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CEWES-ER-W 25 February 1994

MEMORANDUM FOR RECORD

SUBJECT: Results of Preliminary Reconnaissance Trip to Determine the Presence of Wetlands in Wet Forest Habitats on the Island of Hawaii as part of the Hawaii Geothermal Project, October 1993

Executive Summary

In October 1993, we sampled soils, vegetation, and hydrology at eight sites representing a range of substrates, elevations, soil types, and plant community types within rainforest habitats on the Island of Hawaii. Our purpose was to determine whether any of these habitats were wetlands according to the 1987 *Corps of Engineers Wetlands Delineation Manual*. None of the rainforest habitats we sampled was wetland in its entirety. However, communities established on pahoehoe lava flows contained scattered wetlands in depressions and folds in the lava, where water could accumulate. Therefore, large construction projects, such as that associated with proposed geothermal energy development in the area, have the potential to impact a significant number and/or area of wetlands. To estimate those impacts more accurately, we present a supplementary scope of work and cost estimate for additional sampling in the proposed geothermal project area.

Introduction and Objectives

1. At the request of the Regulatory Branch, U.S. Army Engineer Pacific Ocean Division (CEPOD-CO-O), Mr. Robert Lichvar (Botanist), Dr. Steven Sprecher (Soil Scientist), and Dr. James Wakeley (Research Wildlife Biologist) carried out a preliminary reconnaissance of wet forest habitats on the Island of Hawaii as part of the Hawaii Geothermal Project. The U.S. Army Engineer Waterways Experiment Station was asked whether it is feasible to identify and map wetlands within the three identified Geothermal Resource Subzones in the Puna District, Island of Hawaii. If feasible, wetland mapping would be done as input to the US Department of Energy's environmental impact assessment for geothermal development in the area.

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2. The purpose of the reconnaissance trip was to (1) become familiar with the soils and vegetation of the wet forest communities in and around the Geothermal Resource Subzones, (2) determine whether the 1987 *Corps of Engineers Wetlands Delineation Manual* (the Manual) was appropriate for identifying and delineating wetlands in this environment, (3) perform some preliminary wetland determinations in selected plant communities in and around the subzones, (4) determine sampling methods appropriate to identify and delineate wetlands within approximately 25,000 acres in the subzones, and (5) provide a revised scope of work and budget estimate for the wetland mapping effort.

3. Although intended to be national in scope, the Manual was written primarily with temperate zone wetlands of the continental United States in mind. Application of the Manual to the wet forests of Hawaii may be complicated by the presence of plant communities that generally receive 60 to >200 inches of rainfall per year (Cuddihy 1989), and the widespread occurrence of thin organic soils (mapped as Folists) that may or may not be saturated and reduced for long periods of time. Our preliminary studies were designed to answer the following questions:

a. Do any of the wet forest communities mapped within the subzones consist entirely of wetlands according to the rules in the Manual (including recent guidance from Headquarters USACE)?

b. If not entirely wetland, do any of these wet forest communities contain smaller areas of wetland within them?

c. If wetlands are present, what is the best way to identify, delineate, and map them within the subzones (i.e., through interpretation of aerial photography, use of helicopter surveys, or by ground survey)?

4. Our study plans, sampling design, and data collection benefited greatly from various meetings and discussions in the field with local experts on Hawaiian vegetation and soils. We particularly thank Dr. Chris Smith (State Soil Scientist), Mr. Sako Nakamura, and Mr. Bill Laird of the USDA Soil Conservation Service, and botanical consultants Dr. Grant Gerrish and Ms. Winona Char. Dr. Jim Jacobi and Mr. Steve Miller (US Fish and Wildlife Service) provided information about plant communities in the study area. Finally, Ms. Suzanne Baba and MAJ David Samec (CEPOD-CO-O) provided logistical support and tireless assistance with plant and soil sampling.

Methods

5. Vegetation maps of the subzones and surrounding areas by Char and Lamoureux (1985) and Jacobi (1989) were the foundation of our sampling design. Based on general lists of plant species present in each community type, and on

discussions with local experts, we roughly ranked plant communities according to their estimated likelihood of either being or containing wetlands. We concentrated our effort on the higher elevation (>1,000 ft), wet forest communities, which were widespread within the less disturbed portions of the geothermal subzones. Lower elevations within the subzones were dominated by relatively fresh lava flows, widespread agricultural development, and suburban sprawl.

6. We selected representative sites to sample in each community type. Because access to most areas within the Geothermal Resource Subzones was restricted, we chose sites mainly outside the subzones that encompassed the range of variability in vegetation, soils, elevations, and substrate ages and types present on this portion of the island and mapped within the subzones.

7. The eight study sites (Figure 1) ranged in elevation from 750-4,000 ft and substrate ages from 138 yrs to a maximum of 4,000 yrs (Table 1). We concentrated on communities established on pahoehoe lava flows, because (1) these were most widespread in the geothermal area and (2) we judged that there was a higher potential for wetland development on the dense, smooth pahoehoe than on the more blocky and fragmented aa flows. One site (Thurston Lava Tube) was on thick ash and cinder deposits.

8. With one exception, vegetation on all sites was dominated by varieties of 'ohi'a (*Metrosideros polymorpha*). Understory vegetation ranged from predominantly grasses, to shrubs, to matted ferns, to native treefern. One site (Treeless Bog) was a large, open bog that lacked woody vegetation. Soils on five sites were mapped as Folists, two as recent lava flows, and one as silt loam (USDA Soil Conservation Service 1973). Annual precipitation in this part of the island ranges from approximately 100-200 inches per year, but we had no rainfall data for the individual sites.

9. Sites were sampled between 14-21 October 1993. At each site, we established three 10 × 10-m sampling plots. Plots were established in representative locations within the community, but were placed so that each plot also included typical examples of the wetter spots within that community. There was considerable topographic relief within most plots. The wetter spots generally consisted of cracks, depressions, or folds in the lava substrate where there was increased potential for water to accumulate. Within each plot, we established three to five (generally four) 1 × 1-m subplots. Generally, two subplots were placed in what appeared to be the wetter portions and two in the drier portions of the larger plot. Vegetation, soil, and hydrology were sampled in each subplot; vegetation data were taken in the larger plot as well.

10. Soil profiles were described to the depth of the bedrock or 16 inches, whichever was shallower. We recorded the depth to free water, if present. We

did not routinely record whether the soil was saturated in the absence of a water table, because it rained most days and saturation alone was not a reliable indicator of long-term wetness or chemical reduction. However, to determine whether soils were reduced at the time of sampling, we tested samples for the presence of ferrous iron using *α,α'*-dipyridyl solution (Childs 1981). In addition, we used an Orion portable meter (Model 250A) and platinum redox electrode (Orion model 96-78) to measure redox potential of each sampled soil at approximately 6-inch depth or shallower.

