Fishery Population and Habitat Assessment in Puerto Rico Streams
Phase 1 Final Report

Federal Aid in Sport Fish Restoration Project F-50

Thomas J. Kwak, Patrick B. Cooney, and Christin H. Brown

U.S. Geological Survey, North Carolina Cooperative Fish and Wildlife Research Unit
Department of Zoology, North Carolina State University

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Submitted by

Thomas J. Kwak
Patrick B. Cooney
and
Christin H. Brown

U.S. Geological Survey
North Carolina Cooperative Fish and Wildlife Research Unit
Department of Zoology
North Carolina State University
Raleigh, North Carolina 27695-7617

Phone: 919-513-2696
Fax: 919-515-4454
E-mail: tkwak@ncsu.edu

To

Commonwealth of Puerto Rico
Department of Natural and Environmental Resources
Marine Resources Division
P.O. Box 366147
San Juan, Puerto Rico 00936-6147

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Cover Photos

Upper left: Biologists Christin Brown, Patrick Cooney, and Nate Harris sample the fishes of Río Maricao in the Guanajibo drainage basin using backpack electrofishers.

Upper right: The mountain mullet or dajao, *Agonostomus monticola*, a native fish with sporting value found in Puerto Rico rivers.

Lower left: The sirajo goby or olivo, *Sicydium spp.*, a native stream fish with pelvic fins modified to form a suction disk that allow this fish to ascend steep cascades, waterfalls, and other wet barriers. What was once considered one species of sirajo goby in Puerto Rico has recently been redescribed as four distinct species.

Lower right: A 30-m waterfall on the Río Cañas within Hacienda Buena Vista, a renovated plantation operated as an education center by the Puerto Rico Conservation Trust (Fideicomiso de Conservación). Sirajo goby and river goby, species with modified suction pelvic fins that are able to ascend this waterfall, are the only native fishes found upstream of it.

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EXECUTIVE SUMMARY (English)

Understanding fish sampling gear attributes and community dynamics is critical knowledge for management, yet these processes are not well understood, especially for tropical stream ecosystems and even less so for those on islands. Puerto Rico is widely known for its marine sport and commercial fisheries, but the freshwater habitats of the island also support a substantial number of fishes, many of which provide recreational or subsistence fishery values. Its seven native freshwater fish species are of primary management concern for their sport fishing and natural heritage values. It has been suggested that Puerto Rico freshwater fish populations are influenced to varying degrees by the introduction of exotic fishes, construction of dams, instream flow patterns, and water pollution.

Our research was intended to contribute to the knowledge base to improve understanding and management of Puerto Rico stream fish communities and ecosystems. We approached this goal in two primary research components. The objectives of the first component (Chapter 1) were to (1) quantitatively describe electrofishing gear efficiency and selectivity relationships to estimate Puerto Rico fish populations, (2) evaluate population models among species using electrofishing catch results analyzed with mark-recapture and removal methods to identify the most suitable parameter-estimating model, and (3) use these findings to develop a standardized stream fish sampling protocol to be applied island-wide.

We then followed this standardized protocol in our second research component to sample stream fish island-wide. The aim of our second component (Chapter 2) was to describe patterns in occurrence and abundance of stream fish populations and communities as related to physical habitat at multiple spatial scales. Our specific objectives were to (1) sample Puerto Rico stream fish communities island-wide and quantitatively estimate abundance as population density and biomass; (2) conduct instream and riparian physical habitat surveys at each fish sampling site; (3) delineate watersheds and upstream riparian zones of each sampling site and quantify attributes related to land cover and ownership from existing data; and (4) develop empirical, hierarchical models that describe relationships among indices of fish community structure and environmental parameters at the stream reach, riparian, and watershed scales.

In our first research component, we compared two fish sampling gear types (electrofishing and seining) and four models for estimating fish population parameters (Petersen mark-recapture and removal estimators of 2–4 sampling passes) to provide the quantitative basis

for development of a standardized sampling protocol for Puerto Rico stream fish. We found electrofishing substantially more efficient and logistically feasible for collecting fish in these environments. We also determined that the three- and four-pass removal models were more accurate than the Petersen mark-recapture model or the two-pass removal model, and that accuracy was similar between the three- and four-pass removal models. We further investigated variations of models that account for assumption violations and found model M_b, that adjusts for fish behavioral effects, to provide the overall best and most parsimonious fit for estimating population parameters.

Thus, based on our empirical findings, we propose a standard fish sampling protocol that we followed for Puerto Rico wadeable streams that includes sampling reaches from 100 m to 200 m long using the appropriate electrofishing gear (backpack or barge electrofishers) depending on stream morphology and instream habitat conditions. Three sampling passes of equal effort (by time) were conducted with sufficient time between passes for fish to reorient to their environment after the disturbance of sampling (ca. 1 h). Fish were held in suitable containers separately for each pass until they could be measured for length and weight, and all fish, except those retained as voucher specimens, were returned to the stream. A Zippin-type, maximum-likelihood estimator was used to calculate population size estimates for the reach, and then fish catch among passes, fish weight data, and site dimension measurements (length and mean width) were used to calculate estimates of fish catchability, density, and biomass and associated variances in standard units for each species in the community. Ancillary habitat and water quality parameters may be measured in association with fish sampling following the procedures described here as a guide, but specific variables to be measured may vary with study objectives.

In our second research component we sampled a total of 25 fish species from 14 families from 81 stream sampling reaches. Of these, 10 species from seven families were native to Puerto Rico, and 15 species from seven families were introduced. We collected six of the seven predominant freshwater fish species native to Puerto Rico rivers. Of all fish species, the river goby *Awaous banana* was the most ubiquitous, found at 54 of 81 locations. Sirajo goby *Sicydium plumieri* was the second most common native fish species, found at 50 stations, followed by mountain mullet *Agonostomus monticola* at 41 sites, bigmouth sleeper *Gobiomorus dormitor* at 35 sites, American eel *Anguilla rostrata* at 32 sites, and smallscaled spinycheek sleeper *Eleotris perniger* at 26 sites. Introduced fishes were widespread with three introduced species that were detected at the most sites from the Poeciliidae family, including guppy *Poecilia reticulata* found at 50 sites, green swordtail *Xiphophorus hellerii* at 35 sites, and Mexican molly *Poecilia sphenops* at 28 sites. Mozambique tilapia *Oreochromis mossambicus* was the fourth most ubiquitous introduced species, found at 27 locations. We collected one new introduced species that was not previously known to exist on the island (the Chinese algae-eater *Gyrinocheilus aymonieri*).

Mean fish species richness for all sites was 5.16 species, ranging from one to 11 species. Native fish were sampled in 65 of the 81 stream reaches, and the fish community at 20 sites was comprised entirely of native fishes. Total fish community density among sites varied greatly, from about 200 fish/ha to over 83,000 fish/ha, with an overall mean of 9,640 fish/ha. Community density was usually dominated by either native or introduced fish. Total fish community biomass estimates also varied widely, from 0.3 kg/ha to over 622 kg/ha with an overall mean of 88.3 kg/ha.

Native fish species richness, density, biomass and species diversity index values were highest in association with coastal regions. Native fish density was highest in eastern, southern, and western rivers in proximity to coastal regions, but no native fish species were found at any of 10 sites we sampled upstream of large reservoirs. Conversely, introduced species richness, density, and biomass were highest in proximity to mountain regions. Total fish density was lower for native species and higher for introduced species, whereas total fish biomass was higher for native species and lower for introduced species. Thus, a majority of native fish species were represented by a smaller number of more evenly distributed larger-bodied fish, in proximity to coastal regions, whereas a majority of introduced fish species were represented by a larger number, dominated by few species of smaller-bodied fish, in proximity to mountain regions.

We qualitatively sampled 11 species of freshwater shrimp, three species of crab, and one introduced species of crayfish from the 81 stream reaches in association with fish sampling. Shrimp were found at 75 sites, crabs at 58, and the crayfish at one. Native shrimp species were detected at six of 10 sites sampled upstream of large reservoirs. The Puerto Rican freshwater crab *Epilobocera sinuatifrons* was sampled at 57 sites, and the introduced Australian red-claw crayfish *Cherax quadricarinatus* was found at one site.

We measured instream habitat parameters in the field and quantified landscape attributes from existing data and reduced the number of environmental variables to include in hierarchical model development from 43 to 13 primary representative variables without notable loss of information. Primary instream habitat variables described instream geomorphology (width and cover) and the physicochemical properties of water (temperature, conductivity, nitrate concentration, and turbidity). Primary watershed and riparian variables represented position of the sampling site on the watershed (watershed area, river km), occurrence of human structures (downstream reservoir, road density), and land cover and ownership (watershed forest, 30-m riparian forest, watershed public ownership).

The physical, independent modeled variables that explained the most variance with the fewest variables in each of 11 fish community parameters were (1) river-kilometer of the sampling site, (2) the presence of a large downstream reservoir (and dam), (3) area of the watershed above the site, and (4) density of roads in the upstream watershed. Our results demonstrate and strengthen existing evidence on the influence of dams; however, we also examined and quantified insightful relationships on the effects of other physical, chemical, and geographic elements on fish community parameters and the abundance of fish populations.

Our research findings represent the most comprehensive increase in knowledge of Puerto Rico stream fish sampling, distributions, and ecology, since the work of Donald Erdman in the 1960–80s. Our standardized sampling protocol will be useful to improve the resolution, quality, and relevance of fish population and community data and can facilitate the establishment of monitoring programs. Knowledge of the current distribution and abundance of fish populations and their relationship with their environment that we present is critical for management planning and to discern trends over time. Our results may guide specific protection of unique stream resources or assist agency personnel in evaluating impacts of specific construction project proposals that may affect stream resources and associated permitting and mitigation decisions. Our data on stream fish and their habitats can be applied to water impoundment, withdrawal, and flow regulation decisions. The information that we provide on the abundance and distribution of stream sport fishes may enhance the ability to further develop the potential of these sport fisheries. Knowing where and at what density and biomass introduced fishes occur can also direct effort toward limiting their spread or impact on native fauna. Finally, our intention is that these results become the initiation of a stream fish data base that will be useful to a number of agencies, educational institutions, private entities, and the public to manage, conserve, and appreciate the freshwater fish resources of Puerto Rico.

RESUMEN EJECUTIVO (Spanish)

El entendimiento de los atributos del equipo de muestreo de peces y la dinámica de la comunidad es conocimiento crítico para el manejo del recurso. Sin embargo, estos procesos no se entienden muy bien, especialmente para los ecosistemas de ríos tropicales en las islas. Puerto Rico es bien conocido por su pesca marina recreativa y por la industria pesquera. No obstante, en sus habitats de agua dulce también pululan un número substancial de peces, muchos de los cuales proporcionan valores recreativos. Las siete especies nativas de peces de agua dulce son de interés primario para el manejo de la pesca recreativa y son parte de nuestro patrimonio natural. Se ha sugerido que las poblaciones de peces de agua dulce de Puerto Rico son influenciadas a diferentes grados por la introducción de peces exóticos, la construcción de represas, los patrones del flujo, y la contaminación del agua.

Nuestra investigación fue diseñada para contribuir al conocimiento general y el manejo de las comunidades y ecosistemas de los peces de los ríos de Puerto Rico. Atendimos esta meta mediante varios objetivos bajo dos componentes primarios. Los objetivos del primer componente (capítulo 1) fueron: (1) describir cuantitativamente las relaciones de eficacia del equipo de electropesca y selectividad en la estimación de poblaciones de peces en Puerto Rico, (2) evaluar modelos poblacionales de las especies utilizando los resultados de la captura mediante electropesca analizados con métodos captura-recaptura y de remoción para identificar el modelo mas apropiado, y (3) utilizar estos resultados para desarrollar un protocolo estandardizado de muestreo de peces de ríos que pueda ser aplicado a través de la isla.

Luego aplicamos este protocolo estandarizado al segundo componente de la investigación. La meta del segundo componente (capítulo 2) fue la de describir los patrones de presencia y abundancia de las poblaciones y comunidades de peces de ríos en relación con el hábitat físico a múltiples escalas espaciales. Nuestros objetivos específicos fueron: (1) estimar la densidad de la población y biomasa a través de toda la isla; (2) llevar a cabo censos del hábitat físico ribereño en cada estación de muestreo; (3) demarcar las cuencas hidrográficas y zonas ribereñas rió arriba de cada estación de muestreo y cuantificar los atributos relacionados a la cobertura terrestre y propietarios basado en datos existentes; y (4) desarrollar modelos empíricos de jerarquía que describan relaciones entre índices de estructura de comunidades de peces y parámetros ambientales a escalas del segmento del río (localidad), ribereño, y cuenca hidrográfica.

En nuestro primer componente de investigación comparamos dos tipos de equipo de muestreo de peces (electropesca y chinchorro) y cuatro modelos para estimar parámetros de poblaciones de peces (estimación por captura-recaptura Petersen y remoción de 2-4 pases de muestreo) para proveer la base cuantitativa para el desarrollo de un protocolo estandarizado. Encontramos que la electropesca era sustancialmente más eficiente y logísticamente más factible para colectar peces en estos ambientes. Igualmente, determinamos que los modelos de remoción de tres y cuatro pases fueron mas precisos que el modelo de captura-recaptura Petersen o el modelo de remoción de dos pases, y que la precisión fue muy similar entre el modelo de remoción de tres pases y cuatro pases. Investigamos variantes de modelos que toman en cuenta las violaciones de premisas de los modelos y encontramos que el modelo M_b, que ajusta por los efectos de comportamiento de los peces, es el mejor para estimar los parámetros poblacionales.

Por lo tanto, basado en estos hallazgos proponemos un protocolo estándar para muestreo de peces en los ríos poco profundos de Puerto Rico, que incluye segmentos de muestreo de100 hasta 200 m de largo, usando equipo de electropesca apropiados (tipo mochila o tipo barcaza), dependiendo de la morfología del río y las condiciones del hábitat ribereño. Tres pases de muestreo hechos con el mismo esfuerzo (tiempo) se llevaran a cabo a intervalos de suficiente tiempo para que permita que los peces se reorienten en su ambiente después de la perturbación (aproximadamente 1 hora). Los peces capturados en cada pase serán mantenidos en recipientes apropiados y por separado hasta que se mida su largo y peso, y todos los peces, con excepción de los que se retienen para ser identificados posteriormente, serán liberados. Se utilizará un estimador de probabilidad máxima tipo Zippin para calcular el tamaño de la población para cada segmento de río, y luego se usará la captura de peces entre pases, los datos de peso de peces y medidas de las dimensiones del segmento (largo y ancho promedio) para calcular los estimados de probabilidad de captura de peces, densidad, biomasa y las varianzas asociadas en unidades estándares para cada especie en la comunidad. Parámetros auxiliares de hábitat y calidad de agua pueden medirse en asociación con muestreos de peces siguiendo los procedimientos aquí descritos como una guía, pero las variables específicas a ser medidas pueden variar con los objetivos del estudio de interés.

En nuestro segundo componente de investigación, muestreamos un total de 81 segmentos de ríos y encontramos 25 especies de peces representados por 14 familias. De estas, 10 especies, representados por 7 familias, eran nativas de Puerto Rico, y 15 especies, representados por 7 familias, eran introducidas. Recolectamos seis de las siete especies nativas de peces de agua dulce predominantes en los ríos de Puerto Rico. De todas las especies de peces, el saga *Awaous banana* fue la más ubicua, encontrándose en 54 de 81 localidades de muestreo. El olivo *Sicydium plumieri* fue la segunda especie nativa mas común, encontrándose en 50 localidades, seguida por el dajao *Agonostomus monticola* en 41 localidades, la guabina *Gobiomorus dormitor* en 35 localidades, la anguila *Anguilla rostrata* en 32 localidades, y el morón en 26 localidades. Las especies exóticas estaban ampliamente distribuidas con tres especies de la familia Poeciliidae detectadas en la mayoría de las localidades, incluyendo el gupi *Poecilia reticulata* encontrado en 50 localidades, la cola espada *Xiphophorus hellerii* en 35 localidades y el gupi *Poecilia sphenops* en 28 localidades. La cuarta especie exótica mas común fue la tilapia mosambica *Oreochromis mossambicus*, encontrándose en 27 localidades. Recolectamos una especie introducida que no se había reportado anteriormente en Puerto Rico (pez ventosa *Gyrinocheilus aymonieri*).

La riqueza promedio de especies de peces para todos las localidades fue 5.16 especies, fluctuando entre 1 y 11 especies. Los peces nativos fueron muestreados en 65 de las 81 localidades (segmentos) de ríos, y la comunidad de peces en 20 localidades consistió enteramente de peces nativos. La densidad total de la comunidad de peces varió sustancialmente entre localidades, desde aproximadamente 200 peces/ha hasta mas de 83,000 peces/ha, con un promedio de 9,640 peces/ha. La densidad de la comunidad estuvo usualmente dominada por peces nativos o por exóticos. Los estimados de biomasa total de la comunidad también variaron sustancialmente, desde 0.3 kg/ha hasta mas de 622 kg/ha con un promedio de 88.3 kg/ha.

La riqueza de especies nativas, densidad, biomasa y valores de índices de diversidad de especies fueron mas altas cuando estaban asociadas con las regiones costeras. La densidad de peces nativos fue mayor en los ríos cercanos a las regiones costeras en el este, sur y oeste, pero no se encontraron peces nativos en ninguno de las 10 localidades que muestreamos rió arriba, mas allá de embalses grandes. Por el contrario, la riqueza, densidad y biomasa de especies introducidas fue mayor en las regiones próximas a las montañas. La densidad total de peces fue menor para especies nativas y mayor para introducidas, mientras que la biomasa total de peces fue mayor para especies nativas y menor para introducidas. Por lo tanto, una mayoría de especies de peces nativos fue representada por un número menor de peces grandes y distribuidas de forma mas uniforme cerca de la costa, mientras que una mayoría de especies de peces exóticos fue representada por un número mayor de peces, dominado por pocas especies de peces de menor tamaño, cerca de las montañas.

Muestreamos cualitativamente 11 especies de camarones de agua dulce, 3 especies de cangrejos, y una especie de langosta de agua dulce en las 81 localidades (segmentos) de ríos en donde se muestrearon peces. Los camarones fueron encontrados en 75 localidades, los cangrejos en 58, y la langosta de agua dulce en 1 localidad. Los camarones nativos fueron detectados en 6 de 10 localidades muestreadas río arriba, más allá de embalses grandes. El cangrejo de agua dulce puertorriqueño *Epilobocera sinuatifrons* fue muestreado en 57 localidades, y la langosta de agua dulce australiano *Cherax quadricarinatus* fue encontrado en 1 localidad.

