HI- Moorhen

THESIS

STATUS OF THE HAWAIIAN GALLINULE ON LOTUS FARMS AND A MARSH ON OAHU, HAWAII

Submitted by

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ABSTRACT

STATUS OF THE HAWAIIAN GALLINULE ON LOTUS FARMS
AND A MARSH ON OAHU, HAWAII

Little is known about the biology/ecology of the Hawaiian Gallinule, Gallinula chloropus sandvicensis, an endemic subspecies occurring in the Hawaiian Islands. The Hawaiiian Gallinule previously occurred on most of the major islands of the Hawaiian archipelago, but currently is found only on the islands of Oahu and Kauai (possibly Molokai). Two study sites were monitored on the island of Oahu, from February 1979 to January 1980: 1) a marsh used as pasturage and 2) lotus fields (a wetland agricultural crop).

Hawaiian Gallinules nested year-round. In the lotus fields, nesting appeared to coincide with the growth cycle of lotus, where peak nesting was observed 3 to 4 months after the fields were replanted. At the marsh site, gallinules nested around the edges of ponds located centrally in the meadow when under marsh-like conditions, and nested along the canal edge, an area with greater exposure to human disturbance, when the ponds and meadow were dry. Greater nesting success was observed at one of the lotus farms (Kunehiro) as compared to the marsh and another lotus farm (Tantog), all comparable in size. Predation by mongoose appeared to be the major cause of nest failure at the marsh study site.

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INTRODUCTION

The Hawaiian Gallinule, 'Alae 'ula, Gallinula chloropus sandvicensis first described by Streets (1877), is a subspecies of the North American Common Gallinule, Gallinula chloropus. The Common Gallinule is a cosmopolitan species ranging throughout the world, excluding the Australian continent (Am. Ornith. Union 1982, Ripley 1977, Strohmeyer 1977). Strohmeyer (1977) reported the species is not common anywhere within its range in North America, but in areas where research has been conducted, the gallinule appears to be fairly common, in some localities.

In the Hawaiian archipelago, the Hawaiian subspecies is now found on the islands of Kauai and Oahu (Berger 1972) and possibly Molokai, where it was last observed in 1973 (Shallenberger 1977). Previously, gallinules occurred on all the major islands with the exception of Lanai and Niihau (Schwartz and Schwartz 1949, Munro 1960). Estimated populations for the islands of Kauai and Oahu are 500 and 250 respectively (Hawaiian Waterbirds Recovery Team 1977). These, however, are gross estimates due to lack of reliable census techniques and manpower. Currently, the gallinule is listed as endangered on both the State and Federal Endangered Species Lists.

The gallinule has been noted in Hawaiian mythology for its role in bringing fire to the natives (Henshaw 1902, Forbes 1879). They were considered common in 1891 (Munro 1960), inhabiting taro patches, lagoons, freshwater courses, ponds, and marshes. Early in the 1940's the decline in Hawaiian Gallinule numbers along with those of other waterbirds was recognized by Schwartz and Schwartz (1949), who suggested that the gallinule remain on the protected list. Henshaw (1902) reported the disappearance of Hawaiian Gallinules in 1902 in the vicinity of Hilo where it once abounded. Henshaw (1903) also mentioned the extermination of populations in some localities and the diminishing numbers in all districts due to indiscriminate hunting despite the unpalatability of gallinules to most people.

The decline in Hawaiian Gallinule populations is primarily attributed to two factors: 1) direct or indirect destruction and alteration of suitable wetland habitats and 2) predation, perhaps the most important cause of mortality, especially by mongooses (Herpestes a. auropunctatus, feral cats, and feral dogs (Shallenberger 1977). Over the years, wetlands under cultivation have decreased considerably. During 1899 to 1919, the area under rice and taro cultivation decreased by nearly 50% (Freeman 1927). Phillipp and Elliott (1949) reported 150 acres in rice, down from 8000 acres for the territory in 1910. In 1930, 772 and 18 acres respectively, were under taro and lotus cultivation (Coulter 1933). During the intervening years, between 1930 and 1948, there was an increase in acres planted in taro and lotus. However, from 1948 to 1977, there was a decline in the number of acres of taro (930 to 470) under cultivation. In 1960, 66 acres were under lotus cultivation and in 1977, 30 acres (University of Hawaii Agricultural Extension Service 1950, 1951, 1959, University of Hawaii

Cooperative Extension Service 1961, USDA Statistical Reporting Service 1969, 1974, Hawaii Agricultural Reporting Service 1978).

The gallinule's preference for densely vegetated habitat and its cryptic habits make behavioral and ecological studies more difficult than for most other waterbirds. This may explain the lack of comprehensive data on the biology of the Hawaiian subspecies. There are few studies reported by European and American researchers. Breeding biology studies of Common Gallinules in Britain were reported by Relton (1972), Wood (1974), and Huxley and Wood (1976). Fredrickson (1971), Krauth (1972), and Bell and Cordes (1977), conducted breeding biology studies on the North American species. Bent (1926) described the life history of the Florida Gallinule (Gallinula chloropus cachinnans). Anderson (1975) conducted a study on age and sex determinations in gallinules. Karhu (1973) studied developmental stages and Brackney (1979) reported on the population ecology of gallinules on Lake Erie marshes. Because gallinules are closely allied with the American Coot Fulica americana (nesting ecology and behavior being similar for the two species), they are often reported together. Gullion (1952, 1953) studied the calls and displays and territorial behavior of American Coots.

Semi-annual counts and independent observations show that Hawaiian Gallinules reside and reproduce in a variety of wetland habitats throughout the year, but systematic studies have not been undertaken to substantiate the breeding cycle of the gallinule. Management based on such limited information is unlikely to succeed, such as the attempt to reestablish populations on the islands of Hawaii and Maui (Bureau of Sport Fisheries and Wildlife 1966).

Additional data on the Hawaiian Gallinule are needed if proposed objectives of the Hawaiian Waterbirds Recovery Plan (Hawaiian Waterbirds Recovery Team 1977) are to succeed. The primary objective of the recovery plan is to increase the Hawaiian Gallinule population to a minimum of 2000 and ensure its maintenance at that level. The plan proposes to meet this objective by making viable habitats available to the species. Ultimately, the goals are to reach populations with self-sustaining levels and thereby remove it from the endangered and threatened species lists.

The objectives of this study were to develop baseline information on habitat, behavior, and breeding ecology, and to develop better techniques for censusing Hawaiian Gallinules.

Appendix I. Census of Hawaiian Gallinules in individual lotus fields, Haleiwa, Oahu, from December 1978, January to May, November and December 1979, and January 1980.

	Field														
	Kunehiro-a			Kunehiro-b			Tantog			Kamalani			Ung		
Date	Chicks	Juven	Adults	Chicks	Juven	Adults	Chicks	Juven	Adults	Chicks	Juven	Adults	Chicks	Juven	Adults
*Dec. 19			88			8			6						11
*Jan. 15			82	2		7			5						8
*Feb. 6			63		2	4			9			3			7
Feb. 14			64		1	5			6			2			7
Mar. 1			38			4			5			1			2
Mar. 16			24			4			2			2			8
Mar. 24			26			5			8			3			5
Apr. 7			23	3		4			6			3			4
Apr. 15	4		26	3		5			8			2	1		2
Apr. 29	6		23	8		4			9			2	1		6
May 13			24						2	2		2			9
May 14	17	2	24	8	3	5		2	11	2		2			4
Nov. 21			49		6	6			1			2			2
Dec. 1			79		5	7			7			3			2
Dec. 8			77		5	7			10						5
Dec. 15			80		6	6			10			3			4
Dec. 19			73		6	6			9			5			3
Jan. 17			70	1		8			8			4			4

*Data furnished courtesy of Timothy Burr, Division of Fish & Game, State of Hawaii.

Appendix H. Time Hawaiian Gallinules spent gathering nest materials (by sex), at Hamakua marsh, Kailua, Oahu.

Date	Time (minutes)		Sub-total	Pair
	♀	♂		
June 4	22	13	35	1
June 5	2	50	52	1
June 23	0	9	9	1
June 26	0	15	15	1
June 27	7	11	18	1
July 2	0	38	38	2
July 3	17	60	77	2
July 5	9	18	27	2
July 6	0	3	3	2
Total	57	217	274	
Percent	21	79	100	

Appendix G. Time Hawaiian Gallinules spent incubating (by sex), at Hamakua marsh, Kailua, Oahu.

Date	Time (minutes) ♀	Time (minutes) ♂	Pair
June 4	52	32	1
	79	46	1
June 5	55	59	1
	47	21	1
	62	-	1
June 7	54	27	1
	-	46	1
July 2	48	13	2
	-	20	2
July 3	65	40	2
July 5	88	40	2
July 6	77	14	2
Total	627	358	
x	62.7	32.5	

Appendix F. Time budget by sex (pairs 1 and 2 combined) of Hawaiian Gallinules at Hamakua marsh, Kailua, Oahu.

	Minutes					
	Female			Male		
Behavior	Pair 2	Pair 1	Percent	Pair 2	Pair 1	Percent
Feeding	103	708	29.7	107	888	36.7
Incubation	349	1076	45.1	219	570	23.5
Nest gath.	24	81	3.4	72	289	11.9
Sexual act.	5	29	1.2	9	37	1.5
Locomotion	20	69	2.9	10	42	1.7
Bath & preen	6	185	7.8	64	363	15.0
Alarm	25	25	1.0	0	0	0
Hiding	0	16	0.7	2	48	2.0
Resting	18	41	1.7	16	62	2.6
Out-of-sight	10	122	5.1	99	110	4.5
Territorial def.	0	31	1.3	0	12	0.5
Total	560	2383	99.9	598	2421	99.9

Appendix E. Hatching success of Hawaiian Gallinules in individual lotus fields, Haleiwa, Oahu.

Farmer	Date found	Nest number*	Successful	Unsuccessful	Number of chicks
Kunehiro-a	3/8	10a		X	
	3/16	15a	X		4
	4/7	14a	X		4
	4/7	2a	X		8
	4/15	16a	X		4
	4/15	12a	X		1+?
	4/15	12b		X	
	4/29	19a	X		5
	5/14	7a	Unk		
	5/14	10b	Unk		
	5/23	15b	Unk		
	10/18	10c		X	
Kunehiro-b	3/16	9a		X	
	3/24	2a		X	
	3/24	19a	X		3
	4/29	7a	X		2
	4/29	7b	X		6
	12/8	7c		X	
	12/15	9b		X	
	1/17	7d	X		1+?
	1/17	7e	Unk		
Tantog	3/24	51a		X	
	4/29	50a	X		1+?
	12/1	103a		X	
	1/17	102a	Unk		
Kamalani	2/6	118a		X	
	3/1	121a	X		2
Ung	2/6	26a		X	
	4/7	27a		X	
	4/15	29a	X		1+?
	4/15	26b		X	
	5/13	27b		X	
	5/13	30a		X	
	1/17	26c	Unk		

*Number preceding letter indicates plot number and letter denotes succession of nest found per plot.

Appendix D. Distances between Hawaiian Gallinule nests in Haleiwa lotus fields, Oahu.

Farmer	Nest number*	Date found	Distance (m)
Kunehiro-a	10a	3/8	
	15a	3/16	172
	2a	4/7	
	12a	4/15	111
	12a	4/15	
	12b	4/15	38
	14a	4/7	
	16a	4/15	72
	16a	4/15	
	19a	4/29	60
	7a	5/14	
	10b	5/14	35
Kunehiro-b	9a	3/16	
	19a	3/24	45
	9a	3/16	
	2a	3/24	63
	2a	3/24	
	19a	3/24	96
	7c	12/8	
	9b	12/15	40
	7d	1/17	
	7e	1/17	20
Ung	29a	4/15	
	26a	4/15	36
	27b	5/13	
	30a	5/13	38

*Number preceding letter indicates plot number and letter denotes succesion of nest found per plot.

Appendix C. Hawaiian Gallinule nests found in individual farmer's lotus fields, Haleiwa, Oahu, with number and percent distribution of lotus leaves.

Farmer	Date found	Nest number*	Exposed	Number of leaves above	Distribution of lotus
					Percent
Kunehiro-a	3/8	10a		9	<10
	3/16	15a		4	30
	4/7	14a		8	60
	4/7	2a		8	25
	4/15	16a		5	15
	4/15	12a		8	80
	4/15	12b		8	80
	4/29	19a		8	60
	5/14	7a		10	60
	5/14	10b		5	60
	5/23	15b		3	40
	10/18	10c	X		Harvesting
Kunehiro-b	3/16	9a		4	20
	3/24	2a		11	20
	3/24	19a		3	20
	12/8	7c**		2	Replanted
	12/15	9b		3	Replanted
	1/17	7d	X		Replanted
	1/17	7e		2	Replanted
Tantog	3/24	51a		9	30
	4/29	50a		8	50
	12/1	103a	X		Replanted, weedy
	1/17	102a	X		Replanted
Kamalani	2/6	118a	X		Hyacinth
	3/1	121a		3	10
Ung	2/6	26a	X		20
	4/7	27a		6	30
	4/15	29a	X		15
	4/15	26b		3	35
	5/13	27b		4	40
	5/13	30a		5	25
	1/17	26c		4	Replanted

*Number preceding letter indicates plot number and letter denotes succession of nest found per plot.

**Nests 7a and 7b in Kunehiro-b are not included here because nests were not found, but subsequent censuses indicated 2 separate families.

Appendix B. Clutch size and nest status of Hawaiian Gallinule nests found at Hamakua marsh, Kailua, Oahu, February 1979 to January 1980.

Nest ID	Number of eggs	Status of eggs	Later developments
H_a	2	1 broken, 1 floating	
H_b	4	Incubating	3 eggs with holes, 4th missing
H_c	1	Pecked hole	
H_d	Unk	Hatched, 6 chicks	2 survive to juveniles
H_e	3	1 hatched, 2 pipping	1 chick observed; later disappeared
H_f	6	Broken shell fragments	
H_g	7*	Incubating	Abandoned
H_h	Unk	Hatched, 5 chicks	4 preyed on by mongoose; 5th survives to juvenile
H_i	6*	Incubating	Shell fragments
H_j	7*	Incubating	Unknown; no shell fragments
H_k	Unk	Incubating	Unknown
H_l	5*	Incubating	Unknown
H_m	Unk	Nest building	Unknown

*Nests with complete clutches.

Appendix A. Description of Hawaiian Gallinule nests found at Hamakua marsh, Kailua, Oahu, February 1979 to January 1980.

Date	Nest ID	Location*	Vegetation type**	Placement	Exposure	Depth of water (cm)	Number of stems around nest
2/25	H_a	P/M	Scirpus	Above water	Enclosed	18.2	63
2/25	H_b	P/M	Bacopa	On Bacopa	Exposed	7.6	25
2/25	H_c	P/M	Scirpus	On water	Enclosed	7.6	25
2/25+	H_d	P/M	Bulrush	Above water	Enclosed	10.2	63
4/25	H_e	P/M	Paspalum	On paspalum	Exposed	--	>100
4/25	H_f	P/M	Scirpus	Above water	Enclosed	11	49
6/4	H_g	C	Calf. gr.	On water	Exposed	33	--
6/14	H_h	C	Paspalum	On paspalum	Enclosed	>91.4	>100
7/2	H_i	C	Calif. gr.	On water	Enclosed	83	55
11/3	H_j	C	Paspalum	On paspalum	Exposed	--	>100
11/7	H_k	C	Calif. gr.	On water	Enclosed	>91.4	45
11/26	H_l	C	Paspalum	On paspalum	Exposed	61.0	100
1/28	H_m	P/M	Scirpus	Above water	Enclosed	10.2	38

*C = Canal; P/M = pond/meadow.

**Bacopa, B. monnieria; Bulrush = Scirpus californicus; Calif. gr. = Brachiaria mutica; Paspalum = P. vaginatum; Scirpus = S. paludosus.

+Nest discovered in February, but presence of chicks about 3 weeks old indicates nest initiated in January.

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and 9 birds. In the lotus fields, populations varied among the different fields: Kunehiro's fields showed marked changes from prebreeding to postbreeding, the number of birds decreasing just before the onset of nesting. The population in Tantog's and Ung's combined and Kamalani's fields remained relatively stable.

Substrate samples taken from Kunehiro's and Tantog's fields were sorted for macroinvertebrates. Samples with a thick Azolla cover appeared to have more macroinvertebrates than sparse or moderate Azolla cover. Soft mud samples compared with floating Azolla samples tended to have more macroinvertebrates, regardless of the density of Azolla cover. Kunehiro's fields had plots with a mixture of sparse to thick Azolla, both floating and on a soft mud surface. Tantog's field had a few plots resembling Kunehiro's, but many of his plots had harder and drier substrates covered with weeds and did not resemble lotus plots. The condition of the plots may have influenced the food supply available to gallinules. Kunehiro's plots appeared to provide favorable conditions for macroinvertebrates, whereas Tantog's weed-covered plots did not. In addition, these weed-covered plots may have been more attractive to predators because they were more terrestrial than aquatic.

Although territories at Hamakua were maintained throughout the year, they appeared to be maintained only during the active nesting period in Kunehiro's fields. During February 1979, agonistic encounters were frequent, and the population began decreasing, eventually leveling off to about 24 birds by March, representing a 70% decrease from December 1978. In December 1979, the population had increased almost to its former level of the year before. During this time, flocking behavior was observed, and territories were not obvious. In January 1980, agonistic encounters were occasionally observed.

Nesting appeared to be more successful in Kunehiro's fields than other lotus fields as well as Hamakua marsh. One-half of the nest failures recorded at Hamakua were due to predation, and evidence indicated mongooses were likely predators. Clutch and brood sizes were similar to those reported by other studies in the temperate zone.

Both sexes participated in nesting. Males spent more time (2 times) gathering nest materials than females, while females spent twice as much time incubating as males.

Ceratophyllum sp., P. vaginatum, and P. stratiotes, growing primarily along the canal margins and (Ceratophyllum/P. stratiotes) growing in the canal were favored vegetation in which gallinules fed at Hamakua, when the meadow was dry. When the meadow was saturated after heavy rains, gallinules fed in the meadow composed mainly of B. monnieria and S. paludosus.

