# A STUDY OF THE BIOLOGY OF THE ORANGEBLACK HAWAIIAN DAMSELFLY (*MEGALAGRION XANTHOMELAS*), WITH SPECIAL REFERENCE TO CONSERVATION OF THE POPULATION AT TRIPLER ARMY MEDICAL CENTER, OAHU

Neal Evenhuis, Dan Polhemus, Sabina Swift,
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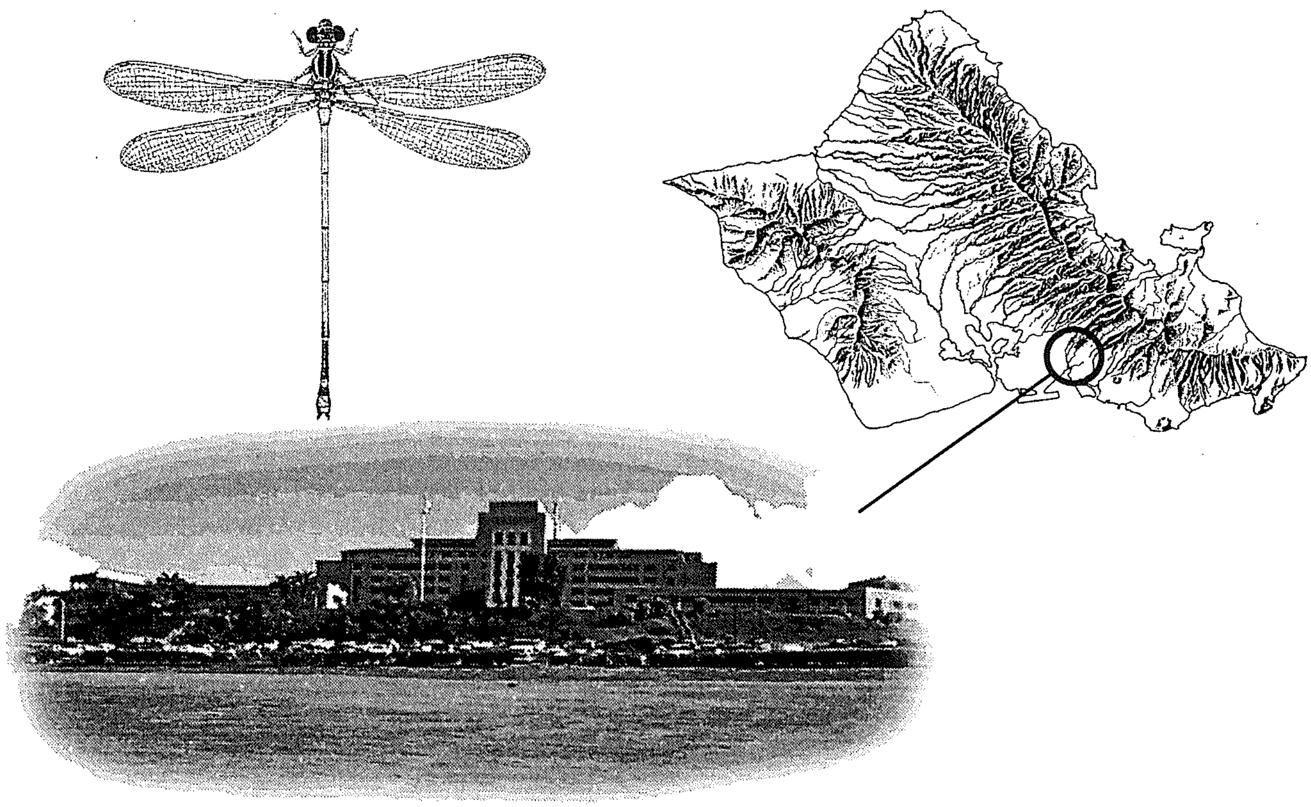

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**Final Report**

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Keith Arakaki and David Preston

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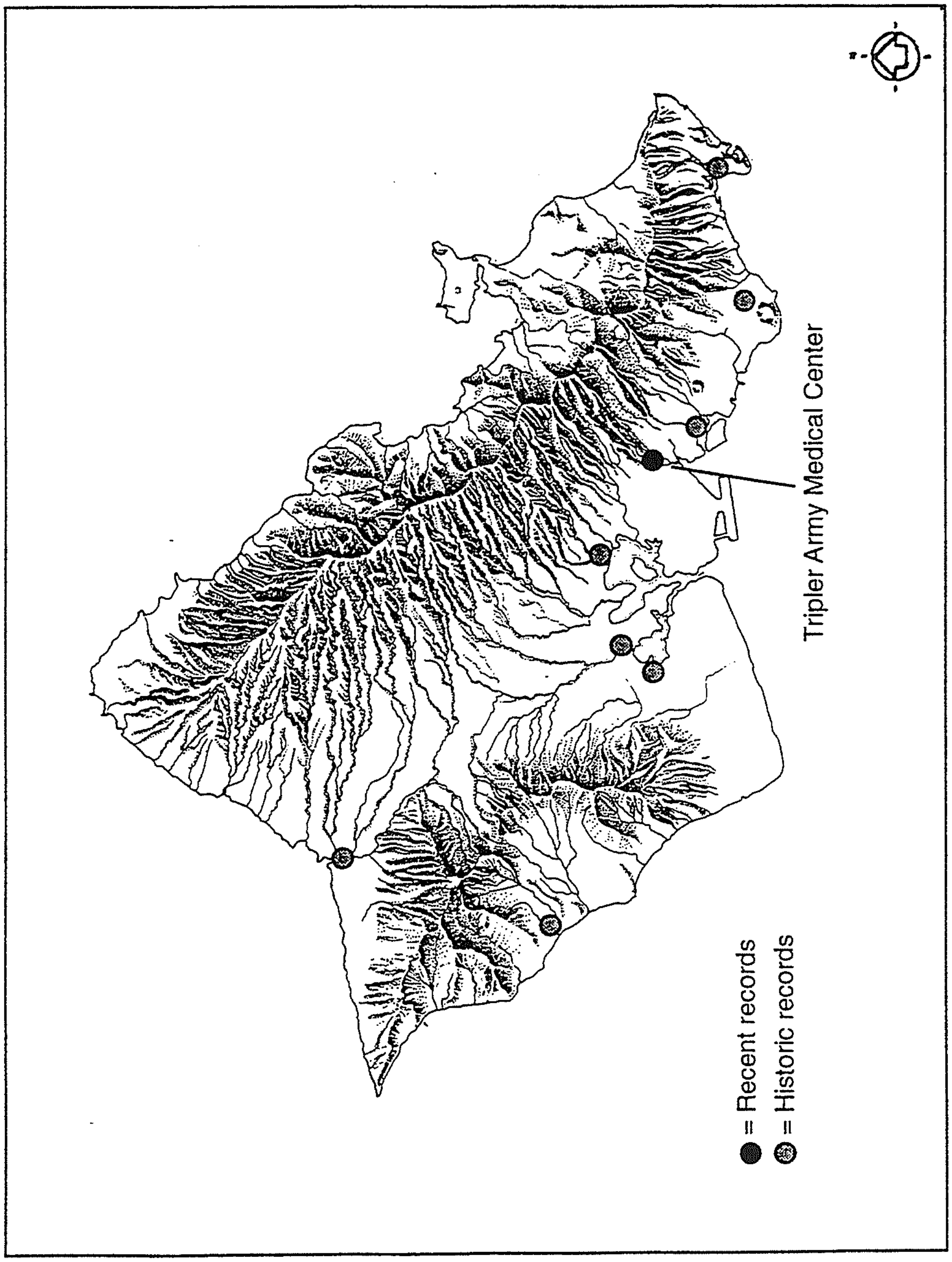
## INTRODUCTION

From 20 March to 31 August 1995, investigations were conducted on the biology of the Orangeblack Hawaiian Damselfly, *Megalagrion xanthomelas*, at the Tripler Army Medical Center (TAMC) on Oahu, and at various other sites on the islands of Lanai, Molokai and Hawaii. These studies were intended to provide baseline information on the biology of *M. xanthomelas* for use in mitigating construction impacts on a population of this species occurring at TAMC. Detailed monitoring of the *M. xanthomelas* population at TAMC was undertaken on a weekly basis, and the basic life history and environmental requirements of the species elucidated. Studies of populations on other islands were shorter in duration, and were intended primarily to determine the range of habitats occupied by the species throughout the Hawaiian islands and the breadth of its ecological tolerances. These latter studies were designed so as to examine populations in a broad spectrum of ecosystems, ranging from lotic to lentic, and from natural to artificial.

## BACKGROUND

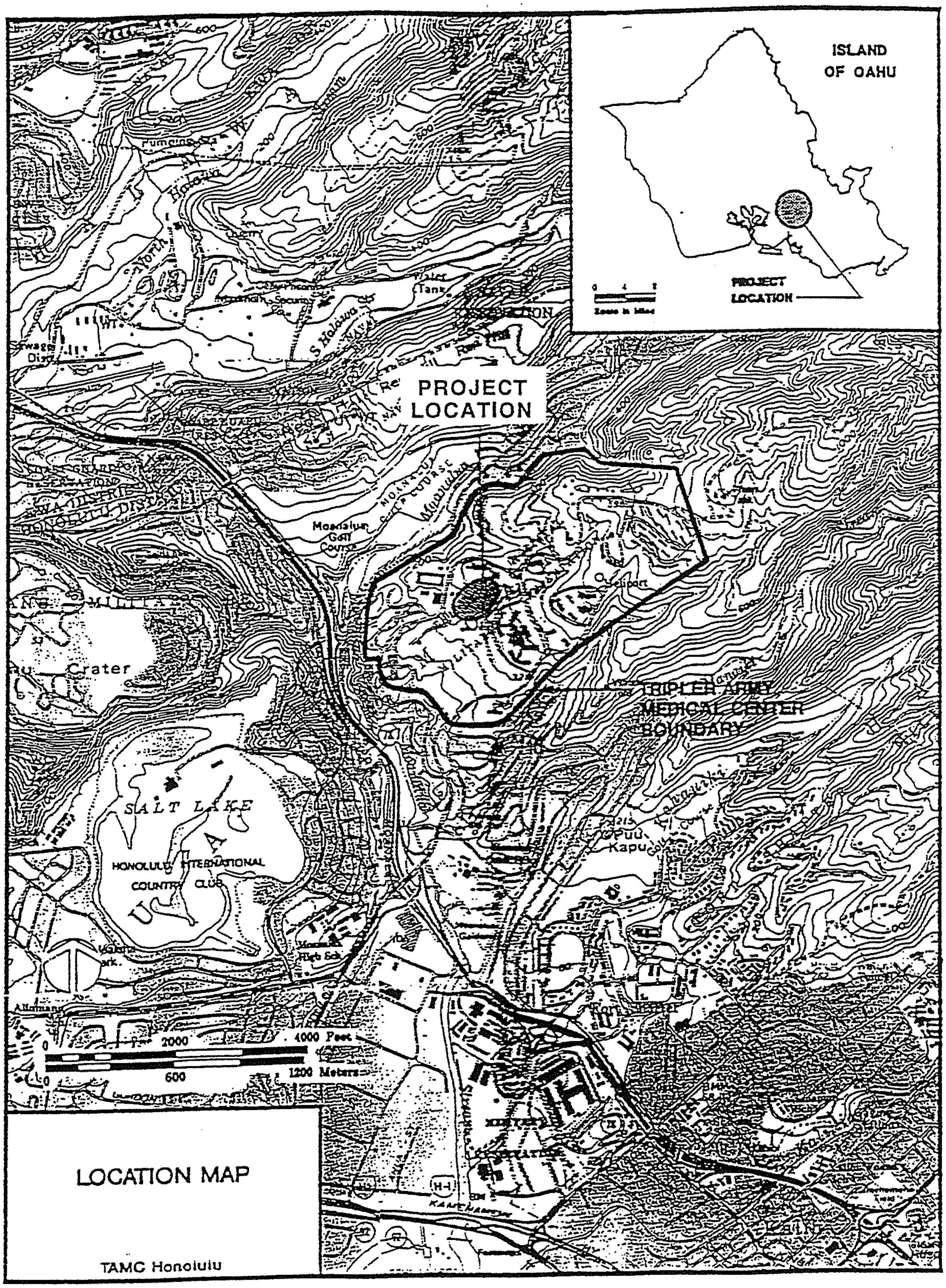
The Orangeblack Hawaiian Damselfly, *Megalagrion xanthomelas*, formerly occurred throughout lowland aquatic habitats on all the high Hawaiian islands with the possible exceptions of Kauai, Niihau and Kahoolawe. Although common at the turn of the century, the species began to experience a progressive decline after World War II, and by the early 1990s had not been seen on Oahu for over twenty years. This fact, coupled with the extensive alteration of lowland habitats in which the species formerly bred, led Polhemus (1993) to conclude that the species was probably extirpated on Oahu when he reviewed the conservation status of *Megalagrion* species for the U.S. Fish and Wildlife Service (USFWS). Based on this assessment, plus the apparent extirpation of the species on Maui as well, USFWS (1994) proposed that *M. xanthomelas* be listed as a Threatened species and given protection under the Endangered Species Act. Due to political considerations, this listing has been temporarily delayed, but the species retains a C1 status on the Federal Register, meaning that the USFWS has on file sufficient information on biological vulnerabilility and threat(s) to support proposals to list it as an endangered or threatened species.

Given this, it was of great interest when a remnant population of *M. xanthomelas* was discovered in the course of an environmental survey conducted by personnel from the Bishop Museum in March of 1994 at the Tripler Army Medical Center (TAMC), on the outskirts of Honolulu (Maps 1–2). This population, so far as is known, is the last remaining colony of *M. xanthomelas* on Oahu, and thus a priority target for conservation efforts. The existence of the population was noted in a report to the R.W. Towill Corporation of Honolulu (Evenhuis and Cowie, 1994); this report also concluded that the insects were confined to a small gully near the greenhouse at the lower end of the TAMC site, in an area that had the potential for being impacted by proposed construction activities further upslope. It was recommended that in order to ensure the continued survival of the *M. xanthomelas* colony at TAMC the population should be continually monitored and managed and, if feasible, moved to a nearby location that would not be subject to construction impacts or other activities taking place on the TAMC grounds.




**Map 1.** Map of Oahu, showing location of current and historic records for *Megalagrion xanthomelas*

**Map 1**. Map of Oahu, showing location current and historic records of *Megalagrion xanthomelas*




**Map 2**. Map of urban Honolulu, showing location of Tripler Army Medical Center (TAMC)

A second environmental survey was conducted by Ogden Environmental at TAMC during the same time as the Bishop Museum survey, but missed the *M. xanthomelas* population. A subsequent study by this same firm (Ogden Environmental, 1994) provided a conceptual mitigation plan for the species, recommending *in situ* mitigation due to the population's small size. In particular, it was proposed that artificial ponds be constructed upslope of the existing population in an area isolated from construction impacts.

In order to properly construct these refugia for the TAMC population, it was necessary to conduct a detailed investigation of the biology of *M. xanthomelas*, which was poorly known at the time. The following report provides the results of this biological study, which was conducted both at TAMC, and at sites on other islands where populations of *M. xanthomelas* still persist. The terminology used to describe these aquatic ecosystems follows Polhemus *et al.* (1992).

## TAXONOMY AND HISTORIC DISTRIBUTION OF *MEGALAGRION XANTHOMELAS*

*Megalagrion xanthomelas* was described by Selys-Longchamps (1876) based on specimens collected by G.F. Matthew of the Royal Navy, and labeled "Sandwich Islands," with no specific island within the group noted on the labels. The location of Selys-Longchamps types is not currently known, although it is suspected that they may be in the Koninklijk Belgisch Instituut voor Natuurwetenschappen, in Brussels. The species has not been confused with others since its original description, thus its taxonomic history is relatively simple and devoid of synonyms.

The original distribution of *M. xanthomelas* within the Hawaiian Islands is a matter of some speculation. It seems unlikely that the species ever inhabited the small, dry islands of Niihau and Kahoolawe, and its presence on Kauai is open to question. Perkins (1899) stated that *M. xanthomelas* "Probably occurs all over the islands," although he lacked any collections from Kauai and Lanai. Kennedy (1917) followed Perkins' opinion and listed *M. xanthomelas* from Oahu, Molokai, Maui, Hawaii, Kauai and Lanai, although once again there were apparently no specimens at hand supporting the latter two records. It was only in 1993 that specimens were finally captured on Lanai (Polhemus, 1993); and to date the species has never been taken on Kauai, although a female specimen of this species was collected on nearby Niihau in 1947.

The ecology of *M. xanthomelas* was discussed anecdotally by Williams (1936), who also illustrated the immatures. They appear to have formerly bred in imponded sections of lowland streams, and in both natural and artificial ponds. The ability of this species to exploit artificial habitats was noted by Perkins (1913), who observed that *M. xanthomelas* was "a common insect in Honolulu gardens and in lowland districts generally, not usually partial to the mountains, though in the Kona district of Hawaii it is common about stagnant pools up to an elevation of about 3000 feet. It is very numerous under conditions changed from the natural; perhaps it now finds more numerous breeding places, and a more abundant prey in the numerous insects that have been introduced by man in the region it frequents." Williams (1936) also noted that *xanthomelas* bred abundantly in sugar plantation reservoirs at Waianae. Zimmerman (1948), by contrast, remarked that the introduction of *Gambusia* top minnows "has changed the lowland situation considerably in recent years, however, and the species is much less abundant than formerly."

The decline in populations of *M. xanthomelas* noted by Zimmerman in the years after World War II has continued to the present day. The species is now apparently extirpated on Maui, with no records from that island for the last hundred years, and reduced to single known population on Oahu (at TAMC). Molokai is known to support four populations, and the species is abundant in artificial golf course ponds on Lanai, although elsewhere on that island it retains only a tenuous foothold in small remnants of its former natural habitat. Only on Hawaii island is the species still truly widespread, being commonly found in the coastal wetlands of the Puna, Kau and Kona districts.

The population of *M. xanthomelas* occurring at TAMC appears to be a remnant of much larger and more continuous populations that formerly occupied the wetlands along the inner margin of Pearl Harbor. Five large basal springs previously emerged from the Koolau Aquifer in this area, these being from east to west the Kalauao, Waiau, Waimano, Waiawa and Waikele springs. The combined discharge of these springs in 1932 was over 80 million gallons a day (Stearns and Vaksvik, 1935), and their outflows formed extensive limnetic and mixohaline wetlands. The above authors noted that these springs issued forth in low, swampy areas along the margin of Pearl Harbor and were affected by tides. Similar types of habitats on Hawaii island currently support large populations of *M. xanthomelas*, and the former presence of this species in the Pearl Harbor area is confirmed by specimens in the Bishop Museum and the University of Hawaii, the last of which was collected as recently as 1977.

A search was made of these Pearl Harbor springs for *M. xanthomelas* during damselfly conservation status surveys funded by the U.S. Fish and Wildlife Service (USFWS), and the results are germane to the present study, since they indicate the absence of other *M. xanthomelas* populations in proximity to TAMC. The closest of the springs to TAMC is the Kalauao Spring, which now forms a watercress farm lying between the Kamehameha Highway and the Pearlridge shopping mall. This spring has been extensively modified by watercress cultivation, and contains large numbers of introduced fish and prawns. A search for *M. xanthomelas* here on several occasions during 1994 and 1995 proved fruitless. The Waiau Spring lies immediately upslope of the Kamehameha Highway and behind a Zippy's restaurant. It is also given over to watercress cultivation, and contains numerous introduced fish species. The Waimano Spring emerged at a site now occupied by the Waiau power generating station, which exploits the spring's water for cooling. The Waiawa Spring lies below the bluff occupied by the Windward Community College, in a highly degraded area of rubbish dumps and excavations; it too supports watercress production, and forms an extensive wetland on its seaward side that has yet to be completely surveyed. The Waikele Springs emerge from the east bank of Waikele Stream upstream from the H-1 freeway bridge; these springs are partially diverted by the Oahu Sugar Company, although significant outflows still emerge, providing the majority of base flow in the terminal reach of Waikele Stream. This area was intensively surveyed by Englund (1993), who found high densities of tilapia, bullfrogs, and other introduced aquatic vertebrates, but no indication of *M. xanthomelas*. Based on current knowledge, it thus appears that all the basal spring wetlands in the Pearl Harbor area that formerly could have supported *M. xanthomelas* are now physically altered or biologically degraded to the point that they no longer harbor this species.

Basal spring wetlands similar to those that occurring at Pearl Harbor are also present on the north shore of Oahu to the east of Haleiwa, near the mouth of the Anahulu River. One of these wetlands, surrounding Emerson Spring, is still relatively intact, although it is now traversed by the recently constructed Haleiwa Bypass highway project. An investigation of these wetland systems by Adam Asquith of the USFWS in early 1995 found them to be dominated by alien aquatic species, and to lack populations of *M. xanthomelas.*

Recent surveys thus indicate that *M. xanthomelas* has been extirpated from suitable lowland habitats throughout Oahu, and reinforce the view of the Tripler population as an isolated remnant that has survived through fortuitous circumstances. Since some of the basal spring wetlands formerly occupied by this species still exist, it might be possible in the future to reintroduce this species to suitably managed sites in the Pearl Harbor and North Shore areas, provided that the Tripler population can be maintained in the interim.

## STUDIES OF *MEGALAGRION XANTHOMELAS* AT TAMC

## FIELD SURVEY METHODS

### Biological Observations

Observations of adult behavior, adult population counts and surveys of arthropods and plants at the study site were conducted twice a week from 2 April to 31 August 1995.

Observations of adult behavior were made primarily at Pool 7 (see stream description) where males and females gathered in large numbers because of the sunny, open situation and presence of *Commelina diffusa*, a preferred oviposition plant. From positions at opposite sides of the pool, male arrival times were recorded as well as their interactions and where they perched in relation to others. Female arrival times, interaction with males leading to pairings, copulation mecahnics, and ovipositing behavior were also observed.

Adult population counts were done chiefly between 1100-1300 h (Figs. 1- 6). This time range was selected based on previous observations that showed adults to be usually most active at this time of day when the pools were bathed in sunlight. The lead counter proceeded downstream from pool 7 to pool 1 followed by the back-up counter trailing a few feet behind. The lead counter noted aloud the sex of each adult and pointed out its location, also noting whether it was tandem or teneral, whether in flight or perched, and in the case of tandems, if copulating or ovipositing. The back-up counter confirmed sightings, tracked adults already counted to avoid recounts, and was alert for any adults that may have been missed by the lead counter. To ensure that all adults and tenerals were counted, rocks and vegetation along the stream were swept with nets to flush out adults from possible perch sites.

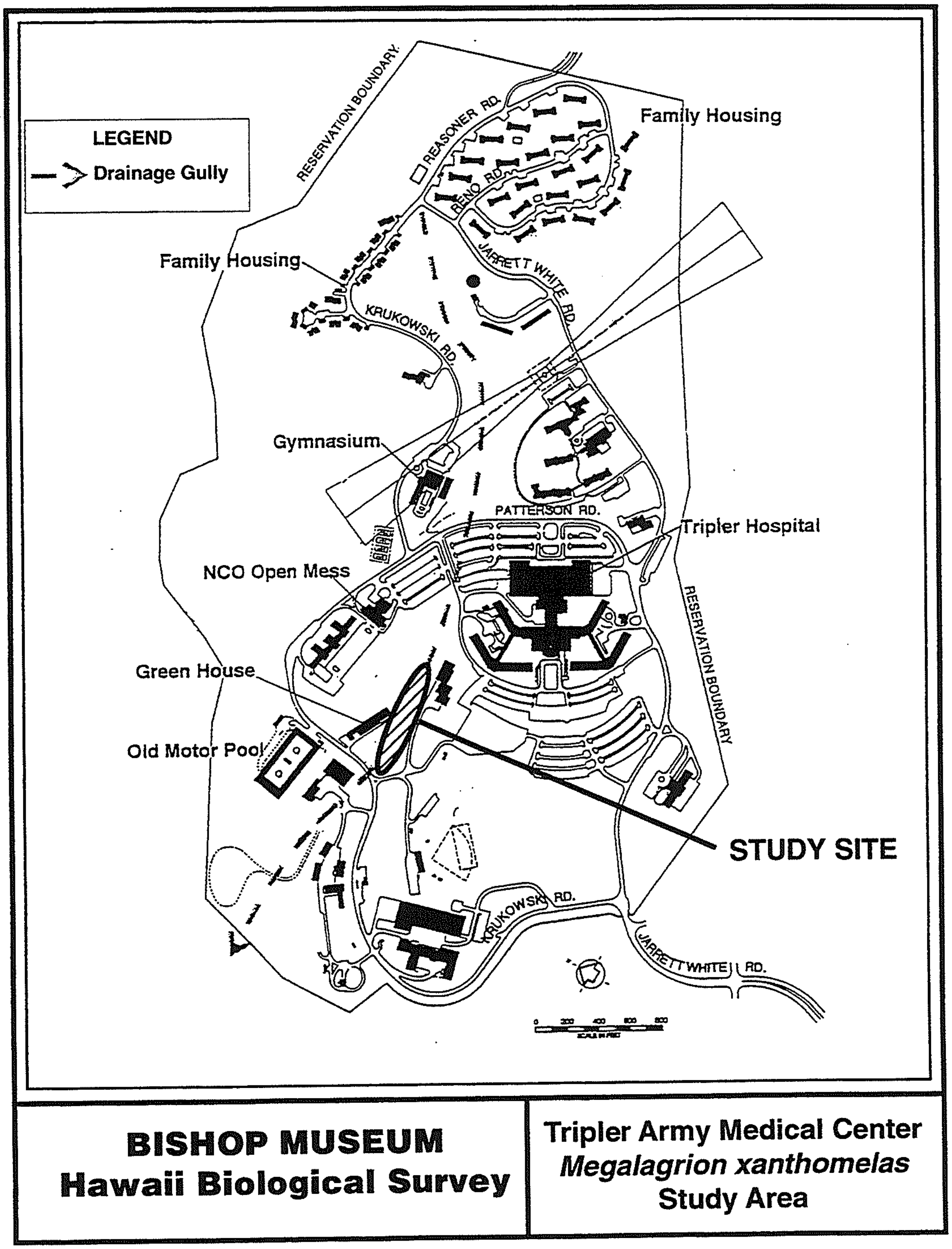
For the closed section of pool 5, the lead counter proceeded to pool 4 along the raised stream bank, the back-up counter then walked down the middle of pool 5 flushing out adults and the lead counter noted any adults that emerged into pool 4. Numbers were compared and recorded. Pool 3 and upper pool 1, which have no natural stepping stones, required a back-up counter to take up a position at the upper limit of the pool and observe any adults disturbed from perches as the lead counter proceeded downstream beating vegetation.

This method of calling out numbers and location of adults between the lead counter and back-up, and reconfirming and noting missed individuals, resulted in more accurate counts than would have been achieved if counting was done individually.

