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LONG-TERM MONITORING OF ONE OF THE MOST RESTRICTED INSECT POPULATIONS IN THE UNITED STATES, *MEGALAGRION XANTHOMELAS* (SÉLYS-LONGCHAMPS), AT TRIPLER ARMY MEDICAL CENTER, OAHU, HAWAII (ZYGOPTERA: COENAGRIONIDAE)

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Long-term monitoring of a remnant population of *M. xanthomelas*, located at Tripler Army Medical Center (TAMC) began in May 1997 and continued to Febr. 2000 for the mitigation ponds and June 2000 for the TAMC stream. This sp. has been reduced to little more than 100 m of stream habitat on Oahu at the TAMC. Threats to *M. xanthomelas* include alien fish spp., stream dewatering, and habitat alteration. The TAMC stream now requires augmented water flow because construction of a facility up gradient of the TAMC stream disrupted the normal hydrology of the small stream. The Oahu race of *M. xanthomelas* will soon become extinct if the stream were allowed to become dry, as nearly happened in June 1997. The most cost-effective way to ensure the survival of this sp. on Oahu would be to continue some mitigation water flows to the TAMC stream. The next step would be the establishment of another wild population to a stream lacking alien fish spp. It is highly recommended that a cooperative association of biologists from the Bishop Museum, University of Hawaii, U.S. Fish and Wildlife Service, and U.S. Army environmental staff continue to monitor the population of *M. xanthomelas*, arguably the rarest insect population in the United States.

INTRODUCTION

Monitoring of the last remnant Oahu population of *Megalagrion xanthomelas* (Sélys-Longchamps), a Candidate for listing under the U.S. Endangered Species Act, began in May 1997 and continued through June 2000. This damselfly population is located in a small unnamed stream (henceforth called TAMC stream) in a U.S. military installation at the Tripler Army Medical Center (TAMC) near

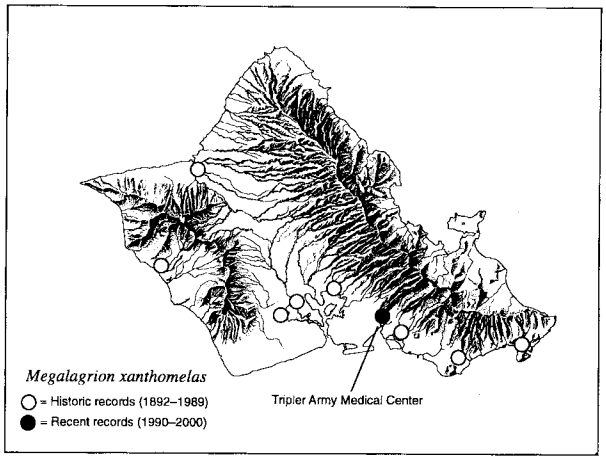

Fig. 1. Map of Oahu, Hawaii showing locations of current and historic records for *Megalagrion xanthomelas* (from EVENHUIS et al., 1995).

Honolulu, Hawaii (Fig. 1). Although formerly a common insect on Oahu LIEBHERR & POLHEMUS (1997), ENGLUND (1999) this species has currently been reduced to little more than 100 m of stream habitat. Threats to the endemic *M. xanthomelas* include alien fish species, stream dewatering, and habitat alteration POLHEMUS (1996). This species was considered extinct on Oahu until the discovery of this remnant population by N.L. Evenhuis of the Bishop Museum in 1994 (EVENHUIS & COWIE, 1994). Concerns were raised about the long-term viability of this remnant damselfly population because construction of a large U.S. Veterans Administration facility had the potential to disturb the watershed. Prior to the construction and large-scale upslope disturbance, four mitigation ponds constructed adjacent to the stream (Fig. 2) and were completed in October 1995. These ponds were built to ensure the survival of *M. xanthomelas* in case a flood event or other catastrophe disrupted their habitat. Because of budgetary constraints the mitigation ponds were drained and dismantled in March 2000, however, stream augmentation flows currently provide suitable aquatic habitats for *M. xanthomelas*.