Medimos parámetros de hábitat ribereño en el campo y cuantificamos atributos del paisaje basado en datos existentes y redujimos el número de variables ambientales a ser incluidos en el desarrollo del modelo jerárquico de 43 a 13 variables primarias sin pérdida notable de información. Las variables primarias de hábitat ribereño describieron la geomorfología ribereña (anchura y cobertura) y las propiedades físico-químicas del agua (temperatura, conductividad, concentración de nitrato y turbiedad). Las variables primarias de la cuenca y ribereñas representaron la ubicación del lugar de muestreo en la cuenca (área de la cuenca, km. de río), presencia de estructuras humanas (embalse río abajo, densidad de carreteras), y cobertura terrestre y a quien pertenecía la propiedad (bosque en la cuenca, bosque ribereño de 30 m, cuenca de propiedad pública).

Los variables físicas e independientes en los modelos que explicaron la mayoría de la varianza con el mínimo de variables en cada uno de 11 parámetros de comunidades de peces fueron: (1) kilómetro del río del lugar de muestreo, (2) presencia de un embalse grande (y represa) río abajo, (3) área de la cuenca hidrográfica río arriba del lugar de muestreo, y (4) densidad de carreteras en la cuenca río arriba del lugar de muestreo. Nuestros resultados demuestran y fortalecen la evidencia existente sobre los efectos de represas; sin embargo, también examinamos y cuantificamos relaciones a mayor cabalidad sobre los efectos de otros elementos físicos, químicos y geográficos en los parámetros de comunidades de peces y la abundancia de poblaciones de peces.

Nuestros resultados representan la aportación más abarcadora al conocimiento sobre muestreo de peces de ríos en Puerto Rico, su distribución y ecología desde el trabajo de Donald Erdman en los años 1960-80. El protocolo estandarizado de muestreo será de utilidad para mejorar la resolución, calidad y relevancia de los datos sobre poblaciones y comunidades de peces y puede facilitar el establecimiento de programas de monitoreo. El conocimiento de la distribución actual y abundancia de poblaciones de peces y su relación con su ambiente aquí presentado es crítico para la planificación del manejo y para detectar tendencias a lo largo del tiempo. Nuestros resultados pueden servir de guía para la protección de recursos únicos en los ríos o ayudar al personal de la agencia en la evaluación de impactos de propuestas para proyectos específicos de construcción que puedan afectar recursos ribereños y decisiones asociadas a mitigación y permisos. Los datos sobre los peces de río y sus habitats pueden ser aplicados a decisiones relacionadas con represar, extraer y regular el flujo de agua. La información que proveemos sobre la abundancia y distribución de peces de valor recreativo es de importancia porque puede mejorar la capacidad para desarrollar el potencial recreativo de este recurso pesquero. El saber la densidad y biomasa y donde se encuentran las especies introducidas pueden dirigir los esfuerzos encaminados a limitar su distribución o impacto sobre la fauna nativa. Finalmente, nuestra intención es que estos resultados se conviertan en el inicio de una base de datos sobre los peces de río que será de utilidad para numerosas agencias, institutos educativos, entidades privadas y el público para manejar, conservar y apreciar los recursos ícticos de los ríos de Puerto Rico.

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CHAPTER 1
INTEGRATING GEAR BIAS AND SELECTIVITY INTO DEVELOPMENT OF A STANDARDIZED FISH SAMPLING PROTOCOL FOR PUERTO RICO STREAMS
(Jobs 1 and 4)

Introduction

Puerto Rico is a 8,959-km² island in the Caribbean Sea with diverse geology and habitats, including tropical rainforest, mountain, karst, and coastal plain regions. A mountain range transects the island longitudinally that averts the Northeast Trade Winds creating a rainshadowing effect, with northern areas receiving more rainfall than those in the south (Hunter and Arbona 1995). These factors contribute to the high diversity of fresh waters in Puerto Rico, and the 1,200 streams in Puerto Rico are a vital part of the ecological and human environment (Erdman 1972). Puerto Rico streams function to provide habitat to aquatic animals and for recreation, irrigation, hydroelectric power, and human drinking water. They also transport excess water off land and connect the coastal and mountain regions (March et al. 2003).

The human history of Puerto Rico has greatly impacted its streams. The early 1900s was a period of rapid industrialization, increasing the need for energy production (Hunter and Arbona 1995). In response to this need, the Puerto Rican government dammed the first stream in 1907 for hydroelectric power. The results of this and subsequent dam construction were positive for industry, but a hindrance for migrating fish species that rely on access between upper and lower stream reaches to complete their life cycle (Erdman 1984; Holmquist et al. 1998). The key to stream migration is unimpeded access to and from the estuarine environment for larvae dispersal (Brasher 2003). Further, the industrial boom was coupled with a large human population expansion that increased water pollution and withdrawal (Hunter and Arbona 1995).

Puerto Rico is isolated with no access to large amounts of freshwater, creating a challenge when supplying drinking water to a growing human population (Hunter and Arbona 1995; March et al. 2003). Streams provide the primary supply of drinking water on the island, so protecting them from pollution is crucial (Hunter and Arbona 1995). The maintenance of freshwater fish populations is also dependent upon pollution control and adequate flow (Erdman 1984). Stream diversion results in a reduction of water flow and depth that directly affects habitat availability (Brasher 2003). A greater understanding of Puerto Rico streams is needed for proper management to sustain fish communities, other aquatic life, and the streams where they reside.

A vast number of organisms live within Puerto Rico stream systems, including fishes, crustaceans, mollusks, and other freshwater vertebrates. There are about 77 fish species that inhabit the freshwaters of Puerto Rico, and many of these have commercial or sport fish value. Some of these fishes are also a vital food source for important recreational and subsistence fisheries. Many of the riverine fish are amphidromous, spending their adult life in streams, and larvae migrate to the estuaries, while others are catadromous, living in freshwater and spawning in the ocean (March 2003). Native species that utilize both upper and lower stream reaches include gobies (Gobiidae), sleepers (Eleotridae), mountain mullets (Mugilidae), and eels (Anguillidae) (Holmquist et al. 1998). Upstream reaches are dominated by sirajo goby *Sicydium plumieri,* whereas, lower stream reaches are dominated by mountain mullet *Agonostomus monticola*, american eel *Anguilla rostrata*, bigmouth sleeper *Gobiomorus dormitor*, and river goby *Awaous banana* (Holmquist et al. 1998). Bigmouth sleeper is the only one of these species that is known to be able to complete its entire life cycle in a riverine environment (Bacheler et al. 2004). Mountain mullet is a recreationally important amphidromous fish, spawning in early summer and returning to upper stream reaches as an adult (Corujo Flores 1980; Erdman 1984). Sirajo goby and river goby have a modified ventral sucker disc that allows them to climb waterfalls or dams with any flow or leakage and return to upper stream reaches after spawning. The larvae of these fish are a local delicacy (Keith 2003). American eels are catadromous and found in lowland stream reaches (Erdman 1972). The smallscaled spinycheek sleeper *Eleotris perniger* and fat sleeper *Dormitator maculatus* are two native stream fishes found restricted to lower reaches or brackish water (Corujo Flores 1980). Understanding the occurrence and relative abundance of each species in a community will serve as the foundation for management of this valuable resource.

Few studies have been conducted on fishes in the streams of Puerto Rico, making it difficult to manage them in these systems. Quantitative knowledge of stream fish can be used to assess the well being of fish communities and their habitats. Fishes can be used as a direct measurement of biological conditions in a stream and are reliable organisms used to indicate environmental quality (Simon 1999). Fish are desirable indicator organisms because they generally remain in the same area seasonally, recover well from natural disturbance, have long life spans, are highly visible, and their life history and taxonomy are well documented (Simon 1999).

Human impacts on streams, such as water quality or habitat degradation, can be assessed by biological monitors in a stream habitat. A fish's relationship with its environment and relative species abundance can be used as biological monitors to characterize stream health and integrity of a stream (Maret 1999). An Index of Biotic Integrity (IBI) was designed to assess biological integrity of aquatic ecosystems by incorporating fish assemblage and population attributes, relative abundance of a species, and condition of individuals within a sample (Karr 1990; Kwak and Peterson 2007). The IBI was first developed in midwestern U.S. warmwater streams by Karr et al. (1986) and would be a useful concept to characterize stream health in Puerto Rico streams if quantitative fish data were available.

Gear selection is an integral part of planning for sampling fish populations, as well as selection of region, amount of effort required within a region, personnel, and data analysis (Willis and Murphy 1996). When sampling fish, use of the appropriate gear is important because all fish sampling gears are variably selective. Types of gear selectivity that can affect sampling are those associated with fish species, size, and sex. All of these factors can lead to an over- or under-representation of the fish present in the region.

Two common gears used in stream fish sampling are seine nets and electrofishing. Seines are inexpensive, light weight, not restricted by turbidity, and have low fish mortality (Onorato et al. 1998). Seines are typically deployed in areas of low flow and relatively flat bottoms because they are not as effective as electrofishing in streams with high flow and large substrate (Hayes et al. 1996). Compared to seining, electrofishing gear is more expensive, heavier, and restricted by turbidity, but it is more effective for measuring stream fish abundance and biomass (Bohlin et al. 1989; Kruse et al. 1998). Relative to seining, electrofishing allows for more standardization of sampling effort, is less selective, and requires fewer personnel (Anderson 1995).

Gear efficiency, the amount of effort expended and the ability of a gear to capture the target organism, is affected by gear selectivity (Hubert 1996). Electrofishing efficiency is influenced by biological, environmental, and technical factors (Hubert 1996; Fievet et al. 1999; Peterson et al. 2004) and is especially important to consider when sampling fish communities (Kwak and Peterson 2007). Influential biological factors include fish morphology, physiology, and behavior. Capture efficiency of electrofishing is affected by fish size and favors capture of larger individuals and species (Bohlin 1982; Anderson 1995; Peterson et al. 2004). Influential environmental factors may be water conductivity, depth, and turbidity. Electrofishing efficiency is inversely related to water depth. Turbidity exhibits a bell-shaped curve with gear efficiency, because in clear waters fish can detect sampling personnel, but as water becomes more turbid, fish detectability decreases (Hubert 1996). Technical factors related to personnel, procedures, and equipment can be controlled to minimize the misrepresentation of a population in a sample and to most accurately represent a fish community (Kwak and Peterson 2007). Catchability is the proportion of fish captured in a standardized unit of effort, and any changes in fishing effort expended by the gear or shifts in spatial distribution of the fish can change the catchability (Fabrizio and Richards 1996). Failure to account for differences in selectivity, efficiency, and catchability can significantly misrepresent population estimates (Peterson et al. 2004).

Estimates of the actual fish population parameters can be obtained by mark-recapture or removal methods (Seber 1982; Pine et al. 2003; Hayes et al. 2007). Mark-recapture methods can be applied to both open and closed populations, whereas the removal method is applied only to closed populations (Pine et al. 2003). In the simple Petersen mark-recapture method, applied to closed populations, an incomplete sample of fish is collected, marked, and returned to the population. Fish are allowed time to return to their original location and resume normal behavior, and a second sample is collected. Marked and unmarked individuals are recorded and compared to the original number of individuals marked to estimate actual population size with associated estimates of sampling error (Ricker 1975; Seber 1982). When applying mark-recapture methods to a closed population, certain assumptions must be met to attain accurate results. These include that all animals have the same probability of being caught, marking does not affect probability of capture, animals do not lose their marks, and all marks are recorded (Otis et al. 1978; Seber 1982). Mark-recapture methods can yield biased estimates, because handling may affect fish behavior (Rodgers et al. 1992; Peterson et al. 2004), but in general, marked fish are assumed to be released in good condition and are as likely to be captured as unmarked fish (Pine et al. 2003). In addition to handling effects, mark-recapture population estimates will be biased if the fish exhibit a behavioral response to the gear. The most common fish behavioral response to gear is a “trap shy” response, where subsequent recapture probability is lower than that for initial capture, and the population estimate will be biased high, or overestimated.

In the removal method, a portion of the population is removed in each of multiple successive sampling passes, and the total population is estimated by the rate of decline over repeated fishing efforts (Seber 1982). The removal method assumes a closed population where there is no migration, and the probability of capture remains constant (Zippin 1958). In stream fish sampling, the assumption of a closed population can be reasonably met by setting blocknets at both ends of the reach or utilizing natural barriers to fish movement (Thompson and Rahel 1996; Heimbuch et al. 1997; Peterson et al. 2004). The removal method is preferred if fish exhibit a behavioral response to the sampling gear; however, this method will generally underestimate fish populations if capture probability varies over time.

Evaluation of gear efficiency and catchability requires an unbiased estimate of the true population of fishes within a site, and there are several approaches used to estimate sampling bias or correct for such bias when it occurs (Fievet et al. 1999; Peterson et al. 2004). Fievet et al. (1999) utilized a three-pass removal method, and corrected for bias by estimating fish populations considering only the last two passes and then adding the catch from the first pass as a total population estimate. They did not estimate fish from the first pass because in the first pass, there was no preliminary disturbance that would affect catchability, and thus, they considered subsequent passes to have equal catchability. Peterson et al. (2004) stratified fish into three size classes for analysis and used two different removal estimators, the Zippin model (M_b) and model M_{bh} (Otis et al. 1978; Pollock et al. 1990). The latter model accounts for size related bias by including heterogeneity in capture probability among individuals. They then used a linear regression analysis to examine the relationship among estimate bias, site characteristics, fish body size, and number of removal passes. Rosenberger and Dunham (2005) estimated bias by comparing a known number of observed fish to estimates from removal and mark-recapture methods.

Population model assumptions that are violated related to variable capture probability can be corrected by using several alternative models available in the program MARK, a software application for estimating population size and capture probability (White and Burnham 1999; Pine et al. 2003). Heterogeneity, or the size, gender, and social status of a fish, among and within species, can lead to violations of the equal catchability assumption for estimating population size (Pollock 1982; Pine et al. 2003). Behavioral responses of a fish to a selected gear may vary after capture; therefore, an animal may be more or less likely to be recaptured (Pine et al. 2003). Behavioral responses include a "trap happy" fish that is easily caught each pass or fish that avoid capture and are never caught, that is "trap shy" fish. Capture probability can also vary over time or subsequent passes; thus, a population can be over- or under-estimated to varying degrees. Population dynamicists have developed models to account for variation in capture probability. Model M_b was designed to allow for trap responses after initial capture; M_h allows for variance in capture probability due to heterogeneity (most common variance due to fish size); M_{bh} adjusts for both heterogeneity and behavioral responses; and M_t allows capture probability to vary over time. Models M_b and M_{bh} are the only models that can be applied to removal data; however, every model can be tested with mark-recapture data (Otis et al. 1978; Pollock 1991). Multiple models may be applied to a single sampling occasion or data set, and Akaike's Information Criterion (AIC; Akaike 1973) model selection approach can be employed to determine which of the considered models is the most parsimonious and yields the least biased population estimates for a particular population (Burnham and Anderson 2002).

There are many scientific and practical reasons to standardize fish sampling procedures within specific habitats and regions (Bonar and Hubert 2002), and knowledge of gear efficiency and catchability for potential sampling gears is critical for protocol development. Ideally, biologists should compile knowledge and information on the sampling attributes of all potential gears, including practical considerations as well their ability to represent actual population parameters, before standardized protocols are developed. Unfortunately, reliable information on those attributes may not be readily available for specific gears, habitats, and regions, and investigators may be required to attain applicable information empirically.

Objectives

The primary focus of this research component was to quantitatively describe gear efficiency and selectivity relationships to estimate fish populations in two river drainages in Puerto Rico, and to use these results to develop standardized sampling techniques that can be applied island-wide. We also intended to evaluate population models among species using electrofishing catch results analyzed with both mark-recapture and removal methods to identify the most suitable parameter-estimating model.

We developed procedures to quantify fish populations and communities in Puerto Rico streams and better understand sampling dynamics by intensively sampling multiple sites repeatedly during three seasons (spring, summer, and fall). Toward the development of a standardized sampling protocol, we used fish catchability estimates to estimate gear efficiency and selectivity of electrofishing gears among species and sizes within and among species. A better understanding of gear bias will increase accuracy in population estimates and provides ecological information on population density, biomass, and community structure. By estimating bias and accuracy of both mark-recapture and removal methods, we could determine the most efficient and accurate stream fish sampling method, and then we applied most efficient, accurate, and practical method to a standardized sampling protocol.

Methods

Site Description

We conducted this research on two watersheds in western Puerto Rico that receive varying annual rainfalls. Río Cañas is a xeric watershed, characterized by lower annual rainfall, dry periods, and reduced flow. Río Guanajibo is a mesic watershed, characterized by relativity high annual rainfall and flow. Within each watershed, a number of representative sampling reaches were selected spanning varying longitudinal gradients, allowing comparison of fish communities based on flow, depth, and longitudinal position in the watershed. The mountain stream headwaters tend to have steep gradients with short pools, well defined riffles, and larger substrates, creating high velocities (Erdman 1972). The coastal regions are mostly comprised of floodplains with low-gradient stream reaches that flow slowly over clay and sand substrates (Erdman 1972; Bass 2003). Within watersheds, we selected sampling sites above and below dams and natural barriers (i.e., waterfalls) that impede fish migration (March et al. 2003; Fievet et al. 1999).

The sampling site closest to the headwaters of the Río Cañas is located at latitude 18°05'10.25"N and longitude 66°39'22.61"W at 220.8 m elevation and is about 5.6 km north-northwest of Ponce (Table 1). The farthest downstream sampling site is located at latitude

18°01'29.14"N and longitude 66°38'24.54"W (Table 1). The Río Cañas drainage area is approximately 16.8 km^2 and is a major tributary of Río Matilde (U.S. Geological Survey 2006).

The Río Guanajibo watershed (89.6 km^2) is over five times larger than that of Río Cañas, with peak stream flows in September and October (U.S. Army Corps of Engineers 1998). The most upstream sampling site is located at latitude 18°10'36.44"N and longitude 66°58'46.78"W and is located about 0.3 km south of the Maricao (Table 1). The highest elevation at a sampling site in the headwater region was 426.2 m (Table 1). The mouth of the stream is located at latitude 18°09'32"N and longitude 47°10'29"W (U.S. Geological Survey 1991-2002).

We sampled 12 stream sites for instream habitat, water quality, and fish populations during each of the three seasons of spring (March-April 2006), summer (June-July 2005), and fall (November-December 2005). Four of the 12 sites sampled were located in the Río Cañas watershed in the Río Cañas proper (Figure 1). The remaining eight stations were located in the Río Guanajibo watershed from five tributaries of Río Guanajibo, including Río Duey, Río Maricao, Río Rosario, Río Nueve Pasos, and Río Hoconuco (Figure 2). The lengths of the 12 sampling reaches ranged from 108 to 144 m (see Chapter 2, Table 5).