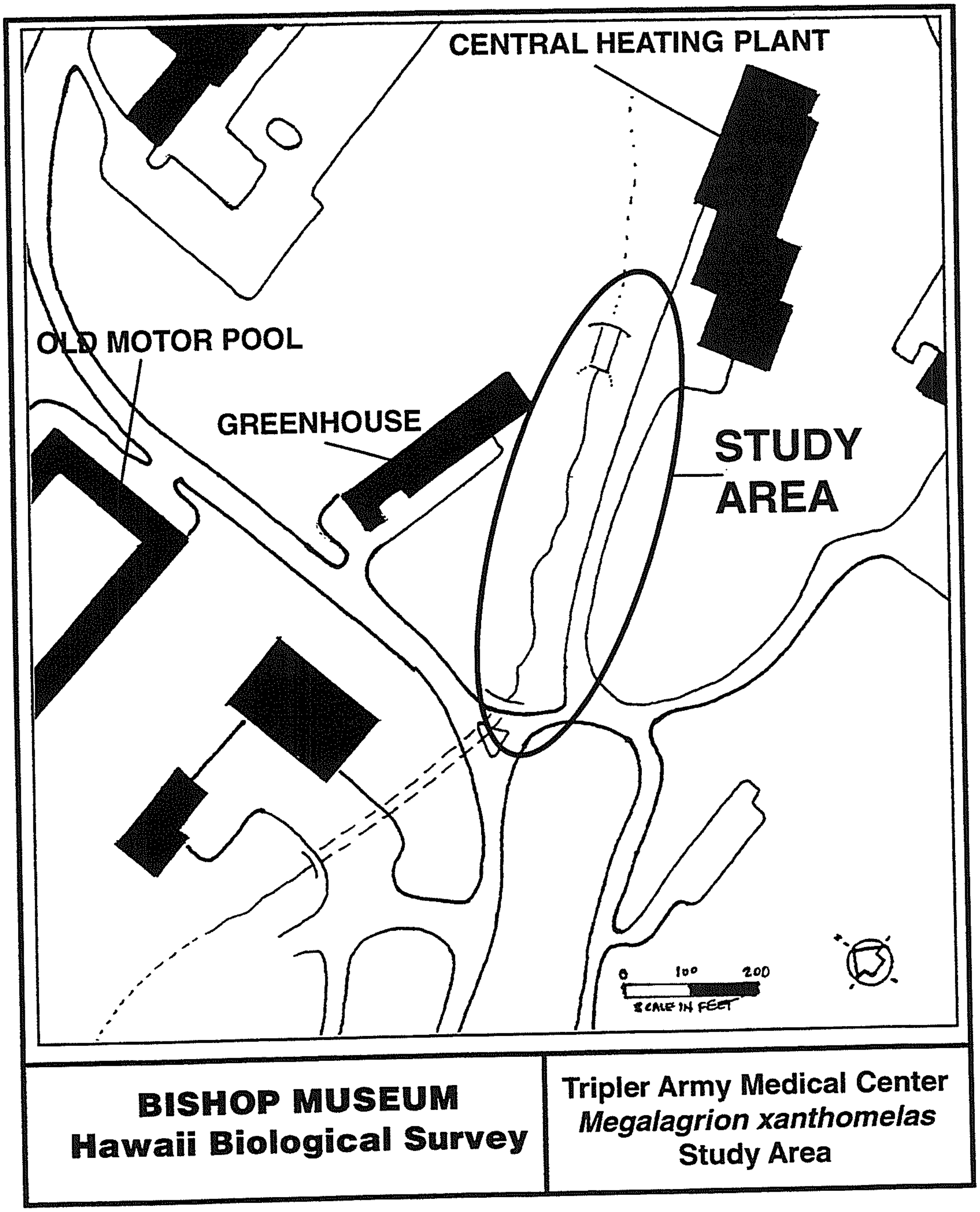
## Environmental Measurements

Environmental measurements of soil and stream temperatures, pH, and a measure of stream water salinity were taken once a week. These measurements were taken from three sites: Site No. 1 (Pool 7), Site No. 2 (Pool 1) and Site No. 3 ("lower pool" near Building 127—see Map 5). Stream water was collected in 2 oz Nalgene® jars and taken back to the laboratory for pH testing using Oakton® No. WD-35624-60 pH Tester. Measurement of soil pH was taken on two soil samples: 1) from the stream bed; and 2) from soil collected 1 meter above the water line. The soil samples were first diluted with neutral pH water, particulates were filtered and the remaining fluid tested as in stream water. Air temperature was measured in the shade using Taylor® No. 5367 digital thermometer; soil temperature measured by sticking the Taylor® probe soil thermometer into the soil in a shady area at each site. All values were recorded in degrees centigrade. Salinity for water samples was measured with the use of A366ATC® hand-held salinity refractometer. Values were recorded in parts per thousand (ppt).

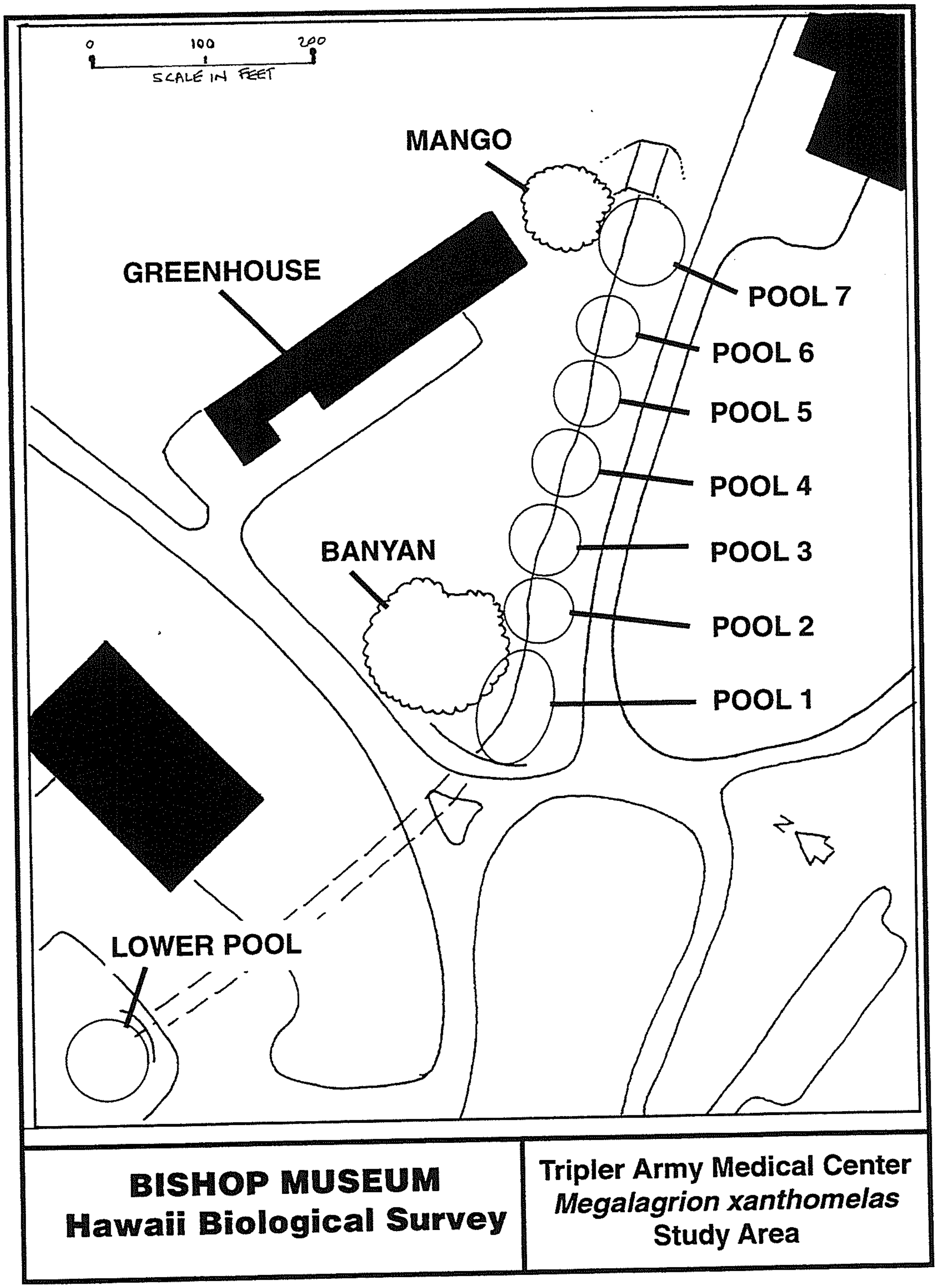
The 366 foot (111.6 meter) stream was divided into 7 pools (see Map 5), measurements taken, and associated vegetation noted. Pool 1 was located downstream, frequently shaded by the large banyan tree (*Ficus microcarpa*) above Krukowski Road. Pool 7, was located upstream towards the Greenhouse and about 500 feet below the Heating Plant.




**Map 3**. Grounds of TAMC, showing study site




**Map 4.** Detail map of TAMC, showing general area of study site




**Map 5**. Detail map of study site, showing pools

## Arthropod Collections

Arthropod samples were collected at the study site by sweeping vegetation with a collecting net, taking soil and litter samples (Pool 1) and aspirating for small arthropods found on rocks and other substrate in and along stream. Floating arthropods on stream surface or swimming in the stream were collected as possible naiad food or naiad predators. Arthropods from soil and litter samples were extracted using a Berlese-Tullgren funnel. Some arthropods were not collected but their presence in the study site was noted in a field notebook. Collected specimens were taken back to the Bishop Museum for processing and identification. Appropriate tools such as keys to particular arthropod groups and comparison of materials with voucher specimens in the collections were used in identification.

## Botanical Observations and Collections

Survey of vegetation along the stream and foraging/resting areas was conducted by noting down names of known plants in a field notebook and taking specimens of unknown plants back to the laboratory for identification by the botany staff of the Bishop Museum. Plants used as oviposition sites were thoroughly searched for and identified.

## Site Description (see Maps 3–5)

From April to August 1995, field work was conducted at Tripler Army Medical Center (TAMC) (Maps 4–5), specifically on "Site 3" of Evenhuis & Cowie (1994). Located in a gully southwest of the Heating Plant and south of the Greenhouse, this depressed area has bedrock substrate that collects upstream runoff, and has pools and slow moving water flow that provide an ideal habitat for a breeding population of damselflies. This collected upstream flow originates from a 48-inch reinforced concrete pipe mauka of Patterson Road with an outlet at about the 250-foot elevation south of the Greenhouse (Ogden Environmental, 1994). For more detailed description of the topography and hydrology of the area, see Odgen Environmental (1994).

*Detailed Stream Description* (see Map 5)

Vegetational and clearing conditions-

Vegetation along the stream creates "open" and "closed" situations. An "open" situation is characterized by *koa haole* and other trees that grow at a distance from the stream edge, creating an open clearing with a high canopy and *Justicia* understory. In open situations, pools are bathed with sunlight. A "closed" situation is characterized by a narrow stream with a dense growth of *Justicia* and/or *Panicum* growing at the stream edge, their stems, roots, and leaves entering the water, creating a low canopy that filters the sun. Less sunlight is seen at the pools in this situation.

Open situations are ideal for perching males awaiting for sexually mature females. Copulation usually takes place in sunnier situations. Oviposition occurs along the entire stream length where preferred oviposition plants grow (e.g., *Commelina*, *Justicia*). Emergence of damselfly adults occurs in both situations where stems, vines, roots, and rocks or twigs rise out of the stream, but sunny locations are preferred. Tenerals (newly emerged adults with wings not fully expanded and hardened for flight) risk attack by ants at this critical time when they rest on vegetation waiting for their wings and cuticle to harden.

The stream is generally composed of shallow pools and small cascades where the elevation gradually drops. Pool depths vary from a few inches to 1.5 ft, and the water is usually slow moving. [N.B.: During the study, heating plant workers used water from a fire hydrant to flush a drainage canal that runs along backside of plant. This silt laden water entered from the eastern edge below the upper culvert outflow (photo 2). This caused some concern for survival of naiads and overall stream health.]

Algae grows on rocks, and along the sides and bottoms of pools, providing a nursery for developing naiads and habitat for naiad food. Periodically, dense algal mats are swept onto rocks downstream, or silt resulting from flushing of heating plant drainage is deposited on the algae, both of which interfere or obstruct the photosynthetic processes of the algae. This results in severe dieback of algae, but there is quick recovery with burst of new growth in a short period of time.

Pool 1 -

66.5 ft in length; 2–3 ft in width; up to 1 ft in depth. There are two distinct sections. The lower "open" section is rocky and the banks are more open without dense vegetation. The upper section is narrower and the stream bottom is bare. *Justicia* and *Panicum* grow to the edge of the bank, with stems and roots dipping into the water. *Panicum* is dense on the western edge of the lower section. A banyan tree dominates this site, its branches shading the entire area. *Maile pilau* vines enter the water.

Pool 2 -

28.25 ft in length; 3.5 ft in width; up to 1.5 ft in depth. "Open"— The main feature is a pool with algae covered rocks of varying sizes. The eastern edge possesses a vertical rock formation with *Justicia*. The western bank is low and is dense with *Justicia*, its stems and roots dipping into the water. *Maile pilau* vines also dip into the water. The water of this pool is still, creating an ideal nursery and emergence site for the orangeblack damselfly.

Pool 3 -

42 ft in length; 2–5 ft in width; to 1.5 ft in depth. "Closed"— The main feature is a narrow stretch with *Justicia* canopy, and fallen *koa haole* crossing the stream. The stream bottom is bare, the eastern edge of the channel is composed of an exposed soil bank with exposed plant roots, and the western edge bears large, flat rocks. Algae grows well here, and *Justicia* stems and roots dip into the water. This is also an ideal situation for a nursery and emergence site for the orangeblack damselfly.

Pool 4 -

48.75 ft in length; 3–4 ft in width; to 10 inches in depth. "Open"— There are several small pools varying in depth up to 10 inches. Several large, flat rocks are situated vertically in the soil, and *Justicia* grows among these rocks along the edges. *Maile pilau* vines dip into the water. The eastern edge slopes up to the roadway leading to the heating plant with sparse *Justicia* and *koa haole*.

Pool 5 -

64.5 ft in length; up to 6 ft in width; up to 1.5 ft in depth. "Open" and "closed" situation— A pool up to 6 ft in width and 1.5 ft in depth. The lower section is a narrow, shallow stretch lined with flat overhanging rocks, with *Justicia* growing to over the edge and creating a dense shaded canopy. *Justicia* roots and stems and *maile pilau* vines enter the water. This is a very dense and shaded site where teneral damselflies were observed. Separating the narrow , shady stretch and the open pool at the upper end is an open sunny area with large rocks and a drop in elevation forming a small cascade. A dense *Panicum* clump separates the cascade area and the pool. The pool possesses algae covered rocks and *Panicum* leaves enter the water.

Pool 6 -

62 ft in length; 2–3 ft in width; 2–4 inches in depth. This is an open pool extension of pool 5— and presents a similar situation to pool 5. The upper stretch of pool 6 has a sticky, gray clay bottom. There is a fallen koa haole on its western bank that crosses the stream. At the base of this *koa haole*, *Commelina* grows and dips into the water. Eggs and tenerals were observed at this pool.

Pool 7 - (Photos 1–3)

54 ft in length; 10.5 ft in width; up to 2 ft maximum depth depending on seasonal water flow. "Open" situation— The upper end of the pool has a small waterfall (4–6 ft) from a man-made culvert descending down to the bedrock pool and stream. Large rocks occur along the eastern edge and continue to the south end of this pool. The western edge is a soil bank (the sunny side) with dense algae. *Commelina* grows over the falls into the water on the western side. Exposed tree roots entering the water on the western side provide perching sites. The western edge of this pool has soil mixed with rocks rising 12 ft or more (leaving a very narrow strip of bank to stand on), with *koa haole* growing at top. The eastern edge of the pool is shady, with partially submerged rocks providing "stepping stones" on which to walk. There is a gradual drop in elevation via small rocks leading to pool 6.

## RESULTS OF TAMC *MEGALAGRION* STUDY

### Field Observations

*Reproductive Behavior of Damselflfies*

Males arrive first at the pool or the rendezvous area near the oviposition site. As mature females arrive, they are promptly taken by the waiting male. Copulation starts immediately with sperm transfer, which lasts for a few seconds, the pair posturing into a "wheel position" lasting from 8 to 21 minutes. Once copulation stops, the female begins searching for oviposition sites and starts oviposition while still in tandem with the male. Usually, while the pair is searching for oviposition sites, a single male is guarding or waiting for the opportune time to overtake the female. Harassment of ovipositing couples by a single male was observed.

Males of *M. xanthomelas* (photos 5–7) exhibit pronounced territorial, aggressive behavior. They not only claim territory horizontally but vertically, and within these territories conspecific males and *Tramea* adults are chased away by aggressive males. A territory can be a rock, part of a rock, a dead twig over the water, a growing *honohono* branch, etc (see photos 6–7). Observed males occupy their territory 50–95% of the time, waiting for a mate, until a suitable female is found. Once paired with a female, the female decides where to perch or oviposit.

*Oviposition Sites and Egg-laying*

The moisture-loving plant *Commelina diffusa* growing on and along stream banks was the most preferred plant by females for oviposition (photos 9–10). Partially submerged young leaves and stems were examined during each visit to the study site. Numerous endophytic egg punctures (photo 10) were found on both sides of the leaves and on the stems. *Justicia betonica* and *Coccinia grandis* were two other plant species observed with *M. xanthomelas* eggs. Observation of oviposition on *J. betonica* was made once, while oviposition on *C. grandis* as was observed five times. Aside from the above plant species, water-soaked soft twigs on the stream surface or partially submerged, floating leaves, green algae, and even a dirt surface with a thin film of water could be used as oviposition sites. It is unknown if eggs laid in seemingly less preferable sites such as the wet dirt hatch successfully and reach the larval stage. Hundreds of eggs were observed inserted into tiny twigs brought back to the laboratory for examination. An important requirement in egg laying is that the substrate must be slightly submerged in water. This oviposition selection by the female ensures that the aquatic environmental requirements of the egg and the newly hatched larva are met for survival. The period from egg laying to hatching lasts 21 days.

*Naiad Development and Feeding*

Naiads of *M. xanthomelas* are aquatic. Different stages of instars were recovered from algal mats on Pools 1 and 7 and presumably they were present in all the pools on the entire stream length. These naiads were observed clinging to algae growing on submerged rocks and in the shallow stream bed. Unlike naiads of *Pantala* or *Tramea* dragonflies, *M. xanthomelas* naiads were less aggressive and less motile. They are passive predators, stalking live prey that swim or crawl within reach of their protrusible labium. Their outstanding vision and the corresponding movement of their neck and thorax allow them to follow larval chironomid or larval mosquito prey. No naiad feeding was observed in the field. However, in rearings of naiads in the laboratory, three dipterous larvae (Chironomidae, Culicidae, Ceratopogonidae) an amphipod (Amphipoda), copepods (Copepoda), ostracods (Ostracoda), and a commercially sold annelid (Oligochaeta: Tubificidae: Tubifex) were successfully offered as food. The shared habitat of the chironomid larvae and the *M. xanthomelas* naiads on the bottom surface of the stream, occupying rocks and algal mats makes such larvae easily available to the naiads, and they seemed to be the preferred food of the *M. xanthomelas,* especially during the later larval stages. Newly hatched naiads fed on planktonic protozoans, tiny annelids and very early instars of dipterous larvae. Based on laboratory rearings, *M. xanthomelas* larval development lasts from 103–111 days (3.4–3.7 months).

Although the following arthropods were not offered as food and no actual feeding was observed in the field, caddis fly (Trichoptera) larvae and aquatic oribatid mites (Acari: Oribatida) are also potential food of *M. xanthomelas* naiads in a natural stream or pool environment. Algal mats are ideal nursery sites for fragile, developing naiads offering relatively safe hiding places and ideal environments for naiad prey items.

*Adult Feeding Behavior*

Williams (1936) reported that *Megalagrion* adults feed on various small insects. He also mentioned that they are fond of small moths. A male adult *M. xanthomelas* was observed flying with a small off-white moth (microlepidopteran) clasped between its labium and mandibles. This was the only record of actual feeding observed during the entire study period. It was possible that adults fed while studies were being conducted but that black mosquitoes or other tiny black flies attached to similarly colored mouthparts of *M. xanthomelas* were difficult to see and thus missed by the study team. Other possible food sources were dipterous adults of culicids, tipulids, ceratopogonids, drosophilids, microlepidopterans, and tiny wasps (Hymenoptera).

*Population Counts*

The number of male and female adults ranged from 20–100 with a mean average of 56 adults (Figs. 1–6). Adults observed at foraging areas 40 to 50 feet away from the pools were not included in the count. However, observations of their presence at certain areas were noted to establish approximate flight distance and foraging behavior.

The adult population seemed stable. Variations in adult counts were due possibly to variable weather conditions at the time of count. Intensive biological observations were conducted at the beginning of field work, in April. Thus, resulting population counts for that time period were predictably low. Low counts in April and on other dates were correlated with instances of bad weather at the study site, circumstances under which damselflies were found not to be as active or frequently observed.

Other factors influencing population counts during the term of the field study included water flow variation. The volume of water redirected to the stream either from the Heating Plant upstream or some broken water pipes has some effect on the naiad and eventual adult population. Strong current flow due to large volumes of water at various times during the term of field study washed algal mats downstream, carrying away the delicate naiads, and killing them.

*Natural Enemies*

Williams (1936) alluded to egg parasitism by a tiny wasp. This was not observed during the study. However, small *M. xanthomelas* naiads were preyed upon by larger naiads, and by naiads of *Pantala* and *Tramea*, which shared the same habitat. Though predation was not observed in this study, *Buenoa pallipes*, a predatory aquatic bug (Heteroptera) probably feeds on early instar naiads. Numerous species of ants (Appendix II) especially large numbers of *Anoplolepis longipes*, are enemies of last instar naiads (which climb out of water to emerge) and newly emerged teneral adults. Adult *M. xanthomelas* are likely preyed upon by birds (Appendix III) and frogs. These animals were observed at Pool 7.

*Associated Vegetation*

Twenty-eight species (19 families) of plants were recorded (Appendix IV). Dominant vegetation along the stream was *Leucaena leucocephala* (*koa haole*), *Paederia scandens* (*maile pilau*), *Justicia betonica* (white shrimp plant), *Commelina diffusa* (*honohono*) and *Asystasia gangetica* (Chinese violet). *Leucaena leucocephala* provided shade along the stream aside from *Ficus microcarpa* (banyan) and *Syzygium cumini* (Java plum). Vines of *P. scandens* hanging over the stream and reaching to the water from the banks provide resting places for adults and tenerals. Of the stream bank plant cover, *C. diffusa* and *A. gangetica* grew densely at Pool 7 while *J. betonica* was the most dominant along the banks of the rest of the pools. Clusters of Guinea grass (*Panicum maximum*) grew on Pools 1, 5, 6 and 7. Green algae (?*Cladophora*) was abundant in all the pools.