The status of gallinule populations varied for each study site. The population was relatively stable at Hamakua, fluctuating between 7

SUMMARY

The Hawaiian Gallinule appeared to breed year-round at the Hamakua marsh. Although nesting occurring in lotus fields could not be observed during the summer months, it was more than likely that second and possibly third clutches were laid. At least 1 second clutch was observed in Kunehiro's fields. Second and third clutches and renests were observed at the Hamakua site.

Nesting appeared to be associated with vegetation, habitat condition, and food availability. Studies have shown Common Gallinules prefer a mixture of vegetation and water, where more edge was available than wide open water areas surrounded by vegetation. Gallinules at Hamakua preferred nesting in the meadow when under flooded conditions and temporary ponds occurred surrounded by dense *S. paludosus* growth, as opposed to nesting alongside the canal. But when the marsh began drying out, gallinules were limited to the canal margins, where they continued to nest. When the meadow was again flooded by heavy rains, gallinules were observed feeding and nesting in the meadow.

Nest placement above, on the water, or on the ground, depended on the physical characteristics of plants. Stronger and/or denser species could support nests above the water, while weaker species provided a substrate on which nests could be placed on the water surface. Lotus leaf stalks, although thick and strong, did not form tight and dense stands for gallinules in which to place their nests, instead all nests were placed on the ground, usually under several lotus leaves.

number of nesting gallinules. Perhaps weedy fields may be favorable to predators because of the harder surface compared to the watery, muddy surface of weed-free fields.

It is interesting to note the adaptability of gallinules to human presence, especially in the lotus fields. I observed gallinules a few feet away from workers in a lotus plot. These gallinules did not show any sign of alarm. It may be useful to the State Fish and Game Department to solicit the help of workers to systematically note numbers, nests, chicks, and juveniles while in the field. Such data would yield year-to-year information on the status of the gallinule.

aquatic invertebrates will occur, attracting other water-related birds in addition to creating more edge which is favorable to both nesting coot and gallinule (McDonald 1955). Conversely, areas susceptible to desiccation should be maintained to preserve a marshy condition. Hamakua marsh dried up over summer, forcing gallinules to the canal edges. When the meadow was saturated and ponds filled with water, gallinules were observed nesting and feeding in the marshy meadow.

Some form of protection is needed in areas where gallinules are exposed to humans and predators. Fences should be constructed or vegetation barriers planted and signs posted to protect gallinules and other water birds from harassment from people. A trapping program for mongooses should be initiated.

In addition to emphasizing the need for habitat and research is the need to educate the public, especially hunters and farmers on the value of gallinules. Many hunters consider Common Gallinules a trash species (Strohmeyer 1977). Although gallinules are not legally hunted in Hawaii, farmers have reported observing people hunting or taking shots at gallinules in their fields. The researcher also observed teenaged boys shooting at gallinules at the Hamakua study site. Lotus farmers do not especially care for gallinules, because gallinules reportedly eat the young lotus shoots. A study may provide useful information on the extent of gallinule-damage on lotus shoots.

Improving farming methods by maintaining sufficient water levels in plots may reduce weed problems in the lotus fields, eliminating the need to weed fields during time of breeding. Weed-free fields may be more favorable to gallinules such as Kunehiro's, resulting in a greater

2. Censusing using recorded playback calls of Hawaiian Gallinules should be tested for future use as a census technique for gallinules occupying habitats overgrown with dense vegetation.
3. Investigating dispersal of gallinules (especially Kunehiro's fields) at the start of the breeding season to determine movement patterns.
4. Studying the effects of dikes (high versus low) and various sizes of plots on the numbers of gallinule pairs occupying a field. Do dikes create more edge?

One of the gallinules' major needs is suitable wetland habitat. Existing wetlands, especially those associated with wetland agriculture appearing favorable to gallinules, should be preserved and improved on Oahu, where the gallinule population is estimated to be half of that on Kauai. Lotus farms, especially Kunehiro's, comprise one of the more important habitats for gallinules on Oahu, and should be formally established as wildlife refuges through cooperative agreements such as the taro farms at Hanalei, Kauai, or by offering tax incentives.

Habitats should be managed for stability, such as lotus fields that follow an annual cycle with very few fluctuations. Stable water levels should be maintained (reservoirs) to prevent unnecessary egg losses from tilting of nests by adults or inundation due to flooding (Wolf 1955) during breeding. In situations where more edge is desired, marshes may be improved by controlling water levels. Where large blocks of dominant plant species such as bulrush exist, more favorable habitat can be created by inducing die-offs; e.g., through flooding. Following die-offs, a greater diversity of plants and subsequently more

RECOMMENDATIONS

Research

Research needs to be conducted to provide a data base for proper management of gallinules. Many questions and hypotheses were generated during the course of this study. Some of those that should be investigated are:

1. Year-round nesting occurring among Hawaiian Gallinules, but nesting by gallinule may be influenced by the stage of growth and physical condition of the vegetation (short and sparse versus tall and dense) and condition of the habitat.
2. Maintenance of adequate water levels and controlling for weeds in lotus fields should result in favorable habitat for gallinules. Wetland agriculture appears to be favorable habitat for nesting gallinules.
3. Increase of food resource, or availability of food, would result in a larger number of nesting gallinules.
4. Controlling predation would result in greater nesting success.

The correlationships among these factors are more important than any one factor alone. Alteration of one factor may affect one or all of the others. Therefore, a comprehensive research design would be necessary to study the effects of all these factors.

Additional research should include:

1. Studying the effects of herbicides on gallinules and their habitats (primary and secondary impacts).

Gallinules, when observed feeding in the lotus fields, often flick the *Azolla* aside and peck at the mud below, and when they swam and fed simultaneously, they were observed pecking at the *Azolla*-covered surface.

I have observed Lepidoptera larvae crawling on the surface of the *Azolla*. According to Lumpkin (1978), *Agrotis ipsilon* is a commonly occurring insect on *Azolla* in Hawaii.

It is widely accepted among ornithologists, that food supply is one of the more important ultimate factors influencing breeding patterns for nearly all species of birds. Huxley (1976) has shown that food supply can act directly on gonads of Common Gallinule by delaying their development if food supply is inadequate. Kendeigh (1934) stressed the importance of a large food resource, mainly insects, required for the development of young birds. Observations reported by Fredrickson (1971), Krauth (1972), Ripley (1977), and Witherby (1947) were indicative of the importance of invertebrates in the gallinules' food supply.

If the food resource is higher in Kunehiro's fields because of better field conditions, as compared to Tantog's, it may help explain the greater number of nesting gallinules. A food habit study, using fecal analysis, may reveal what the gallinules are eating and an intensive survey of available food may show Kunehiro's fields with a greater food resource than Tantog's.

method may prove to be successful if attempted when the vegetation; e.g., lotus, is at its peak abundance during summer.

Macroinvertebrates

Early in the year, after the fields were harvested and at the time nesting occurred, the fields were uniformly covered with Azolla. Newly-emergent lotus leaves were scattered throughout the plots. The condition of the Azolla remained the same until the lotus reached densities which shaded the Azolla, resulting in a thinning of the Azolla and eventual disappearance. Azolla still occurred in thick aggregates where lotus failed to emerge or in areas where height and densities permitted sufficient infiltration of incident light.

Analysis of the data indicated more macroinvertebrates were found when Azolla occurred over a soft mud substrate, compared to Azolla floating on the water surface. Observations of Kunehiro's and Tantog's fields showed Kunehiro's with more plots having conditions where an intermixture of sparse to thick Azolla cover both floating and on mud substrate occurred compared to Tantog's weed-choked field. The ratio of Azolla-covered mud to Azolla-covered water could not be determined by visual inspection because Azolla covered the substrate surface.

Many of Tantog's plots were covered with weeds and had drier, harder mud than Kunehiro's, and were not immediately recognized as lotus plots. Because many of his plots were like those just described, the water/soft mud intermixture did not occur in many of Tantog's plots. A plot with very thick Azolla, soft mud, and relatively weed-free, had a pair of nesting gallinule.

excluding November counts which may not be representative because gallinules may have been in unharvested fields that were difficult to look into. It was uncertain if the cyclic pattern observed in Kunehiro's populations occurred in Tantog's and Ung's combined populations.

Auditory census

Playback recorded calls were used successfully by Brackney (1979) to census Common Gallinules. He found male Common Gallinules responded equally well to taped calls even though population densities varied. Males responded (26 of 28) to the taped calls a greater percentage of the time and with less variability than females (6 of 28). Male and female voices could be distinguished by the differences in vocal tone, the male having lower vocal tones than females (Brackney 1979). Brackney compared nest densities found on strip transects and pair density estimates based on responding males and found them to be comparable. Auditory counts were as precise if not more precise than numbers based on nest searching. He calculated that nest searching took 8 to 12 times more man-hours than censusing using taped calls.

Brackney used the auditory census from mid-June to early August. He did not use an auditory census during May because the lack of suitable cover caused Common Gallinules to flush upon approach. This method of censusing gallinules in the present study was unsuccessful. Perhaps at the time it was attempted, the study areas were still open and vegetation not sufficiently dense to obscure the approach of the observer, and the tape used was not the call of the Hawaiian Gallinules, but the calls of the North American subspecies. This

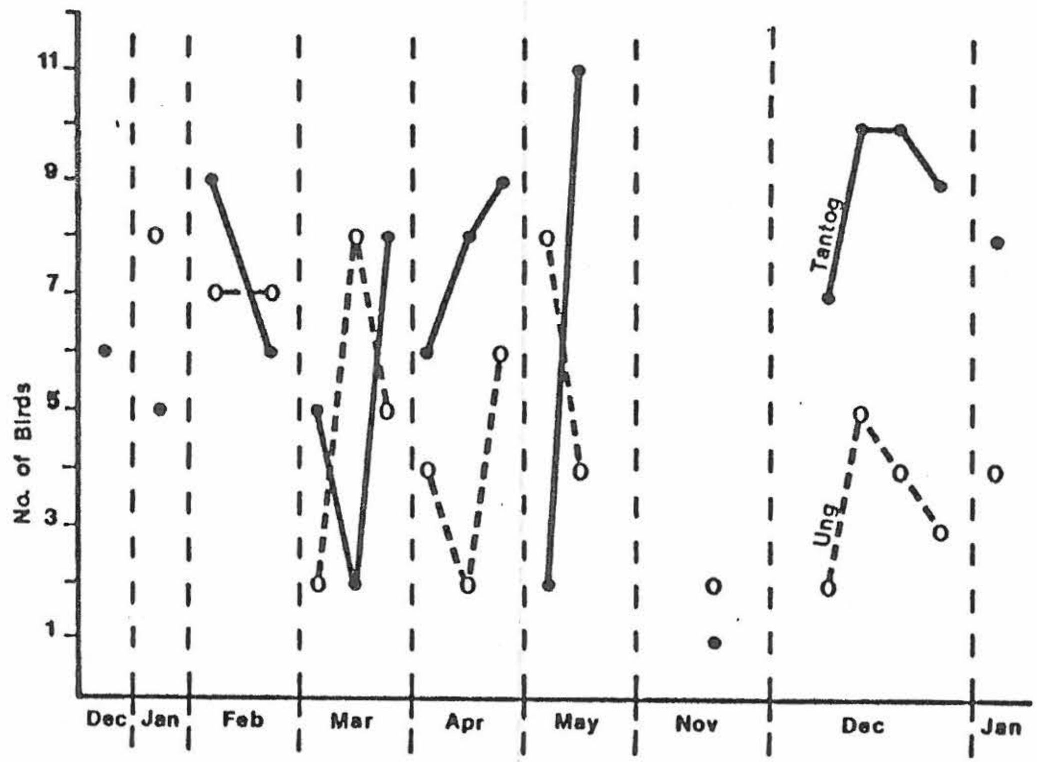

Fig. 18. Counts of adult Hawaiian Gallinules in Tantog's and Ung's lotus fields, December 1978 to May 1979, November and December 1979, and January 1980. Data was not collected from June to October 1979. (Counts for Dec. 1978 and Jan-Feb 1979 were provided courtesy of Timothy Burr, Div. of Fish and Game, State of Hawaii.)

the total adult population) was substantially lower than Kunehiro's (17.4 birds/ha), a field of comparable size to Hamakua.

A marked fluctuation was observed in Kunehiro-a's population. From December 1978 to mid-January 1979, the population ranged from 82 to 88 birds. Beginning the latter half of January, the observed population declined and agonistic behavior was observed. By mid-March, the population stabilized, at which time the population was reduced by about 70% (62 birds) (Appendix I). Also, at this time, pairs were observed, nesting commenced, and territorial maintenance was evident. By the following December, the population had increased almost to its former level of the year before. A similar situation occurred in Kunehiro-b. It is uncertain where the birds dispersed to.

Howard recorded adults chasing and attacking juveniles. Often, adults will chase a juvenile of a previous brood out of the territory before the next clutch is laid. In Kunehiro's, it was not certain whether 2 or more clutches were common, and if so, whether juveniles were chased out before other clutches were laid. Gallinules chased out of territories at the start of breeding were probably juveniles from the preceding season.

Kamalani's population was relatively stable, fluctuating from 2 to 5 birds. Populations in Tantog's and Ung's fields were erratic and varied with each census. However, when looking at counts of both fields together, a pattern appeared to emerge; when the number of birds was low in 1 field, it was higher in the other, suggesting movement between these 2 fields (Fig. 18). The combined count for both fields appeared to be somewhat stable, averaging 12.4 birds (± 1.44, P = .05), eating snails. In a study by Reagan (1977), Common Gallinules were observed feeding off the water surface in 95% of his observations and he noted they fed adjacent to the periphery of sparse Panicum sp. and Paspalum sp.

In a study by Voights (1976), invertebrates became established when dense emergent vegetation was flooded with shallow water. Abundant peaks were observed when narrow-leaved submergent vegetation became established, providing protection for invertebrates. A similar condition may have occurred at Hamakua. When the meadow was marshy and gallinules fed in the meadow, B. monnieria and S. paludosus were flooded with shallow water. These 2 plants were sufficiently dense to provide protection for invertebrates.

From the time lotus fields were planted to early summer, they were a combination of open habitat interspersed with emergent vegetation (lotus). This type of interspersion (open habitat interspersed with the emergent phase) according to Voights (1976), should produce the largest number and diversity of aquatic invertebrates. Gallinules were frequently observed flinging Azolla to one side with their bills and pecking at the exposed substrate. A similar feeding behavior was observed by Bell and Cordes (1977). They observed adult gallinules flipping floating-leaved vegetation with their bills and pecking at the animals under the leaves. Gallinules were also observed pecking at the Azolla-covered water surface in the lotus fields.

Population

Minor fluctuations in the number of birds at Hamakua indicated a stable population. The average number of birds per ha, 2.5 (using 9 as invertebrate densities. He reported a correlation between morphological features of plants that provided shelter and attachments for invertebrates. Of the seven types of submerged aquatic vegetation he studied, Myriophyllum spicatum was found to be the best plant for invertebrates, due to its finely-subdivided leaves. A slightly greater number of invertebrate species were found on Elodea canadensis and Naias flexilis, but the greatest number of organisms was found on M. spicatum.

Ceratophyllum sp. that occurred at Hamakua, is similar morphologically to Myriophyllum and was favored vegetation where gallinules were observed feeding. The stems of P. vaginatum (another favored plant) formed a finer network that provided better shelter and attachments for invertebrates than stems of B. mutica, which were thicker than those of P. vaginatum. The roots of P. stratiotes have fine root hairs where animals can attach themselves. But because P. stratiotes multiplies vegetatively (new plants budding from existing ones), it eventually forms an interconnected mat creating a carpet over the water surface. Gallinules were unable to lift the P. stratiotes to feed off the roots, unless a small portion was broken off from the main mat, in which case gallinules were observed pulling loose P. stratiotes up onto the mat and pecked at the roots.

When feeding among P. vaginatum, gallinules often scratched and pulled at submerged stems to expose them in search of food. Gallinules were also observed feeding at the periphery of P. vaginatum. When feeding among Ceratophyllum sp., they usually swim and peck at the Ceratophyllum sp. on the water surface. Gallinules were observed

Renesting (attempts after preceding nest failed) occurred at Hamakua. Assuming the pairs maintained the same territories, 1 pair renested after the first nest failed, and completed second and third clutches. The pair by the bridge made 2 renesting attempts that failed after abandoning the first nest. Finally, another pair was observed renesting in the pond/meadow after the first (H_1) failed.

Behavior

Nesting behavior

Both sexes participate in gathering nest materials and incubating, but males spent more time gathering nest materials (34%, 3019 minutes of observation) than females (12%, 2943 minutes of observation) (Appendix H), while females spent more time incubating (45%) than males (23%) (Appendix G). Wood (1974) and Krauth (1972) reported observations similar to these, of the role of the male in nest gathering, but Krauth also observed the female spending more time incubating than the male.

Feeding behavior

Gallinules appeared to favor feeding in Ceratophyllum sp., P. vaginatum, and P. stratiotes over other vegetation types. These observations were made when the marsh was dry and gallinules were inhabiting the canal margins. When the marsh regained its former flooded condition, gallinules once again fed in the meadow, where the dominant vegetation types were B. monnieria and S. paludosus.

Krecker (1939) pointed out the importance of physical characteristics of plants (finely-divided leaves) in influencing

low chick mortality and high brood survival, or nesting occurred during the months when observations ceased; either late nests or second and third clutches were laid. From my observations, it appeared that the second possibility may have occurred.

Occurrence of multiple broods, more than 1 brood per pair per season, varies geographically. Karhu (1973) summarized reports by other researchers on the number of broods per pair. He reported 2 broods were common in western and central Europe; 3 broods in Great Britain; and some reports of 3 broods in Germany and possibly in the United States. Hatching intervals between clutches ranged from 26 to 56 days, averaging 44 days (Hoel, cited in Karhu 1973) and 44 days according to Howard (1940). Relton (1972) recorded 2 clutches per pair, but no third clutches. She observed that 42% (15) of first clutches that failed were immediately replaced. Of the total number of pairs observed by her, 36% (13) were double brooded, 11 of them successfully hatching their second clutches.

