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RELATIONSHIPS AMONG WETLAND INDICATORS IN HAWAIIAN RAIN FOREST

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Abstract: We applied established methods for wetland identification in lowland and montane wet forests (rain forests) on the island of Hawaii to determine whether rain forests exhibited wetland indicators specified in delineation manuals and to examine relationships among indicators of hydrophytic vegetation, hydric soils, and wetland hydrology. Morphological characteristics and ferrous iron tests indicated pockets of hydric organic soils within areas mapped as Folists. Hydrophytic vegetation decisions based on prevalence values agreed with hydric soil determinations more often than did decisions based on dominant plant species. None of the rain forest types we studied exhibited wetland indicators throughout, but some sites contained scattered small wetlands occupying microtopographic lows created by cracks, folds, and undulating flow patterns in the lava bedrock. Further work is needed to identify reliable wetland indicators that can be used during drier portions of the year and to distinguish hydric from nonhydric organic rain forest soils.

Key Words: rain forest, Hawaii, wetland indicators, hydric soils, Folists, plant communities, hydrophytic vegetation, prevalence value, delineation manuals

INTRODUCTION

Continuing pressure for highway, powerline, and residential development in the eastern portion of the island of Hawaii has increased interest in the cultural, economic, geological, and ecological characteristics and values of the extensive and relatively undeveloped rain forest in that area. One topic of interest is the extent to which various wet forest community types exhibit wetland indicators specified in recent delineation manuals (Environmental Laboratory 1987, Federal Interagency Committee for Wetland Delineation 1989).

Due to their location in the trade winds and their steep topographic relief (up to 4,200 m) that produce orographic rains, the Hawaiian Islands contain some of the wettest environments on earth (Wagner et al. 1990). Lowland and montane wet forests (rain forests) in Hawaii generally receive 1,500 to >5,000 mm of rainfall annually and occupy an elevational zone between 100 and 2,200 m (Cuddihy 1989, Gagne and Cuddihy 1990). The dominant tree species throughout much of this zone is ʻōhiʻa (*Metrosideros polymorpha*) (see Appendix for complete scientific names and authorities), with an understory that varies from native and introduced grasses and shrubs to native treeferns depending upon substrate, topography, elevation, rainfall, and canopy closure. Rain forest substrates on the island of Hawaii are also varied and include thin organic soils over fragmental (ʻaʻā) or massive (pāhoehoe) lava flows and coarse-textured mineral soils formed in volcanic ash and cinders (Sato et al. 1973).

Hawaiian rain forests present some unique challenges to current national methods of wetland identification, which were developed mainly with temperate zone wetlands of the continental United States in mind. For example, the widespread organic soils (Histosols) in the area are classified as Folists and, despite the extremely high rainfall and high organic content, are considered to be well drained (Sato et al. 1973). Folists are rare in the United States outside of Hawaii and Alaska and have received little study; they are thought to be saturated only briefly after heavy rains (Soil Survey Staff 1992) and therefore are not considered to be hydric (U.S.D.A. Soil Conservation Service 1991). No hydric Histosols are mapped in the area, and it is unclear how one would distinguish hydric and nonhydric Histosols in the field.

Evidence in the botanical literature also does not seem to support the possibility of an important wetland component to Hawaiian rain forests. Most of the plant species listed by Char and Lamoureux (1985) and Jacobi (1989) as typical of wet forest communities are designated as facultative (FAC), facultative upland (FACU), and upland (UPL) by Reed (1988). However, there is considerable microrelief in the lava flows underlying much of the rain forest on the island, and no one, to our knowledge, has investigated whether plant communities in low-lying areas meet criteria for hydrophytic vegetation.

We applied established methods for wetland identification in one of the wettest landscapes in the United States, to determine whether lowland and montane wet forests on the island of Hawaii exhibited wetland indicators specified in recent delineation manuals. Additional objectives were to compare results of hydrophytic vegetation decisions based on dominant species versus prevalence values and examine relationships among indicators of hydrophytic vegetation, hydric soils, and wetland hydrology in Hawaiian rain forests.

METHODS

Study Area

Study sites were located in the Puna and South Hilo Districts in the southeastern portion of the island of Hawaii (Figure 1). We used vegetation maps (Char and Lamoureux 1985, Jacobi 1989) and discussions with local botanists to select seven sites within the extensive, higher elevation, wet forest communities in the area. We chose sites representing a range of wetness conditions within the wet forest type. We focused on the higher elevation forests (mostly ≥300 m) because lower elevations were dominated by recent lava flows, widespread agricultural development, and suburban sprawl.

Study sites ranged in elevation from 230 to 1,220 m and in substrate age from 138 to a maximum of 4,000 yr (Table 1). We concentrated on communities established on pāhoehoe lava flows because this was the most widespread substrate type in the rain forest area and because we judged that there was a higher potential for wetland development on the dense, smooth pāhoehoe than on the more blocky and porous ʻaʻā flows. One site (Thurston Lava Tube) was on thick ash and cinder deposits about 200 yr old overlying an older pāhoehoe surface.

Vegetation on all sites was dominated by varieties of ʻōhiʻa (Table 1). Sites in early successional communities had widely scattered trees and open canopies; other sites had closed ʻōhiʻa canopies. Many ʻōhiʻa stands in Hawaii are experiencing widespread dieback due either to periodic natural cohort senescence (Mueller-Dombois 1985) or to pathogens or other environmental factors (Hodges et al. 1986). We sampled one such dieback stand that had an open canopy and many standing dead trees. Understory vegetation in ʻōhiʻa stands ranged from predominantly grasses, to shrubs, to matted ferns, to native treeferns (Table 1).

