A SURVEY OF THE STREAMFISHES OF THE UPPER REACHES OF THE NGERMESKANG RIVER, PALAU, WITH RECOMMENDATIONS FOR CONSERVATION AND MONITORING

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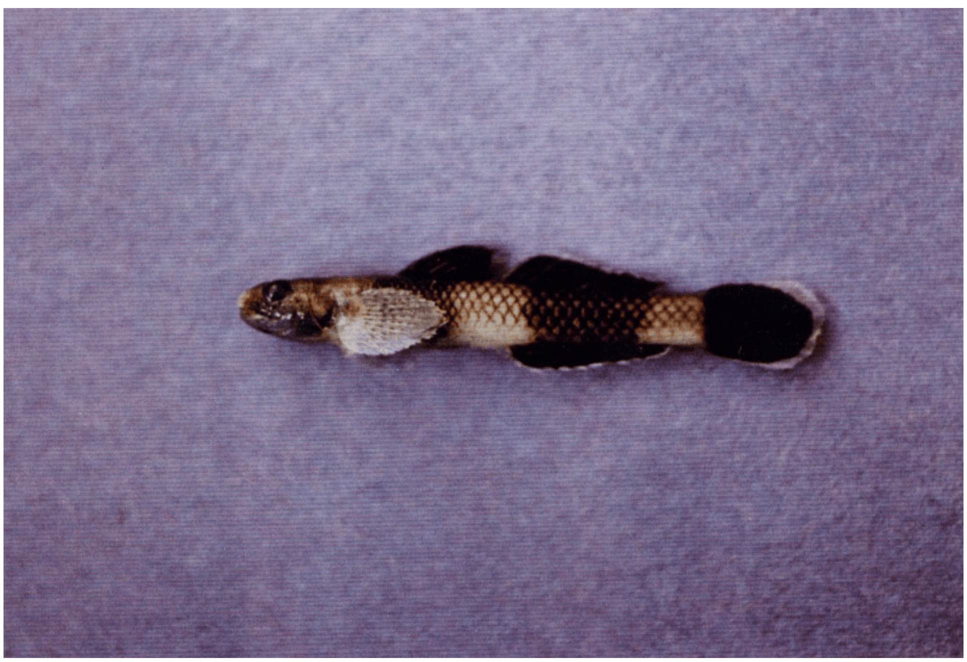

Stiphodon elegans (Steindachner, 1879)

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Introduction

This work was carried out in response to a request of the Palau Environmental Quality Protection Board (EQPB) to assist with the development and implementation of Rapid Bioassessment Protocols (Plafkin et al., 1989) for use at monitoring stations on the Ngermeskang River in Palau. These monitoring stations are to be used in the assessment of the degree of disturbance caused by the construction of the Babeldaob Island Road. The project was broken into three components: establishing a water quality monitoring program for Ngermeskang River, a coral monitoring program at the river mouth, and conducting a survey of stream fishes and providing recommendations for the establishment of a stream fish monitoring program. The first two components are reported elsewhere. This report covers the latter portion of the overall work plan, the objectives of which were to:

- Conduct visual surveys of the stream fishes at potentially impacted and upstream sites in the Ngermeskang River,
- Provide reference collections of fishes and photographs of fishes collected from the inland waters of Palau,
- Provide recommendations for the establishment of a monitoring program for stream fishes of the Ngermeskang River.

The recent economic development occurring in Palau has led to increased interest in the conservation of the inland aquatic fauna and, consequently, to an urgent need for information to serve as a base for policy decisions insuring protection of aquatic habitats. Of particular concern are the roads that are being constructed on the island of Babeldaob, because sedimentation and the destruction of riparian vegetation that result from such projects may have adverse ecological effects on the populations of streamfishes and other aquatic organisms. In addition, the roads open new areas to agricultural development, and the land-clearing associated with this development may pose threats to nearby streams and rivers. In the near future, the application of pesticides and fertilizers on farms bordering aquatic habitats may also become a concern. As road construction and agricultural expansion are already underway, the need for information on the potential impacts of these activities is urgent.

There have been few studies of the freshwater streamfishes of Palau. Fehlmann (1960) made extensive collections of freshwater organisms, focusing on fishes, from the Arakitaoch Stream on Babeldaob in 1956. That study provided information on the species present in the drainage basin and data on their zonation from the headwaters to the mangrove habitat of the lower reaches. This study was part of the expeditions sponsored by the George Vanderbilt Foundation (1955 to 1957) to collect coral reef and freshwater specimens (Parenti and Maciolek, 1993). Bright and June (1981) combined the data of Fehlmann with work by Bright (1979) to provide a checklist of the freshwater fishes of Palau. Additions to, and clarifications of, species within the Sicydiinae goby fauna of Palau have come from the recent work of Parenti and Maciolek (1993), which was based on analysis of specimens collected in Pohnpei by John Maciolek and the specimens that were collected in Palau by the Vanderbilt expeditions.

The taxonomic listings and other data contained in previous works on the streamfishes of Palau, described above, formed a useful background to our work. The primary objective of our study was to provide quantitative data on the distributions, relative abundances, densities, and habitats of the streamfishes of the Ngermeskang River in Palau. To accomplish this we used visual surveys that were confirmed and supplemented by collections.