Second clutches were probably hatched in Kunehiro's fields. Two nests were recorded in plot 15; nest 15_a hatched about 7 April and a second clutch, 15_b was observed about 45 days after the first clutch hatched. Assuming the duration of incubation is 20 days, hatching interval between 15_a and 15_b was about 65 days. Hatching interval between 2 nests by 1 pair at Hamakua was about 50 days. The first nest by the pair in plot 10 in Kunehiro-a was unsuccessful; it disappeared about April 29, but a second nest (renest) was observed 15 days later. Renesting attempts were also observed in Tantog's, Ung's, and Kamalani's fields, but second clutches were not observed.

Brood size and fledging success

The average number of chicks observed per successful pair in this study (Hamakua and lotus fields combined) was 4.5 (s.d. 1.81). This is similar to those observed by Bell and Cordes (1977), 4.7; Karhu (1973), 4.6 - 5.1; and Krauth (1972), 4.7. Wood (1974) reported a lower brood size, 1.6 and 2.6 chicks per pair in 1968 and 1969, respectively.

Fledging success (number of chicks surviving 8 weeks) at Hamakua was 3 juveniles of 11 chicks. Karhu (1973) reported 28.7 to 32% (based on mean clutch size of 8 and 2 broods per pair) and Ticehurst (1940) estimated from a population that had succumbed to unusually cold weather that brood success, that is if the young in the population lived to breed the following year, was approximately 20%. Wood (1974) reported 94% (number of young surviving up to 70 days); Relton (1972), 91% (young surviving up to 42 days); and Brackney (1979), 89% (young surviving up to 42 days). The average number of young per pair reported by Bell and Cordes (1977) and Wood (1974) surviving after 6 weeks was 2.6 and 2.4 juveniles, respectively. It should be noted that the studies just mentioned were all conducted in the temperate zone where chick growth rates may be faster than growth rates in the subtropical zone due to constraints of weather and food availability. In Hawaii, where food resources may be available year-round, or at least for a longer length of time than the temperate zone, the time it takes chicks to fledge may be delayed beyond 8 weeks.

I could only speculate about the fledging success in the lotus fields because of the inability to observe gallinules through the dense lotus leaves. Two possibilities may have occurred. There was either mongoose. A mongoose would initially try to bite into an egg and if successful, lap the contents; if unsuccessful, it would pass the egg back and forth between its legs until it hit an object and broke. The authors observed a mongoose preying on a peafowl egg. The egg was rolled off the nest, punctured on the side, and the contents drained. Eggs found with holes at Hamakua appeared to fit the description. Also, these eggs looked very similar to pheasant eggs preyed on by mongoose (in a picture presented in Schwartz and Schwartz 1949). Caged mongooses have been observed making large holes in eggs under controlled conditions (Rick Coleman pers. comm.). This highly suggests mongoose over avian predation.

Although cats, dogs, and black-crowned night herons (Nycticorax nycticorax hoactli) are usually cited as common predators (Berger 1972, Shallenberger 1977), mongooses are most likely the major predators. Mongooses were observed at both study sites. They were usually observed near the edge of sugarcane fields in Haleiwa and along the earthern dike and canal margin at Hamakua. Farmers at Haleiwa have observed mongooses entering nests and preying on gallinule eggs and chicks. A mongoose was observed at Hamakua stalking a pair of gallinules along the canal, but the pair appeared to be aware of its presence as judged by their calling and tail-flicking. Workers at a shop across the canal from a newly-hatched nest observed a mongoose entering the nest and preying on 4 of the 5 chicks. The adults were nearby calling, but did not attack the mongoose. Broken shell fragments found near nests may be indicative of predation by mongoose.

1968 when heavy rains occurred, and no eggs lost to flooding the following year. Losses due to infertility appeared to be negligible, although Krauth (1972) reported this may be an underestimation because adults were obs[illegible] removing infertile eggs from nests.

At Hamakua, [illegible] of the unsuccessful nests were destroyed, 1 was abandoned, and fates of 4 were undetermined. Cause of nest failure could not be determined in the lotus field because of inaccessibility to the nests. Broken egg shell fragments, however, were found on a dike in Tantog's field (August 1979), suggesting that mongooses may have preyed on the eggs.

Huxley and Wood (1976) and Relton (1972) reported greater numbers of successful nests as the season advanced due to growth of vegetation that provided better cover. When comparing hatching success between nests found on ponds on arable land and ponds on pastures, Relton (1972) found greater success on ponds on arable land than ponds on pasture. This was probably due to the greater exposure and attraction of nests to predators on pastures. She also reported all the eggs (16) of 1 pair were destroyed by trampling of cattle. Avian predators, presumably crows (Corvidae) were also mentioned by Relton.

Hamakua is used as a cattle pasture, but cattle were not frequently observed grazing in the meadow. On one occasion, cattle were observed walking and grazing in a pond in the immediate area where a nest with 4 eggs was located. The nest was not trampled, but a later visit revealed the eggs were destroyed. Holes found in the eggs may have been pecked by birds or bitten by mongoose. Baldwin et al. (1952) cited an observation made by Walker on the feeding manner of a

Table 11. Summary of Common Gallinule nest failures reported by other authors.

Percent*				
Eggs	Nests	Cause	Location	Author
		Swamping		
7			Wisconsin	Krauth (1972)
19			England	Wood (1974)
	13 (rural)**		England	Huxley & Wood (1976)
	23 (urban)		England	Huxley & Wood (1976)
7			Ohio	Brackney (1979)
		Infertility		
3			Wisconsin	Krauth (1972)
<1			England	Wood (1974)
		Abandoned		
7			Wisconsin	Krauth (1972)
29			Ohio	Brackney (1979)
		Natural predators		
83			Wisconsin	Krauth (1972)
80			England	Wood (1974)
43+			England	Relton (1972)
62++			England	Relton (1972)
	8 (rural)		England	Huxley & Wood (1976)
	13 (urban)		England	Huxley & Wood (1976)
64			Ohio	Brackney (1979)
		Human predation		
	23 (rural)		England	Huxley & Wood (1976)
	27 (urban)		England	Huxley & Wood (1976)

*Percentages of total nest or egg failures.

**Nests found in rural and urban areas.

+Ponds located on arable land.

++ponds located on pasture land.

Table 10. Hawaiian Gallinule nesting data for Hamakua marsh (Feb. 1979 to Jan. 1980) and Haleiwa lotus fields (Mar. to May, Oct., Dec. 1979, and Jan. 1980.

Location	Hectare		Number of nests	Nests/ hectare	Number of nests			Percent successful
	Indi- vidual	Total			Succ.	Unsucc.	Unk.	
Hamakua	3.2	3.2	13	4.1	3	9	1	23
Haleiwa		8.0	34	4.4	13	16	5	38
Kunehiro-a and -b	4.3		21	5.1	10	8	3	48
Tantog	3.2		4	1.3	1	2	1	25
Ung	0.3		7	23	1	5	1	14
Kamalani	0.2		2	10	1	1	0	50
Hamakua and Haleiwa		11.2	47	4.2	16	25	6	34

broods; alloparental care also has been observed in Purple Gallinule (Krekorian 1978). Krauth (1972) observed juveniles wandering about his study area which were chased away when they intruded into the territory of a nesting pair, however, he did not observe any pair driving out their own chicks.

Clutch size

The average clutch size for nests in this study was 6.2 (± 1.76, P = .05). This is similar to those given by other authors: Bent (1926), 10-12; Brackney (1979), 8.04 ± 0.53; Huxley and Wood (1976), 6.58; Krauth (1972), 9.17 ± 2.56 and 7.58 ± 1.62; Relton (1972), 6.7; and Wood (1974), 5.32 and 5.39 eggs.

Nesting success

A greater number of successful nests was observed at the lotus fields than Hamakua (13 of 34 and 3 of 13, respectively). More successful nests were found in Kunehiro's fields than Tantog's (comparable field sizes) as well as the 3 fields, Tantog's, Ung's, and Kamalani's combined (Table 10). Together, Hamakua and the lotus fields had a success rate of 34% (16 of 47 nests) (Table 10). Other studies reported nesting success ranging 14 to 65.3%: Huxley and Wood (1976), 65.3%; Krauth (1972), 61%; Relton (1972), 56%; and Wood (1974), 14 and 26%.

A summary of nest failures reported by other authors is shown in Table 11. Most of the studies showed a high percentage of nest failure caused by predation. Nest failure caused by flooding was most likely influenced by direct manipulation; e.g., drawdown, or weather that varies from year to year. Wood (1974) reported 42 eggs destroyed in

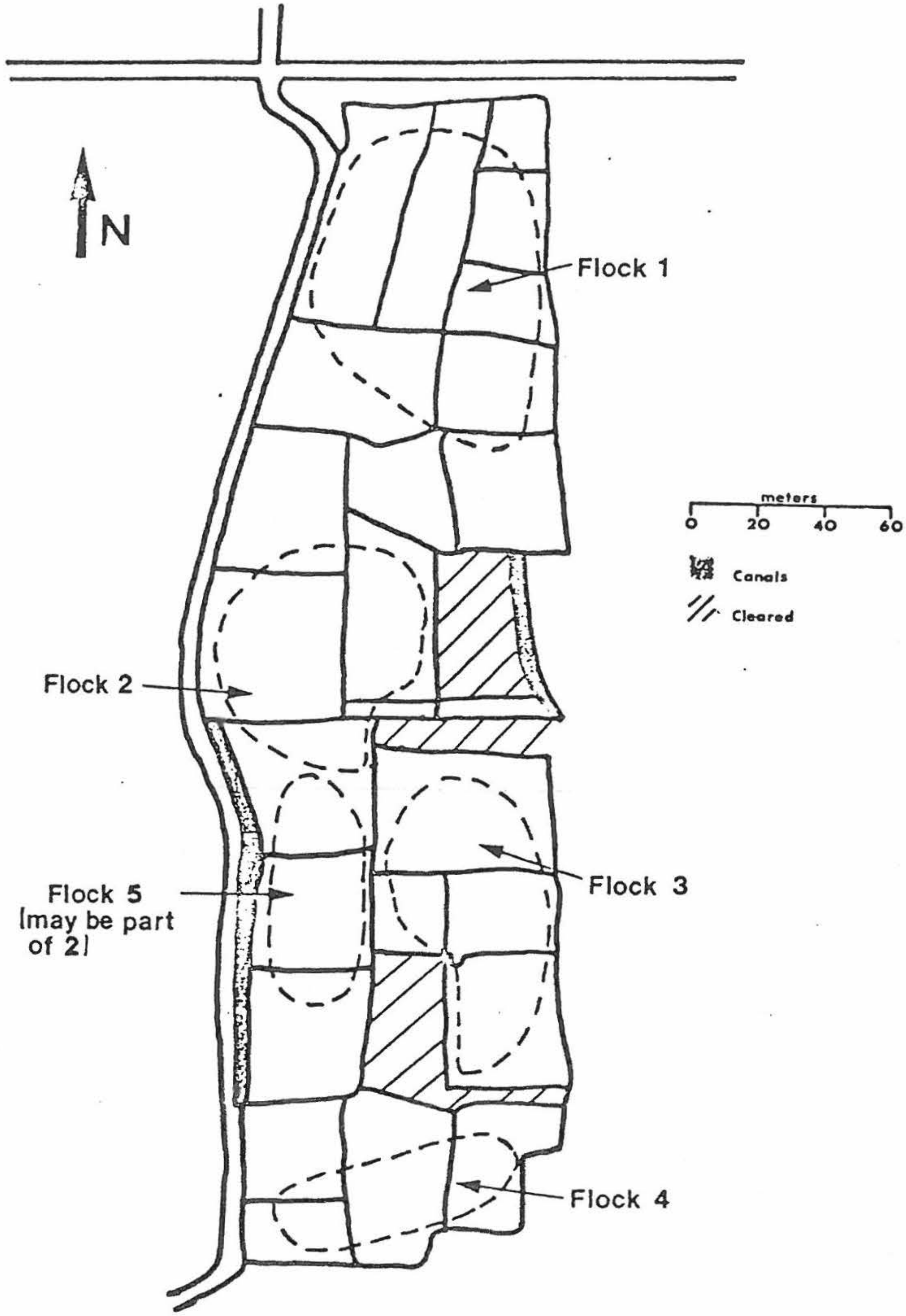

Fig. 17. Location of flocks of Hawaiian Gallinule in Kunehiro-a lotus field, December 1979 to January 1980.

observe one another. The dikes separating lotus plots in addition to creating more edge effect, formed walls blocking the view of the next plot. Unless a gallinule walked up on a dike, it was unable to see gallinules in an adjacent plot. Territorial defense was observed when a gallinule entered a plot occupied by a pair. One member of the pair would chase the intruder out, frequently running into the next plot, and occasionally continuing the chase into an adjacent plot. A defending bird would then slowly make its way back into its own plot, though sometimes resuming the chase again before returning. The dikes may, therefore, provide more territories for gallinules by serving as blinds around nesting gallinules. This coupled with a sufficient food supply may be responsible for smaller territories and more nesting pairs in the lotus fields than Hamakua marsh.

The need to defend a territory based on food availability, temporarily ceases until the start of the next breeding season. A temporary reduction in food availability may have occurred at the time flocking behavior of gallinules was observed, and competition for food decreased when nesting ceased. Flocks observed in Kunehiro-a were most likely composed of offspring from neighboring pairs. Flocking occurred only in Kunehiro-a where 4, possibly 5 flocks were observed (Fig. 17) at the time harvesting of lotus roots was in full operation. After the plots were harvested, they were devoid of lotus leaves and only light scattering of Azolla occurred. Gallinules generally were not observed in those plots, but were in unharvested and replanted plots.

Several studies cited by Wood (1974) mentioned juveniles of Common Gallinule of earlier broods assisting in feeding and nesting of later

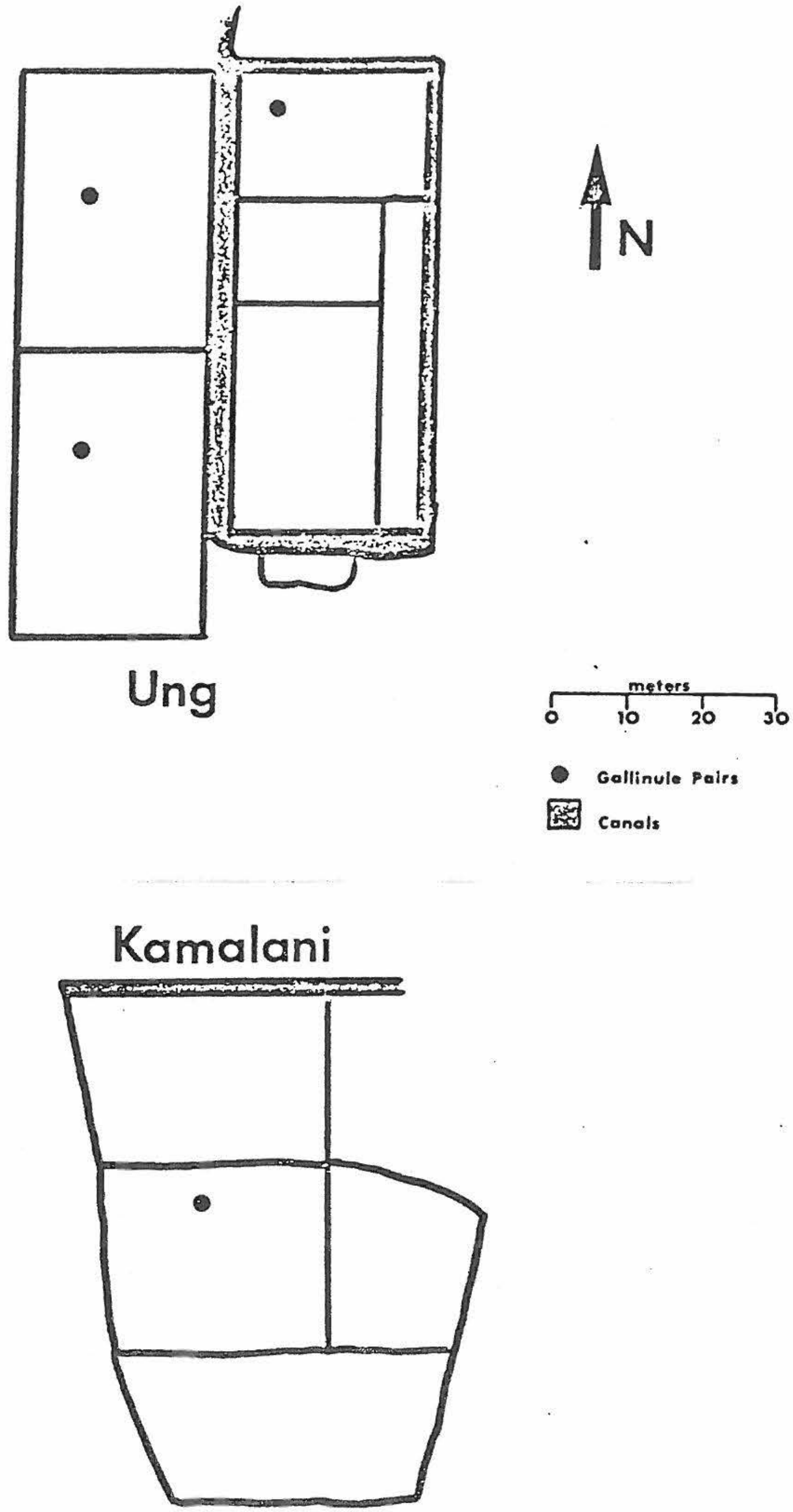

Fig. 16. Location of Hawaiian Gallinule pairs in Kamalani's and Ung's lotus fields, Haleiwa, Oahu, February to May 1979.