11. Our vegetation sampling design was similar to that described in the Manual. On each plot and subplot, we estimated the percent cover of each species present in three strata: herbs (all herbaceous plants and woody plants <1 m tall), shrubs (woody plants >1 m tall and <3 inches dbh), and trees (woody plants >3 inches dbh). Only species rooted within the plot or subplot were tallied. Dominant species in each stratum were the most abundant species that comprised >50% of the total coverage, plus any individual species that was at least 20% of the total. Hydrophytic plant communities were those in which >50% of dominant species from all strata were obligate (OBL), facultative wetland (FACW), or facultative (FAC, but not counting FAC−) on the list of plant species that occur in wetlands in Hawaii (Reed 1988).

12. Helicopter overflights of the general study area and of each site examined on the ground were made to determine the extent to which any identified wetlands could be recognized and delineated in a low-altitude aerial survey. In addition, both before and after field work, we examined 1:12,000 color infrared aerial photography of the geothermal subzones taken in February 1992 and January and March 1993 to determine whether a planning-level wetland inventory could be accomplished solely through photo interpretation.

Results and Discussion

13. Results of the field work are summarized in Tables 2-17. In these tables, each 1 × 1-m subplot is identified with a number and letter (e.g., 1.1W). A 'W' indicates that the subplot was deliberately placed in one of the apparent wetter microsites in the plot, and a 'U' indicates a relatively drier microsite. The 'W' and 'U' were *a priori* assignments made in the field, and may or may not relate to the final conclusion about a subplot's wetland status.

Vegetation

14. The topographic relief in most plots created microsite variations in soils and hydrology that were reflected in the distribution of plants on a plot. Plot-level sampling masked this internal variability; microsite variability was obvious in the subplot samples. Overall, 10 plots (42% of all plots) satisfied the Manual's

criterion for hydrophytic vegetation. The Captain's Drive, Thurston Lava Tube, and Tree Planting Road sites each had ≥2 plots that were dominated by hydrophytic vegetation. None of the plots at the 1855 Flow, Ainaloa, or Pahoa sites were dominated by hydrophytic vegetation. Plant species that were dominant on one or more plots or subplots are listed in Table 18.

15. Plot-level decisions based on average vegetation composition were often contradicted at the subplot level. For example, vegetation on plot 3 at Wailuku River Road was not hydrophytic overall, but the two wetter subplots (3.1W and 3.4W) both met the hydrophytic vegetation criterion (Table 16). In contrast, plot 2 at Captain's Drive was hydrophytic, whereas none of its subplots were (Table 6).

16. One difficulty in applying the vegetation rules in the Manual (although the problem is not unique to Hawaii) was that communities were not very diverse and thus were dominated by only a few species. This was particularly true of the 1 × 1-m subplots, which often had only 1-3 dominants. Therefore, the hydrophytic vegetation decision often hinged on the status of a single species and the outcome was subject to chance. Even the Treeless Bog, which was an obvious wetland in all other respects, failed to meet the hydrophytic vegetation criterion on two plots and two subplots (Table 14). It may be that the prevalence index, which takes into account the abundance and indicator status of *all* species present, would give a more consistent and reliable result in these habitats.

Hydrology

17. Wetland hydrology decisions given in the tables were based on the presence of free water in the soil pits or covering the soil surface at the time of sampling. Because of frequent rainfall, observation of saturated soils in the absence of a water table was considered unreliable. None of the sites exhibited surface indicators of hydrology (e.g., water marks, drift lines). Our sampling period in mid-October was at the end of the dry season in this part of the island. During the wetter portion of the year, evidence of wetland hydrology may be much more widespread.

Soils

18. Hydric soil determinations were based mainly on evidence of soil reduction at the time of sampling. Redox potentials below approximately 150 mV and/or a positive test for ferrous iron were used to identify soils that "develop anaerobic conditions in the upper part" and thus meet the hydric soil definition (USDA Soil Conservation Service 1991). We suspect that additional soils in the communities we studied may also become saturated and reduced later in the rainy season, but investigation would require long-term monitoring of soil redox potentials.

19. We found it almost impossible to identify hydric soils based on morphology in these wet forest habitats, because the distinction between hydric and nonhydric Histosols (i.e., between Saprists and Folists) requires knowledge of saturation and reduction of the soils in question. Soil science is currently unable to distinguish morphological differences between reducing and nonreducing shallow Histosols, so most of the time we relied on redox measurements and *α, α′*-dipyridyl data to distinguish between Saprists and Folists, that is, between hydric and nonhydric soils, respectively.

20. On some of the sites we determined hydric status of the soils from soil morphology rather than from redox measurements. At the wet subplots of the Ainaloa site, soils were floating in open pools of entrapped water. The bulk of these soils was not reducing with respect to iron (Table 5), probably because aerated water from the open pool freely circulated within the loose soil mass. We deemed these soils to fit the intent of the definition of Saprists more closely than that of Folists (Folists "are never saturated with water except for a few days following heavy rains" [Soil Survey Staff 1975]). Gleyed mineral or mineral-rich material was present in some of the soils at the Thurston Lava Tube and Wailuku River Road sites (Tables 11 and 17). We decided to call these soils hydric despite high redox readings because we considered soil color to more reliably indicate long-term reduction than redox status on a single day.

21. In the absence of redox data, landscape position and substrate type may be the most reliable indicators of potential hydric soils in the study areas. We found that in pahoehoe flows, closed depressions where water accumulates are likely to satisfy both hydric soil and wetland hydrology criteria. Sloping sites and areas underlain by ash, cinders, or more porous aa lava are less likely to retain water for long periods.

Wetland Determinations

22. Eleven of the 1 × 1-m subplots exhibited evidence of all three parameters on the day of sampling, and therefore clearly were wetlands according to the Manual (Table 19). Seven of these wetland subplots were at Treeless Bog, three at Ainaloa, and one at Captain's Drive. Therefore, small wetland areas existed within larger plots that overall may or may not have met wetland criteria.

23. However, the Manual allows the investigator to consider not only those indicators that are present during a brief visit, but also those indicators (particularly of hydrology) that would normally be present if sampling were done at the appropriate time of year. Several subplots (e.g., subplots 1.1 and 3.2 at Captain's Drive) that showed evidence of hydrophytic vegetation and hydric soils lacked an obvious water table at the time of our visit. Given that our sampling dates were at the end of the dry season, we are convinced that these and many other

depressional sites in the study area also hold water for long periods during the rainy season. In addition, some subplots had hydric soils and wetland hydrology and clearly functioned as wetlands, but failed by a single dominant species to satisfy the hydrophytic vegetation parameter (e.g., subplots 1.2 and 2.2 at Treeless Bog). Often these subplots would have met the test if the next most abundant plant species had been included in the decision. In our judgment, these situations should be considered to be wetlands as well (Table 19).