STUDY AREA

The TAMC stream is located on leeward Oahu at 79 m elevation, and flows through a forest of introduced plants. An in-depth description and map of the stream study area can be found in EVENHUIS et al. (1995), POLHEMUS (1996), and PANGELINAN (1997). The TAMC stream now requires augmented water flow because construction in 1995 of a large Veterans Administration facility up gradient of the TAMC stream disrupted the normal hydrology of this small stream. The cement-lined mitigation ponds are approximately 200 m northwest of the TAMC stream, and measure 7.3 m long by 3 m wide and have an average water depth of 0.6 m. These ponds contained cobble substrate brought from the TAMC stream and aquatic plants such as algae, water lily (*Nymphaea* sp.), water lettuce (*Pistia stratiotes*), and a large aquatic sedge (*Cyperus alternifolius*). To ensure the survival of this damselfly species, quarterly monitoring of the four mitigation ponds began in May 1997 and continued until their being dismantled in February 2000. Quarterly monitoring of the TAMC stream began in May 1997 and continued until June 2000.

METHODS

STREAM SAMPLING. – The objectives of the damselfly mark--recapture sampling efforts were to (1) document recruitment of new individuals to the population between quarterly sampling efforts, (2) assess the relative abundance of damselflies between monitoring periods using a standardized methodology, and (3) provide a quick means of determining if the TAMC *M. xanthomelas* population was threatened by disturbance or stream dewatering.

The entire length of wetted stream (95 m) was sampled starting at the upstream end of the man-made culvert where stream flow originates. Methods used were identical to previous research conducted on the *M. xanthomelas* TAMC population (PANGELINAN, 1997). For this study, damselflies were marked beginning on 15 May 1997. Two observers conducted monitoring after the first quarter (May 1997) in which methods were established. While slowly walking down the stream each observed damselfly was netted and its wings marked with a permanent black extra fine felt tip marker. The number was recorded if a captured damselfly had been previously marked. After completing the slow downstream walk, which would take up to three hours, we returned slowly upstream and marked any previously unmarked damselflies. Collection and observation times were consistent during each quarterly monitoring event to standardize sample effort, and ranged between 3.5 to 4.0 hours. Individuals were not counted unless they were netted and the wings marked with a number.

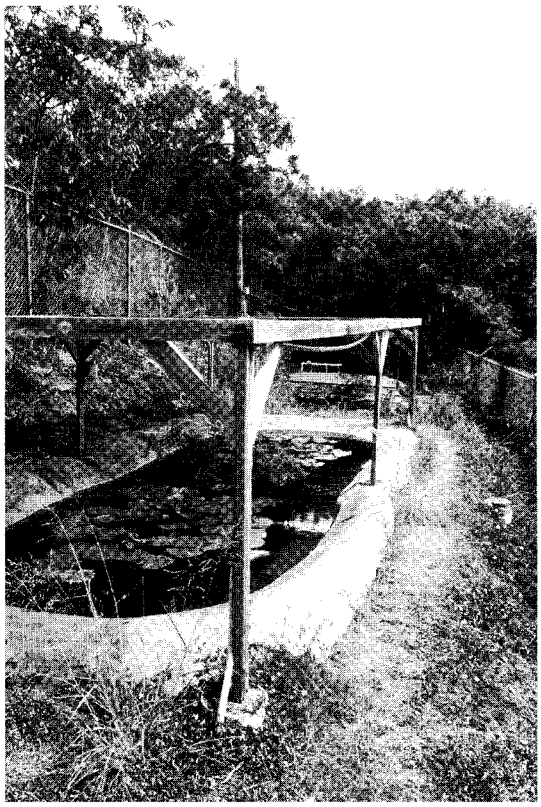

Fig. 2. TAMC mitigation ponds prior to drainage, February 2000.