Soils on four sites were mapped as Folists (Kahaluu, Keei, and Malama series) (Table 1). Two sites were on recent lava flows with very thin and discontinuous organic soils, and one was on a coarse-loamy Inceptisol (Puhimau series) derived from volcanic ash (Sato et al. 1973).

Annual precipitation in the vicinity of the study sites ranged from approximately 2,500 to 5,000 mm/yr. Rainfall in the area was highly variable over short distances and was most abundant from October through April (Sato et al. 1973). To determine whether rainfall during and immediately preceding our site visits was "normal" for this area, we examined monthly total precipitation recorded at four weather stations in the vicinity of field sites. Precipitation data for August, September, and October 1993 for stations at Hawaii Volcanoes National Park (19° 26′ N, 155° 16′ W), Hilo Airport (19° 43′ N, 155° 04′ W), Pahoa (19° 30′ N, 154° 57′ W), and Waiakea (19° 40′ N, 155° 08′ W) were compared with normal ranges calculated by the U. S. Department of Agriculture (USDA) Natural Resources Conservation Service Climatic Data Access Facility (CDAF) in Portland, Oregon. The CDAF uses 30 yr of precipitation records, fitted to a two-parameter gamma distribution, to calculate the upper and lower limits of the normal range, defined such that 30% of monthly totals (i.e., 3 yr in 10) fall below and 30% above this range (P. A. Pasteris, CDAF, personal communication).

Data Collection and Analysis

During October 1993, we sampled three 10×10-m plots at each site. We established plots in representative locations within the community and, to the extent possible, included typical topographic highs and lows in each plot. There was considerable topographic relief within most plots (generally 0.3–1.0 m, up to a maximum of approximately 3.0 m). Topographic lows 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 microtopographically low portions (microlows) and two in high portions (microhighs) of the larger plot. Vegetation, soil, and hydrology were sampled in each subplot; vegetation data were taken in the larger plots as well.

Soil. We examined a total of 85 soil pits, one in each subplot. Soil profiles were described according to standard methods (Soil Survey Staff 1951, 1975) to the depth of lava bedrock or to 40 cm, whichever was shallower. We recorded horizonation, colors according to Munsell soil color charts (Kollmorgen Corp., New-

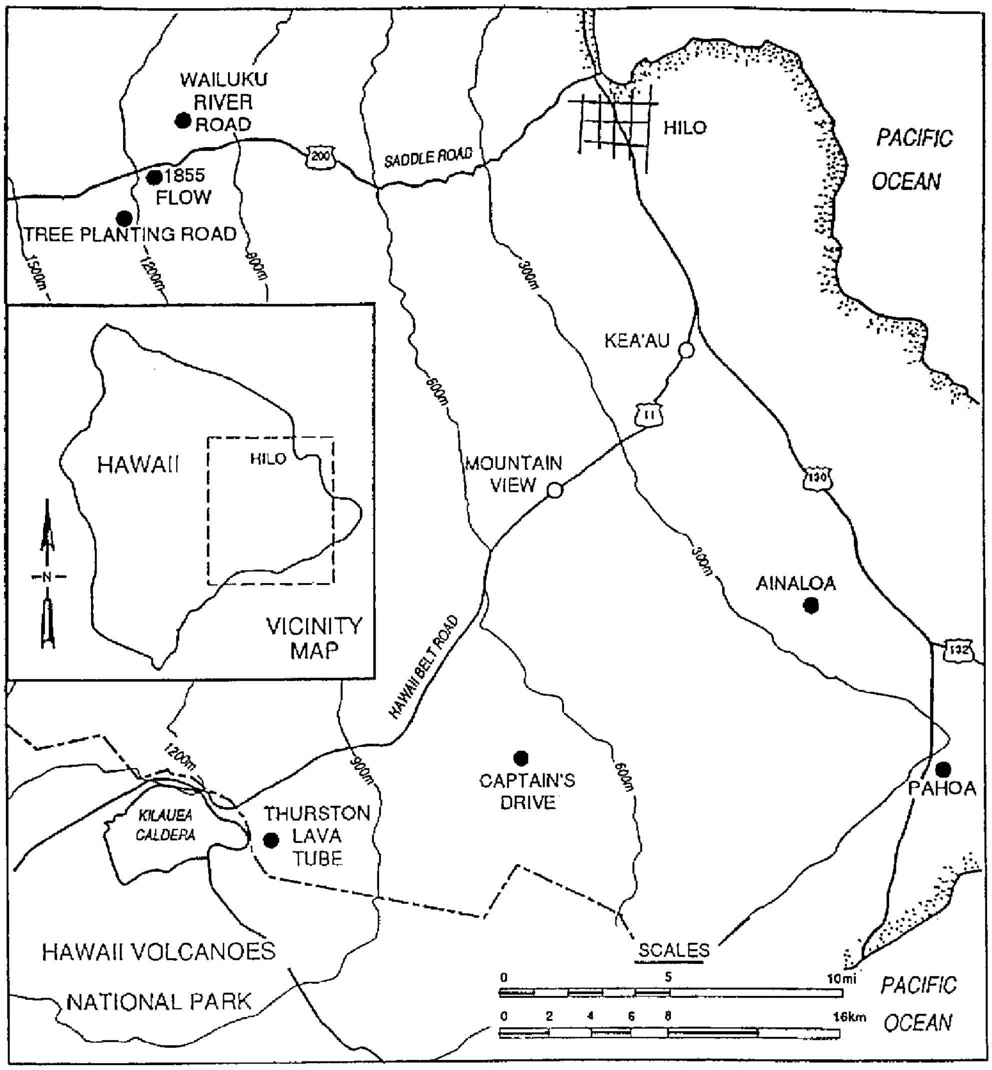

Figure 1. Location of study sites (solid circles) on the island of Hawaii.

