

FIELD SURVEY OF ENDANGERED OAHU TREE SNAILS (GENUS ACHATINELLA)
ON THE MAKUA MILITARY RESERVATION, OAHU, HAWAII

by

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ABSTRACT

Achatinella mustelina Mighels, 1845, is a federally declared endangered species protected under the Endangered Species Act of 1973. Ground surveys of the Makua Military Reservation (MMR) have located numerous populations of A. mustelina inhabiting slopes and gulches in the eastern and southeastern portion of Makua Valley as well as the ridges forming the northeastern boundary of the MMR (eastern ridge of Kahanahaiki Valley and the northeastern ridge of Makua Valley). Additionally, A. mustelina is believed to inhabit one site on the ridge crest at the southern boundary of the MMR (southern ridge of Makua Valley). No other species of Achatinella has ever been recorded from the MMR. The impact of explosive ordnance and, more importantly, the spread of fires resulting from such impact present major threats to the continued existence of A. mustelina in the MMR. Living populations of A. mustelina were found to occur within the high explosive impact area in southeastern Makua Valley. The following actions are recommended: (1) the limits of the high explosive impact area should immediately be modified to exclude areas inhabited or probably inhabited by Achatinella, as well as a buffer zone of sufficient extent to ensure that fires generated by explosive ordnance will not spread into tree snail habitat; (2) a comprehensive fire protection plan for the MMR should be developed and implemented; (3) factors other than fire that may lead to destruction degradation of habitat necessary to the survival of these snails should be investigated; (4) Army authorities should recommend against land use changes on non-Army land adjacent to the MMR if such changes would have an adverse impact on Achatinella populations within the MMR; (5) periodic monitoring of MMR Achatinella populations should be instituted.

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INTRODUCTION

All extant species of Oahu Tree Snails (genus Achatinella) have been listed as Endangered Species under the Endangered Species Act of 1973 (U. S. Department of the Interior, Fish and Wildlife Service 1981). As snails of this genus have been reported to occur within the limits of the Makua Military Reservation (MMR), Oahu, Hawaii (Fig. 1), information regarding their distribution and abundance there is required to assist in the assessment of the environmental impacts of military activities conducted on the MMR.

Information on the occurrence of Achatinella on the MMR was reviewed by Christensen (1980). He provided an estimate of the current status of Achatinella based upon historical data (published reports by Pilsbry and Cooke 1912-1914 and Welch 1938, as well as records and collections in the Division of Malacology, Bernice P. Bishop Museum), available information regarding the modern vegetation of the MMR (Environment Impact Study Corporation 1977), and the results of a one-day field survey. He concluded that it was highly probable that living populations of Achatinella mustelina (Mighels, 1845) survived within the limits of the MMR and presented a map (reproduced here as Fig. 2) showing the extent of possible Achatinella habitat within the MMR. No species of Achatinella other than A. mustelina is known ever to have occurred within the limits of the MMR.

The present study was undertaken to provide additional information on the distribution and abundance of Achatinella within the MMR. An intensive survey was undertaken in areas of Makua Valley adjacent to designated target sites (and thus most likely to be vulnerable to the adverse effects of Army training activities in the MMR) and a reconnaissance-level survey was conducted of other portions of the MMR previously identified as possibly inhabited by Achatinella. This report was prepared under authority of Contract No. DACA-84-82-M-0142 between the U. S. Army Corps of Engineers, Pacific Ocean Division, and the Bernice P. Bishop Museum. This project was co-directed by Dr. Carl C. Christensen (Malacologist, Bernice P. Bishop Museum) and Dr. Michael G. Hadfield (Professor of Zoology, University of Hawaii at Manoa; employed by Bishop Museum during his participation in this survey). Others participating were Mr. Peter C. Galloway (Curatorial Assistant, Division of Invertebrate Zoology, Bishop Museum) and Ms. Barbara

Figure 1. Occurrence of *Achatinella* at Makua Military Reservation, Oahu




-  Known *Achatinella* localities (data from Welch, 1988, Bishop Museum collection)
-  Localities ground-surveyed during current study
-  Makai (seaward) limit of possible *Achatinella* habitat

Fig. 2. Historical occurrence of *Achatinella* at Makua Military Reservation (from Christensen 1980).