Fish Sampling Procedures

We sampled stream fish using electrofishing techniques during three seasons, spring (2006), summer (2005), and fall (2005). Sampling among seasons allowed for a representation of a broad range of habitat types and sampling conditions. Two types of electrofishing gear were employed to capture fish, a backpack electrofisher and a barge electrofisher. The Smith-Root model 12-B, pulsed-DC backpack electrofisher consists of a battery, hand-held anode, and a trailing cathode cable. At each site selected for backpack electrofishing, two backpacks were employed simultaneously operating at about 0.25 A. The Smith-Root SR-6 electrofishing tote barge is a small boat that holds a generator and is pushed by an operator. The barge electrofisher was powered by a Smith-Root GPP 2.5 power source and converter (2.5 kW) that we typically operated at about 3 A. It can power up to three anode probes, and the boat has an attached cathode plate. A minimum of four people operated the barge fisher, and a minimum of three people sampled when using the backpacks. All personnel operating anodes also netted fish, and any additional crew assisted with additional dip nets. The type of gear used at each site was based upon stream width, depth, and substrate composition. All sites selected were shallow enough to effectively sample by wading. Backpacks were most suitable in reaches with large substrate materials (large cobble or boulders), or in reaches of shallow depths and narrow widths. The barge electrofisher was used at all other sites, especially those with few instream impediments (e.g., boulders or physical structure), deep enough draft, and suitable stream width.

We selected sites based on accessibility, stream habitat, and position in the watershed. Sites consisted of at least one pool–riffle sequence (Lyons and Kanehl 1993; Thompson and Rahel 1996; Thompson 2003). A pool was defined as a deep area of sluggish current that flowed over silt, gravel, cobble, or boulder. A riffle was a shallow area with swift current and surface turbulence that flowed over sand, gravel, or cobble substrates. At each site, 21.3-m by 1.8-m blocknets, with 7-mm mesh knotless nylon, surface floats, and a bottom lead-line, were used to close off both upstream and downstream ends of the sampling site. We assumed that blocknets formed a closed system for sampling purposes by preventing fish movement (Weisburg et al. 1997). Sites with natural barriers, such as a waterfall or a low-head dam, eliminated the need for a blocknet at that barrier.

Once a site was closed and the proper gear was selected, three to five upstream electrofishing passes of equal effort (by time) were conducted, and fish of all species and sizes were collected. Following the first pass, fish were weighed (g), measured (total length, mm), and marked with a partial upper caudal fin clip. Each fish was then released in the middle of the reach and allowed at least one hour to recover and return to a suitable location before the next successive pass. One hour has been shown to be sufficient for a fish to recover from the effects of electricity and handling (Rodgers et al. 1992). Following the second pass, each fish collected was weighed, measured, checked for an upper caudal fin clip, received a partial lower caudal fin clip, and was released in good condition. Following the third pass, fish collected were weighed, measured, and checked for upper and lower caudal fin clips.

We conducted a five-pass removal procedure at a subset of locations(C2, C3, C4, G4, G5, and G6) in both watersheds during fall (2005) sampling and at every location during spring (2006) sampling to further evaluate accuracy of the removal method. Fish captured on passes four or five were temporarily removed from the stream and not marked, but marked fish were recorded. Fish that were removed from the stream were temporarily held in a mesh basket that we located in the stream.

We also performed a five-pass mark-recapture procedure at a subset of locations (C1, G1, G3, G7, and G1) during the spring (2006) sampling season on both the Río Guanajibo and Río Cañas watersheds to further evaluate the accuracy of the mark recapture method. Fish collected on the third pass received a partial right pectoral fin clip, and fish collected on the fourth pass received a partial left pectoral fin clip. All fish collected were weighed, measured, and all marks were recorded according to the sampling pass.

Previous accounts of freshwater Puerto Rico fishes (Hildebrand 1935; Erdman 1961, 1986) reported the presence of only one species of *Sicydium,* the sirajo goby, *Sicydium plumieri*; however, Watson (2000) recently examined fish holdings of a number of museums and other collections from Puerto Rico and determined that four species of *Sicydium* occur in the streams of Puerto Rico (*S. buski*, *S. gilberti*, *S. plumieri* and *S. punctatum*). Due to the minute physical distinctions between species that are difficult to distinguish in the field, we considered all four species one taxon, the sirajo goby *Sicydium plumieri*, for this study, as we presumed that their capture probability and sampling attributes would be similar among the species.

Testing Assumption Violations

Upon completion of removal and recapture sampling, we deployed an electrofisher outside of the blocknets at a subset of four sites (G1, G2, G4, and G7) to assess if the assumption of a closed system was violated. We sampled 30-m reaches upstream and downstream of the sampling reach, at an effort sufficient to collect all of the fish within the given area. Fish collected were identified, weighed (g), measured (total length, mm), and any marks were recorded. Any fish captured outside of the reach that was marked would represent a violation of the assumption that the population was closed.

Instream and Riparian Habitat Surveys

We characterized habitat by a cross-sectional transect survey at each sampling site within the two study drainages (McMahon et al. 1996). Ten cross-sectional transects within each sampling reach were measured and spaced at a distance apart that equals one stream width. Placement of the first transect was within the downstream 1/10 of the sampling reach with the exact point chosen randomly. We measured at least 10 equally-spaced points for microhabitat parameters on each transect. Habitat characteristics measured were bank angle, riparian land cover, instream physical cover, substrate composition, water depth, mean column velocity, and stream width (Simonson et al. 1994; McMahon et al. 1996).

We used a clinometer to measure bank angle on both banks, if the bank was undercut the width of the undercut bank was also measured. We visually estimated riparian land cover, instream physical cover, and substrate composition. Riparian land cover was estimated on each bank of each transect in a zone 50 m from the bank and was classified as residential, forested, agricultural, or road. Instream physical cover type was visually classified and listed as one of the following: course woody debris, fine woody debris, rootwad, leaf litter, undercut bank, emersed plant, submersed plant, terrestrial plant, boulder, cobble, or trash. Substrate composition was visually classified as the most dominant size class according to particle diameter (mm) following a modified Wentworth scale (Bovee and Milhous 1978). Substrate particle size was classified as one of the following: silt/clay (>0-0.06), sand (0.06-1.00), very course sand (1-2), pea gravel (2-4), fine gravel (4-8), medium gravel (8-16), course gravel (16-32), very course gravel (50-64), small cobble (64-130), large cobble (130-250), small boulder (250-500), medium boulder (500-1,000), large boulder (1,000-2,000), very large boulder (2,000-4,000), and mammoth boulder (>4000).

We measured stream water depth to the nearest centimeter using a Scientific Instruments, 1.5-m top-setting wading rod, and water velocity was measured using a Marsh-McBirney Flo-Mate Model 2000 digital meter. Mean column velocity was measured at a point 60% of the depth below the surface (McMahon et al. 1996). When depth exceeded 1.0 m, velocity was recorded at 20% and 80% depth below surface, and those rates were averaged for the column mean. Upon completion of the cross-sectional habitat survey, geographic coordinates for the site were recorded using a Garmin Model V Global Positioning System.

We calculated stream discharge volume using the width between points along the cross-sectional transect, depth, and mean column velocity from a transect of laminar flow (McMahon et al. 1996). Total discharge (Q, m^3/s) for that transect was calculated by multiplying for each cell on the transect cell width (w_n), depth (d_n), and velocity (v_n) and then summing the resulting volumes for each cell as below.

$$Q = w_1d_1v_1 + w_2d_2v_2 + \ldots\ldots + w_nd_nv_n.$$

Water Quality Analyses

We measured selected water quality parameters at each sampling site. Water temperature (ºC), total dissolved solids (TDS), conductivity (µS), dissolved oxygen (mg/L), and salinity (ppt) were measured with a Yellow Springs Instrument (YSI) model 556 Multiprobe Instrument. These measurements were taken by lowering the YSI probe into an area of the stream of laminar flow. At each site, a water sample was also collected and placed on ice for subsequent analyses in the lab. A Hach CEL/850 Aquaculture Laboratory was used to measure concentrations of alkalinity, hardness, turbidity, pH, nitrate, nitrite, nitrogen, and phosphorus. Alkalinity was measured by titrating a sample with phenolthaline as an indicator with sulfuric acid, measuring levels from 10 to 400 mg/L as $CaCO_3$ using a digital titrator. Hardness was measured by a digital titration method using EDTA as an indicator to measure levels from 10 to 400 mg/L as $CaCO_3$. Turbidity was measured in FAU using a DR/850 colorimeter and comparing a deionized water blank to the water sample. Measurements of pH were conducted using a sension 1 pH meter and was measured to an accuracy of 0.01. Nitrate concentration was measured by a cadmium reduction method measuring levels from 0.3 to 30.0 mg/L NO_3- using a DR/850 colorimeter. Nitrite concentration was measured by a diazotization method measuring levels from 0.002 to 0.300 mg/L NO_2- using the same colorimeter. Ammonia as nitrogen was measured by a salicylate method that measures levels from 0.01 to 0.50 mg/L NH_3 using the same colorimeter. The phosphorous method was an orthophosphate ascorbic acid method that measure levels from 0.02 to 2.50 mg/L PO_4- using the same colorimeter.

Bias Assessment

We used mark-recapture and removal methods to calculate population estimates of each fish species based on electrofishing catch among samples. We developed and calculated a bias estimator for both mark-recapture and removal methods to indicate relative accuracy and how confident we can be in interpreting population estimates. Our bias estimator analyses on the mark-recapture method was developed using fish that were caught in the first pass and released as a subpopulation of known size. Fish recaptured in the second pass that had been marked in the first pass (upper caudal fin clip) then represented the sample of marked fish (m) from a typical first pass sample in the bias estimator. Fish recaptured in the third pass that had been captured and marked in the first two passes (both upper and lower caudal clips) represented recaptured fish (*r*). All fish caught that were previously marked in either first or second pass (any clip) represented the total catch for the second mark-recapture sample (*c*). A simple Petersen estimate (*N*) was calculated from the data from the second and third passes ($N = mc/r$) and compared to the known population from the first pass total catch. This procedure yielded information on the directional bias and percent accuracy of the mark-recapture method, and demonstrated the level of confidence we may have in the estimating procedure.

The removal method that we evaluated was a maximum-likelihood estimator (model M_b) and was estimated in program MARK. Similar to mark-recapture bias estimating, the removal estimate based only on recaptured fish (upper caudal clip) from the second and third passes was compared to the known population from the first pass. At sampling occasions where a five-pass removal was conducted, maximum-likelihood estimates were calculated on two-, three-, and four-pass removals and compared to the known first-pass population. This allowed for comparison of directional bias and percent accuracy among three removal procedures.

Model Selection

We conducted both mark-recapture and removal method procedures concurrently at all sampling occasions. With these methods, a suite of models can be used to estimate fish capture probability and population sizes. To determine the most efficient model for sampling the entire fish assemblage, we analyzed three models available in program MARK, the null model (M_o), the time variation model (M_t), and the behavioral model (M_b). We then calculated an AIC weight, a probability that allows for model comparison to identify the best fit and most parsimonious model. Each sampling occasion was analyzed separately resulting in a separate AIC weight among each site and species sampled at that site; the best overall model was determined by the percent of times AIC weights selected the model and the mean AIC weight.

We then analyzed Model M_b further to determine if fish displayed a behavioral response to the gear. Using model M_b results, we plotted capture probability (*p*) against recapture probability (*c*) to indicate bias. Any systematic bias between these would represent either a "trap-happy" or "trap-shy" response by the fish to the gear. Based upon results from AIC model selection and these additional analyses on model M_b, we selected the most efficient model for sampling an entire fish community in Puerto Rico streams.

Catchability and Population Sizes

We estimated fish catchability, density (fish/ha), and biomass (kg/ha) of each species sampled using Pop/Pro Modular Statistical Software, a program designed for electrofishing field data that utilizes single-census mark-recapture or removal methods (Kwak 1992). We incorporated length of individual fish to calculate catchability and population density estimates, and both fish length and weight to estimate biomass. We stratified all parameter estimates according to fish size to reduce electrofishing bias related to size selectivity.

Three-pass removal data were used to calculate all of these estimates, but if any population in the community was not depleted in three passes (i.e., fish caught on the last pass exceeded the number of fish caught on the first pass), catchability was not estimated, and population density and biomass were calculated as a minimum estimate with no variance by summing the catch of all passes. For all other samples the entire fish community was estimated by species that were stratified by size. We stratified all estimates into 5-cm size groups, but if sample size was low in any size group, successive groups were combined. Species mean and site mean catchability were then determined for each species and site. Population density and biomass estimates for each species were converted to standard units (fish/ha, kg/ha) using the area of the respective sampling reach. Variance associated with each parameter estimate (sampling error) was calculated and presented as standard error (square-root of variance).

Results

A total of 12 sites were sampled in two Puerto Rico drainages over three seasons (spring, summer, and fall) to yield a total of 36 sampling occasions. Backpack electrofishers were deployed on 19 sampling occasions and a barge electrofisher on 17 sampling occasions. We collected data sufficient to study three-sample mark-recapture estimates for 32 sampling occasions, five-sample mark-recapture for four sampling occasions, three-pass removal for 19 occasions, and five-pass removal for 17 occasions (five-pass removal sampling includes data sufficient for three- or four-pass estimates). A total of 12 fish species were collected in spring sampling, 11 in the summer, and 12 in the fall; six of the seven native riverine species were found among all three seasons. Of the seven native riverine species, the fat sleeper *Dormitator maculatus,* was the only one not collected.

The six native riverine species were sympatrically located among sites downstream of significant migration barriers, and only goby species were sampled upstream of barriers. American eel were located at eight sites consistently among seasons, with the addition of being sampled at site G4 during the summer. Smallscaled spinycheek sleeper were only found at downstream sample locations during fall and summer (C4, G5, and G8); however, they were sampled farther upstream during the spring (G6 and G7). Bigmouth sleeper were collected at all downstream sample locations among seasons, as well as an upstream location (G4, 26.4 km from the river mouth); however, their absence at other upstream sampling sites was probably related to the presence of barriers that impede fish migration. Among seasons, river goby were sampled at both up- and downstream sample locations, but highest densities were found at downstream sites (C3, C4, and G5). Sirajo goby were detected at both up and downstream locations among seasons, and were the dominant fish species collected at site C1, located above a waterfall. Mountain mullet were overall the most abundant fish species collected among seasons, but they were not collected at the most upstream sampling sites (C1, G1, and G3).

Sampling to assess the assumption of a closed system associated with our methods indicated good compliance with that assumption. We electrofished outside of the sample reach at 4 sampling sites during spring 2006. We collected five native species within 30 m of the block nets, American eel, bigmouth sleeper, river goby, sirajo goby, and mountain mullet. Overall we sampled a total of 92 fish outside the nets on the four sampling occasions (Table 2). Of these fish, only two were marked (2.2%), and they were both mountain mullet (2 of 53, 3.8% for the species).

Habitat Characteristics

Instream habitat characteristics varied among seasons and between drainages, but riparian habitat was similar between drainages. The Río Cañas and Río Guanajibo mean bank angles ranged from 96.3º to 163.3º (see Chapter 2, Table 5), and both included sites with undercut banks and vegetation, offering additional cover for fish and invertebrate species. Generally, substrate composition and the presence of rocky cover followed a trend with an increase in substrate size as occurrence of large cobble and boulders with elevation, with sampling reaches following a typical riffle, run, and pool sequence of macrohabitats. Average water velocities and depths varied within and among the stations. Among seasons, average water velocities were lower in the Río Cañas drainage than the Río Guanajibo, and the lowest mean velocities were measured during spring (overall range 0.026-0.236 m/s, see Chapter 2, Table 5). In the Río Cañas and the Río Guanajibo watersheds, average mean stream width was generally lower in headwater reaches (overall range 3.7-5.6 m) and mostly decreased at every site in the spring (overall range 2.43-10.75 m, see Chapter 2, Table 5). Discharge peaked in the fall and summer (overall range = 0.087-1.813 m^3/s). Peak discharge occurred in the fall at sample location G2 (Table 3). The Río Cañas watershed had lower discharge values than the Río Guanajibo for all seasons (overall range = 0.041-0.703 m^3/s, 0.010-1.813 m^3/s, respectively Table 3). Río Cañas riparian habitat was mainly characterized by agricultural and forested land, but site C4 had the highest percentage of urban riparian land cover within the drainage and greater than any site on the Río Guanajibo drainage (15.99%, see Chapter 2, Table 17). Riparian land cover at sites on the Río Guanajibo was generally characterized by agricultural and forested land, and the highest percentage of urban land cover was located at site G8 (10.98%, see Chapter 2, Table 17).

Slight differences in average water quality parameter measurements were apparent between the two river drainages. Within each sampling season, the mean temperature varied and was about 0.5 ºC higher in Río Cañas sites, than in those of Río Guanajibo during summer and fall, perhaps explaining the slightly higher dissolved oxygen concentrations measured in Río Guanajibo sites. However, during the spring sampling season average temperature was lower in the Río Cañas sites by about 2.0 ºC, but dissolved oxygen concentrations did not increase (see Chapter 2, Table 16). Mean turbidity and conductivity levels on average were higher in Río Cañas samples among seasons, although mean turbidity was slightly higher in Río Guanajibo during spring, mostly owing to substantially higher turbidity at sites G2 and G8. Among seasons, mean phosphorus and mean nitrate concentrations were higher in Río Guanajibo. Average pH (8.42, see Chapter 2, Table 16) did not vary greatly among seasons and ranged from 7.71-9.21.

Bias Assessment

We estimated bias for two-sample Petersen mark-recapture population estimates, and two-pass, three-pass, and four-pass removal estimates for four native fish species at 25 sampling occasions. We developed bivariate plots of the estimated population size of each estimate versus the known population size (i.e., the sample marked in initial sampling) and included a 100%-

accuracy line, where the estimated population size was equal to that of the known population (Figure 3). The direction of any bias and accuracy of each method can be derived from these plots; points located above the 100%-accuracy line indicate an underestimation in the population, and points clustered below the line would indicate an overestimation, with proximity to the line representing accuracy. Figure 3 shows points that are distributed equivalently above and below the line for each method, thus indicating no systematic bias for any of the four methods evaluated.

Both the three-pass and four-pass removal methods resulted in relatively concentrated groupings around the 100%-accuracy line, indicating these methods were more accurate than the Petersen mark-recapture or two-pass removal methods (Figure 3). Overall, the three-pass removal mean accuracy was 87.9% (95% CI ± 3.3) and four-pass removal was 89.5% (95% CI ± 4.5; Figure 4). Ninety-five percent confidence intervals suggest that these accuracies were significantly greater than those for the Petersen mark-recapture method (82.6%, 95% CI ± 5.6), but not significantly different than those for the two-pass removal method (85.1%, 95% CI ± 7.2; Figure 4).

Population Model Selection

To determine the best model to estimate fish populations in Puerto Rico, we analyzed the performance of three models for four native species with sufficient sample sizes, bigmouth sleeper, river goby, sirajo goby, and mountain mullet. We based model selection on AIC weights (w_i) and found that it varied among species. For the bigmouth sleeper, there were 10 sampling occasions used to select the best model; according to w_i probabilities, the percent frequency each model was selected was 30% for M_o and 35% each for M_t and M_b (Table 4). The best overall model was M_b for both river goby (10 sampling occasions) and sirajo goby (four sampling occasions) with it selected 70-75% of sampling occasions. The model selected most frequently for mountain mullet was model M_o at 42% among 24 sample sites.