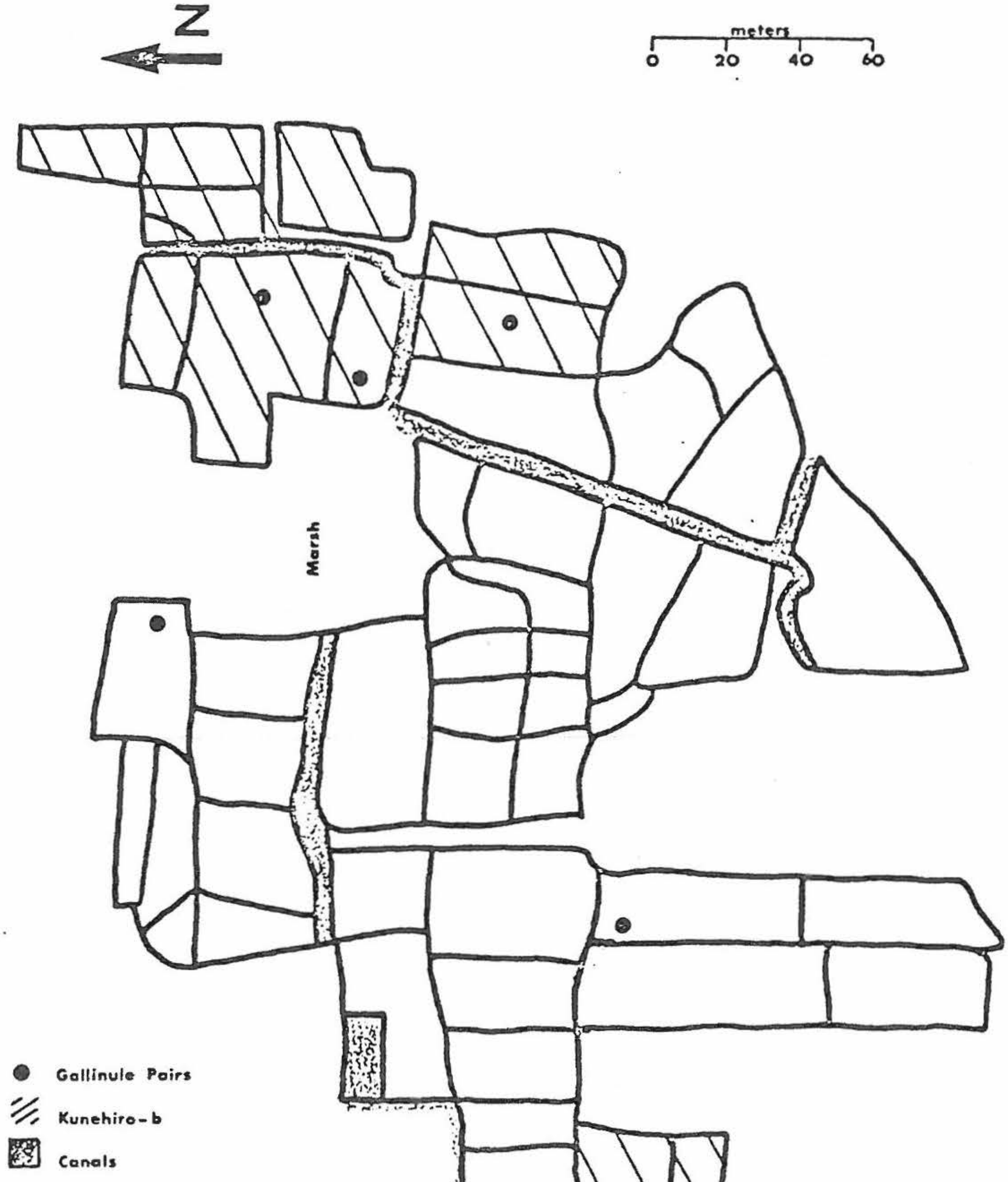

Fig. 15. Location of Hawaiian Gallinule pairs in Tantog's field and Kunehiro-b, Haleiwa, Oahu, February to May 1979.

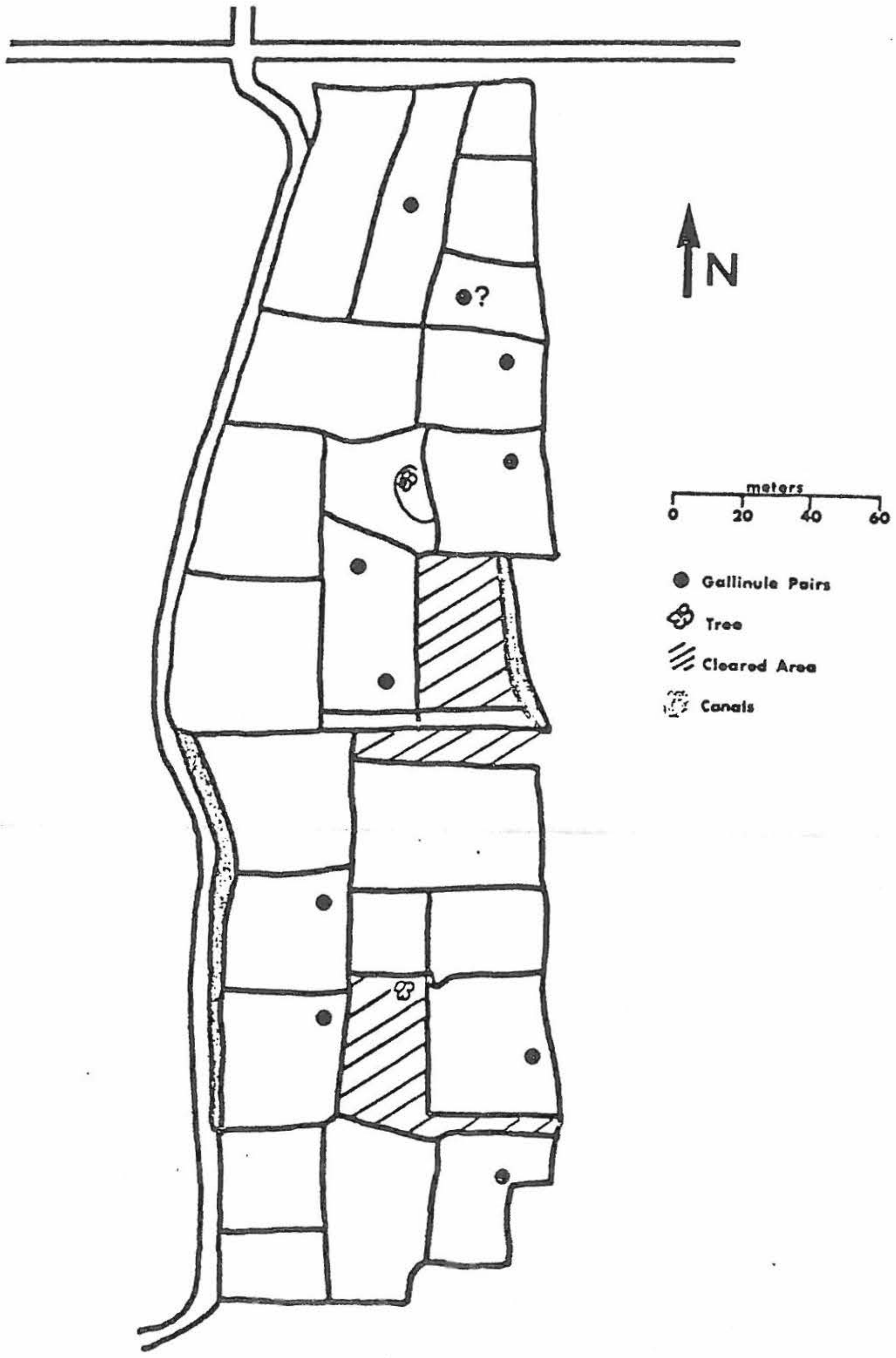

Fig. 14. Location of Hawaiian Gallinule pairs in Kunehiro-a lotus field, Haleiwa, Oahu, February to May 1979.

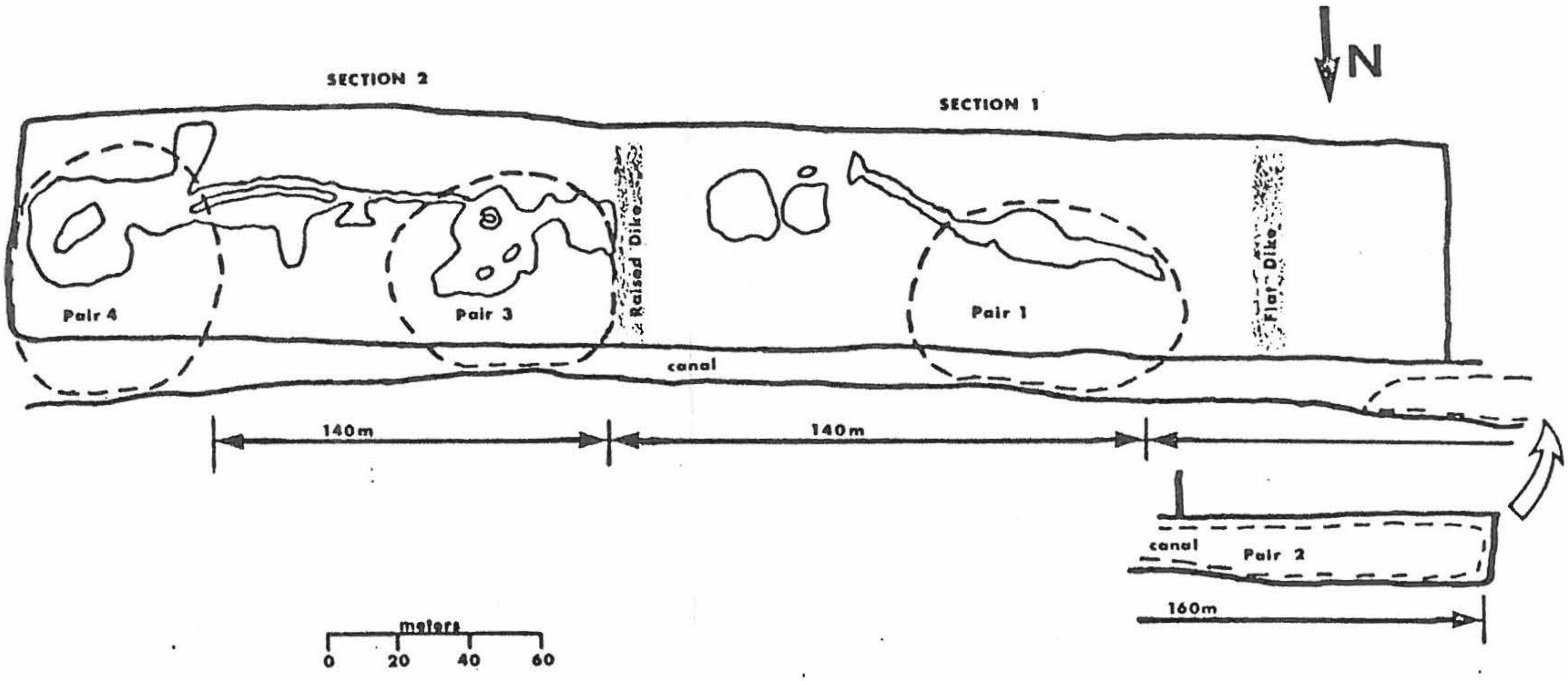

Fig. 13. Location of territories and distance between each territory of 4 nesting Hawaiian Gallinule pairs at Hamakua marsh, Kailua, Oahu.

mutual retreat, challenging, and fighting. Courtship behaviors included meeting and passing, bowing and nibbling, courtship chasing and arching, and coition (Howard 1940, Krauth 1972, Wood 1974). Agonistic and courtship behaviors were frequently observed in lotus fields during the latter half of February and early March. In January 1980, agonistic encounters were occasionally observed.

Territories at Hamakua appeared to be maintained throughout the year. Agonistic encounters were observed in February, June, July, September, October 1979, and January 1980. Although agonistic encounters were not observed in April, nesting was observed. From censuses and observations, there appeared to be 4 nesting pairs in the Hamakua area, 2 in each section (Fig. 13). This was inferred from location of nests and observation of pairs during census counts.

There were at least 18 pairs in the lotus fields: Kunehiro-a, 9-10 pairs; Kunehiro-b, 3 pairs; Tantog, 2-3 pairs; Kamalani, 1 pair; and Ung, 3 pairs (Figs. 14, 15, 16).

Using the distance between nests as an indication of territory size, assuming the nest is placed in the middle of the territory (Orians 1975), and the area is saturated, the distance between nests at Hamakua (Fig. 13) fell within the range of territory sizes defended by breeding Common Gallinules in England (Wood 1974). His study showed most gallinules defended territories along the length of a waterway ranging from 121 to 220 m.

Most of the distances between nests in the lotus fields were less than 100 m. This difference between Hamakua and the lotus fields may be explained by differing food supplies and how well gallinules can

January 1980 were found in plots that were recently replanted (distribution less than 10%, except plot #9, Kunehiro-b), which suggested that vegetation was not the only factor which influenced nesting by gallinule.

Placement of nests depends on the strength of the stems of plant species in which nests are placed (Beecher 1942). Scirpus californicus and S. paludosus in sufficient densities have stems strong enough to support a nest above water. The nest found in S. paludosus, placed on the water, was surrounded by 25 stems compared to the average of 50 stems for 3 other nests placed above water in S. paludosus. Nests found in P. vaginatum were placed on an island or a thick clump forming a root-stem substrate above the water surface. Brachiaria mutica has relatively soft stems and most likely will not support a nest above water, unless the stand is dense enough and stems have formed a thick mat above the water surface. Brachiaria mutica growing adjacent to the canal edge where nests were found did not form a stand thick enough to support nests above the water.

Nests in lotus fields placed on the ground were not susceptible to flooding due to the stable water levels maintained in the fields. Flooding can be a problem to nesting gallinules in areas of unstable water level fluctuations, resulting from drawdown or heavy rains. In a study by Wood (1974), 41% of total egg losses in 1 year was due to flooding caused by heavy rains.

Spatial nesting distribution and territory

From February through May, agonistic and courtship behaviors were observed in lotus fields. Agonistic behaviors included charging, placed in B. mutica and P. vaginatum which grew alongside and in the canal. Weller and Fredrickson (1973) found that species of plants in which American Coots and Common Gallinules nested were unimportant, provided they grew in standing water. Krauth (1972) found Common Gallinules preferred nesting in Sparganium sp. which provided better cover than Typha. Beecher (1942) also noted that plant species were unimportant for nesting and added that physical characteristics of plants were more important. Paspalum vaginatum, S. paludosus, B. mutica, and S. californicus all formed dense stands in standing water which provided cover and suitable nesting substrate. From the data, it was uncertain which species of plant had the most favorable characteristics suitable for nesting, because of the unequal distribution of vegetation, especially along the canal margins, among territories maintained throughout the year. Vegetation in the area occupied by the pair near the bridge was predominantly B. mutica. Additional data are needed to determine if one vegetation type is favored over another.

Lotus leaf stalks, although eventually forming thicker stands in summer, did not form stands as thick as B. mutica, P. vaginatum, and S. paludosus, in which gallinules could place their nests. Instead, gallinules placed their nests directly on the ground, usually under several lotus leaves, which provided some form of shelter, or shade. By April, when nesting was at a peak, lotus reached a level where the distribution of the lotus may have been suitable (for cover) to nesting gallinules. Not all nests, however, appeared to be associated with lotus distribution. Nests found in late December 1979 and early

50:50 in Section 1. Ponds in both sections were interconnected and had thick stands of S. paludosus around the edges. All nests found during this period were located in the meadow-pond area.

Water was always present in the lotus plots (if not in plots, in ditches alongside the plots), but was not equally distributed throughout the entire plots. Azolla-covered mud flats occurred surrounded by Azolla-covered water areas, which were indicated by observing gallinules in the plots alternating between swimming and walking. Because of the difficulty in delineating open water areas, it was not possible to assess a water-vegetation (lotus) ratio. Although a vegetation-open area ratio was easier to assess, a comparison between number of nests with this ratio showed a potential relationship in Kunehiro-a only, which did not suggest that gallinule nesting was necessarily dependent on the distribution of lotus. Perhaps the annual cycle of lotus, replanting to harvest, may have created a stable annual cycle such that the early stages of lotus growth triggers (proximate factor) initiation of the breeding season. Continual growth of lotus ensured adequate cover for developing young. It may still be noteworthy to investigate and compare the water-vegetation ratio with gallinule nesting in lotus fields.

Placement of nests

Plant species in which gallinules nested did not appear to be as important as the physical characteristics of plants growing in standing water. When marsh-like conditions prevailed at Hamakua, S. paludosus growing around the perimeter of ponds in standing water appeared to be favored over other vegetation. When the marsh was dry, nests were noticeably during the study period as did the meadow vegetation. Scirpus paludosus during February (Fig. 12) formed thick stands around the edges of ponds while simultaneously increasing in height in the meadow. Gallinules at this time were not easily observed in the meadow, but could be detected by their movements and popping of their heads up above the vegetation. Lotus leaves emerged out of the ground and grew fairly straight; diameter of the leaves increased with height of the stem. By April, many plots had leaves with stems 46 cm tall.

In addition to height and density of vegetation, vegetation associated with water appeared to be important. Studies have shown that Common Gallinules prefer nesting in vegetation adjacent to or above water (Brackney 1979, Krauth 1972, Relton 1972, Weller and Fredrickson 1973, Weller and Spatcher 1965). Analysis of the vegetation-water relationship by Beecher (1942) showed a positive correlation between amounts of edge and number of nests. An increase in edge per hectare would result in a higher population density for most nesting birds, including gallinules.

Common Gallinule production reached its peak when the water to vegetation ratio was 50:50 (Weller and Fredrickson 1973, Weller and Spatcher 1965). This ratio was more influential in nesting birds when small interconnected open water areas were interspersed among vegetation compared to large open water areas (Weller and Spatcher 1965). This suggests that an increase in edge associated with small interconnected water openings is favorable to gallinule nesting.