burgh, NY), field estimates of unrubbed and rubbed fiber content, redoximorphic features, texture, abundance and size of roots, and presence of free water. To determine if soils were chemically reduced at the time of our site visits, we tested fresh samples in the field for the presence of ferrous iron within 15 cm of the surface using the spray formulation of α,α′-dipyridyl and 1 M ammonium acetate (Childs 1981). We concluded that hydric soil was present in a subplot if one or more of three indicators of hydric soil were present (Environmental Laboratory 1987, Federal Interagency Committee for Wetland Delineation 1989): (1) obvious Saprist morphology and hydrology, (2) low-chroma colors in mineral subsoils, or (3) positive response to the ferrous iron test.

Hydrology. We recorded the presence of standing water on subplots and free water within soil pits, and looked for other indicators of wetland hydrology described in delineation manuals (Environmental Laboratory 1987, Federal Interagency Committee for Wetland Delineation 1989). In addition, ferrous iron tests provided indirect information that some soils had been saturated long enough to be significantly reduced at the time of sampling.

Vegetation. On each plot and subplot, we visually estimated the percent cover of all species present in four potential strata: herbs (all herbaceous plants and woody plants <1 m tall), saplings/shrubs (woody plants >1 m tall and <7.5 cm in diameter at breast height [dbh]), trees (woody plants >7.5 cm dbh), and woody vines (climbing vines >1 m tall) (Environmental Laboratory 1987). Only species rooted within the plot or subplot were tallied. Bryophytes, epiphytes, and species present with $<0.5\%$ coverage were not used to determine whether vegetation was hydrophytic. Dominant species were selected from each stratum

Table 1. Characteristics of field sites, Puna and South Hilo Districts, island of Hawaii.

Site and Location	Elevation (m)	Substrate Type	Substrate Age (yr)[1]	Plant Community Type[2]	Soil Map Unit and Classification[3]
1855 Flow 19°41.48′ N 155°16.60′ W	1,140	Pāhoehoe	138	Wet ʻōhiʻa/matted fern (early succession)	Lava Flows, Pāhoehoe —
Ainaloa 19°30.91′ N 154°59.56′ W	230	Pāhoehoe	350–500	Wet ʻōhiʻa/mixed grasses (early succession after disturbance)	Lava Flows, Pāhoehoe —
Captain's Drive 19°26.71′ N 155°7.39′ W	705	Pāhoehoe	350–500	Wet ʻōhiʻa/tree fern (no dieback)	Keei series Lithic Tropofolist
Pahoa 19°26.52′ N 154°56.84′ W	300	ʻAʻā	750–1000	Wet ʻōhiʻa/introduced shrubs (no dieback)	Malama series Typic Tropofolist
Thurston Lava Tube 19°24.92′ N 155°14.30′ W	1,180	Ash and cinders	203	Wet ʻōhiʻa/tree fern (no dieback)	Puhimau series Hydric Lithic Dystrandept
Tree Planting Road 19°40.32′ N 155°17.03′ W	1,220	Pāhoehoe	1,500–4,000	Wet ʻōhiʻa/tree fern (no dieback)	Kahaluu series Lithic Tropofolist
Wailuku River Road 19°42.59′ N 155°16.18′ W	1,100	Pāhoehoe	1,500–4,000	Wet ʻōhiʻa/matted fern (extensive dieback)	Keei series Lithic Tropofolist

[1] Based on surface lava flow maps by Holcomb (1980) and Lockwood et al. (1988).
[2] Classification follows that of Jacobi (1989).
[3] Sato et al. (1973).

and were the most abundant species, either singly or cumulatively, that comprised >50% of the total coverage in that stratum, plus any individual species that was at least 20% of total coverage (Federal Interagency Committee for Wetland Delineation 1989). Thus, for example, a stratum might be dominated by a single plant species comprising >50% of total cover or by several species each comprising 10–15% of total cover.

We used two methods to evaluate whether vegetation was hydrophytic: (1) by determining whether >50% of dominant species from all strata combined were rated obligate (OBL), facultative wetland (FACW), or FAC (excluding FAC−) on the list of plant species that occur in wetlands in Hawaii (Reed 1988) and (2) by a prevalence value less than 3.0. Prevalence value was calculated as the weighted average wetland indicator status (where OBL = 1, FACW = 2, FAC = 3, FACU = 4, and UPL = 5) of all plant species in the plot or subplot (Wentworth et al. 1988); weighting factors were equal to the percent cover value for the species in the stratum in which it had the most cover.

RESULTS

Soils

Soils in the study area had been mapped at a reconnaissance level as either recent lava flows, Folists, or Dystrandepts (Table 1). Ferrous iron field tests gave positive results in 11 of the 83 soils tested (Table 2). All soils that tested positive for ferrous iron were located in microlows (n = 42 microlows tested), whereas negative results were obtained in the remaining microlows and in all microhighs (n = 41 tested). Two soils at Tree Planting Road contained redox concentrations (accumulations of Fe and Mn oxides), and both tested positive for ferrous iron.

