A Preliminary Survey of Samoan Freshwater Macro-faunal Biodiversity

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Cover photograph: *Stiphodon n.sp*. A species new to science and a new Samoan endemic freshwater fish discovered during this survey. Photo by: Aaron P. Jenkins.

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Executive summary

Prior to this survey, the island nation of Samoa had not been systematically surveyed for freshwater biodiversity despite the clear role of freshwater and the associated biodiversity in providing essential ecosystem services. This report is beginning to address this gap in knowledge in Samoa by presenting the preliminary results from the first of an anticipated series of freshwater surveys and in-field trainings for Samoa with the target organisms being fishes and macro-crustaceans. A two week initial survey and training in the last fortnight of July (2008) was conducted as a collaborative effort led by Wetlands International-Oceania and the Paris National Museum of Natural History and supported by a range of agencies. Materials developed prior to the training and surveys include catchment maps with inferred catchment integrity, a pictorial training and awareness "flashcard" book for common fresh and estuarine fishes, identification keys for crustaceans and fishes, two lectures and a CD of compiled material relevant to the identification of taxa and management of freshwater systems.

Fifteen x 20 meter sections of Samoan freshwater bodies were sampled for macro- fauna. This dry season sampling phase was concentrated on the island of Upolu and included six river systems and two lakes including the Ramsar Site, Lake Lanato'o. The sampling in Savaii was restricted to a single spring and one river. This survey resulted in 30 species of fishes (in 21 genera and 12 families) and 17 species of macro-crustaceans (in 5 genera and 3 families) being collected or observed from Samoan freshwaters. Of these, 3 species of fishes and 8 species of crustaceans are new records for Samoa. Our results indicate that Samoan freshwaters contain at very least 3 and likely 5 endemic species of fishes with one and potentially three new taxa to science among them. One potential new species of crustacean is herein also considered a probable endemic. When cited freshwater and common estuarine fishes are aggregated there are now approximately 86 species of fishes known. If additional cited crustaceans are included there are now 22 species known.

During this survey we observed three species of introduced invasive fishes, the Mozambique Tilapia, *Oreochromis mossambicus*, the goldfish, *Carassius auratus*, and the Mexican livebearer, *Poecilia mexicana*. A further three species of livebearer (Poeciliidae) are also cited to occur in Samoa but were not seen during this survey. Conclusions and recommendations from the survey include: 1) strong recommendation that the Tagaila River catchment and forest system, adjacent to Uafato Village, be included in the Samoan Protected Areas system, 2) freshwater fauna still incompletely known and further surveys needed particularly targeting populations of endemics and potential endemics and Savaii during the rainy season, 3) priority given to mapping and prevention of translocation/ introduction of highly detrimental introduced invasive species, 4) at least 95% of fauna in freshwater is intimately connected to the marine systems as part of their life history, arguing strongly for an integration of terrestrial (catchment –scale) and marine management frameworks, 5) many rivers in Samoa appear in moderate to poor condition in terms of ecological functioning, likely due to long term stressors of pastoral grazing and plantation agriculture, past logging, human settlement waste and minimal river management capacity. Catchment level-management and rehabilitation should be undertaken to restore some of the ecosystem function of these rivers and in turn bring benefit to adjacent nearshore marine areas. Some potential options for assisting in catchment rehabilitation are suggested.

Contents

Index of Tables, Figures & Appendices

Background

Freshwater resources are being threatened globally by anthropogenic influences. The island nations of the Pacific Islands region are particularly vulnerable due to their limited freshwater resources, burgeoning populations and lack of in-country capacity for management. While threats to terrestrial animals, such as birds and mammals, and to dwindling habitats, such as rainforests and coral reefs, have attracted much conservation attention, unfortunately freshwater biodiversity is generally overlooked in Pacific conservation priority setting. Available data suggest that between 20-35 percent of all freshwater fishes (for example) are vulnerable, endangered or presumed extinct (IUCN Redlist). Recent studies of the freshwater biodiversity of Pacific high islands such as New Caledonia, Vanuatu, Solomon Islands and Fiji (e.g. Keith et. al. 2004 a,b; Jenkins and Boseto, 2005; Jenkins, 2007, 2008) reveal numerous previously undescribed taxa and are building a picture of high island-level endemism in freshwater taxa, similar to that described in birds and plants. This work has recently resulted in several of these Pacific island nations being recognized as global priorities for freshwater conservation (Abell et. al. 2008). Prior to this survey, the island nation of Samoa had not been systematically surveyed for freshwater biodiversity despite the clear role of freshwater and the associated biodiversity in providing essential ecosystem services.

This survey has begun to address this gap in knowledge for freshwater biodiversity in Samoa by presenting the preliminary results from the first of an anticipated series of freshwater surveys and in-field trainings for Samoan government officials, University of the South Pacific students and other local actors responsible for the management of freshwater systems. A two week initial survey and training in the last fortnight of July (2008) was conducted as a collaborative effort led by Wetlands International-Oceania and the Paris National Museum of Natural History and supported by a range of actors including; Samoan Ministry of Natural Resources Environment and Meteorology (MNRE), Conservation International (CI), Japan International Cooperation Agency (JICA), the University of the South Pacific (USP) and International Union for Conservation of Nature (IUCN). The surveys were carried out with the financial support of JICA and the United Nations Development Program (UNDP) through the Samoan Protected Area Program of Work (PoWPA). Target organisms surveyed were fishes and macro-crustaceans. Representative samples will be deposited in Samoa, University of the South Pacific and the Paris National Museum of Natural History. It is envisioned that the results of this work will assist the country in addressing an important component of the protected area gap analysis being undertaken by

the Samoan Ministry of Natural Resources and Environment (MNRE) by highlighting key biodiversity areas for freshwater fauna, highlighting important endemic fauna and raising the survey skill levels of field staff. It will also contribute to the longer term goal of producing a Pacific-wide regional assessment of the conservation status of freshwater biodiversity. It should also be recognized that a comprehensive inventory of the freshwaters of Samoa will need at least one follow-up phase of work at a later date that can document seasonal changes in faunal structure and water quality characteristics as well as unsurveyed areas.

Methods :

Pre-survey and capacity building actions

In early April 2008 a series of meetings were held in Apia, Samoa with the MNRE and other support agencies to determine the extent of their needs with regard to survey and training in freshwater habitats. Based on these initial discussions it was determined that for local agency purposes they needed the two lead agencies to provide *1)* systematic survey of faunal and water quality characteristics of key freshwater sites on Upolu and Savaii Islands *2)* in-field training of MNRE field staff and USP students in freshwater survey techniques and basic identification and curation of freshwater fauna *3)* taxonomic identification and scientific description of collected fauna *4)* identification of key freshwater biodiversity areas for inclusion in Samoan PA network *5)* compilation of an up-to-date freshwater biodiversity checklist for Samoa and *6)* provide material for further training and awareness of Samoan freshwater biodiversity.

