



**2010 TRIP REPORT:
GUAM AND PALAU AQUATIC
INSECT SURVEYS**

**Pacific
Biological
Survey**

Final Report

April 2011

GUAM AND PALAU AQUATIC INSECT SURVEYS

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**Final Report
April 2011**

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BISHOP MUSEUM

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Agriocnemus femina femina, collected from Ngerikiil River, Babeldaob, Palau

Executive Summary

From 15 to 26 March, 2010, collections of aquatic insects were made from freshwater habitats on the island Guam and the Republic of Palau. These surveys were part of a developing a regional biosecurity plan, and personnel from the Pacific Biological Survey of the Bishop Museum assisted scientists from the United States Geological Survey Southeast Ecological Science Center (USGS–SESC) based in Gainesville, Florida in obtaining data required for this plan. The results from these surveys will be used in conjunction with the USGS–SESC project entitled “Risk Analysis of Freshwater Nuisance Species Associated with Department of Defense Operations in Micronesia” that obtained critical baseline information regarding native and non–native freshwater invertebrates. The objective of these aquatic insect surveys was to provide a systematic inventory in selected streams on the islands Guam and in the Republic of Palau. Streams on both Guam and Palau were sampled for one week each.

A total of 35 aquatic insect species were collected during surveys on Guam from 15–19 March, and 28 species were found on Palau from 21–26 March, 2010 (Tables 3–5). In the Republic of Palau, the vast majority of freshwater habitats are located on Babeldaob Island, so efforts were concentrated here. These results should be considered preliminary as this was a biological reconnaissance due to limited sampling time and effort for each site. However, this study does provide baseline information regarding particularly rich areas of biodiversity. Although reservoir habitats were assessed on Guam and Palau, lotic habitats were by far the most species-rich habitats. These surveys provided a baseline inventory of aquatic insect species present in each stream assessed and also ensured museum specimens will be available for future researchers.

During the course of this study no obvious invasive aquatic invertebrates were observed in the streams sampled on Guam and Palau. All taxa identified to the species level were ascertained to be native species, and at least three species of aquatic Heteroptera on Guam were island endemics (*Limnogonus lundbladi*, *Microvelia mariannarum*, and *Saldula guamensis*). For Palau, a conservative estimate of finding at least 4 island endemics was made, including the three endemic damselflies (*Drepanosticta palauensis*, *Pseudagrion palauense*, and *Teinobasis palauensis*) and the gyrenid (whirlygig) beetle. The identity of an *Ischnura* found in lentic habitats on Palau remains a mystery, but as it is not a widespread species such as *Ischnura aurora* or *Agriocnemis femina femina* it is likely that it at least is indigenous if not possibly endemic to Palau.

The majority of endemism found during the present study was in relatively undisturbed forested watersheds that appeared to have little to no water diversions. Sampling areas around riffles/cascade areas were found to be particularly species rich. Streams above Fena Reservoir in the Naval Magazine such as the diverse Maulap River are currently strictly protected from development and human impacts, but uncontrolled feral animals such as water buffalo and pigs could disturb the watershed to such an extent to impede water quality. Although feral animals did not appear to be a problem on Babeldaob, logging, increased agricultural development and water withdrawals are all potential future threats to maintaining a highly diverse and unique freshwater aquatic ecosystem on Palau.

Introduction

From 15 to 26 March, 2010, collections of aquatic insects were made from freshwater habitats on the island Guam and the Republic of Palau. These surveys were part of a developing a regional biosecurity plan, and personnel from the Pacific Biological Survey of the Bishop Museum assisted scientists from the United States Geological Survey Southeast Ecological Science Center (USGS–SESC) based in Gainesville, Florida in obtaining data required for this plan. The results from these surveys augment a report by the USGS to provide critical baseline information regarding native and non–native freshwater invertebrates. The objective of these aquatic insect surveys was to provide a systematic inventory in selected streams on the islands Guam and in the Republic of Palau. Streams on both Guam and Palau were sampled for one week each. These surveys provided a baseline inventory of aquatic insect species present in each stream assessed and also ensured museum specimens will be available for future researchers.

Effective conservation strategies of island biotas requires accurate information on the distribution, taxonomic composition, endemism, and local richness of species assemblages found in the highly restricted freshwater habitats on these small Pacific islands. Although certain biotic components in this region such as birds and plants have been reasonably surveyed, many others, particularly freshwater organisms, remain poorly understood. Inventories of the aquatic biota are necessary prior to the development of management plans and risk assessments, and are especially urgent as aquatic insects are the one of the most severe public health problems worldwide.

Study Area

Sampling occurred on the small islands of Guam and Palau in the eastern Pacific region, lying approximately 1300 km apart, with Palau being located closest to a major island landmass. Guam is the largest island in Micronesia and is also the most heavily developed and urbanized at 549 km² in size. Located at the western edge of the Caroline Islands, the Paluan archipelago has the second largest island in Micronesia, Babeldaob. Babeldaob contrasts with the densely populated island of Guam by having a more rural character and being 367 km² in size. Also sampled were the smaller Koror (9.3 km²) and Malakal islands in Palau, which have extremely limited aquatic habitats. Guam has an overall drier climate regime with generally smaller streams draining mainly urban and grassland areas, while Babeldaob, Palau is wetter with larger streams, and maintains most of the original forest canopy. Fena Reservoir on Guam is the largest water body in Micronesia, covering 81 ha. Localities sampled for Guam are shown in Table 1, and for Palau are in Table 2. GPS coordinates were recorded in WGS 84, while altitudes should be considered approximate and were determined with the GPS barometric altimeter.

