Micronesica 37(2):235–247, 2005

Nitrogen and phosphorus concentrations in tropical Pacific insular streams: historical data from Tutuila, American Samoa

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Abstract—Tropical Pacific insular streams are relatively unexplored compared to streams in temperate or other tropical regions, and more stream studies are necessary because human population growth threatens these unique island ecosystems. The population of Tutuila, the largest island of American Samoa, has grown exponentially in recent years. This report presents historical water quality data [total nitrogen (TN), nitrate (NO_3^-+NO_2^-), total phosphorus (TP)] for eleven perennial streams on Tutuila sampled between 1979 and 1996. Data from 1979 show that streams impacted by human activities exhibited a higher median TN concentration (520 µg/L) than reference streams (329 µg/L). A similar difference was observed for NO_3^-+NO_2^-. There was no significant difference between impacted and reference stream TP (129 vs. 102 µg/L, respectively). Data from the entire period indicate that TN and NO_3^-+NO_2^- demonstrated more between year variability (CV=60.2% and 26.5%, respectively) than did TP (CV=19.9%). Overall, though, these data do not demonstrate any obvious trends towards increasing nutrients in these island streams. Data suggest that the baseline nutrient levels are ca. 200–300 µg TN/L and 50–100 µg TP/L for reference streams on this island. These numbers are supported by data collected in 1997 from Laufuti Stream, a stream located in an uninhabited watershed on the nearby island of Ta'u, American Samoa. Future monitoring must examine the full range of stream types to accurately assess these insular stream ecosystems.

Introduction

A few of the stream ecosystems of tropical Pacific islands have been studied for their unique fauna (Buden et al. 2001, Kinzie 1988, Marquet 1991, Ryan 1991) and ecosystem dynamics (Bright 1982, Larned 2000). However, there has been little work on these island ecosystems compared to temperate or other continental tropical regions (e.g., Costa Rica, Brazil, Venezuela, Hong Kong). Furthermore, there are few data from tropical stream ecosystems in their natural condition (Jackson & Sweeney 1995); in most cases scientists and managers lack a baseline against which future impacts can be measured. This neglect is unfortunate because high human population growth in tropical regions including many Pacific islands will, in all certainty, degrade these stream ecosystems. Where possible, any and all historical data need to be gathered and synthesized to estimate baseline conditions and evaluate temporal trends. Recent data can then be compared to historical records to document anthropogenic impacts on tropical streams.

American Samoa, an archipelago of 5 islands and 2 coral atolls, lies at 14º S latitude and 170º W longitude. This territory of the United States is the only US territory in the southern hemisphere. Tutuila, the largest island (136.2 km^2) of American Samoa, contains 96% of the territorial population (55,876 as of the 2000 census, American Samoa Government Department of Commerce [ASG-DOC] 2002). The population of Tutuila has increased at near exponential levels since the mid 1900s.

Of the 162 streams on Tutuila, 141 are considered perennial (US Fish and Wildlife Service, unpublished report). These streams are generally small (median length = 1 km, range = 0.17–11.9 km) and steep (median gradient = 22%, range = 6.7–61.3%), and they drain small land areas (median drainage = 0.30 km^2, range = 0.04–5.91 km^2). Major stream fauna include several fish species (e.g., *Kuhlia* sp., *Anguilla* sp.), gobies (e.g., *Stiphodon* sp., *Eleotris* sp.), shrimps (e.g., *Macrobranchium* sp., *Caridina* sp.), and gastropods (e.g. *Clithon* sp., *Septaria* sp.). A qualitative survey of selected streams and their fauna was reported in US Army Corps of Engineers (1981).

Biological, chemical, and hydrographic data give insight into the ecological condition of streams. In particular, nutrient content (e.g., nitrogen and phosphorus) is a determinant of stream trophic status (Dodds et al. 1998, Dodds 2003) and an important indicator of stream condition. Changes in stream nutrient content and consequent trophic status are often related to human population growth or land use changes within the watershed (Peierls et al. 1991), and excess stream nutrients can impact the biological fauna (Miltner & Rankin 1998). In American Samoa, previous water quality data were collected piecemeal by consultants or local government agencies. Until now, this information had not been synthesized.

