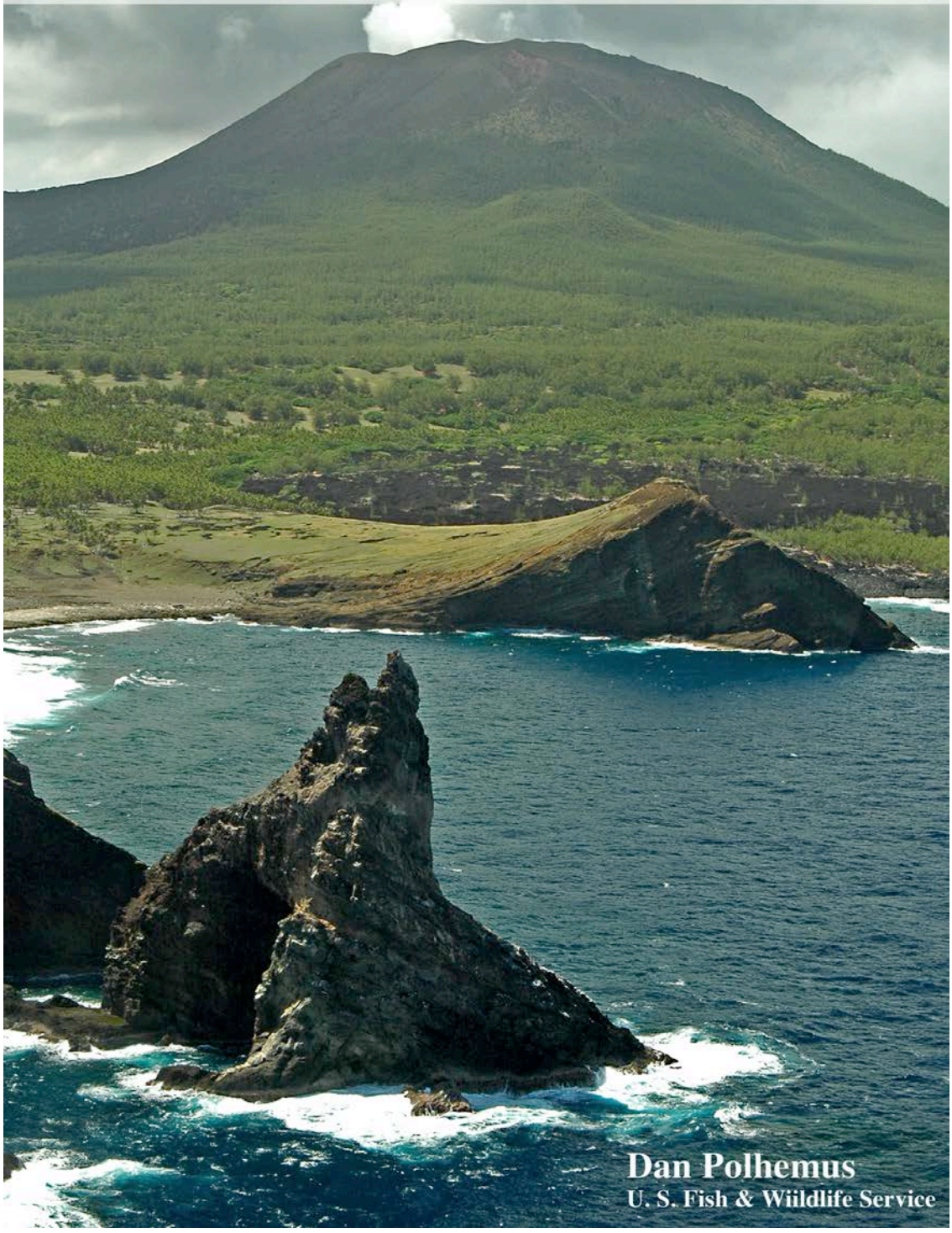
Marine and Freshwater Insect Surveys on Pagan Island, Northern Mariana Islands

Final Report **November 15, 2010**



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FRESHWATER AND MARINE INSECT SURVEYS ON PAGAN ISLAND, MARIANA ISLANDS

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Cover picture: Pagan Island seen from the southeast, with the Sengao Peninsula in the foreground, and active Mt. Pagan (570 m.) in the background (D. A. Polhemus photo).

Fig. 1. Aerial view of Pagan as seen looking south from above Lake Sanhiyon. The Bandeera Peninsula is visible in the middle distance. The prominent mountain massif in the center of the picture consists of the twin peaks of Mt. Maru and Mt. Togari. The highest peaks on the island, lying beyond to the south, are un-named on current topographic maps. Note the plume of low salinity water from the inflow springs cutting at an angle across the lake surface the in the lower right hand portion of the picture.