Table 1. Sample localities, GPS coordinates (WGS 84), and habitat sampled on Guam during aquatic biodiversity surveys in March 2010.

Locality	Date	Lat Long Coords	Habitat	Elev (m)
Tarzan River and Falls (bottom)	15 Mar 2010	13.39696°N 144.72101°E	Waterfalls and stream	55
Asmafines River	15 Mar 2010	13.33407°N 144.65758°E	Stream chutes and pools	80
Ylig River	15 Mar 2010	13.39904°N 144.76044°E	Large river at 2 m high metal weir	
Agana Springs	16 Mar 2010	13.46330°N 144.76044°E	Large springs nr Sinajana Town	
Agana River	16 Mar 2010	13.47511°N 144.75520°E	Urbanized stream nr Bank of Guam parking lot	1-2
Agana River at S. end of Agana Swamp	16 Mar 2010	13.47215°N 144.75946°E	Silty, mucky swamp habitat	5
Masso Stream	16 Mar 2010	13.46031°N 144.69228°E	Small stream nr Piti Village	18
Lost Pond	17 Mar 2010	13.55613°N 144.81712°E	Large, clear karst pond nr Hilaan Point	33
Fensol River	17 Mar 2010	13.28542°N 144.73779°E	Upstream of Fintaso River, large 20 m falls	30
Fena Reservoir	18 Mar 2010	13.36268°N 144.70290°E	Shoreline area	36
Lost River	18 Mar 2010	13.35983°N 144.71088°E	Large spring fed stream starting at base of limestone cliff	25
Maulap River	19 Mar 2010	13.35430°N 144.69586°E	River inside U.S. Naval Magazine, near Bridge #737	90–98

Methods

The current survey of aquatic insects was intended to provide an initial biodiversity profile of selected groups occurring within the islands of Guam and Palau. Similar to previous surveys conducted in the last decade in Papua New Guinea (Polhemus et al. 2004), Solomon Islands (Polhemus et al. 2008), and French Polynesia (Englund 2003, 2008) the primary groups utilized were aquatic Heteroptera (true bugs), Odonata (dragonflies and damselflies), and Gyrinidae (whirlygig beetles). These groups were selected due to their consistency of representation across a wide range of altitudes and habitat types, variation of species assemblages on a local scale between sampling sites, and relatively well investigated taxonomy. The latter factor in particular allowed confidence that identifications could be made at least to the genus level for all specimens collected, and reduced the potential number of undescribed species to be dealt with, a frequently limiting factor in studies involving tropical insects. Although emphasis was placed on these three major groups, all aquatic insect taxa found were collected at each sampling station, particularly aquatic Diptera. In tropical and Pacific insular regions, the adults of most aquatic insect species are found in streams throughout the year and the immature stages of most Pacific island species are unknown (Allison and Englund 2008), thus sampling concentrated on obtaining the adult stages in order to avoid underestimating community diversity (Merritt and Cummins 1997).

Collections of aquatic insects were according Allison and Englund (2008), with collections of both immature and adult specimens being made with aerial sweep nets, yellow pan traps, aquatic dip nets, visual searching, and localized pyrethrin fogging of hygropetric habitats. Specimens were preserved in 80% ethanol and subsequently transported to the Bishop Museum for detailed analysis and identification. Photographs of the larger taxa were also taken when possible, as live coloration is a key factor in species identification for Odonata. Identified insects from each sample station are shown in Tables 3–5.

Where species determination could not yet be made the following notations were employed:

sp. undet.: indicates that the species has not yet been definitively identified, and may be possibly undescribed, or unidentifiable given the limitations of the current taxonomic literature. In most aquatic Diptera males are for needed definitive species identifications.



Lost River below Fena Reservoir in the Naval Magazine, Guam.



Brent Tibbets, Guam DAWR sampling Lost Pond.

Table 2. Sample localities, GPS coordinates (WGS 84), and habitat sampled on Palau during aquatic biodiversity surveys in March 2010.

