Micronesica 30(1): 83–91, 1997

Distributions and Microhabitats of the Amphidromous Gobies in Streams of Micronesia[1]

STEPHEN G. NELSON, JAMES E. PARHAM, R. BRENT TIBBATTS, FRANK A. CAMACHO, TRINA LEBERER AND BARRY D. SMITH

Marine Laboratory, University of Guam, UOG Station, Mangilao, Guam 96923 USA

Abstract—Amphidromous gobies are prominent components of stream fish assemblages of the islands of Micronesia, yet most aspects of their biology are poorly known. The increased pace of development in many of the islands of the tropical Pacific has resulted in an increased threat to the fauna of their inland, aquatic habitats and an urgent need for ecological information on these fishes. We used visual surveys to compare the in-stream distributions, microhabitat use, and densities of stream gobies from two islands within the geographic area of Micronesia in relation to various physical and biotic factors. The species composition of the goby assemblages changes with stream elevation, most abruptly at waterfalls, and between islands. Abrupt changes in the stream fish communities occur at major waterfalls. Waterfalls can be effective barriers to upstream migration for the gobies that are not adapted to climbing, such as those of the genus *Stenogobius*. However, even large waterfalls can be climbed by species in the genera *Stiphodon, Sicyopus, Sicyopterus, Awaous,* and *Redigobius.* Percent canopy cover and substrate type are other determinants of the distributions and densities of these tropical stream gobies.

Introduction

Gobies are prominent components of the stream fish assemblages on islands throughout Micronesia and the other areas of the tropical Pacific (Ryan 1991, Kinzie 1990). As might be expected, the indigenous gobies of the streams of the oceanic islands of the Pacific are, as far as is known, all amphipdromous, spawning in freshwater with the larvae developing in the ocean and returning to freshwater to mature (Dotu & Mito 1955, Ego 1955, Iguchi & Mizuno 1990). Unfortunately, most ecological aspects of the streams of the tropical Pacific islands are poorly known. For most of the freshwater gobies of this region, there is taxonomic confusion as well as a dearth of ecological information.

The rapid pace of development in islands within the geographic area of Micronesia and in other areas of the tropical Pacific has led to an increased threat to these fishes. Conspicuous examples of environmental degradation of some of the streams within Micronesia include: reductions in water quantity and quality, de-

[1]ASIH symposium on freshwater gobies

struction of riparian vegetation resulting from road construction and agriculture, and the introduction of exotic species (Nelson & Eldredge 1991). Information on the distributions and habitats of these fishes is needed in order to develop bioassessment protocols and long-term field monitoring programs for the conservation of the freshwater ecosystems of the tropical Pacific islands.

Materials and Methods

The data reported here were collected from sites in the Ngermeskang River on the island of Babeldaob in Palau and from the Lehn Mesi and Nanpil Kiepw Rivers on the island of Pohnpei. Both islands are in the Caroline Islands, located in the central, western Pacific Ocean.

We used visual survey methods that were slightly modified from those described by Baker & Foster (1992), counting fishes located within quadrats of variable size. The size of the quadrat used was determined by the observer's ability to count fish accurately from a single observation position, but most were 1–2 m^2. We used a stratified random design to determine the location of the quadrats within the stream. The quadrats were categorized according to reach and by habitat type (riffle, run, or pool).

Each quadrat 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 quadrat, data were collected on the number of individuals, the focal point substrate (i.e., substrate directly underneath the fish), their position in the water column, and their use of cover. Substrate codes were 1 through 5 for bedrock, boulders, cobble, gravel, or sand-sized particles, respectively. After recording information on individuals, we determined the quadrat area with a measuring tape and calculated the densities of each species (number of individuals per square meter). Specimens of each species were collected and preserved for identification in the laboratory. Reference works included those of Fehlmann (1960), Bright & June (1981), Allen (1991), Watson (1991, 1992), and Parenti & Maciolek (1993).

For species or groups for which we had sufficient data, we compared densities among areas (i.e., reaches or habitats) with analysis of variance. We tested the assumption of equal variances among groups with Levene's test, and the data were transformed as needed. Our interest was in being able to detect differences in fish densities among groups, and 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. Correlation analysis was used to examine relationships between fish density and environmental factors.