POND SAMPLING. – Thirty-minute damselfly counts were conducted at each of the four concrete mitigation ponds. Damselfly sex and behavioral activity was recorded during each thirty-minute count. Individual adults were not counted unless they were captured and the wings marked with a number. Quantitative aquatic net samples were taken at the ponds starting during the November 1997 monitoring. Three aquatic net sweeps approximately 1.25 m in length were taken at the surface, middle, and bottom of each pond. The net contents were then placed in a 500-micron sieve and inspected for immature damselfly larvae.

The number of distinctive *M. xanthomelas* oviposition scars on water lily leaves in the mitigation ponds was counted each quarter to provide a measure of relative breeding attempts. After observing female *M. xanthomelas* ovipositing on water lilies, it was easy to distinguish *Megalagrion* oviposition scars from dragonflies and *Ischnura* spp. *M. xanthomelas* leaf scars were larger and more curved when compared to *Ischnura* spp. oviposition leaf scars. The presence of other aquatic insects was also recorded. Additionally, the presence of dragonflies, ants, water boatmen (*Notonecta indica*) and other potential predators or threats was noted at each pond. Pond levels were noted and when necessary the pond outlets were cleaned.

TAMC DAMSELFLY COUNTS

STREAM

Long-term monitoring of *M. xanthomelas* populations at the TAMC stream indicates a robust damselfly population after flow restoration started in June 1997 (ENGLUND, 1998). During the present study the number of adult damselflies marked each quarter varied from a low of 17 in May 1997 to a high of 162 in February 1998 (Fig. 3). Observations of adults at the TAMC stream were lower in the month of December 1999, and winter 1999 counts may not be directly comparable to other monitoring periods because of the cool, cloudy weather. Four separate monitoring attempts were made at the TAMC stream in November and December of 1999. *M. xanthomelas* adults are only active during sunny weather (POLHEMUS, 1996), and a long period of cloudy, cool, and very wet weather in the final quarter of 1999 reduced the numbers of captured adult damselflies at the TAMC stream. Additionally, the most severe weather and heavy flooding during the entire study period in November and December 1999 may have caused some adult mortality at the stream area. During this time heavy rains scoured the streambed to bedrock, and caused minor rockslides into some areas of the TAMC stream. Fortunately, numerous immature individuals were observed in the stream immediately after the heavy rains and flooding in December 1999. The restoration of stream flow continues to provide optimal aquatic habitats at the TAMC stream, and also ensured this damselfly population could survive a severe environmental disturbance in the form of heavy flooding in November and December of 1999. Monitoring conducted in February and June 2000 confirmed December results resulted from poor weather conditions, and subsequent visits to the TAMC stream indicate *M. xanthomelas* remains abundant.

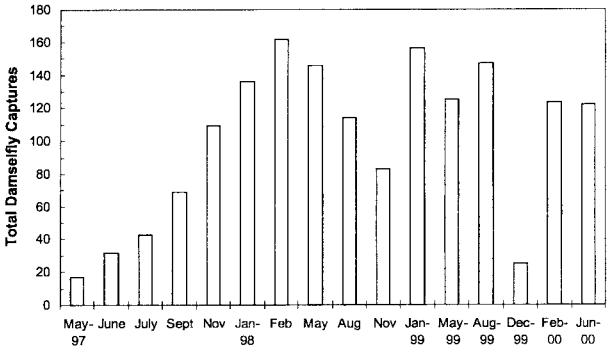

Fig. 3. *Megalagrion xanthomelas* captures at TAMC stream, May 1997-June 2000.