During the first half of the year, Hamakua exhibited similar conditions described above, except the water-vegetation ratio was not

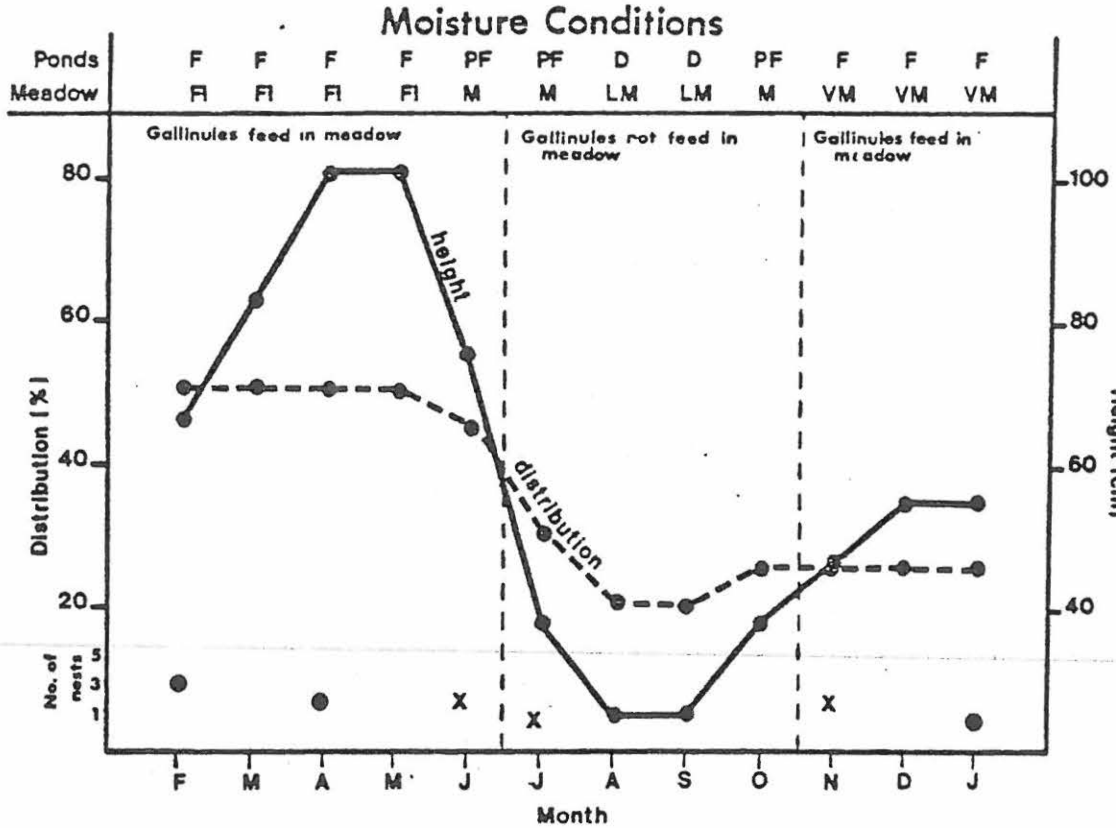

Fig. 12. Number and location of Hawaiian Gallinule nests found at Hamakua marsh, Oahu, January 1979 to January 1980. Nests are plotted with status of S. paludosus (vertical axes) and condition of meadow. (D = Dry; F = filled; Fl = flooded; LM = little moisture-dry; M = moist; VM = very moist; ● = nests in pond/meadow; and X = nests along canal margin).

DISCUSSION

Nesting

Chronology

It was pointed out by Beecher (1942) that early nesting species did not depend on vegetation for cover and nesting substrates. Species such as American Robins (Turdus migratorius) and mourning doves (Zenaidura macroura), nest before woodland and thicket come to leaf. Marsh birds on the other hand, in temperate zones, begin nesting about May. Increasing temperature, according to Beecher, may be indirectly responsible for the rapid growth of aquatic plants, which coincides with nesting of marsh birds. Beecher (1942) and Weller and Spatcher (1965) concluded that the habitat conditions of the breeding grounds determines nesting of marsh birds. Emergents such as sedges and cattails had sprouted new shoots by May which provided cover for nesting birds. In his study of Common Gallinules, Brackney (1979) reported nest initiation peaked when the cattail growth rate was greatest and the height of the cattail was 45 to 100 cm above the water surface.

Nesting activity was greatest during February and November at Hamakua and April at Haleiwa. During February and April, the vegetation, mainly S. paludosus in the meadow at Hamakua and lotus at Haleiwa respectively, was increasing in height and distribution (lotus). Nests occurring at Hamakua in November were located along the canal margin where condition of the vegetation did not change

Table 9. Occurrence of macroinvertebrate taxa in substrate samples from lotus fields that were found to be significant when comparing 2 variables.

Variables[1]	N	Amphipoda	Decapoda	Plesiopora	Polycheata	Turbellaria	Erpobdellidae	Odonata	Diptera	Lepidoptera	Coleoptera	Physidae	Thiaridea
Azolla cover (floating and soft mud substrate combined)													
Moderate	14												
vs. sparse	23									X			
Moderate	14												
vs. thick	23			X	X								
Thick	23	X			X			X		X			
vs. sparse	23												
Substrate													
Floating	26												
vs. soft mud	30	X			X								X
Sparse Azolla cover													
Floating	10												
vs. soft mud	10	X		X	X								X
Thick Azolla cover													
Floating	8												
vs. soft mud	15	X			X					X			
Floating Azolla cover													
Sparse Azolla	10												
vs. thick Azolla	8				X					X			
Soft mud													
Sparse Azolla cover	10												
vs. thick Azolla cover	15	X								X			

[1]Variables underlined indicate those found to be significantly greater.

Samples were first categorized according to the density of Azolla cover, sparse, moderate, or thick, and compared with each other. More taxa occurred when Azolla was thick as compared to moderate and sparse Azolla cover (median one-way analysis of variance, P = .05). Samples were then compared according to Azolla on a soft mud substrate or Azolla floating on water. More organisms in 3 taxa were observed when Azolla occurred on a soft mud substrate than floating on water.

Further analysis showed thick Azolla to have significantly more organisms whether floating or on a mud substrate. Likewise, in spite of the Azolla density, mud substrate samples had significantly more organisms than floating Azolla. Plesiopora and Thiarid snails were found to be significantly greater in mud versus floating Azolla, when Azolla was sparse, and Lepidoptera was significantly greater when Azolla was thick. (Table 9 contains a summary of the above analysis.)

Table 8. Average counts of macroinvertebrates found in substrate samples taken from Kunehiro's and Tantog's lotus fields.

Macroinvertebrates	Kunehiro (N=39)	Tantog (N=21)
Amphipoda	17.7	46.2
Coleoptera	4.9	0.5
Decapoda	0.2	0.1
Diptera	0.2	5.5
Erpobdellidae	2.2	0.4
Lepidoptera	4.7	2.9
Odonata	1.1	0.7
Physidae	9.0	3.1
Plesiopora	15.9	134.0
Polycheata	38.9	28.8
Thiaridae	49.1	18.3
Turbellaria	0.2	0

Table 7. Average counts of adults and total number of Hawaiian Gallinule chicks observed each month in individual lotus fields from December 1978, January to May, November, December 1979, and January 1980.

	Field											
	Kunehiro-a		Kunehiro-b		Tantog		Kamalani		Ung		Total	
Month	Adults**	Chicks+	Adults	Chicks	Adults	Chicks	Adults	Chicks	Adults	Chicks	Adults	Chicks
*Dec. 1978	88		8		6		--		11		113	0
*Jan. 1979	82		7	2	5		--		8		102	2
*Feb. 1979	63.5		4.5		7.5		2.5		7		85	0
Mar. 1979	29.3		4.3		5		2		7.5		48.1	0
Apr. 1979	24	6	4.3	11	7.7		2.3		4.0		42.3	17
May 1979	24	17	5	8	6.5		2	2	6.5	1	44	28
Nov. 1979	49		6		1		2		2		60	0
Dec. 1979	77.3		6.5		9		3.6		3.5		99.9	0
Jan. 1980	70		8	1	8		4		4		94	0

*Data provided by Timothy Burr, Division of Fish & Game, State of Hawaii.

**Population was average for adult birds each month.

+Total number of chicks observed each month.

Census

Hamakua

The adult population remained relatively stable over the 1-year period, fluctuating between 7 to 9 birds. Chicks occurred in 2 peaks (Fig. 7). The presence of chicks in the total population was ephemeral due to high chick mortality. Three of a possible 13 chicks fledged.

Haleiwa

Again limited by the growth of lotus, the fields were impossible to census from June through October. Even after several of the plots were harvested, adjacent unharvested plots provided escape for the gallinule, precluding censusing until November. Although most of the plots were harvested by late November, there were still several plots that were not harvested. These plots still provided cover for the gallinule, which was reflected by the low census counts for November.

Collectively, the adult population in the Haleiwa fields decreased from December 1978 to March 1979 (data for December 1978 and January and February 1979), provided by Timothy Burr, Division of Fish and Game). The population in Kunehiro's fields decreased by nearly 50% and Tantog's, Ung's, and Kamalani's remained relatively stable. Chicks were first observed in January 1979 in Kunehiro-b (nest 19a), but chicks were not observed again until April, following nesting activity in March (Table 7).

Macroinvertebrate Survey

Twelve taxa, including class, order, and family of macroinvertebrates, were identified. The overall average number of organisms per taxon did not appear to differ markedly between Kunehiro's and Tantog's fields (Table 8).

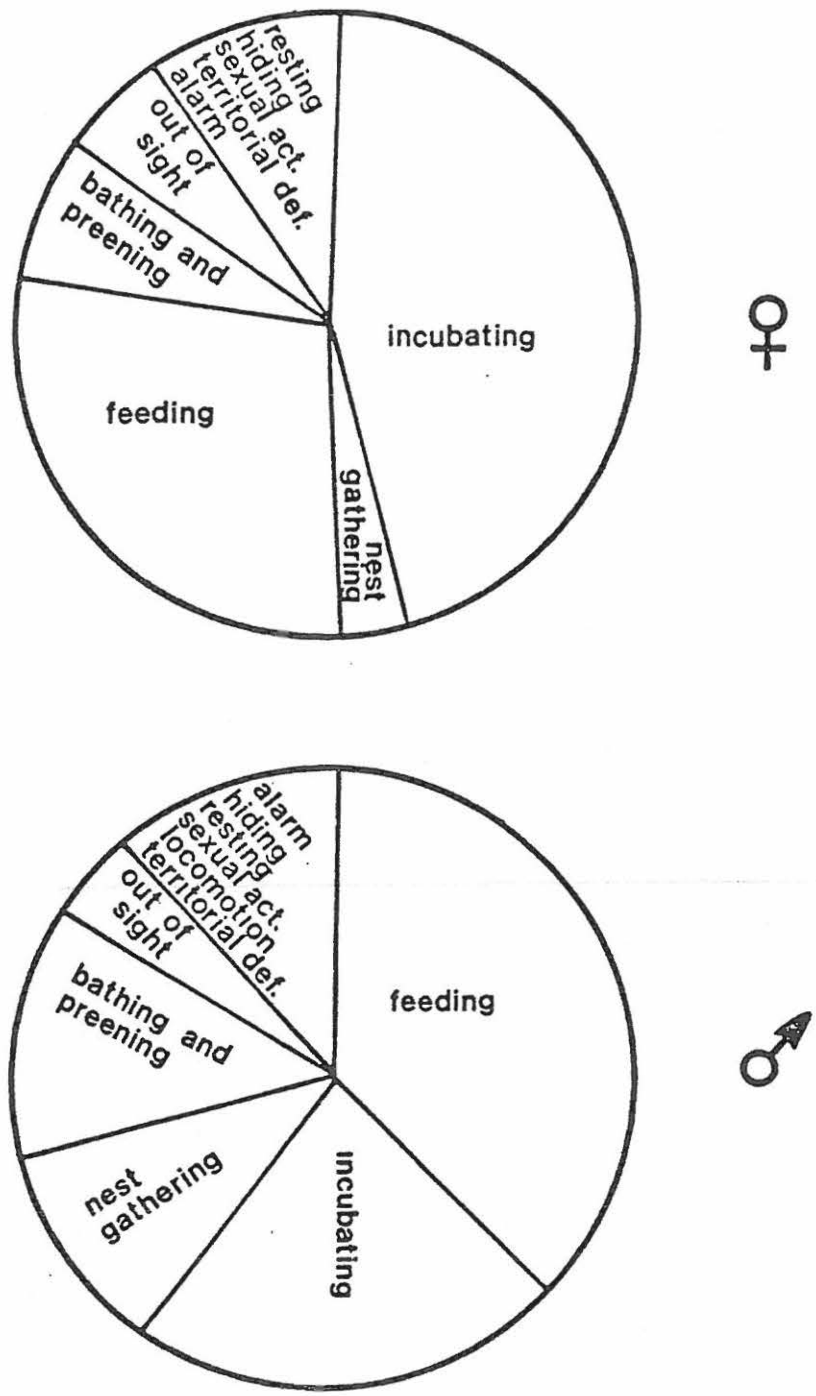

Fig. 11. Time budget for 2 pairs of nesting Hawaiian Gallinules at Hamakua marsh, Kailua, Oahu.

Table 5. Time Hawaiian Gallinule (pair #1) spent feeding where *P. vaginatum*, *B. mutica*, and *B. monnieria*/*S. paludosus* were dominant plant species in pair's territory, Hamakua, Oahu, June 4-7, 1979.

Species		Minutes	Percent
Ceratophyllum sp.		100	11
Pistia stratiotes		19	2
Paspalum vaginatum		286	32
Brachiaria mutica		103	12
Bacopa monnieria/*Scirpus paludosus*		95	11
Ceratophyllum sp./*Paspalum vaginatum*		21	2
Ceratophyllum sp./*Brachiaria mutica*		108	12
Pistia stratiotes/*Paspalum vaginatum*		15	2
Paspalum vaginatum/*Brachiaria mutica*		4	<1
Bacopa monnieria (near shore)		113	13
Ceratophyllum sp./*Pistia stratiotes*		23	3
	Total	887	10

Table 6. Time Hawaiian Gallinule (pair #2) spent feeding in various vegetation types where *B. mutica* and *P. stratiotes* were the dominant plant species in pair's territory, Hamakua, Oahu, July 2-11, 1979.

Species		Minutes	Percent
Ceratophyllum sp.		544	59
Brachiaria mutica		83	9
Pistia stratiotes		294	32
	Total	921	100

Across the canal on the southern edge, P. vaginatum and B. mutica grew along the margin and into the canal. The meadow immediately behind was a mixture of B. monnieria and S. paludosus. Within the canal, mainly along the edges of the margins, Ceratophyllum sp. occurred with patches of P. stratiotes.

Pair #2 inhabited an area with B. mutica growing on both sides of the canal, the growth being much thicker on the southern margin as compared to the northern margin. Unlike the area inhabited by the first pair, P. stratiotes formed a carpet across the canal interspersed with pockets of Ceratophyllum sp.

Total observation times were 887 and 921 minutes for pairs #1 and #2, respectively. Results (Table 5) showed pair #1 spent more time feeding among P. vaginatum (32%) than any other type of vegetation. Pair #2 on the other hand spent 59% feeding among Ceratophyllum sp. and 34% among P. stratiotes (Table 6). Observations were terminated when the nests were no longer maintained by the nesting gallinule pairs.

While the meadow was under wet conditions, gallinules were observed regularly feeding in the meadow. When the meadow was dry, gallinules concentrated along the canal margins and were not observed feeding in the meadow, except during and after rainy periods.

Time budget. Time budgets for pairs #1 and #2 are presented in Figure 11 (Appendix F). Both females incubated almost twice the amount of time spent incubating by males. Conversely, males spent more time gathering nest materials than did females. Both sexes spent about the same amount of time feeding. Males spent more time bathing and preening than did females.

Brood production. It was difficult to observe brood survival because of the density of the lotus leaves. The lotus was sufficiently dense for chicks to run and hide, especially under recently-emerged leaves. Chicks ran and hid under lotus leaves, held very tightly, and remained until the observer left the area. A summary of the number of chicks observed is given in Table 4. Kunehiro's fields averaged 4.5 (s.d. = 1.85) chicks (excluding 12_a and 7_d, because the total number of chicks in these nests was undetermined).

Behavior

Hamakua

Feeding. While observing 2 nesting gallinule pairs, incidental observations were made on their feeding preferences. Although both pairs nested along the canal margins, their territories were dominated by different vegetation types. This nest was located on the northern edge of the canal, where *B. mutica* was the only emergent found growing.

Table 4. Total and average number of chicks per Hawaiian Gallinule nest in individual lotus fields, Haleiwa, Oahu, February 1979 to January 1980.

Field	Chicks		Number
	Total	Average	of nests
Kunehiro-a and -b	38	4.5*	10
Tantog	1	1	1
Ung	1 (1+?)	1	1
Kamalani	2	2	1

*Average is total of 36 chicks from 8 nests. Two nests are not included because total number of chicks was undetermined.

Spatial nesting distribution. Distances between simultaneously active nests were measured. In all but 2 cases, the nests were placed in different plots. The second nest in the first case (12_b), was abandoned or destroyed by a predator, and in the second case (7_d and 7_e), the first nest, 7_d was in the hatching stage while the second nest was still being incubated.

The average distance between nests was 63.5 m (range 30-172 m). In April, when nesting was observed at a peak, the average distance was 63.4 m (Appendix D).

Nest success. Ten of 13 successful nests in the lotus fields were in Kunehiro-a and -b fields. Tantog, Ung, and Kamalani, each had 1 successful nest. The number of successful nests per hectare showed Kunehiro averaging 2.3 nests/ha compared to 0.8 nest/ha in the central fields (excluding Kunehiro-b), and 0.3 nest/ha in Tantog's (Table 3, Appendix E). Due to the small sample size, statistical analysis could not be used to test for statistical significance.

Table 3. Success of Hawaiian Gallinule nests in individual lotus fields, Haleiwa, Oahu, February 1979 to January 1980.

