BIOLOGICAL AND CHEMICAL SURVEY OF THE LOWER PAGO RIVER, ESTUARY, NEAR-SHORE REEF CHANNEL AND ADJACENT INNER REEF FLAT, PAGO BAY, GUAM.

by

Roy T. Tsuda, Jackalyn L. Holbrook, Harold R. Wood, Terry J. Donaldson and Barry D. Smith

UNIVERSITY OF GUAM

Marine Laboratory

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Cover: Background and center insert aerial photos of southern sector of Pago Bay showing river, estuary, channel and reef flat taken by John M.U. Jocson, University of Guam WERI in July 2004. Other insert photos taken by Roy T. Tsuda in April 2004.

TABLE OF CONTENTS

Page

LIST OF FIGURES iv

LIST OF TABLES v

INTRODUCTION 1

General Description of Study Sites 4

Previous Environmental Studies 5

ACKNOWLEDGEMENTS 16

MATERIALS AND METHODS 16

Pago River and Estuary 18

Marine Environment 20

RESULTS AND DISCUSSION 23

Water Depth 23

Temperature 26

Salinity 30

Temperature and Salinity Vertical Profiles 33

Water Circulation 34

Nutrients in Water 42

Heavy Metals in Sediments 46

Biological Transects 49

CONCLUSIONS AND RECOMMENDATIONS 57

REFERENCES CITED 60

PLATES 63

LIST OF FIGURES

Page

1. Map of the Lonfit-Sigua-Pago River System and Pago Bay (after U.S. Department of the Interior Geological Survey, Topographic Map of Guam). 2

2. Temperature values at depths at Pago Bay: a) river mouth, b) mid-channel, and c) outer-channel from January 1981 to October 1990. 8

3. Salinity values at depths at Pago Bay: a) river mouth, b) mid-channel, and outer-channel from January 1981 to October 1990. 9

4. NO_3-NO_2-N (NO_x) values at depths at Pago Bay: a) river mouth, b) mid-channel, and c) outer-channel from January 1981 to October 1990. 12

5. Location of sampling and transect stations on Pago River, reef channel, and Pago Bay reef flat. 19

6. Mean corrected depth (m) in relationship to mean lower low water (MLLW) measured during ebb and flood tides on 4-5 June 2004 and 11-12 August 2004. 25

7. Speed of current (meters per minute) at five stations on the inner reef flat seaward of the Pago River mouth, 14 June 2004. 37

8. Current tracks within the inner reef of Pago Bay observed on 13 September 2004. 40

9. Drift drogue studies at ebb tide within outer Pago Bay channel conducted on 16 September 2004. 41

10. Vertical profiles (m) of the nine parallel-to-shore biological transects corrected to MLLW. 50

LIST OF TABLES

Page

1. Lowest and highest temperature levels in °C at the Pago River mouth and Pago Bay mid-channel and outer channel from January 1981 to October 1990. 6

2. Lowest and highest salinity levels in ppt at the Pago River mouth and Pago Bay mid-channel and outer channel from January 1981 to October 1990. 6

3. Lowest and highest NO_3-NO_2-N (NO_x) levels in mg/l at the Pago River mouth and Pago Bay mid-channel and outer channel from January 1981 to October 1990. 11

4. Freshwater flora and fauna previously recorded in the Lonfit River and Pago River.. 15

5. Daily rainfall (inches) and monthly totals (inches and centimeters) for January to August 2004.. 17

6. Mean corrected depth (m) in relationship to mean lower low water (MLLW) measured during ebb and flood tides on 4-5 June 2004 and 11-12 August 2004, at 20-meter intervals along four 100-meter long perpendicular-to-shore transects. 24

7. Profile of surface temperature in °C at 20-meter intervals along 100-meter long transects (A-D) during ebb and flood tides on inner reef flat of Pago Bay. 27

8. Profile of surface and subsurface temperature in °C during ebb and flood tides along the Pago River and remnant of the inner reef channel. 29

9. Profile of surface salinity in ppt at 20-meter intervals along 100-meter long transects (A-D) during ebb and flood tides on inner reef flat of Pago Bay. 31

10. Profile of surface and subsurface salinity in ppt during ebb and flood tides along the Pago River and remnant of the inner reef channel. 32

11. Water circulation and wind movement on the inner reef flat seaward of the Pago River mouth, 14 June 2004. 35

12. Water circulation and wind movement on the inner reef flat seaward of the Pago River mouth, 13 September 2004. 39

13. Surface nitrate-nitrite-nitrogen (NO_x) and reactive phosphate (PO_4-P) values from the inner reef flat in the vicinity of the Pago River mouth. 43

Page

14. Surface and subsurface nitrate-nitrite-nitrogen (NO_x) along the lower sector of the Pago River and along the remnant of the Pago reef channel, 1 June 2004 (ebb and flood tides), 13 August 2004 (ebb tide) and 7 September 2004 (flood tide). 44

15. Surface and subsurface reactive phosphate (PO_4-P) along the lower sector of the Pago River and along the remnant of the Pago reef channel, 1 June 2004 (ebb and flood tides), 13 August 2004 (ebb tide) and 7 September 2004 (flood tide). 45

16. Heavy metals in sediments from Pago River mouth and remnant of Pago reef channel collected on 9 June 2004, and from reef flat collected on 18 August 2004. 47

17. Surface temperature and salinity measurements during low tide (+0.03 to +0.09) on a hot sunny day along the nine biological transects on the inner reef flat, Pago Bay, 14 June 2004. 51

18. Counts and percent cover of substrata and floral species quantified at three sites (three 50-meter long transects at each site) seaward of the mouth of Pago River, 17 May 2004. 52

19. Counts of conspicuous epibenthic invertebrates along belt transects at the Pago River mouth, 20 May 2004. 55

20. Density (number per square meter) of fishes observed on nine 50 x 5 meter transects on the inner reef flat seaward of the Pago River mouth, 25 May 2004. 56

INTRODUCTION

The existing 52-acre Ordot dump is the only public solid waste disposal facility on Guam and has been in existence since 1940. It is located north and adjacent to the Lonfit River, and just west of the site where the Sigua River, located to the south, converges with the Lonfit River to form the 3.87-kilometer long and up to 15-meter wide Pago River. The perennial Pago River meanders in an easterly direction towards its estuary and the 6.2-meter deep (MLLW) silty mouth of the river (Figure 1). The near-shore sector of the reef channel has been filled with sediments and is located slightly northeast of the mouth of the river; the channel then extends and deepens along a southeasterly direction to the mouth of the Pago Channel.

Action to close the dump was initiated in 1979. The dump was expected to be closed by 1985; however, it continues to operate and accepts about 300 to 350 tons of solid waste per day from the civilian community. On 25 April 1994, Public Law 22-115 was enacted which required the closure of the Ordot dump no later than 25 April 1997; subsequently, Public Law 24-139 extended the closure date to 31 July 1998. In August 2002, the U.S. Environmental Protection Agency (Guam EPA) and the U.S. Department of Justice sued the Government of Guam for its inaction and based its suit on the dump's violation of the Clean Water Act, i.e., release of pollutants into the adjacent Lonfit River. Some pollutants released in the Lonfit River eventually enters the Pago River which leads to the estuary, and adjacent inner reef flats of Pago Bay; during heavy rainfall and ebbing tide, the silty plume traverses the filled inner channel and is very evident flowing within the reef channel and over the reef flat toward the channel's mouth.

The Ordot Dump Consent Decree (U.S. District Court, Territory of Guam, Civil Case No. 02-0022), signed by District Court of Guam on 11 February 2004, required the Ordot dump to be closed by 22 October 2007 and required the Guam Department of Public Works to submit a list of at least three potential landfill sites to both the U.S. Environmental Protection Agency and Guam EPA within 30 days of the signing of the Consent Decree. On 2 March 2004, the Guam EPA announced the location of the three sites. Two of the sites selected by the Government of Guam (Guam EPA, 2004) in March 2004 occur within the Lonfit-Sigua-Pago River drainage system. The 80 to 100-acre Lonfit site (Lot 450R-4, Asan) lies approximately 0.5 km north of

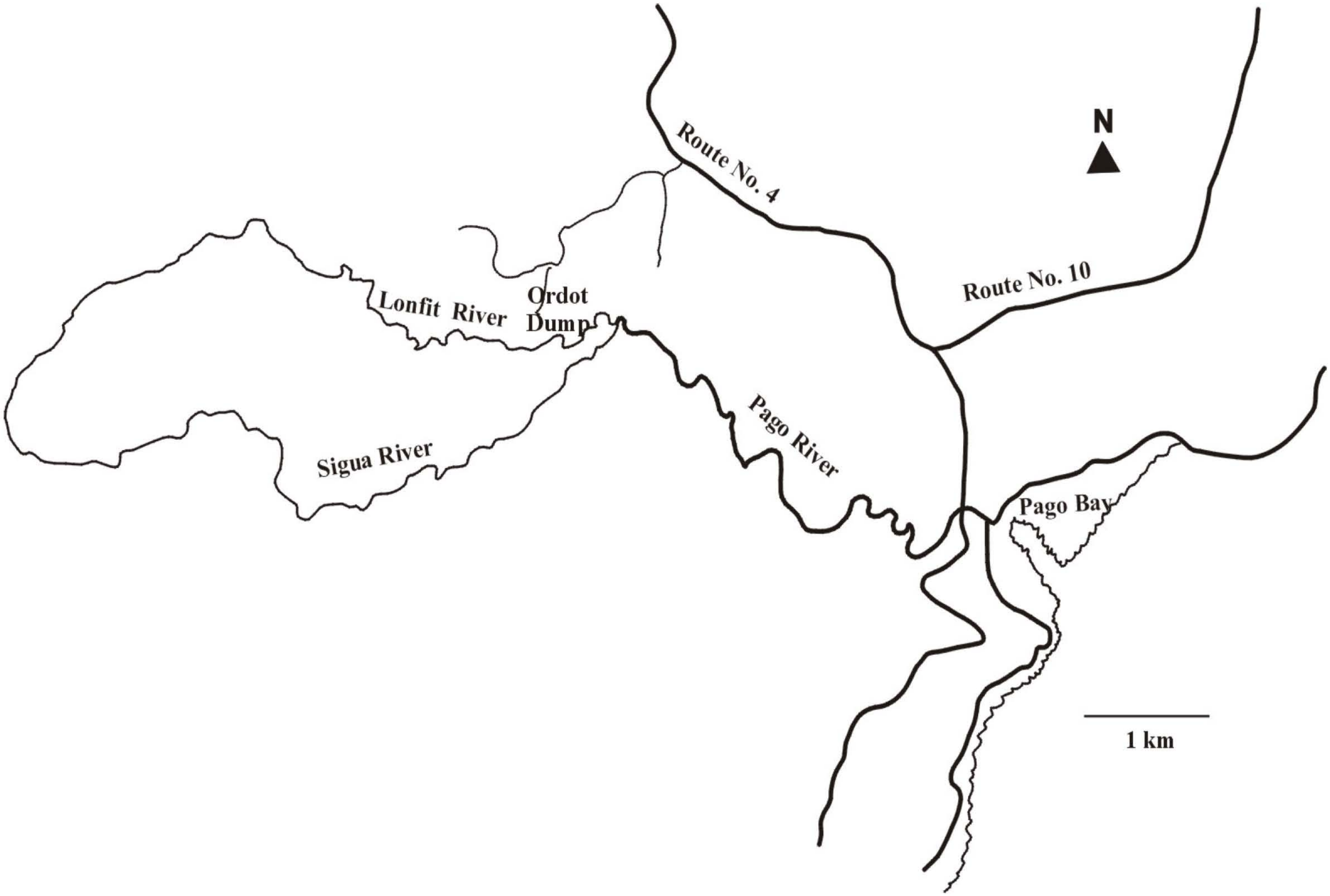

Figure 1. Map of the Lonfit-Sigua-Pago River System and Pago Bay (after U.S. Department of the Interior Geological Survey, Topographic Map of department).

the Lonfit River and 2.2 km ENE (upstream) of the convergence site with the Sigua River. The 200-acre Sabanan Batea site (Lot 177-4-R2, Yona) lies approximately 1.2 km south of the convergence of the Lonfit and Sigua rivers. The third site is the 3,000-acre Dandan site (Lot B-3-REM) in Inarajan. An Environmental Impact Statement to be completed by December 2004 will recommend one of the three sites as the location of the new landfill.

Thus, the biological and chemical surveys of the Pago River, its estuary, near-shore remnant of the reef channel and adjacent inner reef flats are of interest for three practical reasons. First, the area at and adjacent to the Pago River mouth most likely serves as a sink for leachates from the Ordot Dump, effluent from construction projects, and sewage waste from leaching fields along the Lonfit-Sigua-Pago River system. Second, baseline ecological information on the inner reef flat, near-shore reef channel, estuary and the lower Pago River is scarce and additional biological and chemical data will be useful, if either the Lonfit or Sabanan Batea is selected as the new landfill site. Third, the closing of the Ordot Dump will mandate the monitoring of environmental conditions along the Lonfit and Pago rivers during and after the capping of the dump.

This survey targeted the (1) biodiversity and abundance of aquatic flora and fauna in the study areas, (2) salinity and temperature gradients, (3) nutrient levels (i.e., nitrate-nitrite-nitrogen and reactive phosphate) of the marine waters over the inner reef flat and near-shore remnant of the inner reef channel, and stratified layers of brackish and seawaters in the estuary and along the lower 1 km of the Pago River, and (4) levels of selected heavy metals in the bottom sediments at the mouth of the Pago River, at the remnant of the reef channel that extends approximately 60 meters east of the mouth of the river, and in the muddy sediments that settled on the reef flat during the rainy months.

The present survey extends the information on the nutrient and heavy metal levels in leachates from the Ordot dump and in the waters of the Lonfit and Pago rivers obtained by the University of Guam Water and Environmental Research Institute (Clancy et al., 2003; Olsen and Denton, In Prep.). The accumulated findings will serve as the framework for the anticipated long-term monitoring programs, which will be required of the aquatic environment at and downstream of the Ordot Dump during and after the dump's closure. The study site also serves as an opportunity for future community-based volunteer monitoring of the permanently delineated biological transect sites during the next dry season.

General Description of Study Sites

Best and Davidson (1981) reported that the Pago River system, i.e., including the Sigua and Lonfit rivers, drains an area of 2,334 hectares (5,765 acres). The Pago estuary is lined with *nipa* (*Nypa fruticans*) and *pago* (*Hibiscus tiliaceus*). Both plant species occur approximately 0.7 km upstream of the Pago Bridge in association with *tangan-tangan* (*Leucaena leucocephala*) and bamboo (*Bambusa vulgaris*). Herbaceous and forested wetlands are associated with the Pago River, including its estuary, as per Guam's wetland composite map produced by Duenas & Associates, Inc. in 1996. All designated wetlands are considered federal jurisdictional wetlands.

Wilder (1976) reported saltwater intrusion along the bottom approximately 1 km upstream from the mouth of the Pago River and found that the less dense brackish water remained at the surface. Wilder (1976) reported that the maximum depth of 3.7 meters occurred halfway between the Pago Bridge and the mouth of the river (i.e., total distance of 275 meters); Matson (1991) cited the maximum depth of 5 meters adjacent to and seaward of the Pago Bridge. The deepest section of the Pago River lies at its mouth, i.e., 6.2 meters deep at MLLW, as measured on 1 June 2004.

The reef channel begins approximately 180 meters east of the mouth of the Pago River and extends 635 meters to the mouth of the Pago Channel. The channel is 122 meters wide at mid-channel (Emery, 1962). The outer 300 meters of the reef flat along the northern channel edge are exposed during mean lower low waters (MLLW) while the inner 500-meter wide reef flat remains mainly submerged (Tsuda, 1972). The substratum of the inner reef flats adjacent to the mouth of the Pago River consists of volcanic detrital material intermixed with bioclastics (Emery, 1962; Randall and Eldredge, 1976) and possesses no vegetative (i.e., algae or seagrass) cover. Bioclastics are comprised of fragments of hard parts of frame-building organisms, supplemented with those from reef-inhabiting organisms (Keesling, 1957).

Approximately 250 meters northeast of the river mouth, the seagrass *Enhalus acoroides* begins to form conspicuous patches near shore and extends 750 meters in a northeast direction along the coastline. The *Enhalus* patches are exposed during low tides (MLLW). *Halodule uninervis* and *Halophila minor*, the only other seagrasses recorded on Guam, are also quite prevalent on the shallow unconsolidated substratum adjacent to the *Enhalus* patches.

The 2001 *Revised Guam Water Quality Standards* (Guam EPA, 2001) designates the coastal waters of Pago Bay as basically M-2 (good), i.e., "... must be of sufficient quality to allow for the propagation and survival of marine organisms, particularly shellfish and other similarly harvested aquatic organisms, corals and other reef-related resources, and whole body contact recreation. Other important and intended uses include mariculture activities, aesthetic enjoyment and related activities." The same 2001 *Standards* designates the lower sector of Pago River as S-3 (low), i.e., "... primarily used for commercial, agricultural and industrial activities. Aesthetic enjoyment and limited body contact recreation are acceptable in this zone, as well as maintenance of aquatic life." The mid and upper sectors are designated S-2 (medium), i.e., "... used for recreational purposes, including whole body contact recreation, for use as potable water suppy after adequate treatment is provided, and propagation and preservation of aquatic wildlife and aesthetic enjoyment."

Previous Environmental Studies

WATER CIRCULATION. Marsh et al. (1982) described the general water circulation patterns of Pago Bay and showed the water flowing onto the reef flat over the northern reef margin and moving in a westerly and southwesterly direction towards the channel during flood tides. Water also moved over the reef margin on the reefs south of the channel and flowed towards the channel in a northerly direction. The bulk of the water exited through the channel during ebb tides. A long-shore current in the near-shore moat of the inner reef northeast of the Pago River mouth regularly flows in a southwest direction towards the river mouth; a reverse flow occurs on strongly flooding tides along the moat. Current speed ranged from 0 to a high of 0.6 meters per second in the moat and on the reef margin.