Locality	Date	Lat Long Coords	Habitat	Elev (m)
Babeldaob Island				
Unnamed stream estuary	21 Mar 2010	7°21' 38.1" N 134°33'27.6" E	Small mangrove stream estuary at road crossing (no aquatic insects observed)	0
Imeong Village	21 Mar 2010	7.53016°N 134.52876°E	Taro fields	1
Near Melekeok Capital	22 Mar 2010	7.49542°N 134.60983°E	Stream at highway bridge area, and Pandanus wetland draining into stream	35
Ngerchluuk Village	22 Mar 2010	7.56421°N 134.63246°E	Small stream with 3 m diversion dam	10
Ngatpang Waterfall	23 Mar 2010	7.45290°N 134.52901°E	Formerly Tabecheding waterfall, large stream and 15+ m falls	23
Ngardok Lake	23 Mar 2010	7.51118°N 134.60527°E	Largest freshwater lake in Micronesia, lake outflow	30
Ngardok Lake	23 Mar 2010	7.51242°N 134.60463°E	At tourist dock	40
Ngerimel Reservoir	25 Mar 2010	7.37403°N 134.53033°E	Shoreline around reservoir	8
Ngerikiil Pump Station	25 Mar 2010	7.38518°N 134.55536°E	Area around pump station and stream (only 10 minutes sampling here)	12
Diongradid River	25 Mar 2010	7.60512°N 134.58444°E	River/crocodile habitat, downstream of Ngardmau Falls	10 m
Ngermeskang River	25 Mar 2010	7.52740°N 134.56085°E	River at Hycos monitoring gage station by Palau Community College, taro fields nearby	23
Ngertebechel River Site 1	26 Mar 2010	7.58878°N 134.59108°E	Ngardmau Falls area, where trail hits river, Site 1	61
Ngertebechel River (Ngardmau Falls)	26 Mar 2010	7.59124°N 134.59341°E	Same river, but downstream from Site 1, to large Ngardmau Falls	97
Ngardok Lake	26 Mar 2010	7.51242°N 134.60463°E	At tourist dock, checking traps set 23 Mar 2010	40
Koror Island				
Small aquaculture ponds	25 Mar 2010	7.17466°N 134.32104°E	Drained aquaculture ponds with some freshwater seepage	36
Malakal Island				
Japanese WWII fuel tank	25 Mar 2010	7.33411°N 134.45428°E	Old Japanese fuel tank #1 now filled with freshwater	25
Japanese WWII fuel tank	25 Mar 2010	7.33473°N 134.45421°E	Old Japanese fuel tank #2 now filled with freshwater	20
Japanese WWII drydock	25 Mar 2010	7.33507°N 134.44962°E	Old drydock at ocean with freshwater layer of water at surface	0
Quarry Pond	25 Mar 2010	7.33322°N 134.45003°E	Quarry stone washing area, with ponds	0

Results

A total of 35 aquatic insect species were collected during surveys on Guam from 15–19 March, and 28 species were found on Palau from 21–26 March, 2010 (Tables 3–5). In the Republic of Palau the vast majority of freshwater habitats are located on Babeldaob Island, so most effort was concentrated on this island. These results should be considered as preliminary, as this was a biological reconnaissance due to limited sampling time and effort for each site. However, this study does provide baseline information regarding particularly rich areas of biodiversity. Although reservoir habitats were assessed on Guam and Palau, lotic habitats were by far the most species-rich habitats. The following are brief notes regarding the sample sites, with GPS for each locality found in Table 1. None

of the aquatic insect species collected during these surveys were considered either non-native or invasive, although the biogeographic status of taxa identified only to the generic level remains unknown.

Results–Guam

Tarzan River and Falls: Located off Highway 17, Tarzan Falls is a small river 3–5 m wide, located in a parched watershed and is a popular day-hike area. Tarzan Falls are approximately 10 m in height, and amphidromous fauna such as neritid snails and crustaceans were observed on the falls. Seven species of aquatic insects were collected here in a relatively short sample period of approximately 1 hour.

Asmafines River: This upland river was quite small flowing through bedrock basaltic chutes, averaging 50 cm wide and 0.5 to 1.5 m in depth. Pools were up to 1 x 2 m in width interspersed through bedrock chutes. The areas we surveyed had absolutely no loose rubble and the stream bedrock was lined with CaCO₃ precipitate along its bed. This precipitate is characteristic of streams in this region as the water originates from perched limestone cliffs draining the highest mountain on Guam, Mt. Lamlam (Frank Camacho, UOG, pers. comm.). Nine species were collected here, despite the lack of substrate at this station.

Ylig River: The Ylig River was sampled near the village of Yona, and is a larger river for the island of Guam. The river was sampled in its lower reaches at a large metal weir structure that formed a 1 m cascade and diversion pool. Sampling was difficult here due to large deep pools, and only the weir formed a riffle provided suitable habitat for sampling, with the result of only 4 species being collected.

Agana Springs: Located near Sinajana Town, Agana Springs are located on the south side of Agana Swamp at the base of a limestone ridge. The springs have aging retaining walls that line about 50% of the perimeter, and this was from a low dam as the springs were once a municipal water pumping station (Scott 1993). In the 1970's the small area around Agana Springs was declared a conservation preserve by the Guam Department of Parks and Recreation (Scott 1993) but this was not apparent during our field sampling. Water in the springs was clear, and maximum water depth ranged from 2-3 m. Apple snails (*Pomacea canaliculata*) were common at Agana Springs. Sampling conditions were good here, with 9 species collected within the springs and along the vegetation and shoreline area.

Agana River: This sample site was behind the Bank of Guam Parking lot, and is the channelized section of the river draining Agana Swamp that flows for 800 m from the Agana Swamp outlet into Agana Bay (Scott 1993). This urbanized section of stream was totally fresh but appeared tidally influenced. The bank substrate was a mixture of sand/mud and some reef rubble, and four species of aquatic flies and one widespread dragonfly species, *Tramea transmarina* being found here.

Masso Stream: This site was near the village of Piti, and the stream substrate was firm with some rocky areas containing large cobble to finer gravels, with the stream being quite turbid. No aquatic insects were found during

kick samples, and two species of indigenous Heteroptera were collected here along with the native dragonfly *Orthetrum sabina*.

Lost Pond: This limestone sinkhole at about 30 m elevation was accessed by hiking from Tanguisson Beach to near Hilaan Point, and is a large pond formed at the base of steep limestone cliffs. Lost Pond is a favorite day hike area for residents, and was also a hotspot for native dragonflies with 6 species being observed here. Heteroptera found here included the large water strider *Limnogonus fossarium skusei* and the diminutive veliid *Microvelia diluta*, for a total of 8 species. Water quality at Lost Pond appeared good, with clear, deep water surrounding a jagged karst sinkhole.

