Office
Fort Shafter, HI 96858

* Mr. Alan Holt
The Nature Conservancy
1116 Smith Street, Suite 201
Honolulu, HI 96817

Dr. James D. Jacobi
U.S. Fish and Wildlife Service
P.O. Box 44
Hawaii National Park, HI 96718

Ms. Sandy MacPherson
U.S. Fish and Wildlife Service
Division of Endangered Species
18th & C Sts., N.W.
(452 ARLSQ)
Washington, D.C. 20240

Mr. Phil Million
U.S. Fish and Wildlife Service
Office of Public Affairs
18th & C Sts., N.W.
3447 MIB
Washington, D.C. 20240

* Assistant Regional Director
U.S. Fish and Wildlife Service
Fish & Wildlife Enhancement
Eastside Federal Complex
911 N.E. 11th Avenue
Portland, Oregon 97232-4181

Mike Severns
299 Keonekai Road
Kihei, Maui, HI 96753

INDIVIDUALS & AGENCIES CONTACTED DURING REVIEW (cont.)

Robert Shallenberger
U.S. Fish and Wildlife Service
Division of Refuges
(670 ARLSQ)
18th & C Sts., N.W.
Washington, D.C. 20240

Dr. Alan Solem
Malacology
Field Museum of Natural History
Lakeshore Drive and Roosevelt Road
Chicago, IL 60605

* Comments Received



☆ U.S. GOVERNMENT PRINTING OFFICE: 1993—792-126/82,200 REGION NO. 10