This report seeks to summarize the available nutrient data from Tutuila streams, examine specifically the earliest data, and then evaluate whether there are trends in stream nutrient concentration over time. This summary may provide information that can help manage and conserve these threatened Pacific ecosystems.

Materials and Methods

Nutrient data were collected from Tutuila streams between 1979 and 1996. Raw data were gathered from two reports (M&E Pacific 1979, CH2MHill 1984) as well as unpublished records of the American Samoa Environmental Protection Agency (ASEPA). M&E Pacific (1979) sampled 11 perennial streams, 8 of which at that time were judged impacted by human activities (either urbanization, agriculture, or road construction) and 3 of which were considered at that time to represent reference (pristine) sites. CH2MHill (1984) reported data from 5 of those 11 streams, while ASEPA sampled subsets of those 11 streams between 1985 and 1996. The physical characteristics of the study streams are listed in Table 1; Figure 1 shows the locations of these streams on Tutuila.

Sample locations within streams varied, as did the sampling frequency. In most years, only 1 site per stream was sampled. However, during two years (1995, 1996), as many as 3 sites within a stream were sampled. In those instances, multiple site samples were averaged before inclusion in the analyses presented here. In total, between 1 and 18 estimates of nutrient concentration were available for a stream within a particular year. The timing of sample collection also varied between years. For instance, in 1984, all streams were sampled in July during the dry season. However, in 1986, samples were collected in February, May, June, July, September, and December, a period that spans the rainy and dry seasons.

In general, water samples were analyzed for total nitrogen (TN) and total phosphorus (TP). In some cases, stream nitrogen was analyzed as total Kjeldahl nitrogen (TKN) and NO_3^-+NO_2^- (M&E Pacific 1979); TN was calculated by addition. Much of the summary presented here is for TN and TP data. However, NO_3^-+NO_2^- is an important parameter for stream nutrient dynamics (Dodds 2003), and available data are summarized as well.

TN, NO_3^-+NO_2^-, and TP data from 1979 were pooled according to the initial stream condition classification (either impacted or reference; Table 1). A Kruskal-Wallis test was employed to test for differences between streams classes. To discern any historical trends, yearly data were pooled across all streams (whether considered impacted or reference) and plotted to assess temporal trends in nutrient concentration.

Table 1. Physical characteristics of American Samoa streams reported in this study. Bolded streams were considered impacted by agriculture, urbanization, or road construction in 1979. Other streams were considered reference. Stream characteristics are compiled from unpublished sources, except discharge information which comes from Wong (1996). Dashes indicate no data.

Stream Name	Order	Drainage	Length Area (km^2)	Gradient (km)	Median Discharge (L/s)
Asili Stream	3	1.67	5.95	14.0%	80.7
Aua Stream	2	1.26	3.10	31.8%	5.9
Auasi Stream	2	0.31	1.39	19.1%	3.1
Faga'alu Stream	3	1.87	6.48	13.6%	9.1
Fagatogo Stream	2	0.36	2.04	20.1%	–
Laolao Stream	2	0.58	1.03	19.6%	–
Poloa Stream	1	0.54	1.58	13.3%	4.0
Vaipito Stream	3	2.45	9.36	15.8%	49.8
Leafu Stream	3	3.29	11.21	10.9%	73.9
Maloata Stream	3	2.66	7.30	13.0%	93.4
Vaitele Stream	3	5.91	7.80	13.0%	19.0

Figure 1. The island of Tutuila, American Samoa, and the streams reported in this study. Streams are numbered as follows: 1=Poloa Stream, 2=Maloata Stream, 3=Auasi Stream, 4=Aua Stream, 5=Laolao Stream, 6=Vaipito Stream, 7=Fagatogo Stream, 8=Faga'alu Stream, 9= Vaitele Stream, 10=Leafu Stream, 11=Asili Stream. Poloa, Auasi, Aua, Laolao, Vaipito, Fagatogo, Faga'alu, and Asili Streams (#1, 3–8, and 11) were considered impacted in the 1979 survey.