TEMPERATURE AND SALINITY. The Guam Environmental Protection Agency (Guam EPA) has monitored the water quality of the southern shores of Pago Bay since 1981. Tables 1 and 2 summarizes the lowest and highest temperature and salinity readings, respectively, recorded between January 1981 and October 1990. The lowest surface and subsurface temperatures were recorded during the winter months of December, January and February; the highest water temperature occurred in the surface waters in June, July and September. The salinity at the river mouth showed distinct stratification with fresh to brackish

Table 1. Lowest and highest temperature levels in °C at the Pago River mouth and Pago Bay mid-channel and outer channel from January 1981 to October 1991. Data obtained by Guam EPA.

Temperature			
	Depth (m)	**Lowest T (°C)**	**Highest T (°C)**
River Mouth	Surface	25.8 (Dec)	30.9 (Jul)
	0.3	26.6 (Jan)	30.5 (Apr)
	0.9	26.5 (Feb)	29.6 (Aug)
Mid-Channel	Surface	25.6 (Feb)	31.1 (Jun)
	1.5	26.1 (Feb)	30.9 (Jun)
	3.1	26.2 (Feb	30.9 (Jun)
	4.9	26.5 (Jan/Feb)	30 (Jun)
	10.0	26.5 (Jan/Feb)	30 (Jun)
Outer Channel	Surface	26.4 (Feb)	30.4 (Sep)
	3.1	26.3 (Feb)	29.9 (Jul)
	6.1	26.4 (Feb)	29.8 (Jul)
	10.1	26.8 (Feb)	30.4 (Sep)
	20.1	26.8 (Feb)	30 (Jun)

Table 2. Lowest and highest salinity levels in ppt at the Pago River mouth and Pago Bay mid-channel and outer channel from January 1981 to October 1991. Data obtained by Guam EPA.

Salinity			
	Depth (m)	**Lowest S (ppt)**	**Highest S (ppt)**
River Mouth	Surface	2 (Aug/Oct)	37 (Jun)
	0.3	4 (May)	35 (Mar)
	0.9	27 (Nov)	35 (Mar)
Mid-Channel	Surface	19 (Feb)	38 (Feb)
	1.5	34*	35*
	3.1	34*	35*
	4.9	34*	36 (Jun, Aug)
	10.0	34*	36 (Jun)
Outer Channel	Surface	31 (Aug)	36 (Jun)
	3.1	34*	35*
	6.1	34*	35*
	10.1	34*	35*
	20.1	34*	35*

* Various months.

water in the upper 0.3 meters. Vertical mixing does occur, as seen in the high salinity values in June. The salinity within the vertical column at the outer channel is not stratified and is equivalent to normal seawater.

Figures 2 and 3 show the temperature and salinity values at different depths at the Pago River mouth, the reef mid-channel and the reef outer-channel. The surface temperature at the river mouth showed the greatest variation, ranging from 25.8 to 30.9°C. Temperature ranged between 26.6 and 30.5°C at 0.3 m depth and between 26.5 to 29.6°C at 0.9 m. At the river mouth, temperatures greater than 30°C were experienced between April and July; temperature less than 27°C were obtained between November and March. The surface temperature in the mid-channel and outer channel experienced the greatest variation, i.e., ranging from 25.6 to 31.1°C and from 26.4 to 30.4°C, respectively. Temperature equal or greater than 30°C were recorded in the mid-channel and outer channel during May, June, July and September; temperature less than 27°C were recorded between December and March.

Surface salinity values (see Figure 2) showed the greatest variation at the river mouth (2 to 37 ppt) and at mid-channel (7 to 38 ppt); the surface salinity of the outer channel ranged from 31 to 36 ppt. Stratification occurred at the river mouth, i.e., 4 to 35 ppt at 0.3 m and 27 to 35 ppt at 0.9 m depth. Surface water in the mid-channel had a salinity level of 19 ppt during February but was more saline during the other months. The vertical salinity profile at the outer channel was similar to normal seawater except for one surface sample of 31 ppt in August.

Matson (1991) reported the salinity in the vertical water column below the Pago River Bridge on Route 4. The upper 0.4 meters contained brackish water at 7 ppt; the water column between the depth of 1 and 5 meters had a salinity level of about 25 ppt. The surface oxygen level at the depth between 0.3 and 1 meter was greater than 100% saturated; subsurface waters between 1 and 5 meters deep were about 85 to 90 percent saturated with oxygen.

NUTRIENTS AND HEAVY METALS. Marsh (1977) obtained water samples at irregular intervals between July 1974 and July 1976, and reported mean nitrate values of 4.16 µg-at per liter and mean reactive phosphorus levels of 0.22 µg-at per liter on the reefs of Pago Bay. Nitrate-nitrite values (µg-at/l) were highest at the river mouth (mean 7.31, N=8), inshore moat (mean 3.31, N=43) and reef margin (mean 1.77, N=27); the mean nitrate-nitrite values (µg-at/l) at the inner reef flat and outer reef flat were 0.45 (N=9) and 0.22 (N=9), respectively. Reactive phosphate values (µg-at/l) were highest at the reef margin (mean 0.23, N=76) and outer reef flat (mean 0.21, N= 4); the inner reef flat, moat and river mouth showed reactive phosphate values of 0.16 (N=7), 0.15 (N=81) and 0.14 (N=8), respectively.

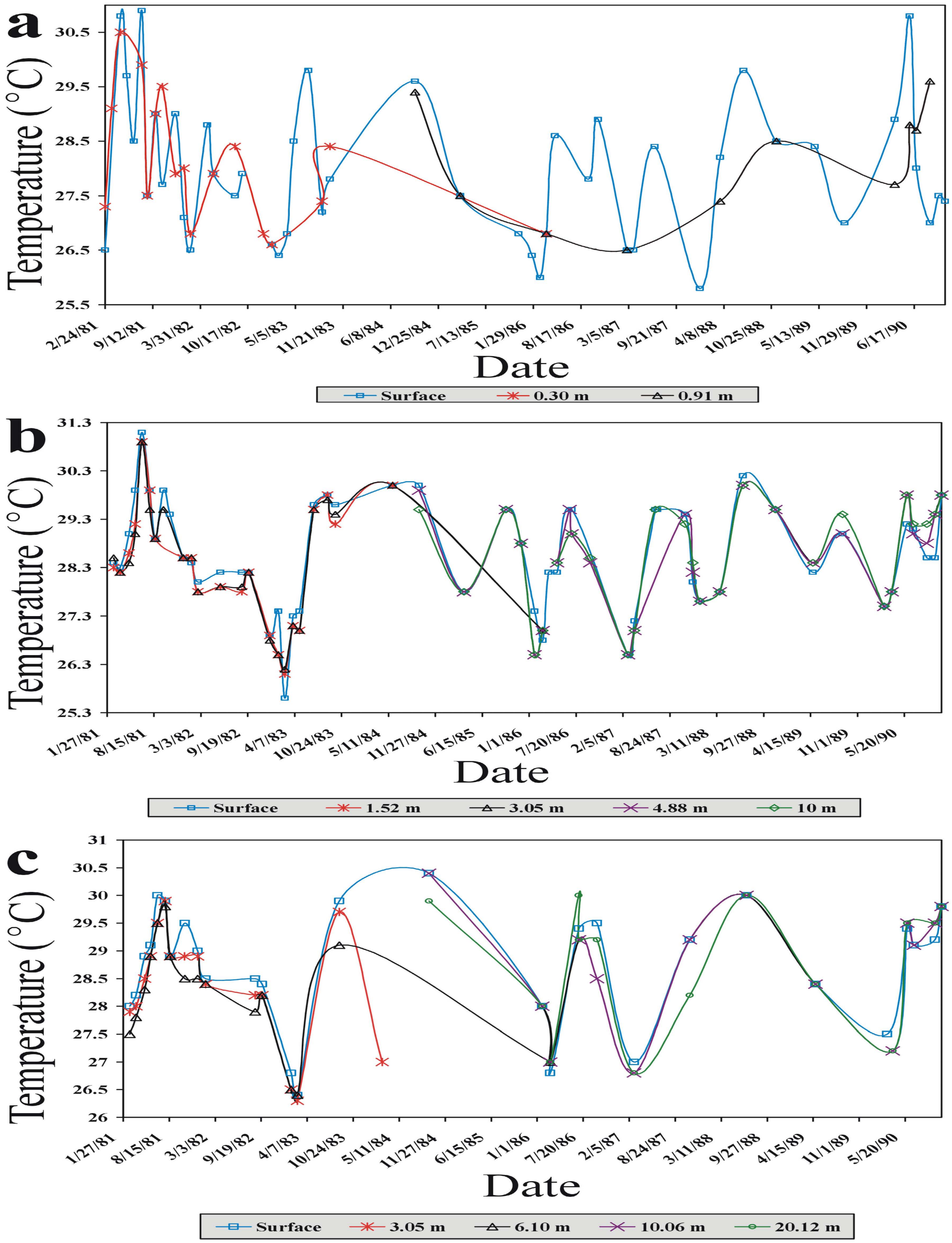

Figure 2. Temperature values at depths in Pago Bay: a) river mouth, b) mid-channel, and c) outer-channel from January 1981 to October 1990. Data obtained by Guam EPA.

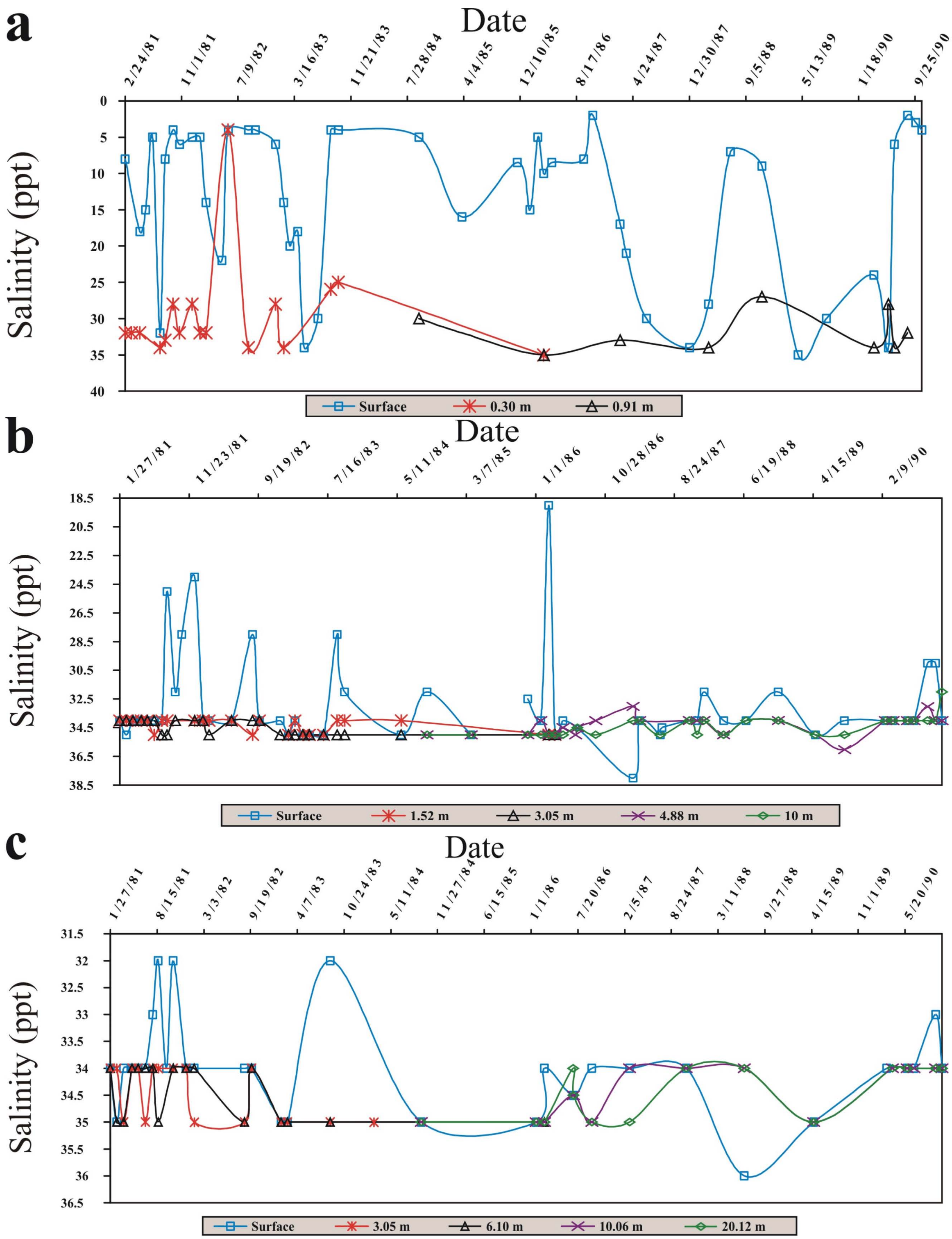

Figure 3. Salinity values at depths at Pago Bay: a) river mouth, b) mid-channel, and c) outer-channel from January 1981 to October 1990. Data obtained by Guam EPA.

Table 3 and Figure 4 provide information on the nitrate-nitrite-nitrogen ($_{NO}$) values collected by the Guam EPA during January 1981 to October 1990 at the river mouth, mid-channel and outer channel. The highest $_{NO}$ levels were present in the surface waters at all three sites. The highest $_{NO}$ level recorded for all depths was 0.96 mg/l in the surface waters at the river mouth, probably attributed to the high rainfall in the month of August. $_{NO}$ was not detected in some samples in the mid-channel and outer channel. The highest $_{NO}$ level, i.e., 0.5 mg/l, was recorded in the mid-channel at a depth of 4.9 m in the month of March; the high value is possibly due to the resuspension of sediments from storm surge. A high $_{NO}$ value of 0.6 mg/l was recorded from surface water in the outer channel in February.

The most informative study of nutrients and heavy metals from the leachate at the Ordot Dump and from the downstream waters of the Lonfit and Pago rivers was conducted by Clancy et al. (2003) between October 2002 and May 2003. The leachate contained high nutrients, i.e., nitrate-nitrite-nitrogen ($_{NO}$), ammonium-nitrogen (NH_4-N), orthophosphate-phosphorus, and levels of heavy metals (i.e., aluminum, copper, lead, nickel and zinc) that exceeded surface water standards (Guam EPA, 2001). No polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), dioxins, furans nor chlorinated pesticides (except p-dichlorobenzene) were present in the leachate. In an earlier study, Wood (1989) sampled surface waters of the Lonfit River adjacent to the Ordot Dump and found no evidence of organic contamination from pesticides.

High levels of $_{NO}$ were present along the Pago River and especially at the mouth of the river, and, most likely, originated from the domestic wastewater inputs within the lower Pago River basin (Clancy et al., 2003). Levels higher than permitted for surface waters (Guam EPA, 2001) were found for iron (mean 14.9 mg/l), manganese (mean 27.4 mg/l) and copper (mean 0.4 mg/l) under the Pago Bridge on Route No. 4.

Olsen and Denton (In Preparation) analyzed heavy metals in sediments along 14 stations along the Lonfit-Sigua-Pago River system, i.e., 8 stations on the Lonfit River, 2 stations on the Sigua River and 4 stations in the Pago River.

COLIFORM. Water samples collected and analyzed by the Guam EPA between January 1981 and October 1990 showed fecal coliform values ranging from 0 to 2000 per 100 ml (most probable number, MPN). The highest level of fecal coliform was found in the surface water at the river mouth and at mid-channel. The average fecal coliform was 98.7 MPN at the river

Table 3. Lowest and highest NO_3-NO_2-N (NO_x) levels in mg/l at the Pago River mouth and Pago Bay mid-channel and outer channel from January 1981 to October 1990. Data obtained by Guam EPA.

NO_x			
	Depth (m)	**Lowest N (mg/l)**	**Highest N (mg/l)**
River Mouth	Surface	0.01 (Apr)	0.96 (Aug)
	0.3	0.01 (Apr, Aug)	0.35 (Dec)
	0.9	0.00 (Jun)	0.21 (May)
Mid-Channel	Surface	0.00*	0.39 (Aug)
	1.5	0.00*	0.37 (Feb)
	3.1	0.00*	0.07 (Aug)
	4.9	0.00*	0.50 (Mar)
	10.0	0.00*	0.16 (Jan)
Outer Channel	Surface	0.00*	0.61 (Feb)
	3.1	0.00*	0.18 (Sep)
	6.1	0.00*	0.09 (Jan)
	10.1	0.00*	0.07 (May)
	20.1	0.00*	0.07 (Feb)

*Various months.