Methods and Materials

Description of Sites

The location of the Ngermeskang River on the island of Babeldaob is shown in Figure 1. Locations of sampling sites in this study are also indicated (Figure 1). The lower site was accessible from an unpaved road. The site coordinates were determined with a Magellan GPS Nav 5000 Pro, and a Peet Bros. Ultimeter (Model 12+) was used to measure elevation (m) from sea level (Table 1). All sites, with the exception of Site 5, are located within Ngeremlengui State.

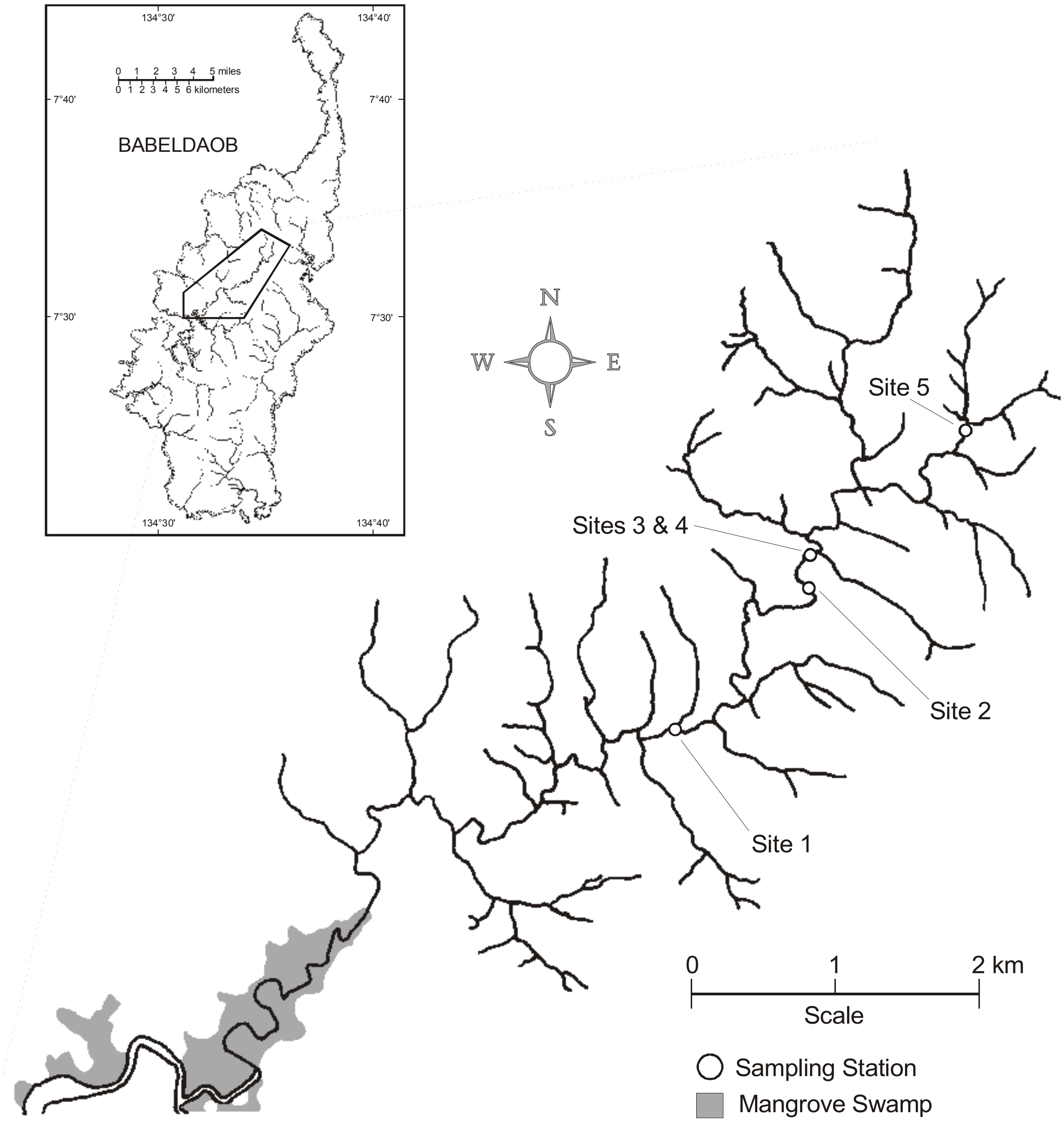

Figure 1. Map of Ngermeskang River drainage basin indicating sites where streamfishes were sampled during this survey.

Table 1. Coordinates and elevations of the five study sites on the Ngermeskang River.

Site Number	Coordinates (latitude, longitude)	Elevation (m)
1	7˚31.6090' N 134˚33.5331' E	<3
2	7˚32.2219' N 134˚34.4649' E	10
3	7˚32.4835' N 134˚34.6881' E	30
4	7˚32.5391' N 134˚34.7114' E	50
5	7˚32.8707' N 134˚35.1757' E	80

Site 1 was situated on the floodplain of the Ngermeskang River. The sampling area was located at the confluence of the main river channel and a small tributary flowing into the river through a culvert constructed under the road (Fig. 1). Evidence of a recent and serious episode of erosion upstream along the tributary was present in the form of a sediment bar extending perpendicularly across the main river channel at the intersection with the tributary and forming a partial sill that rose some 50 cm above the channel floor. The sill consisted of sediments distinctly lighter in color and coarser in particle size than the silty substrate of the river channel (Pl. I, Fig. 2). The riverbed at Site 1 had a minimal gradient, and water clarity was generally poor as a consequence of intermittent rain showers during the study period (Pl. I, Fig. 3). The Ngermeskang River at this location was characterized by steep banks some 3 m in height and was well-shaded by tree growth that included *Ficus* spp. and *Semecarpus* spp.