In the preparation phase, prior to survey and training, a variety of compilation and mapping exercises were undertaken to assist with smooth delivery. Firstly, a series of maps were created by MNRE and CI that showed catchment boundaries, roads, rivers and habitat condition based on land coverage (Appendix 2). These were used to help in the selection of survey sites to get both a representative spread of sites and also target sites likely to yield undiscovered taxa (ie. remote, well forested catchments). Then, in order to leave a product that would assist local actors in field identification and training, we produced an initial version of a pictorial compendium for training and awareness entitled "*Freshwater and Common Estuarine Fishes of the Samoan Archipelago*." This two volume book is designed to be used as laminated "flash" cards to assist training and in-field identification (Appendix 3). Hard copies were provided to MNRE and JICA as well as electronic versions. This version 1 needs to be updated with the resultant new discoveries from this survey. Identification keys were produced for macro-crustaceans (Appendix 4) and provided for most groups of fishes as well as copies of Dr. Alison

Haynes' field guide to "Freshwater Snails of the Tropical Pacific Islands." Relevant literature was also compiled that is both relevant to Samoan freshwater fishes, freshwater crustaceans, freshwater survey techniques and monitoring in the Pacific Island context and provided on a CD. Also provided on the CD are digital copies of freshwater awareness posters created for American Samoa but also relevant to Samoa. During the period of the survey, lectures were given by Paris Museum staff (Philippe Kieth) on their work on freshwater faunas of the Pacific and also by Wetlands International-Oceania (Aaron Jenkins) on *"Freshwater fishes of Samoa: introduction to identification, taxonomy and applications for wetlands management."* These presentations have been provided to MNRE and JICA and can be further used for training and awareness purposes. Members of the survey team included staff from key government agencies and NGO's who were given a hands-on opportunity to familiarize themselves with participation in survey and preservation techniques and in-field identification of freshwater fauna (Appendix 5). This training aspect of the work needs to be repeated with those that are particularly keen and would like to follow on with more advanced skill development.

Sampling

Fifteen x 20 meter sections of Samoan freshwater bodies were sampled for macro- fauna. Habitat characteristics of each site are listed in Tables 3 & 4. A variety of techniques were used to collect fauna from the river, stream or lake depending upon the characteristics of the site. In general, streams and rivers were sampled from the downstream section of the site working upstream and were sampled for approximately one hour per site. The lakes were first sampled along the edge and then sampled mid-lake by means of an inflatable dinghy and using a gill net. The apparatus and techniques used were as follows:

Electro-fisher (Deka 3000, 600V, 10A) was a primary sampling tool in river and stream habitats and on the edges of the lakes. Wearing rubber waders and never venturing deeper than 1.5 meters, the anode (on a meter long rod) was discharged while two people (also wearing rubber waders) held a med-sized, 1 mm^2 mesh net across the stream several meters upstream from the anode. When the anode reached the net, it was raised and fauna within the net were placed in a water-filled plastic bucket.

Gill net (25m x 1.8m, 1 inch mesh) was only used in the lake sampling sites and was deployed with the floaters along the top edge and the lead weights along the bottom in the middle of the lake. Soak time was approximately one hour before the net was removed.

Large seine net (2 m x 7 m, 0.4 cm^2 mesh) This net was pulled in a rough circle, with the bottom edge down as close as possible to the substrate and forward of the top floating edge of the net. This technique was executed before anyone could set foot in the water body to minimize the number of fleeing fishes. This was generally used only in minor tributaries and slow moving or still waters.

Medium pole seine net (1.2 m x 0.8 m, 1mm^2 mesh) This was used in a variety of ways. Firstly, it was held firmly downstream as people kick and dislodge rubble upstream. This was a useful method for collecting small, bottom dwelling fish. On vegetated banks the net was thrust under submerged vegetation and the vegetation was disturbed on the bank dislodging fishes into the net. Also, this net was used to "scoop" (bottom edge held forward, run along substrate for a few seconds then lifted) from any accessible shallow body of water. This net was particularly useful for narrow streams and the net most commonly used in conjunction with the electro-fisher.

Small hand nets (15cm x 10cm + 10 cm x 8 cm , 1mm^2 mesh) These were used to "scoop" the underside of overhanging rocks and in small crevices in the smaller streams and also to collect fauna when in still water bodies.

Observations (mask and snorkel) In areas that were shallow enough and the water was clear enough, a mask and snorkel were used to observe the benthos and fauna that were not being caught by the nets.

Preservation of specimens

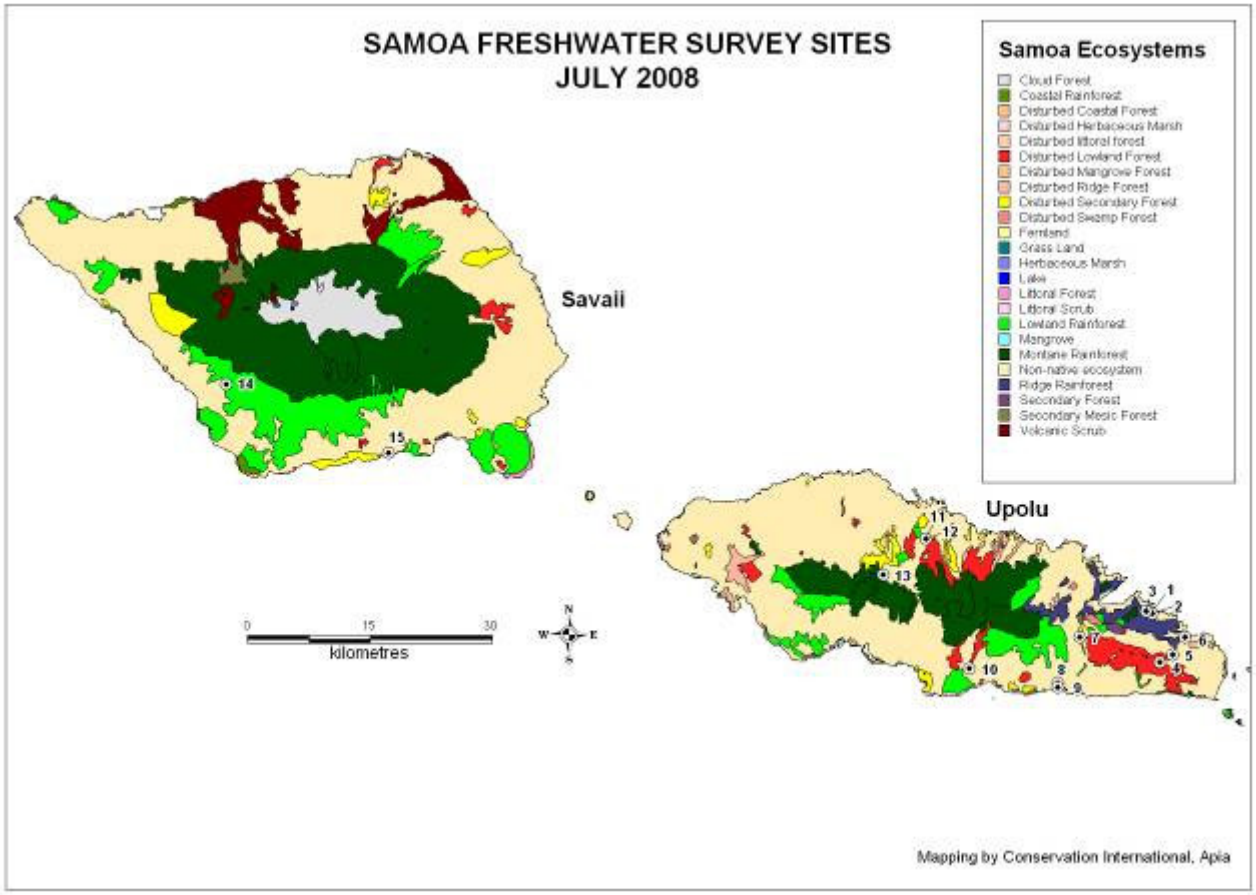
Voucher specimens were collected, fixed in a 10% formalin solution and transferred to 70% ethanol solution after 5 days of fixation. Some specimens were stored directly in 80% ethanol for DNA analysis. As color loss is rapid, accurate preservation of color patterns was recorded by photography. Fresh specimens were placed in a portable aquarium with some local aquatic vegetation and benthos to enhance the photography. Voucher specimens were deposited at the University of the South Pacific , Suva collections and Paris Museum of Natural History. Representative samples are being prepared for deposition at the appropriate venue in Samoa which is currently nominally the MNRE office.