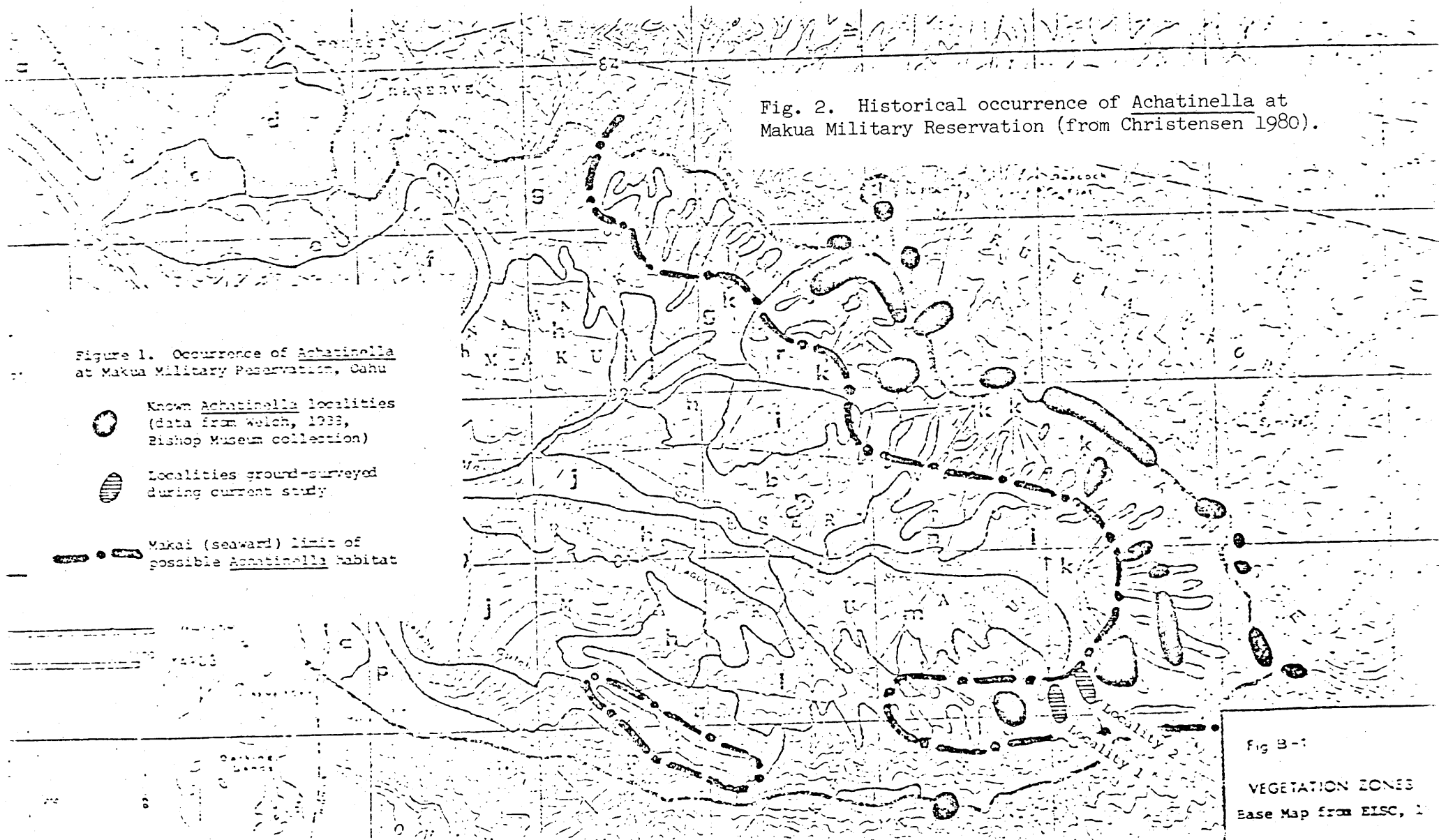


Fig B-1
VEGETATION ZONES
Base Map from EISC, 1

A. Shank (University of Hawaii; employed by Bishop Museum for this project). All of these persons are biologists with advanced training and with extensive prior field experience in locating and studying Hawaiian tree snails.

Because of the presence of hazardous unexploded ordnance in Makua Valley, during all field work within the valley (including Koiahi Gulch) the biological survey party was accompanied by one to three personnel from the 6th Explosive Ordnance Detachment; their assistance is here gratefully acknowledged.

SURVEY PROCEDURES

In accordance with the contract scope of work (U. S. Army Engineer Division, Pacific Ocean, Corps of Engineers 1982), a region in the southeastern portion of Makua Valley was selected for intensive survey for Achatinella. Areas for reconnaissance-level survey were selected by reference to previous records of their occurrence in the region (reviewed by Christensen 1980) and by estimation of the location of those areas providing suitable habitat for Achatinella based upon the botanical survey of the area conducted by Environment Impact Study Corporation (1977) and our own visual reconnaissance from helicopters and from the ridges surrounding Makua Valley. The goals were to learn precisely where snails had been seen in the past and/or where sufficient native vegetation occurred to make snail habitat likely. Tree snails of the genus Achatinella are not seasonal in their occurrence, thus it was not necessary to consider seasonality in the scheduling of field surveys. Weather is likewise not a factor influencing the occurrence of Achatinella. The passage of Hurricane Iwa in November 1982 had no adverse effect on the validity of the survey results obtained; during the December 1982 survey of Transect A, the only area in which heavy storm damage (defoliated vegetation, numerous fallen trees, etc.) was observed, large numbers of living Achatinella mustelina were recorded by the survey team.

The specific areas selected for survey, all lying at elevations above 1000 ft, were then entered on foot by the survey team and searched visually for the presence of living or dead Achatinella. Dead shells are readily

visible on the ground. Live snails, seen with greater difficulty on the leaves and stems of trees and bushes, were frequently located after the presence of dead, ground shells was noted. A number of native or prehistorically introduced tree and shrub species are known to be frequently associated with Achatinella in the Waianae Range, and these were particularly closely scrutinized. They include: Pisonia umbellifera, Osmanthus sandwicensis (olopua), Gouldia terminalis, Diospyros spp. (lama), Psychotria spp., Metrosideros polymorpha (ohia), and Aleurites moluccana (kukui).

Locations both within Makua Valley and on the ridges bounding Makua and Kahanahaiki Valleys were investigated by the field party. Surveys were conducted at elevations between 1000 feet and 1800 feet in the main amphitheater at the eastern end of Makua Valley and in Koiahi Gulch, on the south side of Makua Valley. As much as possible, both stream valleys and intervening ridges were ascended and surveyed, either by all four members of the survey party or by at least two persons. The ridges forming the rim of Makua and Kahanahaiki Valleys were approached by road and trail from the east or northeast; surveys along these ridges extended to elevations of ca. 2750 ft. The southern and southwestern slopes of these ridges drop precipitously to the floor of the valley, and surveys in this area were generally conducted along and immediately adjacent to the trail following the ridge crest at the boundary of the MMR. Also surveyed was the "flat", or gently sloping area, at the head of Kahanahaiki Valley and the upper end of the Kahanahaiki-Makua division ridge; this region lies wholly within the limits of the MMR.

Access to the ridges bounding Makua and Kahanahaiki Valleys was either by road through Mokuleia Homesteads to the abandoned Nike site and the head of the Peacock Flat trail or from the Mount Kaala road. Three field party days were scheduled and expended in survey of these ridges. It was originally intended that access to upper Makua Valley would be by helicopter, a procedure that would have provided quick access to those areas of potential Achatinella habitat most likely to be threatened by ordnance impact and resulting fires. Unfortunately, except for one helicopter pick-up on the first field survey day (Transect F), the anticipated helicopter access was unavailable because of an absence of satisfactory landing sites, and all surveys in the upper valley began with the survey party hiking

inland from the "demolition pit" located approximately in the center of the valley. The distance of this site from potential snail habitat at the back of the valley, as well as the need to proceed with great care through impact areas littered with hazardous unexploded ordnance, meant that much of the field time scheduled for the intensive survey of this region was instead consumed in lengthy overland hikes through areas of the lower valley known to be barren of native tree snails. Scheduled field party days within Makua Valley itself were reduced from seven to five days, reflecting the longer-than-anticipated work days necessary to provide a useful duration of survey time within suitable snail habitat.

To provide vouchers for observations of terrestrial mollusks, selected dead shells of Achatinella mustelina and live-collected or dead shells of other taxa were retained. These have been accessioned into the collection of the Division of Malacology, Bernice P. Bishop Museum.