PONDS

Captures of *M. xanthomelas* at the TAMC mitigation ponds were variable, but

overall the ponds received some use during each quarter. During the present study the number of adult damselflies marked at the ponds each quarter varied from a low of 0 in May 1997 to a high of 23 in January 1998 (Fig. 4). During this study, immature *Megalagrion* damselflies were not collected in dip net sampling at the surface, middle, and bottom layers of each pond. However, at least two cast skins and one teneral *M. xanthomelas* were found at the ponds during the time-frame of this study by U.S. Fish & Wildlife Service personnel, indicating that there was at least limited reproductive success between 1997-2000.

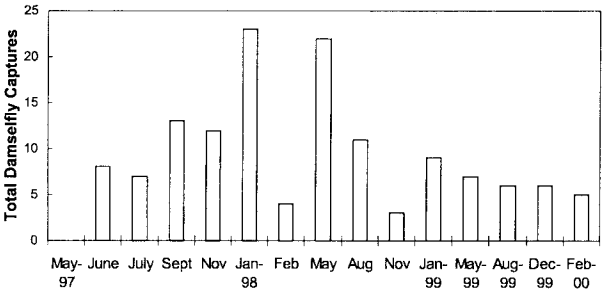

Fig. 4. *Megalagrion xanthomelas* captures at TAMC mitigation ponds May, 1997-Feb. 2000

Five species of native and introduced dragonflies were abundant at the ponds both as adults and larva. Two native dragonfly species, *Anax junius* and *Pantala flavescens* were abundant, as were the introduced *Tramea abdominalis*, *Orthemis ferruginea*, and *Crocothemis servilia*. These immature dragonflies were captured in virtually every dip net sample. Cast skins of these dragonflies were also common and found on vegetation within the ponds. Two species of introduced damselflies were also observed and captured at the ponds, *Ischnura posita* and *I. ramburii*, and cast skins of these damselflies were also found at the ponds. Introduced water boatman (*Notonecta indica*) were common and a potential predator, and introduced long-legged ants (*Anoplolepes longipes*) were observed by U.S. Fish & Wildlife Service personnel (A. Pangelinan, pers. comm.) to kill freshly emerged *M. xanthomelas* at the ponds. The most shaded and lowest pond received the greatest use by adult damselflies, with most damselflies being caught at this pond.

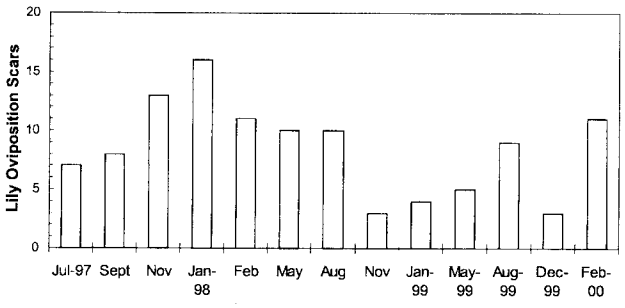

Fig. 5. Oviposition scars on water lilies at the TAMC mitigation ponds July 1997-Feb. 2000.

Damselfly oviposition scars observed on water lily leaves likely reflect a lesser percentage of attempts by females to lay eggs, as it has been observed that *M. xanthomelas* preferentially oviposit on algae both at the TAMC ponds and on Molokai (R. Englund,

pers. obs.). However, these scars provided a useful relative index of breeding attempts at the ponds. Oviposition scars on lily leaves declined since the peak in January 1998 and were variable thereafter (Fig. 5). The presence of some oviposition scars on water lily leaves indicates breeding occurred at the mitigation ponds throughout the study period. Thick algal mats were a continual problem in the ponds and necessitated weekly removal of algae. PANGELINAN (1997) found very limited movement between the TAMC stream population and pond population; thus most of the individuals observed at the ponds were likely the result of pond reproduction.

On 2 March 2000 the mitigation ponds were drained and as many damselfly larvae as possible were recovered and saved for later identification. Hundreds of *Ischnura posita* larvae along with high numbers of dragonfly larvae were examined, but no *M. xanthomelas* larvae were found.