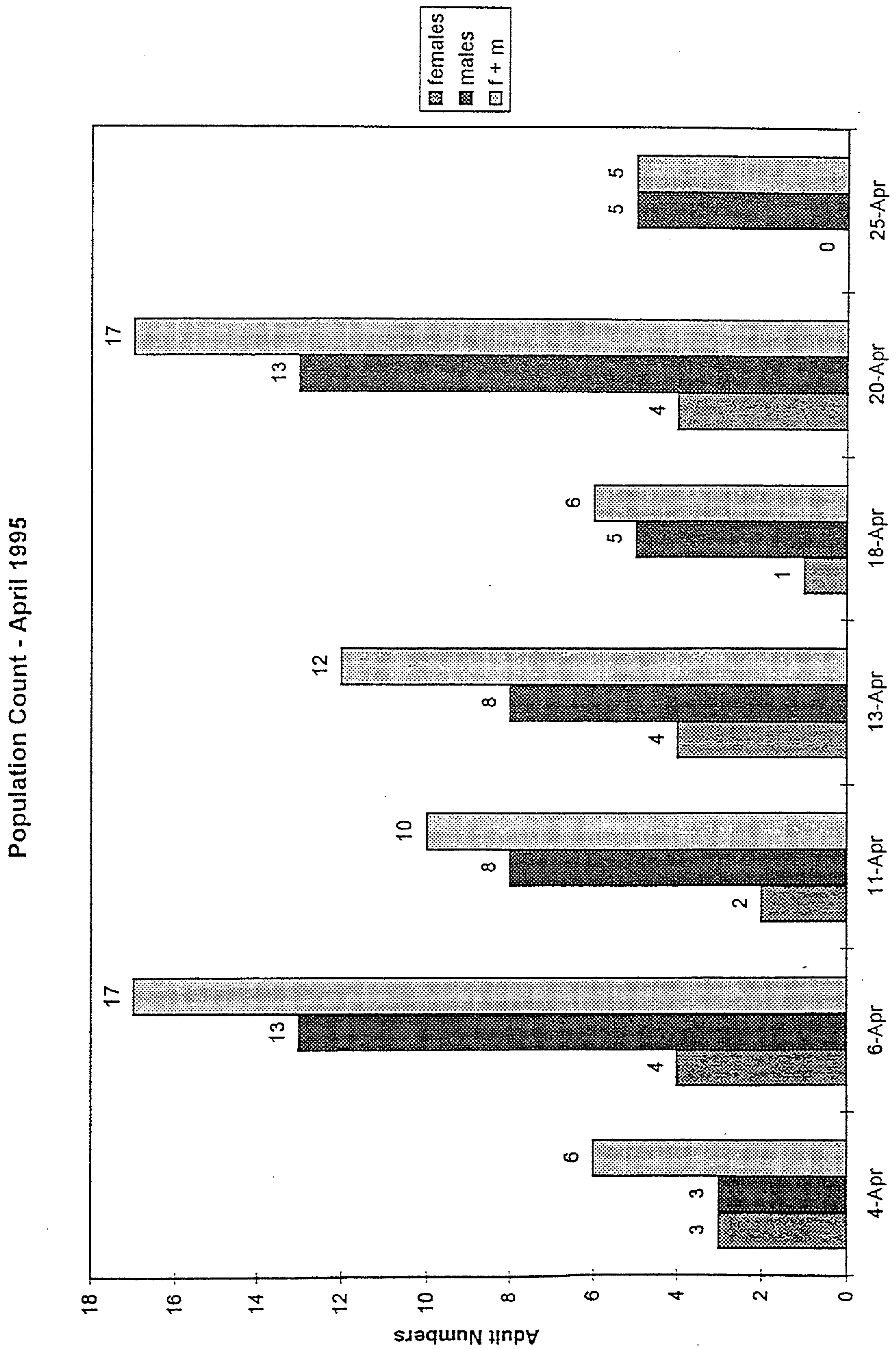



**Figure 1**. Population count of *Megalagrion xanthomelas* at TAMC for April 1995

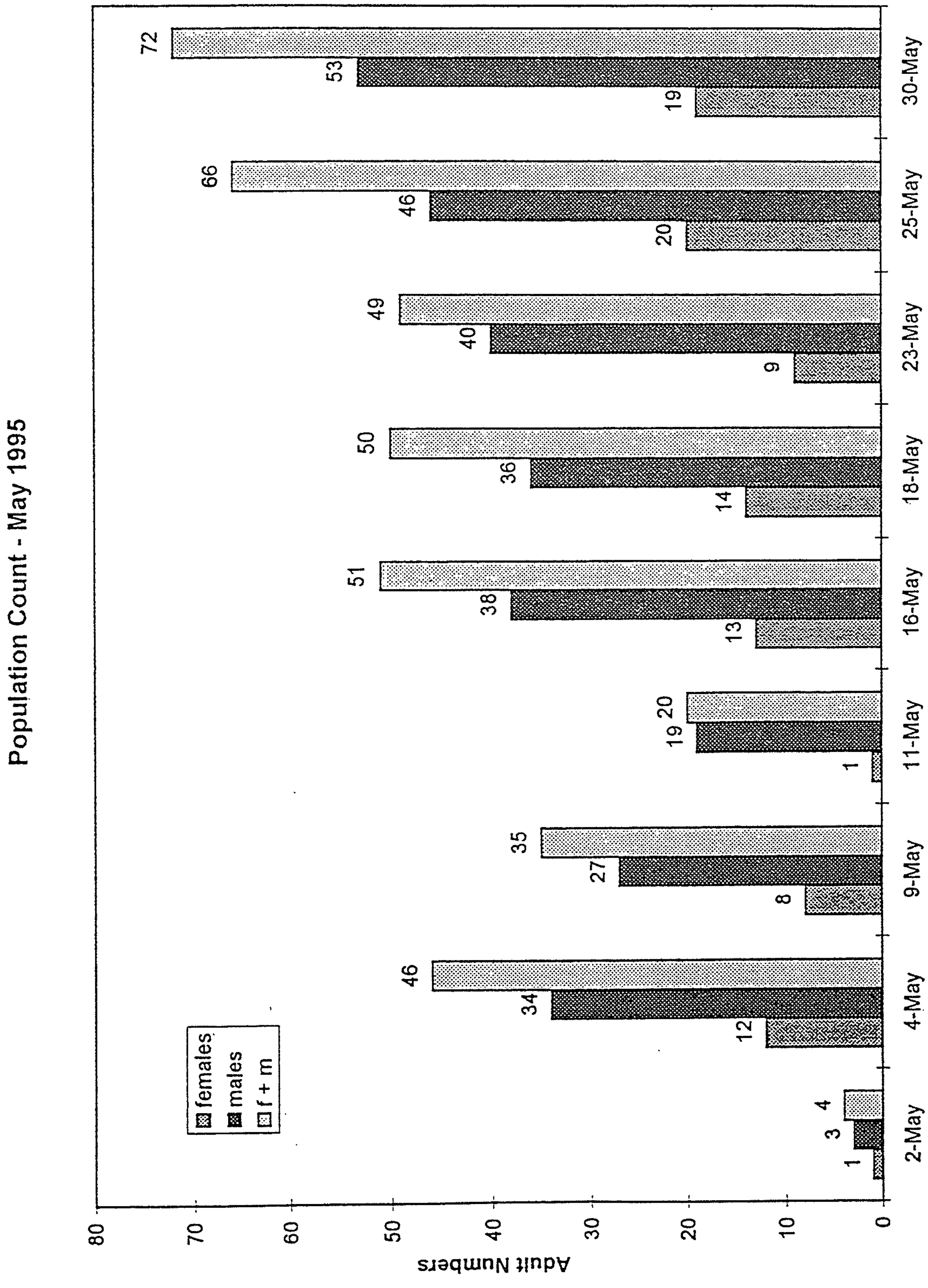



**Figure 2.** Population count of *Megalagrion xanthomelas* at TAMC for May 1995

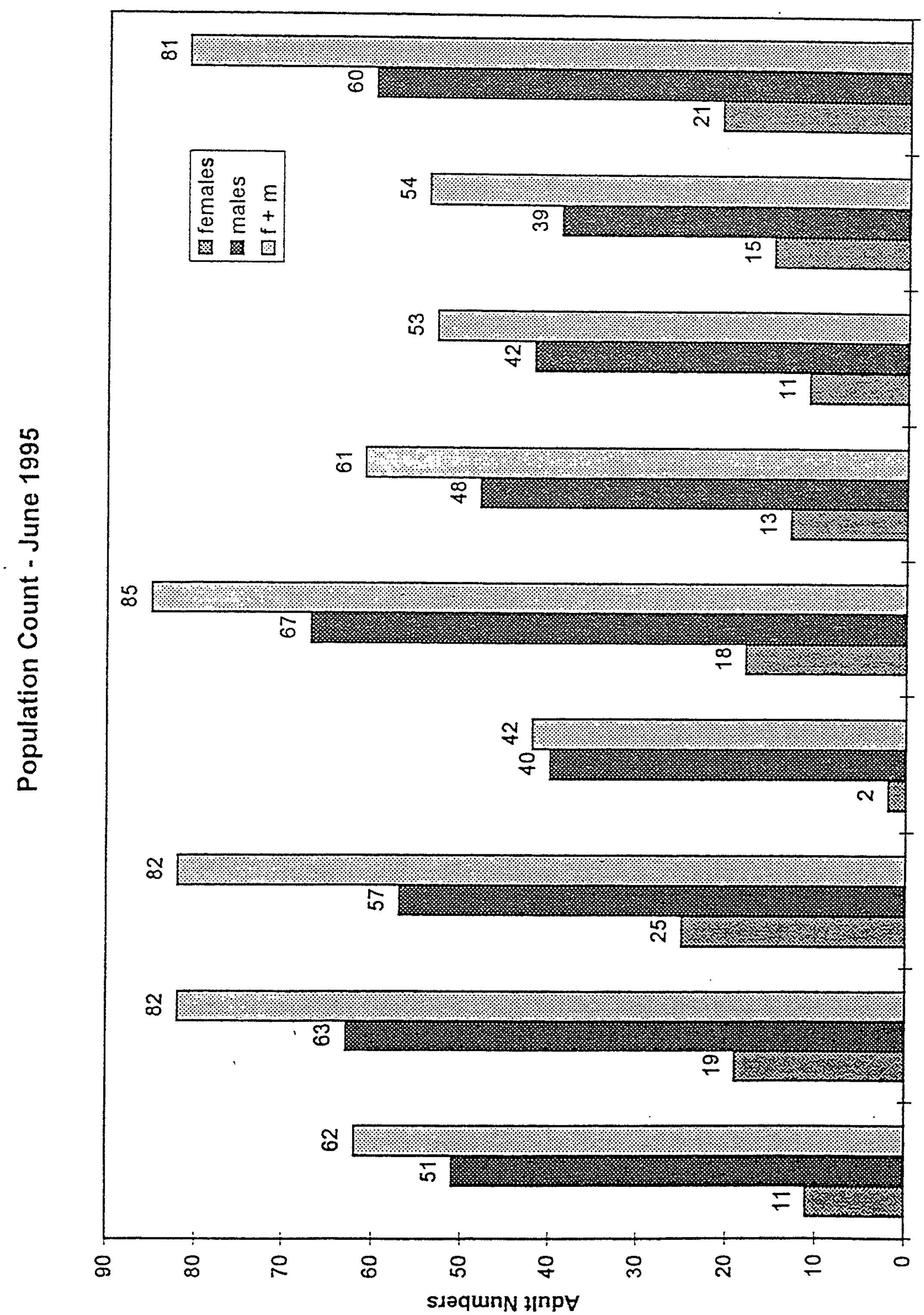



**Figure 3**. Population count of *Megalagrion xanthomelas* at TAMC for June 1995

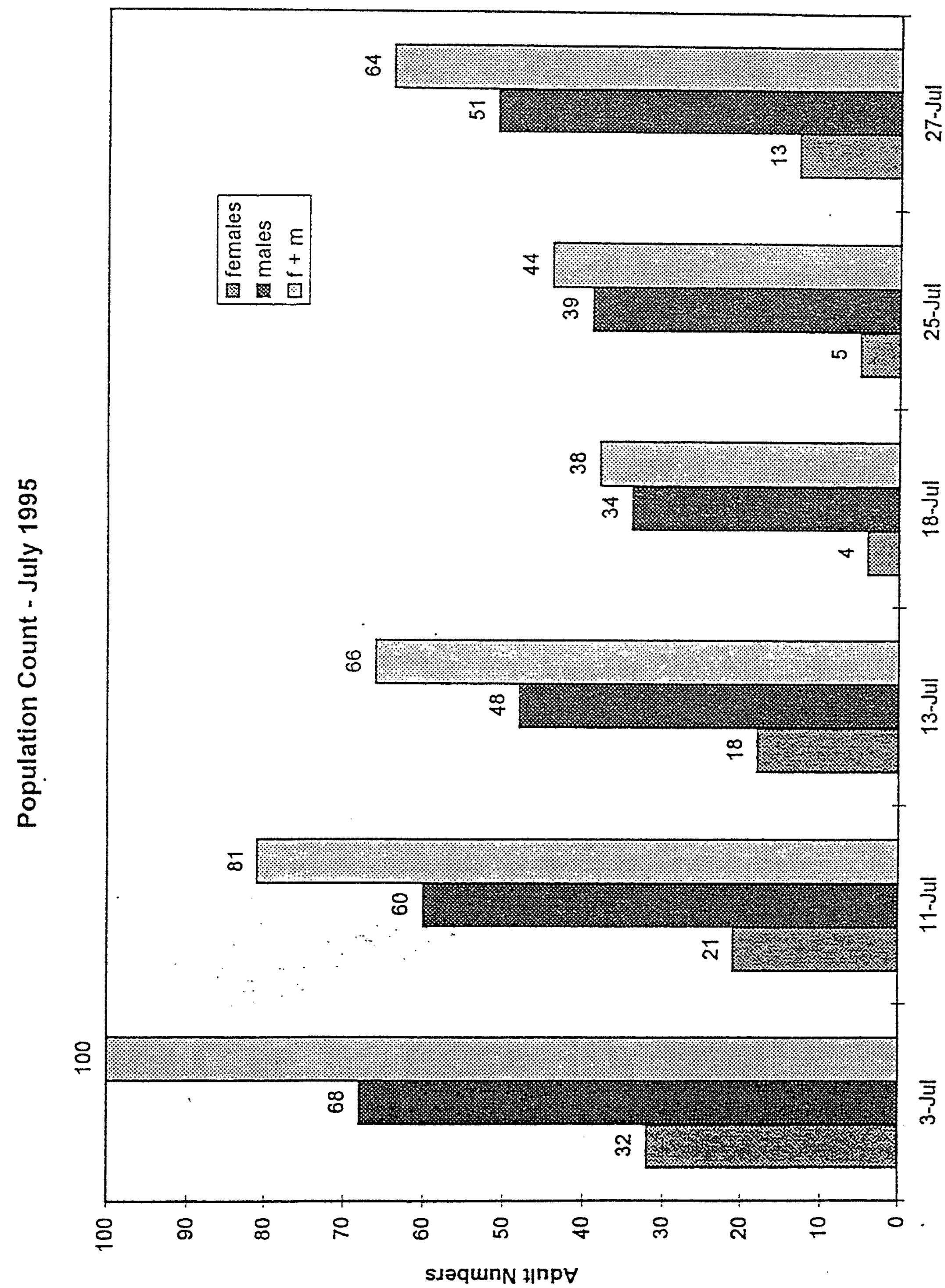



**Figure 4**. Population count of *Megalagrion xanthomelas* at TAMC for July 1995

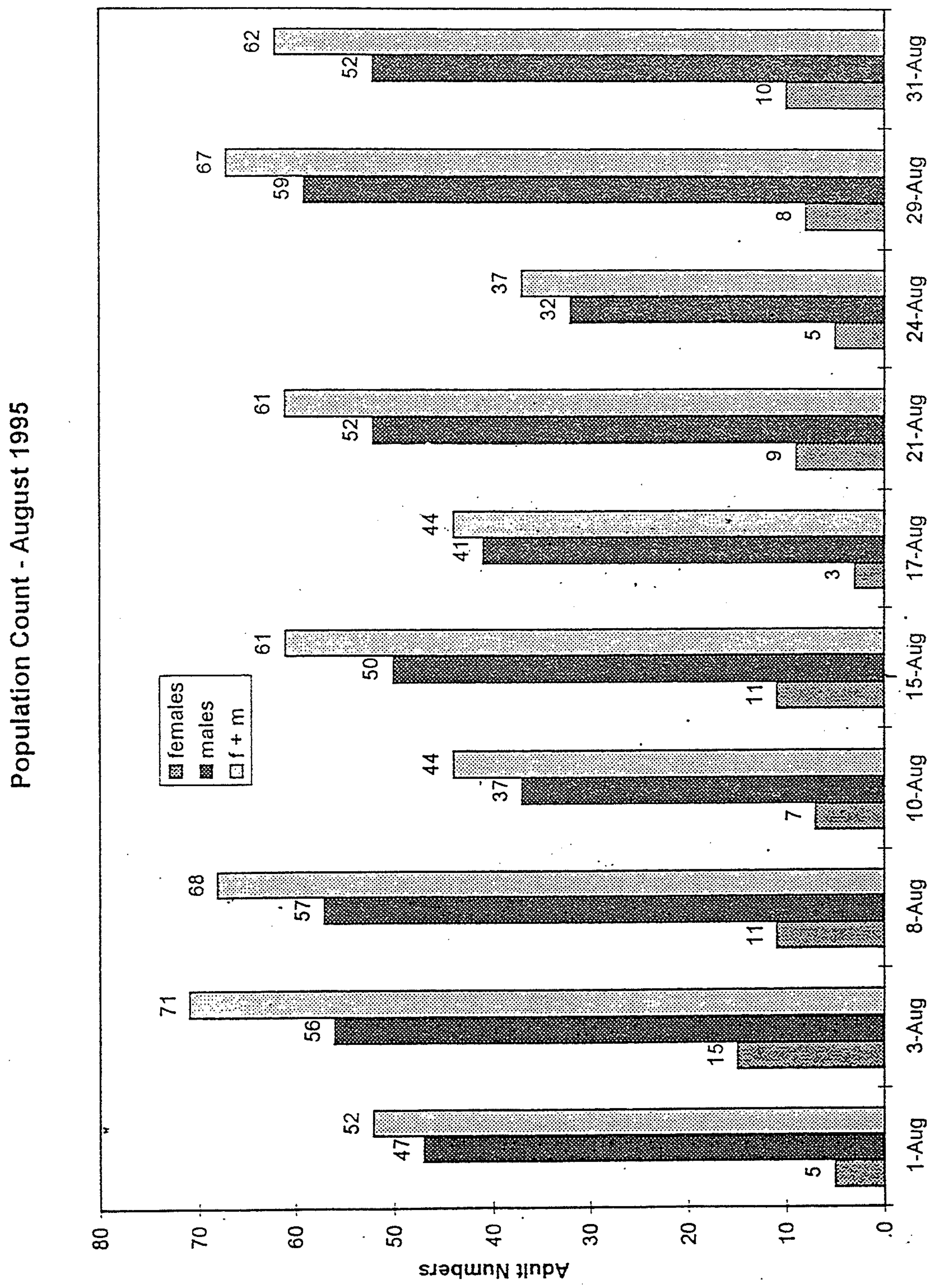



**Figure 5**. Population count of *Megalagrion xanthomelas* at TAMC for August 1995

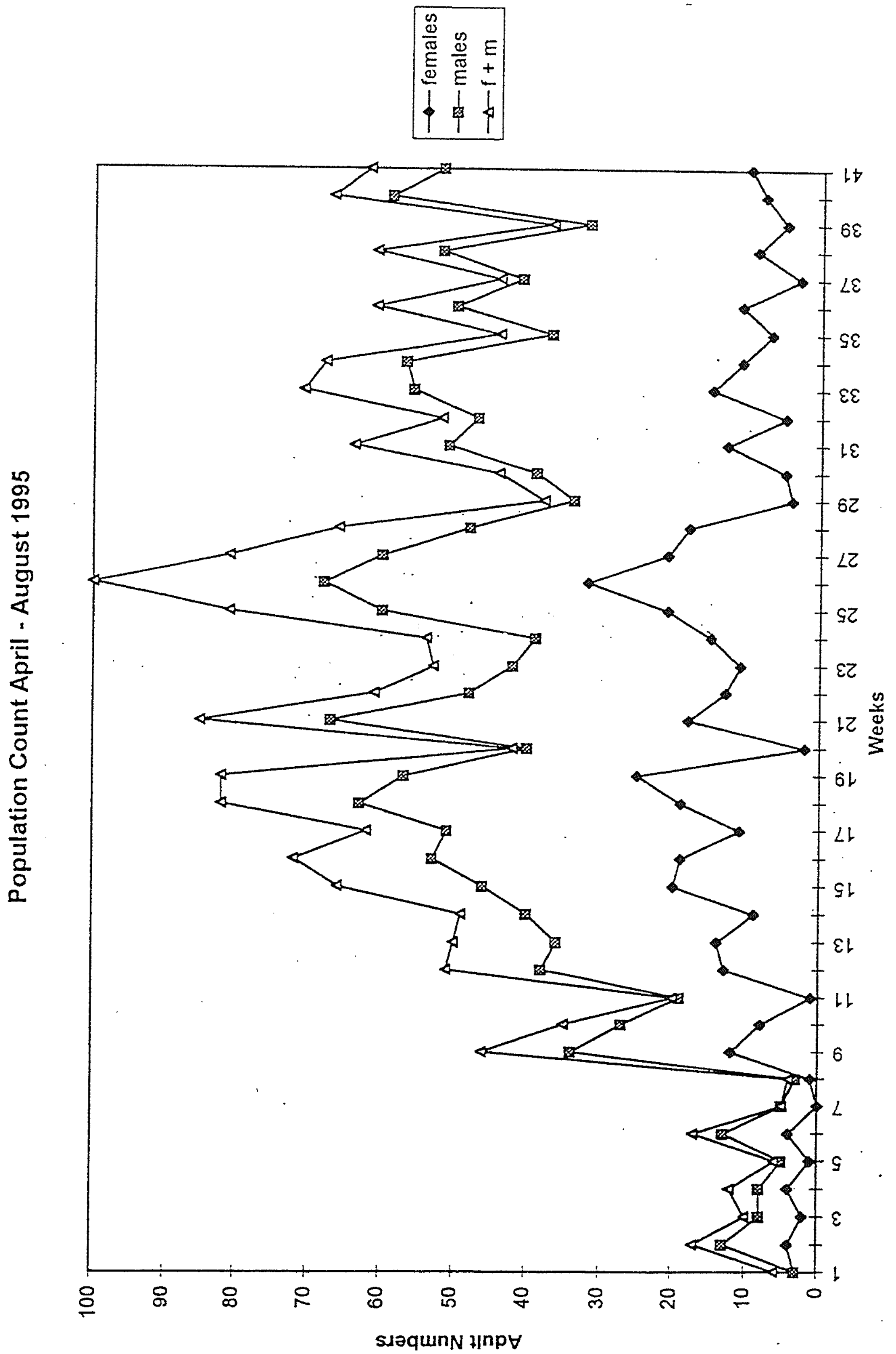



**Figure 6**. Summary population count of *Megalagrion xanthomelas* at TAMC

*Associated Arthropods*

Appendices I and II list the arthropods observed and collected from soil, litter, stream, and the general vegetation area. A total of 127 species in 103 families of arthropods were recorded, insects being the predominant group (80 species in 61 families), followed by mites (29 species in 27 families). The soil and litter habitats generated the most interesting taxa, which were otherwise not normally seen during the project. Aside from the numerous mite species, mostly undescribed, six species in six genera of isopods were recovered. Centipedes, millipedes, and amphipods, were all represented in the soil and litter habitats; ostracods and copepods were found in the stream habitat. *Forcipomyia hardyi* (Diptera: Ceratopogonidae) and *Leptocera brevivenosa* (Diptera: Sphaeroceridae), two endemic species of flies, were also recovered from soil and litter. A single specimen of the aquatic beetle *Copelatus parvulus* (Coleoptera: Dytiscidae) was collected from Pool 7. The earliest-known collection of this species was by R.C.L. Perkins, who collected it on Lanai in 1894 (specimen represented in the Bishop Museum insect collection). Aside from Oahu and Lanai, this species is also known from Maui.

Of the insect groups, microlepidopterans, flies and mosquitoes (Diptera), and bees and wasps (Hymenoptera) are most important as possible prey of adult damselflies; ants may be possible predators of last instar naiads and teneral adults. The true bug *Buenoa pallipes* (Hemiptera: Notonetcidae) and *Copelatus parvulus* are also possible predators of *Megalagrion xanthomelas* naiads. Frogs, freshwater leeches, snails, and a few other non-arthropod animals were also observed at the study site. The frogs is a potential predator of the damselflies, but no activity of this sort was observed during the study. The only observation of feeding by naiads during the study was of a single damselfly individual eating a *Hydrozetes* orabatid mite in the laboratory.

*Environmental Measurements*

pH values taken of stream water, soil in the stream bottom, and on soil along stream bank indicated there were no significant differences of the mean averages in the three collecting sites (Figs. 7–9). Stream water pH for Sites 1–3 was 7.73, 7.62, and 7.75, respectively (Fig. 7); values from soil along bank and on the stream bottom also had insignificant differences (Figs. 8–9). It seemed that waters with pH ranging from 7 to 9 were preferred by naiads and their prey, and by adult females ovipositing eggs.

Ambient temperature ranged from 19.5–27.6 °C with mean averages of 24.54 °C at Site 1, 23.40 °C at Site 2, and 23.43 °C at Site 3 (Fig. 10). On the other hand, soil temperature ranged from 19–24.5 °C with mean averages of 21.28 °C at Site 1, 21.25 °C at Site 2, and 21.44 °C at Site 3 (Fig. 11). Mean averages of water temperature at Sites 1–3 were 21.99 °C , 21.96 °C and 22.22 °C, respectively (Fig. 12).

Water salinity values were expressed in parts per thousand (ppt), which were converted to percentage of sodium chloride (NaCl) by weight. Refractometer readings ranged from 0–3 ppt at all sites. Based on the conversion table provided in the refractometer operating manual, the range 0–3 ppt is equivalent to 0.0–0.3% NaCl by weight per thousand unit of stream water. Mean averages of water salinity values for Site Nos. 1–3 were all less than 1: Sites 1 and 2 both had 0.71 ppt, and Site 3 , 0.55 ppt. These values seemed negligible for NaCl water content, although the salinity graph of readings from the three sites has a dramatic visual impact (Figure 13).