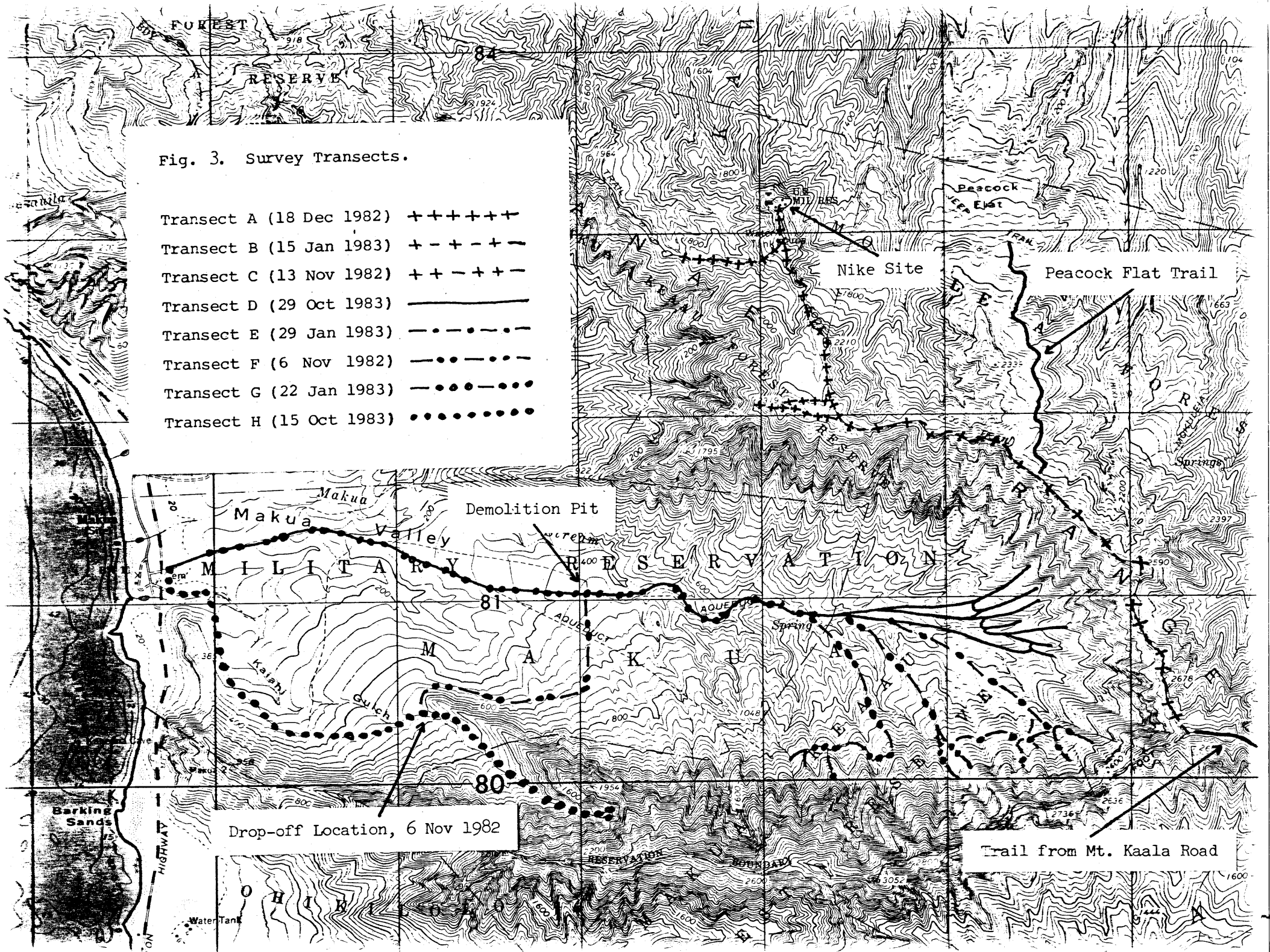
The geographical positions of survey transects were located on topographic maps by reference to watershed and ridge patterns and through careful use of altimeters, comparing survey heights with map elevations. All survey routes have been plotted on the Kaena Quadrangle 1:25000 topographic map (Fig. 3). Plotted locations within the southeastern portion of Makua Valley may be subject to minor imprecision because of the absence of clear landmarks in that region.

In reporting the results of each of the survey transects, the following data are presented: the date of each transect, its location, the amount of actual survey time expended by the survey party (and where applicable, the time expended in areas in which living Achatinella were observed), the length of the transect (excluding portions not covered on foot), the number of observers, and a summary of observations. Relative abundance of Achatinella populations was estimated by calculation of numbers of living snails observed per hour of observer effort expended in localities found to be inhabited by these animals.

In the text of this report exotic mollusk species are indicated with the use of an asterisk (e. g., "*Meghimatium bilineatum"). Exotic plant species are similarly indicated, with the exception of prehistorically introduced taxa such as Aleurites and Cordyline that have become fully naturalized in Hawaii and are often integral components of otherwise "native" ecosystems.

Fig. 3. Survey Transects.

- Transect A (18 Dec 1982) + + + + +
- Transect B (15 Jan 1983) + - + - + -
- Transect C (13 Nov 1982) + + - + + -
- Transect D (29 Oct 1983) —————
- Transect E (29 Jan 1983) - . - . - . - .
- Transect F (6 Nov 1982) - . . - . . - . .
- Transect G (22 Jan 1983) - . . . - . . .
- Transect H (15 Oct 1983)



FINDINGS

A. Field Survey Results

Survey results are presented by transect, arranged in clockwise geographical order commencing at the head of Kahanahaiki Valley (Fig. 3).

1. Transect A, 18 December 1982.

Access was by car up the paved road from Mokuleia Homesteads to the abandoned Nike Missile site north of the Makua rim; then by hiking out on the Makua rim along the Waianae ridgeline. From there, a transect was made to the west along the rim to a high point of 2319 ft elevation on the ridge separating Makua Valley from Kahanahaiki Valley and then back across the shallow "flat" to the ridge trail back to the Nike site. The major Waianae ridgeline was then followed north toward Kaena Point for about 1 mile before returning to the car.

The survey included the entire transect route described above (length ca. 1.6 mi); total survey time 5.0-5.5 hours. Four surveyors worked together counting all snails observed along the route, noting both snail numbers and host vegetation. From a point ca. 300 yds north of hill "2210" southwards this area was found to harbor abundant Achatinella mustelina living mainly on the native tree Pisonia umbellifera. Snails were also seen on Osmanthus sandwicensis (olopua), Diospyros sp. (lama), and Metrosideros polymorpha (ohia). Achatinella were found at elevations of ca. 2000-2319 ft. Other terrestrial mollusks observed in this area were Philonesia sp., Tornatellides sp., Auriculella ambusta, "Succinea" sp., *Meghimatium bilineatum, *Limax maximus, and dead shells of Amastra sp. cf. rubens, Nesopupa sp., and *Bradybaena similaris. A total of 161 living Achatinella mustelina were observed along the survey route over a period of ca. 3 hours, or 13.4 snails/observer/hour. Rat-eaten shells of Achatinella were observed on the ground, and one individual of the predatory flatworm Geoplana was observed in an empty Achatinella shell found on the ground.