Results

POHNPEI

We observed seven species of gobies in the two rivers of Pohnpei. The most abundant species was *Stiphodon caeruleus,* a small herbivorous goby that was found throughout both streams. A second species of *Stiphodon, Stiphodon* cf. *elegans,* was abundant in some locations at lower elevations. We found two large herbivorous gobies of the genus *Sicyopterus,* one of which was common (*S. lividus*) and the other rare (*S. eudentata*). A smaller omnivorous goby, *Sicyopus nigriradiatus,* was relatively uncommon. In addition we found *Glossogobius celebius* and *Redigobius bikolamus* in the lower reaches, the former usually over sand.

In comparing the two rivers at sites above the first major waterfall, we found that there were significant differences in the densities of gobies between rivers ($F_{1,94} = 53.98$; $p < 0.001$) and among habitats ($F_{2,94} = 4.69$; $p = 0.012$), but there was no significant river-habitat interaction. Thus, the fish were not randomly distributed, and their habitat use was similar between rivers. The sites in the Lehn Mesi River generally had higher densities of fish than those in the Nanpil Kiepw River.

We also found relationships between goby densities and environmental characteristics of the sites. For example, goby density was weakly, but significantly, correlated (Pearson's $r = 0.1809$, $n = 131$, $p = 0.039$) with the percentage of hard substrate (bedrock, boulders, and cobble) in the quadrat. Most of the sites in both rivers had more than 50% hard substrate, and there was a greater variation in the densities at sites with high percentages of hard substrate, which weakened the correlation. Still, it can be seen that all sites with goby densities above 10 m^{-2} had more than 60% hard substrate (Fig. 1). Also, at these sites, there was a weak nega-

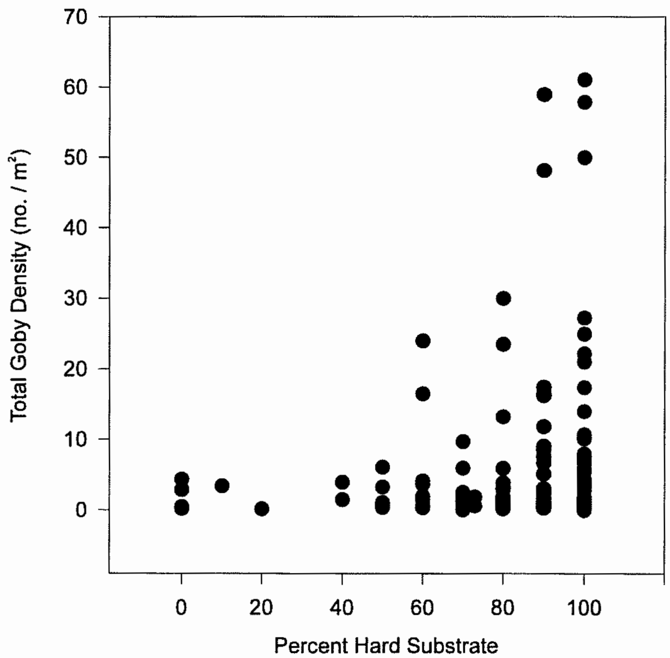

Figure 1. The relationship between goby density and the percent of hard substrate in quadrats within the streams of Pohnpei.

tive correlation (Pearson's $r = -0.2356$, $n = 99$, $p = 0.0189$) between total goby density and percent canopy cover (Fig. 2), with greater variation in densities evident at sites with low percent canopy cover.

PALAU

We observed nine species of gobies in the sections of the Ngermeskang River that we studied. The most common of these was *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. An undescribed species of *Stiphodon,* which we refer to here as *Stiphodon* species 2, was also present, but far less abundant. The data for female *S. elegans* may include females of *Stiphodon* species 2 because we could not distinguish between the females of these species in the field.