Site data

At each sampling site a GPS position and altitude were taken using a Garmin GPS *map* 76Cx. Water quality characteristics were taken before entering the water to minimize disturbance. Temperature, pH, conductivity and dissolved oxygen were taken using a hand-held YSI multi-meter. Salinity was taken

using a refractometer and turbidity was taken using a turbidity tube calibrated to Nepthalometric Turbidity Units. Brief notes were also taken on riparian vegetation and instream condition with particular emphasis on substrate type, flow type, instream cover, aquatic vegetation, riparian vegetation, land use type and major disturbance type. This dry season sampling phase was concentrated on the island of Upolu (Sites 1 – 13) and included six river systems and two lakes including the Ramsar Site (Lake Lanato'o, site 13). The sampling in Savaii was restricted to a spring (Ogogo Spring, site 14) and one river (Pulei'a River, Site 15) due to time constraints, land owner disputes and the general lack of flowing water in Savaii during the survey. See Table 3 for details on habitat characteristics of the sampling sites.

Figure 1. Map of freshwater survey sites in Samoa in July 2008. Sites are numbered in black and are in chronological order.



Results & Discussion

Table 1. Fishes collected, observed or cited from Samoan freshwater sampling sites. ε = endemic to Samoan archipelago; β = probable endemic; ϕ = introduced invasive; α = new record for Samoa; red x = collected or observed during this survey; species not collected or observed but in the table are cited in Wass, 1984.

Family	Genus	Species	1/2	3	4	5	6	7	8	9	10	11	12	13	14	15
Angullidae	*Anguilla*	*australis*														
	Anguilla	*marmorata*	x	x		x	x		x	x		x	x			x
	Anguilla	*obscura*				x				x					x	
	Anguilla	*megastoma*										x				
Ophichthidae	*Lamnostoma*	*polyophthalma*														
Moringuidae	*Moringua*	*microchir* $^{\alpha}$							x							
Clupeidae	*Spratelloides*	*delicatulus*								x						
Cyprinidae $^{\varphi}$	*Carassius*	*auratus*												x		
Poeciliidae $^{\varphi}$	*Gambusia*	*affinis*														
	Poecilia	*mexicana*						x	x	x						

	Poecilia	*reticulata*														
	Limia	*vittata*														
Sygnathidae	*Microphis*	*retzii*							x	x						
	Microphis	*brachyurus*							x	x						
Ambassidae	*Ambassis*	*miops*					x			x						
	Ambassis	*vaivasensis*														
Kuhliidae	*Kuhlia*	*rupestris*	x	x			x		x	x						
	Kuhlia	*salelea* ε	x	x			x		x	x						x
	Kuhlia	*mugil*														
Cichlidae φ	*Oreochromis*	*mossambicus*						x						x		
Kraemeriidae	*Kraemeria*	*samoensis*														
Eleotridae	*Eleotris*	*fusca*	x	x			x		x	x	x					x
	Eleotris	*melanosoma*														
	Hypseleotris	*cyprinoides*							x	x						
	Bostrychus	*sinensis*														

	Ophiocara	*porocephala*							x							
Gobiidae	*Awaous*	*ocellaris*								x						
	Butis	*butis*					x									
	Mugilogobius	*notospilus*														
	Sicyopterus	*lagocephalus*	x	x			x		x	x	x	x	x			x
	Sicyopterus	*pugnans*	x	x							x					x
	Stenogobius	*genivittatus*							x	x						
	Stiphodon	*elegans*	x	x							x					
	Stiphodon	*hydoreibatus* ε	x													
	Stiphodon	*sp* ε α	x													
	Sicyopus	*sp* β	x													
	Yongeichthys	*nebulosus*														
	Redigobius	*bikolanus*														
	Psammogobius	*biocellatus*					x			x						

	Periopthalmus	*argentilineatus*								x						
	Bathygobius	*fuscus*														
	Schismatogobius	*sp* $^{\beta\ \alpha}$	x													
Lutjanidae	*Lutjanus*	*argentimaculatus*					x									
	Lutjanus	*lunulatus*					x									

Table 2. Macro-crustaceans collected, observed or cited from Samoan freshwater sampling sites. ε = endemic to Samoan archipelago; β = probable endemic; ϕ = introduced invasive; α = new record for Samoa; red x = collected or observed during this survey; species not collected or observed but in the table are cited from PMNH literature records.

Family	Genus	Species	1/2	3	4	5	6	7	8	9	10	11	12	13	14	15
Atyidae	*Atyoida*	*pilipes*	x	x		x		x			x	x	x			
	Atyopsis	*spinipes*	x					x				x	x			
	Caridina	*gueryi* $^{\alpha}$							x	x						
	Caridina	*serratirostris*					x		x	x						

	Caridina	*typus* α						x								
	Caridina	*weberi*	x					x				x	x			
	Caridina	*longirostris*														
Palaemonidae	*Macrobrachium*	*aemulum* α										x	x			
	Macrobrachium	*australe*	x						x							
	Macrobrachim	*bariense* α							x							
	Macrobrachium	*gracilirostre*	x				x		x	x						
	Macrobrachium	*grandimanus* α	x													
	Macrobrachium	*lar*	x	x		x	x	x	x	x	x	x	x			x
	Macrobrachium	*latimanus*						x				x	x			
	Macrobrachium	*microps*														
	Macrobrachium	*placidulum* α	x						x	x						
	Macrobrachium	*lepidactyloides*														
	Macrobrachium	*sp* α							x							

	Palaemon	*debilis*														
Grapsidae	*Ptychognathus*	*riedelii*							x							
	Ptychognathus	*pusillus*														
	Utica	*gracilipes* $^{\alpha}$							x							

Table 3. Site location details and water quality characteristics of Samoan freshwater sampling sites.

Site	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Date	7/23/08	7/23/08	7/23/08	7/24/08	7/24/08	7/24/08	7/24/08	7/24/08	7/25/08	7/26/08	7/26/08	7/27/08	7/28/08	7/29/08	7/30/08
Name	Tagaila River	Tagaila River	Namoi River	Lago Lake	Asi River	Tiaveatai River	Fuisipia River	Pineula River	Pineula River	Mataroa River	Vailima River	Vailima River	Lanoto'o Lake	Ogogo Spring	Pulei'a River
GPS - S	13.95145	13.95305	13.95039	14.00721	13.99856	13.97921	13.97902	14.02967	14.03454	14.01368	13.87021	13.87021	13.91046	13.69928	13.77500
GPS -W	171.51007	171.50975	171.51657	171.50092	171.48578	171.47177	171.59217	171.61672	171.61711	171.71768	171.76662	171.76662	171.81579	172.56284	172.37779
Altitude (m)	2	15-40	0-5	428	315	2	225	20	0-2	60	112	100	761	354	23
Temp (°C)	23.1	23.8	24.8	24.1	24.6	25.2	24	25.3	27.6	22.6	24	24	23.2	22.4	26.20
pH	7.44	7.43	7.7	9.27	7.45	8.05	6.24	7.2	7.2-8	7.7	8	8	9.9	7.6	7.59
Conductivity (µS)	65.5	59	88	46.7	60	65-500	35	89	72-3400	79	112	100	10.5	56.1	65.10
Dissolv'd O^2 (ppm)	30	30	NA	NA	NA	33	NA	NA	30	33	NA	NA	NA	NA	NA