EXECUTIVE SUMMARY

The island of Pagan, one of the largest in the Northern Marianas, lacks perennial streams but possesses an interesting set of lentic ecosystems, including two mixohaline lakes lying at differing elevations, and a tidally influenced, diurnally transient freshwater wetland. The island also features diverse intertidal systems on its rugged coastlines with tide pools formed in both basalt and limestone exposures.

Collections of aquatic insects were made from these inland water and intertidal habitats at 8 sampling stations ranging in elevation from 0–15 m. elevation, from 16 to 20 July 2010, inclusive. These sampling stations included lake waters and shorelines, freshwater wetlands, abandoned cisterns, and intertidal pools. The current surveys resulted in the collection of 3 species of Odonata, 6 species of aquatic Heteroptera, and 14 species of aquatic Diptera. Among this suite of taxa, one Heteroptera, a *Hermatobates* species taken on a bay north of the Bandeera Peninsula, and one Diptera, a marine dolichopodid taken in tide pools on a leeward limestone coast, represent undescribed species. In addition, 16 species in the above assemblage represent new taxon records for the island of Pagan. The mixohaline lake systems on Pagan have been degraded by the introduction of tilapia many decades ago, and any specialized crustacean fauna that might have been originally present is no longer evident.

Overall, the inland water ecosystems of Pagan represent unique aquatic ecosystems in the context of both the Mariana Islands and the insular Pacific as a whole, where lentic water bodies are generally rare and are worthy of conservation. The crater lake, Lake Sanhiyon, fed by hot springs, is a particularly notable feature. In addition, the tidally-mediated freshwater wetland at the north end of lowland Lake Sanhiyon represents an graphic manifestation of a freshwater lens floating on top of an underlying saline water table and surfacing as transient pools on a diurnal basis. In terms of management, the major threats to these ecosystems and their associated native biota are physical destruction of the unique mixohaline lake habitats and the introduction of additional invasive species such as fishes, amphibians, or ants.