DISCUSSION

The experience of preserving the Oahu population of *M. xanthomelas* at TAMC for the past 6 years has been one of the most notable conservation success stories in the Hawaiian Islands. A catastrophic flood in 1995 killed the entire stream population because of a massive sediment input into the stream during construction of the previously mentioned Veterans Administration facility. The mitigation ponds provided a reserve population for *M. xanthomelas* that would otherwise have gone extinct on Oahu. The completion of the ponds and translocation of immatures and adults in October 1995 was fortuitous as the flood occurred in November 1995. This success has not come without a major expenditure of money and time by U.S. government agencies such as the U.S. Department of Veterans Affairs and the U.S. Fish & Wildlife Service. For example, the mitigation pond planning, engineering and construction cost totaled U.S. $200,000, while pond maintenance cost $6000 per year, starting in 1995. Other major expenses include a $200-300 per month water bill for maintaining stream flows and pond levels.

While the mitigation ponds initially proved to be a major success and ensured the survival of *M. xanthomelas* on Oahu, the long-term success in native damselfly recruitment was less dramatic, and hampered by sometimes unfavorable conditions. When the ponds were first filled in 1995 there were low numbers of predators such as dragonflies, and the water lacked thick algae growths. In 1995, reproductive success of *M. xanthomelas* was definitive and verified by numerous cast skins found around the ponds (ZOLL, 1995). However, over time, thick growths of filamentous green algae were the biggest problem at the ponds, interfering with emerging larvae and resulting in stagnant water conditions. Floating algae mats also allowed ants access to the interior of the ponds where they would prey on emerging *M. xanthomelas*. High densities of native and introduced dragonfly larvae at the ponds undoubtedly influenced *M. xanthomelas* numbers. These dragonflies were noticeably absent from the TAMC stream most likely because thick riparian

vegetation and flowing water did not provide favorable dragonfly habitat.

With hindsight it appears that the ponds could have been designed to more closely mimic conditions found at the TAMC stream. The sunny and hot exposure of the ponds was the biggest problem because water temperatures at the ponds were much higher than in the TAMC stream. For example during a warm period in August 1999 pond temperatures were 27°C while stream temperatures were 22.5-23°C. A long--term solution for reducing water temperature and also algae growth at the ponds would have been to plant shade trees around the ponds. In contrast to the TAMC ponds, the stream area is heavily shaded but still provides some sun penetration at midday. In the future it is recommended that mitigation habitat more closely resemble a stream channel with riffles and pools and maintaining a moderate current velocity. This would also reduce predatory dragonfly numbers in the mitigation habitat.

The TAMC stream nearly became dry in June 1997 (ENGLUND, 1998) after construction upslope of the stream two years earlier disrupted the hydrology of this small watershed. However, because of mitigative water flows paid for by the U.S. Department of Veterans Affairs, stream flow remained at 100% of stream length and aquatic habitats were optimal at the TAMC stream through May 2000. In March 1999, the U.S. Army and U.S. Fish & Wildlife service attempted to translocate *M. xanthomelas* to another Oahu stream in attempts to establish a second Oahu population. Fifty-five adults and 44 larvae were collected from the TAMC stream and transported to an unnamed stream near Dillingham Airfield. This attempt apparently failed because the translocation stream contained the introduced red swamp crayfish, *Procambarus clarkii* (Girard) (K. Johnson, pers. comm.), a species absent from the TAMC stream.

The taking of a large number of adult and immature damselflies from the TAMC stream had no observable impact on this restricted population (Fig. 3). Although a more suitable translocation site needs to be found, the lack of impacts to the TAMC damselfly population is encouraging. It is imperative that current mitigation flows be provided at the TAMC stream for a minimum of at least two years after it has been shown that translocated populations of *M. xanthomelas* are naturally reproducing. If successful reproduction is observed in the form of unmarked damselflies at the next relocation site, then monitoring at this site should be continued for at least two years to ensure the population is self-sustaining. An example that translocation of a rare tropical damselfly species can be successful is the translocation of *M. xanthomelas* from the TAMC stream to the mitigation ponds.