24. Ainaloa, Captain's Drive, Tree Planting Road, Treeless Bog, and Wailuku River Road were the sites containing the largest number of small, scattered wetlands (Table 19). The presence of these wetlands would have to be considered in any development plans. Sites containing wetlands were all underlain by pahoehoe flows that were at least 350 years old (Table 1). Field sites on aa lava (Pahoa), ash and cinders (Thurston Lava Tube), or very recent pahoehoe (1855 Flow) contained few, if any, wetlands.

Aerial Photography and Helicopter Overflights

25. Our initial examination of color infrared aerial photography of the geothermal subzones indicated several areas that might either be or contain wetlands. Most were in predominantly grass or shrub vegetation with only scattered 'ohi'a trees. We were not permitted on-the-ground access to these areas, but we did examine many of them in a low-level helicopter survey. Scattered small areas of standing water and apparent hydrophytic plant communities indicated that wetlands were indeed present. We selected the Ainaloa study site, outside the subzones, because of its apparent similarity in age and vegetation to the areas of interest within the subzones. Field sampling at Ainaloa confirmed that scattered wetlands were present in that community type.

26. Most of the higher elevation portions of the geothermal subzones were blanketed in continuous 'ohi'a and fern cover, making aerial wetland surveys impossible. Most of the wetlands we studied on the ground were small and scattered, and were completely hidden from above by tree and fern canopies. In areas of recent 'ohi'a dieback and establishment of dense uluhe (*Dicranopteris linearis*) growth, it was difficult to see the ground even in a walking survey.

Conclusions

27. We conclude that:

a. None of the wet forest habitats we studied meets wetland criteria in its entirety. Therefore, existing plant community maps cannot be used to delineate wetlands in the geothermal subzones. Furthermore, the small, scattered wetlands we found generally were not visible on aerial photos or from low-level helicopter flights. These wetlands could be mapped in forested areas only with detailed ground surveys.

b. Most of the higher elevation wet forest types we studied, which are widespread in the Kilauea Middle East Rift and Kamaili Subzones, contained inclusions that met wetland criteria given in the Manual. Wetlands we examined ranged in size from <1 to many square meters, and were fairly common in the brief walking surveys we made of each study site. Our sampling was not designed to estimate the abundance or total acreage of these wetlands. However, in some habitats they appeared to be abundant enough that a large construction project could impact a significant number and/or area of wetlands.

c. Wetlands were more common in communities underlain by relatively dense and continuous pahoehoe lava flows. They occupied isolated depressions formed by cracks, folds, and undulating flow patterns in the lava, and were not associated with major drainageways.

d. Routine application of the 1987 *Corps of Engineers Wetlands Delineation Manual* in this environment was hampered by (1) the relatively low diversity of plant communities (causing inconsistent hydrophytic vegetation decisions due to the small number of dominants) and (2) the difficulty in distinguishing hydric and nonhydric shallow Histosols (necessitating redox data to identify hydric soils).

e. The use of a prevalence index may improve the reliability of vegetation decisions, but additional research on Histosol morphology in relation to soil reduction in this region is needed to make hydric soil decisions more reliable.

f. Wetlands within the rainforest probably should be considered as Problem Areas under the 1987 Manual. They can be identified reliably only during the wet season, and then only if information about soil reduction (e.g., ferrous iron test) is available. During the dry season, they may be recognized mainly by landscape position and the presence of an appropriate plant association.

Proposed Wetland Sampling Plan

28. Our preliminary studies clearly indicate that a complete jurisdictional determination of all wetlands in the geothermal resource subzones is impractical if not impossible. Wetlands are too small, too numerous, and too well camouflaged beneath the tree canopy for a complete survey of such an extensive area to be possible. On the other hand, geothermal development in this area definitely will impact wetlands and there is a need to quantify that impact.

29. Given that remote techniques (aerial photo interpretation and helicopter surveys) are impractical in these forested habitats, we see two alternatives to the problem of determining wetland impacts due to geothermal development in this area:

A. Use an extensive on-site sampling design to estimate the percentage of wetland within each plant community type in the subzones. Then the wetland impacts associated with well drilling, road construction, and siting of powerplants and transmission lines could be estimated by multiplying that percentage by the affected acreage of each community type.

B. Survey only those areas within the footprint of a proposed project plan. The goal would be to determine the acreage of wetland involved, not to map every wet pocket.

30. Alternative B is the more practical and less costly alternative. It is also the information that will be needed eventually if a Section 404 permit for the proposed geothermal development is required. However, alternative A may be necessary if wetland impacts must be estimated for many potential alternative project alignments, or if rough estimates of impacts must be made in advance of a definite project plan. The following are suggested sampling designs for each alternative plan.

Extensive Sampling Throughout the Subzones (Alternative A)

31. Using existing plant community maps (e.g., Jacobi 1989), a number of 200-m belt transects will be established in each of the community types present in the subzones. Transects will be randomly located within accessible areas of each community, perhaps using roads, trails, or helicopter landing zones as starting points for one or more transects.

32. Transect width may vary between community types due to the density of vegetation and other factors. Each transect will be walked by one or two observers, who will record the number and estimated size of all wetlands

encountered within the belt. No intensive sampling of vegetation, soils, or hydrology will be done in this rapid survey. Instead, wetlands will be recognized mainly by landscape position and a hydrophytic plant community. Wetland decisions will be verified occasionally by more detailed sampling at selected sites; if done during the wet season, ferrous iron testing will be used to confirm presence of hydric soils. Means and standard errors of the percentage of wetland in each community will be estimated by combining all transects in a community. Field work will be accomplished with the help of local contractors working under the direction of WES project scientists. WES personnel will design the sampling effort, work closely with sampling teams to ensure quality and consistency, analyze the data, and produce a final report.

Sampling Within the Project Footprint (Alternative B)

33. Detailed maps of the project alignment will be used to identify sampling areas. Some impacted sites may be small enough that a complete survey of wetlands within them is possible. In more extensive tracts, belt transects will be used to estimate the percentage of wetland within them. Sampling will be carried out by WES personnel with the assistance of local experts. The goal will be to determine impacted wetland acreage, not to map the boundaries of all wetlands in the tract.

Estimated Cost

34. The work will be accomplished under the existing scope of work entitled "Wetland Identification and Delineation, Hawaii Geothermal Project." However, project activities would be modified as described above, and the estimated cost would be as follows.

Item	Alternative A	Alternative B[1]
Salaries	90,000.	60,000.
Travel, perdiem, and vehicle rental	24,000.	18,000.
Equipment and supplies	2,000.	2,000.
TOTAL	116,000.	80,000.

[1]This estimate assumes that the acreage involved is small enough that field work could be accomplished by 4-6 people in about 2-3 weeks. Additional costs would be incurred if additional sampling were needed.