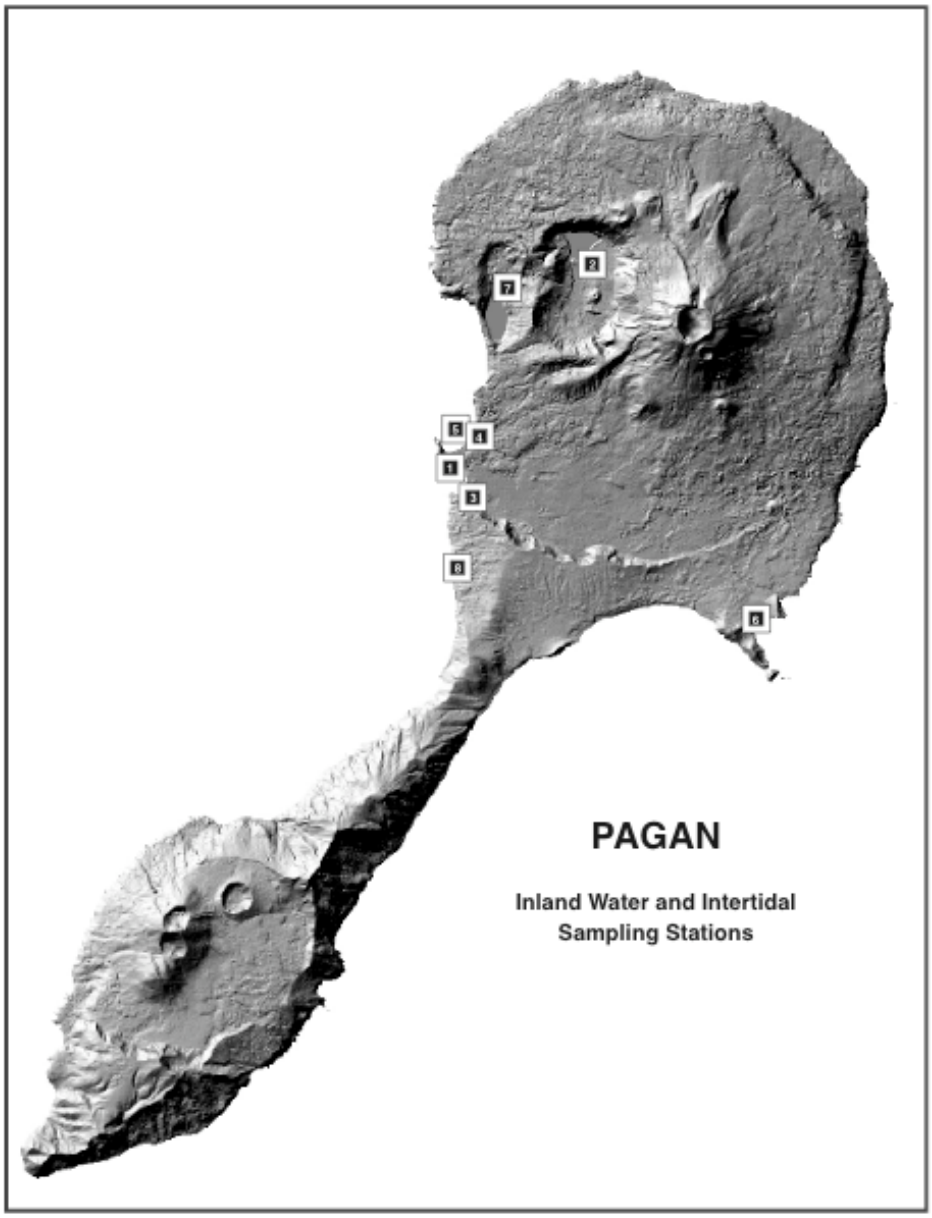

Fig. 2. Hillshade map of Pagan, showing the large northern section dominated by active Mt. Pagan, and its narrow southern section bearing dormant craters. Symbols indicate locations and numbers of inland water and intertidal sampling sites.

INTRODUCTION

From 16 to 20 July 2010, inclusive, collections of aquatic insects were made from inland water and intertidal ecosystems on the island of Pagan, in the Northern Mariana Islands. The current report details the results of these surveys, and is part of the Marianas Expedition Wildlife Survey 2010 (MEWS 2010), a U. S. Fish & Wildlife Service (USFWS) project funded by the Department of Defense. Through this project, USFWS was tasked with gathering natural resource information on fish and wildlife species occurring in the Mariana Islands. This information is required by federal regulations to properly determine the scope of potential impacts that might occur as a result of shifting significant military resources from Okinawa to Guam and the Commonwealth of the Northern Mariana Islands. As part of this military redeployment, the island of Pagan is under consideration as a live fire training area.

Pagan is the largest of the islands in the Mariana chain that extend northward from Saipan. The island has a large, nearly circular northern section dominated by the highly active, 570 m. Mt. Pagan, and an elongate southern section containing a set of dormant craters, including the highest summits on the island (Fig. 2). Pagan is 16 km in length, with widths varying from 6 km in the north to 3 km in the south, with a total land area of approximately 47 square km. The northern section slopes gradually to the sea from Mt. Pagan and its associated craters and is heavily covered by *Casuarina* forest on the south and west, but largely composed of barren volcanic slopes to the north and east (cover figure). The southern portion, by contrast, is heavily eroded into steep slopes, sharp ridges, ravines and valleys, bordered by steep sea cliffs (Fig. 3).

Pagan is notable among the islands of the Northern Marianas is harboring an interesting set of lentic ecosystems, including two mixohaline lakes lying at differing elevations, and a tidally influenced, diurnally transient freshwater wetland. The island also features diverse intertidal systems on its rugged coastlines, with tide pools formed in both basalt and limestone exposures.

METHODS

The current survey of freshwater and intertidal insects was intended to provide an initial assessment of such taxa occurring on Pagan. As with previous aquatic insect surveys undertaken in other parts of the Pacific over the last decade, collections were made by visual searching, hand netting, and localized pyrethrin fogging of intertidal habitats to reveal cryptic species. Specimens were preserved in vials of 80% ethanol and transported to the Bishop Museum in Honolulu for detailed analysis and identification. Voucher specimens from this project are housed in the Bishop Museum.

AQUATIC INSECT SAMPLING STATIONS ON PAGAN ISLAND

Collections of aquatic insects were made at 8 sampling stations on Pagan, ranging in elevation from0–15 m. elevation, from 16 to 20 July 2010. These sampling stations included mixohaline lakes, freshwater cisterns, intertidal pools and flats, and open marine waters. Exemplar photos are provided in Figs. 3–10.

The individual sites sampled are listed below. All GPS readings are in WGS 84 datum, and were taken using a Garmin GPSmap 76S hand-held GPS unit. Water temperatures were taken using a hand-held thermometer. Altitude readings for freshwater stations above sea level were taken in feet using a hand-held barometric altimeter calibrated daily. Collections at each locality were made by D.A. Polhemus.

Station 1 MARIANA ISLANDS, Pagan Is., west coast, rocky shore on south side of Bandeera Peninsula, sea level, sea temp. 30 °C., salinity 38 ppt., 16 July 2010, 1700–1800 hrs., CL 7567
18°07'29"N, 145°45'27"E

Station 2 MARIANA ISLANDS, Pagan Is., Lake Sanhalom, 15 m., water temp. 33 °C., salinity 5 ppt., 17 July 2010, 0800–1130 hrs., CL 7568
18°08'53"N, 145°46'24"E

Station 3 MARIANA ISLANDS, Pagan Is., west coast, abandoned concrete cistern S. of airstrip, 5 m., water temp. 28 ° C., salinity 0 ppt., 17 July 2010, 1530–1600 hrs., CL 7569
18°07'21"N, 145°45'36"E

Station 4 MARIANA ISLANDS, Pagan Is., west coast, pools in lava benches bordering bay N. of Bandeera Peninsula, 5 m., water temp. 30 °C., salinity 2 ppt., 18 July 2010, 0900–1000 hrs., CL 7570
18°07'44"N, 145°45'39"E