Monitoring has also shown that removal of damselflies for translocations does not adversely effect populations at the TAMC stream. Without mitigation stream flows the TAMC stream will cease to flow and cause the extinction of damselflies from the TAMC stream, and Oahu. Thus, it would be prudent to make additional translocations while the TAMC damselflies are abundant, perhaps to a second relocation site at the U.S. Naval Magazine at Lualualei, Oahu. Possible candidate relocation streams were observed during Bishop Museum surveys of Lualualei

(EVENHUIS, 1997), although some of these streams may need to be treated with rotenone to remove alien poeciliid fish such as the western mosquitofish (*Gambusia affinis*), that are believed to be responsible for the decline of this species (ENGLUND, 1999).

The most obvious and cost-effective way to ensure the survival of *M. xanthomelas* would be to continue at least some water flow to the TAMC stream. The $200-300 per month water bill to provide mitigation flows is a small price to pay for one of the most formerly common insects on Oahu. Construction adversely affected water flow at the TAMC stream and caused the stream to become dry before mitigation flows were implemented in June 1997. Now that the ponds have been dismantled there is only one Oahu location where *M. xanthomelas* can be found. As stated earlier, the fate of the translocation efforts for this species are very uncertain, and have failed in at least one attempt to move them out of the TAMC watershed. Thus, to ensure the survival of this species it is necessary to maintain mitigation flows at the TAMC stream until after at least two additional populations have been conclusively established in other areas on Oahu.

Recent genetic work on *M. xanthomelas* indicates that populations between the various Hawaiian islands can be quite different (S. Jordan, pers. comm.). Although the mitochondrial haplotype obtained from TAMC specimens has also been found on Molokai and Lanai, other loci might reveal significant differences between the Oahu TAMC population and other islands, however, more work needs to be done. The Oahu population also has much less genetic diversity than populations on other islands, probably due to genetic bottlenecks (S. Jordan, pers. comm.). Therefore it is critical that habitats and populations from Oahu be maintained to preserve the distinct Oahu race of this damselfly.

In conclusion, it is recommended that a collaboration of specialists from the Bishop Museum, University of Hawaii, U.S. Fish and Wildlife Service, and U.S. Army environmental staff continue to monitor the TAMC population of the *M. xanthomelas*. Additionally, this collaborative team should work on establishing at least two separate populations on the island of Oahu. Until other populations have been established, monitoring on at least a quarterly basis at the TAMC stream could identify potential threats and ensure proper management actions are taken to allow this rare damselfly to survive.

POST SCRIPT

After this paper had been submitted but prior to its publication the TAMC *M. xanthomelas* population faced another severe threat. On 22 October 2000, while showing a University of Hawaii entomology class the site, it was discovered that the four mitigation ponds had been refilled with water, and stocked with the introduced fish tilapia (*Sarotherodon melanotheron* Rüpell). The unauthorized use of the former damselfly mitigation ponds as a private aquaculture facility by the TAMC groundskeepers was in gross violation of the original intent of funding and construction of these ponds. The mitigation ponds are upgradient and drain directly into the TAMC stream. Any large rainfall or pond overflow would have sent large numbers of tilapia into the stream and decimated *M.*

xanthomelas.

The U.S Fish & Wildlife Service took immediate action once their personnel were made aware of the problem. Within a few days the fish were poisoned and the ponds were drained. Heavy rains occurred in November 2000, but the tilapia had been removed prior to these rains. That the ponds were being used as private aquaculture facility at United States taxpayers expense was very disappointing, especially as the TAMC groundskeepers were using water that was supposedly too expensive to be used for the conservation of native damselflies.

Unless the mitigation ponds are going to be used again for damselfly conservation they should be permanently drained and filled. This latest threat again underscores the urgent need for re-establishing additional populations of *M. xanthomelas* on the island of Oahu.

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