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Table 1. Characteristics of field sites, Hawaii forest wetland study.

Site	Elevation	Flow Type	Flow Age[1]	Plant Community Type[2]	Soil Map Unit[3]	Location
1855 Flow	3,740 ft	Pahoehoe	138 yr	Wet 'ohi'a/matted fern (o1-2Me[W:mf,ng])	rLW (Lava Flows, Pahoehoe)	19°41.48' N 155°16.60' W
Ainaloa	750 ft	Pahoehoe	350-500 yr	Wet 'ohi'a/mixed grasses (s1-2Me[W:mg,ns,xs])	rLW (Lava Flows, Pahoehoe)	19°30.91' N 154°59.56' W
Captain's Drive	2,320 ft	Pahoehoe	350-500 yr	Wet 'ohi'a/tree fern (c2Me,nt[W:tf,ns])	rKGD (Keei extremely rocky muck, 6-20% slopes)[4]	19°26.71' N 155°7.39' W
Pahoa	980 ft	Aa	750-1000 yr	Wet 'ohi'a/introduced shrubs (c3Me,nt[W:nt,xs])	rMAD (Malama extremely stony muck, 3-15% slopes)	19°26.52' N 154°56.84' W
Thurston Lava Tube	3,880 ft	Ash and cinders	203 yr	Wet 'ohi'a/tree fern (c3Me,nt[W:tf,ns])	rPHB (Puhimau silt loam, 2-6% slopes)	19°24.92' N 155°14.30' W
Tree Planting Road	4,000 ft	Pahoehoe	1,500-4,000 yr	Wet 'ohi'a/tree fern (c3Me,nt[W:tf,ns])	rKAD (Kahaluu extremely rocky muck, 6-20% slopes)	19°40.32' N 155°17.03' W
Treeless Bog	3,620 ft	Pahoehoe	1,500-4,000 yr	Bog (W:bg,mg)	rKGD (Keei extremely rocky muck, 6-20% slopes)	19°42.53' N 155°16.34' W
Wailuku River Road	3,600 ft	Pahoehoe	1,500-4,000 yr	Wet 'ohi'a/matted fern (o2Me,nt[W:mf]sng)	rKGD (Keei extremely rocky muck, 6-20% slopes)	19°42.59' N 155°16.18' W

[1]Based on surface flow maps by Holcomb (1980) and Lockwood et al. (1988).
[2]Classification follows that of Jacobi (1989).
[3]USDA Soil Conservation Service (1973).
[4]All muck soils on the study sites are classified as Tropofolists (USDA Soil Conservation Service 1973).

Table 2. Summary of vegetation results, 1855 Flow.

Species[1]	Status	Plot 1					Plot 2					Plot 3				
		1.1W	1.2W	1.3U	1.4U	Plot	2.1W	2.2W	2.3U	2.4U	Plot	3.1W	3.2W	3.3U	3.4U	Plot
MAMA	FACU	H[2]	H	H	H	H	H	H	H		H	H	H	H	H	H
LYCE	FAC	H	H		H			H				H	H	H		H
DILI	FACU		H	H		H		H	H	SH	H	H			H	H
MEPOIN	UPL					S	S				S	S	S	S		S
MEPOGL	FAC+															S
Hydrophyte Ratio[3]		1/2	1/3	0/2	1/2	0/3	0/2	1/3	0/2	0/2	0/3	1/4	1/3	1/3	0/2	2/5
Hydrophytic Vegetation		NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

[1] Species codes as in Table 18. Only dominant species are shown.
[2] T=tree stratum, S=shrub stratum, H=herb stratum.
[3] Number of dominant species rated FAC (not counting FAC-), FACW, or OBL/total number of dominant species.

Table 3. Summary of soil and hydrology results, 1855 Flow.

Characteristic	Plot 1					Plot 2					Plot 3				
	1.1W	1.2W	1.3U	1.4U	Plot[1]	2.1W	2.2W	2.3U	2.4U	Plot	3.1W	3.2W	3.3U	3.4U	Plot
Redox Potential (mV)	113	243	305	348	NA	230	154	271	283	NA	322	164	343	331	NA
α,α Dipyridyl[2]	Pos	Neg	Neg	Neg	NA	Neg	Neg	Neg	Neg	NA	Neg	Neg	Neg	Neg	NA
HS Morphology	None	None	None	None	NA	None	None	None	None	NA	None	None	None	None	NA
Hydric Soil	YES	NO	NO	NO	NA	NO	NO	NO	NO	NA	NO	NO	NO	NO	NA
Depth to Free Water	1"	1"	Ø[3]	Ø	NA	1"	5"	Ø	Ø	NA	0"	4"	Ø	Ø	NA
Landscape Position	cd[4]	cd	slope	slope	NA	cd	cd	slope	slope	NA	cd	cd	slope	slope	NA
Wetland Hydrology	YES	YES	NO	NO	NA	YES	YES	NO	NO	NA	YES	YES	NO	NO	NA

[1] Plot-wide information not collected for soils and hydrology; columns left in table for congruence with vegetation tables.
[2] Pos = positive and Neg = negative test for ferrous iron.
[3] Ø = free water not observed above 12 inches or to bedrock, whichever was shallower.
[4] cd = closed depression (micro-relief).

Table 4. Summary of vegetation results, Ainaloa.

Species[1]	Status	Plot 1					Plot 2					Plot 3				
		1.1W	1.2W	1.3U	1.4U	Plot	2.1W	2.2W	2.3U	2.4U	Plot	3.1W	3.2W	3.3U	3.4U	Plot
SCTE	FACU	H[2]	H			H					H					
XYCO	FACW	H	H			H	H	H				H	H			
MEBA	FACU			S	S	S			S		S				S	S
MEPOIN	UPL			S		S									S	TS
ANVI	FACU			H	H	H	H		H	H	H			H	H	H
PTLO	FACU				H											
SCSP	–										S					
Hydrophyte Ratio[3]		1/2	1/2	0/3	0/3	1/5	1/2	1/1	0/2	0/1	0/4	1/1	1/1	0/1	0/3	0/4
Hydrophytic Vegetation		NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	YES	YES	NO	NO	NO

[1] Species codes as in Table 18. Only dominant species are shown.
[2] T = tree stratum, S = shrub stratum, H = herb stratum.
[3] Number of dominant species rated FAC (not counting FAC-), FACW, or OBL/total number of dominant species.

Table 5. Summary of soil and hydrology results, Ainaloa.