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.* Mean densities for groups of these fishes excluding sites where they were absent (zero values) are shown in Table 1. The highest mean density, 5.2 fish m^{-2}, was found for female *S. elegans.*

Although data for some of the species were sparse, there were obvious differences in the fish assemblages below and above the waterfall. The predatory moun-

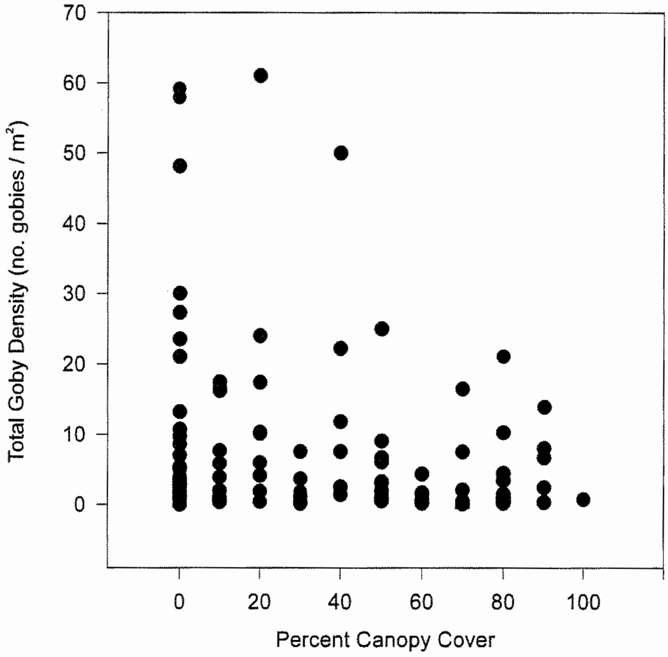

Figure 2. The relationship between goby density and percent canopy cover in the streams of Pohnpei.

Table 1. Mean densities (individuals m^{-2}) of the fishes of the upper Ngermeskang River, Palau.

Species	Habitat	Min.	Max.	Mean	S.D.	Sites
Bunaka gyrinoides	run	0.81	0.81	–	–	1
Glossogobius celebius	pool	0.36	0.73	0.570	0.157	5
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
Sicyopus spp.—females	riffle	2.21	2.21	–	–	1
Sicyopus spp.—females	run	0.25	1.56	0.975	0.280	5
Stiphodon sp. 2	riffle	0.10	0.76	0.390	0.337	3
Stiphodon sp. 2	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

tain bass *Kuhlia rupestris* was very abundant below the fall, but it was absent from sites above the fall. Also, there were more species of small gobies in the reaches above the falls. Three species of gobies (*Stiphodon elegans, Glossogobius celebius,* and *Sicyopus* species 1) were found throughout the river both above and below the waterfall, while the other three species were found only above. In addition, it was noted that the river shrimps *Macrobrachium* spp. were more abundant above the falls.

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 *Stiphodon sp. 2,* the latter species is much less common. The females are virtually indistinguishable in the field.

Data on focal-point substrates were collected for five species and differentiated into eight groups (Table 2). For most groups, the mean focal-point substrate code values fell between 1.0 and 1.8. There were two exceptions, *Stiphodon* sp. 2 (2.2) and *Ophioeleotris aporos* (4.0), although the latter was an observation of only one fish. From additional observations of *Ophioeleotris aporos* made during this study, this fish appeared to relate more to current and cover than to substrate type.

The mean focal point substrate codes differed significantly (Kruskal-Wallis Test Statistic = 27.05, $p < 0.001$) among the four groups of *Stiphodon* (female, black male, and green male *S. elegans* and male *Stiphodon* sp. 2. The lowest mean value of 1.0 was found for *S. elegans* females, and the highest mean was for *Stiphodon* sp. 2 males. For this comparison we used a non-parametric test, as nei-

Table 2. Mean focal point substrate codes for individual gobies 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

ther the assumption of homogeneity of variances nor the assumption of normality could be met for the data. The females were almost always found on bed rock, where they were feeding. This resulted in a low standard deviation for this group. The black barred male *Stiphodon elegans* were often found displaying in the water column. Males of *Stiphodon* sp. 2 were not encountered frequently, but were found over finer substrates. However, the mean had a relatively high standard deviation.