Site 2 was located approximately 1.5 km upstream of Site 1. The predominant physical feature of the river at this site was a cascade developed over basalt bedrock (Pl. II, Fig. 4). Water plunged some 2 m from top to bottom of the cascade. The river above and below the cascade was characterized by deep pools and good water clarity (Pl. II, Fig. 5). Stands of *Cyathea* spp. formed a conspicuous component of the riparian forest at this site.

The Ngermeskang Waterfall was the focus of Sites 3 and 4 (Pl. III, Fig. 6). Site 3 was located below the falls, a distance of approximately 250 m upstream from Site 2. The base of the waterfall was characterized by a well-developed plunge pool that was some 1.5 m in depth. The plunge pool was formed in a platform that extends out 10 m from the base of the waterfall (Pl. III, Fig. 7). Water flowing from the plunge pool dropped an additional 2 m to the riverbed. Discharge from the plunge pool bifurcated around emergent basalt, forming a vegetated island in the middle of the river channel at Site 3 (Pl. IV, Fig. 8). Numerous emergent boulders were scattered the length of the river channel at Site 3 (Pl. IV, Fig. 9). The riparian vegetation was similar to Site 2, although terrain surrounding the river was much steeper.

Site 4 was located immediately above the Ngermeskang Waterfall. The river at Site 4 varied from about 2 to 15 m wide with large runs and deep pools over basalt bedrock (Pl. V, Figs. 10 & 11). There were few emergent rocks in the river at this sampling site. Although the riparian vegetation above the waterfall was similar in species composition to that of Sites 2 and 3, the riverbed was less shaded at Site 4, possibly because of the greater width of the river at this location.

Site 5 was located within the border of Ngerdmau State at a distance of 1.4 km upstream from Ngermeskang Waterfall. The river averaged less than 3 m in width at Site 5, narrower than at downstream sites. A low cascade (<1 m) was located midway in the sampling area (Pl. VI, Fig. 12). Habitats below the cascade were characterized by numerous emergent boulders and water flowing swiftly over cobbles and gravel in riffles and runs, while the area above the cascade consisted predominantly of shallow pools spanning the breadth of the river channel. The river banks at Site 5 were terraced, with two tiers. The lower tier was shaded by a dense canopy of *Pandanus* sp. and other woody tree species (Pl. VI, Fig. 13), but much of the vegetation along the old, cobble-stone trail paralleling the river on the upper tier had recently been cleared from the Ngeremlengui-Ngerdmau border to Site 5.

Visual Survey

The locations of individual streamfishes were determined by direct visual observation by an experienced biologist (JEP). Visual observations were made from the stream bank or in the water with the aid of a mask and snorkel (Pl. I, Fig 2). Observations were temporarily suspended during heavy rain showers and resumed when water clarity permitted. The visual survey method that we used was based on the method described by Baker and Foster (1992). The method involves counting fishes located within quadrats of variable size. The size of the quadrat used is determined by the observer's ability to count fish accurately from a single observation position (Baker and Foster, 1992). We used a stratified random design to determine the sites to be sampled. The sites were categorized according to reach (upper, middle, and lower) and by habitat type (riffle, run, or pool).

At each site, the sampling point was approached from downstream. Conspicuous landmarks along the bank or in the stream were used to mark the boundaries of each quadrat. For each species at each site, data were collected on the number of individuals, the focal point substrate (i.e., directly underneath the fish), their use of cover, and their position in the water column. The quadrat area was then determined with a measuring tape (Pl. V, Fig. 11). Fish were considered to be using cover if they remained underneath or against a sheltering object. Position in the water column, or relative depth, was estimated in tenths from 0 = bottom to 1 = surface. The densities of each species (number of individuals per square meter) were calculated for each quadrat.

Substrate Characterization

The substrate available to the fish within a quadrat consisted of a weighted mean of the two dominant substrate types. A numerical code representing substrate categories (Table 2) and a visual estimate of the substrate available (0 = 0% to 10 = 100% coverage) was recorded for each of the two dominant substrate types (Moyle and Baltz, 1985). We calculated a weighted score for the substrate available for each site using the formula

$$\textit{Substrate Availability} = \frac{(S_1 \times E_1) + (S_2 \times E_2)}{10}$$

where S_1 is substrate code #1, E_1 is an estimate of available substrate #1, S_2 is substrate code #2, and E_2 is an estimate of available substrate #2.

Reference Collection

Representative, freshly collected specimens of each species were photographed for documentation of field markings and coloration. Then the specimens were fixed in 10% formalin. The fixed specimens were later transferred to 70% ethanol and stored at the University of Guam Marine Laboratory to serve as a reference collection for future work. A set of photographs and slides with identifications was provided to the Palau Environmental Quality Protection Board.