Characteristic	Plot 1					Plot 2					Plot 3				
	1.1W	1.2W	1.3U	1.4U	Plot1[1]	2.1W	2.2W	2.3U	2.4U	Plot	3.1W	3.2W	3.3U	3.4U	Plot
Redox Potential (mV)	-52	189	339	331	NA	276	269	269	343	NA	-20	-7	320	316	NA
α,α Dipyridyl[2]	Neg	Neg	Neg	Neg	NA	Neg	Neg	Neg	Neg	NA	Pos	Pos	Neg	Neg	NA
HS Morphology	Hist[3]	Hist	None	None	NA	Hist	Hist	None	None	NA	Hist	Hist	None	None	NA
Hydric Soil	YES	YES	NO	NO	NA	YES	YES	NO	NO	NA	YES	YES	NO	NO	NA
Depth to Free Water	2"	2"	Ø[4]	Ø	NA	2"	2"	Ø	Ø	NA	0"	3"	Ø	Ø	NA
Landscape Position	bog	bog	slope	slope	NA	bog	bog	slope	slope	NA	bog	bog	slope	slope	NA
Wetland Hydrology	YES	YES	NO	NO	NA	YES	YES	NO	NO	NA	YES	YES	NO	NO	NA

[1] Plot-wide information not collected for soils and hydrology; columns left in table for congruence with vegetation tables.
[2] Pos = positive and Neg = negative test for ferrous iron.
[3] Hist = Histosol morphology, not Folist (USDA Soil Conservation Service 1991, p. 1; Environmental Laboratory 1987, p. 30).
[4] Ø = free water not observed above 12 inches or to bedrock, whichever was shallower.

Table 6. Summary of vegetation results, Captain's Drive.

Species[1]	Status	Plot 1					Plot 2					Plot 3				
		1.1W	1.2W	1.3U	1.4U	Plot	2.1W	2.2W	2.3U	2.4U	Plot	3.1W	3.2W	3.3U	3.4U	Plot
CIGL	FAC	S[2]		H		S				H	S	S				SH
LUPA	OBL	H										H	H			
CYHA	FACW+	H											H			
HETE	UPL		H											S	S	
MEPOGL	FAC+			T		T					T					T
BRAR	FAC			S												
DILI	FACU				S											
PSCA	FACU					H	SH			S						
PSHA	UPL						H	S	SH	S				H		
PECL	FAC							S								
FRAR	FACU						H	H	H	H	H			H		H
CYPA	FAC							H								
CHTR	FAC													T		
CICH	FAC													H		
SEAR	NI														H	
PESP	--														H	
Hydrophyte Ratio[3]		3/3	0/1	3/3	0/1	2/3	0/4	2/4	0/3	1/4	2/3	2/2	2/2	2/5	0/1	3/4
Hydrophytic Vegetation		YES	NO	YES	NO	YES	NO	NO	NO	NO	YES	YES	YES	NO	NO	YES

[1] Species codes as in Table 18. Only dominant species are shown.
[2] T=tree stratum, S=shrub stratum, H=herb stratum.
[3] Number of dominant species rated FAC (not counting FAC-), FACW, or OBL/total number of dominant species.

Table 7. Summary of soil and hydrology results, Captain's Drive.

Characteristic	Plot 1					Plot 2					Plot 3				
	1.1W	1.2W	1.3U	1.4U	Plot[1]	2.1W	2.2W	2.3U	2.4U	Plot	3.1W	3.2W	3.3U	3.4U	Plot
Redox Potential (mV)	22	14	104	310	NA	298	300	306	332	NA	71	31	297	294	NA
α,α Dipyridyl[2]	Pos	Pos	Neg	Neg	NA	Neg	Neg	Neg	Neg	NA	Pos	Pos	Neg	Neg	NA
HS Morphology	None	None	None	None	NA	None	None	None	None	NA	None	None	None	None	NA
Hydric Soil	YES	YES	YES	NO	NA	NO	NO	NO	NO	NA	YES	YES	NO	NO	NA
Depth to Free Water	Ø, sat[3]	Ø,sat	Ø	Ø	NA	Ø	Ø	Ø	Ø	NA	1"	Ø	Ø	Ø	NA
Wetland Hydrology	NO	NO	NO	NO	NA	NO	NO	NO	NO	NA	YES	NO	NO	NO	NA

[1] Plot-wide information not collected for soils and hydrology; columns left in table for congruence with vegetation tables.
[2] Pos = positive and Neg = negative test for ferrous iron.
[3] Ø = free water not observed above 12 inches or to bedrock, whichever was shallower; sat = soil saturated to surface but free water did not stand in soil pit.

Table 8. Summary of vegetation results, Pahoa.

Species[1]	Status	Plot 1					Plot 2					Plot 3				
		1.1W	1.2W	1.3U	1.4U	Plot	2.1W	2.2W	2.3U	2.4U	Plot	3.1W	3.2W	3.3U	3.4U	Plot
ATSA	UPL	H[2]														
COAR	UPL	H	S	SH	SH	SH					S	H	S		SH	SH
FRAR	FACU	H					S									
PSHA	UPL		T													
EUUN	UPL		S													
CASP	–		H													
DIPE	UPL			H								H	H		H	H
THDE	FACU			H												
MEPOMA	FAC					T					T					T
ALMO	UPL					T					T					
NEMU	FAC						H	H	H	H	H					
OPHI	FACU						H						H	H	H	
PSCA	FACU								S		TSH					
CIGL	FAC										S	S				
CICH	FAC										S					
Hydrophyte Ratio[3]		0/3	0/3	0/4	0/2	1/4	1/3	1/1	1/2	1/1	4/9	1/3	0/3	0/1	0/4	1/4
Hydrophytic Vegetation		NO	NO	NO	NO	NO	NO	YES	NO	YES	NO	NO	NO	NO	NO	NO

[1] Species codes as in Table 18. Only dominant species are shown.
[2] T=tree stratum, S=shrub stratum, H=herb stratum.
[3] Number of dominant species rated FAC (not counting FAC-), FACW, or OBL/total number of dominant species.

Table 9. Summary of soil and hydrology results, Pahoa.

Characteristic	Plot 1					Plot 2					Plot 3				
	1.1W	1.2W	1.3U	1.4U	Plot[1]	2.1W	2.2W	2.3U	2.4U	Plot	3.1W	3.2W	3.3U	3.4U	Plot
Redox Potential (mV)	286	301	--	292	NA	310	290	292	270	NA	289	267	302	271	NA
α,α Dipyridyl[2]	Neg	Neg	Neg	Neg	NA	Neg	Neg	Neg	Neg	NA	Neg	Neg	Neg	Neg	NA
HS Morphology	None	None	None	None	NA	None	None	None	None	NA	None	None	None	None	NA
Hydric Soil	NO	NO	NO	NO	NA	NO	NO	NO	NO	NA	NO	NO	NO	NO	NA
Depth to Free Water	Ø[3]	Ø	Ø	Ø	NA	Ø	Ø	Ø	Ø	NA	Ø	Ø	Ø	Ø	NA
Landscape Position	cd[4]	cd	slope	slope	NA	cd	cd	slope	slope	NA	slope	slope	slope	slope	NA
Wetland Hydrology	NO	NO	NO	NO	NA	NO	NO	NO	NO	NA	NO	NO	NO	NO	NA

[1] Plot-wide information not collected for soils and hydrology; columns left in table for congruence with vegetation tables.
[2] Pos = positive and Neg = negative test for *ferrous iron.*
[3] Ø = free water not observed above 12 inches or to bedrock, whichever was shallower.
[4] cd = closed depression (micro-relief).