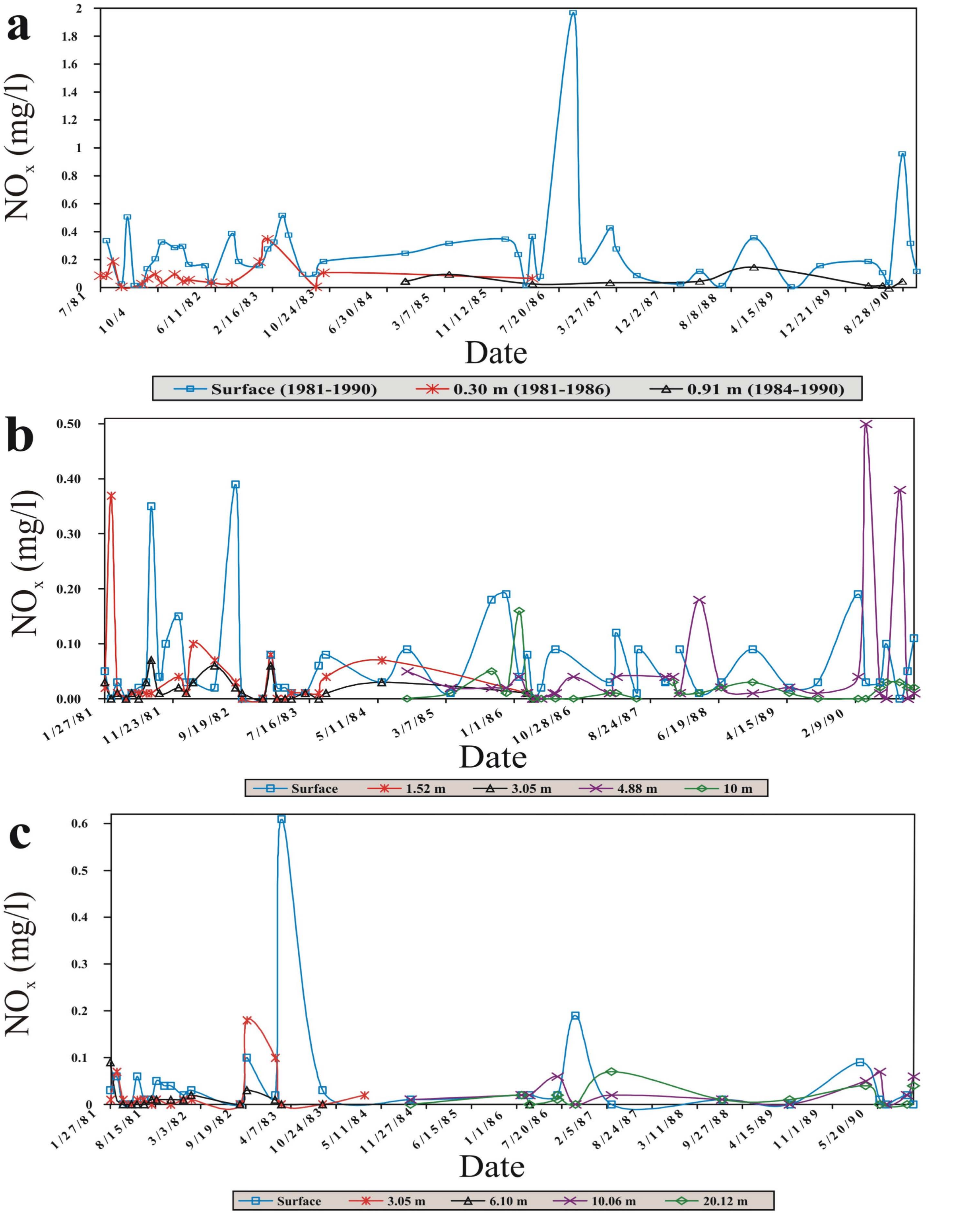

Figure 4. NO_3-NO_2-N (NO_x) values at depths at Pago Bay. a) river mouth, b) mid-channel, and c) outer-channel from January 1981 to October 1990. Data obtained by Guam EPA.

mouth, 18.6 MPN at mid-channel and 24.5 MPN at the outer channel. At the river mouth, above average fecal coliform levels were present during all months, except April and July. At the outer channel, the highest levels of fecal coliform were recorded in September and October. Above average coliform levels at mid-channel were present in samples collected in February, May, July to October and December; likewise, above average coliform levels at the outer channel were present in samples collected in May to November.

Clancy et al. (2003) reported high bacterial counts, i.e., total coliform, *Escherichia coli* and *Enterococci*, in the leachates from the Ordot Dump. Total coliforms in the surface waters of the Lonfit River, however, were reduced 200-fold approximately 500 meters downstream of the Ordot Dump.

BIOLOGICAL CHARACTERISTICS. Most of the biological studies conducted in Pago Bay were undertaken in the more pristine northeastern sector near the University of Guam Marine Laboratory. Chase (1975) surveyed butterflyfish on the reef front and reef terrace of Pago Bay, and compared her findings with that observed at Tanguisson (leeward side of Guam) and Cocos Lagoon to the south. Yamaguchi (1975) described the mass mortality of reef organisms, mainly invertebrates, in the northeast sector of Pago Bay during the abnormal sea level drop in October 1972. Studies on marine gastropods in northeastern Pago Bay included shell growth and mortality rates of *Cerithium nodulosum* (Yamaguchi, 1977), survival of nonlethal shell damage to *Conus sponsalis* (Zipser & Vermeij, 1980) and the predatory nature of gastropods (Taylor, 1984). Seventeen of the 30 known species of Guam holothurians were reported by Rowe and Doty (1977) from Pago Bay; the exact locations in Pago Bay were not described.

A few biological studies, however, included stations or collections near the Pago Bay channel. The reproductive behavior of the green alga *Halimeda macroloba* (Merten, 1971) was conducted in the mud-sand area among the *Enhalus* beds northeast of the river mouth. One of the three transects conducted in Pago Bay to characterize the zonation and seasonality of brown algae (Tsuda, 1972, 1974, 1977) was run a distance of 820 meters perpendicular to shore, and nearly parallel and just northeast of the reef channel. The dominant brown algae on the inner reef flat were *Padina boryana*, *Lobophora variegata*, *Sargassum polycystum* and *Sphacelaria tribuloides*; *Turbinaria ornata* was the dominant brown alga on the outer reef flat. The epiphyte

Hydrolithon farinosum on the seagrass *Enhalus acoroides* and *Neogoniolithon brassica-florida* are crustose coralline algae collected by Gordon et al. (1976) near the river mouth and reef channel.

In a study on the natural habitat of the mangrove crabs (*Scylla serrata*) in Pohnpei and Guam, Dickinson (1977) collected two mangrove crabs in the Pago River estuary; the crabs were tagged and released, but were never recovered. One of three benthic diatom collecting stations, where standard glass microscope slides were submerged for a period of 10 days, was located just north of the mouth of the Pago River (Zolan, 1980). Of the 160 different diatoms recorded, five species (*Diploneis bomboides*, *Diploneis chersoensis*, *Plagiogramma decussatum*, *Navicula brasiliensis* and *Eunotia* sp.) were observed exclusively at this site near the river mouth.

Best and Davidson (1981) listed two shrimps and three fishes from the Pago River - *Macrobrachium lar* (freshwater shrimp), *Atya* sp. (shrimp), *Anguilla* sp. (freshwater eel), *Gambusia affinis* (mosquito fish) and *Oreochromis* sp. (tilapia). The U.S. Army Corps of Engineers (1983) described the Pago, Ylig, Ugum and Inarajan watersheds and listed *Oreochromis mossambicus*, *Anguilla marmorata* and *M. lar* from the watersheds. Pacific Basin Environmental Consultants, Inc. (1990) found the green alga Spirogyra sp. in swift-flowing shallow waters of the Lonfit River. *M. lar* and atyid species were also reported from the Lonfit River. Brasher (1991) described *M. lar* and the flagtail *Kuhlia rupestris* as abundant in the Lonfit River. She found *O. mossambicus* rare in the Lonfit River but common in the Sigua River. The two fish *Awaous guamensis* and *Stiphodon elegans* were described as common in both the Lonfit and Sigua Rivers. Leberer (1999) provides a table of the freshwater fish observed in the Pago River. Table 4 summarizes the biota previously observed in the Lonfit and Pago rivers.

Table 4. Freshwater flora and fauna previously recorded in the Lonfit River and Pago River.

Species	Lonfit	Pago
Algae		
Spirogyra sp.	2	
Mollusks (snails)		
Melanoides tuberculata	3	
Neritina pulligera	3	
Neritina variegata	3	
Crustaceans (shrimps)		
Atya serrata	3	
Atya sp.		1
Caridina serratirostris	2, 3	
Caridina typus	3	
Macrobrachium lar	2, 3	1
Fish		
Anguilla marmorata	3	
Anguilla sp.		1
Awaous guamensis	3	4
Caranx sexfasciatus (marine)		4
Eleotris fusca	3	
Gambusia affinis		1
Kuhlia ruprestris		1, 4
Lutjanus argentimaculatus (marine)		4
Oreochromis mossambicus		1, 4
Sicyopus sp. (*S. leprurus*)	3	
Stenogobius sp.		4
Stiphodon elegans	3	
Stiphodon sp.		4
"Unidentified goby"	3	

Key: (1) Best and Davidson, 1981; (2) PBEC, Inc., 1990; (3) Brasher, 1991; (4) Leberer, 1999.

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We thank Annie D. Leon Guerrero, Guam EPA, for providing us copies of the historical sampling data on temperature, salinity, nutrients and coliform obtained from Pago Bay by the Guam EPA. Our appreciation to Dr. Ernest A. Matson, Professor of Microbiology, University of Guam, for the loan of an Orion Conductivity-Salinity meter during our samplings along the Pago River, estuary and reef channel. Special acknowledgement to Jason Miller, Marine Technician, for his assistance in subsurface sampling and operating the boat over the shallow sand bar on the reef flat and along the Pago River.

MATERIALS AND METHODS

Preliminary surveys on the reef flat and along the river were initiated in April 2004 to plan the general sampling program. The original plan was to utilize a 7-foot long inflatable raft with oars to undertake the sampling along the river. After one trip upstream, this plan was “scrapped” since mobility was very slow and it was extremely difficult to carry out the sampling program from an unstable platform. The inflatable raft, however, was indispensable during transect and sampling work on the shallow inner reef flat. The raft held all the materials and tools, and floated behind the individual with the attached rope tied around the waist.

The biological surveys and chemical samplings were conducted over a five-month period in 2004 during the dry months of May and early June and the wet months of August and September along the lower 1 km of the Pago River and its estuary, and in the remnant of the near-shore reef channel and on the adjacent inner reef flats within Pago Bay, Municipalities of Chalan Pago and Yona, Guam. Table 5 presents the daily rainfall information for January to August 2004.

Table 5. Daily rainfall (inches) and monthly totals (inches and centimeters) for January to August 2004. Compiled by the National Weather Service Forecast Office, Tiyan, Guam. http://www.prh.noaa.gov/guam/climate.html

*T = Trace levels (rainfall values between 0.00 and 0.01 inches)

Day No.	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**
1	0.07	T	0.02	0.00	0.02	0.14	0.03	0.79
2	0.07	T	0.00	0.01	0.10	0.01	0.00	0.15
3	0.02	0.04	0.03	0.02	0.31	T	0.00	0.60
4	0.09	0.03	0.05	0.00	0.01	0.03	1.38	2.38
5	0.09	0.00	0.03	0.06	0.05	0.26	0.03	4.39
6	0.36	0.20	0.05	0.88	0.23	0.09	1.15	2.96
7	T	0.90	T	0.23	2.19	0.15	T	0.54
8	0.00	0.08	0.42	0.18	0.06	0.39	0.35	T
9	T	0.00	0.12	0.02	0.06	0.38	0.03	0.00
10	T	0.85	0.54	0.16	0.02	0.19	1.16	T
11	0.00	0.38	0.02	0.26	T	0.16	0.07	0.11
12	0.82	0.29	0.05	0.00	T	0.15	0.00	0.04
13	0.56	0.14	0.07	0.05	0.06	0.18	0.45	1.72
14	T	0.23	0.22	0.01	0.01	0.50	0.15	0.96
15	0.00	0.05	0.01	0.49	0.02	0.22	1.27	0.13
16	0.02	T	0.09	0.02	0.08	3.15	0.19	0.12
17	0.08	0.53	0.39	T	0.29	0.66	0.80	1.15
18	1.24	0.06	0.27	0.00	0.79	0.49	0.13	0.43
19	0.07	T	0.41	0.30	0.22	0.06	0.09	0.42
20	0.00	0.03	0.39	0.20	0.03	1.18	0.44	0.27
21	0.00	0.93	0.00	0.01	0.00	3.20	0.40	0.02
22	0.00	0.59	0.00	0.00	0.00	2.40	0.01	7.52
23	0.00	0.01	0.00	0.04	0.00	0.47	0.28	1.79
24	0.02	0.00	0.00	0.03	0.01	0.08	0.06	3.64
25	T	0.06	T	0.01	0.19	1.03	0.48	0.25
26	0.15	0.02	0.01	0.31	0.22	0.40	T	1.61
27	0.14	0.13	0.02	T	0.37	16.00	0.15	2.80
28	0.03	1.32	0.01	T	0.10	5.49	0.01	0.37
29	0.15	0.07	T	0.03	T	0.56	0.12	1.96
30	T	T	0.19	0.06	0.05	0.01	0.03	0.17
31	0.19	T	0.01	T	0.02	T	0.85	0.03
Monthly Total (inches)	4.17	6.94	3.42	3.38	5.51	38.03	10.11	37.32
centimeters	10.59	17.63	8.69	8.59	14.00	96.60	25.68	94.79

Pago River and Estuary

TEMPERATURE AND SALINITY. Surface and subsurface temperature, and salinity readings were obtained *in situ* with an Orion conductivity-salinity meter and underwater probe, Model 140, at 10 stations (Figure 5) between the river mouth and 1-km upstream of the Pago River during both ebbing and flooding tides on 1 June 2004 from a 21-foot Whaler, and on 13 August 2004 (ebbing) and 7 September 2004 (flooding) from the Whaler and a 19-foot Bertram, respectively. Red flagging tapes with station numbers were tied on tree branches along the riverbank to relocate the stations. Each station was plotted with a Garmin GPS 72. Subsurface readings were recorded at depths approximately 0.5 m from the bottom substratum after depth measurements were obtained with a transect tape weighted by two 10-ounce lead sinkers.

NUTRIENTS. Surface and subsurface water samples for nitrate-nitrite-nitrogen (NO_x) and reactive phosphate (PO_4-P)were collected during neap and flood tides at the same 10 stations (see Figure 5) on 1 June 2004, 13 August 2004 and 7 September 2004 where temperature and salinity measurements were made. The surface samples were collected directly in 50-ml plastic centrifuge tubes with screw caps, after rinsing the tube once with the sample water. The subsurface samples were obtained with a Van Dorn Water Bottle Sampler approximately 0.5 meters from the bottom substrata.

Nitrate-nitrite-nitrogen and reactive phosphate were analyzed at the University of Guam Water and Environmental Research Institute (UOG-WERI), respectively, by the Lachat method based on the automated cadmium reduction method (Method 4500-NO3 E.) and by the automated ascorbic acid method (Method 4500-P E.) as per procedures described in the American Public Health Association's *Standard Methods* manual (APHA, 1992). The Lachat Flow Injection Analyzer (Quik Chem FIA+ 8000 series) was used for both analyses.

BIOLOGICAL CHARACTERISTICS. The fish and macroinvertebrates (i.e., mainly mollusks and crustaceans) were catalogued during June and August 2004. No benthic algae were observed in the river and estuary. The extreme murkiness of the estuary and the lower sector of the river, even during the dry season, prevented the use of any underwater observational technique to quantify the aquatic organisms. The general abundance of selected organisms was estimated based on surface observations from a boat, and observations of catches in fish and crustacean mesh traps.

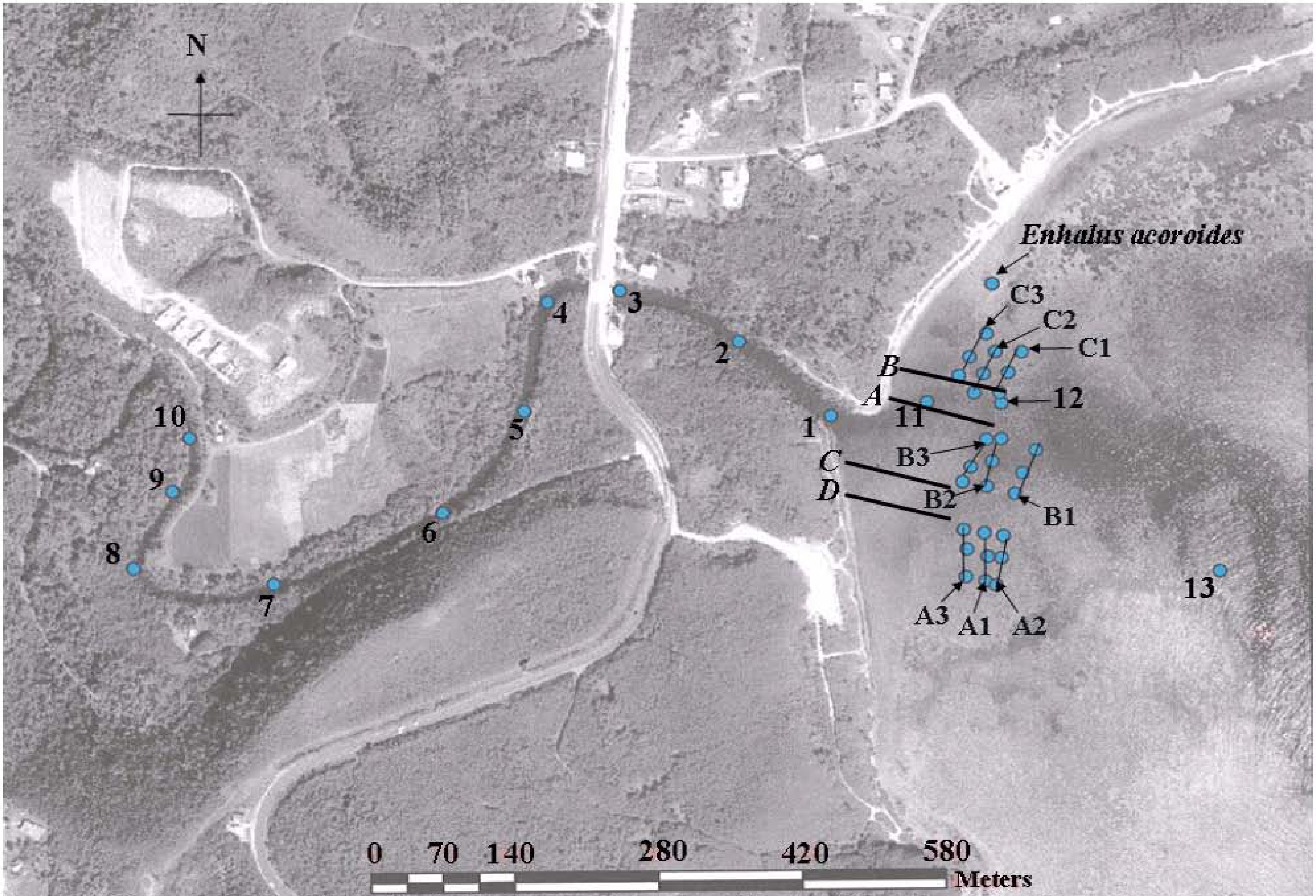

Figure 5. Location of sampling and transect stations on Pago River, reef channel, and Pago Bay reef flat. Guam orthophotographs.