Quality Control Assurance

Quality control assurance plans were important for several aspects of the visual survey. The two primary concerns were: 1) the identification of species in the field, and 2) the reliability of density estimates. Variability in both areas was minimized by having all visual identifications and counts made by one, experienced

Table 2. Substrate categories, codes, sizes and field references (adapted from Baker and Foster, 1992).

Category	Substrate Code	Particle Size Range mm	inches	Field Reference
Bedrock	1	N/A	N/A	N/A
Boulder	2	> 256	> 10	basketball-sized and larger
Cobble	3	64 - 256	2.5 - 10	softball-sized
Gravel	4	5 - 63.9	0.5 - 2.49	marble-sized
Sand or Sediment	5	< 5	< .5	sand-sized
None	6	N/A	N/A	for fish not relating to the substrate

person. In addition, at some sites we made exhaustive collections, using nets and an electroshocker, in order to confirm the field identifications (Pl. I, Figs. 2 & 3; Pl. IV, Fig. 9).

Species Identifications

We used several reference works to identify the species of fishes collected. These included those of Fehlmann (1960), Bright and June (1981), Allen (1991) Watson (1991; 1992), and Parenti and Maciolek (1993) .

Statistical Analysis

For species that we had sufficient sample sizes of, we compared densities among areas (i.e., reaches or habitats) with an Analysis of Variance (ANOVA). One of the major assumptions of ANOVA is that the variances among groups are equal. We tested this assumption with Levene's test (BMDP 7D), and the data were transformed as needed. Although there may be some bias in back-transforming the means, our interest was in detecting differences between groups rather than providing precise estimates of fish density. The use of transformed data allows statistical comparisons of appropriate power with much smaller sample sizes than would be required for raw data (Norris et al., 1992). This point is especially important for small streams where sufficient replication of habitat types can be a problem.

Results

We obtained densities for thirteen species of stream fishes in the sections of the Ngermeskang river that we studied (Table 3). The most common of these fishes was the goby *Stiphodon elegans*. This species is sexually dimorphic, and there are two color forms of the males: courting males that are black and the non-courting, green males. We were able to obtain density estimates for each male type and for females. The data for female *S. elegans* may include females of *Stiphodon caerula* because we could not distinguish between the females of these species in the field.

Table 3. Mean densities of the fishes of the upper Ngermeskang River, Palau.

Species	Habitat	Min.	Max.	Mean	S.D.	Sites
Anguilla marmorata	pool	0.43	0.43	–	–	1
Bunaka gyrinoides	run	0.81	0.81	–	–	1
Glossogobius celebius	pool	0.36	0.73	0.570	0.157	5
Kuhlia rupestris	pool	0.52	3.33	1.794	1.418	3
Kuhlia rupestris	run	0.44	2.42	1.439	0.993	3
Ophioeleotris aporos	pool	0.24	0.78	0.510	0.382	2
Redigobius bikolanus	run	0.40	0.40	–	–	1
Sicyopus zosterophorum	run	0.46	0.46	–	–	1
Sicyopus sp. 1—red male	riffle	2.21	2.21	–	–	1
Sicyopus sp. 2—striped male	run	0.81	0.81	–	–	1
Sicyopus spp.—females	pool	0.10	1.56	0.552	0.290	5
*Sicyopu*s spp.—females	riffle	2.21	2.21	–	–	1
Sicyopus spp.—females	run	0.25	1.56	0.975	0.280	5
Stiphodon caerula	riffle	0.10	0.76	0.390	0.337	3
Stiphodon caerula	run	0.30	2.71	0.936	1.186	4
Stiphodon elegans—black male	pool	0.13	4.55	1.171	1.385	11
Stiphodon elegans—black male	run	0.69	2.01	0.823	0.662	11
Stiphodon elegans—female	pool	0.39	3.67	1.426	1.060	10
Stiphodon elegans—female	riffle	0.59	2.63	1.607	1.440	2
Stiphodon elegans—female	run	0.46	11.01	5.226	4.563	13
Stiphodon elegans—green male	pool	0.29	4.55	2.437	2.133	3
Stiphodon elegans—green male	run	0.29	4.05	2.394	1.343	6

Maximum densities found for each group ranged from 0.4 fish m^{-2} for *Redigobius bikolanus* to more than 11.0 fish m^{-2} for female *Stiphodon elegans*. The highest mean density was found for female *S. elegans*, with 5.2 fish m^{-2}.

Although data for some of the species were sparse, there were obvious differences in the fish assemblages below and above the waterfall (Table 4). Below the fall, the predatory mountain bass *Kuhlia rupestris* was very abundant, but it was absent from sites above the fall. Also, there were more species of small gobies in the reaches above the falls. In addition, it was noted that the river shrimps *Macrobrachium* spp. were more abundant above the falls. In the reach where *Kuhlia* was abundant the shrimp appeared larger and were generally near or under cover, while in the reaches without *Kuhlia rupestris* the shrimp were active in open areas.

Table 4. Presence (**+**) or absence (**–**) of species streamfishes in three reaches (below fall, above fall, and headwaters) of the Ngermeskang River, Palau.