On two sampling occasions, model M_t was clearly selected as the best model ($w_i = 1.00$; one for bigmouth sleeper, one for mountain mullet), but the selection in these two cases was based on high initial capture rather than a variation in capture probability over time. Initial capture probability was 70% of the overall total catch. This suggests that a decline in catch from initial capture to subsequent captures was not related to a decline in capture probability over time but efficient removal; in both cases, over 100 fish were collected.

In further analysis of model M_b results, we found variation among species in their behavioral response to electrofishing. Plots of capture probability (*p*) versus recapture probability (*c*) demonstrated a clear behavioral response ("trap shyness") to the electrofishing gear for bigmouth sleeper, river goby, and sirajo goby (Figure 5b-d). Recapture probability was lower than initial capture probability for every sampling occasion for bigmouth sleeper, nine of 10 for the river goby, and four of five for the sirajo goby. Mountain mullet comparisons suggest no substantial behavioral response in that species (Figure 5a).

Population Size Structure

American eel abundance and size ranges were similar among seasons and sites. Abundance ranged from one to 16 fish at a given location, and size ranged from 132 to 885 mm (Figure 6). The largest American eel was located at site C4 during the summer sampling season. At this location, a total of 15 American eels were captured ranging from 203 to 885 mm. This site made up 28% of the total catch of American eel among all sites and seasons.

Bigmouth sleeper abundance varied among sites and seasons; however, the general size range remained similar among seasons (overall range = 47-441 mm, Figure 7). Size groups greater than 200 mm did not vary greatly in number among seasons. However, there was a peak in the number of 100-200 mm fish during the spring, but this peak coincided with a lower relative biomass. Bigmouth sleeper density was similar between spring and summer, but biomass was 35% lower during the spring, suggesting a high density of juvenile fish during spring (Figure 7, Table 11). During spring, the 100-200 mm size classes made up 70% of the total catch at downstream reaches on Río Cañas (sites C3 and C4) and 72% in the fall. Overall, Río Cañas contributed 65% of total bigmouth sleeper catch of the 100-200 mm size classes.

We found minimal variation in smallscaled spinycheek sleeper abundance and size classes among seasons (overall range = 51-179 mm, Figure 8). The most abundant size class was 100-150 mm fish, and their numbers increased slightly in the summer and peaked in the fall. Overall they were the least abundant native species.

River goby abundance varied greatly among seasons, but the size range remained similar (overall range = 32-303 mm, Figure 9). Peak abundance occurred during the spring with a large mode at 75-100 mm. The lower reaches of Río Cañas (sites C3 and C4) yielded 88% of the total catch of the 25-150 mm size classes for the Río Cañas watershed, and the lower reaches of Río Guanajibo (sites G2, G5, G6, G7, G8) contributed 94% of the total catch of the 25-150 mm size classes for that watershed. This suggests that spawning occurs in late winter or early spring and that juvenile river gobies are utilizing downstream locations.

Sirajo goby abundance varied greatly among seasons, with a similar size range of 12 to 176 mm fish (Figure 10). Abundance peaked in spring, owing to the high occurrence of juveniles (25-50 mm). The lower reach of Río Cañas (site C4), 4.9 km from the river mouth, contributed 50% of the total catch of the 25-50 mm size class, not including the Río Guanajibo catch. Juveniles were collected at both upstream and downstream locations in Río Cañas and were observed ascending the nearly vertical waterfall located at the downstream edge of site C1.

Mountain mullet abundance was the highest of the six native species sampled. It varied widely among seasons with peak abundance occurring in the 50-100 mm size class of approximately 1,600 fish (Figure 11). Size range remained relatively consistent among seasons (overall range = 25-347 mm). The abundance of individuals greater than 100 mm remained similar among seasons and was approximately 5 to 200 fish per size class. The lower reaches of the Río Cañas watershed (sites C3, C4) contributed 95% of the total catch of 25-100 mm fish, not including the Río Guanajibo watershed. The lower reaches of the Río Guanajibo (sites G2, G4, G5, G6) yielded 85% of the total catch of those size classes.

Catchability, Density, and Biomass

Fish catchability means and ranges among sites and species were generally similar among seasons. In the spring sampling season, catchability was estimated for nine of the 13 species from within both watersheds (overall range = 0.223-0.620, mean 0.457, Table 5). Summer sampling results were similar (overall range = 0.172-0.516, mean 0.409, Table 6) and were estimated for nine of the 13 species. We estimated catchability for eight of 13 species for the fall sampling season (overall range = 0.285-0.560, mean 0.450, Table 7).

We estimated species mean catchability for all of the native species encountered among all seasons, and on average estimates were high but varied by species, site, and season. American eel estimates were highest during spring (mean 0.481, Table 5) and ranged from 0.200-0.650 among all seasons (Table 5-7). Catchability estimates for bigmouth sleeper did not vary greatly by site or by season and ranged from 0.112-0.654 among seasons. There were only two catchability estimates less than 0.20 and these were associated with sparse populations (catches less than 20 fish). Smallscaled spinycheek sleeper estimates were highest during fall (mean 0.469, Table 7) and ranged from 0.159 to 0.566; 50% of the total catch of smallscaled spinycheek sleepers among seasons was during fall sampling. Overall catchability for river gobies was high with a range from 0.122 to 0.709, the only estimate less than 0.20 occurred at site G8 where only four river gobies were collected (Tables 5-7). Sirajo goby catchability was highest (0.729) at site C3 during spring, where over 100 sirajo gobies were collected; catchability was generally high at downstream sample reaches on Río Cañas. On average, mountain mullet catchability was high (0.095-0.916, Tables 5-7). We found that the greatest probability of capture occurred at site G7 during spring, where we collected 123 mountain mullet and recaptured 101 fish on the second pass. This site was unique among our 12 sampling sites in being very narrow, shallow, with low flow volume (mean stream width = 2.43 m, mean depth = 7.9 cm, mean column velocity = 0.079 m/s; see Chapter 2, Table 5).

Fish density estimates peaked during the spring sampling season and ranged among sites from 301.0 to 27,492.8 fish/ha (Table 8), the summer range was 648.7-8,078.4 fish/ha (Table 9), and that for fall was 209.4-4,609.3 fish/ha (Table 10). Native fish were found at every sampling site. Densities of American eel and smallscaled spinycheek sleeper were similarly low among sites (range = 9.5-462.0, range = 7.5-212.1, Tables 8-10). Bigmouth sleeper density peaked in the summer at 2,681 fish/ha, and river goby, sirajo goby, and mountain mullet densities peaked during spring (1,544, 11,475, and 17,087 fish/ha, respectively; Table 8). The highest density of non-native species we encountered was at site G7 during spring, which was dominated by green swordtails *Xiphophorus hellerii* (18,018 fish/ha, Table 8). Green swordtails were the most abundant non-native species sampled and were located at one site on Río Cañas and seven sites on Río Guanajibo (Tables 8-10).

Total fish biomass estimates varied widely among sites with a range of 1.6-621.9 kg/ha. The highest biomass estimate (621.9 kg/ha) was associated with site C4 during summer sampling with substantial biomass of American eel, bigmouth sleeper, and mountain mullet (Table 12) This high biomass estimate did not coincide seasonally with the greatest density estimate among sites and seasons associated with this site (C4) during spring (Table 8).

Discussion

Our research objectives were to examine the sampling attributes of fishing gears and deployment methods and applicability of population models to resulting catch data. Our ultimate goal in setting those objectives was to incorporate those findings into development of a standard fish sampling protocol for Puerto Rico stream fishes. Criteria that we considered in protocol development were to prescribe a set of procedures that would be as accurate as possible among options and logistically feasible and efficient in the field.

Ichthyologists routinely sample streams and other shoreline habitats using small seines with the intent of collecting as many fishes as possible to describe species occurrences. Such sampling is important to define geographic distributions of fish species, but is not intended to estimate fish population parameters or community structure for ecological relevance. Such objectives require intensive sampling and the application of parameter-estimating methods that we examined here, such as mark-recapture or removal models (Ricker 1975; Seber 1982; Pine et al. 2003).

We attempted to sample stream fish using two types of sampling techniques, seining and electrofishing. Initial pilot sampling using seines found the gear to be ineffective, owing to fish behavior, instream channel morphology, and associated cover. Thus, we sampled fish using the two electrofishing techniques described in Methods above, backpack electrofishers and a barge electrofisher, and we evaluated their sampling attributes and compared population models to estimate fish catchability and population size among species. The conductivity of Puerto Rico stream water is moderate (100-1,000 µS/cm, with most waters 200-500 µS/cm; Díaz et al. 2005), which is optimal for sampling with typical electrofishing gears (Reynolds 1996). Our water quality sampling confirmed optimal conductivity for electrofishing among 81 stream sampling sites with a mean of 321.6 µS/cm (SD = 131.8 µS/cm; range = 59-780 µS/cm; see Chapter 2). Thus, we expected and demonstrated relatively high catchability in stream habitats using electrofishing gear (seasonal means among sites and species ranged from 0.41 to 0.46; Tables 4-6), and we confidently recommend its application over netting techniques in wadeable Puerto Rico streams.

A Standardized Fish Sampling Protocol

We compared two fish sampling gear types (electrofishing and seining) and four population models for estimating fish population parameters (Petersen mark-recapture and removal estimators of 2-4 sampling passes) to provide the quantitative basis for development of a standardized sampling protocol for Puerto Rico stream fish. We found electrofishing substantially more efficient and logistically feasible for collecting fish in these environments. We also determined that the three- and four-pass removal models were more accurate than the Petersen mark-recapture model or the two-pass removal model, and that accuracy was similar between the three- and four-pass removal models (Figures 3 and 4). We further investigated variations of models that account for assumption violations among models and found model M_b to have the overall best and most parsimonious fit for estimating population parameters (Table 3).

Thus, based on our empirical findings, we propose a standard fish sampling protocol for Puerto Rico wadeable streams that includes sampling stream reaches from 100 m to 200 m long using the appropriate electrofishing gear (backpack or barge electrofishers) depending on stream morphology and instream habitat conditions. Three sampling passes of equal effort (by time) will be conducted with sufficient time between passes for fish to reorient to their environment after the disturbance of sampling (ca. 1 h). Fish will be held in suitable containers separately for each pass until they can be measured for length and weight, and all fish, except those retained as voucher specimens, will be returned to the stream. A Zippin-type, maximum-likelihood estimator (Seber 1982) will be used to calculate population size estimates for the reach, and then fish catch among passes, fish weight data, and site dimension measurements (length and mean width) will be used to calculate estimates of fish catchability, density, and biomass and associated variances in standard units for each species in the community (Kwak 1992; Hayes et al. 2007). Ancillary habitat and water quality parameters may be measured in association with fish sampling following the procedures described here as a guide, but specific variables to be measured may vary with study objectives.

Implications of the Sampling Protocol and its Development

Our findings that support the use of the three-pass removal method and model (M_b) with electrofishing data as a robust estimator of population parameters of Puerto Rico stream fish are contrary to those of several other studies evaluating multipass removal models for stream-dwelling salmonids. In related research in Rocky Mountain (USA) coldwater streams, other investigators found removal estimators for salmonid populations (species) to be systematically biased, yielding inflated catchability estimates and underestimates of actual population size (Riley and Fausch 1992; Peterson et al. 2004; Rosenberger and Dunham 2005). Those researchers cited low sampling efficiency that decreased among successive sampling passes as the likely explanation for the bias. They also found bias related to stream habitat, fish species, and fish size. Our findings that the three-pass removal estimator was 87.9% accurate on average and showed no systematic bias suggest that sampling conditions in Puerto Rico streams and the response by native and introduced fishes in those habitats are conducive to the sampling gear and removal methods. It may not be surprising that results would differ between field studies conducted in Puerto Rico tropical island streams and those in coldwater mountain streams of the western U.S., given the dramatic differences in environments and fish faunas.

In situations where a three-pass fish sampling protocol is not feasible or where data precision for density and biomass is not critical, the estimates of catchability that we developed can be used to approximate fish density and biomass from a single electrofishing pass. The catch from a single electrofishing sample may be divided by catchability (as a proportion, not a percent) to yield an estimate of population number in the sampling reach. The catchability used in such a calculation should be as specific as possible for the fish species, habitat, and sampling conditions. For example, the catchability results that we present in Tables 4-6 are stratified by fish species, site, and season, and applying the specific catchability estimate for a species and season would result in the most accurate population estimate. Other investigators have proposed this approach as an efficient means to index fish population sizes with a single electrofishing sample (Lobón-Cerviá and Utrilla 1993; Kruse et al. 1998). The precision of population estimates by this means can be improved by incorporating environmental covariates (e.g., stream size or water conditions) into regression models, and this is an area for future development.

The scientific and practical benefits of standardizing fish sampling procedures within specific habitats and regions are numerous (Bonar and Hubert 2002). The advantages to using the standard sampling protocol that we present here are many and include the ability to describe the fish communities of Puerto Rico streams in a quantitative manner that allows confident comparison among populations and communities, stream sites and reaches, and over time. This is possible because all parameter estimates account for variation in gear efficiency and selectivity and are presented in standard comparable units. Further, fish population and community data from Puerto Rico streams may be compared and placed in perspective relative to stream ecosystems in other regions. Another benefit of understanding gear efficiency and bias in stream fish sampling is that historical fish collections can be interpreted with greater relevance.

The development of this effective and efficient fish sampling protocol is an important step toward providing the components of information required to further develop management plans for Puerto Rico freshwater streams and fisheries. The first step in management planning is to develop effective sampling protocols for fishery resources, including the fishes and their habitats, and this objective is now complete. This protocol will be useful to improve the resolution, quality, and relevance of fish population and community data and can facilitate the establishment of monitoring programs to identify unique fish resources, document physical and biotic changes in stream fish communities over time, guide the ongoing development of stream fisheries, and evaluate future fishery or habitat management actions.

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Table 1. Geographic descriptions of 12 fish, water quality, and instream habitat sampling sites in the Río Cañas and Río Guanajibo drainages in Puerto Rico.

Site	Drainage basin	River	Municipality	Location	Elevation (m)	Latitude	Longitude
C1	Cañas	Cañas	Ponce	5.6 km NNW of Ponce	220.8	18° 05' 10.25"	66° 39' 22.61"
C2	Cañas	Cañas	Ponce	5.0 km NNW of Ponce	164.2	18° 05' 00.49"	66° 39' 19.22"
C3	Cañas	Cañas	Ponce	3.1 km NW of Ponce	57.7	18° 02' 43.94"	66° 38' 41.64"
C4	Cañas	Cañas	Ponce	2.0 km NW of Ponce	30.0	18° 01' 29.14"	66° 38' 24.54"
G1	Guanajibo	Maricao	Maricao	0.3 km S of Maricao	426.2	18° 10' 36.44"	66° 58' 46.78"
G2	Guanajibo	Rosario	San Germán/ Mayagüez	4.5 km SW of Rosario	48.8	18° 09' 26.93"	67° 05' 07.62"
G3	Guanajibo	Nueve Pasos	San Germán	2.9 km ESE of Rosario	199.3	18° 08' 42.04"	67° 01' 53.51"
G4	Guanajibo	Nueve Pasos	San Germán	1.3 km SE of Rosario	61.4	18° 08' 54.71"	67° 03' 42.44"
G5	Guanajibo	Duey	San Germán	1.5 km SE of Rosario	47.7	18° 08' 14.17"	67° 04' 16.61"
G6	Guanajibo	Duey	San Germán	2.0 km SSE of Rosario	39.2	18° 07' 36.52"	67° 04' 22.98"
G7	Guanajibo	Hoconuco	San Germán	2.6 km SSE of Rosario	41.6	18° 07' 04.12"	67° 03' 45.43"
G8	Guanajibo	Rosario	Hormigueros	1.5 km SE of Hormigueros	10.2	18° 07' 32.63"	67° 07' 23.27"

Table 2. Number and percent of total catch of fish species sampled outside of the closed sampling reach within 30 m of blocknets at four sampling sites during spring 2006 to assess compliance with the closed-population assumption.

Species	Total catch	Number (%)
American eel	8	0
Largemouth bass	5	0
Bigmouth sleeper	10	0
River goby	13	0
Sirajo goby[a]	3	0
Mountain mullet	53	2 (3.8)
Total	92	2 (2.2)

[a] Four species of *Sicydium* occur in Puerto Rico, combined here.

Table 3. Discharge measurements for 12 sampling sites during 2005-2006 in the Río Cañas and Río Guanajibo drainages, calculated from instream measurements (water depth and velocity) taken in association with fish sampling.

	Discharge volume (m^3/s)			
Site	Spring	Summer	Fall	Site mean
C1	0.061	0.361	0.465	0.296
C2	0.041	0.204	0.703	0.316
C3	0.063	0.317	0.155	0.178
C4	0.264	0.508	0.365	0.379
G1	0.019	0.087	0.235	0.114
G2	0.520	1.227	1.813	1.187
G3	0.010	0.322	0.160	0.164
G4	0.036	0.772	0.329	0.379
G5	0.048	0.403	1.661	0.704
G6	0.035	0.319	1.811	0.722
G7	0.024	0.367	0.318	0.236
G8	0.585	1.778	1.657	1.346
Season mean	0.142	0.555	0.806	0.501

Table 4. Percent frequency and the mean probability (AIC weight, w_i) that a model was selected as the most parsimonious according to AIC among a suite of models developed for specific sampling occasions. The number of sampling occasions appears in parentheses.

	Bigmouth sleeper (10)		River goby (10)		Sirajo goby[a] (4)		Mountain mullet (24)	
Model	% Selected	Mean w_i	% Selected	Mean w_i	% Selected	Mean w_i	% Selected	Mean w_i
M_o	30	0.20	10	0.03	0	0	42	0.29
M_t	35	0.45	20	0.27	25	0.27	27	0.41
M_b	35	0.35	70	0.70	75	0.73	31	0.30

[a] Four species of *Sicydium* occur in Puerto Rico, combined here.

Table 5. Spring electrofishing catchability estimates for Puerto Rico stream fishes at 12 sampling sites during 2005-2006 in the Río Cañas and Río Guanajibo drainages. Standard error estimates appear in parentheses.