Marine Environment

TEMPERATURE AND SALINTY. Surface temperature and salinity measurements were obtained every 20 meters (0, 20, 40, 60, 80 and 100 m) along four 100-meter transect lines run perpendicular to the shoreline, i.e., two transects south and northeast, respectively, of the mouth of the Pago River. The 48 measurements, i.e., 6 sets of measurements x 4 transects during ebb and flood tides, were made on 4-5 May and 11-12 August 2004. Temperature readings were taken with a total submersible thermometer; salinity measurements were obtained with a hand refractometer (Aquatic Ecosystems, Inc.).

Temperature and salinity measurements were also obtained from the surface and subsurface at three stations seaward of the Pago River mouth and within the remnant of the reef channel during ebb and flood tides on 1 June 2004, 13 August 2004 and 7 September 2004. The Orion conductivity-salinity meter with underwater probe was used to measure the surface and subsurface water samples in the deeper reef channel.

WATER CIRCULATION PATTERNS. Fluorescein dye was released and tracked with a compass and transect line from five points in the vicinity of the biological transect sites located approximately 60 to 140 meters seaward of the shoreline in the vicinity of the mouth of the Pago River during ebb and flood tides. On 14 June 2004, the starting points were situated at the southern end of Transects A2, A3 and C1, and the northern end of Transects C1 and C3. The length during which the dye was tracked, i.e., 2, 3, 4 or 5 minutes, depended on changes in direction of the water movement. The leading edge of the dye movement was continuously replenished, when needed, with dye from a plastic spray bottle. During the wet month study on 13 September 2004, the starting points were at the south end of biological Transects B1, B2, C1 and C3 and at the north end of biological Transect B2. Since dye movement was basically unidirectional, the dye was allowed to flow for 5, 10, and 11 minutes. Distance was measured with a transect line and with the Garmin GPS 72.

In an effort to confirm and demonstrate the direction of water movement in the Pago reef channel during ebb tide, pairs of drift drogues with vanes 50 cm long and 36 cm wide were suspended on 1-meter long ropes from a styrofoam circular float. Deeper drogues were not used since there is a tendency for them to be grounded along the sides of the shallow channel slopes. Release and retrieval positions in the channel were fixed with the Garmin GPS 72.

NUTRIENTS. Surface and subsurface water samples for nitrate-nitrite-nitrogen and reactive phosphate were collected along the Pago River and at the three reef channel stations. Subsurface samples were obtained with the Van Dorn water bottle sampler. On the reef flat, the 48 surface samples were collected directly with 50-ml plastic centrifuge tubes with screw caps, after one initial rinse, approximately 15 cm below the surface during both ebb and flood tides. Reef flat samples were obtained at 20 meter intervals along the four transects (A, B, C and D) run perpendicular to shore. Water samples were obtained during 1 June 2004 (ebb and flood tides), 13 August 2004 (ebb tide) and 7 September (flood tide).

HEAVY METALS IN SEDIMENTS. One set of sediment samples (Station 1), consisting of three samples and collected approximately one meter apart, was obtained at the mouth of the Pago River in water 6.2 meters deep; a second set of three sediment samples (Station 11) was collected from the bottom of the inner sector of the channel in water 2 to 2.7 meters deep on 9 June 2004. The six samples were collected with 89-ml glass jars and cover. On 13 August 2004, two sets of three samples of the newly settled mud on the reef flat were collected, about one meter apart, seaward of the river mouth (north end of biological Transect B2) and northeast of the river mouth (middle of biological Transect C2). The samples, collected in 50-ml centrifuge tubes with screw caps, were not as anaerobic as the June sediment samples from the mouth and nearshore channel.

The sediments were analyzed by UOG-WERI for cadmium, chromium, copper, iron, lead, mercury, manganese, nickel, silver and zinc. The heavy metals analyzed from sediment samples were the same elements analyzed from sediments in the Lonfit-Sigua-Pago River system by Olsen and Denton (In Preparation).

Heavy metals were extracted and analyzed by wet oxidation in concentrated hydrochloric and/or nitric acid, similar to EPA method 3050A (Denton et al., 1997). In the case of mercury, "Approximately 2 g of dried sediment was accurately weighed into a 125 ml glass Erlenmeyer flask followed by the slow addition of 15 ml of concentrated nitric acid. After all effervescence had subsided, the flask was capped with a Teflon stopper and heated in boiling water bath for 3 h. After cooling, the contents of each flask was diluted to 75 ml with deionized water, thoroughly mixed and set aside to allow residual particulates to settle out. The solutions were then decanted into clean glass vials and stored at 4°C until required for analyses. Analyses was performed by flameless (cold vapor) AAS and involved the generation of metallic mercury vapor (Hg̃) reduction with 2% stannous chloride …." (Denton et al., 1997).

In the case of the other nine metals, "Approximately 2 g of the dried sediment samples were weighed into 125 ml Erlenmeyer glass flasks, loosely capped with a Teflon stopper and digested with approximately 15 ml of concentrated nitric acid at 110-135°C for 2 days. The digests were then evaporated to dryness and redissolved in 20 ml of 10% nitric acid with gentle warming. The contents of each flask was thoroughly mixed and allowed to stand for several minutes prior to analysis to permit settlement of residual particulates. Analysis was performed by flame AAS, the contents of each flask being aspirated directly into the instrument." (Denton et al., 1997).

BIOLOGICAL CHARACTERISTICS. The benthic community, i.e., seagrasses, algae, invertebrates (mainly, crustaceans and mollusks) and fishes were quantified during the dry month of May 2004 along nine 50-meter long transects run parallel to the shoreline (see Figure 5). The thick layer of mud, i.e., minimum thickness of approximately 5 cm, and the murkiness of the water prevented the quantification of biota during the wet months of August and September 2004.

The location of each transect was marked underwater at three sites, i.e., both ends and the midpoint, by masonry nails or rebars with orange surveyor tape which were hammered into the substrata (limestone or sand), respectively. Each site was marked by a small, fluorescent orange, plastic float (11 cm long and 2 cm in diameter) attached to the nail or rebar by a 2 meter long yellow nylon cord. Coordinates were recorded with a Garmin GPS 72.

The nine inner reef flat transects were located at the following sites:

- Three 50-meter long transects run parallel to shore on the south side of the mouth of Pago River and located approximately 140 m (Transect A2), 120 m (Transect A1) and 100 m (Transect A3) from the shoreline at MLLW.
- Three 50-meter long transects run parallel to shore seaward of the mouth of Pago River and located approximately 140 m (Transect B1), 120 m (Transect B2) and 100 m (Transect B3) from the shoreline at MLLW.
- Three 50-meter transects run parallel to shore on the north side of the mouth of Pago River and located approximately 100 m (Transect C1), 80 m (Transect C2) and 60 m (Transect C3) from the shoreline at MLLW.

Algae and Seagrass. The percent cover of the benthic algal and seagrass assemblages along the transect line were quantified using a modified point-intercept method (Tsuda, 1972). A 50 x 50 cm quadrat frame divided into a grid of 25 squares, each 10 x 10 cm, provided 16 interior "points" where the grid line intersected. The quadrat frame was positioned within one meter on each side of the transect line at 5-meter intervals along the 50-meter long transect (n = 20). Each species and substrata type was recorded at every "point" at which it occurred, i.e., n/16 x 100% = % cover per quadrat. Each 50-meter long belt transect provided a total of 320 points (16 points per quadrat x 20 samples). Each set consisted of three transects (960 points). The modified point-intercept method provided percent cover of the substrata, i.e., sand, mud-sand, rubble and limestone pavement, and algal and seagrass species.

Invertebrates. Counts of different species of invertebrates, primarily mollusks and crustaceans, were made during ebbing low tide (i.e., +1.0 to -0.3 feet) along a two-meter wide 10-meter long belt transect, i.e., one meter wide on both sides of a 10-meter long segment of the transect, i.e., 10 m x 2 m or 20 square meters, or a total of five 20-square meter segments along the 50-meter long transect. Observations were first made along one side of the transect line and secondly along the other side of the transect line within each 10-meter long segment.

Fishes. Fishes were counted within a strip approximately 2.5 meters on both sides of the transect line (area = 250 sq. m.). After the transect line was deployed, the site was allowed to settle for 10 to 15 minutes. A single observer swam slowly and at a constant pace down the left side of the line and counted all fishes observed on the substrata and in the water column on that side of the line. At the end of the transect line, the observer returned down the opposite side of the line and repeated the counting procedure for that side only. Species identification followed Myers (1999).

RESULTS AND DISCUSSION

Water Depth

INNER REEF FLAT. The mean corrected depths, in relationship to mean lower low water (MLLW), measured at 20-meter intervals along the four 100-meter long transects and positioned perpendicular to the shoreline, i.e., Transects A, B, C and D, are presented in Table 6 and Figure 6. The mean corrected depths are based on the mean of depth measurements obtained on two different days, i.e., during ebb and flood tides, and subsequently corrected to MLLW.

Table 6. Mean corrected depth (m) in relationship to mean lower low water (MLLW) measured during ebb and flood tides on 4-5 June 2004 and 11-12 August 2004, at 20-meter intervals along four 100-meter long perpendicular-to-shore transects. A1, B1, C1 and D1 were positioned approximately at mean high water (MHW). Positive values represent substrata exposed at MLLW.

Station	Distance	June 4-5, 2004		Mean (m)	August 11-12, 2004		Mean (m)
A1	0	+0.36	-0.34	0.01	+0.03	+0.15	0.09
2	20	-0.30	-0.85	-0.58	-0.42	-0.40	-0.41
3	40	-0.46	-1.14	-0.80	-0.71	-1.75	-1.23
4	60	-1.22	-0.93	-1.08	-1.00	-0.82	-0.91
5	80	-0.43	-0.56	-0.50	-0.70	-0.28	-0.49
6	100	+0.20	-0.21	0.01	-0.03	+0.13	0.05
B1	0	+0.06	-0.24	-0.09	-0.05	+0.07	0.01
2	20	-0.10	-0.29	-0.20	-0.18	-0.20	-0.19
3	40	-0.26	-0.54	-0.40	-0.53	-0.62	-0.58
4	60	-0.65	-0.96	-0.81	-0.80	-0.87	-0.83
5	80	-0.43	-0.70	-0.57	-0.76	-0.79	-0.73
6	100	-0.30	-0.47	-0.39	+0.01	-0.03	-0.01
C1	0	+0.03	-0.04	-0.01	-0.05	-0.14	-0.09
2	20	+0.05	-0.24	-0.10	-0.18	-0.12	-0.15
3	40	-0.04	-0.32	-0.18	-0.42	-0.21	-0.32
4	60	-0.02	-0.23	-0.13	-0.14	-0.07	-0.10
5	80	+0.07	-0.12	-0.03	+0.10	-0.05	0.02
6	100	-0.05	-0.13	-0.09	+0.17	+0.15	0.16
D1	0	-0.03	-0.08	-0.06	0.00	-0.01	-0.01
2	20	-0.02	-0.09	-0.06	+0.03	-0.11	-0.04
3	40	+0.07	+0.08	0.08	+0.13	+0.13	0.13
4	60	+0.04	-0.01	0.02	+0.16	+0.07	0.10
5	80	-0.01	-0.01	-0.01	+0.11	+0.04	0.07
6	100	-0.05	-0.12	-0.09	+0.02	-0.04	-0.01

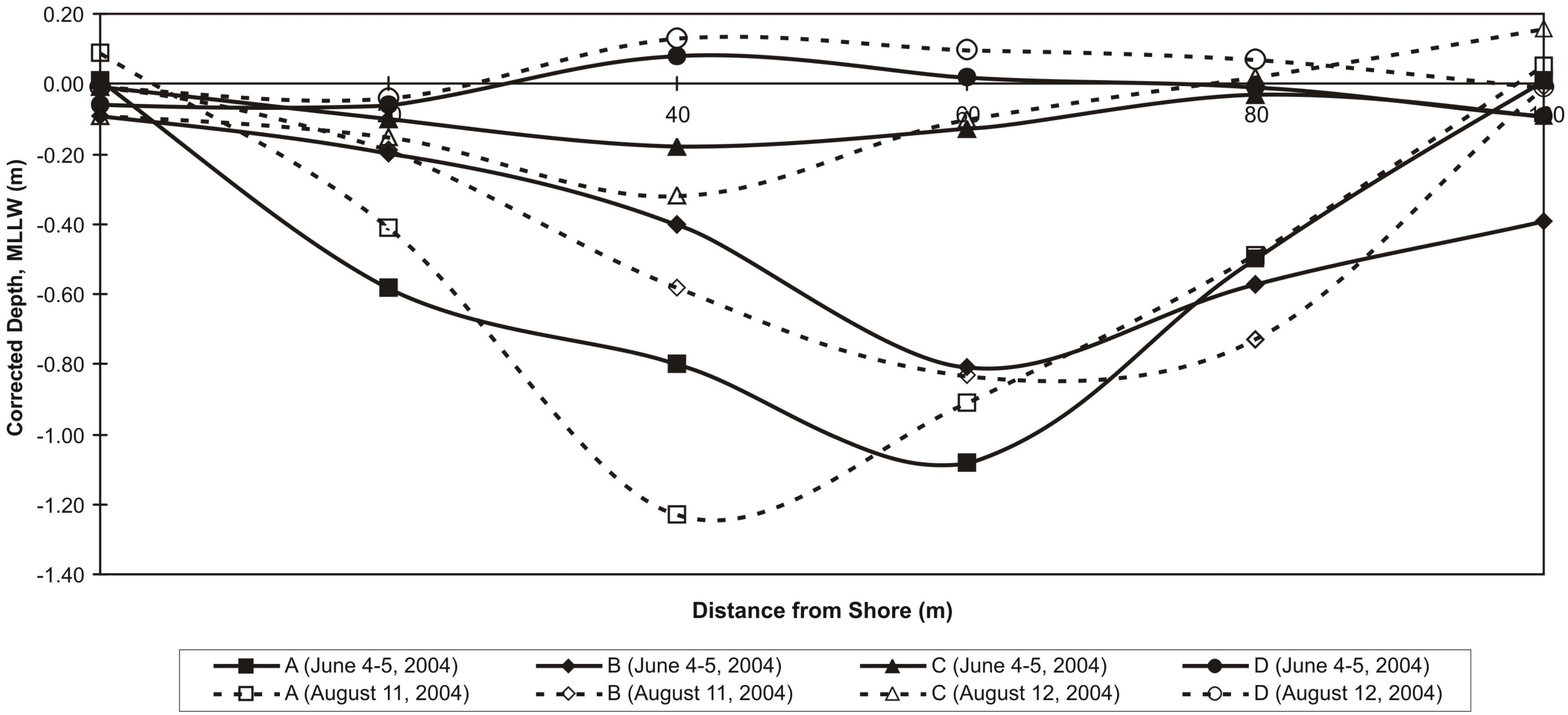

Figure 6. Mean corrected depth (m) in relationship to mean lower low water (MLLW) measured during ebb and flood tides on 4–5 June 2004 and 11–12 August 2004.

Depth measurements were obtained during ebb and flood tides in June and August 2004. At MLLW, Transects A, B and C remain submerged; the mud-sand sill located 30 to 70 meters seaward of the shore on Transect D is exposed during MLLW.

PAGO RIVER AND REMNANT OF PAGO REEF CHANNEL. The lower section of the Pago River ranged in depth from 6.2 meters at the mouth (Station 1) to 1.6 meters deep approximately 1-kilometer upstream (Station 10). The remaining corrected depth (MLLW) obtained during ebbing tide in June 2004 were as follows - Station 2 (3.3 m), S3 (2.4 m), S4 (3.0 m), S5 (2.3 m), S6 (2.1 m), S7 (1.6 m), S8 (2.0 m), S9 (2.5 m.). Depth measurements at the 10 stations along the Pago River were also obtained during flooding tide in June 2004, ebbing tide in August 2004 and flooding tide in September 2004 during collection of bottom water samples and measurements of temperature and salinity. The corrected depths to MLLW were similar to the depths cited above.

The remnant of the Pago Reef Channel near the mouth of the river (Station 11) was 1.2 to 2.6 meters deep at MLLW; the water depth decreased considerably to 0.3 to 0.5 meters to become part of the inner reef flat (Station 12). The shoreward end of the Pago Reef Channel (Station 13) was 1.8 meters deep (MLLW) but rapidly descended to a depth of about 5 meters.

Temperature

INNER REEF FLAT. The surface temperatures (Table 7) obtained during ebb tide (+2.0 to +0.2 feet or +0.61 to +0.06 meters) on 4 May 2004 (0913 to 1144 hours) at the shoreline and at 20-meter intervals along four 100-meter long transects run perpendicular to the shoreline ranged between 28 °C to 33 °C. The surface temperatures were related to the time of day the measurements were made and to some degree in terms of the water depth.