Fensol River: This area was briefly sampled for 45 minutes on 17 March 2010 and was upstream of Fintaso River. Fensol River flows through an open and regularly burned savannah grassland with little riparian vegetation. The reach of river briefly sampled at this site had a series of spectacular falls at least 20 m high incised in basalt, resulting in good cascade habitat for aquatic insects. The case bearing pyralid moth *Eoophyla* sp. was common here in the fast water cascade habitats. Eleven total taxa were collected around the Fensol River cascades during this short visit, and this accounted was the second most species-rich river examined on Guam during this study. Yellow pan traps set along the margins of the waterfall habitat failed to collect any insects during 45 minutes of sampling.

Fena Reservoir: Built by the Navy in 1951 Fena Reservoir is the largest body of freshwater on Guam and Micronesia. The Maulap, Almagosa, Sadog, Gaso and Imong Rivers feed the 81 ha reservoir, which can have depths up to 20 m in the wet season but can drop to half that level during the dry season (Scott 1993). Numerous species of fish such as tilapia (*Oreochromis mossambicus*), tucanare (*Cichla ocellaris*), and others have been introduced into the reservoir in the past (Scott 1993), however, the impacts of these introductions on native aquatic insects and other invertebrates is unknown. Sampling consisted of visual observations of dragonflies and sweeping the shoreline and dip netting for aquatic insects. A total of 6 widespread indigenous lentic species were collected along the shoreline of the reservoir. Yellow pan traps placed along the reservoir shoreline overnight failed to collect any shoreflies.

Lost River: “Lost River” as it is locally known is a short section of stream below the Fena Reservoir spillway, and is a short (ca. 200 m) tributary to the river created by the reservoir spillway. Sampling occurred above and below a bridge crossing, and around a small weir upstream of the bridge. Stream habitat consisted mainly of slow, 1-2 m deep stream pools and little to no riffle habitat, with consequently only 4 species of aquatic insects collected here.

Maulap River: This section was upstream of Fena Reservoir and in the Naval Magazine near the site Navy personnel call the ‘Detention Pit’ by bridge #737. The river ranged from 20–30 cm to 2 m deep and 1–3 m wide. Habitat consisted of a relatively even mix of runs, pool, and small riffles. Flowing through a canopy of mixed native forest of *Pandanus*, coconut and other species, Maulap River was one of the highest quality stream habitats sampled during the current study with 13 species of aquatic insect taxa collected during only 1.5 hours of sampling. Saldids were not collected at this site, but will likely be found here with additional effort.

Results–Palau, Babeldaob Island

Taro Fields around village of Imeong: Low elevation wetland taro fields were briefly sampled with the corresponding mainly lentic or stillwater aquatic taxa collected. Six common indigenous species of Odonata and Heteroptera were found in and around the taro wetlands here.

River near Melekeok Capitol: A small, lowland river bisecting the Compact Road was sampled here, with 5 native taxa collected. Of interest was the first collection of a potentially new species of whirlygig beetle (Al Samuelson, Bishop Museum, pers. comm.), that was found upstream of the Compact Highway bridge, above the influence of the predatory native *Kuhlia rupestris* in shallow spring water. The whirlygig beetle could be undescribed as it keys most closely to *Heterandrus ochs* from Bougainville, and Solomon Islands, and was tentatively identified as (*Dineutus* (*Spinodineutes*) sp. nr. *heterandrus*). The “spine” at the elytral epipleural angle is merely a bump, barely dentate in extreme examples, and further research is needed to ascertain whether this is a new species. The stream around the bridge appeared muddy and silty resulting from disturbance from the highway construction. Upstream of the bridge the stream emerges from a series of springs in a dense *Pandanus* grove, and below the Compact Highway the stream quickly becomes too deep to wade.

Ngerchluuk Village: A small stream that served as a water supply for the village was sampled here, the stream was accessed by hiking upstream through wetland taro fields to the stream source. The concrete diversion was about 3 m tall, and the stream flowed about 200 m above this diversion through undisturbed native forest to where the small (< 0.5–1 m wide) stream emerged as a series of springs. Seven native species were collected above and below the diversion.

Ngatpang Waterfall: This waterfall was formerly known as Tabecheding Waterfalls, and encompasses a large stream and 15 m high waterfall with the watershed eventually draining into Karamadoo Bay. The stream around the waterfall was completely devoid of any rock substrate, and flowed through an incised bedrock channel. In a pattern similar in other regions of Pacific (Polhemus *et al.* 2004), the Palau endemic whirlygig beetle (*Dineutus* (*Spinodineutes*) sp. nr. *heterandrus*) was found upstream of Ngatpang Waterfalls, above the reach of the *Kuhlia rupestris* and other large predatory fish. The endemic damselfly *Teinobasis palauensis* was common in side pools above the waterfall. A total 10 species were collected during the short visit here making this the second most species rich site sampled on Palau during this study. An interesting finding of this station was the dominance of the aquatic muscid fly *Limnophora carolina* around the splash zone of the waterfalls, a habitat usually dominated by ephydrid and canacid flies in Pacific island areas (Englund 2003, Englund *et al.* 2003, 2007). Ngatpang (Falls, presumably?) was one of the type localities for *Limnophora carolina* (Synder 1965).