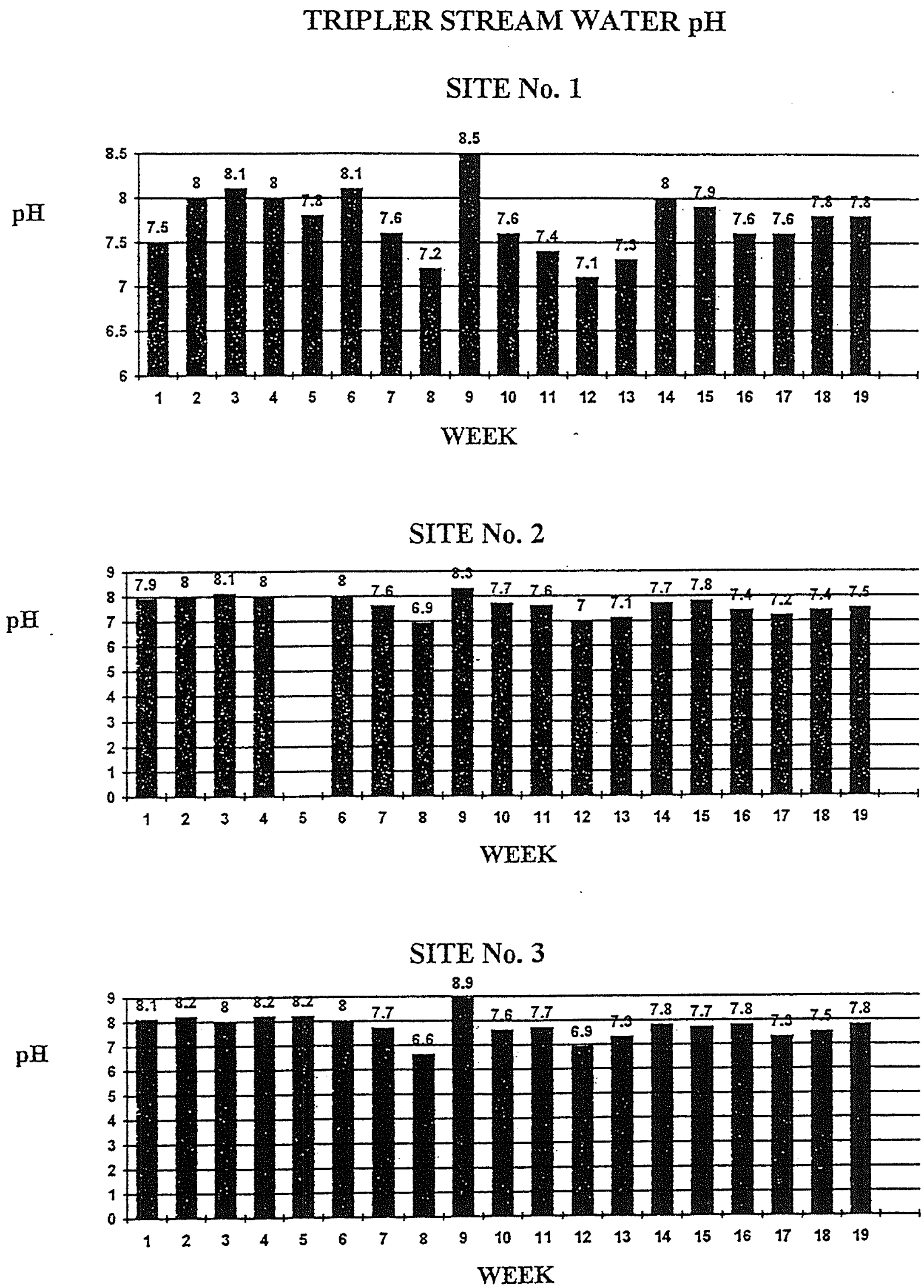



**Figure 7**. Water pH at TAMC, weeks 1–19

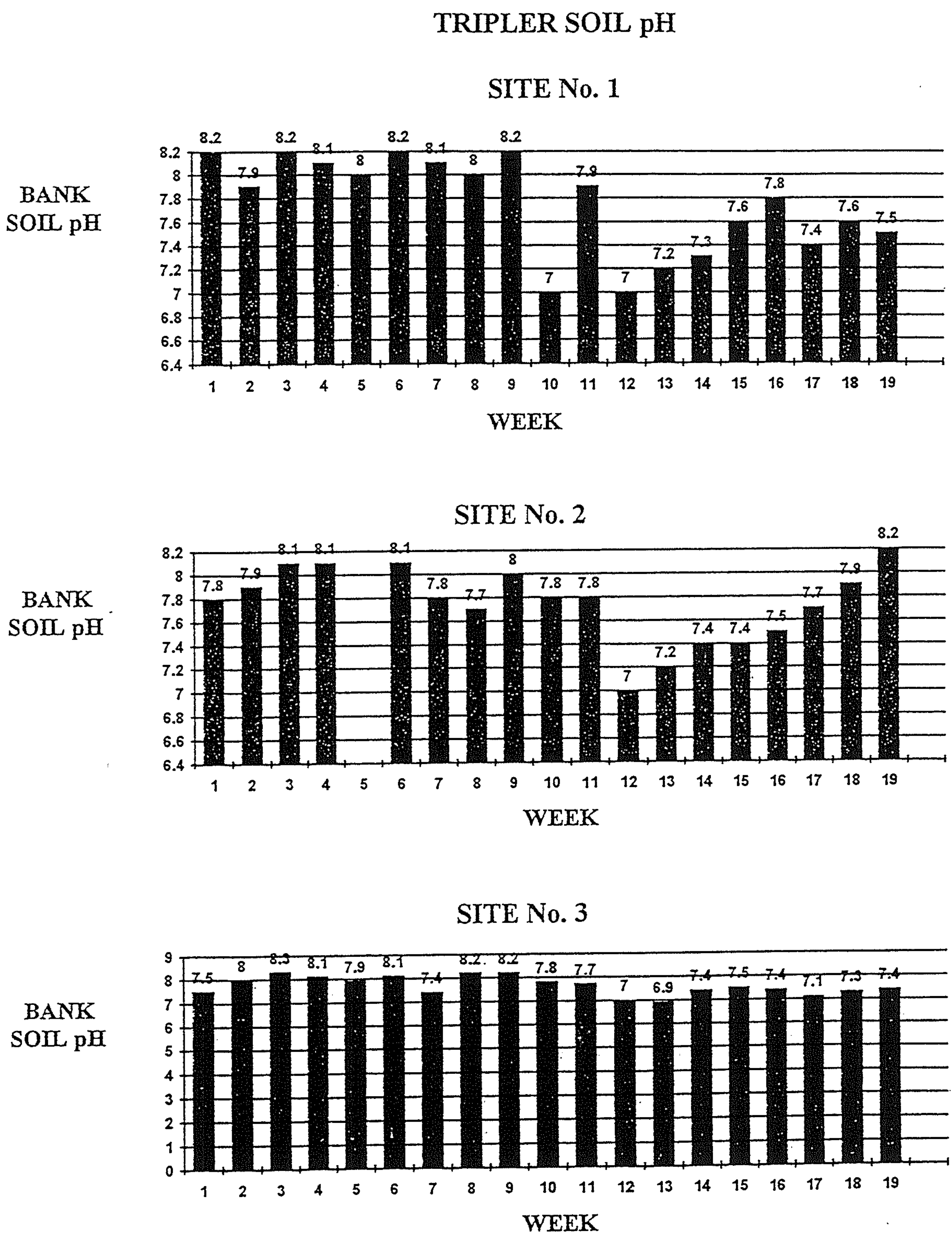



**Figure 8**. Soil pH at TAMC, weeks 1–19 (bank soil)

**FINAL REPORT**

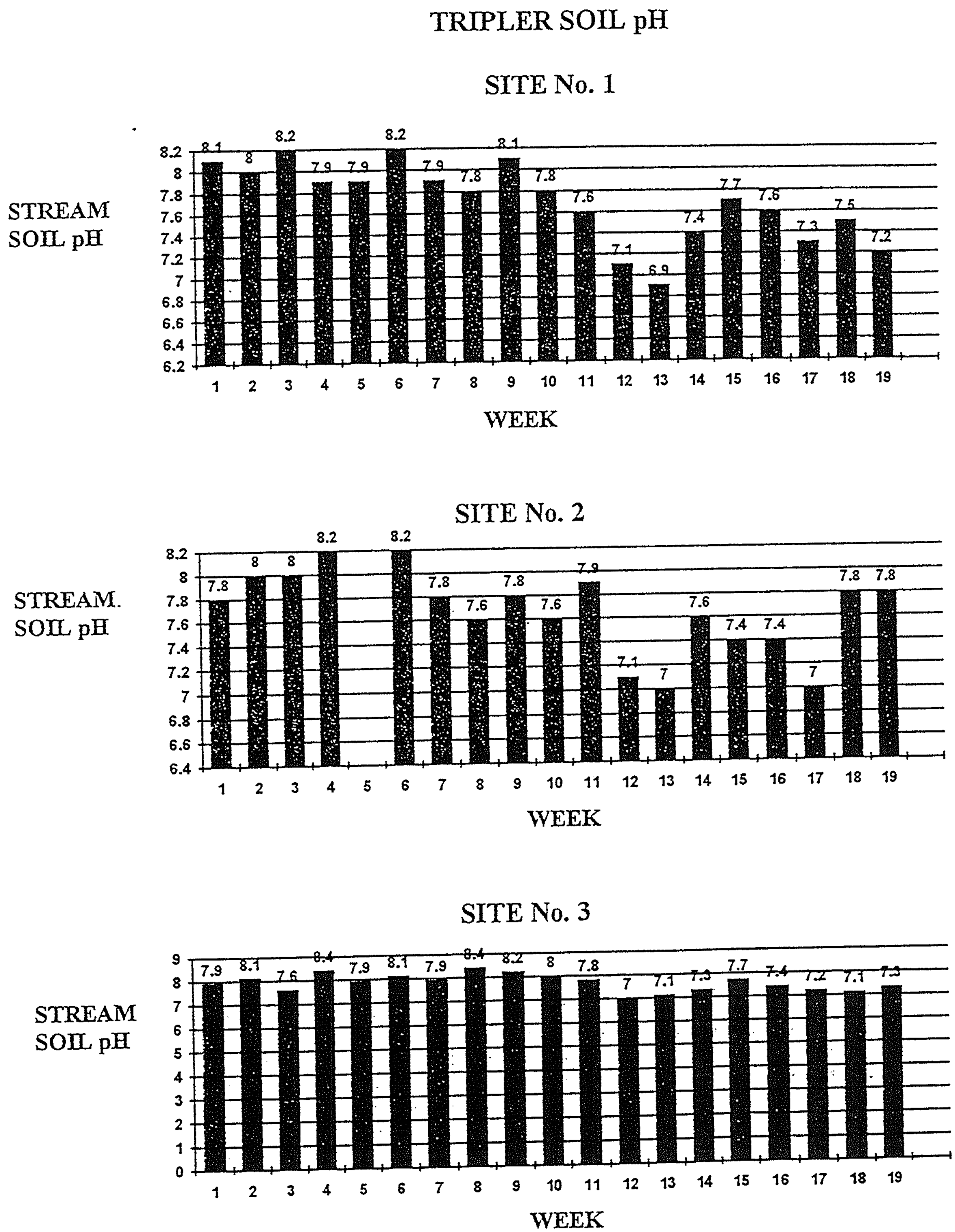
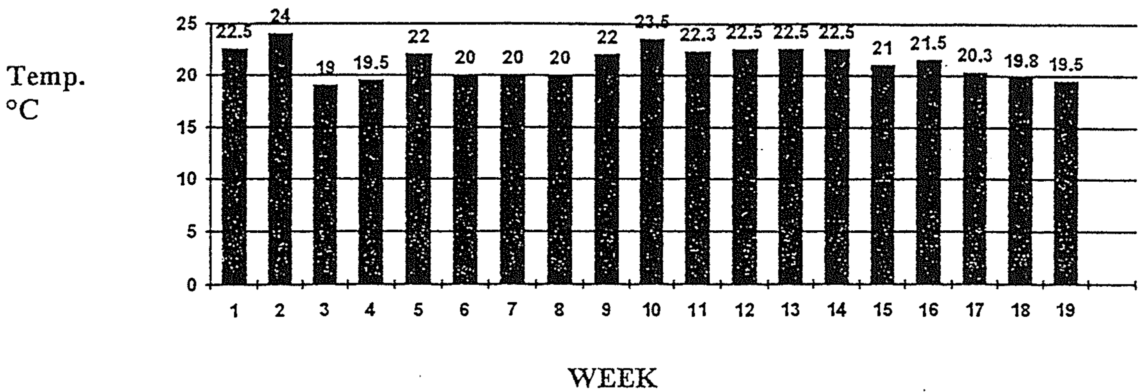


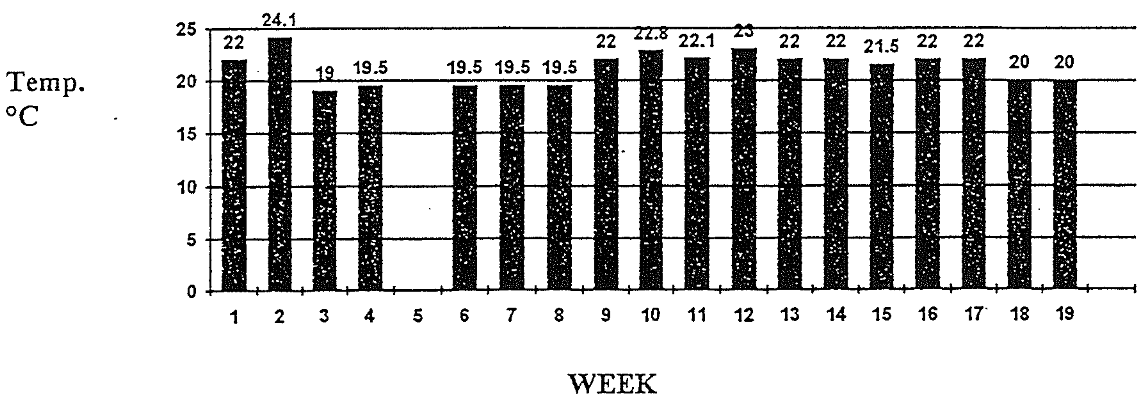

**Figure 9**. Soil pH at TAMC, weeks 1–19 (stream soil)

## TRIPLER STREAM ASSOCIATED TEMPERATURES

### SITE No. 1 Soil Temp.




### SITE No. 2 Soil Temp.




### SITE No. 3 Soil Temp.

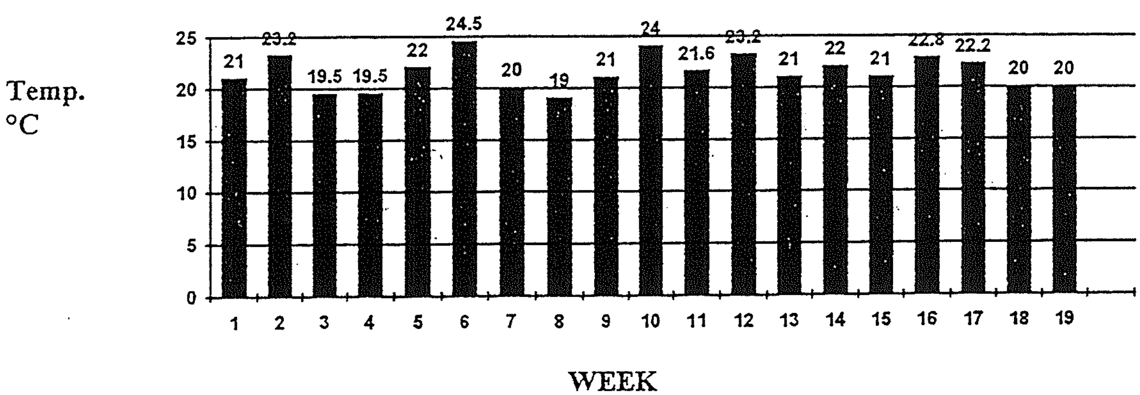
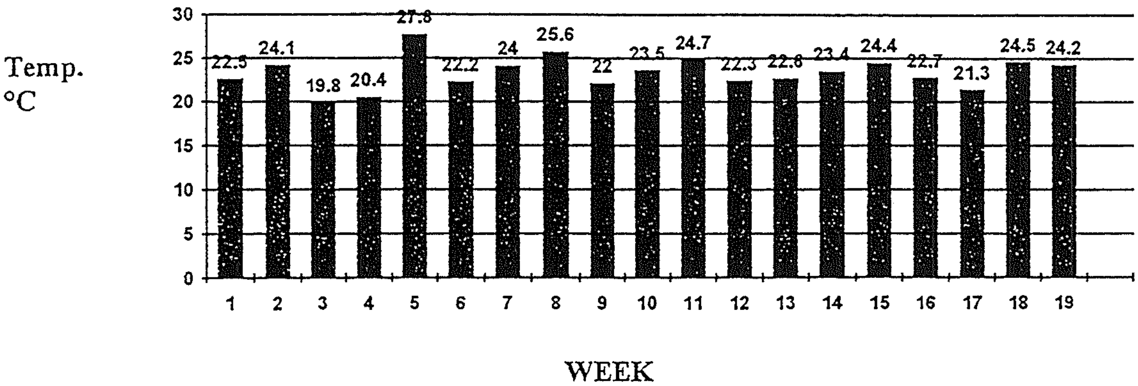


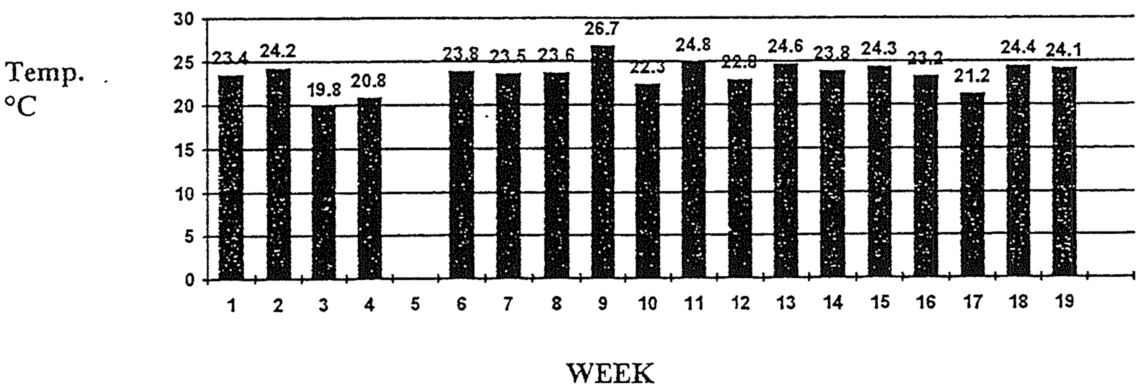

**Figure 10**. TAMC temperatures, weeks 1–19 (air temperature)

## TRIPLER STREAM ASSOCIATED TEMPERATURES

### SITE No. 1 Air Temp.




### SITE No. 2 Air Temp.




### SITE No. 3 Air Temp.

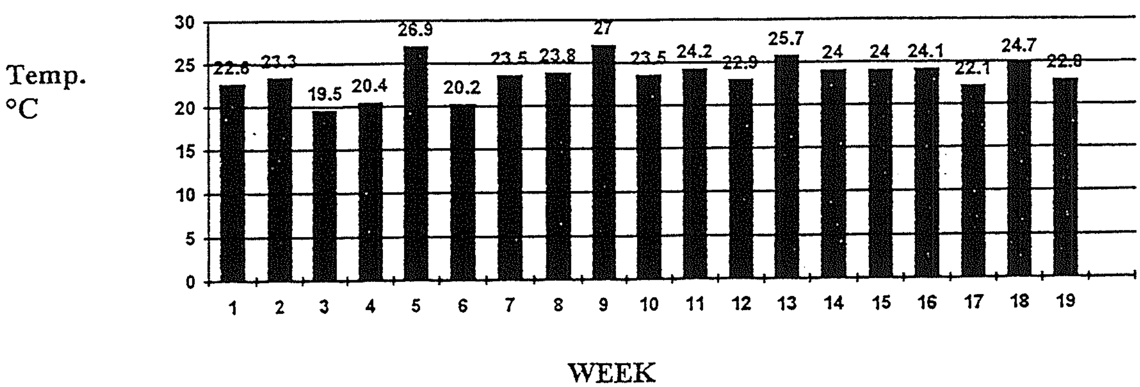
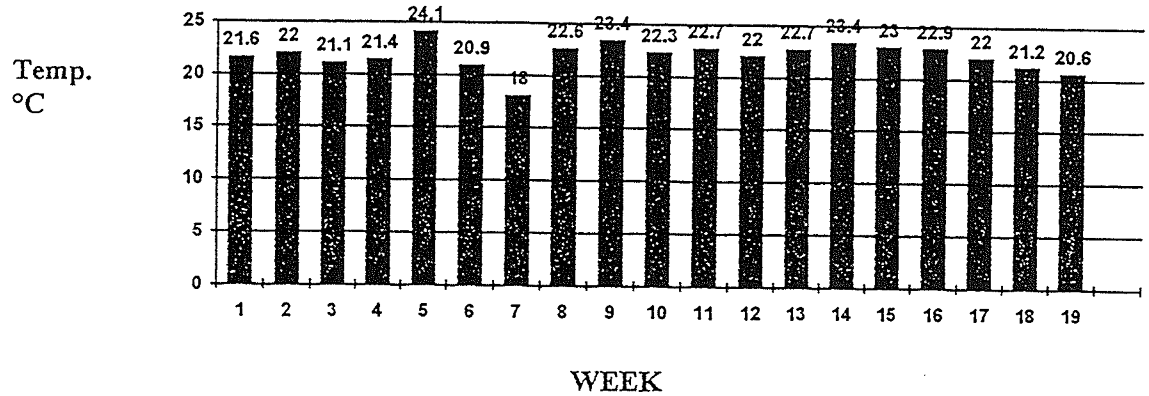


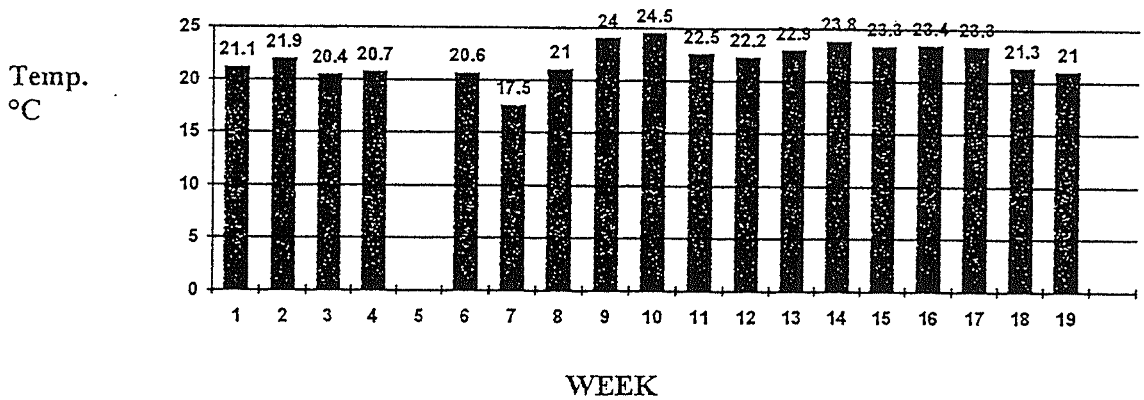

**Figure 11**. TAMC temperatures, weeks 1–19 (soil temperature)

TRIPLER STREAM ASSOCIATED TEMPERATURES

SITE No. 1 Water Temp.




SITE No. 2 Water Temp.




SITE No. 3 Water Temp.

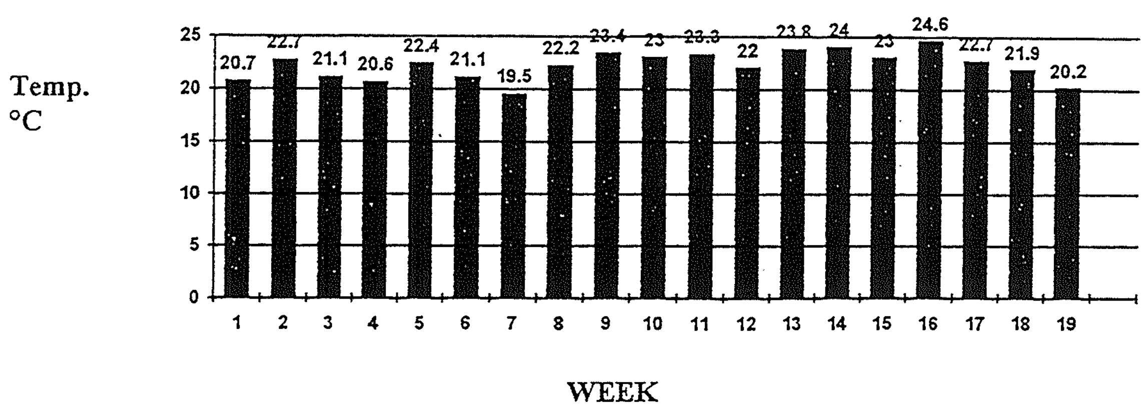



**Figure 12**. TAMC temperatures, weeks 1–19 (water temperature)

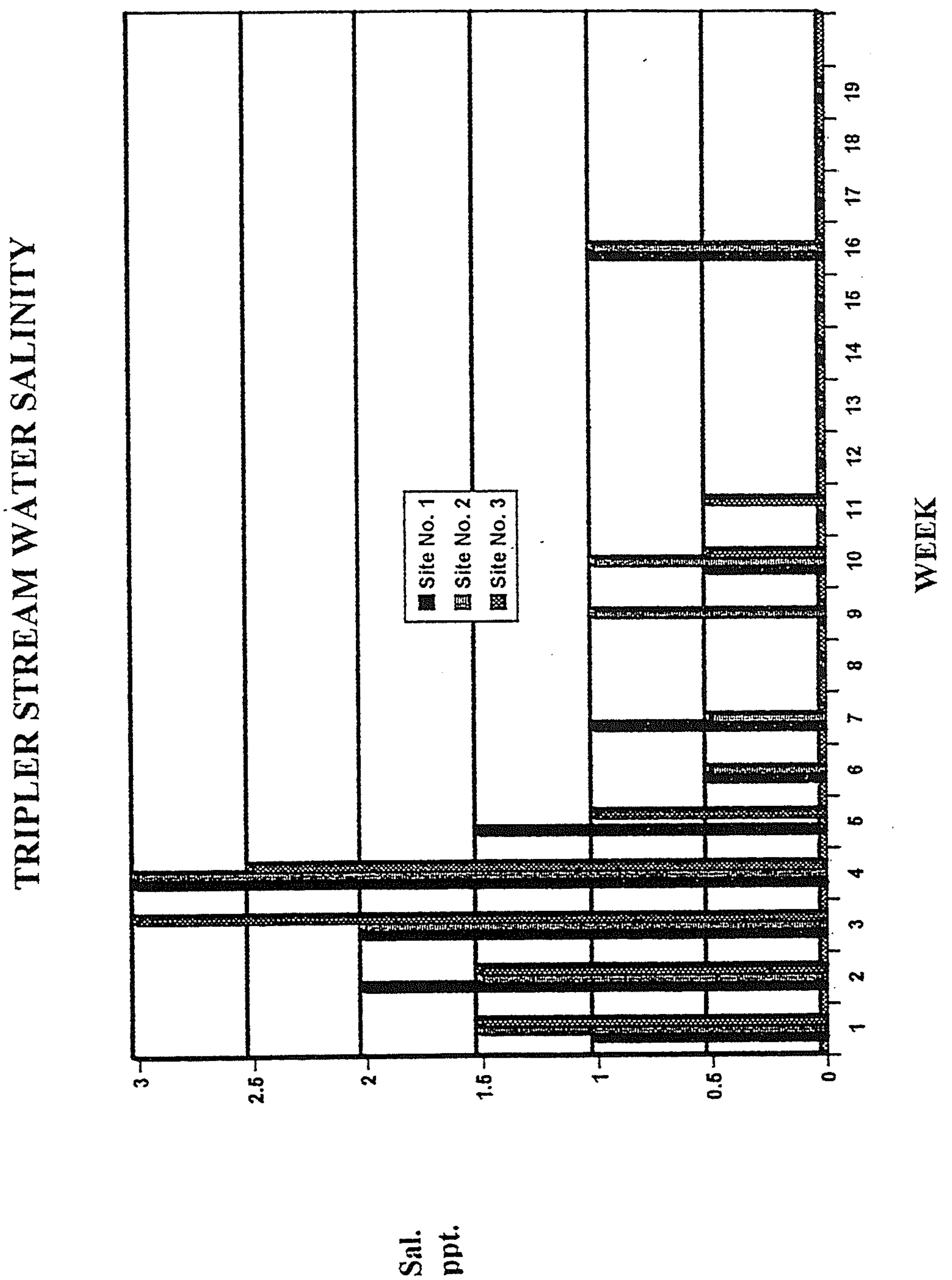



**Figure 13**. TAMC stream salinity—Sites 1–3

# STUDIES OF *MEGALAGRION XANTHOMELAS* POPULATIONS ON OTHER HAWAIIAN ISLANDS

## *HAWAII*

*Ninole Springs* - (Map 6a)

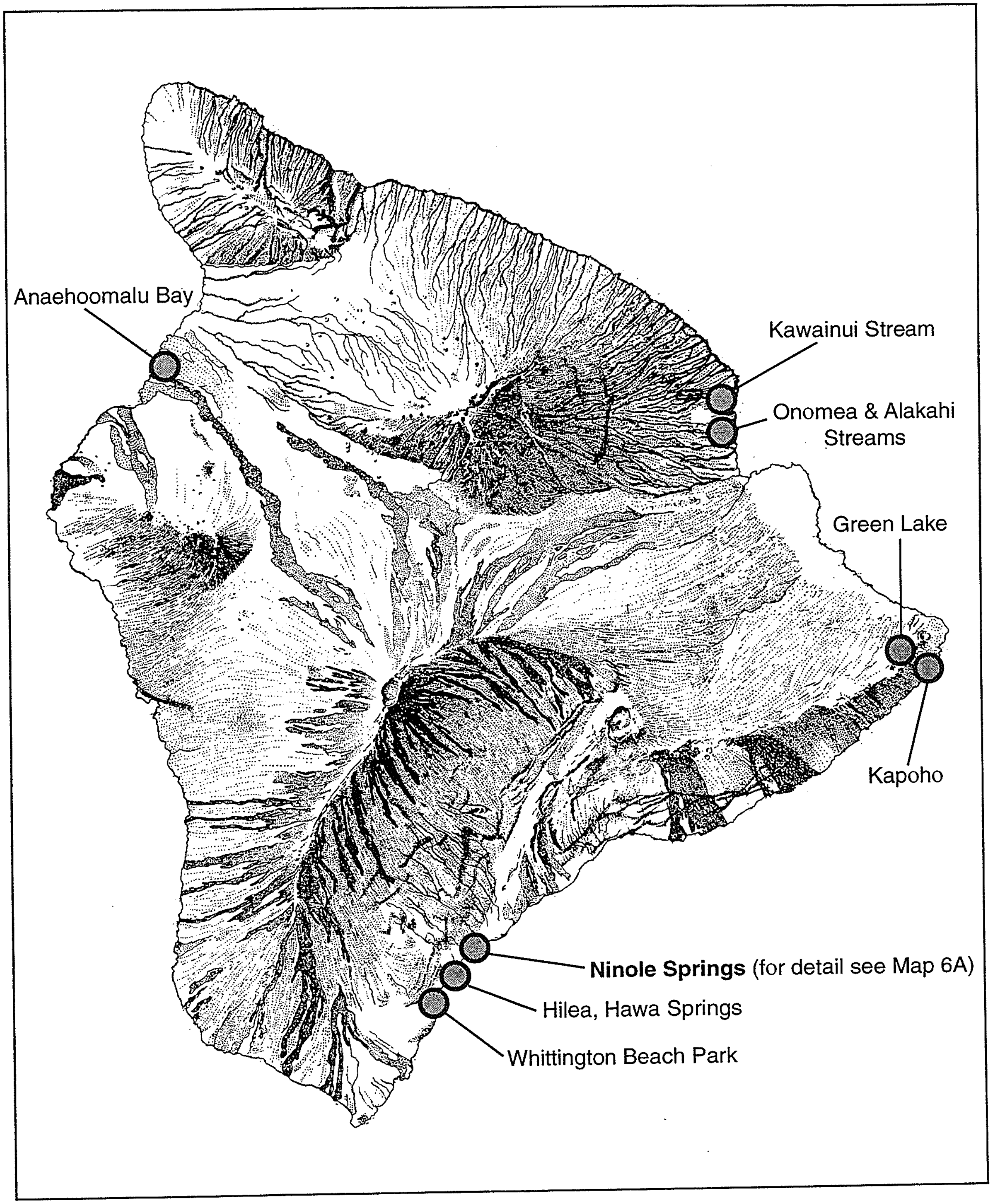
Scattered populations of *M. xanthomelas* are known from coastal wetlands in Puna, Kau and North Kona on Big Island, where limnetic groundwater percolates seaward and mixes with the inland flow marine water table to form horizontally stratified mixohaline systems. The largest of these coastal *M. xanthomelas* populations is found in an extensive set of limnocrenes, rheocrenes, and mixohaline marshes located at Ninole, Kau, where downslope subsurface percolation from the Ninole Hill drainages emerges just above sea level at the mouth of Ninole Stream. A survey in May 1994 found this area to support a robust population of *M. xanthomelas*, making it a potential source of live specimens that might be used for testing various rearing and marking protocols that could be employed in subsequent mitigation efforts on Oahu. A research team therefore visited the Ninole habitat, mapping and characterizing the diverse aquatic features present there in order to understand what range of salinity gradients *M. xanthomelas* can tolerate in such lentic coastal wetland habitats.