Salinity (ppt)	0	0	0	0	0	0-8.1	0	0	18.3	0	0	0	0	0	0
Turbidity (NTU)	<10	<10	<10	15	<10	<10-12	NA	NA	<10-12	<10	<10	<10	15	<10	<10

Table 4. Riparian characteristics and instream condition at Samoan freshwater sampling sites

Site	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Substrate	rock, boulder, gravel	rock, boulder gravel	rock, sand	silt, mud, clay	gravel	Rock& gravel	NA	sand&mud	sand&mud	rock, gravel, pebble	Rock & gravel	Rock & gravel	mud	Gravel	boulders, rocks
Flowtype	riffles, pools	riffles, pools	riffles, runs	still	riffles,runs	riffles, runs & pools	NA	runs	runs	riffles,runs ,pools	riffles, runs & pools	Riffles, runs & pools	still	riffles, runs	runs
Instream cover	mild siltation	mild siltation	filamentous algae	reeds	siltation	filamentous algae	NA	silt	silt	clean	mild sediment	mild sediment	silt	clear	filamentous algae
Aquatic vegetation	clear	clear	filamentous algae	reeds	spare	filamentous algae	NA	paragrass	paragrass	filamentous algae	watercress	clear	reeds	roots	filamentous algae
Riparian vegetation	Native, exotic shrub	native shrub	para grass	native trees	paragrass	native/exotic trees	NA	mangrove, paragrass	mangrove, paragrass	exotic trees,native grass	Water cress	exotic trees	native trees/ paragrass	native trees	para grass
Land use	Bananas /rainforest	rainforest	bananas, cocoa	Taro plantation	grassland	banana/taro/cocoa	NA	coconut plantation	coconut plantation	pastoral /park	Park/ flowers	Park picnic	Park	none	Coconut
Disturbance type	Pigs mainly	subsistence logging	village	Picnic site	bridge/culvert	pigs/cattle	NA	drain &waste outlets	drain &waste outlets	Cattle/Picnic site	garden clearance	trash	Invasive fishes	none	Cattle/ village

Diversity

This survey resulted in 30 species of fishes (in 21 genera and 12 families) and 17 species of macro-crustaceans (in 5 genera and 3 families) being collected or observed from Samoan freshwaters. Of these, 3 species of fishes and 8 species of crustaceans are new records for Samoa (see Tables 1&2). Our results indicate that Samoan freshwaters contain at very least 3 and likely 5 endemic species of fishes with one and potentially three new taxa to science among them. One potential new species of crustacean is herein also considered a probable endemic. In addition to those species of fishes collected, 14 species common to freshwater are cited (Wass, 1984) as occurring in Samoa but not observed during this survey. This is a total of 44 species of fishes common to freshwater in Samoa with 6 of these species as non-native, invasive species. Based on our knowledge of common estuarine and marine migrant species that are often seen in freshwater systems of Fiji (Jenkins & Boseto 2003), Solomon Islands (Jenkins, 2007-2008) and Vanuatu (Kieth et. al., in press) an additional 42 species of fishes can be added to the list for Samoa from Wass, 1984 bringing the total of fresh and common estuarine species of fishes for Samoa up to approximately 86 species (Appendix 1). In addition to the 17 species of crustaceans that were collected, records exist within the literature of an additional five species which are also included in Table 2.

Endemism

Two endemic freshwater fishes have been described for the Samoan archipelago, the Flagtail, *Kuhlia salelea* Schultz, 1943 and the climbing goby, *Stiphodon hydoreibatus* Watson 1999. This survey revealed an additional species of *Stiphodon* (cover photo) that, based on male color patterns and morphometric characters is herein considered a new species, endemic to Samoa. The authors are in the process of describing this species. Two other species of gobiid fishes, *Schismatogobius sp.* (single juvenile specimen collected, photographed, escaped) and *Sicyopus sp.* (observed) are also likely, based on speciation patterns in other nearby island groups, to be new taxa and also endemic to Samoa. However, numerous samples of these other two species will need to be collected in order to verify their status. It is also likely that in clear, upper watersheds that another genera (*Lentipes*) of Sycidiine goby exists that is also often endemic to an archipelagic group. The potentially new species of crustacean *Macrobrachium sp.* may also be a freshwater endemic for Samoa. So, currently we can comfortably say that at least 3 species of fishes and potentially another two fishes and one crustacean are endemic to Samoan freshwater.

Life history patterns

It is extremely important to note for purposes of management that, of the species listed in Tables 1 and 2 at least 95 % of the native species have life history patterns that are intimately connected with the sea and must have cross-biome migrations during their lives (see Appendix 1 for fish life histories by species) including all of the endemic fauna. All of the crustaceans and a majority of fishes have amphidromous life histories, which mean that they spawn in freshwater, the hatched larvae pass to sea and juveniles return to freshwater as post-larvae (e.g. Sicydiine gobies). Other important components of the fauna are obligate catadromous, meaning that they spawn at sea, subadults or juveniles have to access freshwater where they live until migrating to sea to breed (e.g. freshwater eels). So, from a management perspective, these migration stages are particularly vulnerable to catchment alteration (eg. Kieth, 2003). Dams, poorly constructed weirs, deforestation, riparian zone damage, free ranging livestock and water pollution, amongst other factors such as introduced invasive species, can severely reduce and even extirpate populations of these species.

Introduced invasive species

Globally, introduced invasive species are second only to habitat destruction as the major factor driving extinction of native species (eg. Canonico et. al. 2005). During this survey we observed three species of introduced fishes, the Mozambique Tilapia, *Oreochromis mossambicus*, the goldfish, *Carrasius auratus*, and the Mexican livebearer, *Poecilia mexicana*. A further three species of livebearer (Poeciliidae) are also cited to occur in Samoa but were not seen during this survey (Table 1). It is clear, particularly for high altitude sites, where invasive species are found, local native species are depauperate or, in the case of upper Fuisipia river and Lake Lanoto'o, completely absent (Table 1). Lake Lanoto'o is Samoa's Ramsar Site and we did not find any native species in this lake, only goldfish (hence the popular name Goldfish Lake) and Mozambique Tilapia. It is of interest that the now long standing population of goldfish in the lake appears to be diminishing and our catch was dominated by Tilapia. Our research in Fiji has demonstrated that those high island catchments with Tilapia present have, on average, seven less fish species then those without and those native species lost are often the common inland food fishes (Eleotridae) and endemic species (Sicydiinae) (Jenkins et. al., in preparation). On a peculiar note, it should be documented also that we observed a sub-adult marine Green turtle that had apparently also been recently introduced to Lake Lanoto'o. In the Samoan context, there cannot be any rational justification for the introduction of non-native, invasive species and their translocation and introduction should be aggressively discouraged.