The waterfall area was also near a large camp of immigrant workers constructing the Compact Road making this river a prime site for potential aquatic species introductions (Chipper Tellei, pers. comm.), although no invasive aquatic invertebrates were observed during sampling.

Ngardok Lake: At 3.4 ha in size, Ngardok Lake is the largest natural freshwater lake in Micronesia (Pratt and Etpison 2008), and receives input from rivers arising in Melekeok and Ngchesar States. The lake has recently been made into a park, with facilities being built for ecotourism during our visit. Because of accessibility issues due to thick swamp vegetation around the lake shore, and a large population of crocodiles seasonally inhabiting the lake, sampling for aquatic taxa was limited to the stream outflow area and one ecotourist dock. Despite these problems, seven species of aquatic insects were collected or observed at the lake, mostly the highly mobile and widespread Odonata and Heteroptera.

Ngerimel (Airai or Koror) Reservoir: This reservoir is called Airai Reservoir in Scott (1993), and Koror Reservoir in Pratt and Etpison (2008). Ngerimel Reservoir is the main water storage reservoir for Airai State and the entire Koror State, and lies in an watershed that has considerable disturbance from farming, development, oil spills, and lumber cutting (Scott 1993). The reservoir shoreline was sampled for approximately 20 minutes, with 5 species of aquatic Heteroptera and Odonata collected. Ngerimel River upstream of the reservoir was not sampled.

Ngerikiil Pump Station: Located on the Ngerikiil River, only 10 minutes was spent collecting here, but in that brief time period 8 species of aquatic insects were collected. Taxa were collected around the outflow of the pump station, and along the shoreline around the pump station. A zodiac rubber raft tied up to the pump station aided in the collection of insects along the riparian zone of the Ngerikiil River during this brief sampling period.

Diongradid River: This site was located approximately 3 km downstream of Ngardmau Falls, and apparently the river changes name further upstream to Ngertebechel River. Only two species of aquatic insects were collected here, mainly due to this area being favorable crocodile habitat, with one crocodile accidentally observed within 0.5 m. More sampling efforts further upstream in this watershed on the Ngertebechel River, and above crocodile range resulted in more favorable sampling conditions and increased insect collections.

Ngermeskang River: We arrived at this station too late for effective sampling at the Palau Community College campus taro fields and river. The river by the Hycos Gaging Station was too dark to observe or sample aquatic insects, and the two species collected at this site were from the wetland taro fields adjacent to the river, observed just prior to sunset. Further sampling here would undoubtedly yield more species.

Ngertebechel River: This site was accessed from the tourist park for Ngardmau Waterfalls along the main Compact Road, and was a short hike from the tourist pavilion to the Ngertebechel River. The access down the tourist trail first encounters the stream flowing through a long series of bedrock chutes and deep pools. Hiking downstream leads to a larger river and then Ngardmau Waterfalls; habitat upstream leads to mostly forested stream flowing through primary undisturbed forest. Most sampling efforts were focused on the main stream and several small tributaries upstream from the main tourist access trail, and aquatic biota were assessed upstream to the remnants of an old World War II Japanese bauxite mine concrete dam, that was perhaps 0.5 m above the stream bed. Ngertebechel River gains flow quickly from small side tributaries downstream from the tourist access trail, and stream habitat here consisted of

forested long runs interspersed with the occasional deep pool and long bedrock chute habitats. *Kuhlia rupestris* was eventually filtered out of the stream by a series of large and impassable falls and chutes, and above this area the native whirlygig beetle was fairly common in the stream. Ngardmau Falls was briefly sampled, but high concentrations of tourists made sampling here difficult. Benthic samples were not taken at this site here due to time limitations, but likely would have lead to the collection of more species.

The Palau endemic stream damselfly *Pseudagrion palauense* was collected at Ngertebechel River around riffle/chute habitat in shaded areas, but was uncommon. This striking and brilliantly blue colored damselfly species appears to have a narrow habitat preference, and this was the only locality during this present study where it was observed or collected. The other rare endemic damselfly of international interest observed here was *Drepanosticta palauense*, a species not recorded as being collected in the literature since 1957 (IUCN 2011). This relatively large damselfly species is difficult to capture because of its drab coloration and habitat preference for small, heavily shaded streamlets. *Teinobasis palauensis*, the third endemic damselfly from Babeldaob was also collected along the river, and the mossy wet rock faces of the bedrock chutes and falls provided excellent habitat for the indigenous shorebug *Saldula paluana*.

Results–Palau, Malakal Island:

Japanese WWII Fuel Tanks: Despite its small size, several important and unique aquatic habitats were found on Malakal Island. Two large buried fuel tanks from WWII that were bombed and then filled with water provided a large amount of standing water habitat on this small island. The tanks are fringed with vegetation and filled with aquatic plants such as honohono grass (*Commelina diffusa*) that provide ideal aquatic insect habitat. An unfortunate slip by RAE into the lower tank with nearly one full leg revealed the water still maintains a highly oily residue some 66 years after the fuel tanks original bombing. This oily water does not seem to impede aquatic insect life, however. During our brief visit 6 species of aquatic insects were collected, including a common bright blue and green *Ischnura* sp. undet. damselfly that does not key to any species found in Lieftinck (1962), or match with species in the Bishop Museum collection. Further research is needed to determine whether this damselfly is a new species.