The work on Hawaii island was conducted on 8 and 9 June 1995. Active research staff for this work included Dan A. Polhemus and David Preston from the Bishop Museum, and David Foote from the National Biological Service.

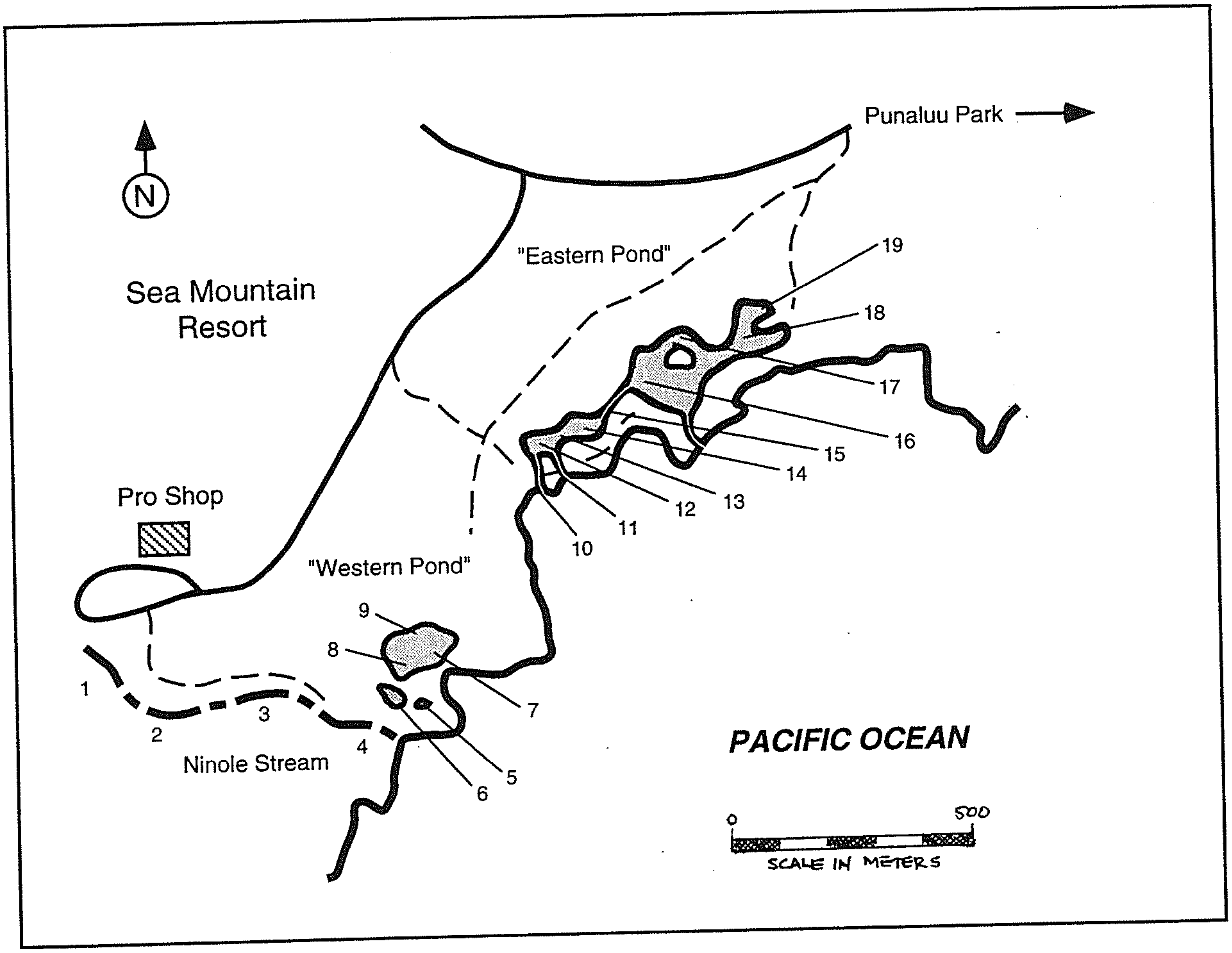
*Site Description* -

The large basal spring wetland at Ninole Springs, in Kau, occupies the mouth of Ninole Stream and lies immediately adjacent to the Sea Mountain golf development (Map 6A). This is the second largest basal spring complex on the island of Hawaii (the largest being Waiakea Pond at Hilo), and was discharging over 20 million gallons per day in 1946 (Stearns and Macdonald, 1946), although this flow may have been subsequently modified by withdrawls from wells to irrigate sugar cane fields near Pahala. The water originates from lava tubes in the Kau volcanic series, and represents the subterranean outflow from ancient valleys in the nearby Ninole Hills that were filled by subsequent eruptions from Mauna Loa. Due to its origination in catchments further upslope, the water is quite cold, with an emergent temperature of 19° C. This seaward percolating groundwater surfaces along the inland sides of coastal lava basins that have some degree of connection to the sea, creating horizontally stratified mixohaline systems with a zone of freshwater marsh along their inner margins. Similar basal spring wetlands are found at several other points along the Kau coast, including Punaluu, the mouth of Hilea Stream at Hawa Bay, Hawa Springs, and Whittington Beach Park.

The Ninole Spring wetland complex contains an extensive set of limnetic to mixohaline marshes, ponds and creeks lying at the stream mouth and in the area directly to the east, between the Sea Mountain golf course parking lot and the lava coastline. Numerous cold freshwater springs emerge just inland of the coast at the base of an a'a flow, some flowing directly into tidepools, others feeding large ponds and sloughs. One large pond with thick beds of watercress along its margins occupies a lava basin immediately east of the stream mouth, and is separated from the sea by a wall of lava approximately 10 feet high, which large waves occasionally overtop. A second, even larger pond lies further to the east, in a basin several feet above sea level, and enters the ocean via a swift freshwater creek approximately 3 feet wide and 6 inches deep. The inland margins of both these ponds grade into




**Map 6.** Map of Hawaii Island (Big Island) showing localities surveyed for *Megalagrion xanthomelas*




**Map 6A**. Detail map of Ninole Springs, Hawaii Island (Big Island), showing sites from which water chemistry data were obtained (sampling station numbers refer to those used in Table 1).

marshes dominated by bulrushes (*Schoenoplectus* sp.) and *honohono* (*Commelina diffusa*); similar marshes are also present in the area between the ponds, in association with smaller spring outflows. The eastern pond also contained water hyacinth (*Eichornia crassipes*) along its inland margin.

This system was originally visited by Bishop Museum scientists on 4 June 1994, as part of a set of *Megalagrion* status surveys funded by USFWS. Large surf caused by the passage of an unusual number of hurricanes and tropical storms during the summer and fall of 1994 subsequently altered the characteristics of some sections of the habitat at Ninole, particularly those lying nearest to the shore. However, the general wetland complex is so extensive that these disturbances did not have a deleterious long term effect on the *M. xanthomelas* population occurring there.

*Results -*

*Megalagrion xanthomelas* was abundant at Ninole Springs, breeding in all suitable habitats. Numerous mating pairs were observed, and many newly emerged adults were seen along the margins of the westernmost pond. A mating pair was also captured above the standing pool formed behind the cobble bar at the mouth of the stream itself.

The introduced damselflies *Enallagma civile* and *Ischnura ramburii* were present along the margins of the eastern pond, especially in seaward areas exposed to the wind, but *M. xanthomelas* was clearly the dominant damselfly species across the entire Ninole system. In general the introduced damselflies seemed more abundant in open areas, while *M. xanthomelas* flew amid the shelter of vegetation along the slough channels, which were difficult to investigate, being heavily vegetated and often over three feet in depth. The large dragonflies *Anax junius* and *Pantala flavescens* were also seen throughout the Ninole area.

Water chemistry readings were taken from 19 sites at Ninole Springs (Map 6A). Salinities throughout the wetland complex varied from limnetic (less than 0.7 ppt) at the outflows to fully euhaline (at least 30 ppt) at the ocean shore, with many degrees of intermediate salinity encountered throughout the ponds and marshes (Table 1). It is clear from other investigations on Molokai (see section below) that *M. xanthomelas* can tolerate salinities of at least 2 ppt. Thus, it is able to breed throughout much of the Ninole wetland system, since salinities here are generally 3 ppt or less.

The estuarine marshes and limnocrenes at Ninole Springs and other coastal wetlands in Kau provide extensive breeding habitats for *M. xanthomelas* that are not currently duplicated on the other high islands, although similar systems may once have existed at Pearl Harbor on Oahu prior to its urban development. Throughout such coastal situations, both here and in north Kona, *M. xanthomelas* is typically found in company with the alien *Ischnura ramburi* and *Enallagma civile*, but the competitive interactions among these species, if any, do not seem to preclude the continued presence of *M. xanthomelas* at these sites.

**Table 1**: Summary of water chemistry and other physical data for sampling sites on Hawaii

| Site | Soil pH (2/site) | | Water pH (2/site) | | Air Temp. (°C) | Soil Temp. (°C) | Water Temp. (°C) | Salinity (ppt) |
|---|---|---|---|---|---|---|---|---|
| Ninole Ponds*: | — | — | — | — | — | — | — | — |
| Site 1 | | | | | | | | |
| Site 2 | — | — | — | 7.1 | — | — | 18.9 | 0.74 |
| Site 3 | — | — | — | 8.4 | — | — | 19.8 | 0.76 |
| Site 4 | — | — | — | 8.6 | — | — | 22.2 | 0.77 |
| Site 5 | — | — | — | 8.9 | — | — | 23.2 | 0.80 |
| Site 6 | — | — | — | 6.9 | — | — | 23.7 | 0.79 |
| Site 7 | — | — | — | 8.2 | — | — | 19.9 | 0.75 |
| Site 8 | — | — | — | 8.5 | — | — | 23.0 | 0.76 |
| Site 9 | — | — | — | 7.4 | — | — | 24.7 | 0.78 |
| Site 10 | — | — | — | 7.5 | — | — | 17.9 | 0.66 |
| Site 11 | — | — | — | 7.4 | — | — | 19.2 | 0.65 |
| Site 12 | — | — | — | 7.1 | — | — | 18.8 | 0.62 |
| Site 13 | — | — | — | 6.5 | — | — | 20.1 | 1.02 |
| Site 14 | — | — | — | 6.3 | — | — | 21.5 | 1.01 |
| Site 15 | — | — | — | 6.7 | — | — | 19.7 | 0.72 |
| Site 16 | — | — | — | 8.6 | — | — | 21.7 | 1.94 |
| Site 17 | — | — | — | 7.4 | — | — | 17.9 | 0.74 |
| Site 18 | — | — | — | 9.0 | — | — | 21.8 | 2.74 |
| Site 19 | — | — | — | 9.0 | — | — | 21.7 | 2.81 |
| Onomea Stream | — | — | 7.0 | 7.0 | 22.6 | 22.0 | 21.3 | 0.0 |
| Alakai Stream | — | — | 7.1 | 7.1 | 23.5 | 22.6 | 21.7 | 0.0 |
| Hawaii Botanical Garden pond | — | — | 6.9 | 6.9 | 24.0 | 23.0 | 23.1 | 0.0 |
| Kapoho | — | — | 7.7 | 7.7 | — | — | — | 10.0 |

* Ninole data collected by D. Foote

## Other Sites Investigated on Hawaii Island

Previous surveys funded by the U.S. Fish and Wildlife Service have produced data on the occurrence of *M. xanthomelas* in the coastal wetlands of Kau and north Kona, and in streams along the southern section of the Hamakua coast. As a result of these surveys, several previously unknown populations of *M. xanthomelas* were located, and the ecological characteristics of their habitats documented. This information is included herein since it provides additional important information relating to the range of ecosystems occupied by this species. These sites are described briefly below, and the water chemistries of selected sites summarized in Table 1.

*Hilea* - (Map 6)

A coastal wetland similar in form and origin to that seen at Ninole but of smaller extent occurs at the mouth of Hilea Stream, approximately one mile to the southwest on the opposite (western) side of an intervening lava flow. The habitat consists of several elements, beginning with a long, deep mixohaline pool at the mouth of the stream channel, which runs parallel to the base of the lava flow. This pool is separated from the sea by a cobble bar that is occasionally overtopped by high swells, and experiences a weak tidal flux. No damselflies were seen along this pool. West of the stream mouth are several small limnetic ponds bordered with sedges, grasses, and *honohono*; these ponds supported *Megalagrion xanthomelas*, *Enallagma civile*, *Ischnura ramburi*, *Anax junius*, *Pantala flavescens*, and *Tramea lacerata*. Even further to the west is a large basin, connecting directly to the sea via a narrow mouth, but with a zone of bulrushes at the back, bordered even further inland by an extensive, apparently limnetic marsh thickly overgrown with tall grasses. No damselflies were seen at this latter basin, but it seems likely that *M. xanthomelas* may occur in the marsh.

When this site was visited on 4 June 1994, water was being pumped from the western marsh by squatters, who were using it to irrigate small taro fields. One of these squatters claimed that the mouth of Hilea Gulch previously consisted of a large, swampy estuary, but that a large flood four or five years before had washed in a large amount of sediment, producing the current configuration.

*Hawa Springs* - (Map 6)

This habitat consists of a small limnetic spring outflow emerging at the base of an eroded lava flow, and flowing into a linked series of progressively more saline ponds scattered along a sinuate depression behind the shoreline. The overall impression is one of an interrupted tidal creek, bordered by grasses and sedges. During a survey on 4 June 1994 the limnetic pools near the head of this system supported populations of *Megalagrion xanthomelas* and *Anax junius*; no introduced damselflies were seen. The area appears to be in a relatively natural condition, and does not appear to be frequently visited.

*Whittington Beach Park* - (Map 6)

A single large pond behind the shoreline at Whittington Beach Park receives limnetic inflow along its inland margin, while connecting to the sea via a narrow mouth along the ocean side. A mixohaline gradient appears to exist across the width of this pond, with the seaward portion being essentially euhaline, but changing to mixohaline as one progresses inland. The basin here is similar in extent to the large eastern pond at Ninole, but is not raised above sea level as in the former case. The back margin of the Whittington pond is bordered with low grasses and bulrushes, indicating that a narrow freshwater zone exists as a result of limnetic downslope percolation into the basin. *Megalagrion xanthomelas* was found here on 4 June 1994, with adults flying low amid the shelter of the vegetation along the back edge of the pond. No individuals were seen along the front edge of the pond nearer to the sea. Cattle have disturbed this system, but do not appear to pose a threat to the long term stability of the marsh.

*Anaehoomalu Bay* - (Map 6)

One of the most extensive sets of anchialine pools known on the north Kona coast formerly occurred along the northern margin of Anaehoomalu Bay, at a site now occupied by the Waikoloa resort. These pools were bulldozed in the course of resort development, but similar systems, though smaller in extent, still exist along the southern margin of the bay, in a complex owned by Parker Ranch and known as the "Parker Ponds." In this area the shore forms a high dune ridge, behind which lie a series of depressions, marked by palms, containing mixohaline marshes and bordered by low, halophytic vegetation, predominantly pickleweed (*Batis mar-*

*itima*). A specimen of *M. xanthomelas* was taken along the margin of one of these basins on 7 June 1994, in company with the introduced *Ischnura ramburi*, which was abundant. Although the salinity of these marshes was not ascertained, females of *Anax junius* were seen ovipositing in them, indicating that in at least some sections it must be quite low.

Beyond the marshy basins to the southwest lies a set of rock-rimmed anchialine pools, some forming large ponds with bulrushes along their margins. No damselflies were seen in this area, but two dragonfly species, *Anax junius* and *Tramea lacerata*, were observed. The overall Parker Pond system is relatively undisturbed, and further surveys in the area would be useful in order to localize the sources of limnetic inflow, around which *M. xanthomelas* would be likely to congregate. Development of this system should be discouraged if possible, since it represents the last remaining undisturbed portion of the formerly extensive Anaehoomalu anchialine pool complex, which was described in detail by Maciolek and Brock (1974).

The large Kuualii and Kahapapa fishponds at the Waikoloa resort were also surveyed, along with a complex of smaller adjacent anchialine pools containing red shrimps. All these habitats proved either too saline or too ecologically altered to support damselfly populations, and a search for further, more limnetic habitats in the general area was unsuccessful. A few specimens of *Anax junius* and *Pantala flavescens* were observed, but these individuals may have been strays from populations breeding in nearby golf course ponds. An extensive set of anchialine pools formerly occurred to the north of this site, near Waiulua Bay (Maciolek and Brock, 1974), but these were destroyed in the course of resort development and no longer exist. The habitat at Anaehoomalu Bay is typical of situations in which *M. xanthomelas* is found along the north Kona coast, with populations also known from anchialine systems at Kiholo Bay and Kaloko Fishpond.

*Onomea Stream* - (Map 6)

This is a relatively short catchment heading at approximately 900 feet elevation and flowing for 2.5 miles to a seaward terminus in Onomea Bay, north of Hilo. The stream exhibits a steep profile typical of drainages on the Hamakua Coast, descending stair-step fashion via waterfalls in a bed of hard basalt. The seaward terminus, which lies within the Hawaii Botanical Garden, consists of a long, flowing freshwater pool impounded behind a cinder beach, with a waterfall at its head. Progressing upstream one encounters a series of falls and plunge-pools heavily shaded by introduced figs, palms, and bamboo until the bridge on the Pepeekeo Scenic Drive is reached. Immediately above this road crossing the stream is less confined, and forms long, partially shaded flowing pools, which continue to the base of another high waterfall.

The terminal reach and lower midreach of this system both up and downstream of the Pepeekeo Scenic Drive were surveyed by Polhemus, Preston and Foote on 8 June 1995. *Megalagrion xanthomelas* and *M. hawaiiense* were found along the pooled midreach section of the stream at an elevation of 180 feet, just upstream from the road. However, no damselflies were seen along the terminal reach in the botanical garden. Individuals of *M. xanthomelas* were observed perching on low ferns, dead palm fronds, and bare rocks along the channel margins. Immatures were not found, but are likely to inhabit trailing submerged root mats that are well developed here.

*Alakahi Stream* - (Map 6)

This is a short, steep catchment approximately 1.5 miles long, heading at about 750 feet elevation and terminating in Onomea Bay adjacent to Onomea Stream. The stream presents a steep profile, descending through a bed of mossy boulders, heavily shaded by a forest of introduced trees. The terminal reach and lower midreach of this system upstream of the Pepeekeo Scenic Drive were surveyed by Polhemus, Preston and Foote on 8 June 1995. *Megalagrion xanthomelas* and *M. blackburni* were found between 180 and 250 feet elevation, up to a point where hau (*Hibiscus tiliaceus*) begins to heavily overtop the stream; the former species was found even in areas of dense shade, an unusual habitat preference (see comments under sections on Lanai and Molokai). No damselflies were seen along the lower section of the stream below the road, in the area where it passes through the Hawaii Botanical Garden, despite the presence of suitable habitat, including a large pond adjacent to the stream itself.

*Kawainui Stream* - (Map 6)

This is a large volume catchment that flows through a steeply dropping basalt bed and reaches the sea in an incised fjord south of Pepeekeo. At 200 feet elevation the stream flows through a natural archway formed by an old lava tube. The lower midreach of this system immediately downstream of the Pepeekeo Scenic Drive was surveyed by Polhemus, Preston and Foote on 8 June 1995. *Megalagrion xanthomelas* adults and immatures were taken at small side pools in bedrock adjacent to the main channel, and bordered by clumps of yellow flowering *Wedelia trilobata.* Other adults were taken next to seepage-fed pools on bedrock shelves along the south bank of the stream immediately across from these side pools. Heavy rains several days later caused the stream to rise appreciably, completely covering the side pool habitats with swiftly flowing water (although the seeps were not affected). It thus appears that at this site *M. xanthomelas* is exploiting temporary habitats on an opportunistic basis.

This and other *M. xanthomelas* populations found along drainages entering Onomea Bay probably represent a northward extension of the populations centered around the estuarine limnocrenes at Hilo. To date *M. xanthomelas* has not been found to the north along the Hamakua coast past Pepeekeo Point, despite surveys at suitable stream mouths between there and Honokaa. Most of the streams in the Hamakua area end in terminal falls, and of those few that do not the following have been surveyed: Kolekole, Hakalau, Honolii, and Laupahoehoe. Several others, such as Maulua and Nanue, still await surveys, but it is considered unlikely that they harbor *M. xanthomelas* populations based on current findings.

*Kapoho* - (Map 6)

An extensive series of anchialine and mixohaline wetlands fed by basal springs is found along the shoreline to the east of Kapoho Crater, in Puna, developed amid a series of recent lava flows that have been subject to coastal subsidence. Searches were made by Polhemus, Preston and Foote along the seaward edge of this system, both north and south of Kapoho Point. *Megalagrion xanthomelas* was found in the former area, which is being developed into residential subdivisions, with adults patrolling along the margins of moderately saline (8.0–8.5 ppt.) pools. Current U.S. Geological Survey (USGS) maps do not correctly reflect the coastline profile and adjacent wetlands in this area, since extensive subsidence took place after their last update in 1981.

*Green Lake* - (Map 6)

The interior of Kapoho Crater contains a water-filled basin known as Green Lake, which has no outlet and appears to be fed by seepage from the surrounding crater walls. This lake, which is essentially circular and several hundred yards across, has silty, greenish waters with a temperature of 27° C., and supports an overwhelmingly alien aquatic biota including frogs, top minnows, and numerous introduced aquatic plants. The shores are thickly lined with bamboo, kukui, breadfruit, mango and other exotic vegetation. Two males of *M. xanthomelas* from this locality, collected by F.X. Williams in 1936, are present in the collection of the Hawaii State Department of Agriculture. A survey of the lake and its surroundings in good weather failed to detect any sign of this species, although the introduced damselflies *Ischnura ramburi* and *Enallagma civile* were abundant, in company with the dragonflies *Anax junius* and *Pantala flavescens.* It is assumed that the introduction of alien fishes and frogs at Green Lake has led to the extirpation of this population of *M. xanthomelas*.

## *LANAI*

***Koele Lodge*** - (Maps 7–8)

One of the largest populations of *Megalagrion xanthomelas* outside of Hawaii island occurs in a set of ornamental streams and pools at the Koele Lodge on upland Lanai. These habitats, lying at 1900 feet above sea level, are also the highest elevations from which the species has been recorded in this century. The existence of this population remained undetected until 1993, although the species presumably occupied the ranch pond that was constructed at this site in the late 1800s. The fact that *M. xanthomelas* has been able to colonize an artificial habitat that was constructed within the last five years with no consideration to damselflies whatsoever has an important bearing on the situation at TAMC, since it indicates that construction of similar habitats at TAMC might be sufficient to mitigate the present threats to the species at this latter site. A research team therefore visited the Koele Lodge in order to a) determine the sequence of aquatic habitats that have existed at this site over time, b) assess the methods that were used in the construction of the present ornamental ponds, c) determine the presence or absence of introduced vertebrate and invertebrate species that might have in impact on *M. xanthomelas*, and d) determine precisely where *M. xanthomelas* is breeding within this system.

The work on Lanai was conducted from 25 to 27 April 1995. Active research staff for this work included Dan A. Polhemus and David Preston from the Bishop Museum, Adam Asquith from the U. S. Fish and Wildlife Service, and John T. Polhemus, a visiting museum research associate.

*Site Description* -

The resort complex at Koele, consisting of The Lodge at Koele and The Experience at Koele golf course (both referred to hereafter as Koele Lodge) was constructed in 1990 on the site on the former Koele ranch, at an elevation of 1900 feet (Map 7). The development includes ten separate aquatic features, including a large reflecting pool and ornamental stream complex behind the lodge itself, a putting course nearby with several small ornamental streams, and 8 large ponds scattered around the golf course that serve as water hazards for the golfers (Map 8). All of these individual habitats were surveyed, and their water chemistries are summarized in Table 2. For purposes of this study the reflecting pool and inflow stream behind the lodge building are treated as a single aquatic feature, as are the two large ponds at Holes 8 and 9 that are connected by a cascading ornamental stream. Several of these water features are also fed by shared recirculating water systems. Most notable among these are the ponds at Holes 4 and 18, which are widely separated topographically and elevationally (Hole 4 lies at 2000 feet, Hole 18 at 1900 feet), but connected hydraulically. Such connections would allow potential transfer of *M. xanthomelas* eggs and immatures from one site to the other through the recirculating water system. All the water features on the golf course are internally recirculating with the exception of the pond at Hole 17. The pond and streams behind the lodge, Holes 4, 8–9, and 18, and the putting green streams occupy sheltered locations at the base of Lanaihale mountain and are surrounded by tall stands of *Araucaria* and other introduced trees. By contrast, the ponds at Holes 12, 15, 16 and 17 are more exposed to the wind and lack shelter from either topography or trees.

The large pond and its associated inflow streams behind the lodge building, referred to subsequently as the Lodge Pond, has a capacity of 3.5 million gallons, and is not currently subjected to any water treatment protocol. The pond is equipped with a downflow biofilter system, but this has never been used in the 6 years since its emplacement due to technical problems. A high rate sand filter is also installed, but like the biofilter is not currently in use. Instead, occasional treatments of potassium permanganate at 5 ppm concentrations are applied to retard the growth of algae. The pond occupies the site of a previous storage reservoir used by the former Koele ranch to water cattle, indicating that an artificial aquatic feature has been continuously present at this site for over a century.