We observed low-chroma (gray) colors below the A or O horizons in soils at Wailuku River Road (7 soils) and Thurston Lava Tube (1 soil) (Table 2). In each case, the color was 10YR 4/1 in <1 to 5-cm thick horizons of sandy loam or loam texture (field estimates). Redox concentrations (7.5YR 4/6 iron masses on ped faces) were present in only one such layer. We found gray horizons in both high and low microsites, often accompanied by a nonhydrophytic plant community (Table 2). Although we used this low-chroma

Table 2. Hydric soil, hydrophytic vegetation, and wetland hydrology indicators on seven rain forest study sites on the island of Hawaii.

	Soils			Vegetation				
						Hydrophytic Vegetation Based On:		
Plot or Subplot[1]	Hydric Soil Morphology	Ferrous Iron Test[2]	Hydric Soil	Dominance Ratio[3]	Prevalence Value	Dominance Ratio	Prevalence Value	Wetland Hydrology
				1855 Flow				
Plot 1	—	—	—	0/3	3.79	No	No	—
S1.1L	None	Pos	Yes	1/2	3.71	No	No	< 15 cm[4]
S1.2L	None	Neg	No	1/3	3.74	No	No	< 15 cm
S1.3H	None	Neg	No	0/2	3.88	No	No	No
S1.4H	None	Neg	No	1/2	3.74	No	No	No
Plot 2	—	—	—	0/3	3.84	No	No	—
S2.1L	None	Neg	No	0/2	3.59	No	No	< 15 cm
S2.2L	None	Neg	No	1/3	3.69	No	No	< 15 cm
S2.3H	None	Neg	No	0/2	3.90	No	No	No
S2.4H	None	Neg	No	0/2	3.96	No	No	No
Plot 3	—	—	—	2/5	3.78	No	No	—
S3.1L	None	Neg	No	1/4	3.62	No	No	< 15 cm
S3.2L	None	Neg	No	1/3	3.41	No	No	< 15 cm
S3.3H	None	Neg	No	1/3	3.31	No	No	No
S3.4H	None	Neg	No	0/2	4.14	No	No	No
				Ainaloa				
Plot 1	—	—	—	1/5	3.54	No	No	—
S1.1L	Saprist	—	Yes	1/2	3.36	No	No	< 15 cm
S1.2L	Saprist	Neg	Yes	1/2	3.05	No	No	< 15 cm
S1.3H	None	Neg	No	0/3	4.07	No	No	No
S1.4H	None	Neg	No	0/3	4.24	No	No	No
Plot 2	—	—	—	0/4	3.60	No	No	—
S2.1L	Saprist	Neg	Yes	1/2	2.63	No	Yes	< 15 cm
S2.2L	Saprist	Neg	Yes	1/1	2.30	Yes	Yes	< 15 cm
S2.3H	None	Neg	No	0/2	3.92	No	No	No
S2.4H	None	Neg	No	0/1	3.85	No	No	No
Plot 3	—	—	—	0/4	3.57	No	No	—
S3.1L	Saprist	Pos	Yes	1/1	2.11	Yes	Yes	< 15 cm
S3.2L	Saprist	Pos	Yes	1/1	2.12	Yes	Yes	< 15 cm
S3.3H	None	Neg	No	0/1	4.03	No	No	No
S3.4H	None	Neg	No	0/3	3.75	No	No	No
				Captain's Drive				
Plot 1	—	—	—	2/3	3.08	Yes	No	—
S1.1L	None	Pos	Yes	3/3	1.80	Yes	Yes	No
S1.2L	None	Pos	Yes	0/1	5.00	No	No	No
S1.3H	None	Neg	No	3/3	3.00	Yes	No	No
S1.4H	None	Neg	No	0/1	4.00	No	No	No
Plot 2	—	—	—	2/3	3.32	Yes	No	—
S2.1L	None	Neg	No	0/4	4.25	No	No	No
S2.2L	None	Neg	No	2/4	3.62	No	No	No
S2.3H	None	Neg	No	0/3	4.40	No	No	No
S2.4H	None	Neg	No	1/4	3.82	No	No	No
Plot 3	—	—	—	3/4	3.22	Yes	No	—
S3.1L	None	Pos	Yes	2/2	1.70	Yes	Yes	< 15 cm
S3.2L	None	Pos	Yes	2/2	1.73	Yes	Yes	No
S3.3H	None	Neg	No	2/5	3.22	No	No	No
S3.4H	None	Neg	No	0/1	4.84	No	No	No

Table 2. Continued.