Japanese WWII dry dock: This drydock along the coast is now filled with water and had a salinity level of 3.6 ppt at the surface. This drydock was formerly stocked with tilapia prior to its treatment with chlorine to eliminate the invasive fish. Despite the low salinity no aquatic insects were observed in or around the dry dock.

Malakal Quarry Pond: This small freshwater pond was created to rinse quarry stones, and was near the ocean. Eight species of aquatic insects were collected around the pond despite the water turbidity appearing to be high from recent rinsing of the quarry rocks. The same *Ischnura* sp. undet. damselfly collected at the bombed WWII fuel tanks were also found here, along other widespread indigenous lentic Odonata and Heteroptera.

Results–Palau, Koror Island

A small aquaculture facility on Koror Island was sampled, but had limited freshwater habitats consisting of a few puddles and ditches with 0.1 ppt salinity water. During our visit the ponds were drained so there was little standing water present. Nonetheless, 4 species of widespread Odonata and Heteroptera were observed here, with the giant water striders (*Limnometra pulchra*) concentrated into the few remaining freshwater puddles. No aquatic insects were observed in the tidally influenced water on the other side of the aquaculture embayment mud walls.



Pseudagrion palauense above, and the collection locality (below) on the Ngertebechel River.



Table 3. Aquatic insect taxa observed and collected during March 2010 Guam surveys.

	Tarzan River	Asmafines River	Ylig River	Agana Springs	Agana River (Bank of Guam parking lot)	Agana River at Swamp	Masso Stream	Lost Pond	Fensoi River	Fena Reservoir	Lost River	Maulap River
Taxon												
Ephemeroptera (Mayflies)												
Baetidae												
<i>Pseudocleon</i> sp. 1 undet.												X
Zygotera (Dragonflies)												
Aeshnidae												
<i>Anax guttatus</i>				X		X		X		X		
Corduliidae												
<i>Hemicordulia mindana</i>			X									
Libellulidae												
<i>Diplacodes bipunctata</i>	X	X						X	X			X
<i>Orthetrum sabina</i>				X		X	X	X	X	X		
<i>Pantala flavescens</i>								X		X		
<i>Rhyothemis phyllis</i>								X				
<i>Tholymis tillarga</i>			X	X					X			
<i>Tramea transmarina</i>	X		X	X	X	X		X	X	X		X
Anisoptera (Damselflies)												
Coenagrionidae												
<i>Agriocnemus</i> sp. undet.				X							X	
<i>Agriocnemus femina femina</i>											X	
<i>Ischnura aurora</i>												X
Heteroptera (True Bugs)												
Gerridae												
<i>Limnogonus hungerfordi</i>				X								
<i>Limnogonus fossarium skusei</i>								X		X		
<i>Limnogonus lundbladi</i>	X	X					X		X		X	X
Mesoveliidae												
<i>Mesovelia vittigera</i>		X										
Notonectidae												
<i>Anisops nasuta</i>									X			X
Saldidae												
<i>Saldula niveolambata</i>		X										
<i>Saldula paluana</i>							X		X			
Veliidae												
<i>Microvelia diluta</i>	X							X				X
<i>Microvelia mariannarum</i>		X									X	
Diptera (Flies)												
Ceratopogonidae												
<i>Atriochopogon</i> sp. 1 undet					X				X			X
Chironomidae												
Chironomid sp. 1 undet.									X			X
Dolichopodidae												
<i>Chrysotus</i> sp. 1 undet.		X		X								X
<i>Paraclius</i> sp. 1 undet.		X							X			
<i>Sympycnus</i> sp. 1 undet.	X											
<i>Sympycnus</i> sp. 2 undet.	X											
<i>Thinophilus</i> sp. 1 undet.		X										X

Table 3 (cont.). Aquatic insect taxa observed and collected during March 2010 Guam surveys.

	Tarzan River	Asmafines River	Ylig River	Agana Springs	Agana River (Bank of Guam parking lot)	Agana River at Swamp	Masso Stream	Lost Pond	Fensoi River	Fena Reservoir	Lost River	Maulap River
Ephydriidae												
<i>Attissa</i> sp. 1				X	X							
<i>Donaceus nigronotatus</i>				X								
Ephydriidae sp. 1					X					X		
Muscidae												
<i>Limnophora</i> sp.		X	X		X							
Trichoptera (Caddisflies)												
Trichoptera sp. 1												X
Lepidoptera (Aquatic Butterflies)												
Pyalidae												
<i>Eoophyla</i> sp. 1	X								X			X
Total Aquatic Insect Species	7	9	4	9	5	3	3	8	11	6	4	13



Ischnura sp. collected from a bombed out WWII Japanese fuel tank, Malakal Island, Palau

Table 4. Aquatic insect taxa observed and collected on Babeldaob Island during March 2010 Palau surveys.