Results

The physical characteristics of streams reported in this study (Table 1) are in many ways atypical of most streams on Tutuila. For instance, the two shortest streams detailed in this paper, Auasi Stream and Poloa Stream (at 1.3 and 1.5 km, respectively), are both longer than half of Tutuila's perennial streams (median length 1 km). Streams reported here also drain larger land areas (1.67 km^2) compared to the median 0.3 km^2 across all Tutuila streams. Furthermore, the median gradient of the study streams was 14%, while the median gradient for all streams on Tutuila is 22%. Mean discharge is generally low (Table 1; Wong 1996), but the tropical rains of American Samoa mean that discharge is flashy and highly variable.

Streams considered impacted by human activities in 1979 displayed a greater range of TN concentrations than the reference sites. The minimum TN concentration from impacted streams at that time was 128 µg/L (in Asili Stream), while the maximum concentration detected was 1443 µg/L in Fogatogo Stream. In the reference streams, the lowest TN concentration was 87 µg/L in Maloata Stream, while the highest was 627 µg/L (in Vaitele Stream). Impacted streams demonstrated a significantly higher median TN concentration than did reference streams (520 vs. 329 µg/L, Kruskal-Wallis test, p=0.002; Figure 2). The NO_3^-+ NO_2^- fraction showed similar differences between impacted and pristine streams. Median concentrations were 171 and 44 µg/L NO_3^-+NO_2^- in

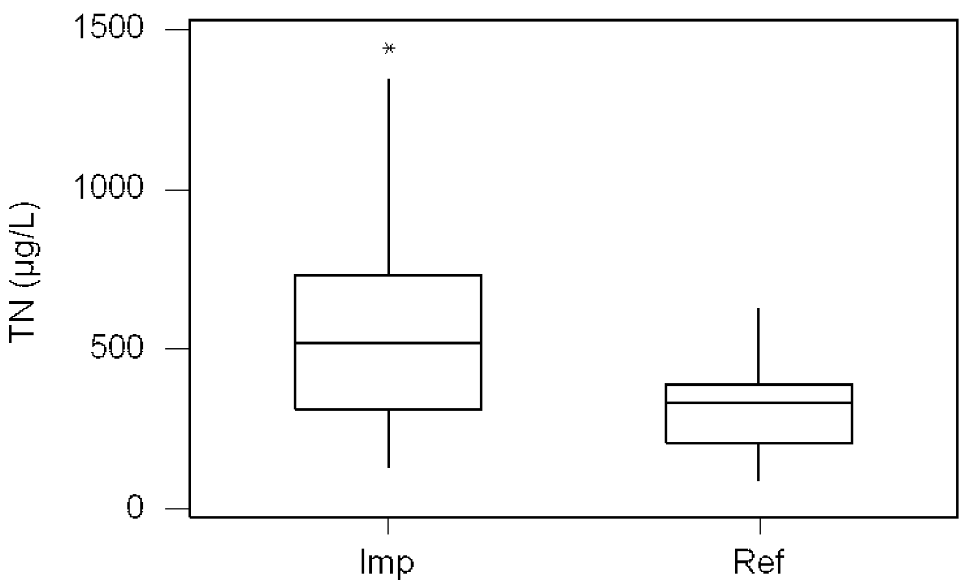

Figure 2. Total nitrogen (TN, µg/L) for impaired (Imp) and reference (Ref) streams sampled in 1979. The median TN concentratition in impaired streams is significantly higher (K-W test, p=0.002) than in reference streams.

Table 2. Median concentrations of total nitrogen (TN, µg/L) in Tutuila, American Samoa, streams. Bolded streams were considered impacted by agriculture, urbanization, or road construction in 1979. Other streams were considered reference. Numbers in parentheses represent the sample size within an annual period. Dashes indicate no data.