Habitat and site observations

In general, the basaltic, volcanic nature of the island can help to explain the predominantly basic nature of the water sampled (Table 3). The lakes, in particular, are quite alkaline with Lake Lago and Lake Lanoto'o showing a pH of 9.27 and 9.9 respectively. Neither of these lakes contained any native species of fishes or crustaceans. Only the upper Fuisipia was slightly acidic with a pH of 6.24 and this site was dominated by introduced invasive species tolerant to a range of pH conditions. While in-water turbidity levels did not seem to be particularly high during the time of the survey, many sites had a fine layer of sediment on the rocks suggesting moderate levels of erosion most likely due to near-river subsistence farming. Turbidity levels during the rainy season are also likely to increase significantly. It is clear from our site observations of in-stream characteristics and riparian conditions that there is a need for concerted management of the anthropogenic activities within the majority of catchments that we visited. Over half of the sites visited showed clear signs of nutrient loading with a heavy coating of filamentous algae (likely genera *Ulothrix*, *Spyrogyra* or *Treparnaldia*) on the substrate (Table 4) within the Namoi, Tiaveatai, Mataroa and Pulei'a Rivers particularly. This is likely the result of a combination of factors including unfenced livestock (particularly pigs and cattle), subsistence gardening and plantations directly adjacent to riverways (no buffer zone), unregulated village waste disposal compounded by low water levels. Conversion to pastoral and plantation land as well as irrigation, dam and weir building are also likely affecting the volume of flow in many watersheds, leading to increased concentrations of nutrients as well as higher water temperatures. Over half of the sites also had severely altered riparian vegetation (Table 4), often due to the aforementioned agricultural activities, which contributes again to erosion, increased water temperatures and reduced abundance and diversity of in-stream fauna.

Conclusions and recommendations

- Samoan freshwater contains three (and potentially six) endemic species. With the exception of a single widespread endemic species, these are all only documented during this survey from a single catchment. Their highly restricted range combined with the nature of their amphidromous life history pattern make these species particularly vulnerable to catchment alteration. Applying IUCN Red List criteria to these species would result in them being listed as Endangered or Critically Endangered. On this basis, we would highly recommend that the

Tagaila River catchment and forest system, adjacent to Uafato Village be included in the Samoan Protected Areas system.

- The diversity of Samoan freshwater fauna is still incompletely understood although based on our current findings is certainly worthy of further study and targeted conservation efforts. Further freshwater surveys are recommended for much of Savaii and permanently flowing areas of Upolu. The Tagaila river system should again be comprehensively surveyed to rigorously assess the population status of the endemic species contained within. Several specimens of *Schismatogobius* sp. and *Sicyopus* sp. need to be collected to ascertain their true taxonomic and endemic status.

- Introduced invasive species such as Tilapia (*Oreochromis mossambicus*) and Poeciliidae (eg. *Poecilia mexicana*) are highly detrimental to natural populations of indigenous fishes. Translocation and introduction of such invasive organisms should be actively discouraged to maintain indigenous populations of fishes and ecosystem services from watersheds. A survey and mapping exercise on all watersheds in Samoa should be undertaken to clearly map the presence/absence of invasive aquatic organisms with the aim of highlighting catchment systems that are invasive free and ensuring that they remain so. Investment in restoration of ecosystem function (eg. replanting buffer zones) will enhance productivity naturally and also benefit nearshore reefs. Stocking of only native species (eg. Gudgeons) should be considered as well as integrated irrigation/aquaculture of prawns (eg. *Macrobrachium lar*) if food security issues are paramount.

- The fauna of Samoan river systems are highly connected to marine ecosystems with 95% of the fauna using the marine or lower estuarine environment during their lives. This fact needs to be made salient to the broader stakeholder community and strongly argues for an integration of terrestrial (catchment –level) and marine management frameworks.

- Several rivers in Samoa appear in moderate to poor condition in terms of ecological functioning. This is likely due to long term stressors of pastoral grazing and plantation agriculture, past logging, human settlement waste and minimal river management capacity. Catchment level-management and rehabilitation should be undertaken to restore some of the ecosystem function of these rivers and in turn bring benefit to the nearshore marine areas. Some potential options for assisting in catchment rehabilitation are:

- replanting of buffer zones particularly in mid-catchment areas adjacent to pastoral and plantation areas and villages (eg. *Vetiver* grass has proven ability to reduce erosion)

- strict enforcement of code of practice (eg. forestry, road building) particularly for buffer zones and road crossings

- village level waste and water management plans (eg. construction of ecological or compost toilets, livestock waste areas, minimize livestock traversing waterways, rainwater harvesting mechanisms for human usage or solar water purification, integrating irrigation with aquaculture of native species (eg. *Macrobrachium sp.*)

- re-examine industrial waste management processes to determine options for minimizing industrial pollution into rivers particularly around urban centres

- Manged tabu (refugia) areas within river systems should be encouraged in addition to the marine protected areas. Ideally a catchment could have managed refugia in upper, middle and lower catchment areas to complement nearshore marine protected areas.

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Appendix 1. Freshwater and common estuarine fishes of Samoa. Scientific names, Samoan names and life history attributes. Compiled by Aaron Jenkins and Philippe Kieth.

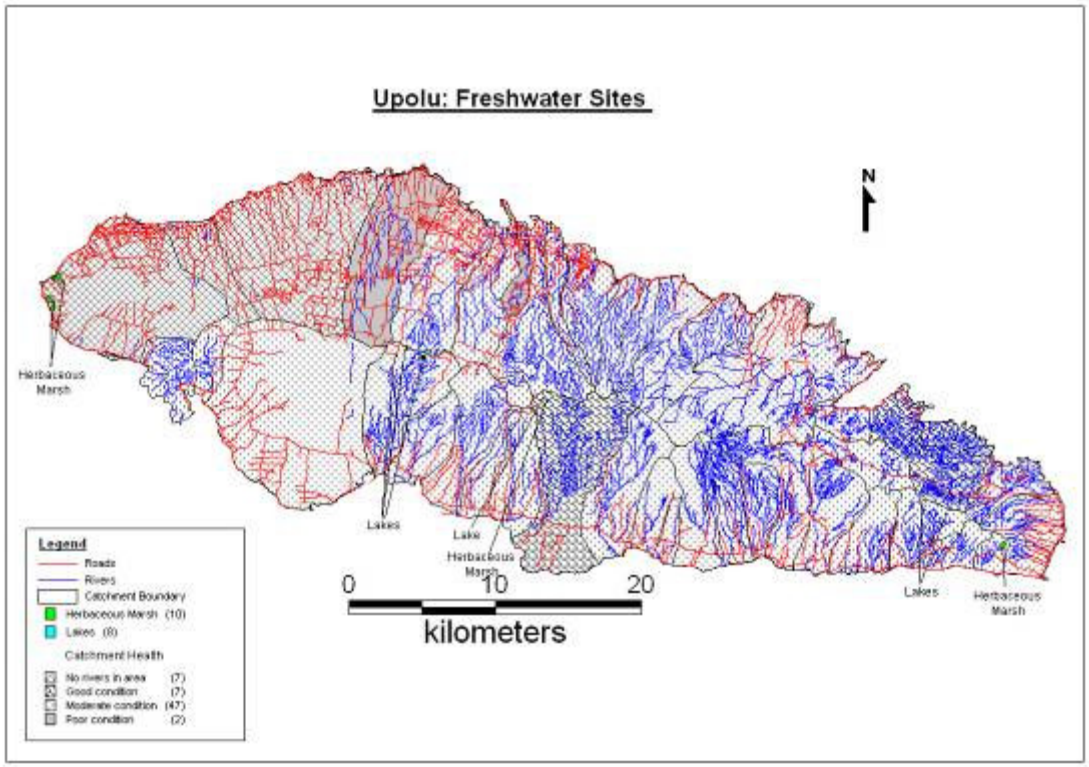
Key: **A** = Amphidromous - Spawn in freshwater. Hatched larvae pass to sea. Juveniles return to freshwater as post-larval fishes; **COB** =Obligate catadromy- Spawn at sea. Subadults or juveniles have to access freshwater where live until breeding; **FC** =Facultative catadromy- Spawn at sea. Juveniles or subadults access freshwater when available. Only a proportion of population develop in freshwater and remainder develop in estuary; **EM** = Estuarine migrant - spawn in estuary, have a marine larval phase and/or migration between estuary and adjacent aquatic habitats; **MW** = Solitary marine wanderer - Euryhaline. Spawn at sea. Occur in small numbers and typically only in the lower reaches of estuaries and rivers; **MM** = Marine migrants - Euryhaline. Spawn at sea. Come in large numbers. Use estuary as juveniles and/or adults; **FM**= Freshwater migrants - Spawn in freshwater and are present in estuaries throughout the year; **FW**= Freshwater wanderer- Spawn in freshwater and enter estuaries briefly if conditions are favorable, i.e. after flood pulse; **FR** - Freshwater resident - Spawn in freshwater and stay in freshwater throughout life cycle