	Imeong Village taro fields	Nr. Melekeok Capitol	Ngerchluuk Village	Ngatpang Waterfall	Ngardok Lake	Ngerimel Reservoir	Ngerikiil Pump Station	Diongradid River	Ngermeskang River ¹	Ngeretebechel River
Taxon										
Zygoptera (Dragonflies)										
Aeshnidae										
<i>Anax guttatus</i>						X				
Corduliidae										
<i>Hemicordulia lulico</i>		X			X					
Libellulidae										
<i>Diplacodes bipunctata</i>						X			X	
<i>Neurothemis terminata</i>	X		X	X						
<i>Orthetrum sabina</i>	X									
<i>Pantala flavescens</i>	X					X				
<i>Rhyothemis phyllis</i>					X					
<i>Tholymis tillarga</i>									X	
<i>Tramea transmarina</i>		X			X		X			
Anisoptera (Damsel flies)										
Coenagrionidae										
<i>Agriocnemis femina femina</i>	X						X	X		
<i>Drepanosticta palauensis</i>										X
<i>Ischnura</i> sp. 1 undet.					X	X				
<i>Pseudagrion palauense</i>										X
<i>Teinobasis palauensis</i>				X	X					X
Heteroptera (True Bugs)										
Corixidae										
<i>Micronecta</i> sp. 1 undet.	X									
Gerridae										
<i>Limnometra pulchra</i>	X	X	X	X	X		X	X		X
Notonectidae										
<i>Anisops nasuta</i>						X	X			
Saldidae										
<i>Saldula paluana</i>				X						X
Veliidae										
<i>Phoreticovelina notophora</i>		X	X	X	X		X			
Coleoptera (Beetles)										
Gyrinidae										
<i>Dineutus (Spinodineutes)</i> sp. nr. <i>heterandrus</i>		X		X						X
Diptera (Flies)										
Ceratopogonidae										
<i>Atriochopogon</i> sp. 1 undet.				X						X
Chironomidae										
Chironomid sp. undet. 1			X							X
Empididae										
Empidid sp. undet. 1										X
Dolichopodidae										
<i>Chaetogonopteron</i> nr. <i>tener</i>			X							
<i>Chrysotus</i> sp. undet. 1			X				X			X
Ephydriidae										
Ephydriidae sp. undet. 1			X	X						X

Table 4 (cont.). Aquatic insect taxa observed and collected on Babeldaob Island during March 2010 Palau surveys.

	Imeong Village taro fields	Nr. Melekeok Capitol	Ngerchluuk Village	Ngatpang Waterfall	Ngardok Lake	Ngerimel Reservoir	Ngerikilil Pump Station	Diongradid River	Ngermeskang River ¹	Ngertebechel River
Muscidae										
<i>Limnophora carolina</i>				X			X			X
Lepidoptera (Aquatic Butterflies)										
Pyralidae										
<i>Eoophyla</i> sp. 1				X						X
Total Aquatic Insect Species	6	5	7	10	7	5	7	2	2	13

¹Collected only for 10 minutes before dark, not a full sample



Ngardmau Falls on the Ngertebechel River, Babeldaob, Palau.

Table 5. Aquatic insect taxa observed and collected on Koror and Malakal Islands during March 2010 Palau surveys.

	Koror : aquaculture ponds	Malakal WW II Fuel tank #1	Malakal WW II Fuel tank #2	Malakal Japanese WW II drydock	Malakal Quarry Pond
Taxon					
Zygoptera (Dragonflies)					
Aeshnidae					
<i>Anax guttatus</i>	X	X	X		
Corduliidae					
<i>Hemicordulia mindana</i>					
Libellulidae					
<i>Diplacodes bipunctata</i>		X	X		X
<i>Neurothemis terminata</i>	X	X	X		X
<i>Orthetrum sabina</i>					
<i>Pantala flavescens</i>					X
<i>Rhyothemis phyllis</i>		X	X		
<i>Tholymis tillarga</i>					
<i>Tramea transmarina</i>					X
Anisoptera (Damselflies)					
Coenagrionidae					
<i>Agriocnemus femina femina</i>	X				X
<i>Teinobasis palauensis</i>					
<i>Ischnura</i> sp. 1 undet.		X	X		X
Heteroptera (True Bugs)					
Corixidae					
<i>Micronecta</i> sp. 1					
Gerridae					
<i>Limnometra pulchra</i>	X				X
Notonectidae					
<i>Anisops nasuta</i>					
Saldidae					
<i>Saldula paluana</i>					
Veliidae					
<i>Phoreticovelia notophora</i>		X	X		X
Diptera (Flies)					
Ceratopogonidae					
<i>Atriochopogon</i> sp. 1					
Chironomidae					
Species 1					
Dolichopodidae					
<i>Chaetogonopteron</i> nr. <i>tener</i>					
<i>Chrysotus</i> sp. 1					
<i>Paraclius</i> sp. 1					
Ephydriidae					
Ephydriidae Species 1					
Muscidae					
<i>Limnophora</i> sp.					
Total Aquatic Insect Species	4	6	6	0 ¹	8

¹Mainly marine habitat

Discussion and Conservation Implications

During the course of this study, and after a thorough review of the literature (see References) no obvious invasive aquatic invertebrates were observed in the streams sampled on Guam and Palau. All taxa identified to the species level were ascertained to be native species, and at least three species of aquatic Heteroptera on Guam were island endemics (*Limnogonus lundbladi*, *Microvelia mariannarum*, and *Saldula guamensis*). It was surprising that an island as large as Guam does not have any endemic damselflies, especially when the smaller nearby island of Rota has one critically rare endemic damselfly, *Ischnura luta* (Polhemus *et al.* 2000), and the regular pattern in the tropical insular Pacific region is one of zygopteran speciation within islands containing permanent lotic habitats. For Palau, a conservative estimate of finding at least 4 island endemics was made, including the three endemic damselflies (*Drepanosticta palauensis*, *Pseudagrion palauense*, and *Teinobasis palauensis*) and one gyrenid (whirlygig) beetle. The identity of an *Ischnura* found in lentic habitats on Palau remains a mystery, but as it is not a widespread species such as *Ischnura aurora* or *Agriocnemis femina femina*, it is likely that it at least is indigenous if not possibly endemic to Palau.