Forest destruction by Hurricane Iwa in late November 1982 was very extensive in this area. Nearly all large trees were downed in some areas, and the remaining trees were broken and defoliate. Snails were easily observed in this unusual leafless forest.

2. Transect B, 15 January 1983.

Access was by car up the paved road from Mokuleia Homesteads toward the Nike site, then a short distance up the unpaved road towards the Peacock Flat trail; the survey party proceeded on foot up Peacock Flat Trail to the rim of Makua Valley at a point above the abandoned forestry cabin. The group divided at this point; Team A (Hadfield and Shank) hiked northwest along the ridge crest to the head of the Kahanahaki-Makua ridge, reaching the area surveyed 18 December 1982. Team B (Christensen and Galloway) hiked southeast along the Makua rim to just beyond the peak of hill "2590". Total survey time was 5.0-5.5 hours along a transect 1.2 mi in length.

Each team spent 4.5 hours in areas inhabited by Achatinella mustelina. This species was found in abundance along the Makua rim at elevations of ca. 2250-2590 ft., particularly in the northwest portion where Team A counted 48 living snails (5.3 snails/observer/hour) on Osmanthus, *Psidium (guava), Alyxia olivaeformis (maile), Pelea, Antidesma (hame), and other shrubs. Team B observed 18 living A. mustelina (2.0 snails/observer/hour), mostly on Metrosideros polymorpha (ohia), but also on *Psidium, Myrsine, and *Schinus (Christmas berry). Other land mollusks observed were Auriculella ambusta, A. sp. aff. perpusilla, Tornatellides spp., Philonesia sp., "Succinea" sp., *Deroceras sp. cf. laeve, and *Bradybaena similaris. Seven individuals of Geoplana septemlineata (ID: L. Winsor, James Cook University, Townsville, Queensland, Australia) were found in the aperture of a ground shell of A. mustelina, apparently feeding upon the body of the recently dead animal.

3. Transect C, 13 November 1982.

Access was by car up the Mt. Kaala road to the ridgeline of the Waianae Range east of Makaha Valley, then on foot along the (essentially non-existent) trail along the Makaleha-Makua ridge to its intersection with the ridge forming the eastern rim of Makua Valley; from there, the group hiked north along the Makua rim ca. 0.5 mi to a small peak (elevation ca. 2500 ft). The return was by the same route. Total survey time was 5.0-5.5 hours.

The team surveyed along the entire hike line once the boundary of the MMR was reached. Four surveyors counted all snails observed along the transect line. This ridge line bears abundant native flora, as well as exotics such as *Psidium and *Grevillea robusta (silk oak). Abundant living

Achatinella mustelina were seen along the transect route. Over a period of two hours, twenty-nine individuals were counted along the Makua rim, on the MMR boundary (3.6 snails/observer/hour); these snails were limited to the area within 600 yards of the ridge junction at the eastern extremity of the MMR, as the area from 600-900 yards north-northwest of that point had no Achatinella and had a higher representation of exotic plants than did the region found to be inhabited by A. mustelina. Additional Achatinella were observed along the Makaleha-Makua ridge to the east of the MMR boundary. These snails were found on both native and exotic vegetation, although most were seen on Metrosideros polymorpha and the more shrub-like Pelea, Dubautia, and Scaevola gaudichaudiana (naupaka kuahiwi). In addition to Achatinella, other land snails seen were Auriculella ambusta, "Succinea" sp., Philonesia sp., and *Bradybaena similaris.

4. Transect D, 29 October 1983.

Access was by car into Makua Valley, parking at the "demolition pit". The group then hiked directly up the stream bed to the center of the rear amphitheater of the valley. At the point where the stream divides into two large sub-streams at about 750 ft elevation, the survey party ascended the ridge between the streams, up the major ridge until the slope became vertical at 1400 ft. At 1050 ft the party split into two teams, Team A (Shank and Hadfield) working two valley and ridge systems to the south, and Team B (Christensen and Galloway) surveying the ridge and valley system to the north. Total survey time was ca. 9.0 hours, total transect length ca. 3.6 mi.

Most of the native forest observed in this region consisted of second growth; except in the heads of the gulches, in the past the native forest had burned off and been replaced by the exotic guava and silk oak trees. Only in the southernmost valley surveyed was extensive native forest observed (Pisonia, Gouldia, Osmanthus, etc.). Although Christensen (1980) reported historical records of the occurrence of Achatinella mustelina within the area surveyed on this transect, no Achatinella, living or dead, were observed by either party. It is probable, therefore, that these snails have been extirpated at this location. The only likely habitat observed by the field parties was that visited by Party A at the southern extent of the day's survey; time did not permit sufficient scrutiny to establish whether

or not Achatinella was present in this area. A number of other terrestrial mollusks were observed, however, including Pleuropoma sandwichiensis, ?Tornatellaria sp., Tornatellides sp., Amastra sp. cf. rubens, Leptachatina sp., *Hawaiia sp. cf. minuscule, Philonesia sp., *Prosopias achatinaceum, *Lamellaxis sp., and *Bradybaena similaris. During this transect Party A observed the predatory snail *Euglandina rosea at an elevation of 1200 ft.

Several very recent burned areas were seen in the forest in the rear of the valley. These burns had destroyed several acres each at elevations at least as high as 1200 ft.

5. Transect E, 29 January 1983.

Access was by car into Makua Valley to the "demolition pit" and on foot deeper into the valley. The area surveyed began at the major target ridge at the southeastern sector of Makua Valley and continued eastward in both gulleys and ridges at elevations from 1400 to 1850 ft. Total survey time was 7.25 hours, total transect length ca. 2.5 mi. The forest was a mix of exotics (mainly *Psidium) and natives, giving way to pure stands of native trees at higher elevations. Here the forest was composed mainly of Osmanthus, Psychotria, Diospyros and Bobea (ahakea); Alyxia was also abundant. The survey party consisted of three malacologists (Christensen, Galloway, and Hadfield). Achatinella mustelina was found widely distributed throughout this survey area on Osmanthus, Psychotria, Bobea (ahakea), and Alyxia at elevations of 1600-1780 ft. In 1.5 hours 18 live snails were seen (4.0 snails/observer/hour). Time limitations prevented determination of the lower altitudinal limits of these populations. Living Tornatellides sp., Leptachatina sp., and Philonesia sp. were observed, as well as dead shells of ?Tornatellaria sp., Auriculella ambusta, Amastra rubens, *Hawaiia sp. cf. minuscule, Succinea sp. cf. waianaeensis, *Lamellaxis clavulinus, and *Bradybaena similaris.