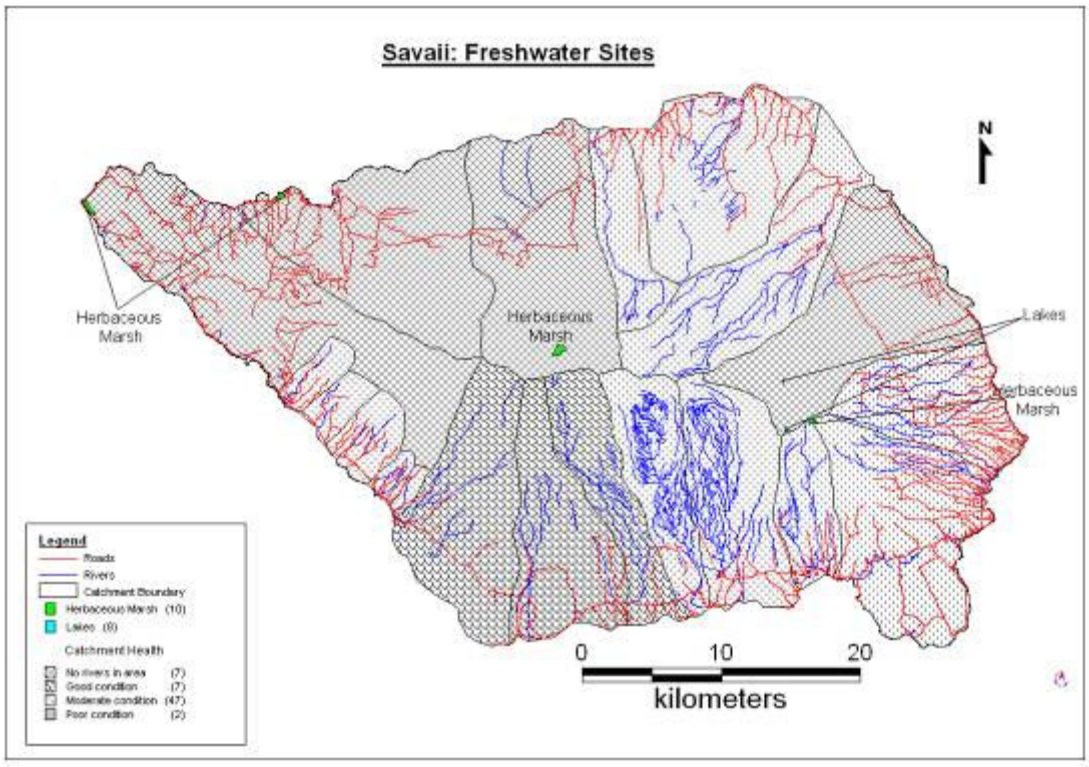
Family	Genus	Species		Samoan name	Life History
Gobiidae	*Awaous*	*ocellaris*		Mano'o-apofu	A
	Mugilogobius	*notospilos*		No name	A
	Sicyopterus	*lagocephalus*		No name	A
	Sicyopterus	*pugnans*		No name	A
	Stenogobius	*genivittatus*		Mano'o-vai	A
	Stiphodon	*elegans*		Mano'o-vai	A
	Stiphodon	*hydoreibatus*		No name	A
	Siphodon	*sp*		No name	A
	Sicyopus	*sp*		No name	A
	Yongeichthys	*nebulosus*		Mano'o-gatala	A
	Redigobius	*bikolanus*		No name	A
	Psammogobius	*biocellatus*		No name	EM
	Bathygobius	*fuscus*		Mano'o-apofusami	A
	Oplopomus	*oplopomus*		Mano'o-lape	MW
	Oxyurichthys	*tentacularis*		No name	EM
	Periophthalmus	*argentilineatus*			EM
	Periophthalmus	*koelreuteri*		Pa'ofu, talae	EM
	Taenioides	*sp.*		No name	A
	Schismatogobius	*sp.*		No name	A
Eleotridae	*Eleotris*	*fusca*		Mano'o-pala, pa'ofa,	A

				apofu	
	Eleotris	*melanosoma*		Mano'o-pala, pa'ofu, apofu	A
	Hypseleotris	*cyprinoides*		No name	FW
	Bostrychus	*sinensis*		No name	A
	Ophiocara	*porocephala*		No name	A
Kraemeriidae	*Kraemeria*	*samoensis*		No name	MW
Sygnathidae	*Microphis*	*retzii*		No name	FW
		brachyurus		No name	FW
	Hippichthys	*spicifer*		No name	EM
Angullidae	*Anguilla*	*australis*		Tuna	COB
		celebesensis		Tuna	COB
		marmorata		Tuna	COB
		megastoma		Tuna	COB
Ambassidae	*Ambassis*	*miops*		Lafa'	FW
		vaivasensis		Lafa'	FW
Kuhliidae	*Kuhlia*	*rupestris*		Sesele, inato	COB
		salelea		Salele	COB
		mugil		Safole	COB
Mugilidae	*Liza*	*melinoptera*		Anae'	FC
		subviridis		Anae'	FC
	Chelon	*macrolepis*		Anae'	FC
	Valamugil	*seheli*		Anae'	FC
		engeli		Anae'	FC
	Crenimugil	*crenilabus*		Anae'	FC
	Mugil	*cephalus*		Anae'	FC
Terapontidae	*Terapon*	*jarbua*		Ava'ava	FC
Carcharhinidae	*Carcharhinus*	*leucus*		Malie	MM
Chanidae	*Chanos*	*chanos*		Avali'I, ava	COB
Hemirhamphidae	*Zenarchopterus*	*dispar*		I'usila	FM
Monodactylidae	*Monodactylus*	*argenteus*		Vavale, valevale	EM
Megalopidae	*Megalops*	*cyprinoides*		Ana'analagi, fa	FC
Albulidae	*Albula*	*vulpes*		Ava	MM
Apogonidae	*Apogon*	*lateralis*		fo'	EM
	Foa	*fo*		fo'	EM
Carangidae	*Caranx*	*papuensis*		Malauli-sinasama	MM
	Caranx	*sexfasciatus*		Malauli-matalapo'a	MM
Lutjanidae	*Lutjanus*	*argentimaculatus*		Mu'-taiva	FC
		fulviflamma		Mu'	FC
		fulvus		Tamala, taiva	FC
Gerreidae	*Gerres*	*kapas*		Matu	EM
		macrosoma		Matu	EM
		oblongus		Matu-loa	EM