Species	Below Fall	Above Fall	Headwaters
Kuhlia marginata	+	–	–
Kuhlia rupestris	+	–	–
Redigobius bikolanus	+	–	–
Toxotes jaculatrix	+	–	–
Anguilla marmorata	+	+	–
Glossogobius celebius	+	+	+
Stiphodon elegans	+	+	+
Sicyopus sp. 1—red male	+	+	+
Sicyopus spp.—females	+	+	+
Sicyopus zosterophorum	–	+	–
Sicyopus sp. 2—striped male	–	+	–
Bunaka gyrinoides	–	+	–
Ophioeleotris aporos	–	+	+
Stiphodon caerula	–	+	+

The mean densities of both male and female *Stiphodon elegans* for each reach are shown in Table 5, and the ANOVA table resulting from a comparison of the densities between sexes and the three reaches is shown in Table 6 . Analysis of Variance was performed on log-transformed data to equalize the variances among groups. The ANOVA showed that there were significant difference between sexes (p=0.03) and reaches (p=0.02), but the interaction between these factors was not significant (p>0.91). For both males and females, densities at the sites above the falls and in the headwaters differed significantly (p<0.01, Tukey's test). There were few sites below the falls, which probably reduces the probability of the detecting differences between those groups and the others.

In each reach the densities of females were higher than those of males. The ratios of females to males were 1.7:1, 2.6:1, and 2.7:1 for the below-fall, above-fall, and headwater sites, respectively. Although some of the females identified in the field as *S*. *elegans* may have actually been *S*. *caerula*, the latter species is much less common. The females are virtually indistinguishable in the field.

Table 5. Densities of *Stiphodon elegans* in three reaches of the Ngermeskang River, Palau.

Sex - Habitat	Mean	Std. dev.	Range	No. sites
Males				
Below falls	1.280	1.239	0.40 to 2.16	2
Above falls	1.173	1.187	0.13 to 4.55	25
Headwaters	0.391	0.242	0.07 to 0.68	6
Females				
Below falls	2.131	1.411	0.54 to 3.22	2
Above falls	3.043	3.286	0.46 to 11.01	13
Headwaters	1.053	0.830	0.39 to 2.84	7

Data on focal-point substrates were collected for 5 species, and differentiated into 8 groups (Table 7). For most groups, the mean focal-point substrate code values fell between 1.0 and 1.8. There were 2 exceptions, *Stiphodon caerula* (2.2) and *Ophioeleotris aporos* (4.0), although the latter was an observation of only one fish. Other observations *of Ophioeleotris aporos* seemed to show this fish relates more to current and cover, than to substrate type.

The mean focal point substrate codes differed significantly (Kruskal-Wallis Test Statistic = 27.05, p<0.001, based on Chi-square distribution with 3 degrees of freedom) among the four groups of *Stiphodon* (female, black male, and green male *S. elegans* and male *S. caerula*). The lowest mean value of 1.0 was found for *S. elegans* females, and the highest mean was for *S. caerula* males. For this comparison we used a non-parametric test, as neither the assumption of homogeneity of variances nor the assumption of normality could be met for the data.

Table 6. Comparison of mean log (density) of male and female *Stiphodon elegans* by reach. Densities were log transformed to insure homogeneous variances (Levene's test).

Source	Sum of Squares	Degrees of Freedom	Mean Square	F-value	Probability
Sex	0.1992	1	0.9112	5.26	0.0272
Reach	1.2022	2	0.6011	3.47	0.0209
Interaction	0.0343	2	0.0171	0.10	0.9061
Error	6.9341	40	0.1734		

The females were almost always found on bed rock where they were feeding. This probably explains both the low mean and the low standard deviation for this group. The black barred male *Stiphodon elegans* were often found displaying in the water column. Individuals of *Stiphodon caerula* were not encountered frequently, but were found over finer substrates, although the mean had a relatively high standard deviation.

Table 7. Mean focal point substrate codes for individuals fish in the Ngermeskang River, Palau.

Species	N	Mean	Std. deviation
Glossogobius celebius	7	1.43	1.33
Ophioeleotris aporos	1	4.00	–
Sicyopus sp. 1—red male	3	1.33	0.58
Sicyopus spp.—females	22	1.41	0.91
Stiphodon caerula—male	9	2.22	1.39
Stiphodon elegans—black male	53	1.34	0.68
Stiphodon elegans—female	150	1.03	0.20
Stiphodon elegans—green male	53	1.72	1.06

Discussion

Within Stream Zonation

The composition of species and their zonation from lower to upper reaches of the Ngermeskang River were similar to those described by Fehlmann (1960) in his studies of the Arakitaoch Stream. A similar pattern of zonation was reported for the streamfishes of Pohnpei by Maciolek and Ford (1987). Some fishes, such as *Kuhlia rupestris,* are numerous in the streams below the first major waterfall and absent upstream. When *Kuhlia* are eliminated, presumably because they are not morphologically adapted to climbing waterfalls, the small gobies become more numerous. River shrimps (*Macrobrachium* spp.) are also noticeably more abundant at sites without *Kuhlia rupestris*. This suggests that the predation by the mountain bass has considerable influence on the communities of fishes and invertebrates in the freshwaters of Palau. Whatever the reason, the zonation in the distributions and abundances of streamfishes in Palau is obvious, and this must be taken in to account when designing monitoring programs aimed at detecting environmental impacts.