Table 10. Summary of vegetation results, Thurston Lava Tube.

Species[1]	Status	Plot 1					Plot 2					Plot 3				
		1.1W	1.2W	1.3U	1.4U	Plot	2.1W	2.2W	2.3U	2.4U	Plot	3.1W	3.2W	3.3U	3.4U	Plot
UNUN	FAC	H[2]	H	H	H	H		H	H		H	H				
COSP	--						SH					S				
MIST	FAC					H	H									
VACA	FAC				H		H			H		S				
CIGL	FAC			S		S					S					S
ILAN	FACU			H				S							H	T
MEPOGL	FAC+				S	T					T					T
SACY	FACU					S					S					S
ISDI	FAC					H						H	H	H	H	H
MYLA	UPL									S						
Hydrophyte Ratio[3]		1/1	1/1	2/3	3/3	5/6	2/2	1/2	1/1	1/2	3/4	3/3	1/1	1/1	1/2	3/5
Hydrophytic Vegetation		YES	YES	YES	YES	YES	YES	NO	YES	NO	YES	YES	YES	YES	NO	YES

[1] Species codes as in Table 18. Only dominant species are shown.
[2] T=tree stratum, S=shrub stratum, H=herb stratum.
[3] Number of dominant species rated FAC (not counting FAC-), FACW, or OBL/total number of dominant species.

Table 11. Summary of soil and hydrology results, Thurston Lava Tube.

Characteristic	Plot 1					Plot 2					Plot 3				
	1.1W	1.2W	1.3U	1.4U	Plot[1]	2.1W	2.2W	2.3U	2.4U	Plot	3.1W	3.2W	3.3U	3.4U	Plot
Redox Potential (mV)	270	195	279	284	NA	305	309	269	283	NA	296	276	312	306	NA
α,α Dipyridyl[2]	Neg	Neg	Neg	Neg	NA	Neg	Neg	Neg	Neg	NA	Neg	Neg	Neg	Neg	NA
HS Morphology	None	None	None	None	NA	None	gley[3]	None	None	NA	None	None	None	None	NA
Hydric Soil	NO	NO	NO	NO	NA	NO	YES	NO	NO	NA	NO	NO	NO	NO	NA
Depth to Free Water	Ø[4]	Ø	Ø	Ø	NA	Ø	Ø	Ø	Ø	NA	Ø	Ø	Ø	Ø	NA
Landscape Position	slope	slope	slope	slope	NA	cd[5]	slope	slope	slope	NA	slope	slope	slope	slope	NA
Wetland Hydrology	NO	NO	NO	NO	NA	NO	NO	NO	NO	NA	NO	NO	NO	NO	NA

[1] Plot-wide information not collected for soils and hydrology; columns left in table for congruence with vegetation tables.
[2] Pos = positive and Neg = negative test for ferrous iron.
[3] gley = matrix with chroma of 1 or less and high value (Environmental Laboratory 1987, p. 31).
[4] Ø = free water not observed above 12 inches or to bedrock, whichever was shallower.
[5] cd = closed depression (micro-relief).

Table 12. Summary of vegetation results, Tree Planting Road.

Species[1]	Status	Plot 1					Plot 2					Plot 3				
		1.1W	1.2W	1.3U	1.4U	Plot	2.1W	2.2W	2.3U	2.4U	Plot	3.1W	3.2W	3.3U	3.4U	Plot
ATSA	UPL		H[2]	H		H								H	H	H
BRAR	FAC				S											
COOC	FAC				H											
CHTR	FAC					T										
MEPOGL	FAC+					T					T					T
CIGL	FAC					S				S	S			S	S	S
LUPA	OBL						H				H					
HYDE	FAC							H								
SACY	FACU								S							
DRSP	--								H	H						H
THCY	FACU								H		H			H		H
CAAL	FACW+										H	H				
MIST	FAC														H	
RURO	FAC-															H
ATMI	FAC										H					
Hydrophyte Ratio[3]		--	0/1	0/1	2/2	3/4	1/1	1/1	0/2	1/1	5/6	1/1	--	1/3	2/3	2/5
Hydrophytic Vegetation		--	NO	NO	YES	YES	YES	YES	NO	YES	YES	YES	--	NO	YES	NO

[1] Species codes as in Table 18. Only dominant species are shown.
[2] T = tree stratum, S = shrub stratum, H = herb stratum.
[3] Number of dominant species rated FAC (not counting FAC-), FACW, or OBL/total number of dominant species.

Table 13. Summary of soil and hydrology results, Tree Planting Road.

Characteristic	Plot 1					Plot 2					Plot 3				
	1.1W	1.2W	1.3U	1.4U	Plot[1]	2.1W	2.2W	2.3U	2.4U	Plot	3.1W	3.2W	3.3U	3.4U	Plot
Redox Potential (mV)	356	363	351	330	NA	-46	38	342	346	NA	245	-49	360	358	NA
a,a Dipyridyl[2]	Neg	Neg	Neg	Neg	NA	Pos	Pos	Neg	Neg	NA	Neg	Pos	Neg	Neg	NA
HS Morphology	None	None	None	None	NA	None	mtls[3]	None	None	NA	None	mtls	None	None	NA
Hydric Soil	NO	NO	NO	NO	NA	YES	YES	NO	NO	NA	NO	YES	NO	NO	NA
Depth to Free Water	Ø[4]	Ø	Ø	Ø	NA	Ø, sat[5]	Ø,sat	Ø,sat	Ø	NA	Ø	0"	Ø	Ø	NA
Wetland Hydrology	NO	NO	NO	NO	NA	NO	NO	NO	NO	NA	NO	YES	NO	NO	NA

[1] Plot-wide information not collected for soils and hydrology; columns left in table for congruence with vegetation tables.
[2] Pos=positive and Neg=negative test for ferrous iron.
[3] mtls = mottles in matrix with 2 chroma and high value colors (Environmental Laboratory 1987, p. 31); applied to organic horizon because of very high mineral content.
[4] Ø = free water not observed above 12 inches or to bedrock, whichever was shallower.
[5] sat = soil saturated to surface but free water did not stand in soil pit.

Table 14. Summary of vegetation results, Treeless Bog.