Site	American eel	Bluegill	Largemouth bass	Fat snook	Mozambique tilapia	Bigmouth sleeper	Smallscaled spinycheek sleeper	River goby	Sirajo goby[a]	Burro grunt	Mountain mullet	Green swordtail	Guppy	Site mean
C1								0.436	0.329					0.383
								(0.342)	(0.043)					(0.172)
C2						0.552		0.453	0.476		0.753			0.558
						(0.133)		(0.136)	(0.096)		(0.037)			(0.054)
C3	0.650					0.517		0.375	0.729		0.733			0.619
	(0.152)					(0.073)		(0.028)	(0.097)		(0.006)			(0.039)
C4	0.641					0.608		0.371						0.540
	(0.051)					(0.066)		(0.112)						(0.047)
G1			0.504						0.334					0.419
			(0.103)						(0.184)					(0.105)
G2	0.404					0.534		0.464			0.503			0.476
	(0.212)					(0.149)		(0.410)			(0.044)			(0.122)
G3												0.339	0.337	0.338
												(0.070)	(0.018)	(0.036)
G4						0.559		0.709	0.580		0.631			0.620
						(0.266)		(0.127)	(0.254)		(0.037)			(0.098)
G5						0.523		0.601	0.436		0.577	0.425		0.512
						(0.039)		(0.055)	(0.281)		(0.008)	(0.055)		(0.059)
G6	0.230					0.310	0.159	0.377			0.606			0.337
	(0.402)					(0.055)	(0.350)	(0.130)			(0.012)			(0.110)
G7						0.374		0.580	0.394		0.916	0.021		0.457
						(0.113)		(0.103)	(0.153)		(0.024)	(0.088)		(0.047)
G8						0.112		0.122			0.436			0.223
						(0.314)		(0.294)			(0.342)			(0.183)
Species mean	0.481		0.504			0.464	0.159	0.449	0.468		0.644	0.261	0.337	0.457
	(0.120)		(0.103)			(0.054)	(0.350)	(0.067)	(0.067)		(0.044)	(0.042)	(0.018)	(0.029)

[a] Four species of *Sicydium* occur in Puerto Rico, combined here.

Table 6. Summer electrofishing catchability estimates for Puerto Rico stream fishes at 12 sampling sites during 2005-2006 in the Río Cañas and Río Guanajibo drainages. Standard error estimates appear in parentheses.

Site	American eel	Bluegill	Largemouth bass	Fat snook	Mozambique tilapia	Bigmouth sleeper	Smallscaled spinycheek sleeper	River goby	Sirajo goby[a]	Burro grunt	Mountain mullet	Green swordtail	Guppy	Site mean
C1									0.396				0.407	0.401
									(0.285)				(0.448)	(0.266)
C2	0.407					0.486					0.358			0.417
	(0.448)					(0.273)					(0.079)			(0.177)
C3	0.200					0.195		0.435			0.733			0.391
	(0.537)					(0.262)		(0.179)			(0.032)			(0.156)
C4	0.288					0.654		0.566	0.660		0.414			0.516
	(0.295)					(0.141)		(0.255)	(0.091)		(0.073)			(0.086)
G1			0.452											0.452
			(0.223)											(0.223)
G2	0.333					0.530		0.486			0.617			0.492
	(0.609)					(0.255)		(0.258)			(0.078)			(0.178)
G3												0.172		0.172
												(0.215)		(0.215)
G4											0.362			0.362
											(0.067)			(0.067)
G5	0.407				0.500	0.315			0.566		0.401			0.438
	(0.448)				(0.612)	(0.221)			(0.442)		(0.099)			(0.182)
G6	0.500					0.486					0.409			0.465
	(0.597)					(0.273)					(0.086)			(0.221)
G7						0.263		0.682	0.382		0.538			0.466
						(0.413)		(0.158)	(0.437)		(0.084)			(0.157)
G8						0.566					0.095			0.331
						(0.442)					(0.287)			(0.264)
Species mean	0.356		0.452		0.500	0.437		0.542	0.501		0.436	0.172	0.407	0.409
	(0.204)		(0.223)		(0.612)	(0.106)		(0.109)	(0.173)		(0.040)	(0.215)	(0.448)	(0.055)

[a] Four species of *Sicydium* occur in Puerto Rico, combined here.

Table 7. Fall electrofishing catchability estimates for Puerto Rico stream fishes at 12 sampling sites during 2005-2006 in the Río Cañas and Río Guanajibo drainages. Standard error estimates appear in parentheses.

Site	American eel	Bluegill	Largemouth bass	Fat snook	Mozambique tilapia	Bigmouth sleeper	Smallscaled spinycheek sleeper	River goby	Sirajo goby[a]	Burro grunt	Mountain mullet	Green swordtail	Guppy	Site mean
C1									0.432					0.432
									(0.104)					(0.104)
C2	0.567					0.629		0.326	0.183		0.750			0.491
	(0.497)					(0.133)		(0.262)	(0.140)		(0.037)			(0.119)
C3	0.399					0.543		0.417			0.706			0.516
	(0.150)					(0.077)		(0.130)			(0.047)			(0.055)
C4	0.272					0.564	0.474	0.490	0.348		0.579			0.455
	(0.245)					(0.073)	(0.157)	(0.060)	(0.079)		(0.032)			(0.053)
G1			0.542						0.381					0.461
			(0.149)						(0.222)					(0.134)
G2	0.515					0.329		0.486			0.351			0.420
	(0.224)					(0.164)		(0.248)			(0.119)			(0.098)
G3									0.500					0.500
									(0.612)					(0.612)
G4						0.571		0.347	0.357		0.402			0.419
						(0.110)		(0.231)	(0.155)		(0.078)			(0.077)
G5					0.230	0.366		0.219	0.259		0.350			0.285
					(0.402)	(0.137)		(0.132)	(0.360)		(0.049)			(0.115)
G6	0.297				0.558	0.348	0.368				0.368			0.388
	(0.191)				(0.169)	(0.141)	(0.147)				(0.081)			(0.067)
G7						0.648	0.566	0.501	0.389		0.696			0.560
						(0.213)	(0.442)	(0.224)	(0.193)		(0.051)			(0.115)
G8						0.500					0.557			0.528
						(0.259)					(0.313)			(0.203)
Species mean	0.410		0.542		0.394	0.500	0.469	0.398	0.356		0.529			0.455
	(0.129)		(0.149)		(0.218)	(0.052)	(0.164)	(0.075)	(0.101)		(0.041)			(0.060)

[a] Four species of *Sicydium* occur in Puerto Rico, combined here.

Table 8. Spring density (fish/ha) estimates for Puerto Rico stream fishes at 12 sampling sites during 2005-2006 in the Río Cañas and Río Guanajibo drainages. Standard error estimates appear in parentheses.

Site	American eel	Bluegill	Largemouth bass	Fat snook	Mozambique tilapia	Bigmouth sleeper	Smallscaled spinycheek sleeper	River goby	Sirajo goby[a]	Burro grunt	Mountain mullet	Green swordtail	Guppy	Total
C1								56.8	11,475.0			116.5	69.9	11,718.2
								(9.6)	(374.5)			(0)	(0)	(374.6)
C2	55.2					294.5		295.0	3,029.0		3,212.0			6,885.7
	(0)					(145.7)		(132.7)	(234.5)		(15.3)			(306.7)
C3	246.4					1,710.0		787.9	3,844.0		5,083.8			11,672.1
	(17.4)					(46.5)		(103.0)	(35.5)		(22.1)			(121.8)
C4	53.5					466.6	212.1	592.7	9,080.9		17,087.0			27,492.8
	(5.1)					(33.3)	(257.2)	(28.8)	(55.2)		(255.4)			(369.3)
G1			807.0		22.6			90.5	208.0			22.6	22.6	1,173.4
			(26.9)		(0)			(0)	(51.1)			(0)	(0)	(57.8)
G2	169.0				6.8	347.0		974.0	20.4	6.8	1,947.9	6.8		3,478.7
	(119.4)				(0)	(25.1)		(111.8)	(0)	(0)	(88.0)	(0)		(187.4)
G3								25.4	76.1			1,599.0	484.0	2,184.5
								(0)	(0)			(144.5)	(102.6)	(177.2)
G4						139.4		265.6	82.4		2,807.0	20.5		3,314.9
						(50.8)		(3.1)	(4.8)		(23.5)	(0)		(56.2)
G5	45.9				76.5	287.9	15.3	1,544.0	94.6		10,544.0	775.1	76.5	13,459.7
	(0)				(0)	(25.0)	(0)	(17.6)	(10.0)		(48.4)	(34.5)	0	(67.5)
G6	37.8					305.5	104.9	197.4	20.2		2,117.9	90.0	10.1	2,883.8
	(28.7)					(57.3)	(162.9)	(22.3)			(51.7)	(0)	(0)	(183.9)
G7	57.5					734.1	28.7	544.5	453.8		3,537.0	18,018.0	86.2	23,459.8
	(0)					(332.2)	(0)	(83.4)	(205.6)		(22.5)	(73,885.2)	(0)	(73,886.2)
G8	11.6			13.1		86.9	91.7	59.9		13.1	24.6			301.0
	(0)			(0)		(172.5)	(0)	(93.1)		(0)	(6.1)			(196.1)

[a] Four species of *Sicydium* occur in Puerto Rico, combined here.

Table 9. Summer density (fish/ha) estimates for Puerto Rico stream fishes at 12 sampling sites during 2005-2006 in the Río Cañas and Río Guanajibo drainages. Standard error estimates appear in parentheses.

Site	American eel	Bluegill	Largemouth bass	Fat snook	Mozambique tilapia	Bigmouth sleeper	Smallscaled spinycheek sleeper	River goby	Sirajo goby[a]	Burro grunt	Mountain mullet	Green swordtail	Guppy	Total
C1								20.5	3,011.7				63.0	3,095.2
								(0)	(336.0)					(336.1)
C2	79.4					134.4		329.0	395.0		4,015.0			4,952.8
	(40.8)					(44.3)		(0)	(0)		(676.0)			(678.7)
C3	462.0					759.0		498.0	18.5		3,159.0			4,896.5
	(1,110.0)					(1,346.5)		(324.8)	(0)		(477.9)			(1,838.2)
C4	388.9					2,681.0	49.7	307.6	624.7		4,026.5			8,078.4
	(236.1)					(3,580.5)	(0)	(21.3)	(32.3)		(488.6)			(3,621.6)
G1			452.8					15.3	180.6					648.7
			(395.0)					(0)	(10.4)					(395.2)
G2	157.0	7.5				90.6		82.6			758.5			1,096.2
	(142.3)	(0)				(19.2)		(18.7)			(25.9)			(147.1)
G3									37.5			1,044.0	56.3	1,137.8
									(0)			(1,050.7)	(0)	(1,050.7)
G4	15.3					107.0		122.3	76.5		4,761.7	18.8		5,101.6
	(0)					(0)		(0)	(0)		(827.3)	(0)		(827.3)
G5	63.8				37.6	324.6		224.9	13.9		4,289.9			4,954.7
	(23.3)				(32.6)	(174.2)		(0)	(4.7)		(1,027.2)			(1,042.6)
G6	55.6				41.7	141.1	166.8	69.5	13.9		2,314.4			2,803.0
	(48.2)				(0)	(37.4)	(0)	(0)	(0)		(247.8)			(255.2)
G7	13.9					137.4		167.1	195.8		2,074.3			2,588.5
	(0)					(142.4)		(12.4)	(86.5)		(121.9)			(206.8)
G8	11.6					25.3	34.8			11.6	670.4			753.7
	(0)					(8.6)	(0)			(0)	(1,825.0)			(1,825.0)

[a] Four species of *Sicydium* occur in Puerto Rico, combined here.

Table 10. Fall density (fish/ha) estimates for Puerto Rico stream fishes at 12 sampling sites during 2005-2006 in the Río Cañas and Río Guanajibo drainages. Standard error estimates appear in parentheses.

Site	American eel	Bluegill	Largemouth bass	Fat snook	Mozambique tilapia	Bigmouth sleeper	Smallscaled spinycheek sleeper	River goby	Sirajo goby[a]	Burro grunt	Mountain mullet	Green swordtail	Guppy	Total
C1								23.5	2,166.0					2,189.5
								(0)	(674.9)					(674.9)
C2	95.4					233.0		62.3	378.0		2,231.0			2,999.7
	(40.8)					(10.0)		(22.8)	(192.6)		(11.3)			(198.7)
C3	188.3					736.0		758.0	181.0		2,746.0			4,609.3
	(50.8)					(63.3)		(158.1)	0		(56.3)			(186.4)
C4	60.9					962.0	90.9	705.0	770.0		1,968.0			4,556.8
	(29.1)					(19.6)	(8.3)	(22.2)	(110.1)		(20.4)			(119.7)
G1			397.9					50.8	308.9					757.6
			(104.9)					(0)	(174.8)					(203.8)
G2	70.1				6.9	287.0	7.5	90.1		6.9	474.6	13.8		956.9
	(14.8)				(0)	(141.9)	(0)	(37.5)		(0)	(103.3)	(0)		(180.1)
G3									74.8			117.8	16.8	209.4
									(64.8)			(0)	(0)	(64.8)
G4						261.0		86.8	189.6		1,565.7			2,103.1
						(19.0)		(24.6)	(34.7)		(84.7)			(96.6)
G5	9.5				26.1	186.2		248.9	57.4		2,896.0	75.9		3,500.0
	(0)				(27.0)	(38.8)		(91.2)	(74.6)		(296.0)	(0)		(322.1)
G6	220.8				108.2	339.0	185.6	153.4	13.9		2,379.0			3,399.9
	(83.9)				(39.6)	(72.1)	(29.6)	(0)	(0)		(355.1)			(375.2)
G7	59.7					347.0	25.7	180.9	149.7		1,612.0	106.0	11.8	2,492.8
	(0)					(87.6)	(8.7)	(182.9)	(36.5)		(182.9)	(0)	(0)	(275.7)
G8	47.6			11.9		95.2	154.7	47.6			57.0			414.0
	(0)			(0)		(24.5)	(0)	(0)			(29.5)			(38.3)

[a] Four species of *Sicydium* occur in Puerto Rico, combined here.

Table 11. Spring biomass (kg/ha) estimates for Puerto Rico stream fishes at 12 sampling sites during 2005-2006 in the Río Cañas and Río Guanajibo drainages. Standard error estimates appear in parentheses.

Site	American eel	Bluegill	Largemouth bass	Fat snook	Mozambique tilapia	Bigmouth sleeper	Smallscaled spinycheek sleeper	River goby	Sirajo goby[a]	Burro grunt	Mountain mullet	Green swordtail	Guppy	Total
C1								2.3	14.8			0.1	0.001	17.2
								(0.5)	(1.4)			(0)	(0)	(1.5)
C2	6.8					30.6		7.0	2.1		95.6			142.1
	(0.4)					(30.2)		(3.2)	(0.2)		(2.6)			(30.5)
C3	48.4					100.2		19.3	1.4		286.0			455.3
	(4.5)					(13.7)		(4.6)	(0.1)		(8.6)			(17.4)
C4	4.0					28.4	7.0	3.8	6.9		118.4			168.5
	(0.8)					(2.5)	(8.5)	(0.3)	(0.2)		(3.2)			(9.5)
G1			83.9		3.7			10.0	4.2			0.005	0.001	101.8
			(3.9)		(0)			(0)	(1.7)			(0)	(0)	(4.3)
G2	32.0				1.1	26.6		15.3	0.1	10.1	48.4	0.01		133.6
	(28.6)				(0)	(2.9)		(5.0)	(0)	(0)	(2.4)	(0)		(29.3)
G3								5.8	2.5			0.6	0.1	8.9
								(0)	(0)			(0.2)	(0)	(0.2)
G4						37.5		4.1	1.6		44.5	0.020		87.8
						(24.3)		(0.3)	(0.4)		(3.6)	(0)		(24.6)
G5	11.1				3.9	30.0	1.1	37.0	0.8		183.0	1.1	0.007	267.9
	(0.7)				(0)	(4.8)	(0)	(2.1)	(0.1)		(4.3)	(0.1)	(0)	(6.8)
G6	4.5					17.6	3.8	4.4	0.5		28.8	0.2	0.001	59.8
	(2.2)					(4.9)	(6.0)	(0.9)	(0.03)		(1.3)	(0)	(0)	(8.2)
G7	6.3					26.7	1.5	14.4	7.6		38.9	19.5	0.008	114.9
	(0)					(25.0)	(0)	(7.6)	(2.6)		(1.8)	(79.8)	(0)	(84.0)
G8	0.3			0.2		7.7	1.2	1.0		0.3	0.2			10.9
	(0)			(0)		(16.4)	(0)	(1.7)		(0)	(0.1)			(16.5)

[a] Four species of *Sicydium* occur in Puerto Rico, combined here.

Table 12. Summer biomass (kg/ha) estimates for Puerto Rico stream fishes at 12 sampling sites during 2005-2006 in the Río Cañas and Río Guanajibo drainages. Standard error estimates appear in parentheses.

Site	American eel	Bluegill	Largemouth bass	Fat snook	Mozambique tilapia	Bigmouth sleeper	Smallscaled spinycheek sleeper	River goby	Sirajo goby[a]	Burro grunt	Mountain mullet	Green swordtail	Guppy	Total
C1								0.9	12.1				0.030	13.0
								(0)	(1.2)				(0)	(1.2)
C2	12.5					9.3		3.3	2.8		94.0			121.9
	(5.2)					(2.6)		(0)	(0)		(17.9)			(18.8)
C3	151.1					113.0		31.1	0.3		225.5			521.0
	(365.5)					(116.4)		(10.0)	(0)		(30.7)			(384.9)
C4	182.9					250.7	2.2	6.9	1.6		177.6			621.9
	(139.8)					(369.9)	(0)	(0.6)	(0.2)		(28.7)			(396.5)
G1			20.8					1.0	3.1					24.9
			(19.7)					(0)	(0.2)					(19.7)
G2	44.1	1.0				8.6		2.1			20.1			75.9
	(43.4)	(0)				(1.1)		(0.8)			(2.4)			(43.5)
G3									1.5			0.644	0.005	2.1
									(0.3)			(0.7)	(0)	(0.7)
G4	1.9					13.1		3.1	1.8		158.4	0.002		178.3
	(0)					(0)		(0)	(0)		(82.6)	(0)		(82.6)
G5	16.3				10.6	41.4		62.5	0.1		172.7			303.6
	(2.6)				(10.4)	(18.8)		(0)	(0.1)		(34.4)			(40.7)
G6	10.0				3.2	14.8	5.7	1.2	0.2		82.6			117.7
	(8.7)				(0)	(2.2)	(0)	(0)	(0)		(18.2)			(20.3)
G7	1.1					15.9		1.8	2.7		34.6			56.1
	(0)					(20.2)		(0.2)	(1.3)		(2.5)			(20.4)
G8	0.5					4.1	0.7			17.4	7.5			30.1
	(0)					(1.7)	(0)			(0)	(20.8)			(20.9)

[a] Four species of *Sicydium* occur in Puerto Rico, combined here.

Table 13. Fall biomass (kg/ha) estimates for Puerto Rico stream fishes at 12 sampling sites during 2005-2006 in the Río Cañas and Río Guanajibo drainages. Standard error estimates appear in parentheses.