Station 5 MARIANA ISLANDS, Pagan Is., west coast, bay N. of Bandeera Peninsula, sea level, sea temp. 30 °C., salinity 38 ppt., 18 July 2010, 1030–11:30 hrs., CL 7571
18°07'48"N, 145°45'32"E

Station 6 MARIANA ISLANDS, Pagan Is., east coast, limestone shore and tidepools at Unaidikiki Bay, N. of Sengao Peninsula, sea level, sea temp. 29 °C., salinity (tide pools) 40 ppt., 19 July 2010, 08:30–10:45 hrs. and 21 July 2010, 0900–1130 hrs., CL 7573
18°06'28"N, 145°47'39"E

Station 7 MARIANA ISLANDS, Pagan Is., Lake Sanhiyon, sea level, water temp. 32.5 °C., salinity 15 ppt., 19 July 2010, 1400–1600 hrs., CL 7574
18°08'37"N, 145°45'51"E

Station 7a: Freshwater springs at north end of lake, water temp. 30° C., salinity 0 ppt, CL 7574a
18°08'43"N, 145°45'46"E

Station 7b: Cold sulphur springs NE side of lake, water temp. 28.5 °C., salinity 5 ppt , CL 7574b
18°08'40"N, 145°45'49"E

Station 8 MARIANA ISLANDS, Pagan Is., west coast, limestone reef flat and tidepools near Lukairu, sea level, sea temp. 29 °C., salinity 36 ppt., 20 July 2010, 0900–1100 hrs., CL 7575
18°06'57"N, 145°45'28"

Fig. 3. Rocky shore on south side of the Bandeera Peninsula (Station 1), with the southern section of Pagan in the distance. This area provided habitat for several species of marine Diptera including a new genus, and for the marine veliid *Halovelia bergrothi*.

Fig. 4. Lake Sanhalom (Station 2), a mildly mixohaline crater lake in the interior of Pagan. The small limnocrenes in the foreground, fed by warm springs, provided habitat for the indigenous water bug *Mesovelia vittigera*, the only site on Pagan where this species was encountered. The damp littoral cinder and ash beaches fronting the lake beyond were favored habitat for the indigenous shore bug *Saldula palauana*. The small indigenous dragonfly *Diplacodes bipunctata* (see Fig. 17) flew in large numbers along the lake's shores and amid the grass patches bordering the limnocrenes.

Fig. 5. Rain-filled cistern (Station 3) near base camp at Pagan airstrip. This cistern provided habitat for the water bug *Microvelia diluta* and the dragonfly *Tholymis tilllarga*.

Fig. 6. Bay on west coast, north of the Bandeera Peninsula (Station 5). The calm waters of the bay in the lee of the cliffs were favored habitat for marine Heteroptera, specifically *Halobates flaviventris* and a *Hermatobates* species.

Fig. 7. Bay on east coast, north of the Sendao Peninsula (Station 6). The tide pools at this site harbored the marine veliid bug *Halovelia bergrothi*.