Plot or Subplot[1]	Soils: Hydric Soil Morphology	Soils: Ferrous Iron Test[2]	Soils: Hydric Soil	Vegetation: Dominance Ratio[3]	Vegetation: Prevalence Value	Vegetation: Hydrophytic Vegetation Based On: Dominance Ratio	Vegetation: Hydrophytic Vegetation Based On: Prevalence Value	Wetland Hydrology
Pahoa								
Plot 1	—	—	—	1/4	4.49	No	No	—
S1.1L	None	Neg	No	0/3	4.81	No	No	No
S1.2L	None	Neg	No	0/3	5.00	No	No	No
S1.3H	None	Neg	No	0/4	4.92	No	No	No
S1.4H	None	Neg	No	0/2	5.00	No	No	No
Plot 2	—	—	—	4/9	3.83	No	No	—
S2.1L	None	Neg	No	1/3	3.86	No	No	No
S2.2L	None	Neg	No	1/1	3.18	Yes	No	No
S2.3H	None	Neg	No	1/2	3.80	No	No	No
S2.4H	None	Neg	No	1/1	3.33	Yes	No	No
Plot 3	—	—	—	1/4	4.14	No	No	—
S3.1L	None	Neg	No	1/3	4.15	No	No	No
S3.2L	None	Neg	No	0/3	4.79	No	No	No
S3.3H	None	Neg	No	0/1	4.09	No	No	No
S3.4H	None	Neg	No	0/4	4.80	No	No	No
Thurston Lava Tube								
Plot 1	—	—	—	5/6	3.18	Yes	No	—
S1.1L	None	Neg	No	1/1	3.00	Yes	No	No
S1.2L	None	Neg	No	1/1	3.00	Yes	No	No
S1.3H	None	Neg	No	2/3	3.14	Yes	No	No
S1.4H	None	Neg	No	3/3	3.12	Yes	No	No
Plot 2	—	—	—	3/4	3.22	Yes	No	—
S2.1L	None	Neg	No	2/2	3.00	Yes	No	No
S2.2L	Low chroma	Neg	Yes	1/2	3.08	No	No	No
S2.3H	None	Neg	No	1/1	3.00	Yes	No	No
S2.4H	None	Neg	No	1/2	4.90	No	No	No
Plot 3	—	—	—	3/5	3.26	Yes	No	—
S3.1L	None	Neg	No	3/3	3.08	Yes	No	No
S3.2L	None	Neg	No	1/1	3.00	Yes	No	No
S3.3H	None	Neg	No	1/1	3.00	Yes	No	No
S3.4H	None	Neg	No	1/2	3.00	No	No	No
Tree Planting Road								
Plot 1	—	—	—	3/4	3.44	Yes	No	—
S1.1L	None	Neg	No	—[5]	—	—	—	No
S1.2L	None	Neg	No	0/1	4.90	No	No	No
S1.3H	None	Neg	No	0/1	5.00	No	No	No
S1.4H	None	Neg	No	2/2	3.00	Yes	No	No
Plot 2	—	—	—	5/6	3.16	Yes	No	—
S2.1L	None	Pos	Yes	1/1	1.19	Yes	Yes	No
S2.2L	Redox Conc.[6]	Pos	Yes	1/1	2.86	Yes	Yes	No
S2.3H	None	Neg	No	1/2	2.10	No	Yes	No
S2.4H	None	Neg	No	1/1	3.05	Yes	No	No
Plot 3	—	—	—	2/5	3.18	No	No	—
S3.1L	None	Neg	No	1/1	2.00	Yes	Yes	No
S3.2L	Redox Conc.	Pos	Yes	—[5]	—	—	—	< 15 cm
S3.3H	None	Neg	No	1/3	3.80	No	No	No
S3.4H	None	Neg	No	2/3	3.09	Yes	No	No

Table 2. Continued.

Plot or Subplot[1]	Soils: Hydric Soil Morphology	Soils: Ferrous Iron Test[2]	Soils: Hydric Soil	Vegetation: Dominance Ratio[3]	Vegetation: Prevalence Value	Hydrophytic Vegetation Based On: Dominance Ratio	Hydrophytic Vegetation Based On: Prevalence Value	Wetland Hydrology
				Wailuku River Road				
Plot 1	—	—	—	0/2	3.78	No	No	—
S1.1H	—	—	No	0/1	3.91	No	No	No
S1.2H	Low chroma	—	Yes	1/3	3.87	No	No	No
S1.3H	None	Neg	No	2/3	3.88	Yes	No	< 15 cm
S1.4L	None	Neg	No	2/2	2.20	Yes	Yes	No
S1.5L	None	Neg	No	3/3	2.90	Yes	Yes	No
Plot 2	—	—	—	4/4	3.13	Yes	No	—
S2.1H	Low chroma	Neg	Yes	2/2	3.05	Yes	No	No
S2.2L	Low chroma	Neg	Yes	3/3	2.76	Yes	Yes	No
S2.3L	Low chroma	Pos	Yes	1/2	3.49	No	No	< 15 cm
S2.4H	Low chroma	Neg	Yes	3/3	3.00	Yes	No	No
Plot 3	—	—	—	2/4	3.83	No	No	—
S3.1L	None	Neg	No	3/4	2.90	Yes	Yes	< 30 cm
S3.2H	Low chroma	Neg	Yes	2/4	3.65	No	No	No
S3.3H	None	Neg	No	0/2	4.00	No	No	No
S3.4L	Low chroma	Neg	Yes	1/1	3.00	Yes	No	No

[1] For each 1 × 1-m subplot (S), L denotes placement within a microtopographic low and H denotes placement within a microtopographic high.
[2] Pos = positive and Neg = negative response to α,α′-dipyridyl (Childs 1981).
[3] Number of dominant species rated OBL, FACW, or FAC (not counting FAC−)/total number of dominant species.
[4] Indicates depth to standing water in soil pit.
[5] No vegetation present in subplot.
[6] Redox concentrations present.

layer as an indicator of hydric soil, we suspect that it may sometimes develop under nonhydric conditions.

Eighteen of 42 rain forest soils (43%) in "low" landscape positions showed at least one indicator of hydric soil (Table 2). Saprists were observed in six microlows, low-chroma mineral horizons in four, redox concentrations in two, and positive ferrous iron tests in 11. In addition, low-chroma horizons were observed on four subplots in "high" topographic positions at Wailuku River Road. Only at Pahoa did all subplots lack indicators of hydric soils, and no rain forest site had hydric soil indicators on all subplots.