The surface water temperature along Transect A, located northeast and adjacent to the mouth of Pago River, was measured during the morning hours of 0913 and 0944 in water 0.20 to 1.65 meters deep, and ranged from 28 to 28.5 °C. The surface water temperature, obtained between 1000 and 1021 along Transect B and located 52 meters northeast of Transect A and in water 0.30 to 0.98 meters deep, ranged from 29 °C at the shoreline to 29.5 °C along the remaining length of the transect. Transect C located just south of the mouth of the Pago River had a consistent surface temperature of 31 °C in waters 0.10 to 0.23 meters deep during 1042 and 1103. The surface temperature along the shallow Transect D, i.e., 0.03 to 0.14 meters deep, located 62

Table 7 . Profile of surface temperature in °C at 20-meter intervals along 100-meter long transects (A-D) during ebb and flood tides on inner reef flat of Pago Bay. Measurements obtained on 4-5 May and 11-12 August 2004.

Surface Temperature

Distance from	A (May)		A (Aug)		B (May)		B (Aug)		C (May)		C (Aug)		D (May)		D (Aug)	
Shore (m)	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood
0	28.0	31.0	30.0	33.0	29.0	31.0	31.0	34.0	31.0	33.0	29.0	31.0	33.0	31.0	29.0	38.0
20	28.0	31.0	29.0	31.0	29.5	31.0	29.0	30.0	31.0	32.0	28.0	29.0	32.0	32.0	28.0	37.0
40	28.0	31.0	29.0	31.0	29.5	31.0	29.0	31.0	31.0	32.0	28.0	29.0	33.0	31.0	29.0	36.0
60	28.0	31.0	29.0	30.0	29.5	31.0	29.0	30.0	31.0	32.0	28.0	29.0	32.0	31.0	28.0	38.0
80	28.5	31.0	30.0	30.0	29.5	31.0	29.0	30.0	31.0	31.0	28.0	30.0	31.5	31.0	28.0	35.0
100	28.5	31.0	28.0	32.0	29.5	31.0	31.0	31.0	31.0	32.0	29.0	30.0	31.0	31.5	28.0	35.0

meters south of Transect C, showed surface temperature of 31.0°C in water 0.14 meters deep and 33°C in water 0.03 meters deep during the near-noon period (1126 to 1144).

During flood tide (-0.2 to +0.6 feet or –0.06 to +0.18 meters), the temperatures along Transects A and B were constant at 31°C in waters ranging from 0.28 to 1.10 meters deep during 1430 and 1514. The surface water temperature along Transects C and D ranged from 31°C to 33°C in water 0.06 to 0.37 meters deep during 1529 and 1610.

On 11 August 2004, water temperature readings obtained along Transects A and B during ebb and flood tides showed similar trends as shown during the May 2004 measurements. Temperature was higher during flood tides. Water temperature obtained along the shallow Transect D showed high temperatures during flood tide, i.e., 35 to 38°C as opposed to temperatures of 18.0 to 29.0°C obtained during ebb tide. In this case, water depth was not a factor since the depth during sampling during both tidal cycles were similar, i.e., 3 to 19 cm (mean of 13 cm) during flood tide and 6 to 22 cm (mean of 14.5 cm) during ebb tide. Water temperatures along Transect C were slightly higher during flood tide (29.0 to 31.0°C) than at ebb tide (28.0 to 29.0°C); the water depth during sampling ranged from 10 to 45 cm (mean of 31 cm) at flood tide and 5 to 59 cm (mean of 27 cm) at ebb tide.

PAGO RIVER AND REMNANT OF PAGO REEF CHANNEL. During ebb tide (Table 8), the surface water temperature along the Pago River in June 2004 ranged from 29.0 to 31.5°C, and the subsurface water temperature, i.e., 0.5 meters above substrata, ranged from 28.8 to 30.7°C. During flood tide, the surface water temperature ranged from 29.7 to 33.1°C, and the subsurface water temperature ranged from 28.8 to 31.0°C. In the majority of cases upstream of Station 6, the water temperatures of the brackish surface water layer were equal or slightly cooler than the subsurface seawater. The trees along both sides of the riverbanks provided a shading effect along the narrow Pago River.

During the August 2004 (ebb tide) and the September 2004 (flood tide) samplings along the Pago River, all stations, except Station 1 at ebb tide, showed lower surface water samples than subsurface samples. During ebb tide, the fresh or brackish surface water ranged from 27.4 to 29.3°C as opposed to the saline subsurface water which ranged from 29.2 to 29.7°C. There was a decrease in surface water temperature as one moved upstream from the river mouth during the ebbing tide. There was a slight increase in subsurface water temperature as one moved upstream. Both surface and subsurface water temperatures showed similar trends during flood tide.

Table 8. Profile of surface and subsurface temperature in °C during ebb and flood tides along the Pago River and remnant of the inner reef channel. River and reef channel measurements obtained on 1 June 2004 (ebb and flood), 13 August 2004 (ebb), and 7 September 2004 (flood). GPS coordinates provided.

Station No.	**Latitude (°N)**	**Longitude (°E)**	**Distance (m)**	**Ebb (June)**		**Flood (June)**		**Ebb (Aug)**		**Flood (Sept)**	
				Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface
PAGO RIVER (Inland)											
1	13.42174147	144.78392819	0	31.5	28.8	33.1	28.8	29.3	29.2	27.7	35.0
2	13.42245896	144.78313384	117	29.8	29.0	32.3	29.3	28.2	29.3	28.7	29.0
3	13.42295668	144.78209213	243	29.7	29.5	32.5	30.9	28.0	29.5	27.3	29.0
4	13.42285099	144.78145712	313	30.4	29.5	30.7	29.6	27.8	29.4	27.0	29.0
5	13.42181087	144.78124447	431	30.1	30.1	30.6	30.3	27.6	29.4	27.0	29.3
6	13.42084126	144.78051659	565	30.1	30.2	31.0	29.9	27.6	29.5	26.9	29.1
7	13.42017062	144.77903492	741	30.7	30.7	30.7	31.0	27.6	29.6	26.6	29.1
8	13.42032854	144.77780454	875	30.7	30.7	29.8	30.7	27.5	29.6	26.6	29.2
9	13.42106614	144.77815138	965	29.3	30.6	29.7	30.6	27.5	29.7	26.5	29.3
10	13.42157694	144.77830703	1002	29.0	30.7	30.7	30.8	27.4	29.6	26.5	29.4
PAGO RIVER (Seaward from Shore)											
11	13.42186653	144.78477619	60	30.8	29.0	32.0	33.1	28.8	28.9	29.6	29.2
12	13.42184985	144.78542327	130	31.5	30.7	32.8	32.5	29.0	29.0	29.6	30.3
13	13.42022452	144.78731741	404	30.1	29.7	31.6	31.2	29.4	29.0	29.6	28.2

During both ebb and flood tides in June 2004 (see Table 8), the subsurface water temperatures were cooler than the surface water temperature along the remnant of the reef channel (Stations 11 and 12) and the inland sector of the reef channel (Station 13), except during flood tide at Station 11. In August 2004, both surface and subsurface water seemed mixed at ebb tide based on similarity of water temperatures. Likewise, the water temperature of surface and subsurface water did not show any stratification during flood tide.

Salinity

INNER REEF FLAT. Based on the surface salinity values (Table 9) obtained during the dry month of May 2004 along the four transects run perpendicular to the shoreline, the surface waters northeast of the mouth of the Pago River (Transects A and B) were less saline than at the two transects located south of the river mouth (Transects C and D). During ebb tide, the surface water south of the Pago River mouth was saline, i.e., between 32 and 33 ppt. The surface salinity along the shoreline south of the river mouth was slightly lower at 30 ppt. During flood tide, the salinity of the surface water adjacent and south of the Pago River mouth was slightly lower, i.e., between 29 and 31 ppt.

Surface salinity readings along Transect A in May 2004 located adjacent and northeast of the Pago River mouth ranged from 20 to 27 ppt during ebb tide and ranged from 15 to 23 ppt during flood tide. Salinity readings during both ebb and flood tides along Transect B located just 52 meters northeast of Transect A ranged from 22 to 26 ppt within 40 meters from shore. Surface salinity ranged from 28 to 31 ppt in waters 60 to 100 meters from shore. Salinity readings increased as one moved seaward from the shoreline.

During the rainy season (August 2004), water flowed both northeast and south from the river mouth as evidenced by the low salinity readings at ebb tide along all four transects, i.e., Transect A (4.0 to 11.0 ppt), Transect B (5.0 to 23 ppt), Transect C (5.0 to 8.0 ppt) and Transect D (7.0 to 10.0 ppt). During flood tide, the salinity increased but still must be considered lower than normal seawater (i.e., 34.0 to 35.0 ppt), i.e., Transect A (10.0 to 25 ppt), Transect B (10.0 to 22.0 ppt), Transect C (9.0 to 17 ppt) and Transect D (13.0 to 20.0 ppt).

PAGO RIVER AND REMNANT OF PAGO REEF CHANNEL. During both ebb and flood tides (Table 10) in June 2004, the salinity of the subsurface water, 0.5 meters above the substrata, along the Pago River remained saline as one moved from the mouth of the river (35.2

Table 9 . Profile of surface salinity in ppt at 20-meter intervals along 100-meter long transects (A-D) during ebb and flood tides on inner reef flat of Pago Bay. Measurements obtained on 4-5 May and 11-12 August 2004.

Surface Salinity

Distance from Shore (m)	**A (May)**		**A (Aug)**		**B (May)**		**B (Aug)**		**C (May)**		**C (Aug)**		**D (May)**		**D (Aug)**	
	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood
0	20.0	15.0	11.0	21.0	23.0	22.0	5.0	22.0	30.0	29.0	8.0	10.0	30.0	31.0	10.0	15.0
20	20.0	15.0	9.0	25.0	23.0	23.0	5.0	17.0	32.0	31.0	5.0	17.0	32.0	30.0	8.0	15.0
40	20.0	15.0	8.0	17.0	26.0	23.0	5.0	15.0	33.0	32.0	5.0	10.0	33.0	30.0	9.0	20.0
60	20.0	21.0	4.0	10.0	28.0	24.0	5.0	10.0	33.0	30.0	5.0	10.0	33.0	29.0	7.0	20.0
80	25.0	22.0	7.0	13.0	31.0	27.0	5.0	14.0	33.0	30.0	5.0	9.0	33.0	29.0	7.0	13.0
100	27.0	23.0	9.0	10.0	31.0	29.0	23.0	16.0	33.0	31.0	7.0	9.0	32.0	29.0	7.0	15.0

Table 10. Profile of surface and subsurface salinity in ppt during ebb and flood tides along the Pago River and remnant of the inner reef channel. River and reef channel measurements obtained on 1 June 2004 (ebb and flood), 13 August 2004 (ebb), and 7 September 2004 (flood).

Station No.	Distance (m)	Ebb (June)		Flood (June)		Ebb (Aug)		Flood (Sept)	
		Surface	Subsurface	Surface	Subsurface	Surface	Subsurface	Surface	Subsurface
PAGO RIVER (Inland)									
1	0	30.4	35.2	28.0	35.7	6.8	35.0	2.7	28.5
2	117	20.6	35.1	23.0	35.5	4.1	34.7	2.8	34.7
3	243	20.2	35.3	27.3	35.2	3.8	34.5	1.6	34.6
4	313	30.8	35.4	21.2	35.3	3.9	35.0	1.2	34.6
5	431	29.9	35.2	20.2	35.2	3.5	34.9	1.2	34.3
6	565	30.6	35.1	13.6	35.2	3.4	34.8	1.2	34.3
7	741	30.9	34.8	10.7	35.2	3.4	34.8	1.3	33.7
8	875	21.2	34.8	14.9	35.5	3.0	34.7	0.7	33.2
9	965	16.1	34.7	18.5	35.3	2.6	34.4	0.4	33.0
10	1002	10.3	34.6	31.8	35.0	2.7	34.6	0.4	32.8
PAGO RIVER (Seaward from Shore)									
11	60	34.1	35.3	29.1	31.9	29.0	34.8	14.3	33.8
12	130	33.9	35.1	30.4	33.6	34.2	34.3	12.1	27.4
13	404	34.9	34.0	34.7	35.4	31.2	35.2	26.5	36.2

ppt at ebb and 35.7 ppt at flood) upstream to Station 10 (34.6 ppt at ebb and 35.0 ppt at flood). During ebb tide, the salinity readings of the surface water in June 2004 were 30.4 ppt at the mouth, 20.2 ppt to 20.6 ppt in the estuary (Stations 2 and 3), and 10.3 ppt at Station 10 located one kilometer upstream. During flood tide, the salinity of the surface water remained brackish as one moved upstream with the exception of Station 10 where inadvertent mixing, i.e., outboard engine, of the two layers most likely occurred during the June measurements.

During the wet months of August and September 2004, the salinity of the surface water along the Pago River was much lower than the subsurface saline water, i.e., 2.6 to 6.8 ppt at ebb tide and 0.4 to 2.8 ppt at flood tide. The salinity of the subsurface water remained saline (i.e., 28.5 to 34.8 ppt) from the river mouth to Station 10 during both ebb and flood tides.

Temperature and Salinity Vertical Profiles

On 9 June 2004, *in situ* temperature and salinity vertical profiles were taken at Station 10 in water 2.4 meters deep, i.e., surface (28.8°C and 5.0 ppt), 0.5 m (30.2°C and 30.4 ppt), 1.0 m (30.4°C and 34.0 ppt), 2.0 m (30.1°C and 34.1 ppt), and between Stations 6 and 7 in water 3.0 m deep, i.e., surface (30.1°C and 18.7 ppt), 0.5 m (30.8°C and 34.1 ppt), 1.5 m (29.6°C and 34.9 ppt) and 2.5 m (29.6°C and 34.9 ppt).

During the flooding tide on 7 September 2004, a temperature and salinity profile was taken at Station 4, located upstream of the Pago Bay Bridge, in water 2.9 meters deep, i.e., surface (27.0°C and 1.2 ppt), l.0 m (27.3°C and 2.6 ppt), 2.0 m (29.0°C and 34.2 ppt), 2.6 m (29.0°C and 34.6 ppt). A temperature and salinity profile at the Pago River mouth showed a brackish water layer in the upper one meter with saline water below, i.e., surface (27.7°C and 2.7 ppt), 1 m (28.3°C and 4.5 ppt, 2 m (28.7°C and 33.9 ppt), 3 m (28.8°C and 34.6 ppt) and 4 m (28.8°C and 34.8 ppt). During both ebb and flood tides, the salinity of the surface water increased as one moved seaward from the mouth of the Pago River towards the Pago reef channel.

The salinity profile strongly supports Matson's (1991) previous finding that the freshwater and brackish surface layer lies within 0.5 meters of the surface and that the denser seawater occurs below the 0.5-meter level along the lower section of the Pago River. The limit of the seawater intrusion upstream could not be delineated since the vegetation from both sides of the banks obstructed movement upstream along the river approximately 100 meters beyond Station 10.

Temperature and salinity profiles were obtained adjacent to Station 13 in the reef channel at flood tide on 7 September 2004, i.e., surface (29.6°C and 26.5 ppt), 1 m (29.2°C and 29.4 ppt), 2 m (28.3°C and 36.0 ppt), 3 m (28.3°C and 36.1 ppt), 4 m (28.3°C and 36.2 ppt), 5 m (28.2°C and 36.2 ppt) and 5.6 m (28.2.°C and 36.2 ppt), and at ebb tide on 17 September 2004, i.e., surface (30.0°C and 33.5 ppt), 1 m (29.3°C and 34.0 ppt), 2 m (28.9°C and 34.3 ppt), 3 m (29.0°C and 34.3 ppt), 4 m (29.0°C and 34.3 ppt), 4 m (29.0°C and 34.3 ppt), 5 m (29.3°C and 34.5 ppt) and 6 m (29.3°C and 34.5 ppt). As shown, the outer channel water was not vertically stratified.

Water Circulation

The general water circulation pattern on the reefs of Pago Bay, as described previously, was best illustrated by Marsh et al. (1982). During flood tides, seawater enters the mouth of the Pago River and moves more than 1 kilometer upstream with the approximately 0.5-meter thick fresh or brackish water layer at the surface. During neap tide, the stratified water column moves downstream towards the mouth of the Pago River and disperses over the shallow, inner reef flat. The rise and fall of the water level in the Pago River can be visibly seen when traversing with a boat under the Pago Bridge on Route No. 4, i.e., 275 meters upstream from the mouth of the Pago River. During neap tide on 14 June 2004 (ebbing from +0.3 to +0.03 m), fluorescein dye released at the middle of the mouth of the Pago River moved in a southeasterly direction (130°) towards the exposed boulders at a speed of 8.8 meters per minute against winds blowing 2.8 meters per second from the southeast (128°).

Table 11 and Figure 7 present the results of the tracking of fluorescein dye during both ebb and flood tides observed on the inner reef flat in the vicinity of the biological transects located northeast and south of the mouth of the Pago River on 14 June 2004. During morning ebb tide, the winds were generally blowing from the southeast and speed ranged from 2.5 to 3.8 meters per second; during the afternoon flood tide, the winds continued to blow from the southeast and speed ranged from 3.2 to 4.4 meters per second.

- Transect A2 (South End). During ebb tide (+0.24 to +0.15 m, MLLW), water moved in a northerly to north-northeasterly direction at an average speed of 5.0 meters per minute. During flood tide (+0.06 to +0.09 m), average water movement slowed to 1.0 meter per minute and followed a zigzag pattern towards the northwest.
- Transect A3 (South End, approximately 40 meters inshore of Transect A2). During ebb tide (+0.15 to +0.09 m, MLLW), water moved in a north-northeasterly and northeasterly direction at a mean speed of 4.4 meters per minute. During flood tide (+0.09 to +0.15 m, MLLW), water moved slowly in a northeast direction at a mean speed of 1.1 meters per minute.
- Transect C1 (South End). During ebb tide (+0.09 to +0.06 m, MLLW), water movement was generally towards the southwest at a mean speed of 2.3 meters per minute. During flood tide (+0.15 to +0.18 m), water movement was generally towards the southeast at a mean speed of 2.0 meters per minute.