Rocket fragments were found embedded in trees harboring living Achatinella and a recent fire had burned into the lower reaches of the forest in this survey area; evidence of fire was observed at elevations to 1350 ft.

6. Transect F, 6 November 1982.

Access was by helicopter from Wheeler AFB to the landing site at mouth of

Koiahi [sic; mis-spelled "Kaiahi" on the Kaena Quadrangle 1:25000 topographic map] Gulch, lower Makua Valley. The survey party hiked first to the demolition pit, then along the main stream of Makua Valley to the major target ridge in the south-rear quadrant of the valley, then uphill into the forest. Return was by helicopter from a landing zone established next to the target area. Four malacologists made up the survey party. Total survey time was ca. 5.75 hours, total transect length ca. 2.9 mi.

Along the stream in the lower valley (below ca. 800 ft elevation) many shells of *Achatina fulica and the predatory snail *Euglandina rosea were observed. The exotic slug *Meghimatium bilineatum was found at an elevation of ca. 800 ft. After climbing the ridge leading to the principal target site in the southern portion of upper Makua Valley, the survey party divided into two parts. Team A (Hadfield and Shank) proceeded up the major ridge above the target area to an elevation of 1900 ft; good native vegetation was encountered. The endemic snail Philonesia sp. was observed, but no Achatinella were found. Team B (Christensen and Galloway) hiked into the first high valley west of the target ridge, attaining an elevation of 1840 ft. They observed no Achatinella, but found living Philonesia sp. as well as dead shells of the Amastra sp., Leptachatina sp., "Succinea" sp., *Lamellaxis sp., and *Bradybaena similaris.

Total survey time in suitable Achatinella habitat was brief (little more than one hour) because of the necessity of returning to the up-valley landing zone in time for the helicopter pick-up. While no Achatinella spp. were seen, suitable habitat was encountered and other endemic snails were observed.

7. Transect G, 22 January 1983.

Access was by car into Makua Valley to the "demolition pit" in mid-valley, then on foot up the stream bed and on to the first target ridge along the southern slope of the valley. The group surveyed a series of five gulches and ridges along the upper south wall of the valley. The survey party consisted of 4 malacologists. Total survey time ca. 6.5 hours, transect length 1.9 mi.

In this transect area two dead shells of Achatinella mustelina were found at an elevation of ca. 1480 ft, providing evidence that living snails probably exist in these trees. All were found in a deep forest of large

Aleurites (kukui) and Diospyros trees. A single living individual of Partulina dubia, a rare achatinelline snail not definitely seen alive since 1941 (B. P. Bishop Museum collection records), was observed sealed in a knothole on the trunk of a kukui tree at an elevation of 1300-1500 ft. Also seen in this area were living Tornatellides spp., Amastra rubens, Leptachatina sp., *Meghimatium bilineatum, *Deroceras sp. cf. laeve, *Hawaiiia sp. cf. minuscula, Philonesia sp., and *Lamellaxis clavulinum, as well as dead shells of Pleuropoma sandwichiensis, Succinea sp. cf. waianaensis, and *Bradybaena similaris. The predatory flatworm Geoplana was also observed.

8. Transect H, 15 October 1983.

Access was by car to the observation post at the mouth of Makua Valley, by four-wheel drive truck along the fire break road to the mouth of Koiahi Gulch, and on foot into the gulch itself. Total survey time ca. 6.0 hours, transect length ca. 0.8 mi. The survey party of three malacologists (Christensen, Galloway, and Hadfield) went to the uppermost accessible reaches of this valley including all sub-gulches at the eastern limit of the valley to elevations of 1600 ft where the walls became vertical. Vegetation in the lower part of the valley is the introduced woody shrub *Leucaena leucocephala (koa haole); in the mid-level it consists of Aleurites and *Coffea arabica (coffee); higher up there is abundant Cordyline (ti) and small Diospyros. *Psidium was found at the very back of the valley.

No Achatinella, living or dead, were observed in Koiahi Gulch, but numerous other native snails were found, including Pleuropoma sandwichiensis, Lamellidea sp., Tornatellides sp., ?Tornatellaria sp., Amastra rubens, Leptachatina spp., Nesopupa sp., Philonesia sp., and Succinea sp. cf. waianaensis. Exotic snails seen included *Hawaiiia sp. cf. minuscula, *Euglandina rosea, *Lamellaxis sp., *Bradybaena similaris, and (in the lower portion of the gulch) *Achatina fulica.

Recent fires had burned across the mouth of this gulch and ascended its southern slope, into large trees, as high as 1200 ft.

B. Distribution and Abundance of Achatinella on the Makua Military Reservation

Fig. 4 shows the current distribution of Achatinella mustelina on the MMR. Achatinella mustelina was found to be generally and in places abundantly distributed along the ridges forming the eastern rim of Kahanahaiki Valley and the northeastern rim of Makua Valley; a particularly rich population exists in the region at the head of the Makua-Kahanahaiki division ridge and in the "flat" at the head of Kahanahaiki Valley. Within Makua Valley, small numbers of these snails inhabit persistent mixed native forest in the eastern and southern slopes of the amphitheater at the head of the upper valley above 1200 ft elevation; Achatinella may also occur on the northern slope of the upper valley, but no field observations are available. Because of the difficulties encountered in gaining access to the upper valley, survey time in this region was limited; the maximum extent of this snail population was accordingly not determined with precision, and it thus must be assumed that all such native vegetation in this area is inhabited by A. mustelina. A second, even rarer, achatinelline, Partulina dubia, also occurs in this area. An isolated population of A. mustelina at the crest of the Makua-Makaha division ridge, on the southern boundary of the MMR, was not visited during this study but was extant in 1976 (John Obata, personal communication, 1984) and undoubtedly persists. Comparative figures for other Oahu Achatinella populations are not available, but the authors know of no locations where Oahu Tree Snails occur more abundantly than in the area of Transect A, where 13.4 living snails/observer/hour were recorded.

Table 1 contains a list of host plants on which living Achatinella were found. Pisonia and Metrosideros were most commonly associated with Achatinella; only rarely were exotic plants found to be hosts for Achatinella, and only in areas where snails were particularly abundant.