Hydrology

During August and September 1993, the two months preceding on-site sampling, precipitation was within normal limits at two weather stations (Hawaii Volcanoes National Park, Waiakea), above (August) and below (September) normal at Hilo Airport, and normal (August) and below normal (September) at Pahoa. In October, rainfall was normal at Waiakea and above normal at the other three stations.

During site visits, we observed standing water in depressions on or in the vicinity of our rain forest plots at the 1855 Flow, Ainaloa, and Tree Planting Road. When digging soil pits, we avoided standing water but sometimes took samples on the edge of ponded depressions. We observed free water within 15 cm of the surface in soil pits in all of the "low" subplots at the 1855 Flow and Ainaloa (Table 2). In addition, we found free water within 15 or 30 cm in subplots at Captain's Drive, Tree Planting Road, and Wailuku River Road. No free water was observed in any soil pit at Pahoa or Thurston Lava Tube.

Despite moderately sloping terrain, there were no surface streams on our study sites; all flow was subsurface through cracks and tubes within the lava. Therefore, surface indicators of wetland hydrology, such as water marks, drift lines, and sediment deposits, were absent from our plots. Water-stained leaves were present in a few obviously ponded depressions; no oxidized rhizospheres were found in these dark, organic-rich soils.

Vegetation

All seven rain forest sites were dominated by one or more varieties of ʻōhiʻa (*Metrosideros polymorpha,*

Table 3. Comparison of hydrophytic vegetation decisions on the subplots based on dominant species versus prevalence values.

	Hydrophytic Based on Prevalence Value:		
	Yes	No	Total
Hydrophytic Based on Dominance Ratio:			
Yes	13	19	32
No	2	49	51
Total	15	68	83

M. p. var. *grabberima, M. p.* var. *incana,* or *M. p.* var. *macrophylla*). Tree ferns (particularly *Cibotium glaucum*) were co-dominants on several sites; uluhe fern (*Dicranopteris linearis*) was abundant in early successional and dieback 'ōhi'a forests. Except for these common species, sites tended to be dominated by different combinations of plant species (Appendix).

At the 10×10-m plot level, vegetation generally failed to meet hydrophytic vegetation criteria at four sites (1855 Flow, Ainaloa, Pahoa, Wailuku River Road) no matter which vegetation test (dominance ratio or prevalence value) was used (Table 2). Vegetation at three sites (Captain's Drive, Thurston Lava Tube, Tree Planting Road) generally was hydrophytic based on dominance ratios but not hydrophytic based on prevalence values.

Plant species associations within plots were quite heterogeneous, reflecting the microtopographic variability at all rain forest sites. Even in plots whose overall vegetation was not hydrophytic, 1×1-m subplots in microtopographic lows often met one or both hydrophytic vegetation tests (Table 2).

At both the plot and subplot levels, hydrophytic vegetation decisions based on dominant species and prevalence values often were contradictory (Table 2). In general, more samples were found to be hydrophytic based on dominant species than on prevalence values. At the subplot level, hydrophytic vegetation decisions based on the two methods disagreed in 21 of 83 cases (25%) (Table 3). Outcomes of the two methods were not independent ($X^2 = 17.79$, 1 df, $P < 0.001$). Significantly more of the disagreements were due to a positive conclusion based on dominant species and a negative conclusion based on prevalence values, rather than the reverse.

Relationships Among Wetland Indicators

Hydric soil decisions agreed with hydrophytic vegetation determinations on 65% (54 of 83) of rain forest subplots when the vegetation determination was based on dominant species and on 81% (67 of 83) of subplots when based on prevalence values (Table 4). Thus, our results suggest that the prevalence value may be more reliable than the dominance ratio as an indicator of wetland conditions in this environment.

Table 4. Relationship between presence of hydric soil indicators on subplots and presence of hydrophytic vegetation based on dominant species and prevalence values.

	Hydric Soil		
	Yes	No	Total
Hydrophytic Vegetation Based on Dominance Ratio:			
Yes	12	20	32
No	9	42	51
Hydrophytic Vegetation Based on Prevalence Value:			
Yes	10	5	15
No	11	57	68
Total	21	62	83

Only 4 subplots (three at Ainaloa, one at Captain's Drive) had indicators of all three wetland characteristics—hydric soils, hydrophytic vegetation by dominance, and wetland hydrology—and thus would have been identified as wetlands under a strict interpretation of the 1987 Corps manual. One additional subplot at Ainaloa would have qualified if prevalence values were used for the vegetation decision.

Our study sites were not hydrologically altered; therefore, hydric soil and hydrophytic vegetation indicators should be reliable evidence of current wetland conditions. By this approach, either 10 or 12 subplots, depending upon vegetation method, had indicators of both hydric soil and hydrophytic vegetation (Table 4) and would have been identified as wetlands.

Wetland subplots were nearly all in topographically low positions capable of accumulating water. We believe that, during the rainy season, most low-lying microsites on pāhoehoe substrates in the rain forest have the potential to become ponded and/or saturated for long periods, and thus satisfy wetland hydrology criteria. Many of these depressions, however, may still fail to meet wetland requirements due to the lack of a hydrophytic plant association or hydric soil characteristics.

No rain forest study site exhibited wetland indicators in its entirety (Table 2). Wetlands were absent from the 1855 Flow, Pahoa, and Thurston Lava Tube sites. Wetlands were present in some microtopographically low positions at all other sites, although not all such low areas exhibited wetland indicators.