Table 11. Water circulation and wind movement on the inner reef flat seaward of the Pago River mouth, 14 June 2004.

Station	Start Time	Minutes	Current			Wind	
			Distance (m)	Speed (m/min)	Direction (°)	Speed (m/sec)	Direction (°)
EBB							
A2 (S)	0930 (+0.8')	2	5.4	2.7	12	2.5	120
		2	7.3	3.6	2		
		3	16.4	5.5	26		
		3	18.3	6.1	36		
		3	16.0	5.3	10		
		3	19.1	6.4	35		
		3	16.7	5.6	34	3.8	126
A3 (S)	1002 (+0.5')	3	9.2	3.1	30	2.7	114
		3	14.7	4.9	24		
		3	16.1	5.4	24		
		3	16.3	5.4	14		
		3	15.6	5.2	38		
		3	12.9	4.3	3		
		3	12.0	4.0	42		
		3	8.6	2.9	46		
C1 (S)	1042 (+0.3')	3	9.4	3.1	272	3.2	144
		2	3.5	1.8	240		
		2	3.0	1.5	158		
		2	2.3	1.2	258		
		3	11.0	3.7	100		
C1 (N)	1104 (+0.2')	3	4.5	1.5	72	3.4	126
		3	8.2	2.7	120		
		3	10.3	3.4	120		
		3	15.7	5.2	120		
C3 (N)	1125 (+0.2')	5	Back and forth movement			2.7	130

Table 11. Continued.

Station	Start Time	Minutes	Current			Wind	
			Distance (m)	**Speed (m/min)**	**Direction (°)**	**Speed (m/sec)**	**Direction (°)**
FLOOD							
A2 (S)	1315	5	5.0	1.0	338	3.6	140
	(+0.2')	5	3.6	0.7	280		
		5	6.6	1.3	12		
		5	4.2	0.8	320		
A3 (S)	1258	4	3.7	0.9	56	4.4	150
	(+0.3')	4	6.0	1.5	350		
		5	3.9	0.8	296		
C1 (S)	1350	5	11.3	2.3	158	3.2	128
	(+0.5')	5	8.2	1.6	218		
		5	9.0	1.8	170		
		5	12.6	2.5	152		
C1 (N)	1420	5	18.0	3.6	92		
	(+0.6')	4	13.0	3.2	120		
C3 (N)	1435	5	8.1	1.6	234	3.3	150
	(+0.7')	5	10.0	2.0	116		
		5	7.0	1.4	38		

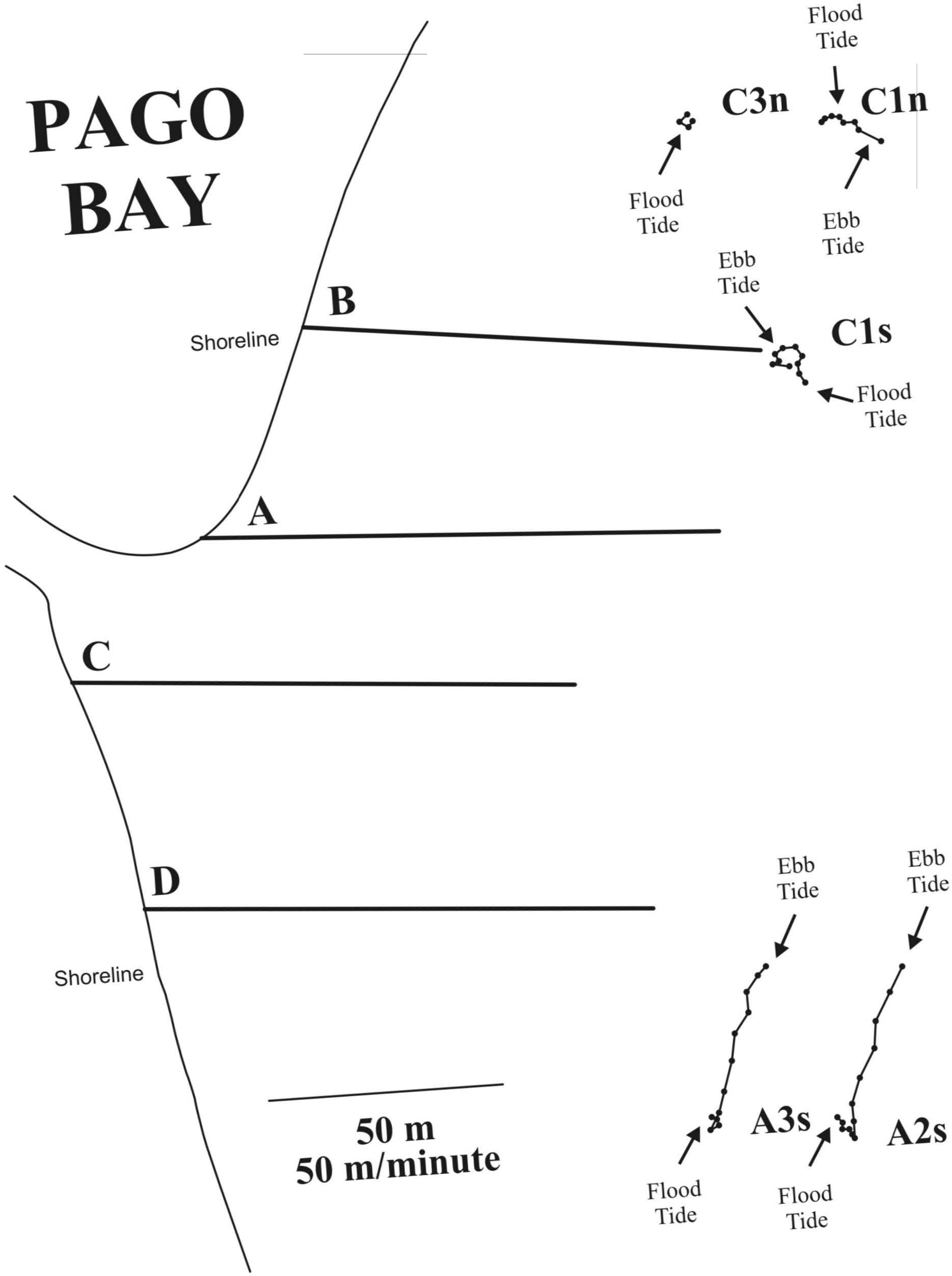

Figure 7. Speed of current (meters per minute) at five stations on the inner reef flat seaward of the Pago River mouth, 14 June 2004.

- Transect C1 (North End). During ebb tide and approaching slack tide (+0.06 m), water moved at a mean speed of 3.2 meters per minute towards the southeast. Water movement was in a similar southeast direction at a mean speed of 3.4 meters per minute during flood tide (+0.18 to +0.21 m, MLLW).
- Transect C3 (North End, approximately 40 meters inshore of Transect C1). During ebb tide and approaching slack tide (+0.06 m), the fluorescein dye simply moved back and forth during a 5-minute time period. During flood tide (+0.21 to +0.24 m), water movement slowed to a mean of 1.7 meters per minute with movement in a counterclockwise manner.

On 13 September 2004, dye studies (Table 12 and Figure 8) were conducted on the reef flats during ebb tide (0.58 m to 0.49 m deep) and flood tide (0.46 m to 0.61 m deep) at biological Transects B1 (south end), B2 (south end), B2 (north end), C1 (south end) and C3 (south end). Replicate runs were conducted at each station, except at the south end of B2 where only one run was conducted since little water movement occurred. The winds were blowing from the northwest during most of day at speeds of 2.4 to 4.5 meters per second. The one exception was in the late afternoon at 1542 when the wind was blowing from the east at 1.5 m/sec.

- Transect C3 (South End). During ebb and flood tides, water movement was generally towards the northeast and east.
- Transect C1 (South End). During ebb tide, water movement was towards the northeast, while water movement was towards the southeast and south during flood tide.
- Transect B2 (North End). During ebb tide, water movement was towards the northeast and north; water movement was towards the south during flood tide.
- Transect B2 (South End). During ebb tide, very little movement occurred; the dye simply moved back and forth (west and east). During flood tide, water movement was towards the west.
- Transect B1 (South End). During ebb tide, water moved towards the north and northeast and flowed in the opposite direction, i.e. southwest, during flood tide.

During neap tide, pair of drogues set below one-meter long lines attached to a float on the surface were released at three points (Figure 9) within the reef channel. Drogues released from Stations 1 and 2 moved towards the southeast towards the channel mouth over a 0.85 (Station 1) and 1.00 hour (Station 2) time period. The drogues released at Station 3 initially moved towards the southeast, then moved slowly back over the one-hour period. The wind direction over the study period varied from north to southeast with wind speed of 0.7 to 3.2 meters per second.

Table 12. Water circulation and wind movement on the inner reef flat seaward of the Pago River mouth, 13 September 2004.

Station	No.	Start Time	Tide (ft)	Minutes	Current			Wind	
					Distance (m)	Speed (m/min)	Direction (°)	Speed (m/sec)	Direction (°)
EBB									
C3 (S)	1	0857	+1.9	10	56	5.6	70	3.1	290
	2	0908		11	89	8.1	80		
C1 (S)	3	0930	+1.9	10	54	5.4	56	3.7	264
	4	0944		10	60	6.0	60		
B2 (N)	5	1002	+1.9	10	21	2.1	23	4.2	280
	6	1017		10	19	1.9	4		
B2 (S)	7	1033	+1.9	5	3 (back and forth)	0.6	Shore to margin		
B1 (S)	8	1043	+1.6	10	34	3.4	19	4.2	289
	9	1055		10	37	3.7	32	4.5	286
FLOOD									
C3 (S)	10	1410	+1.5	10	31	3.1	64	4.5	286
	11	1422		10	35	3.5	76		
C1 (S)	12	1435	+1.6	5	17	3.4	90	3.8	270
				5	14	2.8	154		
	13	1448		10	53	5.3	166		
B2 (N)	14	1502	+1.6	10	47	4.7	174	2.4	260
	15	1514		10	61	6.1	190		
B2 (S)	16	1532	+1.6	5	11	2.2	242	2.4	252
B1 (S)	17	1542	+2.0	10	41	4.1	224	1.5	100
	18	1554		10	55	5.5	232		

Nutrients in Water

Table 13 shows values of nitrate-nitrite-nitrogen (NO_x) and reactive phosphate (PO_4-P) from the surface water along four 100-meter long transects (Transects A, B, C and D) run perpendicular to the shoreline during both ebb and flood tides during May and August 2004. Reactive phosphate values on the reef flat during May 2004 were about five times lower than the numerical water quality exceedance value (i.e., 0.05 mg/l) used by Guam Environmental Protection Agency (2001) for M2 marine waters. Reactive phosphate values obtained during the wet season were, likewise, below the exceedance value of 0.05 mg/l.

NO_x values obtained in May 2004, however, exceeded the numerical water quality exceedance value of 0.20 mg/l for M2 marine waters (GEPA, 2001) along Transects B (3 of 6 samples during flood tide), C (3 of 6 samples during ebb tide) and D (12 of 12 samples during flood and ebb tides). NO_x values were higher during August 2004 along Transects A, B and C, and were similar during ebb tide along Transect D. During flood tide, the May NO_x values were higher than the August values.

Table 14 presents the surface and subsurface NO_x values sampled along the lower one kilometer of the Pago River and along the remnant of the Pago reef channel adjacent and seaward of the Pago River mouth during 1 June 2004 (ebb and flood tide), 13 August 2004 (ebb tide) and 7 September 2004 (flood tide). All surface and subsurface NO_x values obtained in June 2004 were less than the 0.50 mg/l exceedance criterion for S3 river waters. The fresh to brackish surface water collected during ebb tide in August 2004 had NO_x values ranging from 0.489 to 0.526 mg/l. NO_x values ranged from 0.396 to 0.418 mg/l during flood tide sampling in September 2004. The values for NO_x in the subsurface saline water collected in August and September 2004 had much higher values, i.e., <0.002 to 0.516 mg/l (ebb tide) and 0.063 to 0.404 mg/l (flood tide), than the June 2004 samples.

Reactive phosphate values (Table 15) in the surface river waters were similar to the surface waters on the inner reef flat. All surface and subsurface PO_4-P values were substantially less than the 0.10 mg/l exceedance criterion for S3 river waters (GEPA, 2001). There was a slight tendency for the fresh and brackish surface waters collected in August 2004 to have a higher PO_4-P value than samples collected in June 2004. Generally, the saline subsurface waters had similar PO_4-P values. Reactive phosphate values seaward of the Pago River mouth in both surface and subsurface waters were higher in samples obtained during flood tide.

Table 13. Surface nitrate-nitrite-nitrogen (NO_x) and reactive phosphate (PO_4-P) values from the inner reef flat in the vicinity of the Pago River mouth. Samples taken on 4 May 2004 (ebb, Transects A-D), 5 May 2004 (flood, Transects A-D), 11 August 2004 (ebb and flood, Transects A-B) and 12 August 2004 (ebb and flood, Transects C-D). Analyses conducted by UOG-WERI.

Station	Distance from Shore (m)	May: NO_x (mg/l)		Aug: NO_x (mg/l)		May: PO_4-P (mg/l)		Aug: PO_4-P (mg/l)	
		Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood
Transect A									
1	0	0.185	0.177	0.318	0.187	0.005	0.005	0.009	<0.002
2	20	0.181	0.132	0.315	0.098	0.005	0.006	0.025	<0.002
3	40	0.167	0.138	0.437	0.173	0.006	0.004	0.006	<0.002
4	60	0.154	0.122	0.316	0.315	0.005	0.004	0.002	<0.002
5	80	0.121	0.129	0.336	0.352	0.003	0.004	0.012	0.008
6	100	0.086	0.089	0.371	0.392	0.003	0.003	0.019	0.011
Transect B									
1	0	0.162	0.155	0.245	0.187	0.009	0.006	0.017	0.032
2	20	0.157	0.157	0.389	0.216	0.005	0.005	0.010	<0.002
3	40	0.143	0.194	0.381	0.296	0.004	0.005	0.004	0.002
4	60	0.107	0.274	0.412	0.395	0.003	0.003	0.005	0.005
5	80	0.107	0.255	0.367	0.317	0.003	0.004	0.004	0.003
6	100	0.096	0.273	0.333	0.066	0.003	0.003	0.014	0.026
Transect C									
1	0	0.312	0.088	0.342	0.329	0.005	0.008	0.013	0.012
2	20	0.262	0.162	0.374	0.332	0.004	0.004	0.020	0.007
3	40	0.223	0.182	0.392	0.346	0.003	0.004	0.011	0.009
4	60	0.188	0.083	0.398	0.355	0.005	0.003	0.012	0.011
5	80	0.177	0.082	0.387	0.352	0.004	0.003	0.013	0.008
6	100	0.161	0.109	0.365	0.346	0.004	0.003	0.011	0.009
Transect D									
1	0	0.358	0.200	0.360	0.223	0.014	0.004	0.010	0.007
2	20	0.214	0.286	0.377	0.231	0.003	0.003	0.015	0.008
3	40	0.284	0.356	0.357	0.251	0.003	0.003	0.008	0.014
4	60	0.303	0.427	0.400	0.198	0.004	0.003	0.012	0.008
5	80	0.360	0.421	0.345	0.214	0.004	0.003	0.009	0.009
6	100	0.407	0.472	0.363	0.265	0.004	0.004	0.016	0.012

Table 14. Surface and subsurface nitrate-nitrite-nitrogen (NO_x) along the lower sector of the Pago River and along the remnant of the Pago reef channel, 1 June 2004 (ebb and flood tides), 13 August 2004 (ebb tide) and 7 September 2004 (flood tide). Analyses conducted by UOG-WERI.

Station	Distance (m) from mouth	Surface NOx (mg/l)		Surface NOx (mg/l)		Subsurface NOx (mg/l)		Subsurface NOx (mg/l)	
		Ebb (June)	Flood (June)	Ebb (Aug)	Flood (Aug)	Ebb (June)	Flood (June)	Ebb (Aug)	Flood (Sept)
PAGO RIVER (Inland)									
1	0	0.073	0.308	0.526	0.409	0.004	<0.002	0.013	0.063
2	117	0.098	0.103	0.489	0.400	<0.002	<0.002	0.420	0.094
3	243	0.116	0.146	0.490	0.415	0.006	0.004	0.211	0.097
4	313	0.289	0.366	0.515	0.421	0.006	0.009	0.031	0.084
5	431	0.289	0.299	0.509	0.411	<0.002	<0.002	<0.002	0.079
6	565	0.391	0.335	0.503	0.398	0.003	<0.002	0.115	0.284
7	741	0.062	0.380	0.497	0.396	0.007	<0.002	0.474	0.345
8	875	0.065	0.059	0.513	0.418	0.007	0.011	0.004	0.089
9	965	0.067	0.059	0.518	0.397	0.011	0.003	0.359	0.319
10	1002	0.060	0.073	0.524	0.408	0.015	0.003	0.516	0.404
PAGO RIVER (Seaward from Shore)									
11	60	0.050	0.410	0.432	0.285	<0.002	0.080	0.051	0.307
12	130	0.073	0.162	0.077	0.304	0.003	0.057	0.033	0.251
13	404	0.024	<0.002	0.304	0.169	0.004	<0.002	0.005	0.003

Table 15. Surface and subsurface reactive phosphate (PO4-P) along the lower sector of the Pago River and along the remnant of the Pago reef channel, 1 June 2004 (ebb and flood tides), 13 August 2004 (ebb tide) and 7 September 2004 (flood tide). Analysis conducted by UOG-WERI.