C. Predators of Achatinella

The predatory land snail *Euglandina rosea was observed in the koa haole zone of lower Makua Valley (below 800 ft elevation) and also in Koiahi Gulch, where it extended into the forested region inhabited by ground-dwelling native snails (Achatinella was not found to occur in Koiahi Gulch).

Table 1. Host plants of Achatinella on the Makua Military Reservation.

Scientific Name	Common Name	Status
ANACARDIACEAE		
<u>Schinus terebinthifolius</u>	Christmas berry	Exotic
APOCYNACEAE		
<u>Alyxia olivaeformis</u>	Maile	Native
COMPOSITAE		
<u>Bidens</u> sp.	Ko'oko'olau	Native
<u>Dubautia</u> sp.	Na'ena'e	Native
EBENACEAE		
<u>Diospyros</u> sp.	Lama	Native
EUPHORBIACEAE		
<u>Antidesma</u> sp.	Hame	Native
GOODENIACEAE		
<u>Scaevola gaudichaudiana</u>	Naupaka-kuahiwi	Native
MYRSINACEAE		
<u>Myrsine</u> sp.	Kolea	Native
MYRTACEAE		
<u>Metrosideros polymorpha</u>	Ohia	Native
<u>Psidium</u> spp.	Guava	Exotic
NYCTAGINACEAE		
<u>Pisonia umbellifera</u>	Papala-kepau	Native
OLEACEAE		
<u>Osmanthus sandwicensis</u>	Olopua	Native
RUBIACEAE		
<u>Bobea</u> sp.	'Ahakea	Native
<u>Gouldia terminalis</u>	Manono	Native
<u>Psychotria</u> sp.	Kopiko	Native
RUTACEAE		
<u>Pelea</u> sp.	---	Native
VERBENACEAE		
<u>Stachytarpheta jamaicensis</u>	Jamaica vervain	Exotic

*Euglandina is apparently absent from the ridge crests above Kahanahaiki and Makua Valleys, where Achatinella mustelina is sometimes abundant, or in the regions of upper Makua Valley (above ca. 1000 ft elevation) where A. mustelina was observed. It was, however, encountered on Transect D in the back of Makua Valley at an elevation of 1200 ft; our survey party found no Achatinella at that location.

The predatory flatworm Geoplana was observed during Transects A, B, and G, and these inconspicuous ground-dwelling invertebrates are probably found throughout the forested regions of the MMR. It is noteworthy that on two occasions these worms were found in the shells of dead Achatinella mustelina; on Transect B several individuals since identified a G. septemlineata were found apparently feeding on the flesh of a dead Achatinella.

Rats, including the roof rat Rattus rattus, were reported by Environment Impact Study Corporation (1977) as probable residents of the MMR. R. rattus was considered by the U. S. Department of the Interior, Fish and Wildlife Service (1981) to be an important predator on Achatinella, and numerous dead shells of A. mustelina were observed along the Makua and Kahanahaiki ridge crests that showed evidence of rat predation.

D. Other Terrestrial Mollusks

In addition to the endangered Oahu Tree Snails (Achatinella) that were the object of this study, a number of other native terrestrial mollusks were observed, as well as a variety of exotic taxa (Table 2). As observations on taxa other than Achatinella were merely incidental to the search for Achatinella, our records of them by no means represent a complete inventory of the land mollusk fauna of the MMR. The Kahanahaiki and Makua ridge crests supported several species of native achatinellids (two species of Auriculella and one or more of Tornatellides), succineids ("Succinea"), and helicarionids (Philonesia) in addition to Achatinella mustelina, and the exotic slugs *Meghimatium bilineatum (Philomycidae), *Limax maximus, and *Deroceras sp. cf. laeve (Limacidae) as well as the exotic bradybaenid snail *Bradybaena similaris were also present. Dead shells of two more native taxa, Amastra sp. cf. rubens (Amastridae) and Nepopupa sp. (Pupillidae) were

Table 2. Occurrence of terrestrial mollusk taxa by transect.

Taxon	A	B	C	D	E	F	G	H
<u>Pleuropoma sandwichiensis</u>				X			X	X
<u>Lamellidea</u> sp.								X
<u>Tornatellides</u> spp.	X	X		X	X		X	X
? <u>Tornatellaria</u> sp.				X	X			X
<u>Auriculella ambusta</u>	X	X	X		X			
<u>A. sp. aff. perpusilla</u>		X						
<u>Achatinella mustelina</u>	X	X	X		X		X	
<u>Partulina dubia</u>							X	
<u>Amastra rubens</u> , <u>A. sp. cf. rubens</u>	X			X	X	X	X	X
<u>Leptachatina</u> spp.				X	X	X	X	X
<u>Nesopupa</u> sp.	X							X
* <u>Meghimatium bilineatum</u>	X					*	X	
" <u>Succinea</u> " sp.	X	X	X			X		
<u>Succinea</u> sp. cf. <u>waianaensis</u>					X		X	X
<u>Philonesia</u> sp.	X	X	X	X	X	X	X	X
* <u>Hawaiiia</u> sp. cf. <u>minuscula</u>				X	X		X	X
* <u>Limax maximus</u>	X							
* <u>Deroceras</u> sp. cf. <u>laeve</u>		X					X	
* <u>Lamellaxis clavulinum</u> , <u>L. sp.</u>				X	X	X	X	X
* <u>Prosopias achatinaceum</u>				X				
* <u>Euglandina rosea</u>				X		*		X
* <u>Achatina fulica</u>						*		*
* <u>Bradybaena similaris</u>	X	X	X	X	X	X	X	X
No. of Native Taxa	7	6	4	6	8	4	8	9
No. of Exotic Taxa	3	2	1	5	3	2+3*	5	4+1*

*Taxa limited to low elevation portion of transect.