	1979	1984	1985	1986	1987	1988	1989	1990	1991	1995	1996
Asili Stream	354 (6)	–	200 (1)	–	–	–	–	–	–	122 (18)	102 (6)
Aua Stream	501 (6)	512 (4)	–	322 (5)	562 (4)	340 (1)	370 (3)	380 (4)	500 (1)	–	–
Auasi Stream	474 (6)	–	790 (1)	–	–	–	–	–	–	–	–
Faga'alu Stream	574 (6)	484 (5)	–	273 (6)	428 (4)	352 (1)	370 (3)	690 (4)	410 (1)	–	–
Fagatogo Stream	1238 (6)	2150 (5)	–	1005 (6)	746 (2)	300 (1)	1080 (3)	570 (3)	1120 (1)	–	–
Laolao Stream	731 (6)	1400 (5)	–	365 (6)	710 (4)	566 (1)	390 (3)	775 (4)	420 (1)	–	–
Poloa Stream	310 (5)	–	330 (1)	–	–	–	–	–	–	–	–
Vaipito Stream	551 (6)	1023 (4)	–	334 (6)	429 (4)	438 (1)	440 (3)	490 (4)	530 (1)	-	-
Leafu Stream	305 (6)	–	180 (1)	–	–	–	–	–	–	184 (18)	214 (6)
Maloata Stream	316 (6)	– (1)	330	–	–	–	–	–	–	–	–
Vaitele Stream	373 (6)	– (1)	760	–	–	–	–	–	–	–	–
Yearly Median	444	1200	330	364	562	352	440	650	500	149	188

impacted and pristine streams, respectively, and were statistically different (Kruskal-Wallis test, p<0.001).

In contrast, TP concentrations in both impacted and reference streams sampled in 1979 were statistically indistinguishable (respective median concentrations: 129 vs. 102 µg/L, Kruskal-Wallis test, p=0.189). The minimum TP concentration in impacted streams at that time was 5 µg/L in Asili Stream, while the maximum concentration was 425 µg/L in Fogatogo Stream. In the reference streams, 19 µg/L in Maloata Stream and 363 µg/L in Vaitele Stream were the lowest and highest TP concentrations, respectively.

Table 3. Median concentrations of NO_3^-+NO_2^- (µg/L) in Tutuila, American Samoa, streams. Bolded streams were considered impacted by agriculture, urbanization, or road construction in 1979. Others were considered reference. Numbers in parentheses represent the sample size within an annual period. Dashes indicate no data.

	1979	1984	1985	1986	1987	1988	1989	1990	1991	1995
Asili Stream	44 (6)	–	150 (1)	–	–	–	–	–	–	15 (6)
Aua Stream	130 (6)	168 (4)	–	184 (5)	297 (4)	117 (1)	188 (3)	174 (4)	317 (1)	–
Auasi Stream	120 (6)	–	510 (1)	–	–	–	–	–	–	–
Faga'alu Stream	204 (6)	275 (4)	–	134.5 (6)	240 (4)	265 (1)	175 (3)	332 (4)	169 (1)	–
Fagatogo Stream	690 (6)	971 (5)	–	600 (6)	369 (2)	262 (1)	420 (3)	314 (3)	836 (1)	–
Laolao Stream	317 (6)	268 (5)	–	163.5 (6)	271 (4)	205 (1)	221 (3)	308 (4)	206 (1)	–
Poloa Stream	39 (5)	– (1)	260	–	–	–	–	–	–	–
Vaipito Stream	243 (6)	318 (4)	–	194.5 (6)	247 (4)	205 (1)	235 (3)	299 (4)	345 (1)	–
Leafu Stream	42 (6)	–	100 (1)	–	–	–	–	–	– (6)	70
Maloata Stream	35 (6)	– (1)	210	–	–	–	–	–	–	–
Vaitele Stream	58 (6)	– (1)	530	–	–	–	–	–	–	–
Yearly Median	110	293	235	192	273	205	235	276	317	33