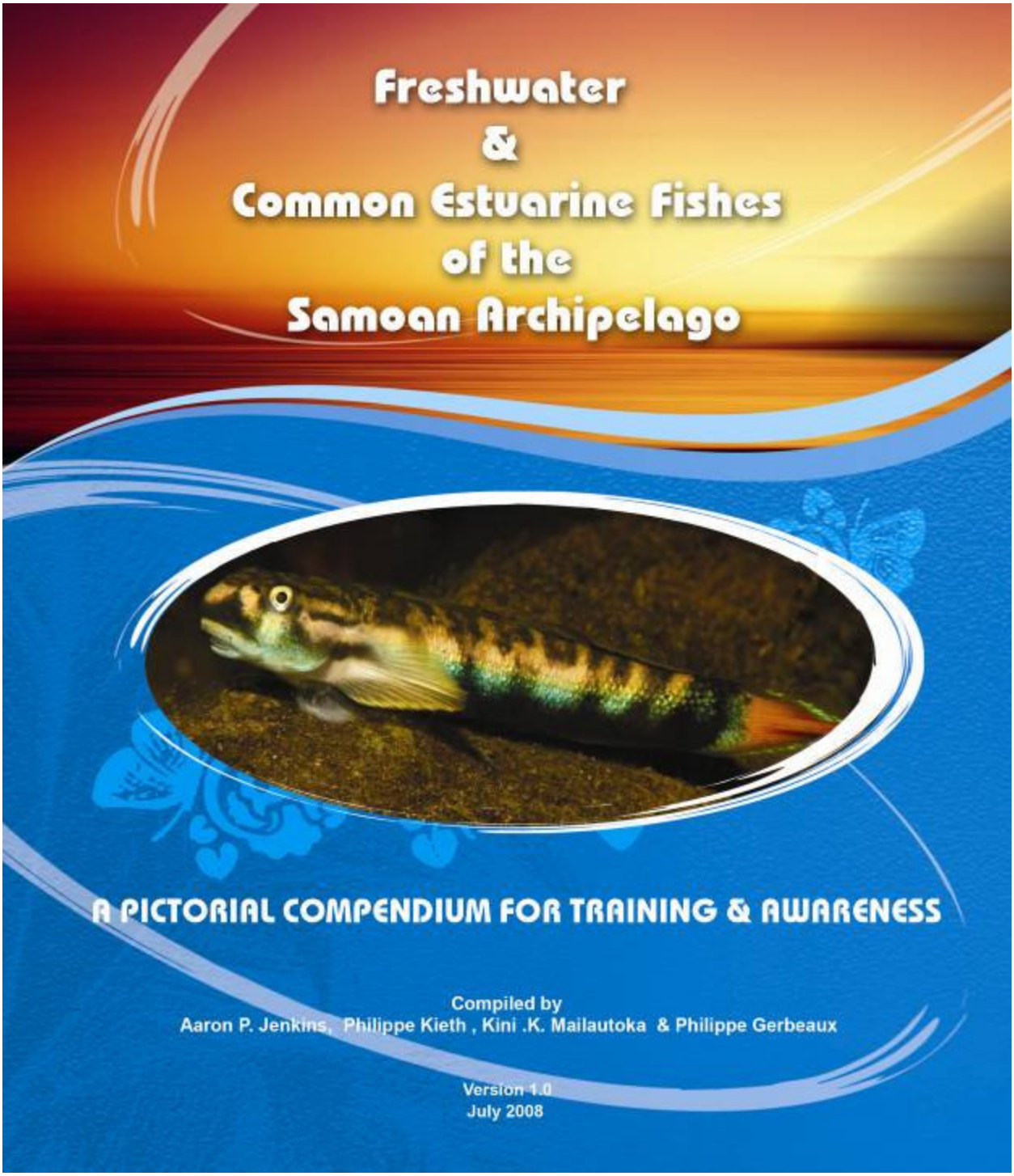
		oyena		Matu	EM
		setifer		Matu	EM
Mullidae	*Parupeneus*	*indicus*		Ta'uleia	MM
	Upeneus	*vittatus*		Ula'oa	MM
Sphyraenidae	*Sphyraena*	*flavicauda*		Sapatu'	MM
Clupeidae	*Spratelloides*	*delicatulus*		Poi, Nefu	MM
Engraulidae	*Stolephorus*	*indicus*		Pelupelu	MM
	Thryssa	*baelama*		Pelupelu	MM
Moringuidae	*Moringua*	*abbreviata*		fa'fa'	MW
	Moringua	*macrochir*		fa'fa'	MW
	Moringua	*microchir*		fa'fa'	MW
Ophichthidae	*Lamnostoma*	*polyophthalma*		No name	EM
	Pisodonophis	*cancrivorus*		No name	EM
Leiognathidae	*Gazza*	*minuta*		Mumu	EM
	Leiognathus	*equula*		Mumu	EM
	Leiognathus	*fasciatus*		Mumu	EM
Polynemidae	*Polynemus*	*plebius*		Umi'umi'a	MW
		sexfilis		Umi'umi'a	MW
Cyprinidae	*Carassius*	*auratus*		No name	FR
Cichlidae	*Oreochromis*	*mossambicus*		No name	FR
Poeciliidae	*Gambusia*	*affinis*		No name	FR
	Poecilia	*mexicana*		No name	FR
		reticulata		No name	FR
	Limia	*vittata*		No name	FR

Appendix 2. Maps of catchment boundaries, roads, rivers and inferred catchment condition used in the selection of survey sites. Maps created by Samoa MNRE and Conservation International.