Site	American eel	Bluegill	Largemouth bass	Fat snook	Mozambique tilapia	Bigmouth sleeper	Smallscaled spinycheek sleeper	River goby	Sirajo goby[a]	Burro grunt	Mountain mullet	Green swordtail	Guppy	Total
C1								1.2	12.1					13.3
								(0)	(1.1)					(1.1)
C2	22.2					20.5		3.5	2.0		70.4			118.6
	(12.1)					(2.1)		(2.3)	(1.2)		(1.5)			(12.6)
C3	21.7					62.3		1.4	1.2		142.6			229.2
	(4.4)					(4.2)		(2.6)	(0)		(3.7)			(7.6)
C4	12.7					38.5	4.2	5.9	3.3		38.6			103.2
	(6.8)					(1.3)	(0.7)	(0.4)	(0.5)		(1.3)			(7.1)
G1			24.1					2.7	4.3					31.1
			(4.0)					(1.7)	(0.9)					(6.1)
G2	10.3				2.0	29.2	0.3	1.9		10.3	18.3	0.023		72.3
	(3.4)				(0)	(19.5)	(0)	(0.2)		(0)	(4.9)	(0)		(20.4)
G3									1.5			0.1	0.003	1.6
									(1.5)			(0)	(0)	(1.5)
G4						27.7		1.9	2.3		46.5			78.4
						(1.6)		(0.8)	(0.6)		(5.0)			(5.3)
G5	5.4				0.7	34.1		6.6	1.2		66.3	0.1		114.4
	(0)				(0.9)	(13.7)		(2.9)	(1.7)		(4.7)	(0)		(14.9)
G6	26.1				8.3	33.1	6.8	4.9	0.3		54.5			134.0
	(15.4)				(2.6)	(9.8)	(1.3)	(0)	(0)		(5.0)			(19.1)
G7	13.3					17.4	2.2	9.4	1.9		22.1	0.1	0.001	66.4
	(2.6)					(1.5)	(0.8)	(11.7)	(0.6)		(1.1)	(0)	(0)	(12.2)
G8	2.5			1.9		5.4	2.7	0.3			1.2			14.0
	(0.7)			(0)		(2.5)	(0)	(0)			(0.4)			(2.6)

[a] Four species of *Sicydium* occur in Puerto Rico, combined here.

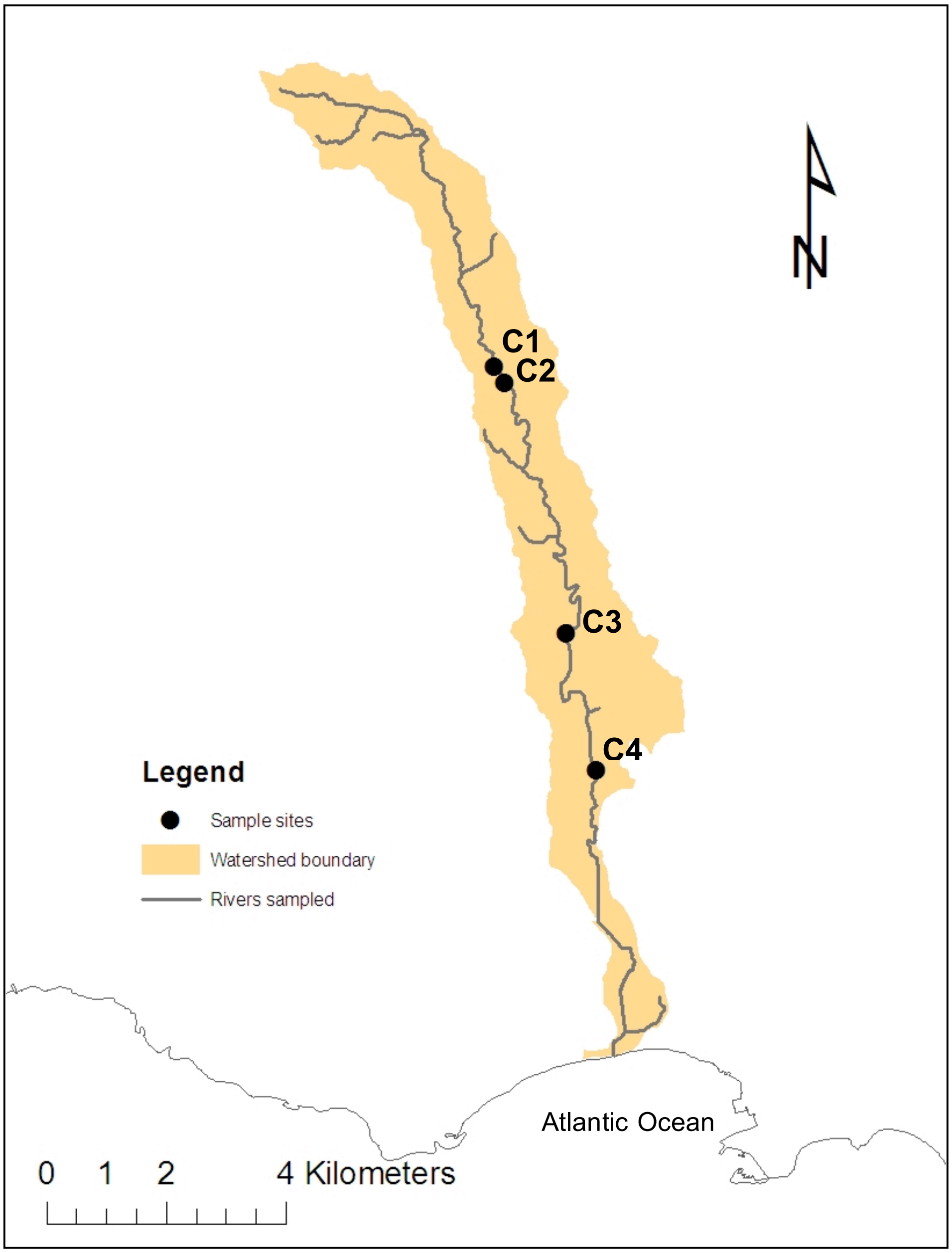


Figure 1. Four fish, water quality, and instream habitat sampling sites (C1-C4) within the Río Cañas watershed, a major tributary of Río Matilde near Ponce, Puerto Rico.

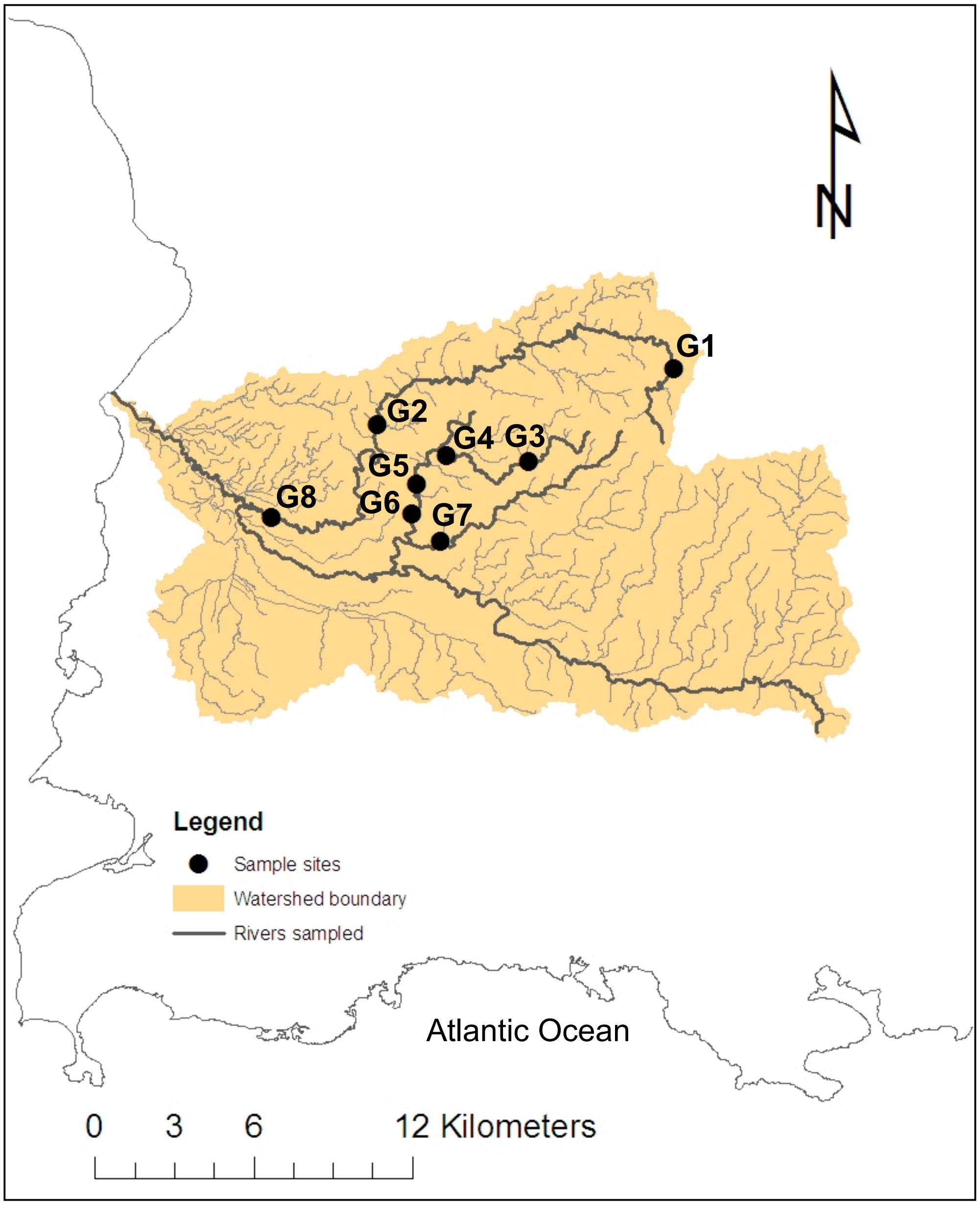


Figure 2. Eight fish, water quality, and instream habitat sampling sites (G1-G8) within the Río Guanajibo watershed near Mayagüez, Puerto Rico.

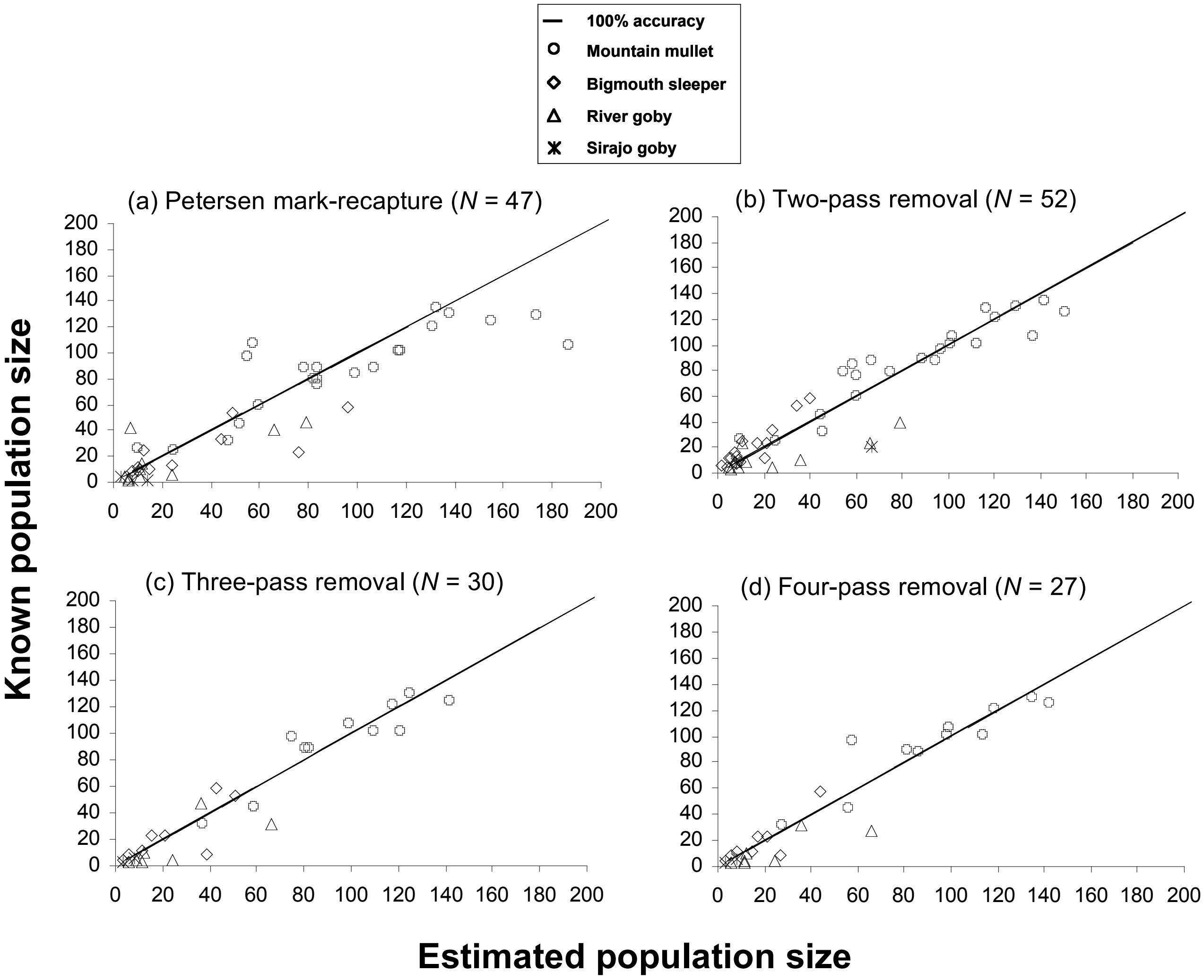


Figure 3. Accuracy assessment of four population models for estimating population size of Puerto Rico stream fishes. Points falling on the diagonal line represent high accuracy. Those above the line indicate underestimation, and those below the line are overestimates of population size.

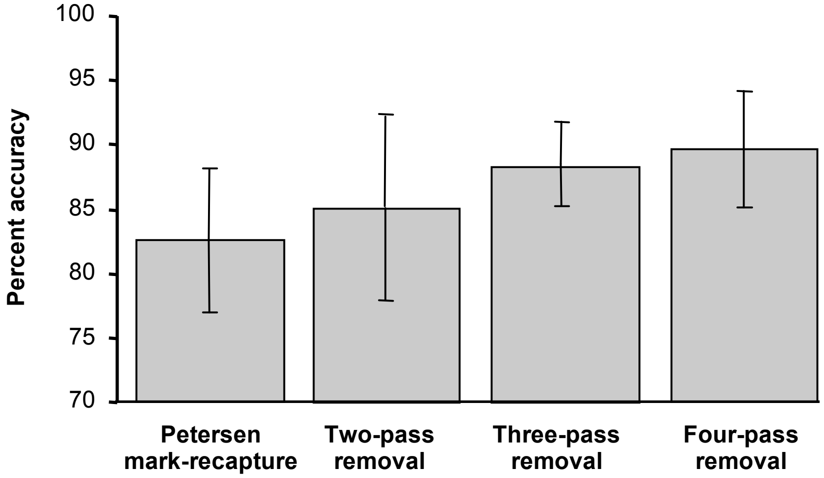


Figure 4. Mean percent accuracy of Petersen mark-recapture (N = 47), two-pass (N = 52), three-pass (N = 30), and four-pass removal (N = 27) models to estimate population size of Puerto Rico stream fishes. Error bars represent 95% confidence intervals.

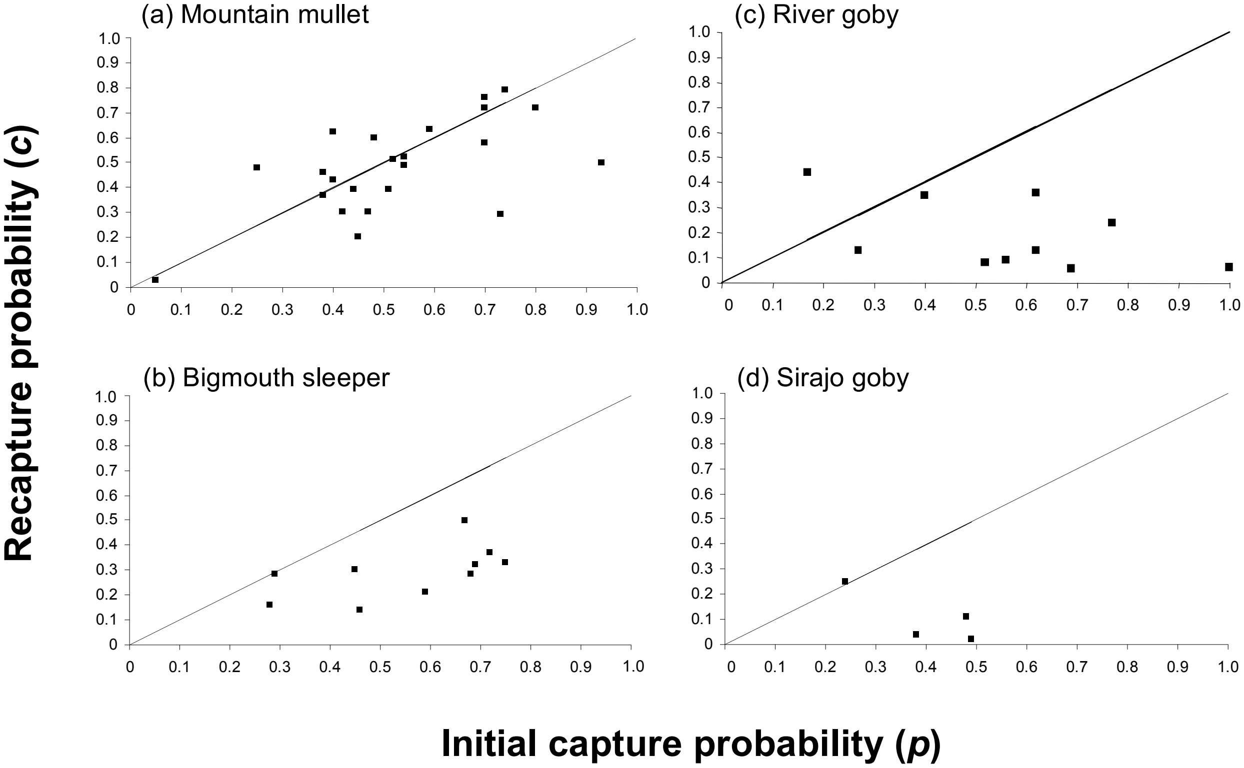


Figure 5. Plots of initial capture probability versus recapture probability to assess behavioral response of four Puerto Rico stream fishes to electrofishing gear. Points above the diagonal line of equal capture probability indicate a “trap-happy” response, and those below indicate “trap-shy” behavior.