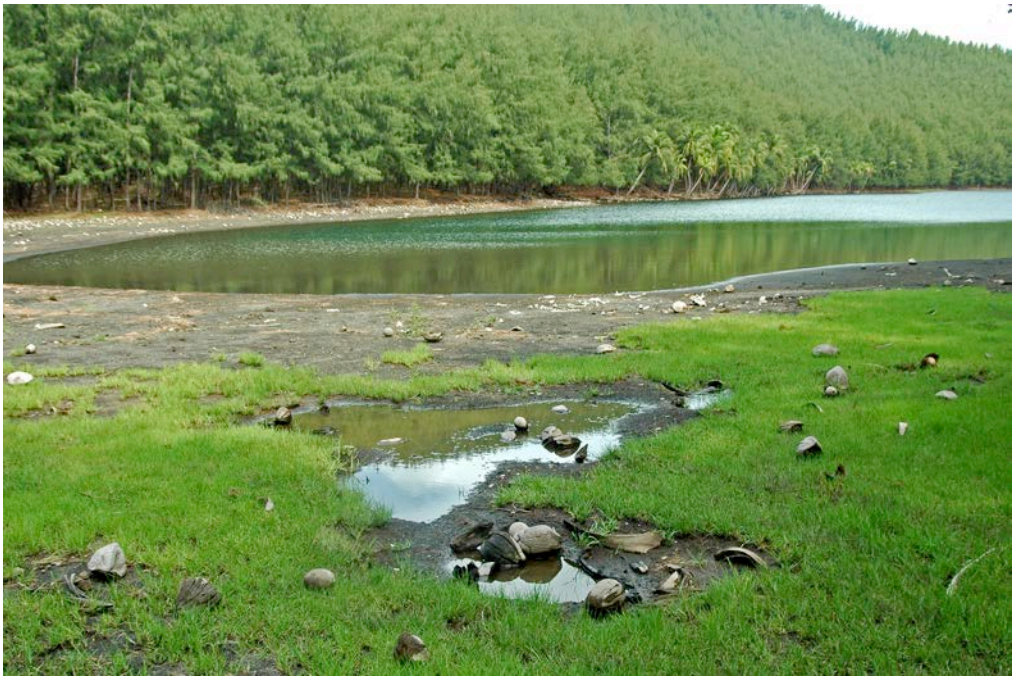

Fig. 8. Lake Sanhiyon and a small wetland at its north end (Station 7). The waters of the lake are mixohaline, with a salinity of 15 ppt. By contrast, the small pools in the foreground are limnetic, with salinities of 0 ppt. The extent of these wetland pools fluctuates with the tidal cycles due to the presence of a freshwater lens lying above the lake's mixohaline waters. In this picture, taken at high tide, the pools are extensive, whereas at low tide the water recedes, reducing the pools to shallow, muddy basins.

Fig. 9. Bay on west coast, north of the Bandeera Peninsula (Station 5). The calm waters of the bay in the lee of the cliffs were favored habitat for *Halobates flaviventris* and a *Hermatobates* species.

RESULTS

The current surveys resulted in the collection of 23 species of marine and freshwater insects on Pagan. These are listed in Appendix 1. One of these taxa, the a marine dolichopodid fly, appears to represent a genus and species new to science.

A preliminary listing of local distributional data for these taxa is provided in the tables for Stations 1–8 below. Where an exact species determination could not yet be made, the following notations were employed:

n.sp.: indicates that the species is clearly new to science.

sp. undet.: indicates that the species has not yet been definitively identified, and may possibly be undescribed, or simply unidentifiable given the limitations of the current taxonomic literature.

Table 1: Species taken at Station 1, Pagan Is., west coast, rocky shore on south side of Bandeera Peninsula (Fig. 3)

DIPTERA
- **Canaceidae**
  - *Nocticanace pecularis* Malloch
- **Chironomidae**
  - *Thalassomyia maritima* Wirth (new Pagan record)

HETEROPTERA
- **Veliidae**
  - *Halovelia bergrothi* Esaki

Notes: This site consisted of a black sand beach scattered with rocks and boulders at its western end, and a basalt platform offshore which was exposed at low tide. The offshore platform was sampled at low tide and yielded an interesting assemblage of intertidal Diptera. A single female specimen of the marine veliid *Halovelia bergrothi* was also taken from a quiet water pocket amid basalt boulders. A diligent search produced no further specimens of *Halovelia* at this locality.

Table 2: Species taken at Station 2, Pagan Is., Lake Sanhalom (Fig. 4)

DIPTERA
- **Ceratopogonidae**
  - Genus and species undet.
- **Dolichopodidae**
  - *Thinophilus* sp. undet.*[NE7]
- **Ephydridae**
  - *Paralimna lineata* Meijere
  - *Paralimna fusca* Bock 1988[NE8]
- **Muscidae**
  - *Musca sorbens* Wiedemann
- **Sphaeroceridae**
  - Genus and species undet.

ODONATA
- **Coenagrionidae**
  - *Ischnura aurora* (Brauer)
- **Libellulidae**
  - *Diplacodes bipunctata* (Brauer)

Table 2 (cont.)

HETEROPTERA
Mesoveliidae
Mesovelia vittigera Horvath
Saldidae
Saldula palauana Drake

Notes: Lake Sanhalom is an upland lake lying in a large crater on the west flank of Mt. Pagan. The lake is mildly mixohaline (5 ppt) and the water is warm and clear. Neubauer (1981) reported the lake basin has a depth in excess of 20 m, but that the water column is well mixed and unstratified, This study also noted presence of both *Tilapia mossambicus* and *Gambusia affinis* in this lake, and the presence of the former fish species was reconfirmed during the current surveys. The lake shores are composed of fine, firm, compacted volcanic ash, overlain with scattered basalt gravel, and lined by *Casuarina* trees. Slightly saline warm springs enter the lake at various points along the south shore, although the main source of such inflow had been covered by a delta of mud formed by a flash flood resulting from a strong rain storm the night before sampling was conducted. The waters of these springs were not analyzed during the current survey, but were reported by Neubauer (1981) to be alkaline and high in silica. A few smaller, undisturbed spring heads immediately adjacent to the lake shore yielded the water bug *Mesovelia vittigera*, the only place at which this species was found on Pagan. The damp littoral areas of the nearby lake beaches supported *Saldula palauana* and ephydrid Diptera, as well as *Mesovelia*, which were present amid the mosaic of cobbles and water at the very margin of the lake. The Odonata assemblage here consisted of the small red dragonfly *Diplacodes bipunctata*, which was abundant, and the small damselfly *Ischnura aurora*, which was found only in places where *Casuarina* trees had fallen into the water, creating suitably complex breeding and perching habitat. Numerous small *Tilapia* fish were present in the shallows along the shores of the lake, perhaps accounting for the paucity of subaquatic insect taxa.