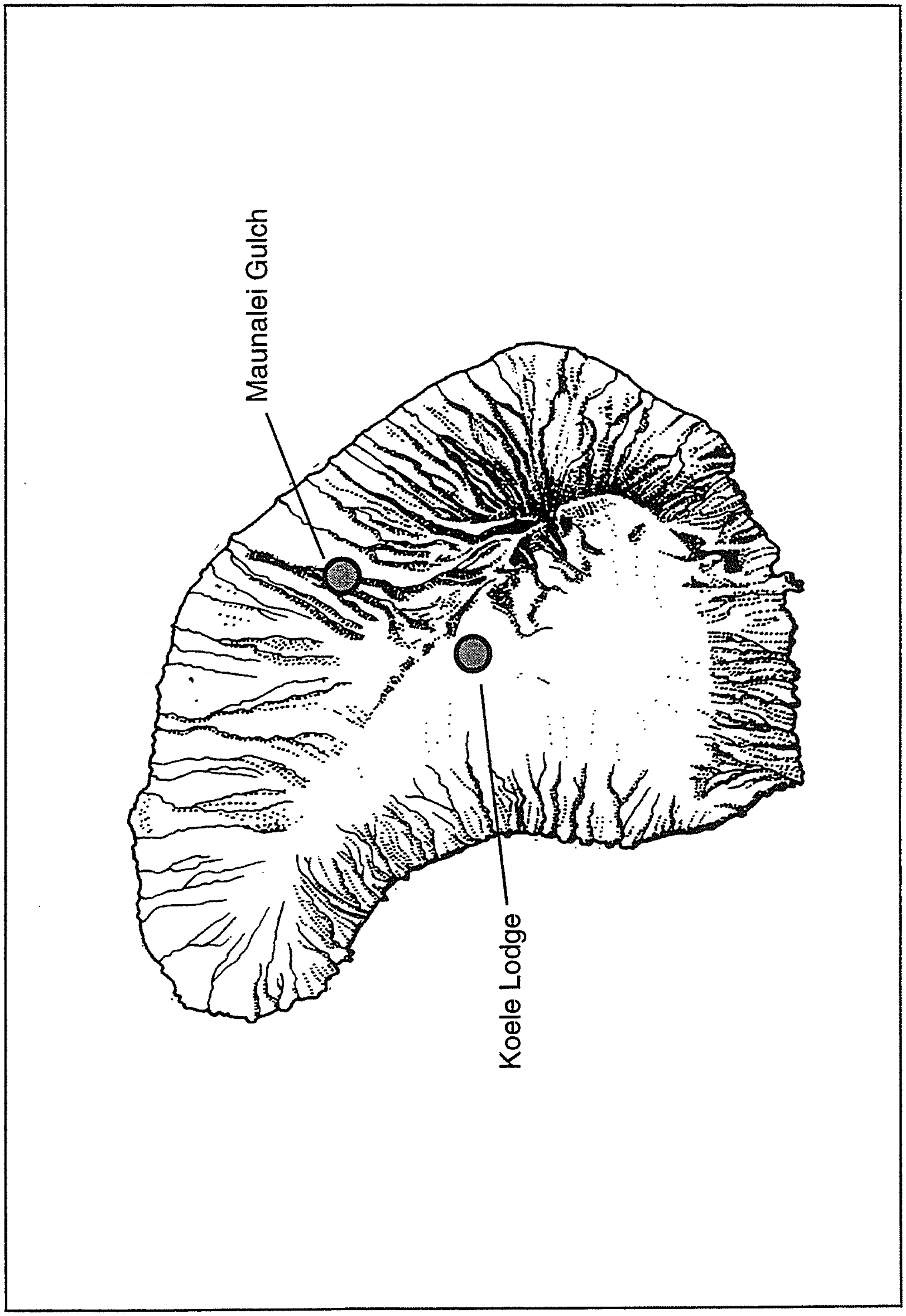
The recirculating inflow stream feeding the Lodge Pond originates in a small lily pond upslope from the lodge. This pond is a roughly circular basin approximately 15 feet in diameter and 3 feet deep. The surface is covered with numerous floating lily pads, and the western margins are composed of set rock walls bearing a growth of ferns, whose roots hang into the water. This pond previously received applications of Aqua Shade© to retard algal growth, but this practice has been discontinued for the last 2.5 years.

The several small streams present on the putting green, immediately east of the lodge building, are swift and unshaded, originating in small ponds lined with ornamental rock walls. They are lined by plantings of exotic flowering plants, and receive an application of Aqua Shade© once a month to eliminate algae.

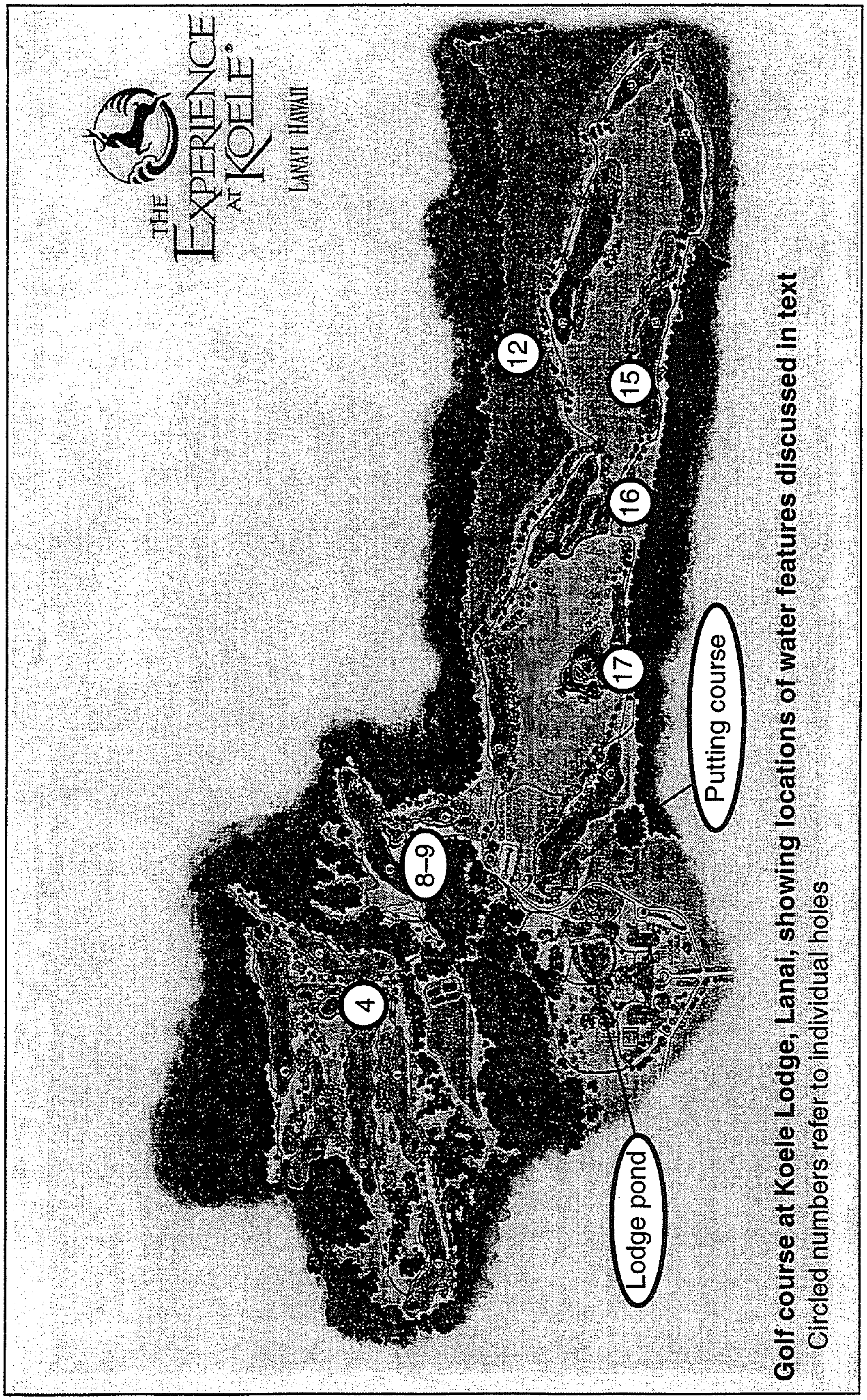
None of the other water features on the golf course are currently subjected to filtration or chemical treatments. Ornamental carp are present in the Lodge Pond, guppies were seen at Holes 12 and 15, a large dead non-ornamental carp was found at Hole 12, and apple snails were present at Hole 15. Apart from this, and the exotic Odonata noted in Table 3, the water features at Koele Lodge seem to be relatively free of introduced aquatic biota.

*Results -*

The research team arrived on Lanai on the evening of 25 April, and made an initial visit to Koele Lodge the following morning. The managers of the property were very helpful, and provided extensive background information relating to the construction of the lodge and golf course, and their attendant aquatic features. Following preliminary meetings with lodge general manager Kurt Matsumoto and landscape director Michael Dixon, the group assessed the distribution of *M. xanthomelas* populations in the Lodge Pond area. *Megalagrion xanthomelas* was common here, particularly in the lily pond at the upper end of the system. Other popula




**Map 7**. Map of Lanai showing localities surveyed for *Megalagrion xanthomelas*




**Map 8**. Map of The Experience at Koele golf course, showing localities surveyed for *Megalagrion xanthomelas*

tions were located in water features at the adjacent putting course and 18th hole. Most of the team (Asquith, Preston and J.T. Polhemus) remained near these sites to collect specimens, make detailed behavioral observations, and conduct water chemistry analysis, while D.A. Polhemus accompanied Michael Dixon on a tour of the remaining water features on the golf course. This tour revealed that *M. xanthomelas* populations were also present at the 4th, 8th and 9th holes (the latter two a connected aquatic system), but apparently absent at the ponds adjacent to the 12th, 15th, and 16th holes (see Table 2).

**Table 2**: Summary of water chemistry and other physical data for sampling sites on Lanai

| Site | Soil pH (2/site) | | Water pH (2/site) | | Air Temp. (°C) | Soil Temp. (°C) | Water Temp. (°C) | Salinity (ppt) |
|---|---|---|---|---|---|---|---|---|
| Lodge pond (upper) | — | — | 8.6 | 8.6 | 19.1 | 19.0 | 21.6 | 0 |
| Lodge pond (lower) | — | — | 9.3 | 9.4 | 20.3 | 19.5 | 20.7 | 0 |
| Putting course | — | — | 9.1 | 9.1 | 20.9 | 19.0 | 21.9 | 0 |
| Hole 12 | | | 8.8 | 8.9 | 18.5 | 19.0 | 20.1 | 0 |
| Hole 15 | | | 9.8 | 9.9 | 18.7 | 20.0 | 20.3 | 0 |
| Hole 16 | | | 9.0 | 9.1 | 18.1 | 19.0 | 20.0 | 0 |
| Hole 17 | | | 9.1 | 9.2 | 17.4 | 19.5 | 20.4 | 0 |
| Maunalei Gulch | | | 8.0 | 8.1 | 22.5 | 21.0 | 24.5 | 0 |

**Table 3:** Distribution of Odonata taxa at aquatic habitats in the vicinity of Lanai City

| Taxon | LG | PC | 4 | 8–9 | Locality 12 | 15 | 16 | 17 | 18 | WW |
|---|---|---|---|---|---|---|---|---|---|---|
| M. xantho | x | x | x | x | - | - | - | x | x | - |
| E. civile | x | x | x | x | x | x | x | x | x | x |
| I. ramburii | - | - | - | - | x | - | - | x | - | x |
| A. junius | x | x | - | - | x | x | x | x | x | x |
| O. ferru x | - | x | x | x | - | - | x | - | - | - |
| P. flaves | x | - | x | x | x | x | x | x | - | - |

Explanation of locality codes:
LG = Lodge reflecting pond; PC = putting course, 4 = 4th hole, 8–9 = 8th and 9th holes; 12 = 12th hole; 15 = 15th hole; 16 = 16th hole; 17 = 17th hole; 18 = 18th hole; WW = wastewater treatment plant.

Explanation of taxon codes:
M. xantho = *Megalagrion xanthomelas*; E. civile = *Enallagma civile*; I. ramburii = *Ischnura ramburii*; A. junius = *Anax junius*; O. ferru = *Orthemis ferruginea*; P. flaves = *Pantala flavescens*

On the morning of April 27, the group divided, with Preston and J.T. Polhemus investigating the ponds at the 12th, 15th, and 16th holes, while D.A. Polhemus and Asquith visited the ponds at the wastewater treatment plant south of Lanai City, where they found robust populations of introduced damselflies, particularly *Ischnura ramburi*, but no *Megalagrion*. These two researchers then returned to Koele and visited the 4th, 8th and 9th holes, photographing the oviposition sites used by *M. xanthomelas* at these locations. They then joined Preston and J.T. Polhemus at the 15th hole; these latter two researchers had over the course of the morning determined that *M. xanthomelas* was indeed absent from these sites, as noted by D.A. Polhemus the previous day, and had completed the water chemistry analysis for all aquatic features at Koele (this data is summarized in Table 2). The general consensus was that the sites at the 12th, 15th, and 16th holes were too exposed and windy, and thus not preferred by *M. xanthomelas*, although they did support the introduced damselflies *Ischnura ramburi* and *Enallagma civile*. A brief stop was then made at the pond surrounding Hole 17, which did harbor low numbers of *M. xanthomelas*.

In summary, populations of *M. xanthomelas* were found at the Lodge Pond and its inflow streams, Holes 4, 8–9, 17 and 18, and at the small streams on the putting course, but the species was absent at the ponds adjoining Holes 12, 15 and 16 (see Table 3). It was evident that the insects preferred the more sheltered sites, an observation congruent with that made at Ninole Springs in Kau (see previous section). Numerous other Odonata were also found in these artificial systems, including the introduced damselflies *Enallagma civile* and *Ischnura ramburi*, and the dragonflies *Anax junius*, *Pantala flavescens* and *Orthemis ferruginea*. No clear correlation was evident between the presence of any of these other species at a site and the absence of *M. xanthomelas*, indicating that competitive interactions are not structuring Odonata guilds in this system.

Detailed observations were made regarding *M. xanthomelas* behavior at several of the Koele sites. The most robust population appeared to be in the lily pond at the source of the ornamental stream feeding the Lodge Pond. Females were seen ovipositing here on floating lily pads, which exhibited numerous brown oviposition scars, and immatures were taken from the submerged roots of ferns that grew on the rock wall bordering the pool. Adults were also observed emerging from their immature casings at this site. Emergence took 30–60 minutes, after which the insects flew away from the water to perch in sheltered spots amid vegetation, presumably to allow their cuticle to harden. By contrast, adults in later stages of maturity were active around and above the pond, with males aggressively defending territories approximately two meters in diameter. These adults quickly ceased activity if the sunlight was interrupted by passing clouds, indicating that *M. xanthomelas*, at least at this elevation, is very photosensitive.

At the Hole 8–9 complex tandem pairs of *M. xanthomelas* were observed ovipositing in collapsed lily stems that hung into the water, while at Hole 4 a female was observed ovipositing on algal mats in the lowermost of three inflow basins below an ornamental waterfall. The pond at this latter site had relatively open, grass-lined banks, and in this area adults were observed only in areas where small irregularities in the shore line, such as coves formed by large rocks, provided some form of shelter.

## Other Sites Investigated on Lanai

*Maunalei Gulch* - (Map 7)

The population of *M. xanthomelas* currently extant at the Koele Lodge occupies artificial habitats that did not exist prior to the early 1990s. The source of the *M. xanthomelas* population that colonized this site must thus lie elsewhere. It is possible that the insects colonized the former Koele Ranch cattle pond from populations inhabiting small springs emerging at the base of Lanaihale mountain, but no such outflows are mentioned by Stearns (1940). Instead, the most logical source from which the colonists could have come is Maunalei Gulch, a deep canyon on the northern side of Lanai that previously contained the only perennial stream on the island. A survey previous to this project of the upper reaches of this gulch by D.A. Polhemus in 1993 revealed that three species of *Megalagrion* damselflies, *M. hawaiiense* (McLachlan), *M. blackburni* McLachlan and *M. calliphya* (McLachlan), still persisted in this catchment, but *M. xanthomelas* was not seen. In 1994, however, a specimen of *M. xanthomelas* was taken in dry forest near the mouth of Maunalei Gulch by Dr. Richard Baumann, a visiting entomologist from Brigham Young University. This discovery indicated that a population of *M. xanthomelas* did indeed persist somewhere in the lower Maunalei system, and a attempt was thus made to locate it during the current investigations on Lanai.

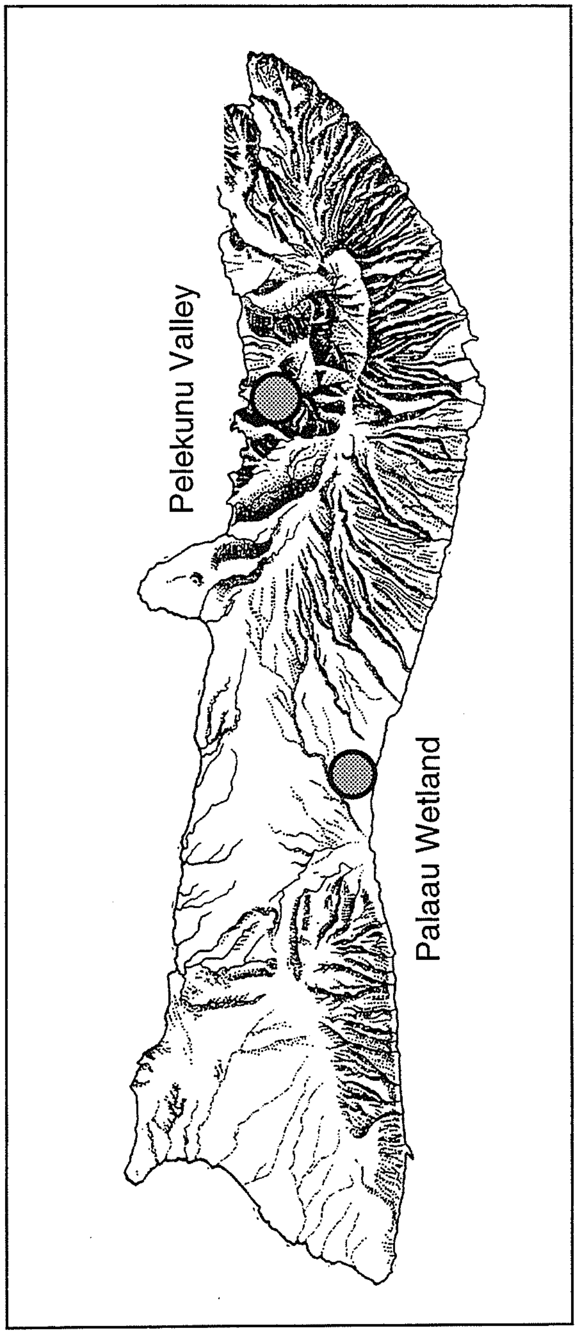
An initial reconnaissance of the coast revealed no wetlands that might support the species. A foray was then made up the lower reaches of Maunalei Gulch, which is at this point a dry bed shaded by kiawe forest. D.A. Polhemus eventually discovered a leak in a small water pipeline at approximately 400 feet above sea level, which created a limited outflow on a bench above and to the south of the gulch bed. *M. xanthomelas* was relatively abundant along this seepage, but since it was discovered at sunset there was little chance to characterize the habitat in detail before darkness compelled a return to Lanai City. A second visit was made to the site on the following day at midafternoon, with the air temperature at 22.5° C., and under these sunny conditions *M. xanthomelas* was found to be quite common. The habitat was photographed, the water chemistry evaluated, and voucher specimens taken. The water at this site was found to have the following characteristics: temperature: 24.5° C.; salinity: 0.0 ppt; pH: 8.0. This habitat is extremely limited, and could easily be eliminated should the Lanai Company decide to repair or replace the currently leaking pipeline.

## *MOLOKAI*

***Pelekunu Valley*** - (Map 8)

Only four populations of *M. xanthomelas* are known on Molokai, one of which is a small colony breeding in the terminal pond at the mouth of Pelekunu Stream, which was documented by Polhemus (1991). This is one of the few undisturbed stream termina remaining in Hawaii, and is indicative of the habitats that the species may previously have occupied on Oahu. A research team therefore visited the mouth of Pelekunu valley to investigate the ecology of *M. xanthomelas* in a natural lentic setting.

The work on Molokai was conducted from 29 to 30 August 1995. Active research staff for this work included Dan A. Polhemus and David Preston from the Bishop Museum, and Bill Puleloa of the Hawaii State Division of Aquatic Resources. Due to the remote nature of Pelekunu Valley, access was accomplished by helicopter.




**Map 9**. Map of Molokai showing localities surveyed for *Megalagrion xanthomelas*

*Site Description -*

Pelekunu Stream is a swift, rocky, perennial stream that begins as a set of plunging streamlets at elevations near 4000 feet on the sheer northern face of the Molokai Crest. The catchment takes the form of a giant bowl, ringed by peaks including Kaunuohua, Olokui and Kamakou, the latter at 4970 feet being the highest point on Molokai. The headwater reaches are nearly vertical, with the stream profile making an abrupt transition to a more moderate gradient at approximately 3000 feet elevation, which is interpreted as the head of the midreach. From this elevation downstream to the mouth the channel exhibits a moderate but continuous gradient, with numerous riffles and small cascades, and thus retains a midreach character completely to its seaward terminus.

The extreme lower section of Pelekunu Valley consists of a vegetated fan of debris, laced by various stream channels that are continually cut-off and reoccupied. These abandoned channels in many cases contain pools with weak flow that are fed by seepage through the pore spaces in the coarse surrounding alluvium. At the mouth of the stream the debris fan forms a transverse barrier of water-rounded rocks and cobbles, behind which the stream pools to form a small pond before entering the sea by way of a small rapid. The size of the terminal pond varies according to spates and other stream fluctuations, and at certain times of year a black sand beach is also exposed seaward of the cobble bar that impounds it.

Further upstream at the head of the debris fan the bed narrows and vertical walls of coarse volcanic conglomerate occasionally confine the channel. The basic channel substrate throughout this terminal section consists of rounded cobbles averaging 8 to 16 inches in diameter, alternating with beds of coarse gravel. Except for the large pool at the mouth, the stream profile is composed primarily of erosional zones formed by rapids and riffles. In the first half-mile upstream from the mouth numerous streamlets and rheocrenes enter from the east bank off the steep flanking wall of the Olokui massif, forming swampy areas at the base of the eastern valley wall. To the west of the stream mouth is an extensive complex of abandoned taro fields, now dry and heavily overgrown by introduced grasses.

During the initial visit to lower Pelekunu Valley in 1991, D.A. Polhemus captured individuals of *M. xanthomelas* along the margins of the terminal pond formed behind a cobble bar at the stream terminus. This bar was high enough and steep enough that the waves did not overtop it, and thus retained a limnetic character despite its proximity to the sea. The adults observed here did not range far from the pond, flying low and perching amid vegetation on the stream margins which offered protection from the sea breeze, and since the species was not encountered elsewhere in the lower valley it was assumed that this terminal pond was the breeding site.

This area in 1995 showed a number of changes from its aspect in 1991. The alluvial delta bordering the terminal pond was now heavily overgrown with tall stands of Job's tears (*Coix lachryma-jobi*), and the riparian vegetation further up the valley was also much denser. This revegetation appears to indicate recovery from a major flood that took place immediately prior to the initial 1991 survey. The stream channel itself also exhibited a different configuration, splitting into a D-shaped loop just before its seaward terminus. The previously ponded section now occupied a small area along the outside curve of the D near the point where this side branch rejoined the main channel. The pond, which in its present configuration could more properly be considered a deep, flowing pool, was bordered along its seaward side by the terminal cobble bar covered with *honohono* plants, along its eastern side by steep bedrock face, and along its remaining margins by cobble bars overgrown with Job's tears (*Coix lachryma-jobi*) and Guinea grass (*Panicum maximum*). The pond was measured and found to be 36.7 feet in length and 31.4 feet in width, with an inflow width of 17.4 feet. The maximum depth of the pond was 4.5 feet, and the depth at the inflow was 1.6 feet. The substrate of the pond consisted of stream-rounded rocks and cobbles sitting on coarse, dark gravel. The water chemistry of this site is summarized in Table 4.

*Results -*

*Megalagrion xanthomelas* was found at the mouth of Pelekunu Valley, but only in a small area along the seaward margin of the pond. At least four males were observed perching amid marginal vegetation and making short forays over the open water; no females were seen. A detailed search was made of the leaves of the *hono-hono* plants that bordered the pond but no oviposition scars were found, although tissues of this plant are known to be a favored oviposition sites for *M. xanthomelas* at TAMC. Other Odonata co-occurring with *M. xanthomelas* at the terminal pond included the introduced damselfly *Ischnura ramburi*, which was not seen during the 1991 surveys and may be a recent invader in the valley, and the indigenous dragonflies *Anax junius* and *Pantala flavescens*.

Of particular note at Pelekunu was the short time duration of *M. xanthomelas* activity during the day. When the survey team arrived at 9:00 AM the weather was clearing after a brief rain shower and the sun was just rising above the rim of the Olokui massif. Although fair and sunny conditions prevailed for the next several hours after this, no *M. xanthomelas* were observed. In the absence of any activity, surveys were made a short distance up the main stream to see if populations might be present there. None were found, although three other *Megalagrion* species, *M. pacificum*, *M. blackburni* and *M. hawaiiense*, were observed. The survey party returned to the pond area at approximately 1130 hours and at this point found adult *M. xanthomelas* to be active, allowing the capture of several specimens. By 1230 hours, a brief shower passed over and activity ceased. Although the remainder of the day was characterized by alternating periods of sun and light showers, no additional *M. xanthomelas* were observed. At this site the total duration activity on the day that surveys were made thus appeared to be approximately one hour during midday when the valley received its most direct sunlight. This preference for high light conditions corresponds to similar observations made at the Koele Lodge on Lanai (see previous section).

**Table 4**: Summary of water chemistry and other physical data for sampling sites on the island of Molokai

| Site | Soil pH (2/site) | | Water pH (2/site) | | Air Temp. (° C) | Soil Temp. (° C) | Water Temp. (° C) | Salinity (ppt) |
|---|---|---|---|---|---|---|---|---|
| Palaau: Kaluaapuhi | — | — | inlet 7.2<br>boat: 7.1 | inlet: 7.2<br>boat: 7.1 | — | — | 24.5 | inlet 2.0<br>boat 3.0 |
| Palaau: Molokai Sea Farms Pond | — | — | 6.6 | 6.6 | — | — | 31.0 | 2.0 |
| Pelekunu Valley breeding site | — | — | 8.2 | 8.3 | | — | 23.0 | 0.0 |

## Other Sites Investigated on Molokai

*Palaau Wetland* - (Map 9)

An extensive basal spring wetland is present at Palaau, 2 miles west of Kaunakakai on the southern coast of central Molokai. At least six individual spring outflows of varying sizes are present in this area, many being marked by stands of bulrushes (*Schoenoplectus* sp.), bordered peripherally by expanses of pickleweed (*Batis maritima*), and others emerging along the margins of shallow coastal basins to form large, horizontally stratified mixohaline ponds, most notably the Kaluaapuhi Pond. Most of the larger springs that emerge above sea level have been boxed, although their outflows still reach the ponds, and water from others is being used to supply an expanding series of aquaculture projects, and for cooling and steam generation at the local power plant. The vegetation of the area is highly altered from its original state, being a *kiawe* (*Prosopis pallida*) savannah along the inland margins, and bearing a thick band of mangroves seaward, the latter having become established after World War II. A more complete vegetative description of this ecosystem type may be found in Wagner *et al.* (1990). Although the Palaau wetland is still partially intact, the continued spread of aquaculture facilities, which are being actively promoted and funded by the County of Maui, will likely alter this area in the near future, both by reconfiguring the mixohaline pools and marshes, and by diverting the spring waters upon which these systems depend.