Annual median TN, NO_3^-+NO_2^-, and TP concentrations for each stream for which there are data are presented in Tables 2–4. Nitrogen concentrations (both TN and NO_3^-+NO_2^-) were highly variable both between streams and between years within streams (Tables 2 & 3). Annual median TN concentrations fell between 300 and 600 µg/L in 7 of the 11 years. TN concentration peaked in 1984 (1200 µg/L) and was lowest in 1995. The coefficient of variation (CV) of median annual TN concentrations was 60.2%. The annual median NO_3^-+NO_2^- concentration ranged from 33 µg/L (in 1995) to 317 µg/L (in 1991); the CV was 26.5%. Annual median TP concentrations were less variable (CV=19.9%) than either

Table 4. Median concentrations of total phosphorus (TP, µg/L) in Tutuila, American Samoa, streams. Bolded streams were considered impacted by agriculture, urbanization, or road construction in 1979. Others were considered reference. Numbers in parentheses represent the sample size within an annual period. Dashes indicate no data.

	1979	1984	1985	1986	1987	1988	1989	1990	1991	1995	1996
Asili Stream	50 (5)	–	62 (1)	–	–	–	–	–	–	64 (18)	56 (6)
Aua Stream	131 (5)	90 (4)	–	86 (5)	179 (4)	68 (1)	120 (3)	92 (4)	83 (1)	–	–
Auasi Stream	293 (6)	–	266 (1)	–	–	–	–	–	–	–	–
Faga'alu Stream	181 (6)	234 (5)	–	198 (6)	211 (4)	133 (1)	221 (3)	185 (4)	145 (1)	–	–
Fagatogo Stream	335 (5)	499 (5)	–	203 (6)	209 (2)	144 (1)	192 (3)	100 (3)	147 (1)	–	–
Laolao Stream	98 (5)	122 (5)	–	77 (6)	139 (4)	152 (1)	105 (3)	135 (4)	92 (1)	–	–
Poloa Stream	60 (5)	– (1)	129	–	–	–	–	–	–	–	–
Vaipito Stream	128 (5)	127 (4)	–	161 (6)	144 (4)	84 (1)	185 (3)	139 (4)	144 (1)	–	–
Leafu Stream	102 (6)	–	142 (1)	–	–	–	–	–	–	129 (18)	108 (6)
Maloata Stream	70 (5)	– (1)	60	–	–	–	–	–	–	–	–
Vaitele Stream	120 (5)	– (1)	210	–	–	–	–	–	–	–	–
Yearly Median	111	167	136	139	151	133	178	130	144	100	89

nitrogen parameter. The peak TP concentration was 178 µg/L in 1989, while 1996 showed the lowest concentrations (89 µg/L). Neither TN nor TP showed obvious trends over the sampled period (Figures 3 & 4).

Discussion

This paper is the first summary of existing nutrient data for Tutuila streams. These data were collected over a 17-year period (1979–1996) that overlaps a period of explosive population growth. Between 1980 and 2000, human population on Tutuila increased from 30,538 to 55,876 (ASGDOC 2002), an 83% increase. While these data suggest the extent of human impacts on Tutuila streams, both historically (>25 yrs ago) and more recently, more data will be necessary to further evaluate stream condition and trends and potentially safeguard these ecosystems from the burgeoning human population.

These data reveal apparent human impacts on streams, even when the population was only half its current size. In 1979, TN was significantly higher in impacted than reference streams (Figure 2), and a similar difference was observed for NO_3^-+NO_2^-. Increased stream nitrogen on Tutuila mirrors a worldwide phenomenon where human population growth and attendant development have increased nitrogen transport in rivers (Peierls et al. 1991). However, while early data demonstrate elevated nitrogen concentrations in Tutuila streams, there is no evidence of increased stream TP. Anthropogenic impacts on streams in 1979 did not appear to influence phosphorus transport.