Table 3: Species taken at Station 3, Pagan Is., west coast, abandoned concrete cistern S. of airstrip (Fig. 5)

ODONATA
Libellulidae
Tholymis tillarga (Fabricius)
HETEROPTERA
Veliidae
Microvelia diluta Distant

Notes: This site consisted of a rectangular concrete cistern next to an old dwelling site at the old Pagan settlement near the airstrip. The water lay approximately 3 feet below the vertical walls of the cistern and was green with algae. The biota here consisted of the small water bug *Microvelia diluta*, which was abundant on the water surface, skating Diptera, and the strikingly marked dragonfly *Tholymis tillarga*, individuals of which patrolled aggressively above cistern and would also range into the survey camp on the airstrip nearby, seeking to oviposit in the water tanks used for rainwater catchment there. Other cisterns similar to that seen at Station 3 were encountered on the trail south of the Miari Cliffs, but were either dry, had standing water too far below the rim to safely sample or had only recently refilled due to heavy night rains. None of these latter cisterns supported Odonata or *Microvelia*, but given the ubiquitous nature of such remnant anthropogenic habitats on Pagan, it is likely that other cisterns on the island continue to provide important localized breeding sites for freshwater insects.

Table 4: Species taken at Station 4, Pagan Is., west coast, pools in lava benches bordering bay N. of Bandeera Peninsula (Fig. 6)

ODONATA
Libellulidae
Diplacodes bipunctata (Brauer)
HETEROPTERA
Veliidae
Microvelia diluta Distant

Notes: A set of massive pahoehoe lava benches fronts the eastern shore of a broad, crescentic bay north of the Bandeera Peninsula. The relatively level tops of these bedrock exposures contain freshwater pools of varying sizes and depths, which supported the small dragonfly *Diplacodes bipunctata* and the water bug *Microvelia diluta*. The latter species was very localized in its occurrence at this site, with aggregations being located in the shade of small rock overhangs. The pools on these benches appear to be rain-fed but also seem to be durable features due to the relatively impervious nature of the lava flows. In some cases drainage from these pools formed small freshwater seeps trickling down the sides of fractures in the lava benches and into descending chains of tidepools with gradually increasing salinity, forming an interesting array of localized mixohaline habitats,

Table 5: Species taken at Station 5, Pagan Is., west coast, bay N. of Bandeera Peninsula (Fig. 6)

HETEROPTERA
Gerridae
Halobates flaviventris (Eschscholtz)
Hermatobatidae
Hermatobates sp. undet.

Notes: The sea offshore of the lava benches discussed under Station 4 (above) was protected from the prevailing easterly winds during the period of the surveys and thus provided favored habitat for *Halobates* sea striders. These were sampled by trolling a net in the bow wash of an inflatable dinghy driven near the base of the cliffs and on the open waters of the bay immediately beyond. The samples thus obtained contained numerous adult *Halobates flaviventris*, as well as a few scattered adults and immatures of a *Hermatobates* species, the latter mostly taken further offshore; no *Halovelia* were captured in these samples. During the period of sampling the waters near the cliffs were smooth and calm, and those further offshore slightly wind-ruffled, but without significant swell. Coral cover in this bay is low with only scattered colonies on the vertical underwater faces of the cliffs, and there is no offshore reef crest or platform with the bottom of the bay instead consisting of a jumble of massive basalt boulders interspersed with flats of black volcanic sand. Although it is generally hypothesized that *Hermatobates* species are reef-associated, and seek shelter amid reef crest air pockets at high tide, it is difficult to see how this pattern of behavior could be utilized at Station 5, indicating that the Pagan *Hermatobates* species may utilize habitats other than coral reefs for breeding and shelter.

Table 6: Species taken at Station 6, Pagan Is., east coast, limestone shore and tidepools at Unaidikiki Bay, N. of Sengao Peninsula (Fig. 7, and cover photo)

HETEROPTERA
Veliidae
Halovelia bergrothi Esaki

Notes: This station lay along the shores of the bay immediately north of the Sengao Peninsula. The bay is bordered in its central section by an elevated limestone paleo-reef bench with numerous well-preserved fossil corals, and also bears many deep depressions and tidepools. A series of the marine veliid *Halovelia bergrothi* was taken here by scooping with a net under deep, shaded overhangs along the pool margins, and by applying a light pyrethrin fog to

similar habitats. As is typical on Pagan, the *Halovelia* were localized, present in low numbers, and difficult to locate. A search was also made for the marine saldid genus *Salduncula*, which is known from Guam, but without success. Although the offshore surf at this site was rough, the tide stage was low and stable, and as a consequence the waters of the pools were calm. Weather at this site during the period of sampling was overcast for the first hour, then rainy for the next two hours before finally clearing; a strong onshore breeze prevailed during the entire period.