*Megalagrion xanthomelas* was present here along the along the inland margins of the wetland, in company with two introduced damselfly species, *Ischnura ramburi* and *Ischnura posita*, and two larger dragonfly species, *Anax junius* and *Orthemis ferruginea*. Individuals of *M. xanthomelas* were observed along the back edge of Kaluaapuhi Pond, in the nearby mangroves along a flooded trail, and emerging as tenerals from small water pockets at the base of an isolated *Schoenoplectus* clump. Measured salinities in Kaluaapuhi Pond varied from 2 ppt at a small spring inflow to 3 ppt in middle of the pond away from this inlet. Stearns and Macdonald (1947) noted that the entire basal lens underlying west and central Molokai is brackish, thus all basal springs in this area are saline to some degree. The fact that *M. xanthomelas* is breeding in the Palaau wetland, which is supplied by such brackish springs, clearly indicates that the species can tolerate salt concentrations of at least 2 ppt.

This conclusion was reinforced by the discovery of *M. xanthomelas* at a small pond adjacent to the Molokai Sea Farms aquaculture facility at western end of the Palaau wetland complex. This pond occupied an elongate, steep sided basin bordered by pickleweed (*Batis maritima*) and other introduced weeds. The waters of the pond were heavily covered with a layer of duckweed (*Lemna* sp.), which was maintained by the aquaculture farm as a means of deterring algal growth. The steep sides and elongate form of the basin suggest that it is an artificial modification of a former spring outflow.

*Megalagrion xanthomelas* was present at this small pond, in association with the same damselfly and dragonfly species seen at Kaluaapuhi pond, but did not occur at the adjacent aquaculture ponds, which lacked floating or marginal vegetation. Individual males were seen perching on sticks and weeds that projected over the water, and a tandem pair was observed ovipositing on the thick duckweed mat. The salinity of the water in this pond was taken and found to be 2 ppt., the same as that of the springs at Kaluaapuhi Pond (the water chemistry of these sites is summarized in Table 4). This once again clearly demonstrates that *M. xanthomelas* can breed in mildly saline waters.

## SUMMARY OF OUTER ISLAND STUDIES

The present surveys of *Megalagrion xanthomelas* on Hawaii, Lanai, and Molokai demonstrate that the species occupies a wide range of habitats and has broad ecological tolerances. The most common habitats in which this species occurs are coastal wetlands fed by basal springs, as seen in the Puna, Kau and north Kona districts of Hawaii, at Palaau on Molokai, and formerly at Pearl Harbor on Oahu. This species also occasionally breeds along the terminal and lower midreaches of perennial streams, as illustrated by the populations at Pelekunu Valley on Molokai and Onomea Bay on Hawaii island. Given the absence of introduced aquatic biota, *M. xanthomelas* can also breed in reservoirs and ornamental ponds, as recorded previously by Williams (1936) and currently documented at the Koele Lodge on Lanai. The species will also opportunistically exploit temporary habitats, as shown by its occupation of ephemeral side pools bordering flashy streams on Hawaii island, and pipeline seepages on Lanai.

Although *M. xanthomelas* has a recorded elevational range of 0 to 3000 feet above sea level (Perkins, 1899), it is generally a lowland species, with most of the known populations now occurring below 200 feet, and the highest recent records coming from 2000 feet, in artificial settings on Lanai. Results from salinity readings taken at Palaau, Molokai demonstrate that the species can tolerate saline concentrations of at least 2 ppt, and circumstantial evidence from habitats in Puna and north Kona indicates that the tolerance may be as high as 8 ppt. Based on results from Lanai the species also does not seem to be adversely affected by commercial anti-algal treatments such as Aqua Shade© and potassium permanganate, which are commonly used in hotel and golf course water features. The species was found breeding in habitats with water temperatures ranging from 20–31° C, and with pHs ranging from 6.6–9.2 (Tables 1–4).

In terms of interactions with alien aquatic species, *M. xanthomelas* seems to be able to tolerate the presence of carp and apple snails, but does not do well in habitats containing guppies or top minnows. There is no indication of adverse competitive interactions between *M. xanthomelas* and the widespread introduced damselflies *Ischnura ramburi*, *Ischnura posita*, and *Enallagma civile*, with which it frequently co-occurs.

## RECOMMENDATIONS FOR RELOCATION OF *MEGALAGRION XANTHOMELAS*

Surveys were undertaken to identify potential sites for relocation of the existing *Megalagrion xanthomelas* population on the grounds of TAMC. Ogden Environmental (1994) conducted a similar survey, and proposed relocating the population upslope of the existing population in an area likely to receive little if any impact from construction or other activity. We concur with the location chosen by Ogden as the most suitable area for siting artificial ponds to which the existing population may be relocated. Artificial ponds were determined to be potential suitable habitats for *Megalagrion xanthomelas* based on the fact that existing populations of this species have been established in artificially created ponds at Koele Lodge on Lanai and are doing well. This site has the advantage of being relatively close to the existing population and should be easy for adult males and females to investigate and repopulate once required plants and other environmental requirements are met.

### Criteria Used for Selection of Potential Relocation Site

Numbered in order of priority ranking:

1. Close proximity to the current habitat.
2. The site requires some level area, or areas would need to be leveled in order to allow construction of artificial ponds to harbor the relocated population of *Megalagrion xanthomelas*.
3. The site must be in an area that would have little or no deleterious impact from the effects of construction or other activity.

The proposed site identified by Ogden Environmental (1994) meets all of these criteria.

### Relocation Methods for Establishment of Population at Artificial ponds

Probably the safest way of ensuring establishment of a breeding population of *Megalagrion xanthomelas* at the proposed artificial ponds is to manually transfer existing algal mats and *Commelina* leaves with eggs and immatures to the artificial ponds. Some naiads or eggs of *Pantala* dragonflies may also be present in these mats and leaves, but since the two species coexist in nature, this should not present a problem.

## RECOMMENDATION FOR PROTECTION, MONITORING, AND REQUIREMENTS FOR RELOCATION OF *MEGALAGRION XANTHOMELAS*

### Requirements for relocation of *Megalagrion xanthomelas*

In order to attain a potentially successful relocation of the *Megalagrion xanthomelas* population from where it currently exists to the proposed relocation site upslope, certain environmental requirements must be met.

Based on studies at TAMC and at locations harboring successful populations of *M. xanthomelas* off-island, we have found that the following environmental parameters are recommended for survival of a breeding population of this species in any area:

**Water temperature**: range of 20.2–24.5 °C.

**pH of water**: range of 6.9–8.9.

**Salinity of water**: 0.5–2.0 ppt.

**Teneral adult emergence sites**: safe sites away from ants; sheltered areas with *Commelina* or other twigs or rocks rising out of the water or where branches expose roots, and leaves of *Panicum* dip into the water.

**Shelter** (nursery): algal mats, submerged twigs and rocks covered with algae, or other submerged object that can provide a surface upon which naiads can cling.

**Plants for oviposition**: *Commelina* or other soft-tissued plants, such as lily pads. Area surrounding artificial pools should be lush with vegetation, making them attractive to females searching for ovipositing sites.

**Perches for adults**: Rocks, twigs, boulders, and/or plants growing in water are needed by male adults for defensable territories.

**Associated fauna for prey** (adults): potential prey items for adults occur naturally in the area selected for relocation. No stocking necessary.

**Associated fauna for prey** (naiads): Planktonic protozoans required for early instars, which should be associated with algal mats used for oviposition. As naiads mature, copepods, ostracods, fly larvae (ceratopogonids, chironomids, culicids) should be present for potential food items.

**Absence of potential predators**: Efforts should be made to prevent potential predators (fish) from becoming established in the relocation area. In artificial pond habitats this is easily done through not stocking the habitat with fish. In natural areas, exclosures and/or barriers should be constructed to prevent fish from entering the damselfly naiad habitat.

### Protection and monitoring of relocated population of *Megalagrion xanthomelas*

In order to ensure the continued existence of the relocated population of *Megalagrion xanthomelas* in the artificial ponds, a system of monitoring and protection will be necessary. Periodic monitoring should be conducted in order to ascertain that environmental requirements are met and continued. After initial restocking of the ponds with damselfly individuals, this monitoring should include weekly observations, which can gradually be scaled back to monthly or quarterly observations. The water system to the ponds should be adequately maintained and vegetation and shading checked regularly. Fauna should be inventoried periodically to check that suitable prey items exist in and surrounding the pond areas and that potential predators are excluded from the area. Population counts of males and female adults as well as naiads in the ponds should be conducted weekly or monthly, but only after a suitable time has elapsed following the initial restocking in order to allow for establishment and maturation of individuals at the site.

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## GLOSSARY

**alien**—in the context of this report, organisms not naturally occurring in the Hawaiian Islands. See also *exotic.*

**alluvium**—sediments weathered from bedrock.

**amphipod**—a small invertebrate that can be found in aquatic or terrestrial habitats including sow (or pill) bugs.

**anchialine**—euhaline to mixohaline lentic waters occurring primarily in lava fields or elevated fossil reef rock, and having no surface connection with ocean but still exhibiting tidal fluctuations.

**annelid**—worms of the phylum Annelida; common earthworms.

**arthropod**—insects and related invertebrate animals.

**aspiration**—to collect by sucking through a tube, with collections of samples being sucked into a screened and filtered collection vial.

**basal spring**—a fresh to mildly saline groundwater outflow lying at or near sea level and resulting from drainage out of aquifers upslope.

**Berlese-Tullgren funnel**—equipment used to extract small organisms from soil and leaf litter samples by using the heat of a lamp. The heat causes the organisms to migrate downward into the funnel away from the heat source. Eventually, they fall from the funnel into a collecting device filled with fluid attached to the bottom of the funnel and are preserved therein for examination.

**biota**—the complete plant and animal components of an area.

**caddis fly**—aquatic insects of the Order Trichoptera, which are characterized by the immature stages being found in tube-like cases made of stone, dirt, and various debris.

**casing**—the insect case left over after the adult emerges from the last instar.

**catchment**—an area or container receiving water from a higher point of origin.

**ceratopogonid**—flies of the family Ceratopogonidae (biting midges, no-see-ums).

**chironomid**—flies of the family Chironomidae; aquatic non- biting midges.

**colonists**—individuals that started a population at a particular area.

**conspecific**—two or more individuals that belong to the same species.

**copepod**—very small aquatic invertebrates found in marine and freshwater; important organism in the food chain.

**copulation**—the coupling of two individuals during mating.

**culicid**—flies of the family Culicidae, or mosquitoes.

**cuticle**—the insect body wall or integument.

**Diptera**, **dipteran**—flies, mosquitoes.

**drosophilid**—flies of the family Drosophilidae (fruit or pomace flies).

**endemic**—native organisms occurring only in one restricted geographical area such as an island or country.

**endophytic**—inside plant tissue.

**ephemeral**—lasting for a short period of time.

**estuarine**—aquatic system lying at the interface between land and sea.

**euhaline**—seawater, salt content 30–40 ppt.

**exotic**—in the context of this report, not naturally occurring in the Hawaiian Islands. See also *alien.*

**extirpated**—removed by various means from an area of previous occurrence.

**guild**—a set of functionally similar species.

**halophytic**—individuals occurring in saline areas.
**immature**—the stage of an animal that is not an adult. In the context of this report, damselfly and dragonfly immatures are termed naiads; other insects are called larvae.
**incised**—sharply cut geographical feature.
**indigenous**—native organisms that occur in more than one area (i.e., not restricted to being endemic to one island or geographical area)
**instar**—an immature life stage of an insect. Insects normally go through various numbers of instars before becoming adults.
**introduced**—plants or animals not native to a particular area. They may have been either accidentally or purposefully introduced.
**invertebrate**—animals without backbones including insects, mites, spiders, shrimp, protozoans, crabs, worms, etc.
**labium**—the lower portion of the insect mouth. In damselfly naiads, a large basket-like structure used to capture prey.
**larva/larval**—an immature stage of an insect.
**lentic (standing)**—water not subject to direct gravitational movement, although internal currents may occur.
**limnetic**—freshwater, salt content <0/5 ppt.
**limnocrene (spring pool)**—a pond or pool having a noticeable, discrete, subterranean water source.
**litter**—usually, plant and other mixed organic debris found on the surface of a substrate such as rock or soil; often harboring small organisms that can be potential prey for other animals.
**lotic (flowing)**—water moving unidirectionally in response to substrate altitudinal (elevational) gradient. Excludes waters moving in response to wind current, waves, and tides.
**mandible**—in insects, the jaw-like clasping portions of the mouthparts.
**microlepidopteran**—small moths usually less than 10 mm in length.
**mixohaline**—brackish water, salt content 0.5–30 ppt.
**motile**—mobile, having an ability to move freely.
**naiad**—the immature aquatic stage of a damselfly or dragonfly.
**Odonata/odonates**—damselflies and/or dragonflies.
**oribatid mites**—soil-inhabiting mites that resemble small beetles; they feed on fungi or decaying organic matter in the soil.
**ostracod**—small invertebrates found in both fresh- and seawater; used as a food source by damselfly naiads.
**oviposition**—egg laying behavior of an individual.
**perennial stream**—water draining from the land surface in a discrete channel and flowing year-round.
**photosensitive**—activity of individuals dependent or sensitive to sunlight.
**pH**—the measured relative acidity or alkalinity of a particular substrate. pHs less than 7.0 are considered acidic; pHs more than 7.0 are considered alkaline.
**planktonic**—small organisms that float passively with limited mobility in aquatic systems.
**predatory**—the state of being a predator; preying on other biota for food requirements.
**protozoa**—mostly microscopic planktonic organisms used as food for early instar naiads.
**protrusible**—the ability to extend a structure outward from its normal stationary position.

**rheocrene** (**flowing spring**)—lotic water from a subterranean source, but not in a well developed channel, and flowing in relatively low and constant volume.
**riffle**—stream reach with sufficient gradient to create small standing waves.
**salinity**—the relative amount of salt in a circumscribed area or situation.
**sinuate**—a wavy or curved shape.
**spates**—floods
**stage**—a particular level of instar development, determined by age.
**tandem**—when two individual damselflies are attached to each other during flight, copulation, or while stationary on a substrate.
**teneral**—adult insects newly emerged from the immature stage having characteristic pale coloration and a relatively soft body cuticle that requires a short time to harden.
**territory**—in the context of this report, areas that are defined and defended by males of a species when awaiting females for mating.
**thorax**—the portion of the insect body that has the wings and legs.
**tipulid**—flies of the family Tipulidae (crane flies; daddy long-legs)
**vertebrate**—animals with backbones including mammals, fish, birds, etc.
**voucher specimen**—preserved specimen used as reference in future studies.
**wetlands**—permanently to seasonally inundated areas inland from the shoreline.

## APPENDIX I
## Arthropod Taxa of TAMC from Litter and Soil, and Stream

### ACARI (mites)

**Oribatida**
- **Carabodidae**
  - *Carabodes* sp.
- **Cepheidae**
  - Undetermined genus sp.
- **Galumnidae**
  - *Pergalumna hawaiiensis* (Jacot)
- **Hydrozetidae**
  - *Hydrozetes* sp.
- **Liacaroidea**
  - *Liacarus* sp.
- **Oppiidae**
  - *Oppia* sp.
- **Otocepheidae**
  - *Dolicheremaeus* sp.
- **Phthiracaridae**
  - *Atropacarus* sp.
- **Scheloribatidae**
  - *Scheloribates* spp.
- **Tryhypochthoniidae**
  - *Hydronothrus crispus* Aoki

**Mesostigmata**
- **Amerosiidae**
  - *Ameroseius* sp.
- **Ascidae**
  - *Asca* sp.
  - *Gamasellodes bicolor* sp. complex
- **Laelapidae**
  - *Echinonyssus* sp.
- **Macrochelidae**
  - *Macrochelus* sp.
- **Ologamasidae**
  - *Gamasiphis* sp.
- **Parasitidae**
  - *Parasitus* sp. cf. *crassipes* group
- **Podocinidae**
  - *Podocinum sagax* Leonardi
- **Phytoseiidae**
  - *Phytoseius* sp.
- **Uropodidae**
  - Undetermined genera and spp.

## APPENDIX I
## Arthropod Taxa of TAMC from Litter and Soil, and Stream
(continued)

### ACARI (mites)

**Prostigmata**
- **Bdellidae**
  - *Bdellodes* sp. nr. *haramotoi* Swift & Goff
- **Cheleytidae**
  - *Bak deleoni* Yunker
  - *Hemicheyletia bakeri* (Ehara)
- **Cryptognathidae**
  - *Favognathus pictus* Summers & Chaudhri
- **Cunaxidae**
  - *Neocunaxoides andrei* (Baker & Hoffmann)
- **Erynetidae**
  - *Ceenus* sp.
- **Eupodidae**
  - Undetermined genus sp.
- **Stigmaeidae**
  - *Storchia robusta* Berlese

**Astigmata**
- **Acaridae**
  - *Tyrophagus putrescentiae* (Schrank)

### ARANEAE (spiders)

- **Linyphiidae**
  - Undetermined genus sp.
- **Salticidae**
  - Undetermined genus sp.

### DIPLOPODA (millipedes)

- **Cambalopsidae**
  - *Calyphyiulus granulatus* (Gervais)
- **Julidae**
  - Undetermined genus sp.
- **Paradoxomatidae**
  - *Oxidus* sp.
- **Polyxenidae**
  - *Polyxenus* sp.

### CHILOPODA (centipedes)

- **Geophilidae**
  - Undetermined genus sp.
- **Scolopendridae**
  - *Scolopendra subspinipes* Leach

## APPENDIX I
## Arthropod Taxa of TAMC from Litter and Soil, and Stream
(continued)

### ISOPODA (sow bugs, pill bugs)

**Armadillidae**
- *Reductoniscus costulanus* Kesselyak

**Philosciidae**
- *Australophiloscia societatis* (Maccagno)
- *Burmoniscus okinawaensis* (Nunomura)
- *Tropicana minuta* Manicastri & Taiti

**Platyartridae**
- *Trichorhina tomentosa* (Budde-Lund)

**Porecellionidae**
- *Porcellio laevis* Latrielle

### AMPHIPODA

**Talitridae**
- Undetermined genus sp.

### OSTRACODA

Undetermined family

### COPEPODA

Undetermined family

### INSECTA

### EMBIIDINA (web-spinners)

**Oligotomidae**
- *Aposthonia oceania* (Ross)

### COLLEMBOLA (springtails)

**Entomobryidae**
- *Entomobrya* sp.
- *Lepidocyrtus* sp.
- *Tomocerus minor* (Lubbock)

**Neelidae**
- *Neelus (Megalothorax)* sp.

**Sminthuridae**
- *Dicyrtoma (Papirioides) dubia* (Folsom)

### HOMOPTERA

**Agallidae**
- *Agalliopsis* sp.

### HETEROPTERA (true bugs)

**Lygaeidae**
- *Cligenes marianensis* Usinger

**Notonectidae**
- *Buenoa pallipes* (Fabricius)

## APPENDIX II
### Arthropods Collected or Observed at TAMC Study Site
(non-litter, soil, or stream)

**DIPTERA** (flies, mosquitoes, gnats)

**Ceratopogonidae**
*Atrichopogon jacobsoni* (de Meijere)
E *Forcipomyia hardyi* Wirth & Howarth
**Chloropidae**
*Rhodesiella* sp.
**Sphaeroceridae**
E *Leptocera brevivenosa* Tenorio

**BLATTARIA** (cockroaches)

**Blaberidae**
*Pycnoscelus indicus* (Fabricius)

**ORTHOPTERA** (grasshoppers)

**Tettigoniidae**
Undetermined genus sp.

**PSOCOPTERA** (book and bark lice)

Undetermined family

**ODONATA** (dragonflies and damselflies)

**Libellulidae**
*Anax strenuus* (Hagen)
*Ischnura posita* (Hagen)
*Orthemis ferruginea* (Fabricius)
*Pantala flavescens* (Fabricius)
*Tramea abdominalis* (Rambur)

**HOMOPTERA**

**Clastopteridae**
*Clasoptera* sp.
**Flatidae**
*Melormenis* sp. [?*basalis* Walker]
**Psyllidae**
*Heteropsylla cubana* Crawford

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E = endemic species

## APPENDIX II
## Arthropods Collected or Observed at TAMC Study Site
(non-litter, soil, or stream)
(continued)

### HETEROPTERA (true bugs)

**Pentatomidae** (stink bugs)
*Nezara viridula* (Linnaeus)
**Reduviidae** (assassin bugs)
*Zelus renardii* Kolenati
**Tingidae**
*Leptodictya tabida* (Herrich-Schaeffer)

### TRICHOPTERA (caddis flies)

**Hydropsychidae**
*Cheumatopsyche pettiti* (Banks)
**Hydroptilidae**
*Hydroptila arctia* Ross

### LEPIDOPTERA (moths and butterflies)

**Cosmopterygidae**
Undetermined genus sp.
**Noctuidae**
*Ascalapha odorata* (Linnaeus)
**Nymphalidae**
*Agraulis vanillae* (Linnaeus)
**Papilionidae** (swallowtails)
*Papilio xuthus* Linnaeus
**Tineidae**
Undetermined genus sp.

### COLEOPTERA (beetles)

**Cantharidae**
*Caccodes oceaniae* (Bourgeois)
**Cerambycidae**
*Sybra alternans* (Wiedemann)
**Coccinellidae**
*Curinus coeruleus* Mulsant
*Olla abdominalis* (Say)
**Corylophidae**
E? *Corylophodes suturalis* (Sharp)
**Curculionidae**
*Oxydema fusiforme* Wollaston
**Dytiscidae**
E *Copelatus parvulus* (Boisduval)

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E = endemic species

## APPENDIX II
## Arthropods Collected or Observed at TAMC Study Site
(non-litter, soil, or stream)
(continued)

### COLEOPTERA (continued)

**Elateridae**
*Conoderus exsul* Sharp
**Scarabeidae**
*Adoretus sinicus* Burmeister
**Staphylinidae**
*Osorius rufipes* Motschulsky

### DIPTERA (flies, mosquitoes)

**Calliphoridae**
*Chrysomya megacephala* (Fabricius)
**Chironomidae** (non-biting midges)
*Chironomus hawaiiensis* Grimshaw
**Culicidae** (mosquitoes)
*Aedes albopictus* (Skuse)
**Dolichopodidae** (long-legged flies)
*Chrysosoma globiferum* (Wiedemann)
E *Chrysotus parthenus* Hardy & Kohn
*Pelastoneurus* sp.
*Syntormon flexibile* (Becker)
**Drosophilidae** (pomace flies)
*Drosophila* sp. prob. *melanogaster* Meigen
**Ephydridae** (shore flies)
E *Brachydeutera hebes* Cresson
*Brachydeutera ibari* Ninomiya
E *Scatella bryani* (Cresson)
**Lauxaniidae**
*Poecilominettia* sp.
**Phoridae**
*?Spiniphora* sp.
**Psychodidae**
*Psychoda* sp.
**Sphaeroceridae**
*Poecilosomella punctipennis* (Wiedemann)
**Syrphidae** (flower flies)
*Allograpta obliqua* (Say)
**Tachinidae**
*Trichopoda pilipes* (Fabricius)
**Tephritidae** (true fruit flies)
*Bactrocera cucurbitae* (Coquillett)
**Tipulidae** (crane flies)
*Limonia advena* (Alexander)

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E = endemic species

# APPENDIX II
## Arthropods Collected or Observed at TAMC Study Site
(non-litter, soil, or stream)
(continued)

### HYMENOPTERA (bees, wasps, ants)

**Agaonidae** (fig wasps)
*Odontofroggattia* sp.
**Anthophoridae** (carpenter bees)
*Xylocopa sonorica* Smith
**Apidae** (honey bees)
*Apis mellifera* Linnaeus
**Braconidae**
*Apanteles trifasciatus* Muesebeck
**Eulophidae/Aphelinidae**
Undetermined genus sp.
**Eupelmidae**
?*Eusandalum* sp.
**Eurytomidae**
*Eurytoma* sp.
*Sycophobia* sp.
**Formicidae** (ants)
*Anoplolepis longipes* (Jerdon)
*Camponotus* sp.
*Leptogenys falcigera* Rogers
*Pseudomyrmex gracilis mexicanus* Rogers
*Solenopsis geminata* (Fabricius)
*Tapinoma melanocephalum* (Fabricius)
**Proctotrupidae**
Undetermined genus sp.
**Sphecidae**
*Scelipheron caementarium* (Drury)
**Trichogrammatidae**
Undetermined genus sp.

# APPENDIX III
## Birds Observed at TAMC Study Site

**Ardeidae**
*Bubucus ibis* (Linnaeus)—Cattle Egret

**Charadriidae**
*Pluvialis fulva* (Gmelin)—Pacific Golden Plover

**Columbidae**
*Streptopelia chin*ensis (Scopoli)—Spotted Dove
*Geopelia striata* (Linnaeus)—Barred Dove

**Pycnonotidae**
*Pycnonotus cafer* (Linnaeus)—Red-vented Bulbul

**Muscicapidae**
*Copsychus malabricus* (Linnaeus)—White-rumped Shama

**Sturnidae**
*Acridotheres tristis* (Linnaeus)—Common Myna

**Zosteropidae**
*Zosterops japonicus* Temminck & Chlegel—Japanese White-eye

**Emberizidae**
*Cardinalis cardinalis* (Linnaeus)—Northern Cardinal
*Paroaria coronata* (Miller)—Red-crested Cardinal

**Fringillidae**
*Carpodacus mexicanus* (Muller)—House Finch; Linnet

**Passeridae**
*Passer domesticus* (Linnaeus)—House Sparrow

**Estrildidae**
*Estrilda astrild* (Linnaeus)—Common Waxbill
*Lonchura punctulata* (Linnaeus)—Nutmeg Mannikin
*Padda oryzivora* (Linnaeus)—Java Sparrow

## APPENDIX IV
## Flora Collected at TAMC Study Site
(all plants in this list are alien and common)

**Acanthaceae**
*Asystasia gangetica* (L. T. Anders.—Chinese violet; coromandel
**Justicia betonica* L.—white shrimp plant
*Thunbergia fragrans* Roxb.—white thunbergia, sweet clockvine

**Agavaceae**
*Dracaena fragrans* (L.) Ker-Gawl.

**Anacardiaceae**
*Mangifera indica* L.—mango, *manako*

**Araceae**
*Philodendron lacerum* (Jacq.) Schott—philodendron
*Syngonium* sp.

**Arecaceae**
*Caryota urens* L.—wine palm, toddy palm

**Commelinaceae**
**Commelina diffusa*. N.L. Burm.—*honohono, honohono wai, makololo*

**Cucurbitaceae**
**Coccinia grandis* (L.) Voigt—ivy gourd or scarlet-fruited gourd
*Momordica charantia* L.—bitter melon, balsam pear

**Cycadaceae**
*Cycas circinalis* L.—sago palm

**Cyperaceae**
*Cyperus papyrus* L.—papyrus, *kaluha, papulo*

**Euphorbiaceae**
*Ricinus communis* L.—castor bean tree, *pa'aila, ka'apeha*

**Fabaceae**
*Haematoxylum campechianum* L.—bloodwood tree, logwood
*Leuceana leucocephala* (Lam.) deWit—*koa haole, ekoa, lilikoa*
*Senna surratensis* (N.L. Burm.) H. Irwin & Barneby—*kalamona, kolomona*

**Malvaceae**
*Abutilon grandifolium* (Willd.) Sweet—hairy abutilon, *ma'o*

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* Plants upon which eggs of *Megalagrion xanthomelas* were observed and recorded in field. Eggs were also observed on water-soaked minute twigs floating on the stream surface.