Station	Distance (m)	Surface PO4-P (mg/l)		Surface PO4-P (mg/l)		Subsurface PO4-P (mg/l)		Subsurface PO4-P (mg/l)	
	from mouth	Ebb (June)	Flood (June)	Ebb (Aug)	Flood (Aug)	Ebb (June)	Flood (June)	Ebb (Aug)	Flood (Sept)
PAGO RIVER (Inland)									
1	0	0.004	<0.002	0.009	0.017	<0.002	<0.002	<0.002	<0.002
2	117	<0.002	0.004	0.007	0.016	<0.002	0.005	0.006	<0.002
3	243	0.005	<0.002	0.007	0.016	<0.002	<0.002	0.002	<0.002
4	313	<0.002	0.005	0.005	0.017	0.004	<0.002	<0.002	<0.002
5	431	0.005	0.005	0.006	0.017	0.004	0.005	<0.002	<0.002
6	565	0.005	0.013	0.007	0.016	<0.002	<0.002	0.004	0.014
7	741	0.005	0.011	0.007	0.016	0.005	0.004	0.007	0.017
8	875	0.005	0.008	0.008	0.018	<0.002	0.007	<0.002	0.002
9	965	0.006	0.005	0.008	0.016	0.003	0.089	0.005	0.018
10	1002	0.009	0.008	0.008	0.016	0.005	0.003	0.008	0.021
PAGO RIVER (Seaward from Shore)									
11	60	<0.002	0.006	0.005	0.013	0.003	<0.002	<0.002	0.014
12	130	<0.002	<0.002	<0.002	0.012	<0.002	<0.002	<0.002	0.009
13	404	<0.002	<0.002	0.003	0.003	<0.002	<0.002	<0.002	<0.002

Heavy Metals in Sediments

Table 16 presents the concentration of heavy metals extracted from the muddy sediments collected in water 6.2 meters deep at the mouth of the Pago River (Station 1) and at the near-shore channel (Station 11), 1.2 to 2.6 meters deep, located 75 meters east of the river mouth on 9 July 2004, as well as concentrations from supposedly fresh mud deposited on the reef flat during the rainy season, i.e., 18 August 2004.

PAGO RIVER MOUTH AND NEAR-SHORE CHANNEL. Except for the concentration of manganese, the concentrations of heavy metals at both sites were similar. Manganese ranged between 372 and 418 ppm at the river mouth; lower concentrations, i.e., 258 to 288 ppm, were found in the reef channel. Both iron and manganese occur naturally in Guam's soil and parent rock materials. The concentrations of iron at both the river mouth and reef channel were high with similar means of 41,570 ppm and 41,490 ppm at the river mouth and in the reef channel, respectively. Iron is the fourth most abundant element in the soil after oxygen, aluminum and silica (Siegrist et al., 1997). Approximately 10% of the iron concentrations measured in the Taelayag wetland soil surpassed the marine sediments (Siegrist et al, 1997). Concentrations of manganese in the Taelayag wetland soil were 10 to 20 times higher than concentrations in the marine sediments. Both iron and manganese concentrations were similar to those found by Olsen and Denton (In Prep.) approximately 137 meters upstream of the river mouth and at a second site upstream and adjacent to the Pago Bay Bridge.

In an effort to compare the concentrations of heavy metals obtained in the muddy sediments of the Pago River mouth and channel with a set of sediment quality standards, the Threshold Effects Level (TEL) and Probable Effects Level (PEL) reported by MacDonald et al. (1996) for Florida coastal waters were used as guidelines of sediment quality. The TEL represents the upper limit of the minimum effects range of sediment contaminant concentrations, i.e., highly predictive of nontoxicity; the PEL defines the lower limit of the probable effects range associated with adverse biological effects, i.e., highly predictive of toxicity.

The concentrations of cadmium, silver and mercury in the muddy sediments of the Pago River mouth and channel were more than 169 times lower than the respective TEL values of the three metals. Concentrations of lead were less than the TEL guideline of 5.8 ppm. Denton et al. (1997) found the highest levels of mercury in localized areas of Apra Harbor, i.e., 403 ng/g, most likely attributed to the previous extensive use of anti-fouling paints on ships' hulls. The sources of mercury in Pago Bay may be the incidental burning of domestic refuse and from domestic wastewater. Mercury is highly toxic to marine organisms.

Table 16. Heavy metals in sediments from Pago River mouth and remnant of Pago reef channel collected on 9 June 2004, and from reef flat collected on 18 August 2004. Threshhold Effects Level (TEL) and Probable Effects Level (PEL) taken from McDonald et al. (1996). Analyses conducted by UOG-WERI.

METALS	CONCENTRATIONS (ppm)					
	07/09				08/18	
	Pago River Mouth Range (Mean, N=3)	Pago Reef Channel Range (Mean, N=3)	TEL	PEL	South Reef Flat Range (Mean, N=3)	North Reef Flat Range (Mean, N=3)
Terrigenous Source						
Iron (Fe)	37,500-45,850 (41,570)	40,550-42,030 (41,490)	---	---	42,390-47,170 (45,343)	46,670-50,080 (48,243)
Manganese (Mn)	372-418 (396)	258-288 (272)	---	---	359-407 (379)	468-651 (576)
Less Than TEL						
Cadmium (Cd)	0.02-0.05 (0.0330	0.03-0.04 (0.033)	5.6	70.8	0.01-0.03 (0.017)	0.01-0.02 (0.013)
Silver (Ag)	<0.01 (<0.01)	<0.01 (<0.01)	6.6	60.5	<0.01 (<0.01)	<0.01 (<0.01)
Mercury (Hg)	0.022-0.026 (0.025)	0.020-0.026 (0.022)	7.8	36.7	0.018-0.020 (0.019)	0.020-0.024 (0.022)
Lead (Pb)	3.06-3.30 (3.20)	3.04-3.15 (3.08)	5.8	58.4	1.17-1.28 (1.23)	0.80-0.96 (0.90)
Mean Greater Than TEL But Less Than PEL						
Copper (Cu)			9	55.9	51.6-52.4 (51.9)	47.4-55.1 (52.1)
Zinc (Zn)	61.2-63.7 (62.7)	55.0-62.6 (60.0)	3.8	64.8	58.3-67.1 (61.4)	53.9-56.8 (54.9)
Greater Than PEL						
Copper (Cu)	56.8-60.3 (58.5)	54.8-59.9 (58.1)	9	55.9		
Nickel (Ni)	52.7-60.2 (55.7)	52.2-57.3 (55.4)	3.3	9.4	61.2-63.7 (62.5)	57.6-63.6 (60.3)
Chromium (Cr)	85.6-103.8 (96.6)	97.2-106.4 (101.8)	3.5	52.9	60.1-73.1 (65.9)	49.1-62.5 (54.3)

47

The concentration of zinc, i.e., 61.2 to 63.7 ppm and 55.0 to 62.6 ppm, at the river mouth and inner reef channel, respectively, was substantially greater than the TEL value but lower than the PEL value. The levels of zinc concentration at the Pago River mouth and reef channel were similar in value to those found by Denton et al. (1997) at the three inshore piers at Merizo (Malesso). The source of zinc, like mercury, can originate from the discharge of domestic wastewaters.

The concentrations of copper, i.e., 54.8 to 60.3 ppm, at the Pago river mouth and reef channel were similar but slightly higher than the PEL value of 55.9 ppm. The concentration of copper in the sediments also exceeded the numerical exceedance criteria for marine waters of 48 ppm (Guam EPA, 2001). The source of copper could be from domestic sewage. Copper is highly toxic to aquatic plants, invertebrates and fish (Denton and Burdon-Jones, 1982 and 1986).

Nickel, i.e., 52.2 to 60.2 ppm, and chromium, i.e., 85.6 to 106.4 ppm, exceeded the PEL values by six and two times, respectively. Nickel is moderately toxic to aquatic plants, and is the least toxic heavy metal to invertebrates and fish (Denton and Burdon-Jones, 1986). The concentrations of nickel, as well as copper, were approximately double than that found by Olsen and Denton (In Prep.) in the muddy sediments obtained 137 meters upstream from the Pago River mouth. The source of nickel, like copper, could be from domestic wastewater entering the Lonfit-Sigua-Pago River system. The concentration of nickel in the sediment of the Lonfit River adjacent to the Ordot Dump (Olsen and Denton, In Prep.) was approximately twice the concentration at the Pago River mouth. Thus, the source of nickel could be from the Ordot Dump. Chromium is moderately toxic to aquatic organisms (Denton et al., 1997). Ordot dump as the primary source of chromium is possible, but, unlikely, since sediments in the Lonfit River adjacent to the Dump (Olsen and Denton, In Prep.) contained less chromium that at the Pago River mouth. Guam EPA (2001) did not provide a numerical criterion for chromium (III) in marine waters.

REEF FLAT. Late June and August 2004 were extremely wet with sediments exiting the Pago River on several occasions as dark brown plumes spreading layers of mud throughout the inner reef flat and channel. This situation provided an opportunity to obtain supposedly fresh mud sediments for analyses of heavy metals. As seen in Table 16, manganese concentration was much higher, i.e., ranging from 468 to 651 ppm, in the sediments on the north reef flat collected in August 2004. The reef flat mud at both sites collected in August 2004 had a 3-fold decrease in lead than mud collected at the mouth of the river and at the near-shore channel. The reef flat mud at both sites had a lower concentration of copper and chromium but a higher concentration of nickel than at the river mouth and channel. Nickel and chromium levels from the reef flat mud exceeded their respective PEL level. Copper from the reef flat mud, however, did not exceed the PEL value of 55.9 ppm.

Biological Transects

The nine 50-meter long biological transects (see Figure 5) on the inner reef flat were situated parallel to the shoreline and located within 140 meters from shore. None of the transects were exposed during MLLW (Figure 10). Table 17 provides temperature and salinity measurements obtained from the midpoint and two ends of each transect during a hot sunny noon period when the tides were +0.03 to +0.09 meters in June 2004. The water temperatures along the three transects (Transects A2, A1 and A3) located to the south of the Pago River mouth and those transects (Transects B1, B2 and B3) off the river mouth were one to two degrees warmer than the water temperature along the transects (Transects C1, C2 and C3) to the northeast of the river mouth. The slightly deeper water during low tides along Transects C1, C2 and C3 was most likely responsible for the slightly lower water temperature of 32° C. Only in one of the three measurements did the subsurface water at Transect C3 surpass the water temperature of the surface water, i.e., subsurface water temperature of 30°C at the north end.

The salinity of the surface water during the low tide along the nine biological transects showed lower readings (mainly 30 to 31 ppt) on the inner reef flat northeast of the Pago River mouth as compared with the salinity to the south and seaward of the river mouth (33 to 35 ppt). During the dry season, the northeast side is influenced by the brackish water from the estuary during ebbing tides.

Table 18 quantifies the percent cover of the substrata. Except for Transect C1 (outermost transect north of the river mouth) with coral rubble, the other eight transects were dominated by sand. Transect B3 (innermost transect just seaward of the mouth of the Pago River), however, did possess muddy sand, i.e., characterized as soft black anaerobic sand.

ALGAE AND SEAGRASSES. Quantification of the nine 50-meter long transects (Table 18) revealed only 9 species of algae, one species of seagrass (*Halophila minor*) and two species of cyanobacteria or blue-green algae (*Hormothamnion enteromorphoides* and *Lyngbya* sp.). Only two of the nine species, i.e., *Halimeda macroloba* and *Padina boryana*, were calcified.

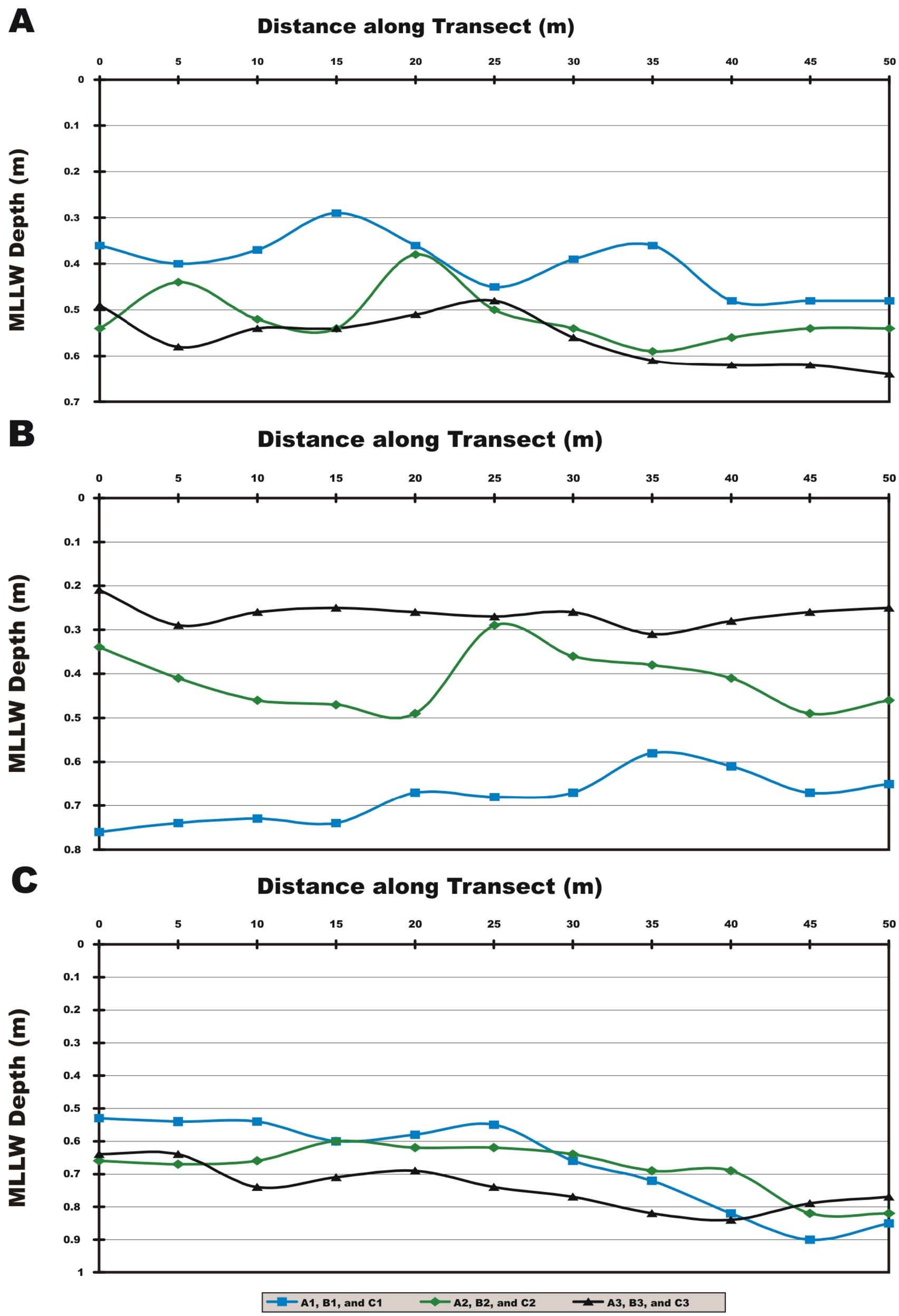

Figure 10. Vertical profiles (m) of the nine parallel-to-shore biological transects corrected to MLLW.

Table 17. Surface temperature and salinity measurements during low tide (+0.03 to +0.09 m) on a hot sunny day along the nine biological transects on the inner reef flat, Pago Bay, 14 June 2004. GPS coordinates provided.

Transect	Position	Latitude (°N)	Longitude (°E)	Time	Temperature (°C)			Salinity (ppt)		
					N	Mid	S	N	Mid	S
A2	N	13.42057689	144.78542629	1230	33	33	34	35	35	35
	M	13.42036441	144.78540952							
	S	13.42010608	144.78535714							
A1	N	13.42060656	144.78526385	1240	34	34	34	35	35	35
	M	13.42038101	144.78528782							
	S	13.42014363	144.78526653							
A3	N	13.42063942	144.78508213	1245	34	32	34	33	32	35
	M	13.42045309	144.78511247							
	S	13.42018872	144.78509738							
B1	N	13.42139807	144.78572275	1220	33	32	33	34	35	35
	M	13.42118072	144.78560222							
	S	13.42098534	144.78553358							
B2	N	13.42150988	144.78541807	1210	33	33	33	33	34	34
	M	13.42129103	144.78533543							
	S	13.42105432	144.78529151							
B3	N	13.42150343	144.78528857	1200	34	34	33	33	34	34
	M	13.42124183	144.78515312							
	S	13. 42110034	144.78507970							
C1	N	13.42234162	144.78560599	1150	32	32	32	31	32	31
	M	13.42214305	144.78548722							
	S	13.42194758	144.78540860							
C2	N	13.42234304	144.78537893	1147	32	32	32	30	31	31
	M	133.42213425	144.78527114							
	S	13.42194750	144.78519034							
C3	N	13.42.251537	144.78529746	1135	32	32	32	29	30	31
	M	13.42229292	144.78515211							
	S	13.42211489	144.78505706							

Table 18. Counts and percent cover of substrata and floral species quantified at three sites (three 50-meter long transects at each site) seaward of the mouth of Pago River, 17 May 2004.