Table 7 - Species taken at Station 7, Pagan Is., Lake Sanhiyon (Figs. 1, 8)

DIPTERA
- **Chironomidae**
  - *Chironomus longilobus* Kieffer
- **Culicidae**
  - *Aedes (Stegomyia) albopictus* (Skuse)
- **Dolichopodidae**
  - *Tachytrechus* sp. undet.
  - *Thinophilus* sp. undet.
- **Ephydridae**
  - *Paralimna lineata* Meijere
  - *Paralimna fusca* Bock
  - *Hecamedoides* sp. undet.
  - *Scatella septempunctata* Malloch
  - *Allotrichoma* sp. undet.

ODONATA
- **Coenagrionidae**
  - *Ischnura aurora* (Brauer)
- **Libellulidae**
  - *Diplacodes bipunctata* (Brauer)
  - *Tholymis tillarga* (Fabricius)

HETEROPTERA
- **Veliidae**
  - *Microvelia diluta* Distant
- **Saldidae**
  - *Saldula palauana* Drake

Notes: Lake Sanhiyon is a lowland, mixohaline lake occupying a roughly ovate basin with a north-to-south axis, adjacent to the central-western shore of northern Pagan. The slopes surrounding the lake are predominantly *Casuarina* forest, and the shores are composed of fine, firmly compacted black ash, which forms a beach of varying widths around the entire lake. The surface waters of the lake are moderately mixohaline, with a salinity of 15 ppt (slightly less than half the salinity of seawater). Neubauer (1981) reported that this mixohaline surface water mixolimnion rests as a well-mixed layer approximately 10–15 m deep on top of a warmer, stagnant, more strongly saline (32 ppt) moniolimnion bottom layer, with the two layers rarely, if ever, mixing. The depth for this lake reported in the above study would also indicate that the lowest point in the lake basin lies below mean sea level. Along its seaward margin, the lake is separated from the ocean by a porous berm of coarse black volcanic sand approximately 6 m high and 30 m wide. This berm was formerly forested with *Casuarina*, but most of these trees have died in the recent past. Along its inland margin the lake is fed by a set of cold, mildly mixohaline (5 ppt) springs with a distinct odor of sulphur to their waters, which emerge at the northeast corner of the basin. The salinity of these springs and their general flow rate are similar to the salinity and inflow rate of the warm springs feeding Lake Sanhalom, which lies approximately 15 m higher, on the other side of an intervening volcanic ridge. The gully from which the inflow springs for Lake Sanhiyon emerge runs eastward toward the upper lake, suggesting the two systems may be linked through subsurface flow.

Another set of small, cold, limnetic, non-sulphurous limnocrenes exists at the northern end of the lake, set amid a grassy swale. These springs consist of 4 small pools, each less than 0.3 m deep, lying at the mouth of a northward-trending gully. Several stands of *Hibiscus tiliaceous* occur further up this gully, indicating the presence of subsurface water, but a long reconnaissance inland revealed no further pools. The size and depth of the 4 pools

adjacent to the lake fluctuates with the tides – as the mixohaline water in the lake rises with each tide cycle, the freshwater lens above it "floats", thus filling the pools in the wetland at the north end. When the tide cycle is at an ebb the wetland pools are greatly reduced in size, with some becoming muddy basins.

The small spring and wetland complex at the northern end of Lake *Sanhiyon* was the richest site sampled on Pagan in regard to Odonata, supporting three species, the damselfly *Ischnura aurora*, and the dragonflies *Diplacodes bipunctata* and *Tholymis tillarga*. The former species was taken only at the spring outflows on the northeastern shore, where both immatures and adult females were collected. The small veliid Microvelia diluta occurred in the most inland and persistent of the standing pools in the wetland, but was not seen elsewhere around the lake. By contrast, the shore bug *Saldula palauana* was common on the open ash beaches, in combination with several dipteran species in the families Dolichopodidae and Ephydridae. Neubauer (1981) reported the presence of both *Tilapia mossambicus* and *Gambusia affinis* in this lake, and the presence of the former fish species was reconfirmed during the current surveys.

Table 8 - Species taken at Station 8, Pagan Is., west coast, limestone reef flat and tidepools near Lukairu (Fig. 9), sea level, sea temp. 29 °C., salinity 36 ppt., 20 July 2010, 0900–1100 hrs., CL 7575 18°06'57"N, 145°45'28"

DIPTERA

Canaceidae

Nocticanace pecularis Malloch

Chironomidae

Thalassomyia maritima Wirth

Dolichopodidae

Hydrophorinae new genus and species

HETEROPTERA

Veliidae

Halovelia bergrothi Esaki

Notes: Collections at this station were made from tidepools formed in a broad limestone bench lying along the western shore of Pagan in the isthmus between the northern and southern portions of the island. The limestone bench along this coastline was very broad, had been worn smooth by wave action, and contained many tide pools of varying sizes and depths. Many of these ponds were very warm (up to 33 °C, in contrast to a sea temperature of 29 °C), and if not connected directly to the sea also tended to be slightly hypersaline (40 ppt). The limestone bench was bordered on its inland side by a narrow sand beach with forested hill slopes rising up steeply behind. The marine veliid *Halovelia bergrothi* was taken sporadically here, being found only in sheltered, shaded spots formed under limestone overhangs at tide pool margins, or in crevices. This species was uniformly absent from the warm or hypersaline pools. The damp, vertical limestone margins of the tide pools also harbored a rich assemblage of marine Diptera, including members of the families Ephydridae, Canaceidae, and Dolichopodidae. Among the latter was a genus and species new to science.