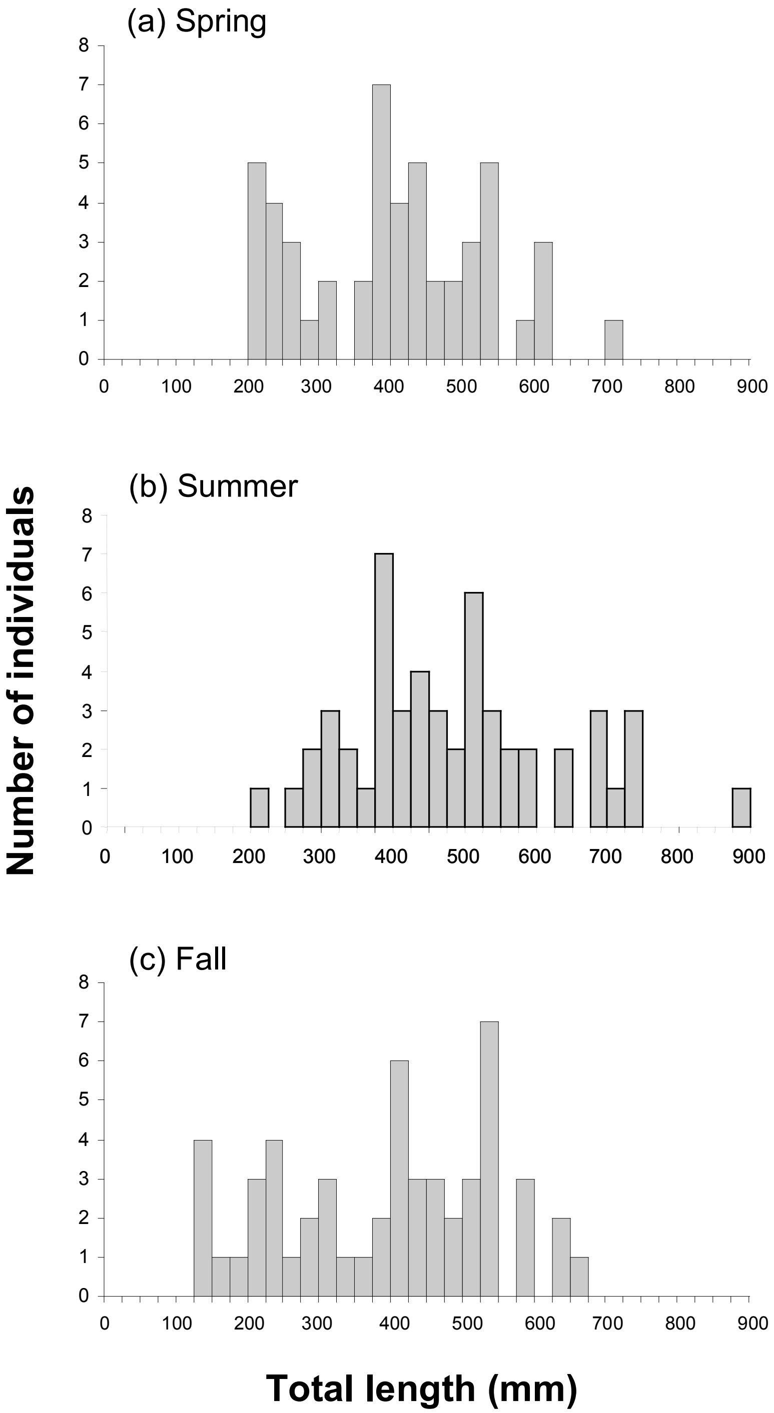


Figure 6. Length-frequency histograms of American eel combined for populations from nine sampling sites in Río Cañas (three sites) and Río Guanajibo (six sites) among three seasons during 2005-2006.

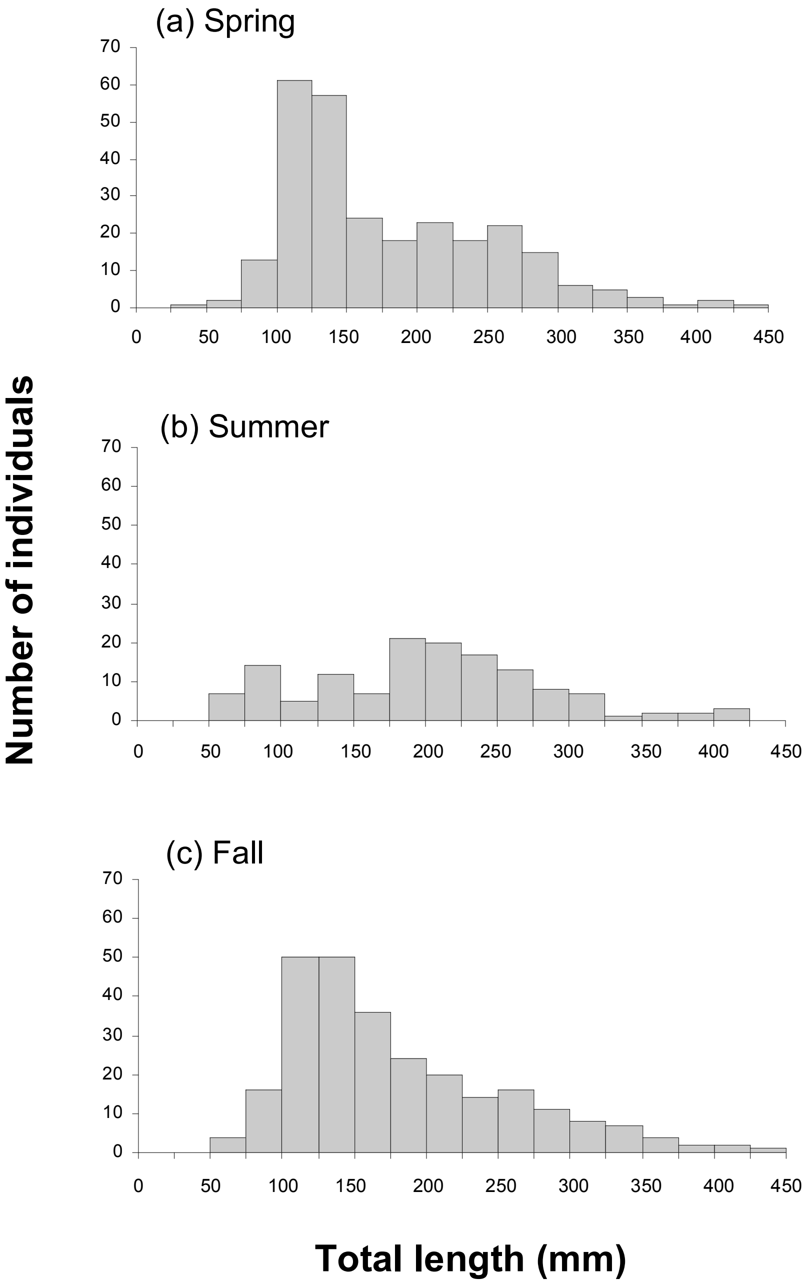
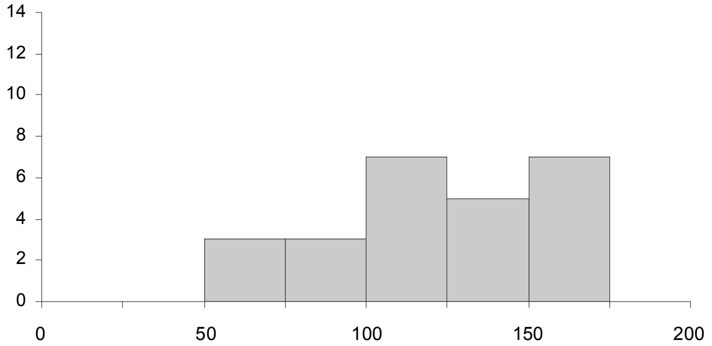
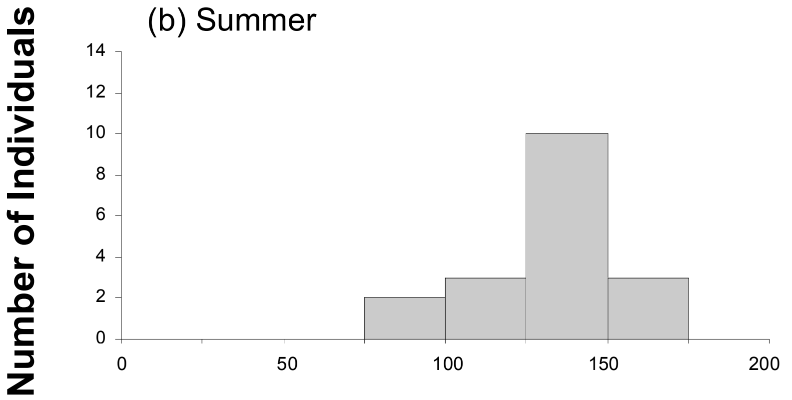


Figure 7. Length-frequency histograms of bigmouth sleeper combined for populations from nine sampling sites in Río Cañas (three sites) and Río Guanajibo (six sites) among three seasons during 2005-2006.

(a) Spring



(b) Summer



(c) Fall

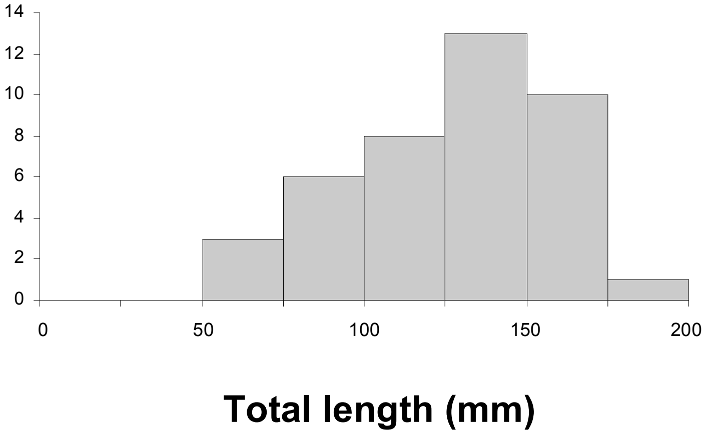


Figure 8. Length frequency-histograms of smallscaled spinycheek sleeper combined for populations from six sampling sites in Río Cañas (one site) and Río Guanajibo (five sites) among three seasons during 2005-2006.

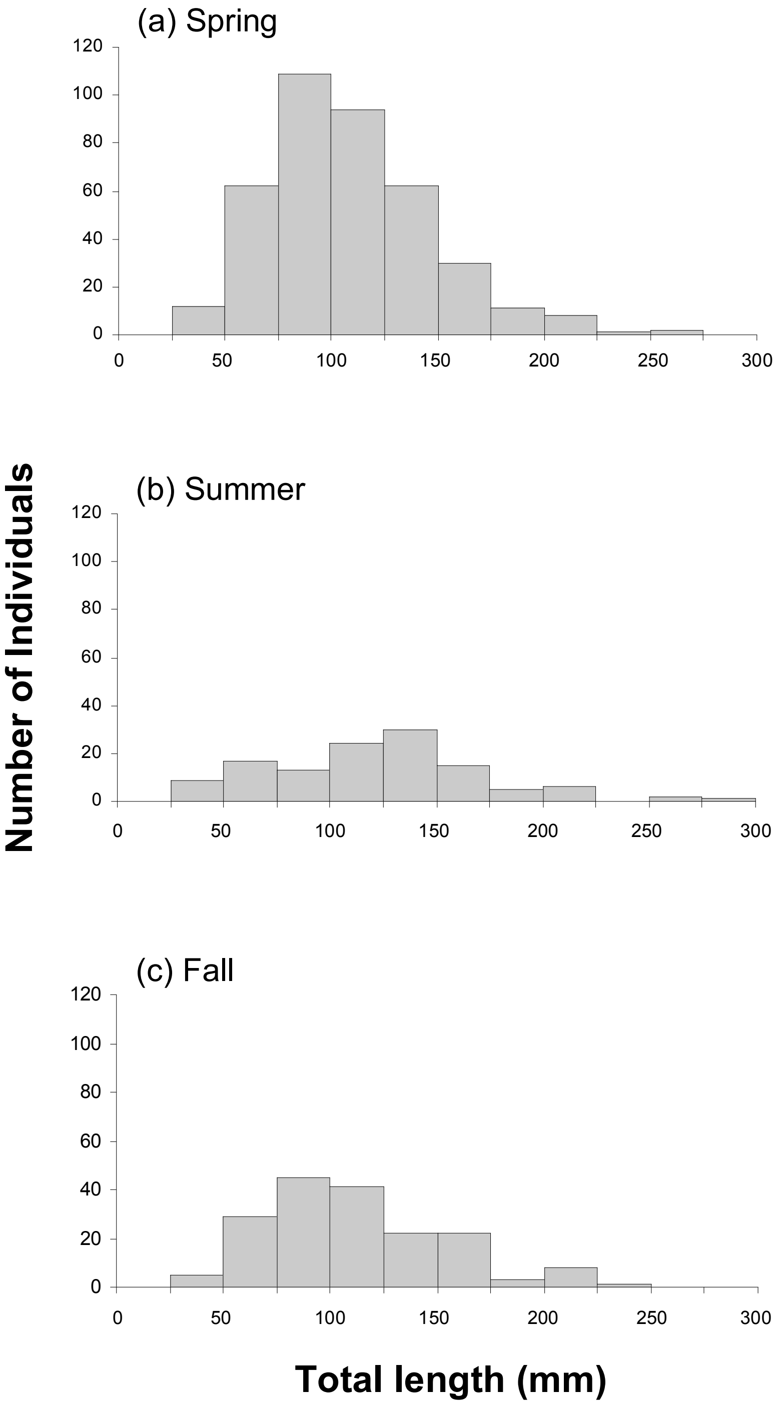


Figure 9. Length-frequency histograms of river goby combined for populations from 12 sampling sites in Río Cañas (four sites) and Río Guanajibo (eight sites) among three seasons during 2005-2006.

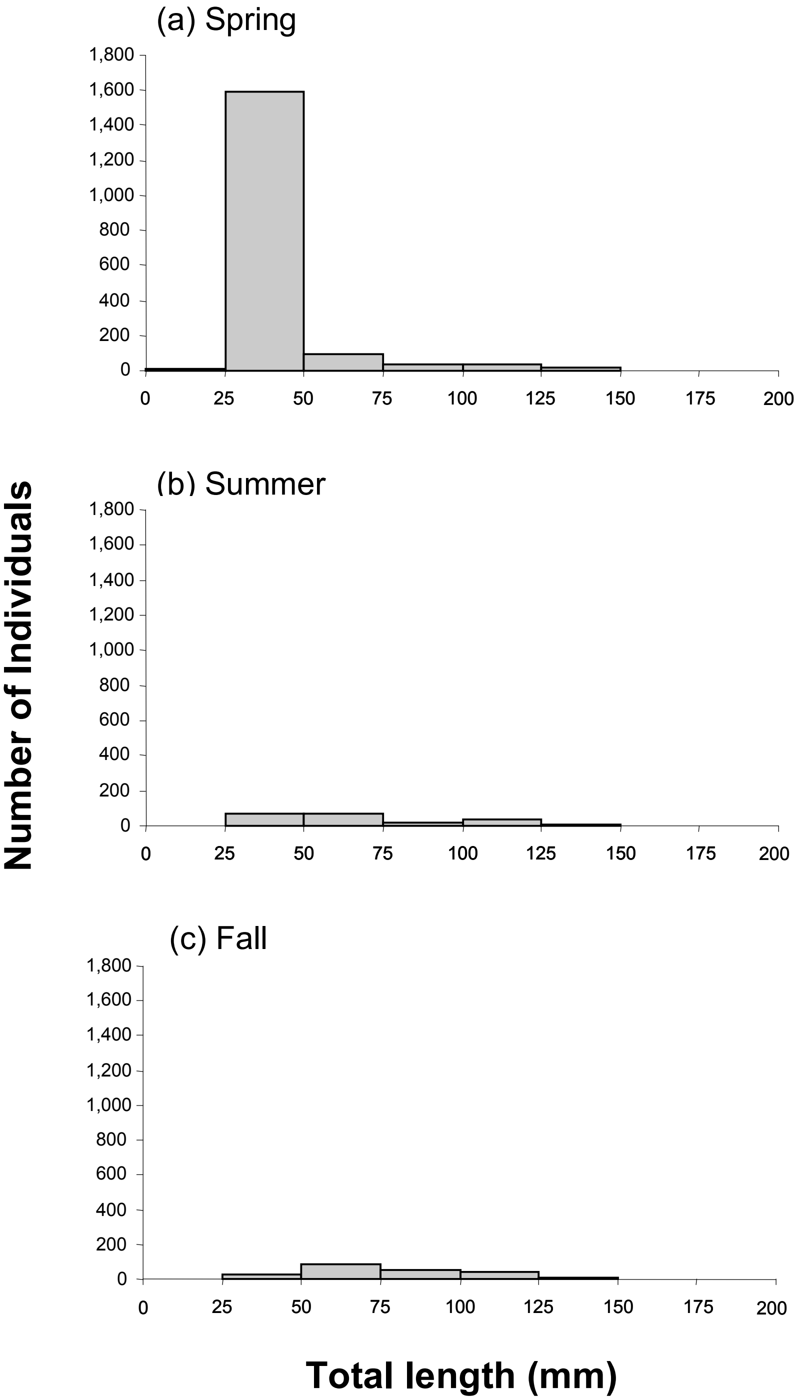


Figure 10. Length-frequency histograms of sirajo goby combined for populations from 11 sampling sites in Río Cañas (four sites) and Río Guanajibo (seven sites) among three seasons during 2005-2006.