Species[1]	Status	Plot 1				Plot 2				Plot 3			
		1.1W	1.2W	1.3W	Plot	2.1W	2.2W	2.3W	Plot	3.1W	3.2W	3.3W	Plot
ANVI	FACU		H[2]		H		H		H				
RHCA	FACW			H						H	H	H	H
ELCA	OBL	H		H	H	H	H	H	H	H	H	H	H
JUPL	FACW	H	H	H									
Hydrophyte Ratio[3]		2/2	1/2	3/3	1/2	1/1	1/2	1/1	1/2	2/2	2/2	2/2	2/2
Hydrophytic Vegetation		YES	NO	YES	NO	YES	NO	YES	NO	YES	YES	YES	YES

[1] Species codes as in Table 18. Only dominant species are shown.
[2] T=tree stratum, S=shrub stratum, H=herb stratum (see text for definitions).
[3] Number of dominant species rated FAC (not counting FAC-), FACW, or OBL/total number of dominant species.

Table 15. Summary of soil and hydrology results, Treeless Bog.

Characteristic	Plot 1				Plot 2				Plot 3			
	1.1W	1.2W	1.3W	Plot[1]	2.1W	2.2W	2.3W	Plot	3.1W	3.2W	3.3W	Plot
Redox Potential (mV)	49	65	-12	NA	96	112	113	NA	66	47	40	NA
α,α Dipyridyl[2]	Pos	--	--	NA	--	--	--	NA	--	--	--	NA
HS Morphology	Hist[3]	Hist	Hist	NA	Hist	Hist	Hist	NA	Hist	Hist	Hist	NA
Hydric Soil	YES	YES	YES	NA	YES	YES	YES	NA	YES	YES	YES	NA
Depth to free water	0"	0"	0"	NA	0"	0"	0"	NA	0"	0"	0"	NA
Landscape Position	bog	bog	bog	NA	bog	bog	bog	NA	bog	bog	bog	NA
Wetland Hydrology	YES	YES	YES	NA	YES	YES	YES	NA	YES	YES	YES	NA

[1] Plot-wide information not collected for soils and hydrology; columns left in table for congruence with vegetation tables.
[2] Pos=positive and Neg=negative test for ferrous iron (-- indicates no data).
[3] Hist = Histosol morphology, not Folist (USDA Soil Conservation Service 1991, p. 1; Environmental Laboratory 1987, p. 30).

Table 16. Summary of vegetation results, Wailuku River Road.

Species[1]	Status	Plot 1						Plot 2					Plot 3				
		1.1U	1.2U	1.3U	1.4W	1.5W	Plot	2.1U	2.2W	2.3W	2.4U	Plot	3.1W	3.2U	3.3U	3.4W	Plot
COSP	--	S[2]													S		
DILI	FACU	H	H	H			H			H					SH		SH
PECL	FAC		S											S			
SACY	FACU		S											H			
CICH	FAC			S													
MEPOGL	FAC+			S		S			S	S	S	TS	S	S			TS
MIST	FAC				H	H		H	H		H	H					
CAAL	FACW+				H				H				H				
PAUR	FAC					H		H									
MEPO	FAC-						S						S				
CIGL	FAC										S	S	H			H	
STOW	UPL													S			
Hydrophyte Ratio[3]		0/1	1/3	2/3	2/2	3/3	0/2	2/2	3/3	1/2	3/3	4/4	3/4	2/4	0/2	1/1	2/4
Hydrophytic Vegetation		NO	NO	YES	YES	YES	NO	YES	YES	NO	YES	YES	YES	NO	NO	YES	NO

[1] Species codes as in Table 18. Only dominant species are shown.
[2] T = tree stratum, S = shrub stratum, H = herb stratum.
[3] Number of dominant species rated FAC (not counting FAC-), FACW, or OBL/total number of dominant species.

Table 17. Summary of soil and hydrology results, Wailuku River Road.

Characteristic	Plot 1						Plot 2					Plot 3				
	1.1U	1.2U	1.3U	1.4W	1.5W	Plot[1]	2.1U	2.2W	2.3W	2.4U	Plot	3.1W	3.2U	3.3U	3.4W	Plot
Redox Potential (mV)	382	407	317	393	314	NA	120	361	104	339	NA	378	408	332	351	NA
α, *α* Dipyridyl[2]	--	--	Neg	Neg	Neg	NA	Neg	Neg	Pos	Neg	NA	Neg	Neg	Neg	Neg	NA
HS Morphology	-	gley[3]	None	None	None	NA	gley	gley	gley	gley	NA	None	gley	None	gley	NA
Hydric Soil	NO	YES	NO	NO	NO	NA	YES	YES	YES	NO	NA	NO	YES	NO	YES	NA
Depth to Free Water	Ø[4]	Ø	3"	Ø	Ø	NA	Ø	Ø	4"	Ø	NA	11"	Ø	Ø	Ø	NA
Wetland Hydrology	NO	NO	YES	NO	NO	NA	NO	NO	YES	NO	NA	YES	NO	NO	NO	NA

[1]Plot-wide information not collected for soils and hydrology; columns left in table for congruence with vegetation tables.
[2] Pos=positive and Neg=negative test for ferrous iron.
[3] gley = gleyed matrix with chroma of 1 or less and high value (Environmental Laboratory 1987, p. 31); applied to organic horizon because of very high mineral content.
[4] Ø = no free water noted to bedrock.

Table 18. Species codes and indicator status for dominant species identified on sample plots.

Code	Scientific Name	Status
ALMO	Aleurites moluccana	UPL
ANVI	Andropogon virginicus	FACU
ATMI	Athyrium microphyllum	FAC
ATSA	Athyrium sandwichianum	UPL
BRAR	Broussaisia arguta	FAC
CAAL	Carex alligata	FACW+
CASP	Callistopteris sp.	
CHTR	Cheirodendron trigynum	FAC
CICH	Cibotium chamissoi	FAC
CIGL	Cibotium glaucum	FAC
CLPA	Clermontia parviflora	FACU
COAR	Coffea arabica	UPL
COOC	Coprosma ochracea	FAC
COSP	Coprosma sp.	
CYHA	Cyperus haspan	FACW+
CYPA	Cyrtandra paludosa	FAC
DILI	Dicranopteris linearis	FACU
DIPE	Dioscorea pentaphylla	UPL
DRSP	Dryopteris sp.	
ELCA	Eleocharis calva	OBL
EUUN	Eugenia uniflora	UPL
FRAR	Freycinetia arborea	FACU
HETE	Hedyotis terminalis	UPL
HYDE	Hypericum degeneri	FAC
ILAN	Ilex anomala	FACU
ISDI	Isachne distichophylla	FAC
JUPL	Juncus planifolius	FACW
LUPA	Ludwigia palustris	OBL
LYCE	Lycopodium cernuum	FAC
MAMA	Machaerina mariscoides	FACU
MEBA	Melastoma malabathricum	FACU
MEPO	Metrosideros polymorpha	FAC-
MEPOGL	Metrosideros polymorpha var. glaberrima	FAC+
MEPOIN	Metrosideros polymorpha var. incana	UPL
MEPOMA	Metrosideros polymorpha var. macrophylla	FAC

(Continued)

Table 18. Concluded.