DISCUSSION

Soils

Several of our hydric soil determinations were based on positive ferrous iron tests in the absence of other hydric soil indicators. This can be a problem for wetland regulators because ferrous iron tests are only useful during periods of the year when soils are wet long enough for chemical reduction to occur. During dry periods, when oxidizing conditions prevail, many hydric rain forest soils may be indistinguishable from nonhydric soils. We obtained positive ferrous iron tests only in low microsites that were capable of accumulating water, but many such sites tested negative. Our study was done in October at the onset of the rainy season; therefore, our determinations probably were conservative in that additional microlows may have become reduced later in the season.

Our designations of Saprists at Ainaloa were based partly on a hydrologic regime that appeared to be too wet to meet the definition of Folists (i.e., "Histosols which are never saturated with water except for a few days following heavy rains" [Soil Survey Staff 1992]). These soils were all located in closed depressions that contained standing water at the beginning of the wet season and apparently did so for long periods each year. We also identified a number of Histosols in low microsites at Captain's Drive, Tree Planting Road, and Wailuku River Road that tested positive for ferrous iron, indicating long-duration saturation; these soils too may not fit the concept of a Folist.

The fact that positive α,α'-dipyridyl readings occurred in only low landscape positions indicates that, at the onset of the wet season, reducing conditions occurred only in small, isolated depressions in the rain forest. Saprists, too, were found only in closed depressions. Therefore, our work indicates that hydric soils are common but do not dominate in Hawaiian wet forests.

Vegetation

Vegetation sampling based on large plots usually led to the conclusion that Hawaiian rain forest communities did not meet criteria for hydrophytic vegetation. Sampling within large plots tended to mask the presence of hydrophytic plant associations located in small depressional wet areas; 1×1-m subplots were needed to characterize these wet spots.

Hydrophytic vegetation decisions based on dominant species often disagreed with those based on prevalence values. Even in these multi-layered forest communities, there were generally only three to five dominant species on the large plots and two to four dominants on the subplots. Therefore, dominance ratios were based on small numbers of species, and vegetation decisions could easily be swayed by the chance occurrence of a single dominant species. Furthermore, many communities were dominated by FAC species, which can cause the two methods to produce different conclusions. On the other hand, dominance ratios are easy to determine in the field with rapid visual sampling, without the need to identify all plants on a site. This is an important advantage to regulatory personnel who have little time for extensive on-site sampling.

The procedure for point-intercept sampling of vegetation and determination of the prevalence index described by the Federal Interagency Committee for Wetland Delineation (1989) was inappropriate for use in this study. That procedure is designed to be used in areas of confirmed hydric soils and wetland hydrology that are large enough to accommodate at least three 61.0-m transects having sampling points at 0.6-m intervals. Our procedure used percent cover data gathered on sample plots to estimate a prevalence value that could be compared with vegetation decisions based on dominant species and with soil and hydrology data gathered at a particular soil pit. Because they are based on the presence and relative abundance of all species in a plot, prevalence values provide more information about wetness conditions than does a simple tally of dominants.

Fewer plots and subplots in the rain forest met hydrophytic vegetation criteria based on prevalence values than on dominance ratios, and prevalence values often gave more consistent results within a site. For example, none of the subplots at Pahoa or at Thurston Lava Tube were hydrophytic based on prevalence values, whereas some subplots were hydrophytic based on dominants.

Vegetation decisions based on prevalence values also agreed with hydric soil determinations more often than did dominance ratios. Most of the disagreements occurred on subplots with nonhydric soils that had hydrophytic communities based on dominant species but not on prevalence values. Previous work on relationships between soils and vegetation in wetland transition zones (e.g., Adams et al. 1987, Segal et al. 1987, Josselyn et al. 1990, Segelquist et al. 1990, Carter et al. 1994) did not compare these two methods for making hydrophytic vegetation decisions. The better agreement with hydric soil decisions suggests that prevalence values may be more reliable indicators of wetland conditions than dominance ratios, but additional studies are needed in a variety of wetland types.

Wetland Determinations

None of the rain forest community types we studied exhibited wetland indicators throughout, but some sites contained scattered wetlands occupying microtopographic lows created by cracks, folds, and undulating flow patterns in the lava bedrock. The National Research Council (1995) recently stressed the difficulties of using wetland hydrology field indicators to infer long-term hydrologic status, concluding that hydrophytic vegetation and hydric soils were reliable indicators of wetland conditions in areas that have not been hydrologically altered. Based on this approach, isolated wetlands were present at Ainaloa, Captain's Drive, Tree Planting Road, and Wailuku River Road. All of these sites were underlain by pāhoehoe flows that were at least 350 years old. Study sites on 'a'ā lava (Pahoa), ash and cinder deposits (Thurston Lava Tube), or very recent pāhoehoe (1855 Flow) contained few, if any, wetlands.

Wetland determinations in the rain forest are made more difficult by (1) lack of consistent morphological evidence of hydric soils independent of ferrous iron tests, and (2) lack of wetland hydrology indicators except for direct observation of inundation or shallow water tables. During the dry season, hydric soil and wetland hydrology decisions may be difficult or impossible. Research is needed to identify reliable wetland indicators that can be used during drier periods and to distinguish hydric and nonhydric organic rain forest soils with methods other than short-term chemical tests. Studies are also needed to determine to what extent these scattered small wetlands, which occupied a minor part (<10% visual estimate) of the area of any rain forest type we studied, perform significant or valuable wetland functions.