Field	Area (ha)	Number of nests			
		Successful	Unsuccessful	Undetermined	Total
Kunehiro-a	3.5	6	3	3	12
Kunehiro-b	0.8	4	4	1	9
Tantog	3.2	1	2	1	4
Kamalani	0.3	1	1	-	2
Ung	0.3	1	5	1	7

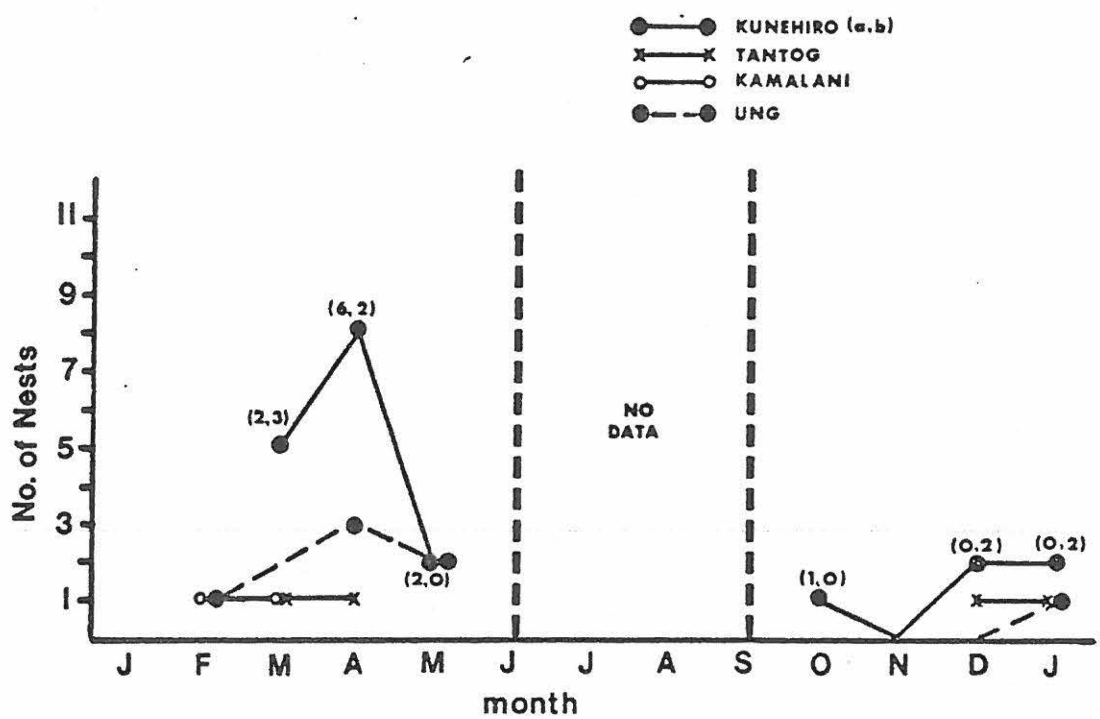

Fig. 10. Number of Hawaiian Gallinule nests found in 4 lotus fields, Haleiwa, Oahu, February 1979 to January 1980.

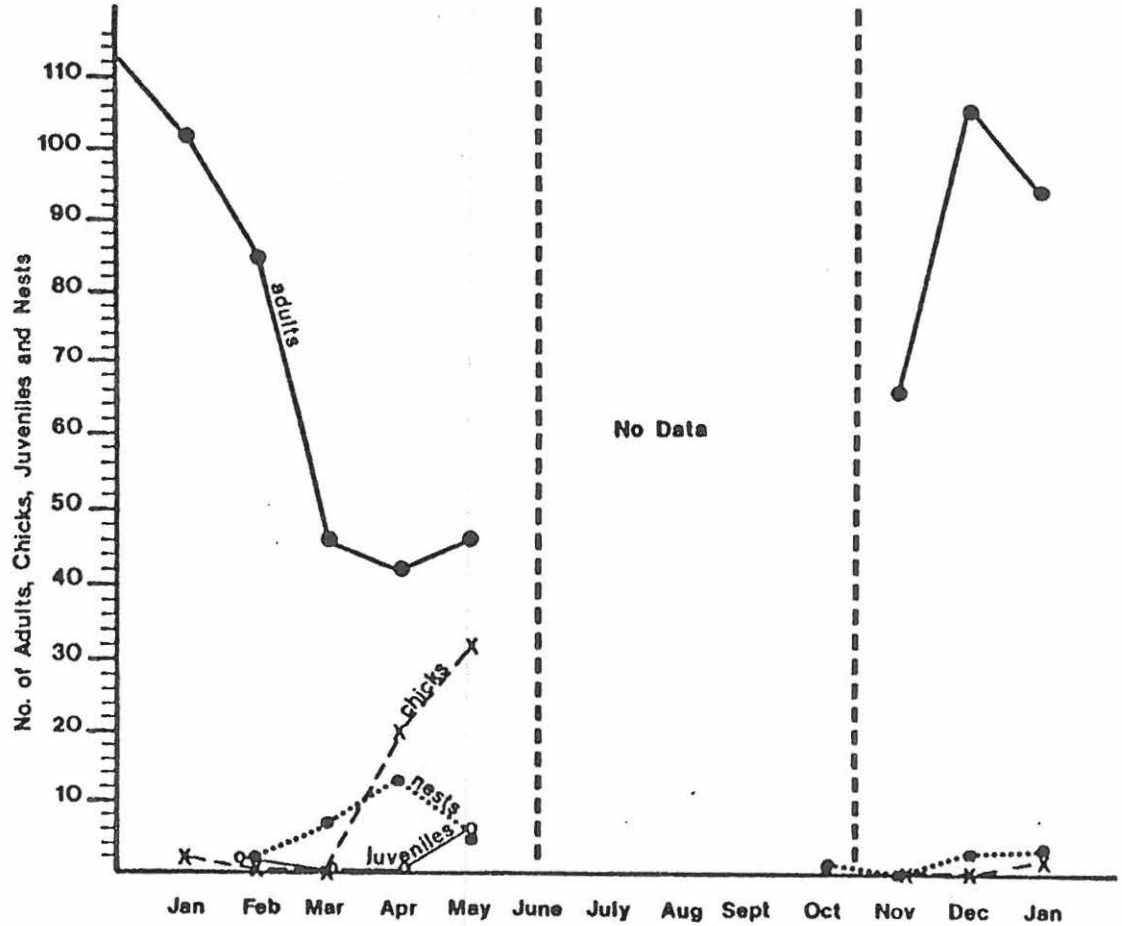

Fig. 9. Number of adults, chicks, juveniles, and nests of Hawaiian Gallinule in lotus fields, Haleiwa, Oahu, January 1979 to January 1980.

margin of the canal was abandoned; earlier, children were observed throwing rocks at the incubating birds from the grassy curbside.

Haleiwa

Temporal distribution. The increased density of lotus during the summer months, extending from June through October, precluded observation of gallinules. Nesting in lotus fields during these months is unknown, although fragments of an egg shell were found on a dike in Tantog's field and 1 nest was referred to me in October, by a field worker of Kunehiro-a. Workers first discovered the nest (still being incubated) when they began harvesting the plot, but was abandoned by the time I was informed of the nest.

Nesting activity was observed February through May, December 1979, and January 1980, during which time 34 nests were observed. The greatest number of nests (13), was observed in April, 6 more than March and 8 more than May (Fig. 9). Nests were observed in the central fields and Kunehiro-b in December and January, but no nests were observed in Kunehiro-a (Fig. 10).

Placement of nests. All nests observed were found in the lotus fields and all but 1 were placed directly on the ground. The remaining nest was placed on the top of a mat of floating water hyacinth *Eichornia crassipes*, in one of Kamalani's plots that was not planted with lotus. Most of the nests were placed under lotus leaves ranging from 2 to 11 and averaging 5.7 leaves. Six nests found in lotus plots were completely exposed (Appendix C). No nests in Kunehiro-a were found in plots adjacent to the dirt road, except where tall *B. mutica* formed a barrier between the road and field.

Table 2. Distances between Hawaiian Gallinule nests occurring simultaneously or approximately the same time at Hamakua marsh, Kailua, Oahu, February through November 1979.

Date nest found	Nest identification	Distance (m)
February 25	H_a and H_d	100
February 25	H_d and H_b	87
April 25	H_c and H_f	137
June 14	H_g and H_h	216
November 3 and 7	H_j and H_k	377
November 7 and 26	H_k and H_l	175

The largest broods observed were H_d with 6 chicks, followed by H_h with 5 chicks and H_e with 1 chick of a possible 3. When H_e was first discovered, 1 chick had already hatched and the 2 remaining eggs had chicks that had pipped holes large enough to see the chicks within. Three days later, only 1 chick was observed swimming with its parents.

From clutches H_d and H_h, only 3 of the 11 chicks survived beyond 8 weeks, which according to Karhu (1973) and Wood (1974) is the time it takes a Common Gallinule chick to fledge in Europe. Workers immediately across the canal from nest H_h reported a mongoose had entered the nest and preyed on all but 1 chick. At least 2 chicks from nest H_d fledged. The 1 chick from nest H_h survived beyond 8 weeks.

The cause of nest failure for most of the 9 nests that failed could not be determined. Eggs with holes that appeared to be pecked, and broken shell fragments found near the nest site, suggested birds or mongoose as possible predators. The only nest located on the northern

Table 1. Location and environmental features of Hawaiian Gallinule nests at Hamakua marsh, Kailua, Oahu, February through November 1979, and January 1980.

Environmental feature	Location of nest: Pond/meadow	Location of nest: Canal edge
Vegetation type		
Scirpus paludosus	4*	
Scirpus californicus	1	
Paspalum vaginatum	1	3*
Brachiaria mutica		3
Bacopa monnieria	1	
Placement of nests		
On water	1	3
Above water	4	
On vegetation	2	3
Exposure of nest		
Exposed	2	3
Enclosed	5	3
Depth of water		
0-25 cm	6	
26-50 cm		1
51-75 cm		1
76-100 cm		3
Number of stems around nest		
≤25	2	
26-50	2	1
51-75	2	1
≥76	1	3

*Number of nests.

remaining nests, 1 each in B. mutica and B. monnieria, were completely exposed lacking both canopies and concealing vegetation (Table 1 and Appendix A).

Gallinules were observed placing their nests in 3 ways: directly on the water (4 nests), above the water (4 nests), and on top of vegetation (5 nests). These 3 nest placement types appear to be associated with three major vegetation types. Nests found in B. mutica were placed directly on the water, those found in S. paludosus above the water, and P. vaginatum nests on top the vegetation. One nest found in S. paludosus was placed directly on the water, the nest found on B. monnieria on top the vegetation, and the nest in bulrush above the water (Table 1 and Appendix A).

Spatial nesting distribution. The range of distances between nests was 87 to 377 m, averaging 182 m (Table 2). The distance between nests H_b and H_c was not included. An active nest (H_c) with 4 eggs, was probably a renesting attempt after failure of H_b which was already abandoned (1 broken egg) upon discovery. Although H_d was not an active nest (no eggs), the presence of chicks represented a successful nest. The territory in which H_d was placed was maintained due to the presence of the chicks.

Nest success and brood success. Nests were considered successful if at least 1 egg hatched. Three of 13 nests were successful, 9 failed, and observations ended on 1 nest in January 1980 before success could be determined. From nests with complete clutches, the size of the clutch ranged 5 to 7, averaging 6.2 (± 1.76, P = .05) eggs (Appendix B).

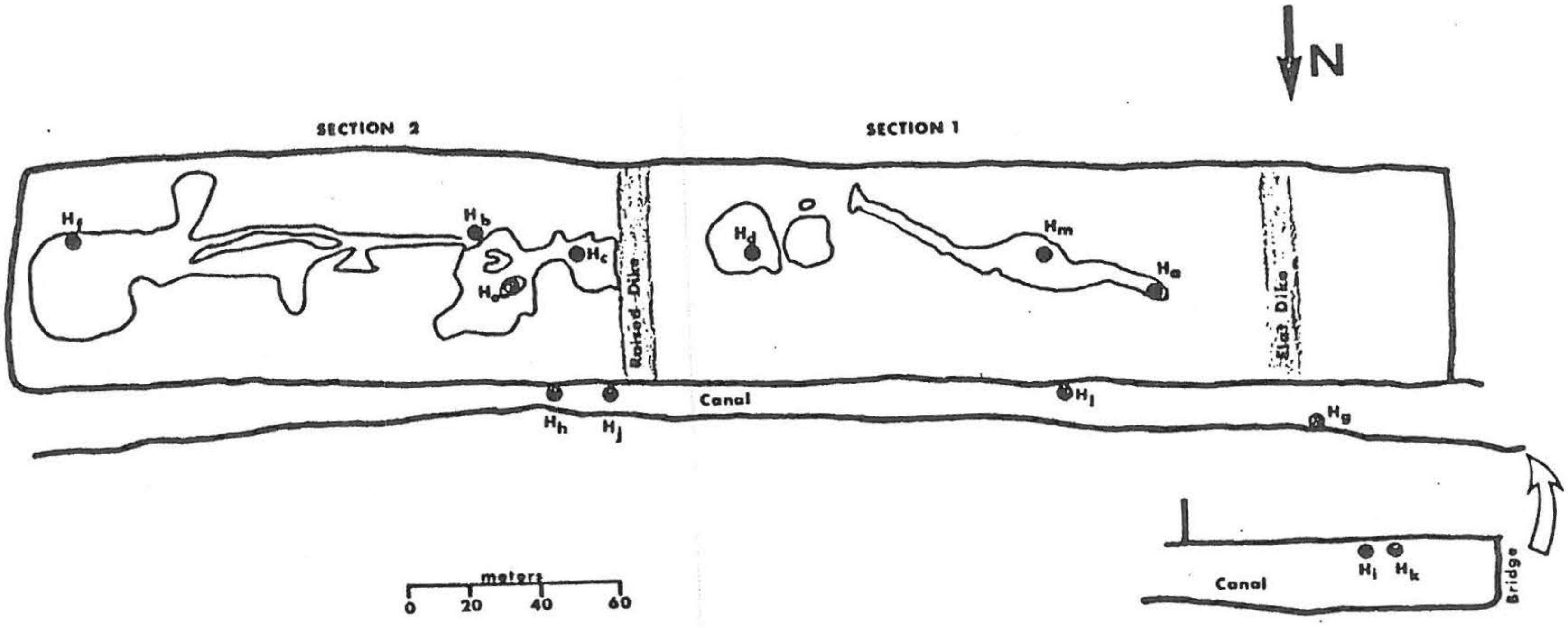

Fig. 8. Location of Hawaiian Gallinule nests at Hamakua marsh, Kailua, Oahu, February 1979 to January 1980.

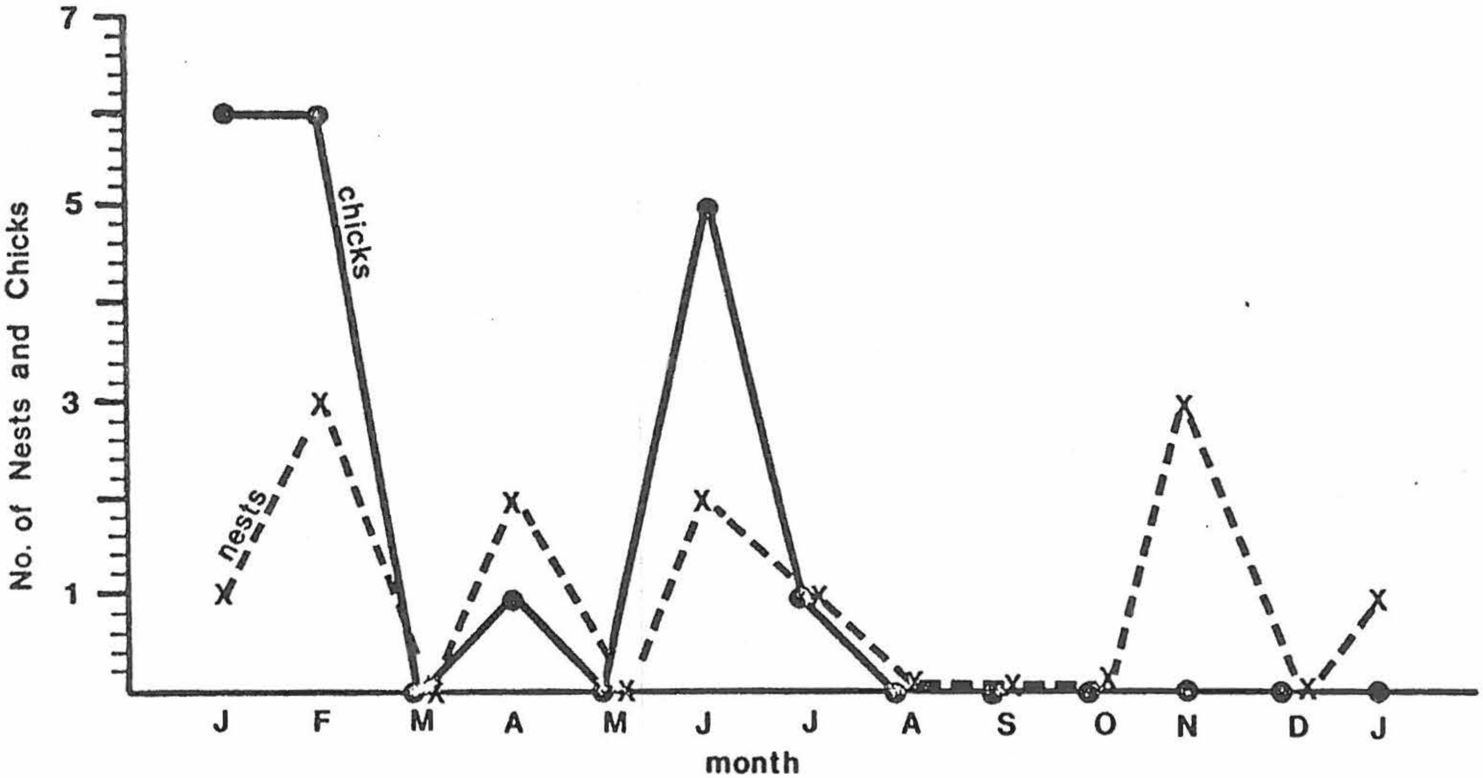

Fig. 7 Occurrence of Hawaiian Gallinule nests and chicks at Hamakua marsh, Kailua, Oahu, February 1979 to January 1980.

number occurring in February (3 nests) and November (3 nests) (Fig. 7). New nests were not found the month following either of the 2 peaks, despite courtship behavior in preceding months. Likewise, courtship behavior was observed in August, September, and October, 3 successive months during which no nests were found.