also encountered. Such a fauna is probably rather typical of the higher regions of the Waianae Mountains. More unusual, perhaps, are the assemblages of native taxa encountered in some locations within Makua Valley itself. Although comparative data for other comparable areas of the Waianae Mountains are few, the presence of Pleuropoma sandwichiensis (Helicinidae) and Amastra rubens (Amastridae) is noteworthy. Of greatest interest, however, was the observation on Truncet G of a single living individual of Partulina dubia, a rare achatinelline tree snail closely related to Achatinella (on the islands of Molokai, Lanai, Maui, and Hawaii Partulina replaces Achatinella as the dominant group of conspicuous tree snails; Oahu representatives of the genus are P. dubia and two fossil species). Bishop Museum collections document the occurrence of P. dubia in Makua Valley in 1939 and 1941, but to our knowledge there have been no confirmed sightings of this species anywhere on Oahu since that time (there is a hearsay report of a single juvenile individual collected in the 1960's in the Kanehoa region south of Kolekole Pass, but no specimen is extant to document the identification; W. R. Hay, in litt., 1983). Fig. 5 shows the occurrence of Pleuropoma sandwichiensis, Partulina dubia, and Amastra rubens within the MMR. Other native snails observed in this region were Tornatellaria sp., Tornatellides sp., and Auriculella ambusta (Achatinellidae), Leptachatina sp. (Amastridae), Succinea sp. cf. waianaensis (Succineidae), and Philonesia sp. (Helicarionidae). Exotic taxa observed were *Meghimatium bilineatum, *Deroceras sp. cf. laeve, and *Bradybaena similaris, as well as *Hawaiiia sp. cf. minuscula (Zonitidae), and *Prosopeas achatinaceum and *Lamellaxis clavulinum (Subulinidae). *Achatina fulica (Achatinidae) was generally restricted to below 800 ft elevation, and as mentioned above *Euglandina rosea (Spiraxidae) was present in lower Makua Valley and in Koiahi Gulch.

E. Fire, Explosive Ordnance, and Other Hazards to Achatinella Within the Makua Military Reservation

Explosions from impact of ordnance and fires generated by these explosions pose major threats to the continued existence of Achatinella in the MMR. Comparison of the limits of the high explosive impact area (Fig. 1) and of the occurrence of Achatinella (Fig. 4) shows that much of the portion of southeastern Makua Valley inhabited by these snails lies within

the impact area; other areas inhabited by tree snails are closely adjacent to the impact area. The practice firing activities carried out by the Army in Makua Valley undoubtedly start many fires each year. The extensive grasslands of the mid- and lower valley appear to burn annually, some fires extending uphill at least as far as the forested slopes. Fires are also ignited in the forests at the eastern end of the valley. We observed three such recent burns in late 1983. The median ridge at the rear of Makua Valley bears evidence of complete burning and subsequent invasion by exotic forest trees up to at least 1400 ft elevation. The Kahanahaiki-Makua division ridge shows evidence of fire to a considerable elevation, and it should be noted that the densest Achatinella populations observed during this study were found at and near the head of this ridge. Fires in locations inhabited by Achatinella will result in death of individual snails and in the probable permanent extirpation of impacted populations. Burned-over forest lands are likely to be invaded by exotic plants, and even after regrowth of their vegetation such regions would be unlikely to support living Achatinella. These circumstances, plus the sedentary habits of these snails, indicate that affected regions are unlikely ever to be successfully recolonized by native tree snails.

Maneuvers by ground troops in the snail habitats are also deleterious because such movements can physically knock the snails to the ground and because such troop movements provide a mechanism for the invasion of the native forest by deleterious exotic plant species. Such forest degradation has occurred extensively along trails in the Koolau Range and would be very unfortunate if it were to occur to a similar extent in the snail habitats in and adjacent to Makua Valley. Because of restrictions on civilian access to the floor of Makua Valley, however, impacts of this nature are probably less significant there than in comparable sites not under Army control elsewhere on Oahu.

Because of the factors cited above, we must conclude that military activities clearly jeopardize the continued survival of populations of Achatinella mustelina within the Makua Military Reservation, principally as a result of the direct killing of individual snails that may result from explosive impact of ordnance and from fires set by such ordnance.

RECOMMENDATIONS

1. In our opinion, the risk of fire and explosive impact is the greatest threat posed by military training activities to the continued survival of endangered Oahu Tree Snails on the MMR. It is imperative that fire not be permitted in areas inhabited by Achatinella. The limits of the high explosive impact area must be modified to exclude areas known or believed to be inhabited by Achatinella, as well as to provide buffer zones of sufficient extent to ensure that fires generated by ordnance will not spread into Achatinella habitat. The following priorities should be applied to protection of Achatinella habitat within the MMR (see Fig. 4): Priority 1, areas in which living or dead Achatinella were observed during this study or by Christensen (1980); Priority 2, additional areas probably inhabited by Achatinella (most of this area was not surveyed, but is adjacent to or near surveyed areas in which Achatinella was encountered, is within the historical range of Achatinella, and appears to provide suitable Achatinella habitat); Priority 3, unsurveyed areas possibly inhabited by Achatinella. Pending completion of a historical review of the extent of fires within the MMR and development of a comprehensive fire protection plan (Recommendation 2, below), we recommend that certain land in southeastern Makua Valley, within the Makua Keaau Forest Reserve, be excluded from the high explosive impact area; impact of ordnance on certain additional land within and adjacent to the Forest Reserve should be prohibited except during periods of low fire danger because of the danger that fires originating in this area would extend uphill into Achatinella habitat. The areas to which these interim restrictions would apply are shown in Fig. 6. It is possible that the limits of these areas may be modified somewhat after implementation of the comprehensive fire protection plan recommended below; deletion of a major portion of the current high explosive impact area in southeastern Makua Valley is inevitable, however. We note that the authors of the botanical survey of the MMR (Environment Impact Study Corporation 1977) made a similar recommendation regarding relocation of targets located above the Forest Reserve boundary in upper Makua Valley.

2. We recommend that military authorities develop a comprehensive fire protection plan for the MMR. Matters to be addressed by such a plan should