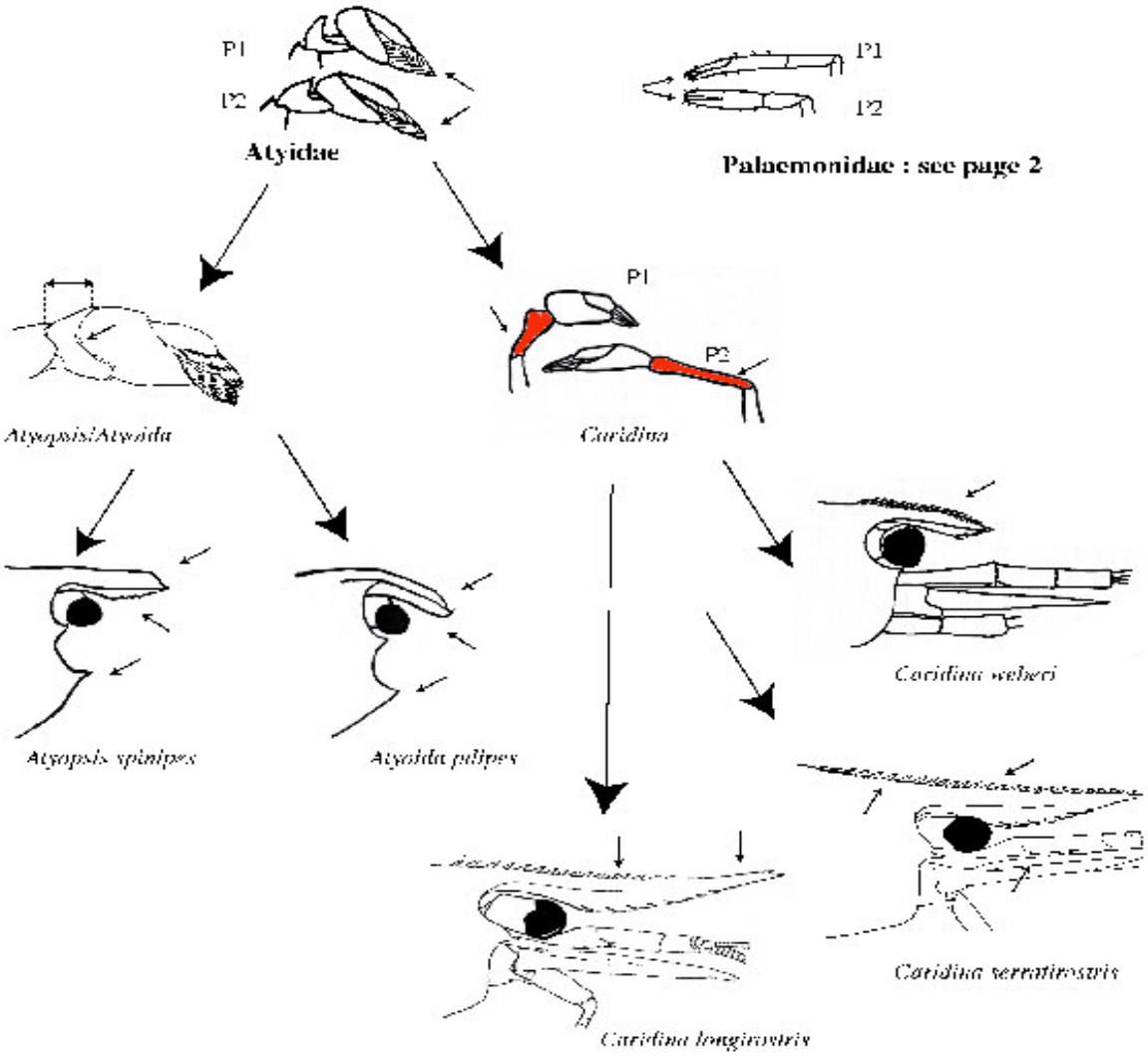


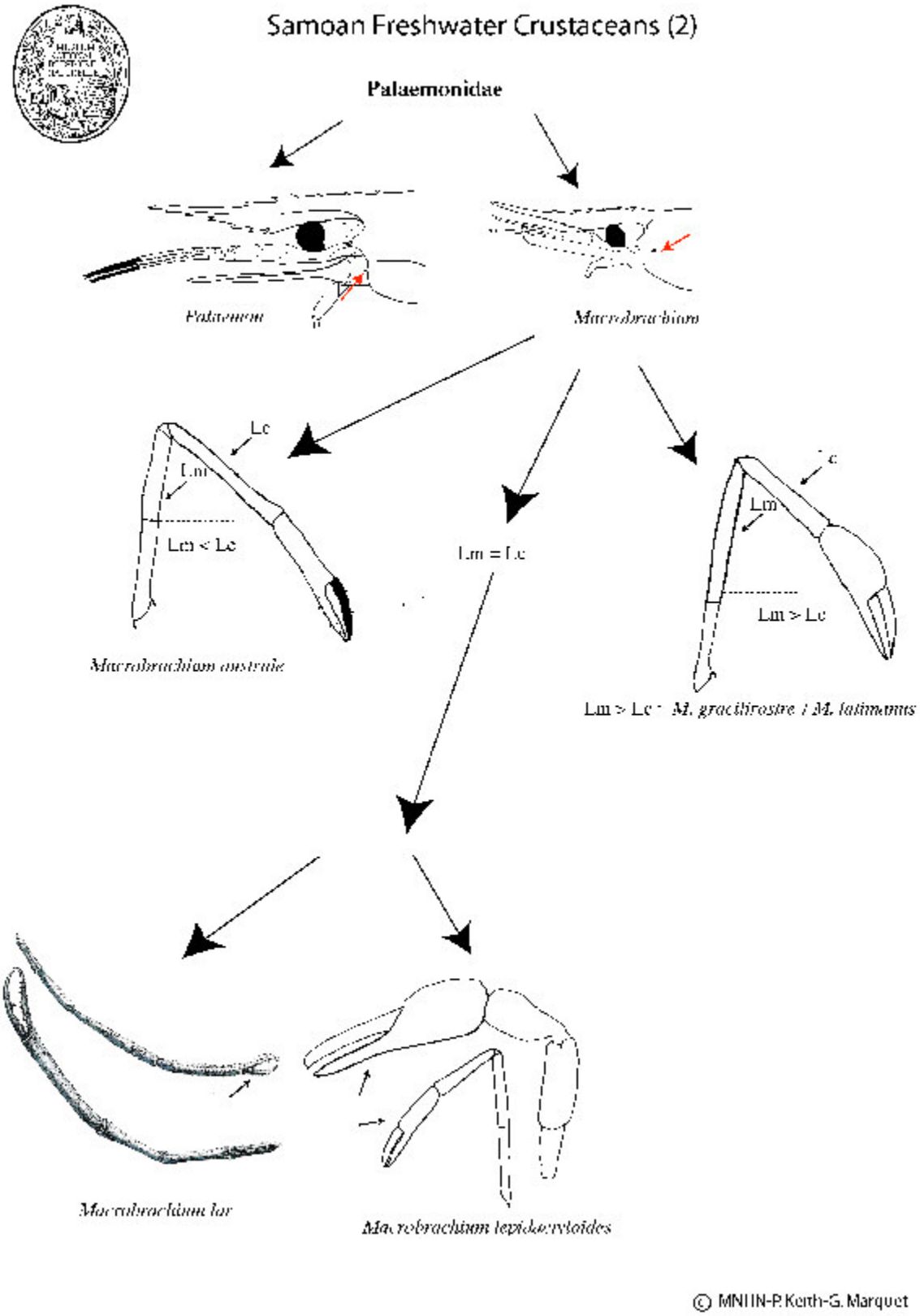
Appendix 3. Cover of Version 1 of training and awareness book developed prior to survey and training.



Appendix 4. Examples of Keys for crustaceans developed prior to survey and training by Paris Museum of Natural History.

Samoan Freshwater Crustaceans




Samoan Freshwater Crustaceans (2)
Palaemonidae
Palaemon
Macrobrachium
Lc
Lm
Lm < Lc
Macrobrachium australe
Lm = Lc
Lm
Lm > Lc
Lm > Lc : M. gracilirostre / M. latimanus
Macrobrachium lar
Macrobrachium lepidactyloides
© MNHN-P.Keith-G.Marquet

Appendix 5. List of Participants in the Samoan freshwater survey and training in July 2008

Name	Organization
1. Aaron Jenkins	Wetlands International
2. Philippe Gerbeaux	IUCN
3. Philippe Keith	Paris Museum
4. Gérard Marquet	Paris Museum
5. Kinikoto Mailautoka	USP/Wetlands International
6. Faleafaga Toni Tipama'a	MNRE – DEC – RS
7. James Atherton	Conservation International
8. Moeumu Uili	MNRE – DEC – TCS
9. Isamalei Asotasi	MNRE – DEC – MCS
10. Yvette Kerslake	MNRE – WD
11 Maturo Paniani	MNRE - FD
12. Joe Reti	MNRE - FD
13. Tone Simanu	MNRE –FD
14. Hitofume Abe	JICA - MNRE DEC/FD
15. Natasha Doherty	MNRE – DEC – RS
16. Paulo Amerika	MNRE – CS – CB
17. So'oalo Tito	MNRE – FD
18. Shigeyuki Hashizume	JICA - USP