These data can be considered as baseline nutrient levels for reference Tutuila streams. In 1979, the median TN and TP concentrations were 329 µg/L and 102 µg/L, respectively, in reference streams. These levels reflect baseline nutrient levels, a conclusion offered by M&E Pacific (1979). Since that time, another study has provided further support for these nutrient baselines. Cook (2001) reported data from Laufuti Stream on Ta'u island, another island in the American Samoa

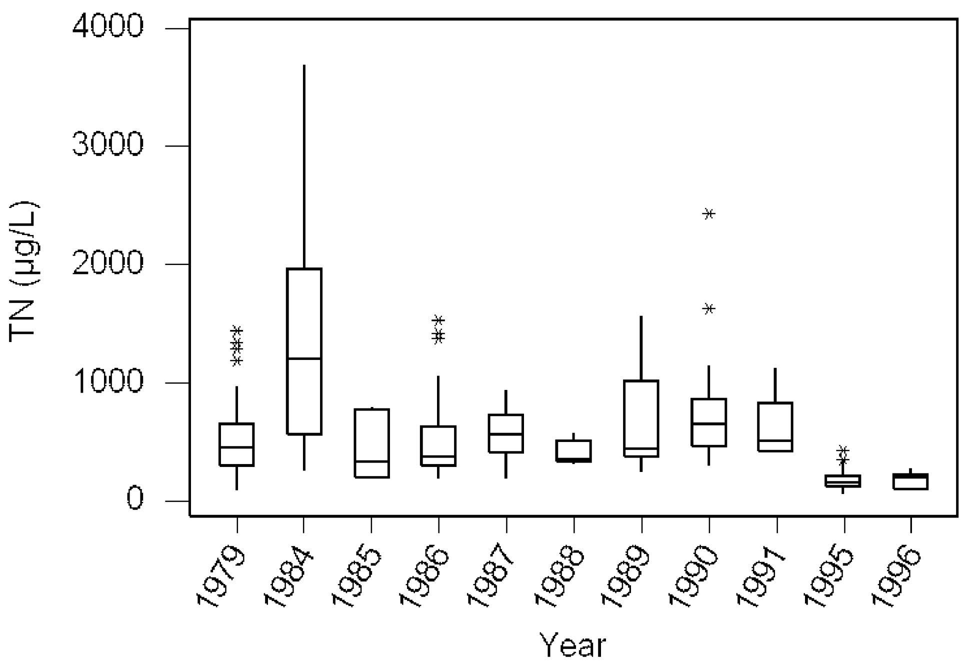

Figure 3. Annual median concentrations of total nitrogen (TN, µg/L) from streams of Tutuila, American Samoa.

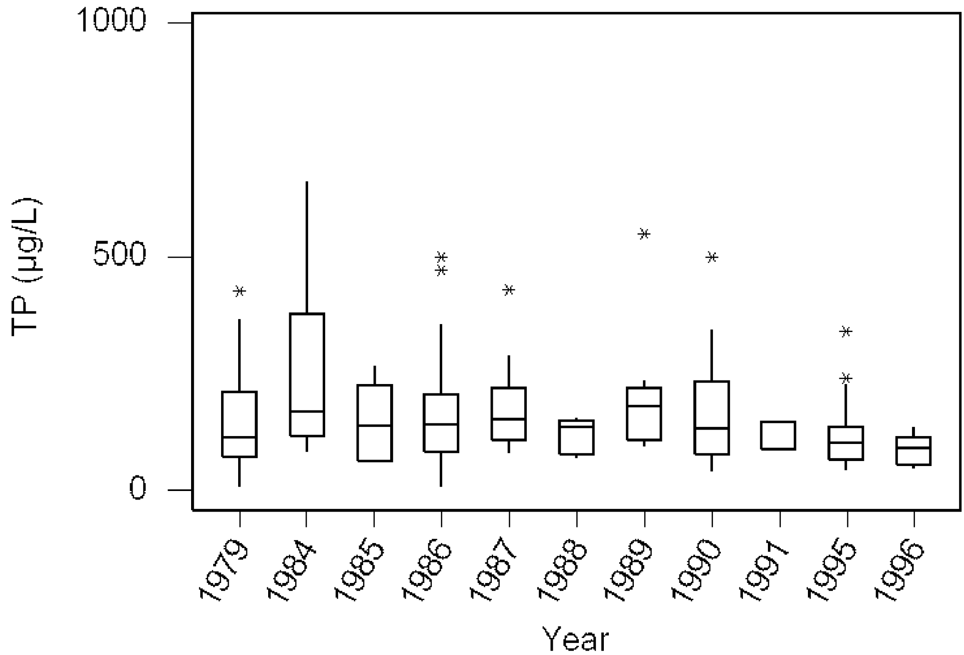

Figure 4. Annual median concentrations of total phosphorus (TP, µg/L) from streams of Tutuila, American Samoa. One outlier (2850 µg/L) from 1984 was not included in the graph for visual reasons.