Discussion

Gobies are the most common fishes in the upper reaches of the streams within the tropical Pacific islands (Ryan 1991, Kinzie 1990), and this was the case for the rivers that we surveyed in Palau and Pohnpei. In Palau, as in Guam (Parham 1995), the most abundant fish in the upper stream reaches were species of *Stiphodon.* The predominant fish in the streams of Pohnpei is *S. caeruleus,* with *Stiphodon* cf. *elegans* abundant at some sites. These fishes were found in all reaches and habitats of these streams. These fishes are active throughout the day and are often observed feeding, which they accomplish by scraping algae from the hard surfaces of bedrock, boulders, and cobble. Courting male *Stiphodon* are brightly colored and were often seen in the water column displaying towards females or chasing rival males.

WITHIN-STREAM ZONATION

As is typical of the streams of Micronesia, there is a marked zonation of the assemblages of the aquatic organisms within the streams of Pohnpei, with the first major waterfall constituting a major factor determining the zonation. Within-stream patterns of zonation have been described for the Arakitaoch Stream in Palau (Fehlmann 1960), the Asmafines River in Guam (Parham 1995), and for the streams of Pohnpei (Maciolek & Ford 1987). The mountain basses of the genus *Kuhlia* are abundant in the lower reaches of Micronesian streams below the first major waterfall, but they are absent upstream. In the Nanpil and Lehn Massey rivers of Pohnpei, there are two species of mountain bass; these are *Kuhlia rupestris* and *K. marginata.* These and other species, such as gobies of the genus *Stenogobius,* that can not climb the falls are restricted to the lower reaches.

The restricted upstream movement of these predators appears to affect the distribution of some of the other stream organisms. Small gobies, palaemonid shrimps (*Macrobrachium* spp.), and atyid shrimps are in much greater abundances in the upper areas, where there are no *Kuhlia* present. Predation by mountain basses, therefore, is likely to have a major influence on the gobies in the freshwater streams of Micronesia.

HABITAT AND MICROHABITAT

In this work we have provided the first quantitative data on the densities and microhabitats of gobies in the streams of Micronesia. In our previous work in the streams of Guam, we found that habitat type (riffle, run, pool) and substrate type are important determinants of the distribution and abundances of the stream fishes (Parham 1995). We found this to be true also for the gobies of Pohnpei and Palau.

The significant positive correlation between goby density and percentage of hard substrate at a site is most likely a result of the herbivorous diet of these fishes. The gobies feed by scraping diatoms or algae growing on the hard surfaces in the stream. Many of these species have teeth specialized for this purpose; their teeth wear out and are continually replaced. The correlation between goby density and quadrat substrate is weak because the gobies are found in all types of habitats. However, in other studies (Parham 1995) when we examined the substrate at the specific location of an individual fish, rather than that of the site in which it is found, the use of hard substrate by these herbivorous gobies becomes more apparent. Also, Fehlmann (1960) reported that in Palau many of the mountain gobies are found only in areas where there was cobble, boulder, or bedrock substrate. In the streams of Pohnpei, most of the sites have high percentages of hard substrates; and the sites with the highest goby densities have high percentages of hard substrate. However, we found considerable variation in goby density, even at sites with high percentages of hard substrate. This indicates that other factors are also operating to determine goby densities at a particular site.

Another factor that proved interesting was the percentage of canopy cover. Because most of the common gobies are herbivorous, we hypothesized that their densities would be higher at sites that were exposed to more sunlight because these areas would have higher rates of primary productivity. Our Pohnpei data support our hypothesis because goby densities declined as percent canopy cover increased. Although the correlation between percent canopy cover and goby density at Pohnpei was significant and negative, it was not a very strong correlation, indicating that this not a major determinant of goby distribution but a contributing factor.

Our data provide a first step in determining the habitat requirements of Micronesian stream gobies and, thus, are useful for predicting the ecological effects of stream modification or disturbance. In their studies of stream fish assemblages in Sri Lanka, Moyle & Senanayke (1984) were able to construct an "ecological key" to the species based on velocity, substrate, relative depth, and diet. Similarly, Parham (1995) combined factor analysis of detailed data on microhabitat use with distributional data to show how the gobies of the Asmafines River on Guam were segregated according to environmental factors. Further detailed ecological studies of the gobies of Micronesia are needed in order to construct and refine "ecological keys" for these species for use in the design of monitoring and conservation programs throughout the region.