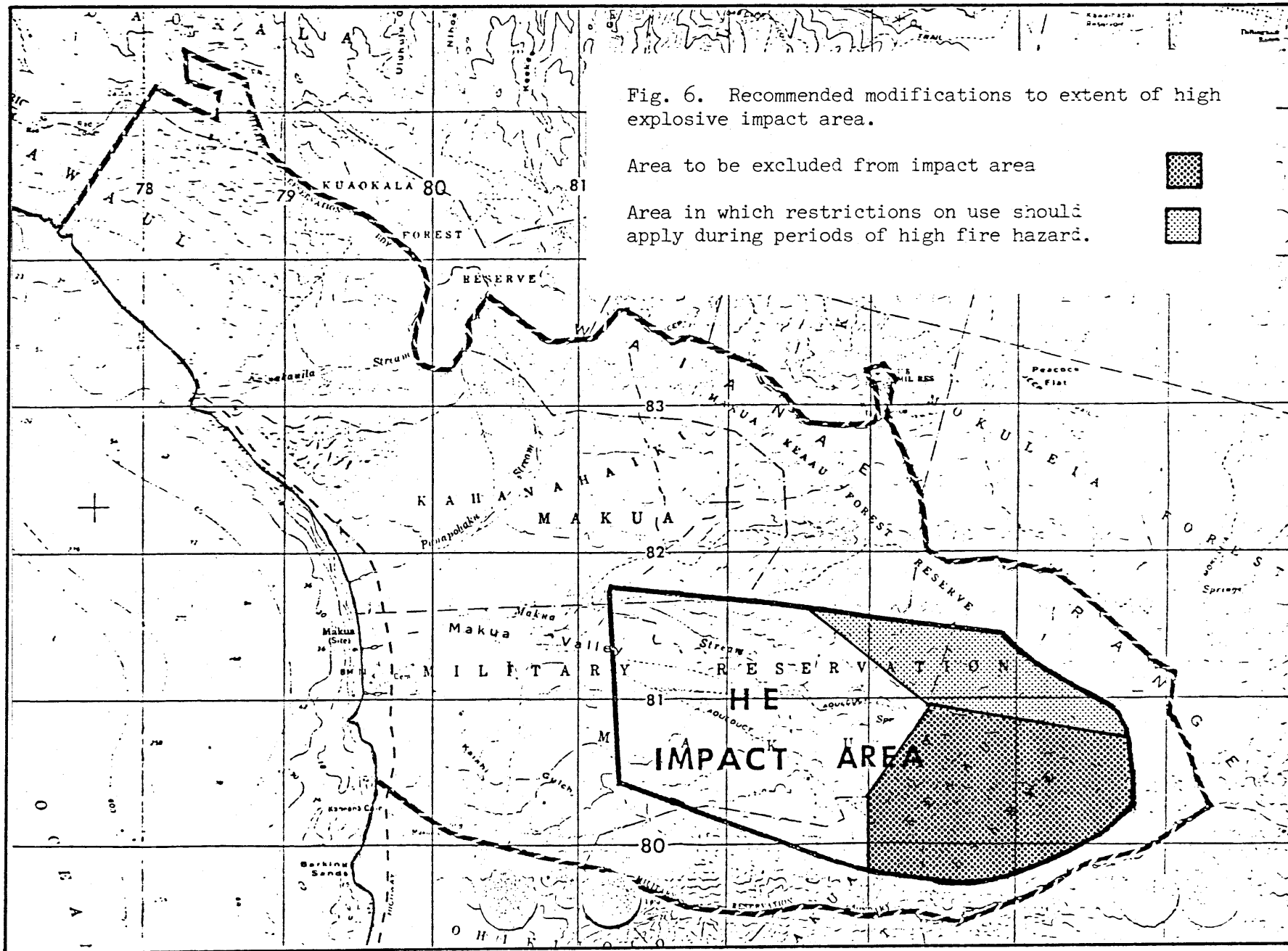


Fig. 6. Recommended modifications to extent of high explosive impact area.

Area to be excluded from impact area



Area in which restrictions on use should apply during periods of high fire hazard.



include: (a) the historical occurrence of fires within the MMR; (b) construction and maintenance of fire breaks to prevent the spread of fires from the grasslands in the valley floor to adjacent forested slopes and ridges; (c) restrictions on the use of specific categories of ordnance that pose a high fire risk or that may be likely to impact beyond the limits of designated target areas; (d) upgrading of firefighting capabilities at MMR; (e) restrictions on use of MMR during periods of high fire danger due to drought, high winds, etc.; (f) instruction of Army personnel regarding the fragility of native Hawaiian ecosystems and the devastating effects of fire upon them; (g) restrictions on controlled burning; and (h) such other matters as may be necessary for the development and conduct of a successful program of fire prevention and suppression. A final determination regarding the limits of the high explosive impact area should be made based on analysis of biological survey data and the information regarding fire hazards within the MMR that will be assembled during preparation of the comprehensive fire protection program.

3. Continued survival of Oahu Tree Snails on the MMR is dependent upon the preservation of suitable habitat. Environmental assessment of the impacts of Army activities within the MMR should analyze factors other than fire and explosions that may adversely affect the relatively undisturbed environment in which these snails now live.

4. Along the northeastern boundary of the MMR Achatinella inhabits a narrow strip of Army land at and adjacent to the crests of the ridges bounding Makua and Kahanahaiki Valleys; adjoining land not under Army control is also inhabited by these snails. Certain changes in land use on this adjoining land (i. e., planting of exotic trees, logging, etc.) would inevitably have an adverse impact on snail populations inhabiting this narrow strip of suitable habitat along the boundary of the MMR. We recommend that Army authorities monitor any proposed changes in land use on adjacent non-owned land with the aim of recommending against any that would adversely impact Achatinella populations on the MMR.

5. To provide data on the status of Achatinella populations on the MMR, a monitoring program should be instituted. Such a program need not be

elaborate or costly, and its most important element would be periodic observations to confirm that Achatinella habitats are not being invaded by fire. In the event that research workers should request access to the MMR for the purpose of studying Achatinella, they could be required to provide a brief summary of their observations of the distribution and abundance of tree snail populations as well as of the occurrence of the predatory snail Euglandina rosea in areas not now infested by that pest.

REFERENCES

CHRISTENSEN, Carl C. 1980. A report on preliminary reconnaissance of Achatinella (Oahu Tree Snails) at Makua Military Reservation, Oahu. Prepared for Department of the Army, Corps of Engineers, Pacific Ocean Division, Honolulu, Hawaii.

ENVIRONMENT IMPACT STUDY CORPORATION. 1977. A report on the biological survey of the Makua Military Reservation, O'ahu, Hawaii. Prepared for Department of the Army, Corps of Engineers, Pacific Ocean Division, Honolulu, Hawaii.

PILSBRY, Henry A., and C. Montague COOKE, Jr. 1912-1914. Achatinellidae. Manual of Conchology (2nd series) vol. 22. Academy of Natural Sciences of Philadelphia.

U. S. ARMY ENGINEER DIVISION, PACIFIC OCEAN, CORPS OF ENGINEERS. 1982. Scope of work, a survey of the endangered Oahu Tree Snail (Genus Achatinella) on U. S. Army Support Command, Hawaii installations, with an intensive survey of Makua Military Reservation.

U. S. ARMY SUPPORT COMMAND, HAWAII, DIRECTORATE OF PLANS AND TRAINING. 1979. Makua Valley Range Book.

U. S. DEPARTMENT OF THE INTERIOR, FISH AND WILDLIFE SERVICE. 1981. Endangered and threatened wildlife and plants; listing the Hawaiian (Oahu) Tree Snails of the genus Achatinella as Endangered Species. Federal Register 46(8):3178-3182.

WELCH, d'Alte A. 1938. Distribution and variation of Achatinella mustelina Mighels in the Waianae Mountains, Oahu. B. P. Bishop Museum Bull. 152. 164 pp., 13 pl.