Location and placement of nests. Nests were nearly equally distributed between the meadow (7 nests) and the canal (6 nests) (Fig. 8). Nests found during February and April 1979 and January 1980, were all located in the meadow adjacent to the ponds, except for 1 nest located in a bulrush stand. Five of the 6 nests found during June, July, and November 1979, were found along the southern margin of the canal, with the sixth located along the northern margin.

Eight of 13 nests were placed among and enclosed by vegetation, 4 in S. paludosus, 2 in B. mutica, 1 in P. vaginatum, and 1 in S. californicus. Nests in S. paludosus and B. mutica had canopies made from loosely-woven stems surrounding the nest. Nests found in P. vaginatum and S. californicus lacked such canopies. A nest located in P. vaginatum (H_h) was in the middle of a clump completely concealing the nesting bird. The birds entered the nest through an opening at the base of the clump rather than from the top.

The remaining 5 nests, although placed among vegetation, were exposed and lacked a canopy of enclosing vegetation. Three of these nests were found in P. vaginatum and differed from the nest described above by being placed on top rather than inside the P. vaginatum clump. These nests were surrounded by stems of sufficient height (average 27.7 cm) to provide at least partial concealment. The 2 resulting in a sudden growth spurt manifested by an increased height and distribution of lotus leaves. As lotus leaves increased in density, creating a shady understory, there was an apparent decrease in Azolla. During the peak of their growth the lotus completely shaded the understory and Azolla no longer occurred in thick mats, but was sparse and scattered. Where there was enough incident light to permit growth; e.g., along the edges of the plots, Azolla occurred in thick mats.

A difference in field conditions existed between Tantog's, Ung's, and Kunehiro's fields. Mr. Kunehiro did not need to pump water into his plots except for 1 plot in Kunehiro-a and a couple in Kunehiro-b. Tantog's and Ung's fields required nearly constant pumping, however, the pumping did not appear to be sufficient to maintain conditions like those found in Kunehiro's. It was observed while taking samples for invertebrates that some of Tantog's plots had harder and drier mud than Kunehiro's fields. Tantog's and Ung's fields had weed problems, mainly honohono grass (Commelina diffusa), kamole (Ludwigia octivalvis and Cyperus polystachus) (Elliott and Hall 1977). Their fields, especially Tantog's, were overgrown with weeds, such that the plots were no longer recognizable as lotus plots. Tantog and Ung were observed weeding their plots at the same time nesting occurred.

Nesting

Hamakua

Temporal distribution. Thirteen nests were observed in the Hamakua study area. Nesting occurred in January, February, April, June, July, and November 1979, and January 1980, with the greatest

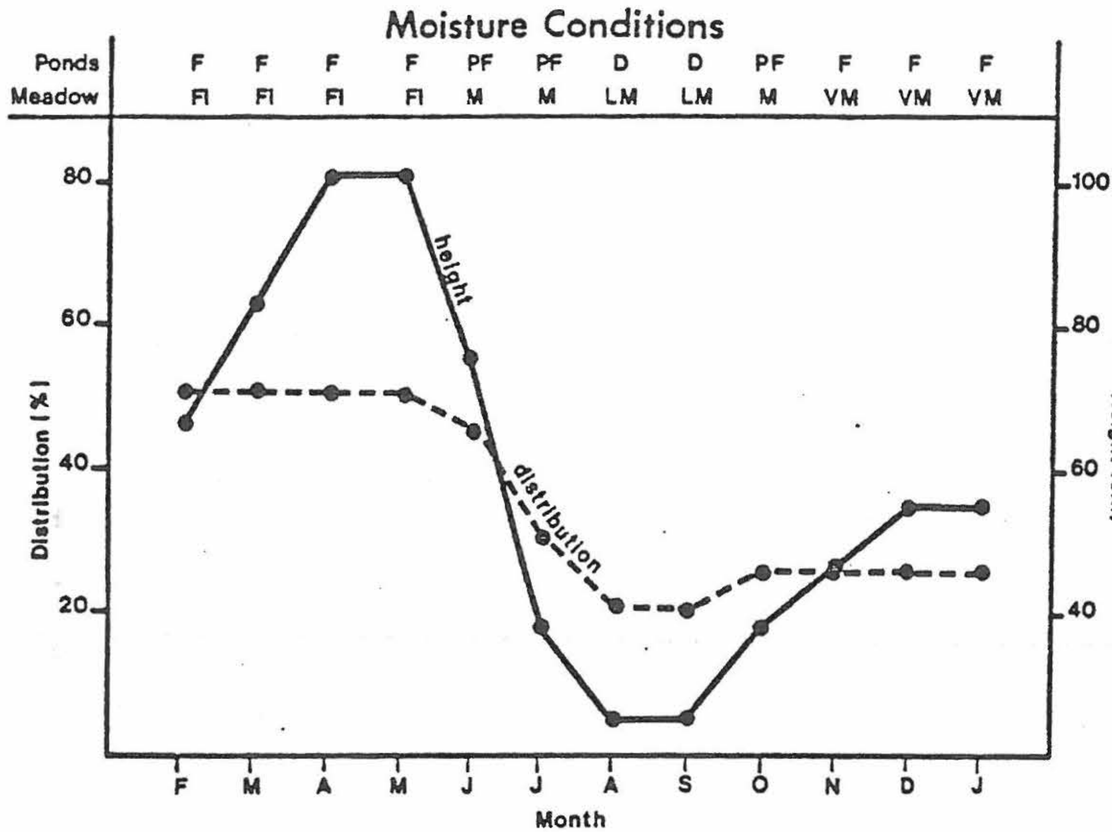

Fig. 6. Moisture condition of meadow and status of S. paludosus (vertical axes) at Hamakua marsh, Oahu, February 1979 to January 1980. (D = dry; F = filled; FL = flooded; LM = little moisture-dry; M = moist; PF = partially filled; VM = very moist).

rainfall and subsequent refilling of the ponds and resaturation of the meadow were followed by a regeneration of S. paludosus, but not to its former level of February; instead, a steady rise in distribution and height occurred, leveling off at 25% and 55 cm in December 1979 and January 1980 (Fig. 6). Scirpus paludosus was taller and formed denser stands around the perimeter of the ponds. Scirpus californicus stands likewise wilted and died back; those growing in and along the edge of the ponds disappeared.

Periodically, the City and County of Honolulu applied an herbicide to the vegetation in and alongside the canal to control the growth of P. stratiotes, B. mutica, and P. vaginatum. A tank truck would drive slowly along the north side spraying the vegetation in and along the slopes of the canal. Near the bridge, P. stratiotes multiplied, forming a green carpet across the width and eastward down the canal. The herbicide killed most of P. stratiotes, causing it to turn brown and eventually sink. Paspalum vaginatum and B. mutica were affected to a lesser degree, turning yellow or brown, but a mass die-off did not occur. Pistia stratiotes grew back only to be treated again. Ceratophyllum sp. was also found in the canal but did not appear to be affected by the herbicide; instead, it was raked out of the water. Like P. stratiotes, this species also multiplied and recovered fairly rapidly.

Haleiwa

Early in the year, lotus fields were covered with a thick layer of water fern Azolla filiculoides (Elliot and Hall 1977) (hereafter referred to as Azolla) and scattered, short, newly-emergent lotus leaves. To speed the growth of lotus, farmers fertilized their fields, RESULTS

Vegetation

Hamakua

During the first 5.5 months of this investigation, marsh-like conditions prevailed throughout the study area. Ponds in the marsh were filled and the meadow remained flooded. Heavy precipitation during January and early February 1979 was responsible for maintaining the marsh-like conditions.

During the latter half of May, the ponds and meadow began to dry up. By August they were completely dry. Intermittent rains filled the ponds temporarily, but not until October were the ponds once again partially refilled and remained so till the end of the study period. The meadow did not regain its former flooded condition of January and February, except after heavy rains the meadow was temporarily flooded.

The dominant vegetation found growing around and encroaching into the ponds was S. paludosus and B. monnieria. Together they comprised 90% of the meadow vegetation cover. A few stands of bulrush scattered in Section 1 and P. indica composed the remaining 10%. Pluchea indica shrubs formed a border around the perimeter of the marsh.

Following the desiccation of the ponds and meadow was the thinning and dieback of S. paludosus resulting in thin short stands. In August, the distribution and height of S. paludosus decreased to 20% and 25 cm, respectively, from 50% and 80 cm recorded in February. Intermittent a sampler. The sampler was shoved into the ground and all contents within the sampler (water, mud, or both) were removed, preserved in 10% formalin, screened through a 0.5-mm mesh screen, picked, and sorted according to their major taxa.

stopping for 10-minute periods. The arbitrarily-set 10-minute periods were used to observe gallinules that might emerge from hiding in the vegetation. The clear view from the canal eliminated the need to stop at measured distance intervals, but stopping points occurred when a better viewing point was attained. It was not likely that a bird was counted more than once because of the wide spatial distribution of the gallinules.

In the Haleiwa fields, gallinules were censused by walking the perimeters of the plots and counting the number of birds per plot. Gallinules on plots observed from the road were counted from a vehicle, otherwise a walking survey was necessary. Gallinules do not readily fly unless suddenly disturbed. When the approach of an observer was slow, they tend to walk or run from the approaching observer. By slowly walking along the dikes, the observer was able to count those birds that were blocked from view by slowly flushing them from under or behind lotus leaves.

Invertebrate Sampling

A survey of macroinvetebrates was conducted to determine if differences in invertebrate numbers existed between the two lotus fields. Macroinvertebrates were selected for study because of observations of feeding habits and mention of Common Gallinules feeding insect larvae to their young insect larvae; i.e., mayflies and dragonflies (Fredrickson 1971, Krauth 1972, Witherby 1947).

Substrate samples were taken from randomly-selected locations, using a random numbers table, around the perimeter of the plots. The top half of an aluminum can 28 cm in diameter and 4 cm deep was used as

Observations from behind a blind and under a shelter were attempted in Kunehiro-a. Gallinules, however, flicked their tails, a sign of alarm (Wood 1974, Howard 1940), and observations were, therefore, discontinued.

Nesting

Nests in Hamakua were located by walking through the marsh and searching in vegetation. In the lotus fields, the lateral growth of lotus roots prohibited walking into the plots to search for nests; instead, nests were located by walking around the perimeters of the plots. A record of nests found was made, of the type of vegetation, number of stems around the nest or number of lotus leaves over the nest, how the nest was placed, and type of materials used in nest construction. Clutch size was not recorded for some of the nests found in the lotus fields due to the inability to see directly into nests from plot perimeters, but was recorded for those found in Hamakua. The number of chicks per nest was recorded for both sites. Juveniles were distinguished from chicks if they survived after 8 weeks, which according to Karhu (1973) and Wood (1974) is the time it takes a common gallinule chick to fledge in Europe.

Census

Censusing of gallinules was attempted with playback recorded calls. A tape of North American Gallinule calls was obtained from Cornell Laboratory of Ornithology, but preliminary trials showed no response by Hawaiian Gallinules and the method was abandoned. A visual count was then used to census the birds. At the Hamakua site, gallinules were counted by walking, or driving along the canal, and

MATERIALS AND METHODS

The study was conducted from February 1979 to mid-January 1980. Vegetation dynamics, nesting characteristics, behavior, censusing, and invertebrate sampling, were investigated.

Vegetation

Plant species were recorded monthly and plotted on maps. Height and percent cover were recorded to measure dynamic changes in the vegetation. Percent cover was estimated by visual inspection per plot (lotus fields) or section (Hamakua) and height was measured using a metric roll tape.

Behavior

Gallinule behavior, including feeding, incubation, nest building, bathing and preening, and agonistic encounters was observed. All behavioral activities, durations (time budgets), and locations, were recorded whenever possible, by sex. Sex of the birds was distinguished by coition, assuming the bird observed mounting was the male. Birds were identified for future observation by markings on the upper frontal plate. A nesting pair was recognized upon subsequent visits by marks on their frontal plate.

Observations were made from a vehicle parked alongside the canal using a pair of 7 X 50 binoculars and a 15 X 60 zoom spotting scope. Presence of the vehicle did not have any obvious affect on the behavior of gallinules, whereas standing or walking alongside the canal did.

An earthen dike divides the marsh into two sections: west (Section 1) and east (Section 2). The canal is exposed along Section 1; paralleling the canal of Section 2 were light industries and small businesses. Cattle have been observed grazing in the meadows in both sections, but generally remained on the slope of the ridge.

The 2 major marsh meadow plants were Scirpus paludosus, a bulrush, and Bacopa monnieria, a low-growing succulent. Another type of bulrush (Scirpus californicus) occurred in scattered clumps in Section 1 and the perimeter of the marsh was surrounded primarily by pluchea (Pluchea indica) (Elliott and Hall 1977) shrubs.

The marsh was bordered by a low-lying ridge to the south and a canal to the north. The canal was frequently covered with water lettuce (Pistia stratiotes) and coontail (Ceratophyllum sp.). Pistia stratiotes, B. mutica, and Paspalum vaginatum (Elliott and Hall 1977) (a grass growing along the canal), were controlled with herbicide, and coontail, by raking. Vegetation was not equally distributed on both sides of the canal. The northern edge of the canal was bordered by a relatively steep slope from the curb to the water, vegetated at the water's edge primarily by B. mutica. The southern edge of the canal is vegetated mainly by P. vaginatum, which often forms thick clumps growing into the canal itself.

The area receives 64 to 102 cm of rain per year. The red desert soil is nonstony, deep, fine-textured with expanding clay properties, and poorly drained. The overall productivity rating for the area is C (on a scale A, highest to E, lowest) (University of Hawaii Land Study Bureau 1972).

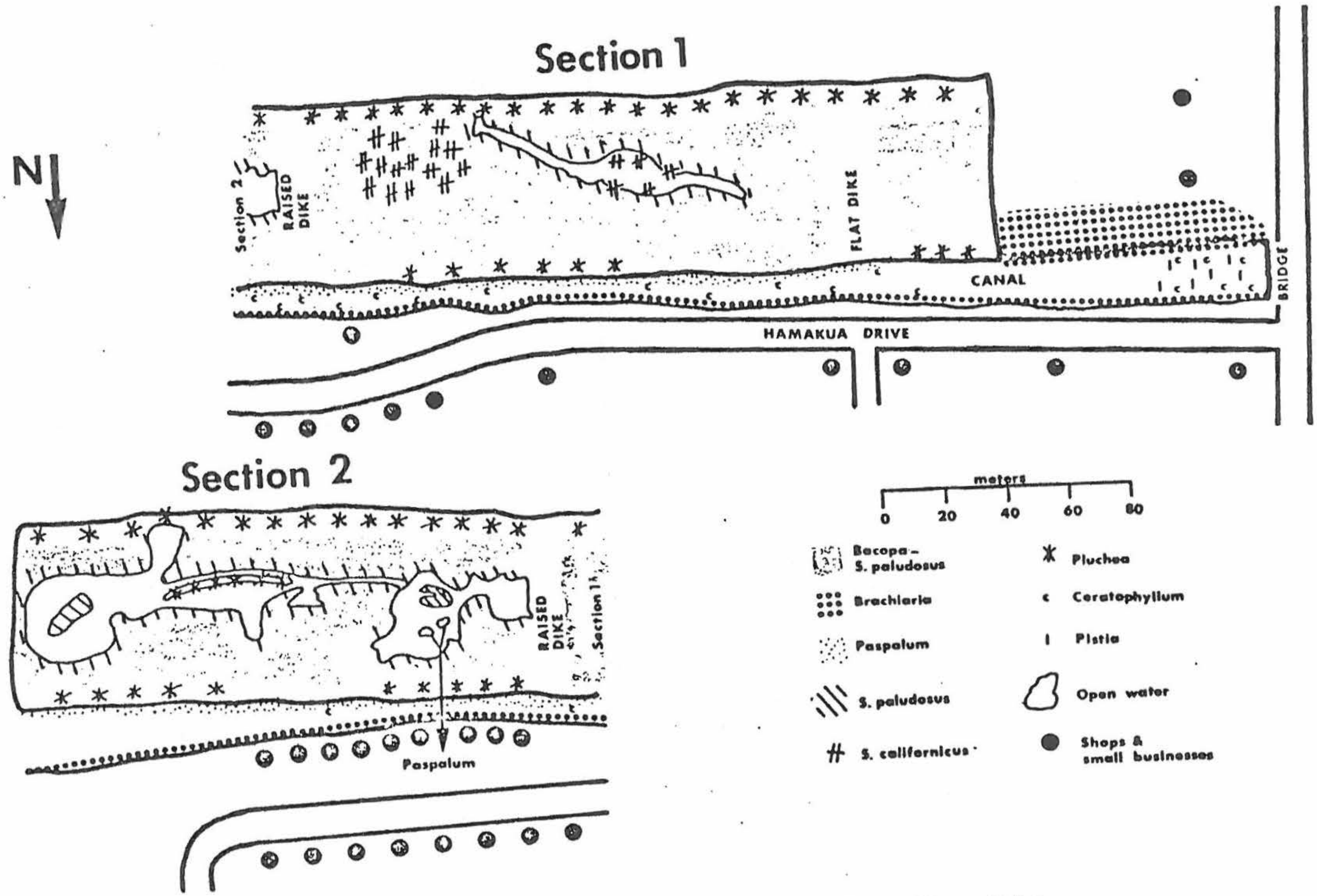

Fig. 5 Vegetation map of Hamakua marsh, Kailua, Oahu.