Acknowledgments

Our work in Pohnpei was supported by a contract with the South Pacific Regional Environmental Programme, Biodiversity Conservation Project. We are grateful to Bill Raynor and his staff at the office of the Nature Conservancy in Pohnpei and to Spensin James and Ahser Edward of the College of Micronesia for their support and assistance. In Palau, our work was supported through a contract with the Palau Environmental Quality Protection Board. We are grateful to Gilbert U. Demei, Dorthea Panayotou, Barry Pollock, Portia Franz, Ongerung K. Kesolei, Jerome Sakurai, and Denicio Mariur for their kind assistance in our work.

References Cited

Allen, G. R. 1991. Field guide to the freshwater fishes of New Guinea. Madang, Papua New Guinea: Christensen Research Institute. 268 p.

Baker, J. A. 1991. Sampling Hawaiian stream gobies. p. 238–271. *In* New Directions in Research, Management, and Conservation of Hawaiian Freshwater Stream Ecosystems. State of Hawaii, Department of Land and Natural Resources.

Baker, J. A. & S. A. Foster. 1992. Estimating density and abundance of endemic fishes in Hawaiian streams. State of Hawaii, Department of Land and Natural Resources, Division of Aquatic Resources. 50 p.

Bright, G. R. & J. A. June. 1981. Freshwater fishes of Palau. Micronesia 17: 107–111.

Dotu, Y. & S. Mito. 1955. Life history of a gobioid fish, *Sicydium japonicum* Tanaka. Sci. Bull. Fac. Agr. Kyushu Univ. 15: 213–221.

Ego, K. 1956. Life history of fresh water gobies. Project Number f-4-R. Fresh water game fish management research, Department of Land and Natural Resources, Territory of Hawaii, Honolulu, 24 p.

Fehlmann, H. A. 1960. Ecological distribution of fishes in a stream drainage in the Palau Islands. Ph.D. Dissertation, Stanford University. 172 p.

Iguchi, K. & N. Mizuno. 1990. Diel changes of larval drift among amphidromous gobies in Japan, especially *Rhinogobius brunneus.* Journal of Fish Biology 37: 255–264.

Kinzie, R. A. 1990. Species profiles: Life histories and environmental requirements of coastal vertebrates and invertebrates, Pacific Ocean region. Report 3. Amphidromous macrofauna of Hawaiian island streams. Technical Report EL-89-10. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi. 28 p.

Maciolek, J. A. & J. I. Ford. 1987. Macrofauna and environment of Nanpil-Kiepw River, Ponape, Eastern Caroline Islands. Bulletin of Marine Science 4: 23–632.

Moyle, P. B. & F. R. Senanayake. 1984. Resource partitioning among the fishes of rainforest streams in Sri Lanka. Journal of Zoology, London 202: 195–223.

Norris, R. H., E. P. McElravy & V. H. Resh. 1992. The sampling problem. *In* P. Calow & G. E. Potts (eds.), The river handbook, Volume 1, pp. 282–306. Blackwell Scientific Publications, London.

Parenti, L. R. & J. A. Maciolek. 1993. New sicydiine gobies from Ponape and Palau: Micronesia, with comments on systematics of the subfamily Sicydiinae (Teleostei: Gobiidae). Bulletin of Marine Science 55: 945–972.

Parham, J. E. 1995. Habitat use by an assemblage of tropical oceanic island streamfish. MS Thesis in Biology, University of Guam.

Ryan, P. A. 1991. The success of the Gobiidae in tropical Pacific insular streams. New Zealand Journal of Marine and Freshwater Research 18: 25–30.

Watson, R. E. 1991. A provisional review of the genus *Stenogobius* with descriptions of a new subgenus and thirteen new species (Pisces: Teleostei: Gobiidae). Records of the Western Australian Museum 15: 627–710.

Watson, R. E. 1992. A review of the gobiid fish genus *Awaous* from the insular streams of the Pacific Plate. Icthyological Explorations of Freshwaters 3: 161–176.