South of Mouth of Pago River

	Counts				% Cover			
Substrata/Species	**A2**	**A1**	**A3**	**Sum**	**A2**	**A1**	**A3**	**Average**
Sand	181	234	156	571	56	73	49	59
Mud-Sand			29	29	0	0	9	3
Rubble		4		4	0	<1	0	<1
Pavement	3			3	<1	0	0	<1
Seagrasses								
Halophila minor		12	25	37	0	4	8	4
Non-Crustose Algae								
Avrainvillea obscura	2	3	9	14	<1	<1	3	1
Boergesenia forbesii	1			1	<1	0	0	<1
Dictyota bartayresiana	19			19	6	0	0	2
Gracilaria salicornia	7	15		22	2	5	0	2
Halimeda macroloba	35	4	3	42	11	1	<1	4
Padina boryana	66	46	7	119	21	14	2	12
Sargassum polycystum	1			1	<1	0	0	<1
Spyridea filamentosa	5	2	7	14	2	<1	2	1
Cyanobacteria								
Lyngbya sp.			84	84	0	0	26	9
No. of Species	8	6	6	10				

Seaward of Mouth of Pago River

	Counts				% Cover			
Substrata/Species	**B1**	**B2**	**B3**	**Sum**	**B1**	**B2**	**B3**	**Average**
Sand	225	252	118	595	70	79	37	62
Mud-Sand		64	147	211	0	20	46	22
Rubble		3	2	5	0	1	<1	<1
Pavement	11		4	15	3	0	1	1
Seagrasses								
Halophila minor	74			74	23	0	0	8
Non-Crustose Algae								
Avrainvillea obscura	2	1		3	<1	<1	0	<1
Gracilaria salicornia			13	13	0	0	4	1
Padina boryana	6			6	2	0	0	<1
Spyridea filamentosa	1		6	7	<1	0	2	<1
Cyanobacteria								
Hormothamnium enteromorphoides	1		1	2	<1	0	<1	<1
Lyngbya sp.			29	29	0	0	9	3
No. of Species	5	1	4	7				

Table 18. Continued.

Northeast of Mouth of Pago River

	Counts				% Cover			
Substrata/Species	**C1**	**C2**	**C3**	**Sum**	**C1**	**C2**	**C3**	**Average**
Sand	91	247	291	629	28	77	91	65
Mud-Sand								
Rubble	176	67	18	261	55	21	6	27
Pavement								
Seagrasses								
Halophila minor	1			1	<1	0	0	<1
Non-Crustose Algae								
Acanthophora spicifera	3			3	<1	0	0	<1
Avrainvillea obscura	1	4		5	<1	0	1	<1
Gracilaria salicornia	2	1	1	4	<1	< 1	< 1	<1
Spyridea filamentosa	46	5	6	57	14	2	2	6
Cyanobacteria-None								
No. of Species	5	3	2	5				

When the three transects in each set are pooled, for example, A1, A2 and A3, the percent cover of marine flora was highest for A at 35%. The percent cover of marine flora at the three transects (B1, B2 and B3) was 14% and at the three transects (C1, C2 and C3) was 9%.

The seagrass, *Halophila minor,* covered 4% of the transect area south of the mouth of the Pago River (Transects A1, A2 and A3) and 8% of the transect area seaward of the river mouth (Transects B1, B2 and B3). The transect area northeast of the river mouth revealed less than 1% cover of the seagrass *Halophila minor*; cyanobacteria was absent at this site. *Lyngbya* sp. comprised 9% cover in the transect site south of the river mouth; this cyanobacterium was recorded only along the inner Transect A3 (26% cover). *Lyngbya* sp., likewise, was present only along the inner Transect B3 (9% cover) seaward of the river mouth. The other cyanobacterium, *Hormothamnium enteromorphoides*, comprised less than 1% in transect area B.

MACROINVERTEBRATES. Table 19 provides counts of conspicuous epibenthic invertebrates along the same nine biological transects on the inner reef flat seaward of the Pago River mouth. Overall, invertebrates were very scarce along the transects. Although very few live *Strombus gibberulus* were present, i.e., at Transects B2 and C1, this gastropod represented the only live species quantified within the belt transects. The dominant bivalve was *Tellina* sp.; however, all specimens were dead. *Calcinus* sp. was the dominant crustacean but present only in Transects B3, C1, C2 and C3. Although 17 holothurians were documented from Pago Bay by Rowe and Doty (1977), no holothurians were observed on the inner reef flat within the transect study area. Only two live specimens of the sponge *Callyspongia* sp. were quantifed at Transects A3 and B2.

Corals were absent on the inner reef flat; one specimen of *Leptastrea purpurea* was observed near the south edge of the reef channel seaward of Transect A2.

FISHES. A total of 16 species in 10 families (Table 20) was observed at all sites. Fishes were most abundant on Transects A1 and A2. Fishes were not abundant on transects B1, B2 or B3. No fish was observed on Transect C2. Densities (number per m^2) ranged from 0.004 to 0.712. The most abundant species was the shrimp-associated burrowing goby *Cryptocentrus* sp. A, that was found at all A and B transects and on Transect C1 but was especially abundant on Transect A1. Densities of this species ranged from 0.008 to 0.712 per m^2 and accounted for 78.8% of total density of all fishes observed.

PAGO RIVER FLORA AND FAUNA. A listing of freshwater flora and fauna reported from the Lonfit and Pago River (Best and Davidson, 1981; PBEC, Inc., 1990; Brasher, 1991; Leberer, 1999) was presented previously. The following species of fish were observed on the surface of the lower 1-km of the Pago River in June 2004 - *Ellochelon vaigiensis* (Mugilidae: mullets), *Moolgarda engeli* (Mugilidae: mullets), *Zenarchopterus dispar* (Hemirhamphidae: halfbeaks), *Lutjanus argentimaculatus* (Lutjanidae: snappers), *Kuhlia mugil* (Kuhliidae: flagtails), *Kuhlia rupestris* (Kuhliidae: flagtails), and *Arothron manilensis* (Tetraodontidae; pufferfishes). One specimen of portunid crab, probably *Thalamita* sp., was found in a trap 1 km upstream (Station 10). All species are typical inhabitants of estuaries and lower reaches of insular freshwater streams. Some of these species also occur in bays, lagoons, and inshore waters.

Table 19. Counts of conspicuous epibenthic invertebrates along belt transects at the Pago River mouth, 20 May 2004. Each transect covered an area of 100 sq. m. Numbers of dead specimens are enclosed in brackets, e.g., [2], and numbers of dead bivalves with the hinges and ligaments still intact are enclosed in parenthesis, e.g., (2).

	Transect								
	A1	**A2**	**A3**	**B1**	**B2**	**B3**	**C1**	**C2**	**C3**
Demospongia									
*Callyspongia*sp.	0	0	1	0	1	0	0	0	0
Polychaeta									
Eurythoe complanata	0	0	1	0	0	0	0	0	0
Gastropoda									
Cerithium rostratum	0	0	0	0	0	0	0	[1]	0
Cerithium zonatum	[1]	0	0	0	0	0	0	0	0
Natica gualtieriana	[2]	0	0	0	0	0	0	0	0
Polinices melanostomus	0	0	0	0	0	0	0	[1]	0
Pyramidellus sulcatus	0	0	0	0	0	0	[1]	[1]	0
Strombus gibberulus	0	0	0	0	6,[2]	[3]	1,[11]	[5]	[5]
Strombus mutabilis	0	0	0	0	[1]	[1]	[2]	[1]	[1]
Bivalvia									
Ctena bella	[1]	0	0	[1]	1,[2]	[1]	0	[2]	[1]
Anodontia sp.	0	0	0	0	[1]	[1]	0	0	0
Gafrarium pectinatum	0	[2]	0	[3]	[1]	0	[3]	[1]	[1]
Pitar prora	0	0	0	0	0	0	[3]	[1]	[1]
Quidnipagus palatum	[3],(2)	[1]	[1]	[2]	[8],(1)	[3]	0	(1)	(1)
Tellina sp.	[2]	[2]	0	0	[9]	[4]	[22]	[25],(1)	[15]
Crustacea									
Calappa hepatica	0	0	0	0	1	0	0	0	0
Calcinus sp.	0	0	0	0	0	5	8	3	1
Clibanarius sp.	0	0	0	0	0	1	0	0	0
Dardanus megistos	0	0	0	0	0	0	2	0	0

Table 20. Density (number per square meter) of fishes observed on nine 50 x 5-meter transects on the inner reef flat seaward of the Pago River mouth, 25 May 2004. (*) indicates a potential new record.

Family	Species	A1	A2	A3	B1	B2	B3	C1	C2	C3	Total
Lutjanidae	*Lutjanus fulvus*	0	0.004	0	0	0	0	0	0	0	0.004
Nemipteridae	*Scolopsis bilineata*	0.004	0	0	0	0	0	0	0	0	0.004
Mullidae	*Parupeneus barberinus*	0.004	0	0	0	0	0	0	0	0	0.004
Mullidae	*Parupeneus multifasciatus*	0.008	0	0	0	0	0	0	0	0	0.008
Pomacentridae	*Chrysiptera biocellata*	0.008	0.004	0	0	0	0	0	0	0	0.012
Labridae	*Halichoeres trimaculatus*	0	0.012	0.024	0	0.008	0.004	0	0	0	0.048
Labridae	*Stethojulis strigiventer*	0.048	0.020	0	0	0	0	0	0	0	0.068
Gobiidae	*Crytocentrus sp. A*	0.712	0.032	0.120	0.012	0.008	0.064	0.004	0	0	0.952
Gobiidae	*Vanderhorstia sp. A*	00	0	0	0	0	0	0	0		0
Gobiidae	*Asterropteryx semipunctatus*	0.004	0.008	0	0.008	0	0	0	0	0	0.020
Gobiidae	*Istigobius ornatus*	0.024	0	0	0	0	0	0	0	0	0.024
Siganidae	*Siganus argenteus*	0.024	0	0	0	0	0	0	0	0	0.024
Acanthuridae	*Acanthurus leucochilus**	0	0.004	0	0	0	0	0	0	0	0.004
Acanthuridae	*Acanthurus nigricauda*	0.004	0	0	0	0	0	0	0	0	0.004
Balistidae	*Rhinecanthus aculeatus*	0	0	0	0	0	0	0.004	0	0	0.004
Tetraodontidae	*Arothron manilensis*	0	0	0	0	0	0	0	0	0.004	0.004
	Total density of fishes	0.840	0.084	0.144	0.020	0.016	0.068	0.008	0	0.004	1.184
	Density of other fish species	0.128	0.052	0.024	0.008	0.008	0.004	0.004	0	0.004	0.232
	Density of *Cryptocentrus sp. A*	0.712	0.032	0.120	0.012	0.008	0.064	0.004	0	0	0.952
	Percent *Cryptocentrus sp. A* from total	84.8	38.1	83.3	60.0	50.0	94.1	50.0	0.0	0.0	80.4
	Abundance of all fishes	210	21	41	5	4	19	1	0	1	302
	Species richness of all fishes	10	7	7	2	2	4	0	0	1	
	Species diversity of all fishes	0.697	1.646	0.963	0.673	0.693	0.610	0	0	0	

CONCLUSIONS AND RECOMMENDATIONS

The lower one kilometer of the turbid Pago River, including its estuary, is basically an extension of the deeper saline outer reef channel but with a less dense 0.5-meter layer of fresh or brackish water on the surface. During the wet season, the surface salinity is extremely low, i.e., 0.7 to 4.1 ppt; in contrast, the surface salinity during the dry season ranges from 10.3 to 30.9 ppt. The salinity of the subsurface water ranges from 33.0 to 35.7 ppt at ebb and flood tides during the dry and wet seasons. The fresh to brackish surface water layer is cooler during the wet season (i.e., 26.5 to 28.7°C) than in the dry season (i.e., 29.0 to 32.5°C). The subsurface saline water is slightly cooler in the wet season, i.e., 29.0 to 29.7°C, than in the dry season, i.e., 29.0 to 31.0°C.

During ebbing tides, the bulk of the water from the Pago River flows towards the northeast reef flat during the dry season; water on the northeast reef flat had a lower salinity (i.e., 20 to 31 ppt) than the water on the south reef flat (i.e., 30 to 33 ppt). On the south side, water moved in a northeasterly direction during ebb tide and moved towards a northwest direction during flood tide. On the northeast reef flat, water moved in an erratic manner or flowed towards the southeast or south during both flood and ebb tides.

During the wet season, the volume of water from the Pago River increased substantially and radiated in various directions from the river mouth. Salinity measurements on the northeast reef flat, i.e., 4 to 11 ppt (one measurement of 23 ppt), were similar to the salinity on the south reef flat, i.e., 5 to 10 ppt, during the ebbing tide. Water circulation studies on the northeast reef flat showed water movement basically to the northeast during ebb tide; water movement on the south reef flat was towards the northeast and north. During flood tide on the south reef flat, water flowed towards the south and southeast; water flowed towards the northeast, southeast and south on the northeast reef flat.

In the dry and wet seasons, reactive phosphate values were lower than the numerical water quality exceedance value of 0.05 mg/l for M2 reef flat waters. Few NO_x values obtained during the dry season on the northeast and south reef flats exceeded the numerical water quality exceedance value of 0.20 mg/l for M2 marine water. The wet season NO_x samples exceeded values obtained during the dry season. In the Pago River, a few NO_x surface and subsurface values obtained during ebb tide slightly exceeded the 0.50 mg/l exceedance criterion for S3 river water, i.e., 0.526 mg/l for surface waters and 0.516 mg/l for subsurface waters. All reactive phosphate measurements were less than the exceedance criteria for M2 marine waters and S3 river waters.

Four of the 10 heavy metals, i.e., zinc, copper, nickel and chromium, analyzed from the sampled sediments exceeded the Threshold Effects Level (TEL). The concentration of zinc in all sediments, i.e., river mouth, near-shore channel and reef flats, were similar with mean values of 62.7 ppm (river mouth), 60.0 ppm (reef channel), 61.4 ppm (south reef flat) and 54.9 ppm (north reef flat). Slightly higher concentrations of copper were present in the sediments from the river mouth and channel (mean of 58.5 and 58.1 ppm, respectively) than in the sediments from the south and northeast reef flat (mean of 51.9 and 52.1 ppm, respectively). The source of the zinc and copper could be from the discharge of domestic waste. The concentration of nickel from all four sediment samples, i.e., river mouth (mean of 55.7 ppm), channel (mean of 55.4 ppm), south reef flat (mean of 62.5 ppm) and northeast reef flat (mean of 60.3 ppm), exceeded the PEL value of 9.4 ppm by five to six-folds. The source of the nickel could be the Ordot Dump since Olsen and Denton (In Prep.) obtained values approximately twice the concentration than that found at the Pago River mouth. The concentration of chromium at the river mouth (mean of 96.6 ppm) and channel (mean of 101.8 ppm) were nearly twice the amount found in the sediments of the south reef flat (mean of 65.9 ppm) and northeast reef flat (mean of 54.3 ppm). The possible source of chromium is not known; Olsen and Denton (In Prep.) found less chromium in sediments in the Lonfit River than the concentrations found at the river mouth. Except for iron, manganese and nickel, the concentrations of heavy metals in the sediments of the reef flat mud were less than that in the sediments of the river mouth and channel.

The marine flora and fauna on the reef flat adjacent to the mouth of the Pago River was considered depauperate when quantified in May 2004. The marine floral components of the sand-mud reef flat of Pago Bay were meager, with seagrasses, cyanobacteria and selected algae, e.g., *Avrainvillea obscura, Halimeda macroloba* and *Gracilaria salicornia*. The shrimp-associated burrowing goby *Cryptocentrus* sp. was the most abundant fish. The total absence of any holothurians was unusual for such a sandy area.

The onset of the wet season in July 2004 with the heavy downpours during August and September 2004 and the accompanying settling of mud, 5 to 20 cm deep, over the reef flat study sites provided insight into the reason for the depauperate flora and fauna in the area. Although the water was sufficiently clear to observe and quantify organisms during May 2004, the muddy layer over the reef flat and poor to no visibility in August and September 2004 made it not feasible to repeat any type of biological transects.

As summarized above, the baseline chemical and biological study of the river, estuary, near-shore reef channel and adjacent inner reef flat of Pago Bay during the months of May through September 2004 revealed the contrasting environmental characteristics of the dry and wet seasons. It did not, however, pinpoint any detrimental physical or chemical conditions of the bay that can be directly attributed to the effluents released from the Ordot Dump. The most detrimental situation within the study sites of Pago Bay was the release of large quantity of sediment-laden water onto the inner reef and reef channel during the wet season.

The primary environmental question applicable to the south sector of Pago Bay is the time period and mechanism by which the layer of mud will be flushed from the reef flat. Since few seasonal studies of the southern Pago Bay reef flat exist, there is no historical data of the cleansing of this reef flat sector which is fed by a large stream. Wolanski *et al.* (2003) discussed the water and fine sediment dynamics of transient river plumes in Fouha Bay in the southeast coast of Guam. Surely, typhoon-driven storms must also flush large bays, such as Pago Bay, each year.

Thus, the first recommendation is to monitor the sediment level on the reef flat seaward of the Pago River mouth. It would be ideal to conduct a study similar to Wolanski *et al*. (2003) in the Pago reef channel. The organisms can be monitored via the same transects at a later date. A second recommendation is to further monitor the levels of nickel, chromium, copper and zinc along the Lonfit and Pago rivers. Further information on heavy metals along the Lonfit-Sigua-Pago River system is forthcoming (Olsen and Denton, In Prep.).

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CAPTION FOR PLATES

1. Aerial view of Pago Bay study site. Photo by John M.U. Jocson, UOG-WERI, July 2004.
2. Mouth of Pago River and estuary with *nipa* palms in the background, April 2004.
3. Sand-silt sill, exposed during low tide, outside the mouth of the Pago River, April 2004.
4. Inner reef flat northeast of the mouth of the Pago River, during low tide, April 2004.
5. Inner reef flat south of the mouth of the Pago River, during low tide, April 2004.
6. Pago River Bridge on Route No. 4 looking inland, April 2004.
7. Pago River facing seaward with *nipa* palm (left) and bamboo (right), April 2004.
8. Portunid crab, *Thalamita* sp., in trap one kilometer upstream, Pago River, June 2004.
9. Sediments released from Pago River after heavy rains, 6 August 2004.


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