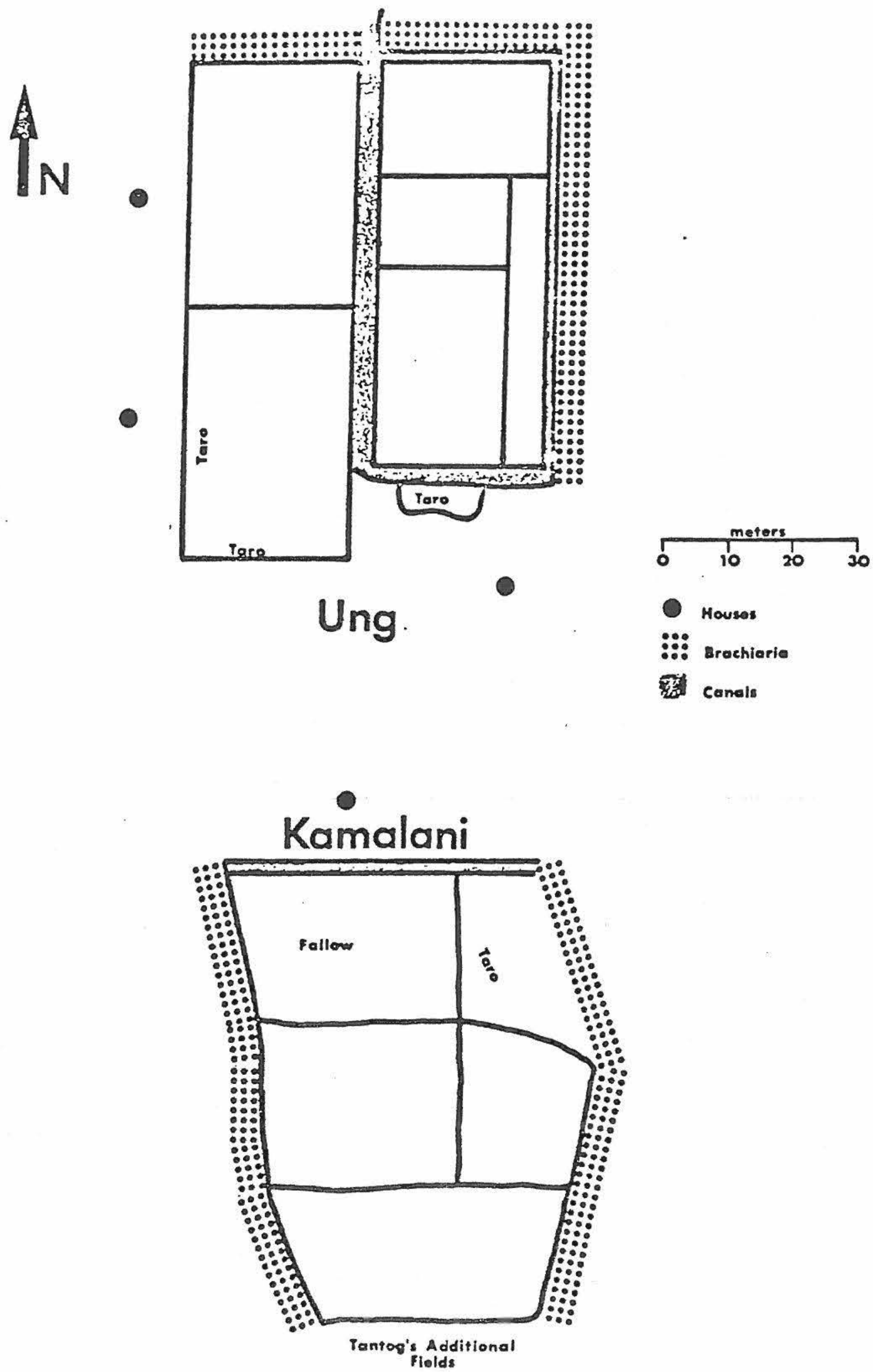

Fig. 4 Vegetation map of Ung's and Kamalani's lotus fields (part of central field), Haleiwa, Oahu.

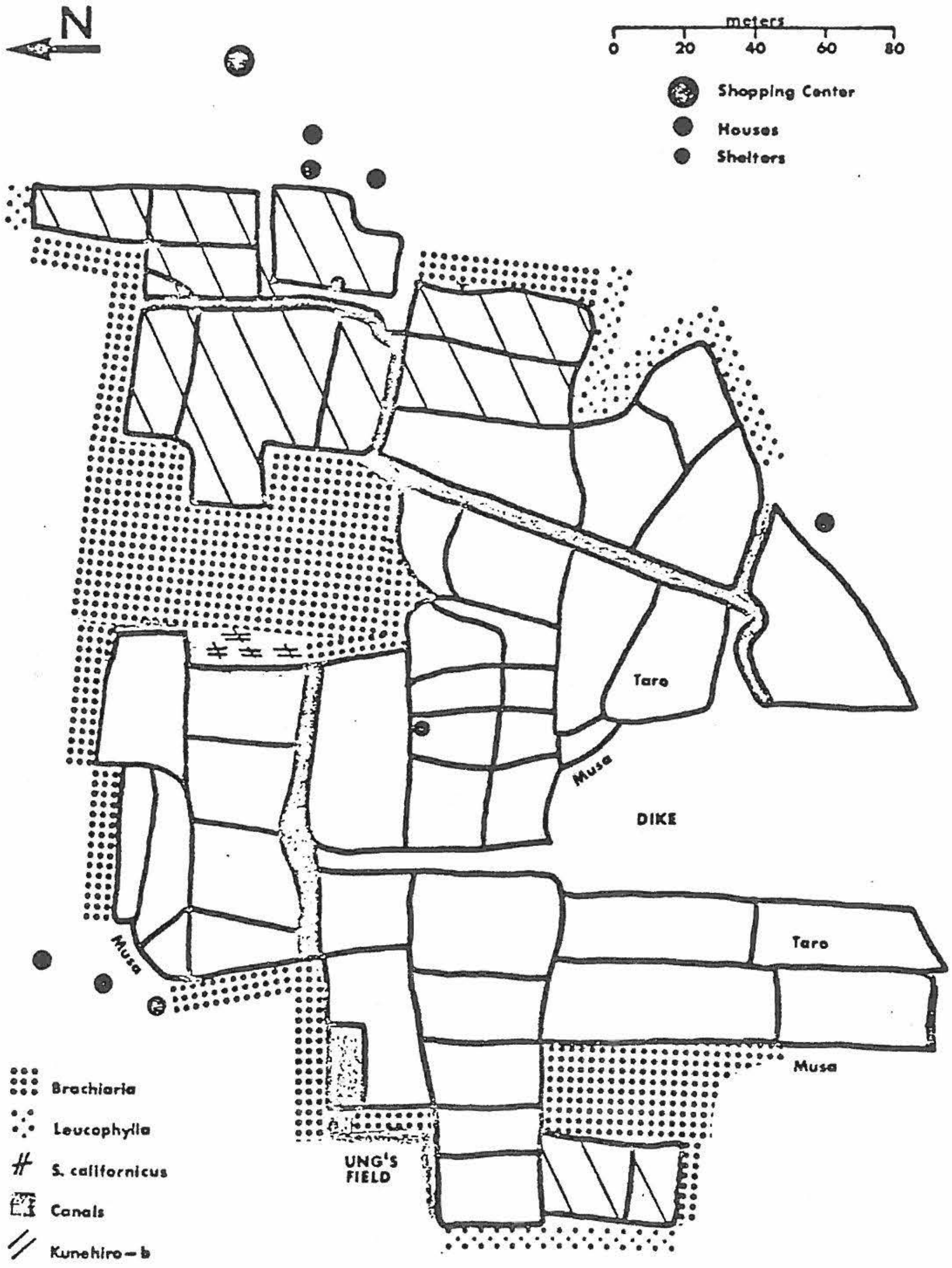

Fig. 3. Vegetation map of central lotus fields, excluding Kamalani's and Ung's, Haleiwa, Oahu.

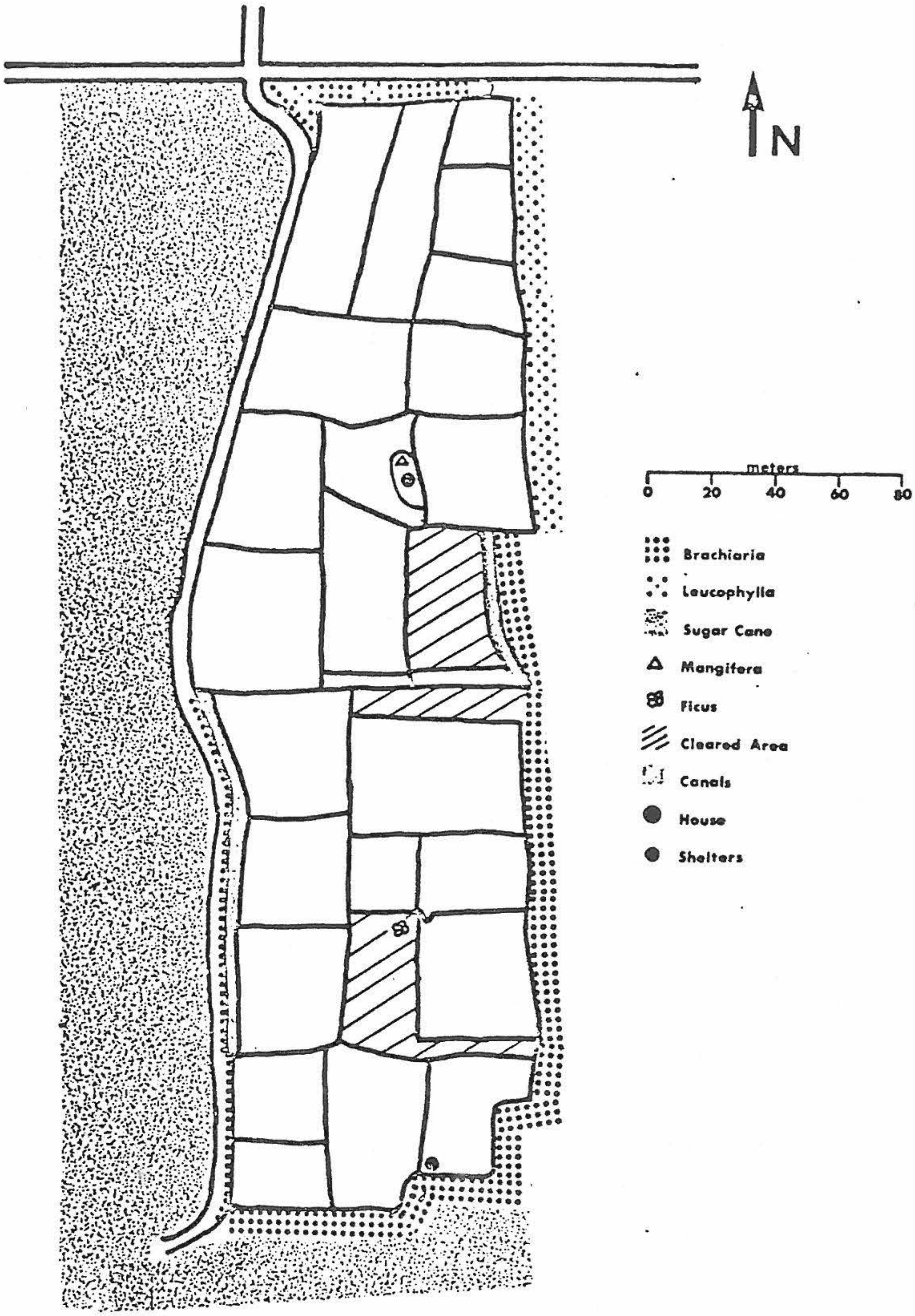

Fig. 2. Vegetation map of Kunehiro-a lotus field, Haleiwa, Oahu.

referred to as Kunehiro-b). Kunehiro-a is bordered on the north by a road, sugarcane fields on the west and south, and hale koa (Leucaena leucophylla) and California grass (Brachiaria mutica) on the east (Fig. 2). The central fields are farmed by 4 farmers: Mr. Tantog (3.2 ha), Mr. Kamalani (0.3 ha), Mr. Ung (0.3 ha), and Mr. Kunehiro (hereafter central fields refer to the first three farmers and excludes Kunehiro's portion) (Figs. 3, 4). Both Kunehiro's and the central fields were subdivided into plots separated by mud dikes.

Annual rainfall for the area ranges from 51 to 102 cm per year, averaging 76 cm. Soil types include well-drained, nonstony, deep (greater than 76 cm) red desert soils, low humic latasols, and alluvial soils. Texture of the soil is rated moderately fine to medium with nonexpanding clay properties. Despite the close proximity of the fields, the overall productivity rating for the central fields is A. Kunehiro-a is rated D on a scale of A, highest to E, lowest (University of Hawaii Land Study Bureau 1972).

The second study site (a 3.2-ha marsh in Kailua located in windward north-central Oahu), hereafter referred to as Hamakua (Fig. 5), is used as a cattle grazing pasture. Following heavy precipitation, ponds in the marsh were filled (ranging 4 to 24 cm in depth) and the meadow portion of the marsh was completely saturated and often flooded. During this study, the ponds and marsh began drying in mid-May. By August, they were completely dry and remained dry until October, when heavy showers refilled the ponds and remoistened the meadow.

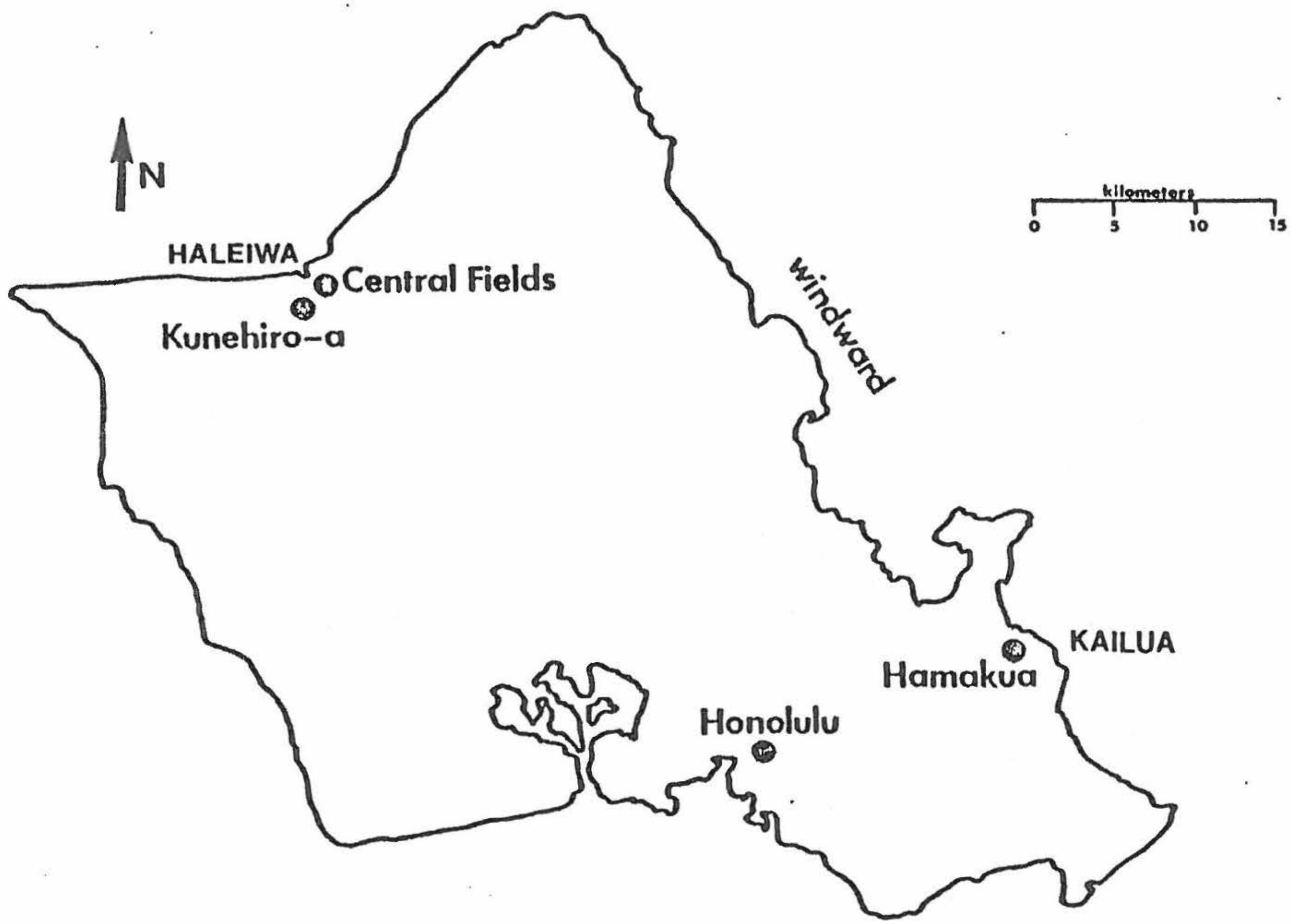

Fig. 1. Map of the island of Oahu showing location of the 2 study sites at Haleiwa (Kunehiro-a and central fields) and Kailua (Hamakua marsh).

DESCRIPTION OF STUDY AREA

Two study sites, a group of lotus farms at Haleiwa and a marsh in Kailua, were selected, primarily on availability and visibility of gallinules. Haleiwa, a town located on the northwestern coast of Oahu, is the center for lotus (Nelumbo nucifera) (Elliot and Hall 1977) agriculture on Oahu (Fig. 1). Lotus, which is harvested for its roots, is a wetland agricultural crop requiring standing water. Farmers maintain over-saturated soil conditions by flooding their fields from naturally-occurring freshwater springs. Because soil condition prevents utilization of heavy machinery, lotus farming relies mainly on manual labor.

Once lotus was planted, the fields were generally entered only to fertilize and weed, usually early in the growing season. After fertilizing, the lotus was left alone until it was harvested from October to December. Lotus leaf stalks grow more than 150 cm tall, attaining densities thick enough to preclude observation of gallinules during summer months. Beginning in late September lotus leaves and stalks began to wilt and dry up, indicating the lotus was ready for harvest. The lotus dries up in intervals, depending on the timing of replanting and fertilizing earlier in the season.

The Haleiwa lotus fields were divided into sub-sites consisting of Mr. Kunehiro's fields and the central fields. Mr. Kunehiro's fields are composed of a 3.5-ha field (hereafter referred to as Kunehiro-a) and an additional 0.8-ha field located in the central fields (hereafter