## APPENDIX IV
## Flora Collected at TAMC Study Site
(continued)

**Moraceae**
*Ficus microcarpa* L.fil—Chinese or Malayan banyan

**Myrtaceae**
*Psidium guajava* L.—guava, *kuawa*
*Syzygium cuminii* (L.) Skeels—Java plum

**Passifloraceae**
*Passiflora edulis* Sims—passion fruit, *liliko'i*

**Phytolaceae**
*Rivina humilis* L.—rouge plant, coral berry

**Poaceae**
*Digitaria insularis* (L.) Mez ex Ekman—sourgrass
*Panicum maximum* Jacq.— Guinea grass

**Rubiaceae**
*Paederia scandens* (Lour.) Merr.—*maile pilau, maile ka kahiki*

**Solanaceae**
*Solanum americanum* Mill.—*popolo, 'olohua, polopolo*
*Solanum seaforthianum* Andr.—potato vine

# APPENDIX V

## RESEARCH DESIGN FOR *MEGALAGRION XANTHOMELAS* RECOVERY PLAN

submitted by
Department of Natural Sciences
Bishop Museum
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Honolulu, HI 96817

Primary contact: Dr. Neal L. Evenhuis
Secondary contact: Dr. Dan A. Polhemus

**Phase 1: Determination of locations and sizes of populations in Tripler Army Medical Center study area.**

a. *Determination of population locations* MILESTONE: 28 February 1995

Locations of *M. xanthomelas* populations at Tripler Army Medical Center (TAMC) will be determined by walk through census of all aquatic habitats lying on the base. In addition, populations will be searched for in areas downstream from the base.

b. *Initial determination of population sizes* MILESTONE: 28 February 1995

Population size will be visually estimated using simultaneous observations from a team of researchers. We feel this is preferable to a mark-recapture protocol because 1.) the habitats involved are small in size, and thus suitable to visual estimation techniques, and 2.) no mark-recapture studies have ever been done on *Megalagrion* species, thus the potential for mortality during development of marking protocols is high, an unacceptable risk when dealing with populations as small as those remaining at TAMC.

A team of entomologists from Bishop Museum will be arrayed at even intervals along the reach of stream habitat containing *M. xanthomelas* at TAMC. These observers will be assigned specific sectors of the habitat to monitor, and at five minute intervals will note all adult damselflies present in their sector. these counts will be repeated over the course of one hour on three successive weeks to derive an estimate of overall population size.

c. *Ongoing monitoring of population at TAMC* MILESTONE: 30 September 1995

In an effort to obtain as much biological information as possible for the TAMC population of *M. xanthomelas*, weekly monitoring at the site will take place. This will entail population size determination using the methods described above plus measurements of the various ecological parameters (see below under Phase 2) at the site through the term of the project. This data may assist in explaining any possible population fluctuations throughout the year and will give a more complete profile of population requirements and conditions at various times.

### Phase 2: Determination of ecological and habitat requirements among *M. xanthomelas* populations statewide

A thorough understanding of a species' ecology is a necessary prerequisite to effective conservation measures. To this end, surveys will be undertaken to determine the habitat associations and ecological requirements of *M. xanthomelas* at four disparate sites on different islands in the Hawaiian chain. At each of these sites the specific breeding habitats of *M. xanthomelas* will be ascertained, the habitats themselves photographed, and the physical and chemical features of these habitats analyzed. Measurements that will be taken at each site include air temperature and relative humidity, plus physiochemical parameters of the aquatic habitat itself, including water temperature, salinity, pH, depth, and current velocity. The associated aquatic biotic associations, if any, are consistently characteristic of habitats in which *M. xanthomelas* persists. Possible threats to the survival of *M. xanthomelas* at each site will also be noted.

MILESTONE: 31 August 1995

1. Oahu *(TAMC)*

   The distribution and density of the population at Tripler Army Medical Center will be ascertained as described in the previous section.

2. Lanai *(Koele Ledge)*

   On of the largest known remaining populations of *Megalagrion xanthomelas* occurs in a set of ornamental streams and pools at the Koele Lodge on upland Lanai. The existence of this population remained undetected until 1993, although presumably the species was present all along in spring outflows at the base of the mountain, and then in the ranch pond that was subsequently constructed at this site in the late 1800s. The fact that *M. xanthomelas* has been able to colonize an artificial habitat that was constructed within the last five years with no consideration to damselflies whatsoever has an important bearing on the situation at TAMC, since it indicates that construction of similar habitats at TAMC might be sufficient to mitigate the present threats to the species at this latter site. A research team will thus visit the Koele Lodge in order to a.) determine the sequences of aquatic habitats that have existed at this site over time, b.) assess the methods that were used in the construction of the present ornamental ponds, c.) species that might have an impact on M. *xanthomelas*, and d.) determine precisely where *M. xanthomelas* is breeding within this system.

3. Big Island *(Ninole)*

   Scattered populations of *M. xanthomelas* are known from coastal wetlands in Puna, Kau and North Kona on Big Island, where limnetic groundwater percolates seaward and mixes with the inland percolating marine water table to form horizontally stratified mixohaline systems. The largest of these coastal *M. xanthomelas* populations is found in an extensive set of limnocrenes, rheocrenes, and mixohaline marshes located at Ninole, Kau, where downslope subsurface percolation from the Ninole Hill drainage emerges just above sea level at the mouth of Ninole Stream. A survey in May 1994 found this area to support a robust population of *M. xanthomelas*, making it a potential source of live specimens that might be used for testing various rearing and marking protocols that could be employed in subsequent mitigation efforts on Oahu. A research team will visit the Ninole habitat, mapping and characterizing the diverse aquatic features present there in order to understand what range of salinity gradients *M. xanthomelas* can tolerate in lotic coastal wetland habitats.

4. Molokai *(Pelekunu)*

The only population of *M. xanthomelas* known on Molokai is a small colony breeding in the terminal pond at the mouth of Pelekunu Stream, which was documented by Polhemus (1991, *Prelim. rep. on aquat. insect fauna of Lower Pelekunu Valley, Molokai.* Report prepared for Hawaii State DLNR, Div. Aquat. resources. 5 p). This is one of the few undisturbed stream termina remaining in Hawaii, and is likely indicative of the habitats that the species previously occupied on Oahu. A research team will thus visit the mouth of Pelekunu valley to investigate the ecology of *M. xanthomelas* in a natural lentic setting.

### Phase 3: Identification of potential relocation sites

On of the major hurdles to effectively conserving the *M. xanthomelas* population occurring at TAMC is its apparently small size. Although no density estimates have yet been made, it seems likely that the entire adult population at any single time consists of considerably less than 50 individuals. Given this low number, any removal of individuals from the TAMC population for breeding or relocation purposes could have potentially serious impacts on the overall population structure and could possibly impact overall population stability. In addition, even if removals are undertaken, only a few individuals could be secured, and these would likely be insufficient to insure successful breeding or alternate colony establishment. It is therefore proposed that initial mitigation measures should be focused on *in situ* enhancement of habitat at or near the location of the current TAMC population.

As noted above, *M. xanthomelas* has successfully colonized artificial aquatic systems at Koele Lodge on Lanai. This indicates that if similar systems were constructed at TAMC in an area not subject to impacts of construction and protected from the introduction of alien vertebrate species, then *M. xanthomelas* might colonize such habitats there as well. Such a course of action would be worth investigating because it 1) would not require long distance relocation of individuals from an already small population to other sites on Oahu, and 2) it would be more cost effective. An intensive study of the Lanai population will therefore be made (see above) in order to understand how it has been able to persist in a man-made ecosystem, and then to apply this knowledge to the construction of a damselfly refugium at TAMC.

Following the surveys of natural habitats on Lanai, Hawaii, and Molokai, recommendations will be drafted for the creation of a temporary refugium on site at TAMC in an area not immediately threatened by construction activities. Once the TAMC population has been stabilized in such a refugium a search can be made for alternative sites to which the population can be permanently relocated. Two areas that seem to offer promise in this latter regard are the West Loch area of Pearl Harbor, and Schofield Barracks, and research teams will be sent to each of these sites to investigate their suitability, comparing the physical and chemical characteristics of habitats there to those supporting *M. xanthomelas* populations on other islands (see previous discussion above).

This approach, if successful, should allow construction at TAMC to proceed on a timely schedule, and also provide the biologists involved with the long term relocation efforts sufficient time to adequately study alternative habitats and produce viable relocation plans.

MILESTONE: 15 September 1995

**Phase 4: Preparation of draft technical report**

Following the completion of the field research outlined above, a technical report summarizing the results of this work will be prepared and submitted.

MILESTONE: 15 October 1995

**Phase 5: Submission of Final Report**

After review and comment, a final report of the project will be submitted.

MILESTONE: 15 December 1995

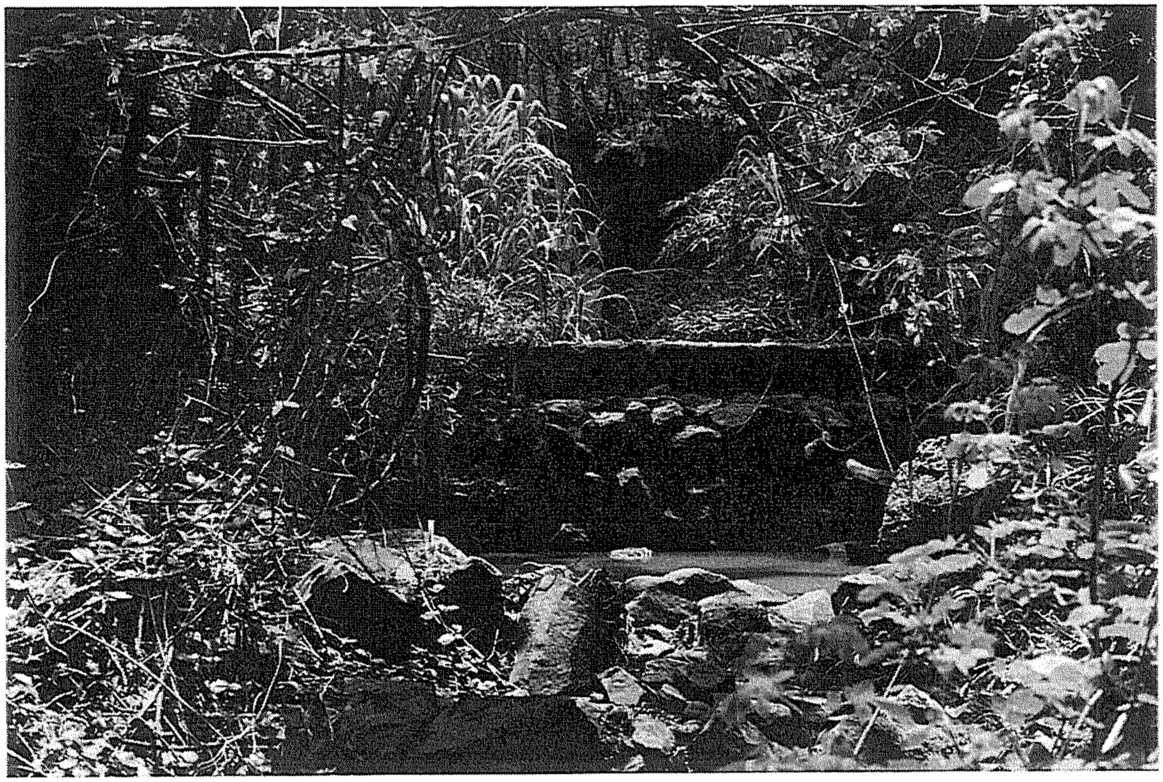

**Photo 1.** Pool 7, looking mauka toward culvert

**Photo 2.** Pool 7, looking makai, showing silty runoff from hydrant flushing (left) down bank into stream

**Photo 3.** Pool 7, looking downstream toward pool 6

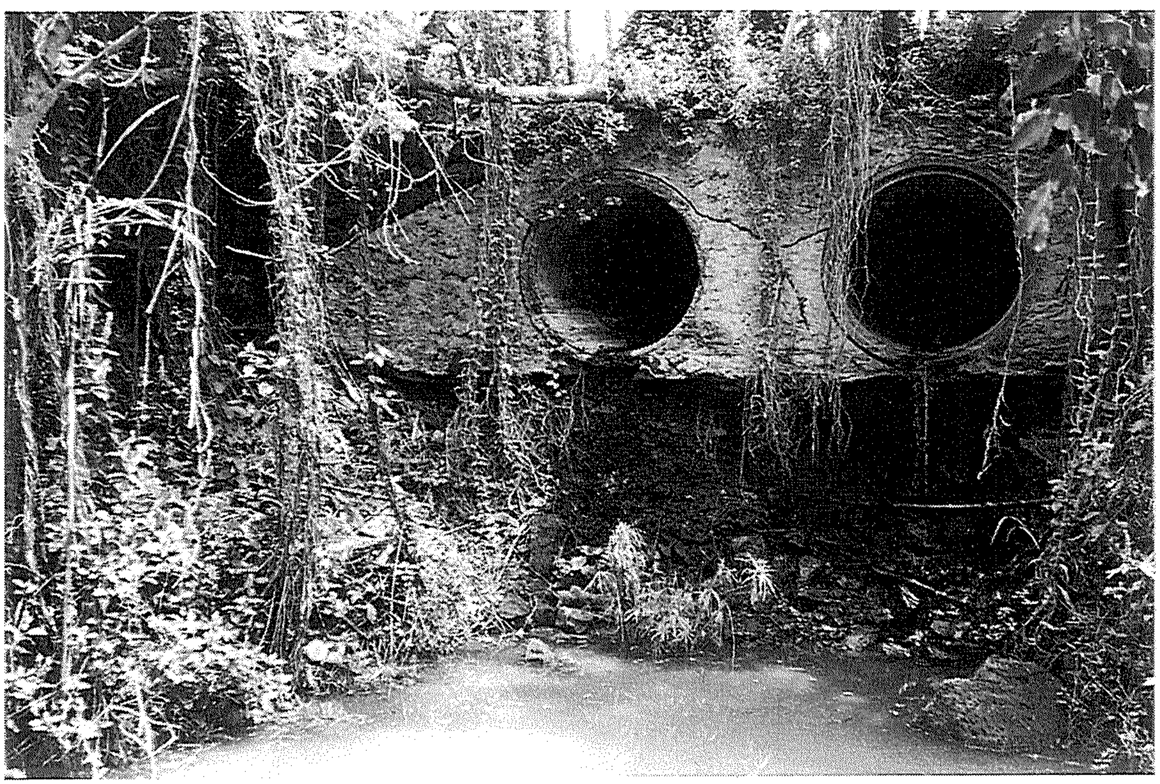

**Photo 4.** Lower pool, looking mauka toward culverts

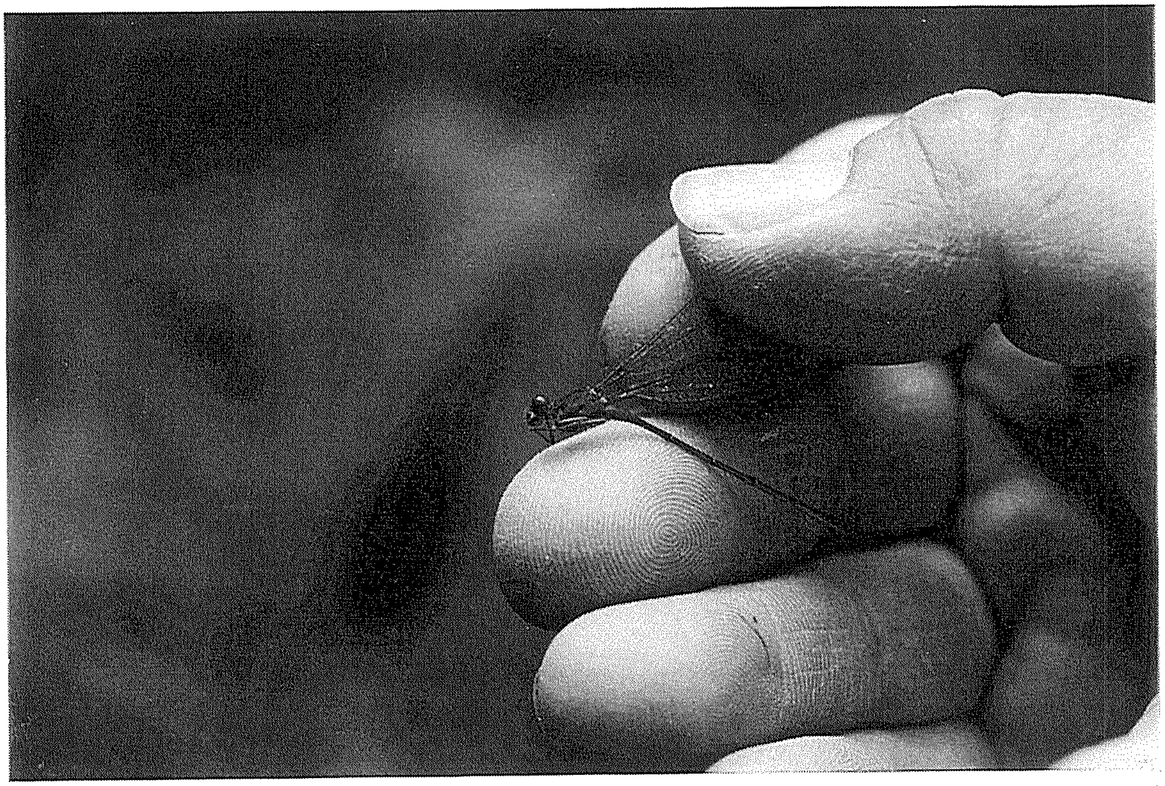

**Photo 5.** Male *Megalagrion xanthomelas*

**Photo 6.** Male *M. xanthomelas*, exhibiting territoriality on rock surface

**Photo 7**. Male *M. xanthomelas*, showing territoriality on emerged rock

**Photo 8**. Last instar *Pantala* just prior to adult emergence

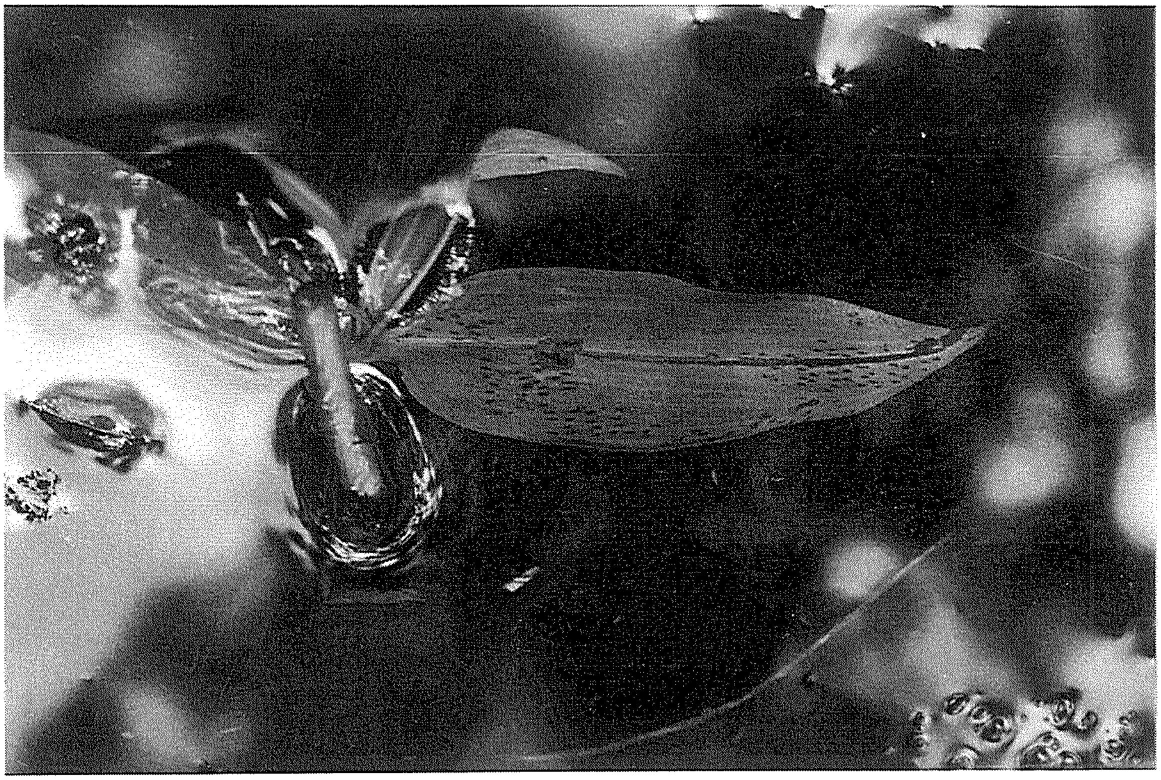

**Photo 9.** *Commelina* leaves, showing egg punctures

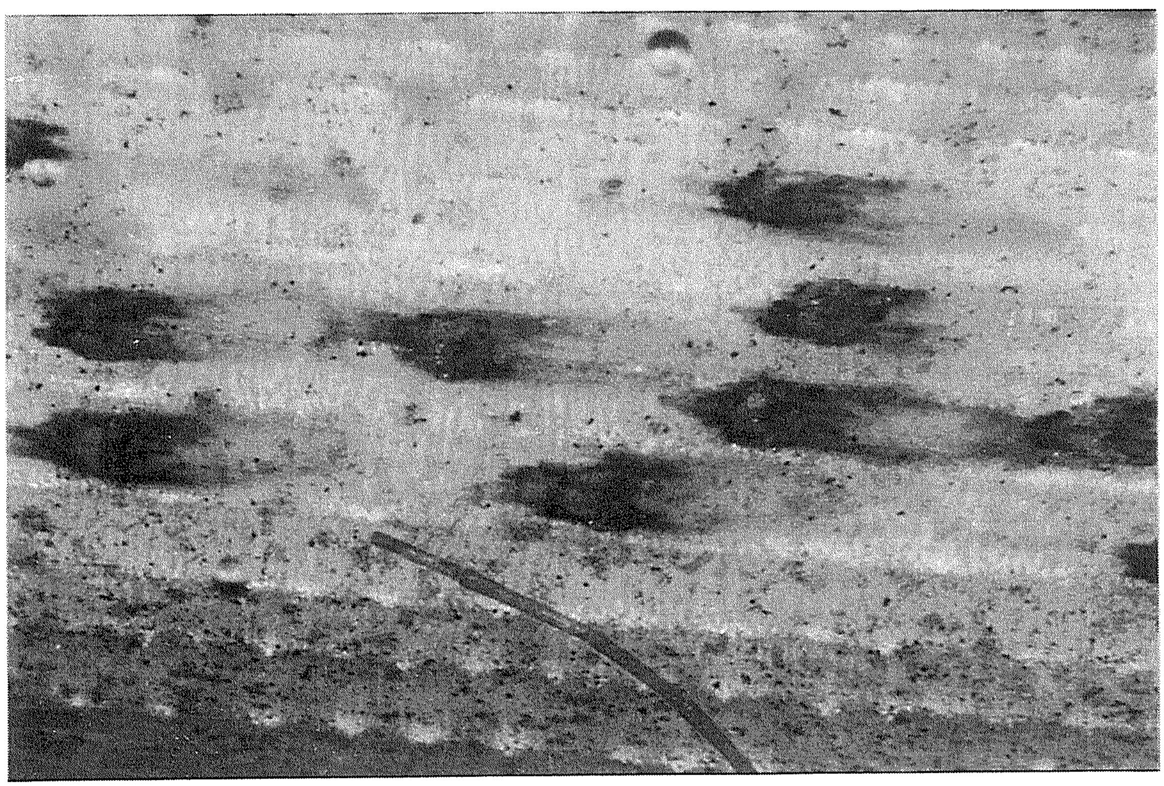

**Photo 10.**Close up of *Commelina* leaves, showing egg punctures

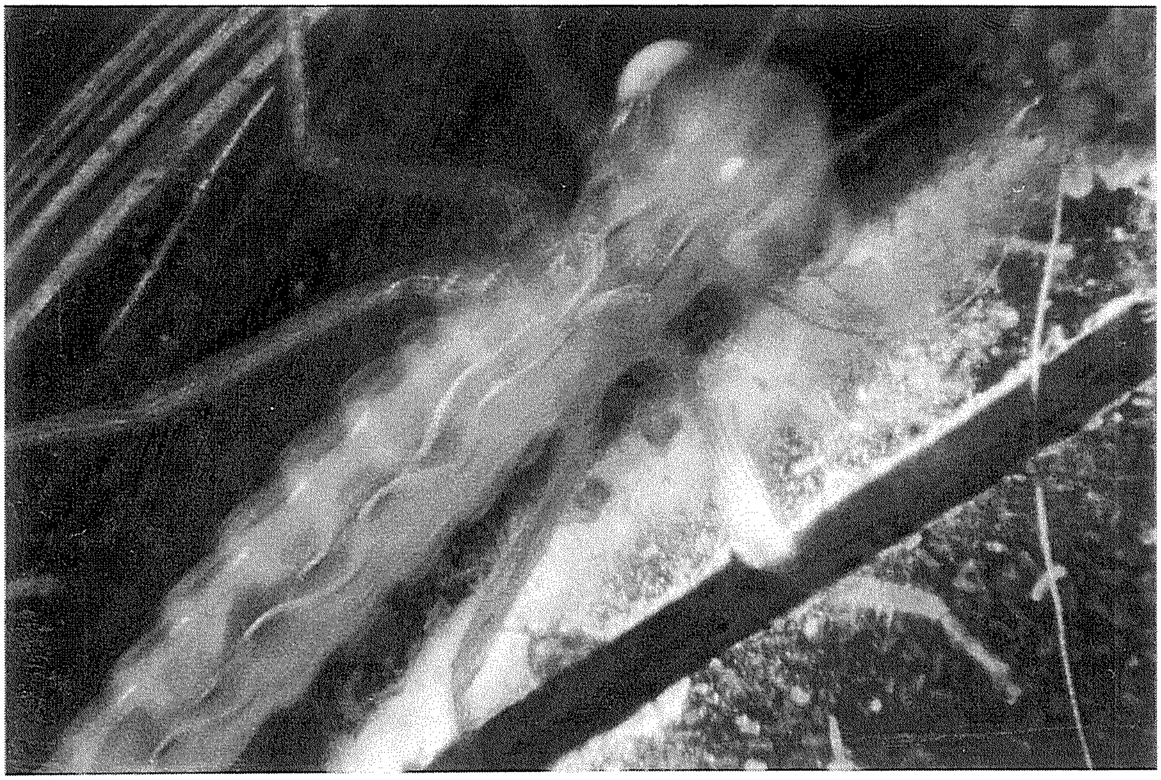

**Photo 11.** Early instar naiad of *Megalagrion xanthomelas*

**Photo 12.** Cast skin of *Megalagrion xanthomelas* on leaves of *Paederia scandens* (maile pilau)