Habitat and Microhabitat

Our work, while limited because of the short sampling period, provides some of the first quantitative data on the densities and microhabitats of streamfishes in Palau. This information will be useful in designing future studies of streamfishes of Palau and other islands of the insular, tropical Pacific. Both habitat type (riffle, run, pool), which could be best categorized quantitatively by relative water column velocity, and substrate type are important determinants of the distribution and abundances of some of the streamfishes in the Ngermeskang River. This is consistent with the qualitative observations of Fehlmann (1960) who noted that some fishes, such *Eleotris fusca* and *Anguilla marmorata* were found over a wide variety of substrate types while many of the mountain gobies were found only in areas where there was cobble, boulder, or bedrock substrate. We found also that male and female *Stiphodon elegans* were both found in sites with substrate codes of just greater than 2.0 but the focal point substrate codes were lower, ranging from 1.0 to 1.7. Further, the variance of the mean focal-point substrate codes for male and female *Stiphodon elegans* differed considerably, with the female variance being much less than that of either type of male. Also, in contrast to *Stiphodon elegans*, the males of *Stiphodon caerula* had mean focal point substrate codes very close to the mean of the substrate codes for the sites where they were found. However, we had few observations of this species, and further work with it, especially in regard to comparing its microhabitat with that of *Stiphodon elegans*, should prove interesting.

These data indicate that substrate type is an important component of the microhabitat of many of the gobies of Palau and that substrate type is one resource axis that is partitioned, at least to a degree, between males and females. In their studies of streamfish assemblages in Sri Lanka, Moyle and Senanayke (1984) were able to construct an “ecological key" to the species based on velocity, substrate, relative depth, and diet. A similar key for the stream fishes of Palau would require some additional work, but would be a useful aid in designing monitoring programs.

Potential Effects of Sedimentation

The most serious threat to the streams of Palau presently is the erosion from road construction and land clearing. Recent road construction within the Ngermeskang River watershed has led to increased development of farming in areas that have been little utilized for decades. Clearing the vegetation near rivers can result in sediments being washed into the streams, and these can have negative effects on the stream fauna as well as on the marine areas near the mouths of impacted rivers. Increased suspended solids in the water column reduce the light reaching the attached macroalgae and algal films in the streams and cause a reduction in the rate of primary production. Stream algae are browsed or grazed by gastropods, freshwater shrimp, and several fishes.

Some stream gobies, such as those of the genus *Awous,* are omnivorous and known to consume macroalgae (Kinzie, 1990). Fishes of the genus *Stiphodon* are specialized algal grazers and would be especially vulnerable to reductions in benthic algal productivity. A closely related genus is *Sicyopterus*, which appears to be herbivorous based on intestine lengths. However, Moyle and Senanayake (1984) found that small *Sicyopterus halei* feed on larval insects clinging to rocks, especially mayfly larvae, although they suspected that larger fish were omnivorous. Sediment in streams could obviously impact several components of the food web, if either the rock substratum is smothered or the algal production is reduced as a result of increased turbidity. Although supporting data are difficult to find, Pethiyagoda (1994) reported that some of the tropical stream fishes of Sri Lanka are found only in clear, shaded waters, while the populations of others are reduced in areas impacted by increased turbidity.

Increased sediment loads can be also be detrimental to benthic invertebrates. In slow-moving reaches of streams, especially at lower elevations, sediments can eliminate the hard substrates needed by stream gastropods. The gastropods will also be negatively affected by the smothering of benthic algal food sources. In the streams of Palau the gastropods constitute a major portion of the secondary productivity and are preyed upon by fishes and crustaceans. For example, in many areas, the diet of the eleotrid *Eleotris fusca* is reported to include stream gastropods in large proportions. This has also been known for the genera *Eleotris* and *Bunaka* collected at Palau (Bright, 1979). In our work at Guam and in Yap, we also found snails in the stomachs of *Kuhlia rupestris*. Species of *Macrobrachium* are also known to prey on snails, and we have observed *Macrobrachium lar* preying on snails in our laboratory studies at the University of Guam.

Reductions in the densities of gastropods, shrimp, and small fishes could also affect the larger predators such as eels. Eels are known to feed on insects, crustaceans, gastropods, and fishes (Tesch, 1977). We have found both fishes and invertebrates in stomachs of *Anguilla marmorata* collected on Guam. It is clear that problems resulting from sedimentation can, potentially, have effects throughout the food web.

Riparian Reserves

Removal of riparian vegetation also can increase the temperature of the nearby aquatic habitats and can increase the exposure of aquatic organisms in these habitats to ultraviolet radiation. The effects of riparian disturbances on streams have been documented in some temperate areas. In trout streams of the Oregon desert, cattle grazing resulted in a reduction of riparian vegetation (Li et al., 1994). In that study, trout biomass was found to be negatively correlated with solar radiation, although algal biomass increased with increases in solar input . Removal of shade by reduction of riparian vegetation results in substantial, cumulative temperature increases downstream of the disturbance (Barton et al., 1985; Li et al., 1994).