archipelago. The Laufuti watershed is uninhabited and considered pristine. Based on multi-site sampling in July, 1997, the median TN concentration in Laufuti Stream was 200 µg/L (range: 124–556 µg/L) while the median TP concentration was 38 µg/L (range: 11–96 µg/L). These data support the determination that 200–300 µg/L TN and 50–100 µg/L TP represent baseline levels for American Samoa reference streams.

Data from 11 years of stream sampling after 1979 do not demonstrate any dramatic changes or obvious temporal trends in stream TN, NO_3^-+NO_2^-, or TP. In fact, TP showed little variation between years (Table 4, Figure 4). TN and NO_3^-+NO_2^- concentrations, on the other hand, demonstrated higher annual variation (Tables 2 & 3) but still no obvious trends. While tempting, it is difficult to attach much meaning to the TN spike in 1984 and the relative lows in 1995–6 (Figure 3); they are likely attributable to the streams surveyed during those periods. Specifically, the spike in TN concentration from 1984 may have resulted from sampling streams only in the Pago Pago area, a region of extensive human disturbance, and only during a small window of time during the dry season. Conversely, only two streams were sampled during 1995–6. Of these streams, Leafu Stream was originally classified as pristine while Asili Stream was considered impacted (M&E Pacific 1979). The concentrations of both TN and TP over the period sampled, however, were low. This may indicate good water quality but also suggests that the limited sample population may not reflect the condition of other island streams.

The American Samoa Water Quality Standards (ASWQS) establish permitted levels for stream TN and TP. The current standards require that average TN and TP levels do not exceed 300 µg/L and 150 µg/L, respectively, and these levels reflect the accepted baseline values for local island streams. For comparison, I have calculated the overall TN and TP medians across all samples collected between 1979 and 1996. The TN median was 409 µg/L, meaning that more than half the samples exceeded the 300 µg/L TN criterion. On the other hand, the median sampled concentration of TP in Tutuila streams (122 µg/L) shows that TP exceeded the ASWQS in less than half the samples. This suggests that total nitrogen is the bigger problem for Tutuila streams with respect to the ASWQS.

Likely sources of nitrogen pollution include human and/or animal waste. One pernicious problem is the direct polluting of island streams with swine waste from small, family-operated pigpens. Concentrated animal feeding operations (CAFOs) have had a negative impact on rivers and estuaries of the US mainland (Mallin 2000), and these smaller operations on Tutuila may have a similar effect on the small island streams. While the law carefully delineates site restrictions associated with pigsties, those rules are rarely enforced. The proliferation of family pig houses means severe nutrient pollution in many local streams.

Human impacts on streams and rivers is proportional to human population and landscape alteration (Peierls et al. 1991), but the human population and stream impacts are not evenly distributed across Tutuila. For instance, over 10,000 people live in the Pago Pago watershed, an area of 10.4 km^2 (1018 persons/km^2) with 11 perennial streams (5 of which have been reported in this paper). In contrast, the northern side of the island has 5538 people over 52.1 km^2 (106 persons/km^2), and the 76 perennial streams in this sparsely populated area would be expected to show fewer anthropogenic disturbances. At this time, few north-side streams have been sampled to evaluate that prediction.

These historical data are a useful first characterization for the streams of Tutuila, but they do not provide an unbiased estimate for general stream water quality because the sample population was biased towards streams in heavily impacted areas. That shortcoming leaves an important question unanswered: what is the water quality or condition of the average stream on Tutuila? To answer this question, future sampling efforts must examine the entire range of stream ecosystems, both in terms of their physical characteristics (e.g., size, stream order) as well as the level of anthropogenic impacts. In particular, future monitoring efforts should include streams from areas of low population density without an extensive history of settlement and modification.