Fig. 13. *Ischnura aurora*, male, specimen from Tutuila, American Samoa. This very small species is widespread in the western and central Pacific and was found breeding at both lakes on Pagan.

Fig. 17. *Diplacodes bipunctata*, male, specimen from Tutuila, American Samoa. This small species is widespread in the western Pacific, and on Pagan was found in a wide variety of standing freshwater habitats.

DISCUSSION

The aquatic insect biota of Pagan Island is typical of that found on isolated volcanic islands in the western Pacific. Overall, species richness is low, and the taxa present are members of groups with demonstrable ability to colonize isolated islands throughout the Pacific region. Even so, the lake systems of Pagan support a higher species richness of aquatic insects than has been reported elsewhere in the Mariana Islands. In addition, the marine insect biota of the intertidal zone and adjacent nearshore waters is distinctive and noteworthy.

Lake Sanhiyon and its associated spring and wetland systems represent the most unique and important aquatic ecosystem on Pagan, and one of the most significant aquatic ecosystems in the Mariana Islands. The lake and its environs are far from pristine: according to local guides, a sugar mill (remants of which can still be seen) formerly existed on the coastal ridge southwest of the lake, and an old road traverses the slope above the lake's eastern shore. Therefore the hydrological features seen today, particularly the small, tidally transient wetland at the northern end, may have had somewhat different configurations in the last century. Even so, the current system is in good condition, and little disturbed by feral cattle or other ungulates, perhaps because of the brackish nature of the lake waters, and the sulphur content of the inflow springs. As such, Lake Sanhiyon represents a system that has retained good biological integrity, and supports an aquatic insect biota that is rich and intact by regional standards. It should be a high priority in terms of conservation and protection from further disturbance.

ACKNOWLEDGMENTS

The current aquatic insect surveys on Pagan represent the aggregate sum of combined efforts by scientists, government officials, and local residents. It is impossible to properly acknowledge every contribution, but I wish to give particular thanks to certain individuals. Foremost among these are Kurt Kessler and Earl Campbell, of the U. S. Fish & Wildlife Service, who coordinated the logistical organization of these surveys in a remote location. Sincere thanks are also due to the staff of the Department of Land and Natural Resources of the Commonwealth of the Northern Mariana Islands, who determined that this research was in the best interests of their jurisdiction, and graciously granted us the necessary permissions to conduct the work. Assistance with identification of Ephydridae and Dolichopodidae was also kindly provided by Keith Arakaki and Neal Evenhuis, respectively, of the Bishop Museum, Honolulu, Hawaii.

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Appendix 1: Checklist of marine and freshwater insects known from the island of Pagan, based on literature sources and recent collections.

DIPTERA

Canaceidae

Nocticanace pecularis Malloch*

Ceratopogonidae

Genus and species undet.

Chironomidae

Chironomus longilobus Kieffer*

Culicidae

Aedes (Stegomyia) albopictus (Skuse)

Dolichopodidae

Tachytrechus sp. undet.*

Thinophilus sp. undet.*

Hydrophorinae new genus and species*

Ephydridae

Paralimna lineata Meijere*

Paralimna fusca Bock*

Hecamedoides sp. undet.*

Scatella septempunctata Malloch*

Allotrichoma sp. undet.*

Muscidae

Musca sorbens Wiedemann

Sphaeroceridae

Genus and species undet.

ODONATA

Coenagrionidae

Ischnura aurora (Brauer)

Libellulidae

Diplacodes bipunctata (Brauer)

Tholymis tillarga (Fabricius)*

Rhyothemis regia chalcoptilon (Brauer)

Note: This is a distinctive species that was not seen during current surveys on Pagan, but was listed from the island by Lieftinck (1962). Previous records of this species from Pagan may represent misidentifications of *Tholymis tillarga*, which is of similar appearance on the wing.

HETEROPTERA

Gerridae

Halobates flaviventris Eschscholtz*

Hermatobatidae

Hermatobates sp. undet.*

Mesoveliidae

Mesovelia vittigera Horvath*

Saldidae

Saldula palauana Drake*

Veliidae

Halovelia bergrothi Esaki*

Microvelia diluta Distant*

Notations

* = New species record for Pagan