Severe reduction of riparian vegetation can even result in lowering of the water table. This could even cause a permanently flowing stream to become intermittent. In a study of the ecological effects of altering riparian vegetation in desert streams in Oregon, Li et al. (1994) found that a stream in an area of heavy cattle grazing had intermittent flow, while its sister (control) stream, in a nearby area unaffected by grazing, had permanent flow. Riparian reserves along the banks of streams are needed to prevent these and other effects associated with development (i.e., such as increased sedimentation, reduction of cover, reduction of organic inputs). The widths of riparian reserves needed varies greatly between sites and is dependent on factors such as the size of the stream, the stream biota, and the nature of the sediments (Forest Ecosystem Management Assessment Team, 1993).

Monitoring

Where the water clarity is adequate, visual surveys have been found to be both practical and appropriate for determining the microhabitats (Moyle and Blatz, 1985) and estimating the densities of stream fishes (Baker and Foster, 1992). A detailed protocol for estimating stream fish abundances based on visual survey was recently developed and tested in the streams of Hawaii (Baker and Foster, 1992). In this study we found that this technique is also effective in the streams of Palau. In contrast to the commonly used methods involving electroshocking or poisoning, visual surveys have proven reliable, and they are non-destructive. We found that electrofishing was highly effective for some species (*Eleotris fusca* is particularly sensitive) but almost totally ineffective for collecting others (the small gobies such as *Stiphodon elegans* seem oblivious to the electroshocker). Poisons have been used to collect stream fishes in Palau, but this technique would not be suitable for monitoring. Fehlmann (1960) intensively collected streamfishes in Palau with an ichthyocide and found that some sites had not recovered 11 months later, when they were surveyed again.

There are several drawbacks to the use of visual survey techniques in monitoring. One of these is that some species are more cryptic than others. Fishes that hide readily, blend well with the background, or stay in the shadows may be under-represented. Densities of schooling fishes such as the mountain bass *Kuhlia rupestris* are difficult to obtain in some areas because the fish are numerous and constantly moving. In addition, well trained personnel are needed for the field work involved with visual surveys.

Recommendations

1. Because there is a marked zonation of fishes in the streams of Palau with fewer fishes found above the first major waterfall than below, control sites and those where there is to be an intervention or impact should be matched with regard to stream order, elevation, and position relative to major waterfalls or other barriers to upstream migration.

2. Because the mountain goby *Stiphodon elegans* is common and found in a wide range of habitats throughout the stream above the mangrove zone, this species would be a likely candidate for use as an indicator species.

3. Because identification of streamfishes in the field and estimating their densities is labor intensive and requires a high degree of training, it would be worth considering the monitoring of common stream invertebrates that could be more easily collected and identified by personnel with only a minimum of training. Studies of the distribution and abundances of stream invertebrates of the Ngermeskang River are needed.

4. Additional data on the microhabitat use by the more common streamfishes of the Ngermeskang River are needed along with data on the availability of microhabitat. This information could be used in predicting the effects of environmental impacts on the streamfishes in Palau. Data are needed on the change in microhabitat use between wet and dry seasons.

5. The data base for the streamfishes of Palau is meager. Additional work is needed particularly needed on reproduction, microhabitat use, trophic relations, and species interactions.

6. The effects of land clearing near streams should be minimized by establishing riparian reserves as buffers. Studies are needed to determine the minimum effective widths of such reserves for the streams of Palau. In the absence of such studies, we recommend that minimum widths of ten meters be established for riparian reserves on each stream bank, although greater widths would be desirable in many (perhaps most) cases.

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PLATES

Plate I

Figure 2. Ngermeskang River at Site 1. The snorkeler is swimming upstream and passing over the sediment bar. Note lighter-colored sediments beneath snorkeler's left leg.

Figure 3. View downstream from sediment bar at Site 1.

Plate II

Figure 4. Cascade at Site 2.

Figure 5. Sampling pool upstream of cascade at Site 2.