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Appendix. Plant species that were dominant on one or more plots or subplots at rain forest field sites, island of Hawaii. Calculation of prevalence values included nondominant species not listed here.

Species	Status	F[1]	A	CD	P	TL	TP	WR
Aleurites moluccana (L.) Willd.[2]	UPL[3]	—	—	—	D	—	—	—
Andropogon virginicus L.	FACU	—	D	—	—	—	—	—
Athyrium microphyllum (Sm.) Alston	FAC	—	—	—	—	—	D	—
Broussaisia arguta Gaud.	FAC	—	—	D	—	—	D	—
Callistopteris baldwinii (D.C. Eaton) Copeland	UPL	—	—	—	D	—	—	—
Carex alligata Boott.	FACW+	—	—	—	—	—	D	D
Cheirodendron trigynum Gaud.	FAC	—	—	D	—	—	D	—
Christella cyatheoides (Kaulf.) Holttum	FACU	—	—	—	—	—	D	—
C. dentata (Forssk.) Brownsey & Jermy	FACU	—	—	—	D	—	—	—
Cibotium chamissoi Kaulf.	FAC	—	—	D	D	—	—	D
C. glaucum (J.E. Smith) Hook. & Arn.	FAC	—	—	D	D	D	D	D
Coffea arabica L.	UPL	—	—	—	D	—	—	—
Coprosma ochracea W. Oliver	FAC	—	—	—	—	D	D	D
Cyperus haspan L.	FACW+	—	—	D	—	—	—	—
Cytandra paludosa Gaud.	FAC	—	—	D	—	—	—	—
Dicranopteris linearis (Burm.) Underw.	FACU	D	—	D	—	—	—	D
Diplazium sandwichianum (Presl.) Diels	UPL	—	—	—	D	—	D	—
Dioscorea pentaphylla L.	UPL	—	—	—	D	—	—	—
Dryopteris glabra (Brack.) Kuntze	FAC	—	—	—	—	—	D	—
Ehrharta stipoides Labill.	FAC	—	—	—	—	D	D	D
Eugenia uniflora L.	UPL	—	—	—	D	—	—	—
Freycinetia arborea Gaud.	FACU	—	—	D	D	—	—	—
Hedyotis terminalis (Hook. & Arnott) W.L. Wagner & Herbst	UPL	—	—	D	—	—	—	—
Hypericum parvulum Greene	FAC	—	—	—	—	—	D	—
Ilex anomala Hook. & Arnott	FACU	—	—	—	—	D	—	—
Isachne distichophylla Munro ex. Hillebr.	FAC	—	—	—	—	D	—	—
Ludwigia palustris (L.) Elliott	OBL	—	—	D	—	—	D	—
Lycopodium cernuum L.	FAC	D	—	—	—	—	—	—
Machaerina mariscoides (Gaud.) J. Kern	FACU	D	—	—	—	—	—	—
Melastoma candidum D. Don	FACU	—	D	—	—	—	—	—
Melicope clusiifolia (A. Gray) T. Hartley & B. Stone	FAC	—	—	D	—	—	—	D
Metrosideros polymorpha Gaud.	FAC−	—	—	—	—	—	—	D
M. p. Gaud. var. *glaberrima* (H. Lev.) St. John	FAC+	D	—	D	—	D	D	D
M. p. Gaud. var. *incana* (H. Lev.) St. John	UPL	D	D	—	—	—	—	—
M. p. Gaud. var. *macrophylla* (Rock) St. John	FAC	—	—	—	D	—	—	—
Myrsine lanaiensis Hillebr.	UPL	—	—	—	—	D	—	—
Nephrolepis multiflora (Roxb.) Jarrett ex Morton	FAC	—	—	—	D	—	—	—
Oplismenus hirtellus (L.) P. Beauv.	FACU	—	—	—	D	—	—	—
Paspalum urvillei Steud.	FAC	—	—	—	—	—	—	D
Peperomia membranacea Hook. & Arnott	FAC	—	—	D	—	—	—	—

Appendix. Continued.

Species	Status	F[1]	A	CD	P	TL	TP	WR
Psidium cattleianum Sabine	FACU	—	—	D	D	—	—	—
Psychotria hawaiiensis (A. Gray) Fosb.	UPL	—	—	D	D	—	—	—
Pteris vittata L.	FACU	—	D	—	—	—	—	—
Rubus rosifolius Sm.	FAC−	—	—	—	—	—	D	—
Sadleria cyatheoides Kaulf.	FACU	—	—	—	—	D	D	D
Scaevola L. sp.	—	—	D	—	—	—	—	—
Scleria testacea Nees	FACU	—	D	—	—	—	—	—
Selaginella arbuscula (Kaulf.) Spring	NI	—	—	D	—	—	—	—
Sticherus owhyhensis (Hook.) Ching	UPL	—	—	—	—	—	—	D
Uncinia uncinata (L. fil.) Kukenth.	FAC	—	—	—	—	D	—	—
Vaccinium calycinum Sm.	FAC	—	—	—	—	D	—	—
Xyris complanata R. Br.	FACW	—	D	—	—	—	—	—

[1] F = 1855 Flow, A = Ainaloa, CD = Captain's Drive, P = Pahoa, TL = Thurston Lava Tube, TP = Tree Planting Road, WR = Wailuku River Road.
[2] Most plant names according to Wagner et al. (1990); some pteridophytes according to Neal (1965).
[3] Reed (1988).