The pyralid moths collected on both Guam and Palau are most likely island endemics as these lentic aquatic moths speciate quite readily (Mey 2009), and although species identification of these moths requires adults (collected by light trapping along the stream at night), the larvae found on Guam and Palau appeared different enough to warrant them as two distinct species. Several species of long-legged flies in the genera *Sympycnus* and *Chrysotus* were collected both on Guam and Babeldaob, and are at least indigenous; further taxonomic identification is needed to ascertain if they are new species and/or island endemics.

Although time and effort was limited at each sampling station, some general observations can be made from the aquatic insect findings at each site. As similar to streams in the Hawaiian archipelago (Englund *et al.* 2007), the most species rich streams flowed in areas with the least disturbed watersheds. With a wide variety of habitats, and flowing through a forested stream, the Maulap River had a Guam high of 13 aquatic insect species collected there. The Maulap River flows through a forested and secure watershed inside the Naval Magazine. Some low-level disturbance from water buffalo and feral pigs appears to already occur with the Naval Magazine, but not at high enough levels to disturb the native aquatic insect biota. On Babeldaob, the waterfall sites of Ngatpang and Ngardmau Falls (Ngtertebechel River) were found to have the greatest biodiversity of aquatic insects. Ngtertebechel River had a wide variety of small wooded tributaries, open bedrock chutes, riffles, cascades, runs, waterfalls, resulting in 13 species being found there with at least 4 probable Babeldaob island endemics.

The lowland biota found on both Guam and Palau, in taro fields, wetland areas, and disturbed sections of lowland streams, had a similar suite of aquatic insect taxa, with widespread but indigenous species of aquatic Heteroptera and Odonata being predominant but less species rich than the upland sites. Streams in the Hawaiian and French Polynesian archipelagos have the greatest biodiversity of aquatic invertebrates around the splash-zone areas of riffles and cascades (Englund *et al.* 2003, 2007). Splash zones are numerically dominated by taxa in the marine shore fly families such as Ephydriidae and Canacidae that have invaded secondarily from marine splash-zone habitats

(Howarth and Polhemus 1991), while in French Polynesia black flies (Simuliidae) are also predominant (Craig 2003) along with shoreflies in freshwater splash zone areas. On Babeldaob, the shore fly families were much less common around cascades and riffles than in other areas of the Pacific, and instead the splash zone was dominated by the aquatic muscid *Limnophora carolina*. Although Guam and Babeldaob each have an endemic simuliid, none were collected during the present survey due to time constraints, and the larval habitat preference for the Palau species is unknown as they were described from adults only (Stone 1964).

Threats to Freshwater Biota in Guam and the Republic of Palau

The main water quality perturbations impacting tropical Pacific insular freshwater biota are increased silt and sediment loads from land disturbance, chemical pollutants, and water diversions. Species found in lotic or flowing water habitats on these islands are more vulnerable to disturbances than those more adaptable species found in lentic habitats. Those species found in still waters by the nature of the habitat are more tolerant of lower oxygen and higher turbidity levels than their counterparts found in riffle/cascade areas of streams. Invasive species are also a primary threat to these small islands through direct predation, competition for resources, and habitat modifications. As invasive aquatic species are normally released in the lowlands adjacent to human population centers, lowland species will bear the brunt of invasive introductions as has been the case in Hawaii. In the Hawaiian archipelago, virtually all species of native low elevation damselflies have been extirpated from their original wetland, pond, and low-elevation stream habitats (Englund 1999), and only remain in the few isolated areas lacking invasive fish species (Englund and Arakaki 2003).

The majority of endemism found during the present study was in relatively undisturbed forested watersheds that appeared to have little to no water diversions. Riffles and cascade areas were found to be particularly species rich, especially those reaches containing some forest canopy. Streams above Fena Reservoir in the Naval Magazine such as the diverse Maulap River are currently strictly protected from development and human impacts, but uncontrolled feral animals such as water buffalo and pigs could disturb the watershed to such an extent to impede water quality and eventually impact the aquatic biota. Although feral animals did not appear to be a problem on Babeldaob, logging, increased agricultural development and water withdrawals are all potential future threats to maintaining a highly diverse and unique freshwater aquatic ecosystem on Palau.

Rare and Endangered Species

The island of Guam has no Federally listed or candidate freshwater organisms, or freshwater organisms on the IUCN Red List. The Republic of Palau has one listed rare aquatic insect species on the IUCN Red List (IUCN 2011), the endemic *Drepanosticta palauensis* damselfly. This species was found during the present study in very low numbers at Ngertebechel River, Babeldaob. According to the IUCN website, this damselfly is known only from 6 type specimens collected in 1938, 1947, and 1958, and had not been collected since. During our field surveys only one individual *D. palauensis* was observed but not collected at Ngertebechel River in a small, densely wooded side tributary. This species is of great biogeographic interest as the Palau endemic is the easternmost range for the *Drepanosticta* genus, with its nearest relatives found in New Guinea (Lieftinck 1962). Collections of *D. palauensis*

are extremely difficult because of its preference for small, heavily shaded streamlets where visibility is often marginal to catch or observe this drab brown-colored damselfly. Deforestation and stream flow alterations would be the greatest threat to this species.

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Sampling Tarzan Falls, Guam, for aquatic insects.

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