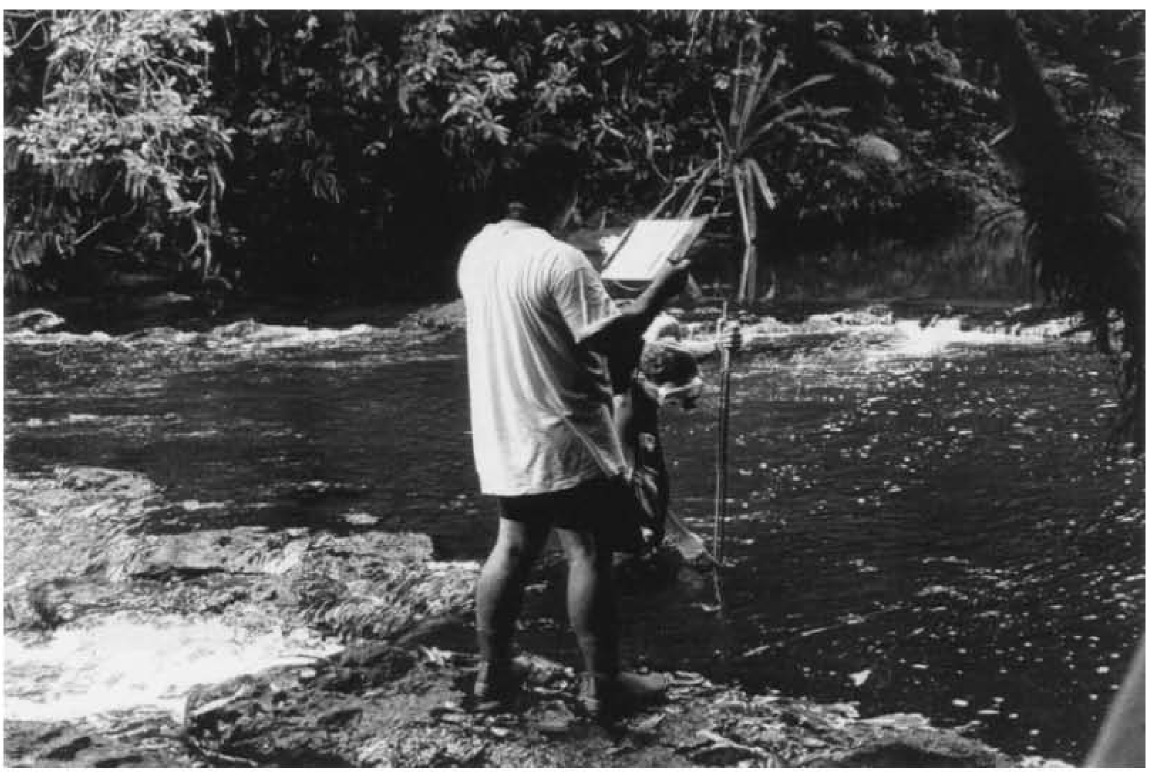

Plate III

Figure 6. Site 3 below Ngermeskang Waterfall. Note discharge cascading from the main plunge pool at the lower left of the photograph.

Figure 7. Main plunge pool at base of Ngermeskang Waterfall. Biologists are standing in the plunge pool.

Plate IV

Figure 8. View of Site 3 from the top of the Ngermeskang Waterfall. Note vegetated island at the top center of the photograph.

Figure 9. River channel at Site 3 downstream of Ngermeskang Waterfall. Note numerous boulders in stream flow.

Plate V

Figure 10. Site 4 above the Ngermeskang Waterfall.

Figure 11. Pool at top of Ngermeskang Waterfall. Biologists are measuring dimensions of quadrat sampling area.

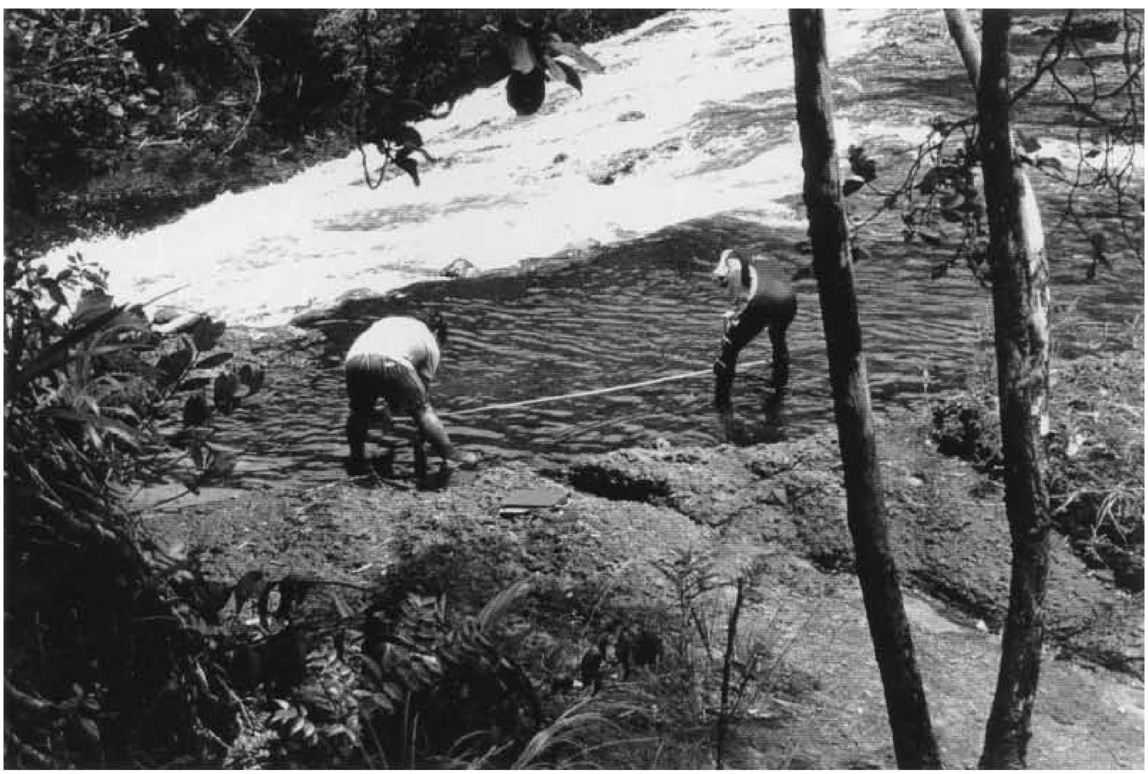

Plate VI

Figure 12. Low cascade near middle of Site 5.

Figure 13. Riparian vegetation of lower tier at Site 5.