The extensive data collection that has occurred in stream ecosystems in temperate areas has afforded large databases for analysis. For instance, Dodds et al. (1998) used published stream nutrient data from North America and New Zealand to examine the entire range of ambient nutrients and classify stream trophic state. Such an exercise is impossible for tropical Pacific streams because stream data spanning the gradient of human disturbance have not been widely collected. Only after those data are available will we be able to classify tropical streams or place streams from one Pacific island in the context of those on other islands. Presenting historical data where available is the first step in this important regional endeavor.

Acknowledgements

All data reported in this paper were collected either by ASEPA staff, M&E Pacific, or CH2MHill. CH2MHill was under direct contract to the American Samoa Government, while M&E Pacific was contracted by the U.S. Army Corps of Engineers as part of the American Samoa Water Resources Study. E. Bardi, E. Buchan, E. DiDonato, E. Paselio, D. Vargo, and one anonymous reviewer provided constructive comments on the manuscript. Mapping assistance was provided by K. Cronk.

References

Bright, G. R. 1982. Secondary benthic production in a tropical island stream. Limnology and Oceanography 27: 472–480.

Buden, D. W., D. B. Lynch, J. W. Short & T. Leberer. 2001. Decapod crustaceans of the headwater streams of Pohnpei, Eastern Caroline Islands, Federated States of Micronesia. Pacific Science 55: 257–265.

CH2MHill. 1984. Joint study of fish cannery wastewater effluent loading reduction at Pago Pago Harbor, American Samoa. Report prepared for the American Samoa Government. Bellevue, WA.

Cook, R. P. 2001. A survey of Laufuti stream, Ta'u island, National Park of American Samoa. Water Resources Division, National Park Service, Technical report NPS/NRWRD/NRTR–2001/290.

Dodds, W. K., J. R. Jones & E. B. Welch. 1998. Suggested classification of stream trophic states: distributions of temperate stream types by chlorophyll, total nitrogen, and phosphorus. Water Research 32: 1455–1462.

Dodds, W. K. 2003. Misuse of inorganic N and soluble reactive P concentrations to indicate nutrient status of surface waters. Journal of the North American Benthological Society 22: 171–181.

Jackson, J. K. & B. W. Sweeney. 1995. Present status and future directions of tropical stream research. Journal of the North American Benthological Society 14: 5–11.

Kinzie, R. A. 1988. Habitat utilization by Hawaiian stream fishes with reference to community structure in oceanic island streams. Environmental Biology of Fishes 22: 179–192.

Larned, S. T. 2000. Dynamics of coarse riparian detritus in a Hawaiian stream ecosystem: a comparison of drought and post-drought conditions. Journal of the North American Benthological Society 19: 215–234.

M&E Pacific, Inc. 1979. Baseline water quality survey in American Samoa. Report prepared for the U.S. Army Engineering Division. Honolulu, HI.
Mallin, M. A. 2000. Impacts of industrial animal production on rivers and estuaries. American Scientist 88: 2–13.
Marquet, G. 1991. Freshwater crustaceans of French Polynesia: taxonomy, distribution and biomass (Decapoda). Crustaceana 61: 125–140.
Miltner, R. J. & E. T. Rankin. 1998. Primary nutrients and the biotic integrity of rivers and streams. Freshwater Biology 40: 145–158.
Peierls, B. L., N. F. Caraco, M. L. Pace & J. J. Cole. 1991. Human influence on river nitrogen. Nature 350: 386–387.
Ryan, P. A. 1991. The success of the Gobiidae in tropical Pacific insular streams. New Zealand Journal of Zoology 18: 25–30.
US Army Corps of Engineers. 1981. American Samoa stream inventory: island of Tutuila. Honolulu, HI.
Wong, M. F. 1996. Analysis of streamflow characteristics for streams on the island of Tutuila, American Samoa. U.S. Geological Survey, Water Resources Investigations Reports 95–4185, Honolulu, HI.

Received 24 Sep. 2003, revised 26 Apr. 2004