Code	Scientific Name	Status
MIST	Microlaena stipoides	FAC
MYLA	Myrsine lanaiensis	UPL
NEMU	Nephrolepus multiflora	FAC
OPHI	Oplismenus hirtellus	FACU
PAUR	Paspalum urvillei	FAC
PECL	Pelea clusiifolia	FAC
PESP	Peperomia sp.	
PSCA	Psidium cattleianum	FACU
PSHA	Psychotria hawaiiensis	UPL
PTLO	Pteris longifolia	FACU
RHCA	Rhynchospora caduca	FACW
RURO	Rubus rosifolius	FAC-
SACY	Sadleria cyatheoides	FACU
SCSP	Scaevola sp.	
SCTE	Scleria testacea	FACU
SEAR	Selaginella arbuscula	NI
STOW	Sticherus owhyhensis	UPL
THCY	Thelypteris cyatheoides	FACU
THDE	Thelypteris dentata	FACU
UNUN	Uncinia uncinata	FAC
VACA	Vaccinium calycinum	FAC
XYCO	Xyris complanata	FACW

Table 19. Summary of wetland determinations at Hawaiian wet forest field sites[1].

Site	Plot 1					Plot 2				Plot 3			
	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	2.4	3.1	3.2	3.3	3.4
1855 Flow	NO (YES)	NO	NO	NO	--	NO	NO	NO	NO	NO	NO	NO	NO
Ainaloa	NO (YES)	NO (YES)	NO	NO	--	NO (YES)	YES	NO	NO	YES	YES	NO	NO
Captain's Drive	NO (YES)	NO (YES)	NO	NO	--	NO	NO	NO	NO	YES	NO (YES)	NO	NO
Pahoa	NO	NO	NO	NO	--	NO	NO	NO	NO	NO	NO	NO	NO
Thurston Lava Tube	NO	NO	NO	NO	--	NO	NO	NO	NO	NO	NO	NO	NO
Tree Planting Road	NO	NO	NO	NO	--	NO (YES)	NO (YES)	NO	NO	NO	NO (YES)	NO	NO
Treeless Bog	YES	NO (YES)	YES	--	--	YES	NO (YES)	YES	--	YES	YES	YES	--
Wailuku River Road	NO	NO	NO	NO	NO	NO	NO	NO (YES)	NO	NO	NO	NO	NO

[1] Conclusion given first is conservatively based strictly on presence of indicators at the time of sampling (Tables 2-17). Conclusions in parentheses are based on weight of evidence and professional judgment, given that (1) our sampling period was at the very end of the dry season, when water tables may have been lacking in depressions that will retain water for long periods later in the rainy season, and (2) vegetation decisions were often based on very small numbers of dominants (see text for details).

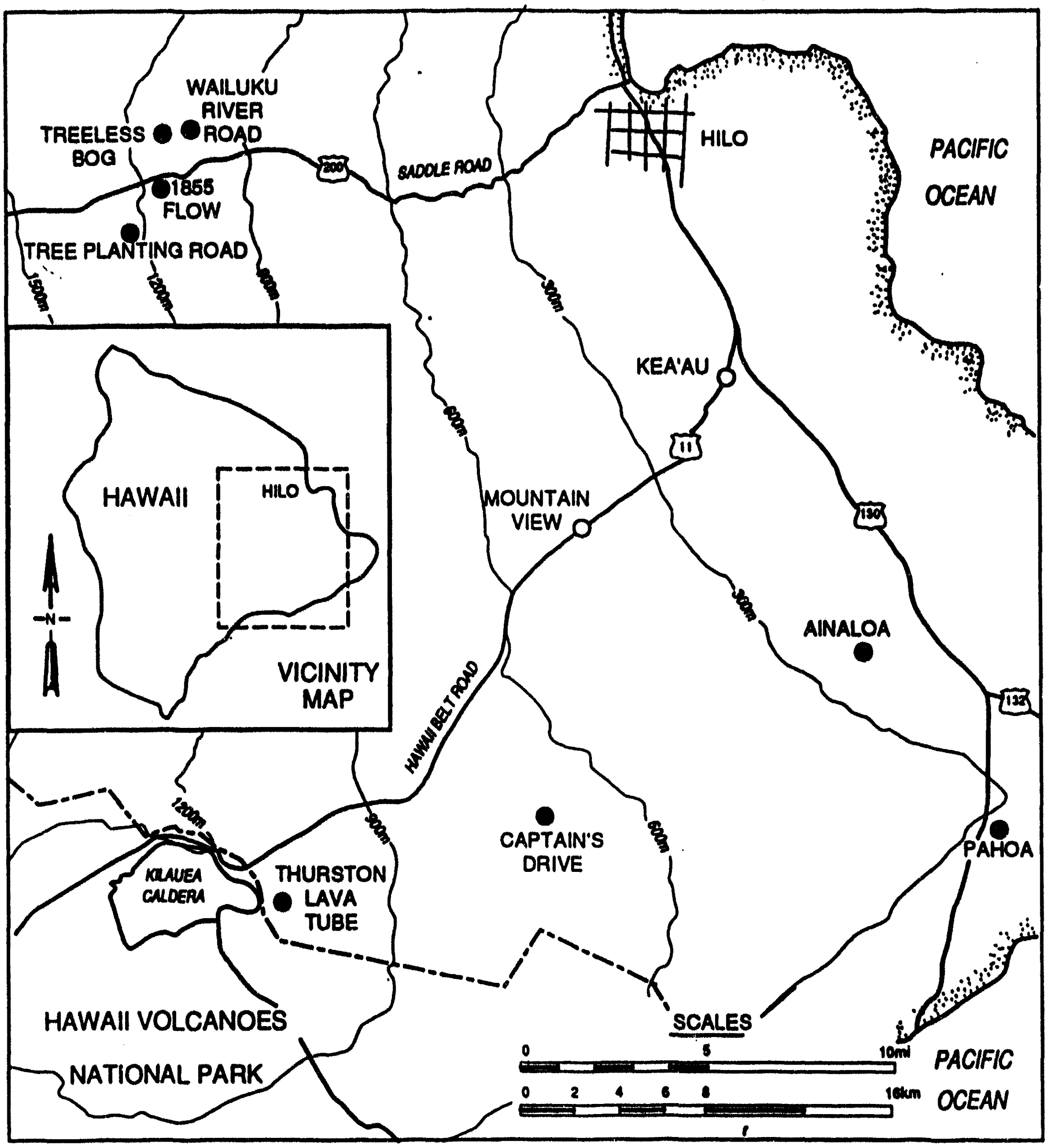

Figure 1. Location of study sites on the Island of Hawaii.

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