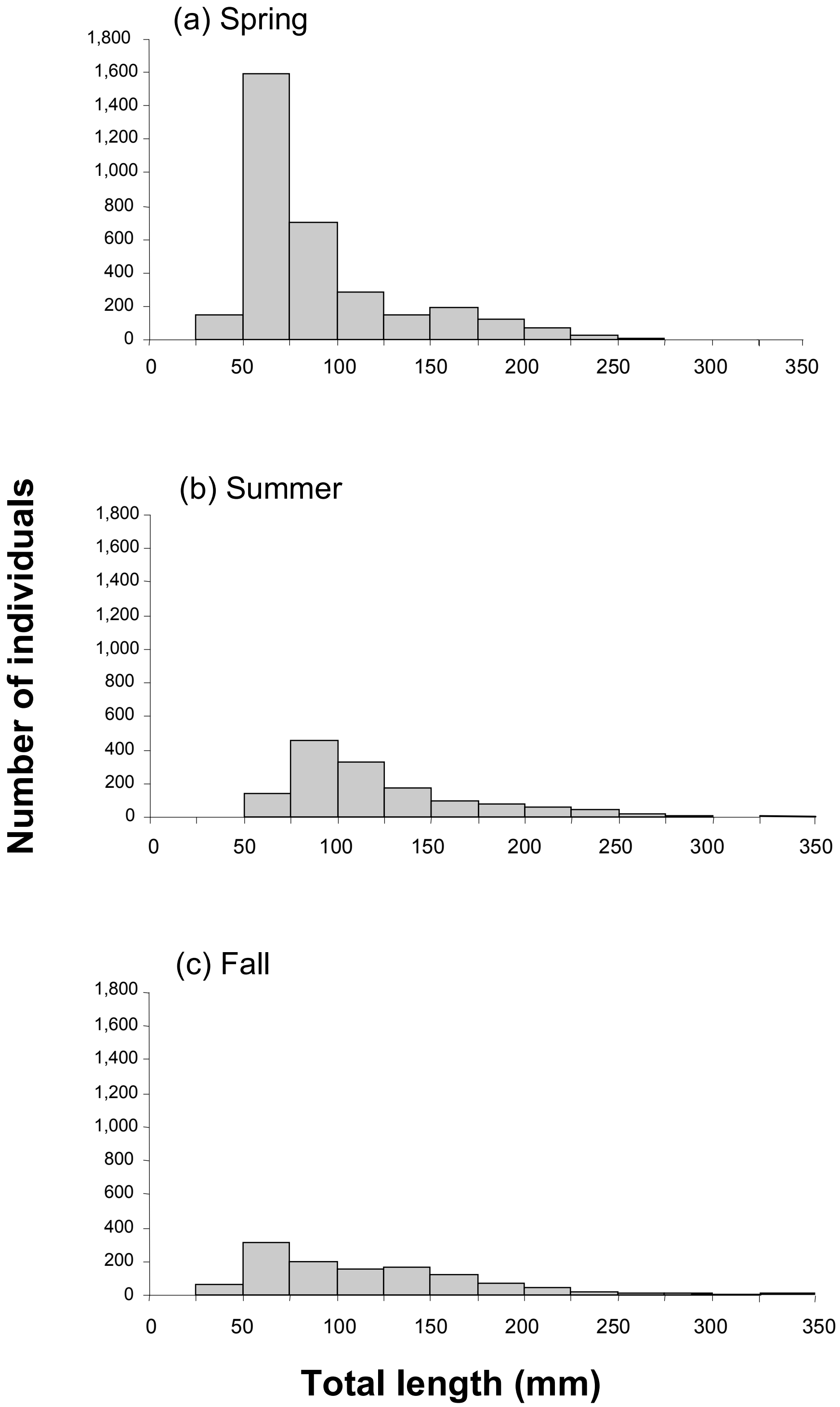


Figure 11. Length-frequency histograms of mountain mullet combined for populations from nine sampling sites in Río Cañas (three sites) and Río Guanajibo (six sites) among three seasons during 2005-2006.

Chapter 2

PUERTO RICO STREAM FISH DISTRIBUTION, ABUNDANCE, COMMUNITY STRUCTURE, AND ENVIRONMENTAL RELATIONSHIPS

(Jobs 2–4)

Introduction

Understanding and describing the spatial and temporal patterns in stream fish communities has been a fundamental theme in aquatic ecology for decades (Matthews 1998). The gains made in this ecological topic have direct application to fishery and ecosystem management in the stream environment. While much of traditional fishery management may have focused on single-species approaches aimed at target fishes of value, that approach is rarely appropriate for stream fisheries, where fishes are typically concentrated into restricted physical and biotic habitats that are subject to dramatic and rapid changes. As important as understanding fish community dynamics may be for management, these processes are not well understood, especially for tropical stream ecosystems and even less so for those systems on islands (Pringle et al. 2000; Smith et al. 2003).

Warmwater stream and river fishery resources provide substantial angling opportunities and yield associated monetary expenditures, yet are allocated minimal management resources, relative to their importance as fisheries (Fisher et al. 1998). This disproportionate management effort for warmwater streams may be related to several points that separate these habitats from other fishery environments (Rabeni and Jacobson 1999). First, warmwater streams tend to be subject to human modification and may have severe habitat or water quality problems. They may support multispecies recreational fisheries that are complex to manage. And much of the basic ecological information necessary for management is not available.

Puerto Rico is widely known for its marine sport and commercial fisheries, but the freshwater habitats of the island also support a substantial number of fishes, many of which provide recreational or subsistence fishery values. Of the approximately 77 fish species found in the freshwater habitats of Puerto Rico, 25 are primarily freshwater species, and only seven of these are native fishes. Further, a majority of these fishes are important to humans by providing sport fishery and food values. Many of the fishes known to occupy freshwater habitats are also found in estuarine or marine waters, and many are dependent upon movements between freshwater and marine habitats for their existence (Erdman 1984; Holmquist et al. 1998). Even with the substantial number of fishes found among the 1,200 streams and rivulets in Puerto Rico and their importance to humans, they have received relatively little attention by fisheries scientists, but that interest is expanding.

The seven native freshwater fish species are of primary management concern for their sport fishing and natural heritage values. Native species that utilize both upper and lower river reaches include gobies (Gobiidae), sleepers (Eleotridae), mountain mullet (Mugilidae), and eels (Anguillidae) (Holmquist et al. 1998). Generally, the sirajo goby *Sicydium plumieri* is found in upstream river reaches, whereas, lower river reaches are dominated by mountain mullet *Agonostomus monticola*, American eel *Anguilla rostrata*, bigmouth sleeper *Gobiomorus dormitor*, and river goby *Awaous banana*. The bigmouth sleeper is the only one of these species that is known to complete its entire life cycle in a riverine environment (Bacheler et al. 2004). The pelvic fins of the sirajo goby and river goby form a modified ventral sucker disc that allows them to ascend waterfalls and return to upper river reaches after spawning, and the larvae of these fish are a local delicacy (Keith 2003). The smallscaled spinycheek sleeper *Eleotris perniger* and fat sleeper *Dormitator maculatus* are found only in lower river reaches or brackish water (Corujo Flores 1980).

It has been suggested that Puerto Rico freshwater fish populations are influenced to varying degrees by the introduction of exotic fishes, the construction of dams, instream flow patterns, and water pollution (Erdman 1984; Holmquist et al. 1998; March et al. 2003). Erdman, in a 1984 review on Puerto Rico freshwater fishes, concluded that “With proper management and protection of water quality, freshwater fishes will continue to be a valuable resource for the people of Puerto Rico.” However, such fishery management and habitat protection or enhancement actions require sound science to guide strategic planning and decision-making. The research objectives proposed here represent an important advancement in providing additional information toward that end.

The goal of our research was to describe patterns in occurrence and abundance of stream fish populations and communities as related to physical habitat at multiple spatial scales. Our specific objectives were to (1) sample Puerto Rico stream fish communities island wide and quantitatively estimate abundance as population density and biomass; (2) conduct instream and riparian physical habitat surveys at each fish sampling site; (3) delineate watersheds and upstream riparian zones of each sampling site and quantify attributes related to land cover and ownership from existing data; and (4) develop empirical, hierarchical models that describe relationships among indices of fish community structure and environmental parameters at the stream reach, riparian, and watershed scales.

Methods

Sampling Sites

We sampled Puerto Rico stream fish communities from 81 stream reaches within 34 of the 46 major river drainages (Table 1; Figure 1). Our study sites were located in 41 municipalities and dispersed throughout the approximately 8,900-km^2 main island of Puerto Rico. Global Positioning System (GPS) coordinates were recorded at each site with a Garmin GPS Model V (Table 1). Sampling was conducted during three seasons, spring (March and April), summer (June and July) and fall (November and December), from June 2005 to April 2007, for a total of six sampling seasons (Table 2). Twelve sites from the Río Matilde (Río Cañas tributary) and Río Guanajibo drainages, in conjunction with research from Chapter 1, were sampled during three seasons (summer 2005, fall 2005, spring 2006), whereas all other sites were sampled once, for a total of 105 sampling occasions (Table 2). All sampling sites were wadeable and were selected as representative river reaches based on accessibility, riverine habitat, and to spatially complement the diverse ecosystems of the island; estuarine environments were not sampled.

The volcanic origins of Puerto Rico create numerous high-gradient, narrow streams along the southern coast of the island that receive lower annual rainfall, whereas karstic limestone formations and longer reaches along the northern coast, accompanied by higher annual rainfall, create lower gradient, wider streams. The El Yunque National Forest, situated in the northeastern corner of the island, is also characterized by steep gradients, but unlike the southern portion of the island, receives high amounts of rainfall, creating high-gradient streams with continuous flow. Sampling sites were selected throughout these differing environments to characterize fish communities across the island (Figure 1).

Study sites varied with respect to stream size and physical characteristics. Thus, sufficient sampling reach lengths (all equaled or exceeded 100 m) were chosen to include at least one riffle-pool sequence and minimize the effect of localized species-specific distribution patterns. We generally avoided including bridge crossings within the sampling reach to reduce their atypical influence on the fish community samples.

High human population density and lack of freshwater lakes on the island led to the development of over 30 high dams to create reservoirs for human water consumption, electricity generation, flood control, and agricultural and recreational uses. These dams and reservoirs, along with other human barriers, such as road crossings and culverts, as well as natural barriers, including waterfalls and habitat constraints, create barriers to migration of native fish populations. Our sampling sites were selected across the longitudinal river gradient of these obstacles to attempt to describe and quantify the constraints they pose.

Fish Sampling

The upstream and downstream boundaries of each stream sampling reach were blocked with 7-mm mesh knotless nylon blocknets, equipped with surface floats and a bottom lead-line. Stream reaches with greater depths and widths, lower gradients, and smaller substrate were sampled using a Smith-Root SR-6 tote barge equipped with a 2.5 GPP electrofisher system powered by a 2,500-watt generator operating at approximately 3.0-A pulsed DC with three anode probes (Table 2). Stream reaches with shallower depths and narrower widths, higher gradients and larger substrate were sampled using two Smith-Root Model 12-B pulsed-DC backpack electrofishers operating at approximately 0.25-A pulsed DC (Table 2). A three-pass removal protocol was followed (see Chapter 1), with all passes of equal effort (electrofishing time) and proceeding in an upstream direction.

A four or five person crew was utilized for tote barge electrofishing, with one crew member maneuvering the barge, three operating anode probes and collecting fish, and one collecting and transporting fish to a holding tank in the barge. A three or four person crew was utilized for backpack electrofishing, with two crew members operating the electrofishers and collecting fish, and one or two others collecting and transporting collected fish. Crew members operating anodes moved upstream at the same rate in a zig-zag pattern to form a barrier, preventing fish from swimming around the sampling crew. All stunned fish from each pass were collected, identified to species, measured for total length (mm TL), weighed (0.1 g) and held in mesh pens outside of the sampling reach until sampling was completed at each site.

Macroinvertebrate Sampling

Quantitative sampling and parameter estimating for fishes was the primary objective of our research, but we also qualitatively sampled decapod macroinvertebrates (Crustacea) concurrently with the fish sampling protocol. Shrimp and crab species captured during fish sampling at each site were identified to species (Chace and Hobbs 1969) and recorded. No assessment of density or biomass was made, and results are represented as presence of species at each site.

Instream Habitat Measurements

Immediately following fish sampling and block net removal at each sample site, a line-transect survey method was implemented to measure physical habitat characteristics. Habitat parameters were measured on at least 10 evenly-spaced points along 10 cross-sectional transects that were spaced apart at a distance equal to one river width. Placement of the initial transect was random within one stream width of the downstream terminus of the sampling reach, and point measurements proceeded from the left to right bank of the river.

At each transect, wetted stream width was measured perpendicular to the flow to the nearest 0.01 m. The bank angle on each edge of each transect was measured with a clinometer in degrees. At each point along a transect, we visually determined the dominant substrate category from a modified Wentworth scale (Bovee and Milhous 1978) and the presence or absence of immediate physical cover. Cover was considered any structure that could provide fish shelter, and categories included undercut bank, rootwad, roots, submerged vegetation, woody debris, and substrate categories equal or larger in size than small cobble. We also measured mean column water velocity to the nearest 0.01 m/s with a Marsh-McBirney 2000 Flo-Mate digital flow meter and depth to the nearest 0.01 m with a Scientific Instruments, Inc. 1.5-m top-setting wading rod. At water depths less than 1.0 m, mean column velocity was measured at 60% of total depth, whereas mean column velocity at greater depths was calculated as the mean of measurements taken at 20% and 80% of total depth. For each site, average mean column velocity and mean water depth were estimated by averaging all point measurements, mean wetted width was calculated by averaging the widths among transects, and mean bank angle was the average of the bank angles from both ends of all transects. Area of each sampling site was calculated by multiplying the mean wetted width by the length of the reach. The dominant substrate for each site was determined as the modal substrate from all points, and percent cover was expressed as the number of points with immediate cover available divided by the total number of points sampled.

Water Chemistry

Upon first arriving at each sample site, a 1-L water sample was collected from an area of laminar flow and placed on ice for subsequent analyses. The sample was returned to the lab and analyzed using a Hach CEL/850 Portable Aquaculture Laboratory for nitrate (mg/L NO_3^-), nitrite (mg/L NO_2^-), ammonia (mg/L NH_3), phosphorus (mg/L PO_4) and turbidity (FAU) with a DR/850 colorimeter. Nitrate concentration was measured by a cadmium reduction method within a range of 0.3 to 30.0 mg/L NO_3^-. Nitrite concentration was measured by a diazotization method within a range of 0.002 to 0.300 mg/L NO_2^-. Ammonia as nitrogen was measured by a salicylate method that measures concentrations from 0.01 to 0.50 mg/L NH_3. The phosphorous method was an orthophosphate ascorbic acid method within a range of 0.02 to 2.50 mg/L PO_4^-. We measured turbidity in FAU comparing a deionized water blank to the stream water sample. Alkalinity (mg/L $CaCO_3$), and hardness (mg/L $CaCO_3$) were measured with a digital titrator, and pH with a sension1 pH meter. We measured alkalinity by titrating a sample with phenolthaline as an indicator with sulfuric acid within a range of 10 to 400 mg/L $CaCO_3$. We similarly measured hardness using EDTA as an indicator to measure levels from 10 to 400 mg/L $CaCO_3$. Water temperature (ºC), conductivity (µS/cm), salinity (ppt), total dissolved solids (TDS; g/L) and dissolved oxygen (mg/L) were measured on-site in an area of laminar flow, with a calibrated Yellow Springs Instrument (YSI) 556 multi-probe system.

Community Indices

Several community indices were estimated based on fish density for each sampling site to allow comparison among sites. Species richness, defined as the total number of species represented in a sample (Kwak and Peterson 2007), was derived for all sites, and further categorized into native and introduced species richness. Shannon's species diversity index (H'; Krebs 1999; Kwak and Peterson 2007), which accounts for number of species in a sample as well as their relative abundance, was also calculated for each site and for native species.

Fish density and biomass were estimated using Pop/Pro Modular Statistical Software (Kwak 1992) following algorithms of Seber (1982) and Newman and Martin (1983) for all fish species that declined in number at each site in accordance with the removal method. We stratified population estimates by size group to minimize size bias that is associated with electrofishing (Kwak 1992). Size groups for population estimates were 50 mm, but consecutive size groups with small sample sizes were combined. Population estimates from sampling reaches were standardized to units of fish/ha for density and kg/ha for biomass according to species and total for a site. Standard error (SE) as a measure of sampling error was also estimated for each species and total. Density and biomass estimates for those species for which catch did not decline in number from the first to the final pass were calculated by summing the catch of the three passes, as a minimum estimate and multiplying the number and biomass of each species by an area conversion factor. Total, native, and introduced fish species density and biomass estimates were each calculated by combining respective species estimates. Average weights were calculated for the predominant native freshwater fish species by dividing biomass (kg/ha) by density (fish/ha) to obtain average fish weight (kg/fish).

Geographic Analyses

Watershed Delineation.—The upstream catchment of the 81 fish sampling sites was delineated using ArcHydro 1.2, an extension of ArcGIS 9.1, a spatial analysis tool used to delineate watersheds and stream networks using Digital Elevation Models (DEMs). A National Elevation Dataset (NED) with 30-m resolution was used in delineation and was provided by the United States Geological Survey (USGS) via the Puerto Rico Gap Analysis Project (PRGAP) (Table 3).

The processes involved in delineation included filling sinks in the NED and determining flow direction and flow accumulation. A flow accumulation grid was used to construct a stream definition grid, and a stream link grid was then created using the stream definition grid. The next step was to create catchment grids using flow direction and stream link grids. Catchment polygons were then processed, and fish sampling sites were added to the map using batch-point delineation. Each watershed was delineated upstream of the respective batch point. Once a watershed was delineated, we created an attribute table using Arcmap 9.1 that estimated watershed area (km^2). The National Hydrography Datasets (NHD) flowline data were added to Arcmap for comparison of the stream grids created via ArcHydro (Table 3).

Land Cover.—The 81 polygon shapefiles created during watershed delineation were overlaid with land cover data, provided by PRGAP, in Arcmap to characterize proportions of land cover type within each watershed (Table 3). These data were obtained by selecting all land cover classes contained within the watersheds, and creating a new layer file. The attribute table for this layer was extracted and exported into a spread sheet application, and 71 land classes were combined into five major classes: Agriculture, Forest, Freshwater, Shrub and Woodland, and Urban. The percentage of total area each land class occupied within the watershed was then calculated.

Riparian buffer analysis of the 81 fish sampling locations was used to extract land cover data for an area 30-m and 100-m on each side of all stream segments in the upstream catchment. Each buffer was created in Arcmap by buffering around each stream segment and clipping land cover data within the buffer. The resulting attribute tables for 30-m and 100-m buffers were extracted and exported to a spreadsheet application. The land cover classes were merged into the five classes above, and percentage of the total area of each class was calculated.

Land Ownership.—The 81 polygon shapefiles created in ArcHydro were overlaid with ownership data, provided by PRGAP, in Arcmap to characterize relative ownership within each watershed and 100-m riparian upstream buffer (Table 3). The attribute table created by each new extracted ownership layer file was exported into a spreadsheet application. Ownership data were classified into three major classes: Private, Public (including land owned by the Puerto Rico Department of Natural and Environmental Resources (DNER) and U.S. Forest Service), and Utility and Non-Governmental Organizations (NGO) (including land owned by the Autoridad de Energia Electrica and Conservation Trust of Puerto Rico). The percent ownership within each watershed and 100-m stream buffer was then estimated utilizing these three classes.

Road Density.—Road density was determined using Topologically Integrated Geographic Encoding and Referencing System (TIGER/line) road coverage layers (Table 3). The layers were merged and clipped to the extent of the 81 sample locations. A new layer file was then created, extracted, and exported to a spreadsheet (Excel). In Excel, the road density (km/ha) was determined by summing the lengths of road (km) within each watershed, divided by the area (ha) of the watershed.

Elevation and Stream Gradient.—Elevation and stream gradient were determined for 81 sampling locations using the original NED and overlaying sample locations and NHD flowline data in Arcmap. Elevation (m) was identified at the sampling site. To determine gradient, or stream slope, elevation was measured 100-m upstream and 100-m downstream of the linear midpoint of the sampling reach. Stream gradient was estimated by dividing the change in vertical elevation between these two points by 200 m, then multiplying by 100 and expressed as a percent.

Distance to River Mouth.—River km, the number of kilometers between the sampling site and the Atlantic Ocean, was estimated for each sampling site using NHD flowline data and overlaying sampling sites onto the map. The distance from each sampling site to the river mouth was created as a new layer file with its own attribute table. The table included stream length from the sample location to the river mouth. These data were extracted and exported into a spreadsheet, and distance (km) was calculated.

Correlation Among Environmental Variables

We conducted thorough instream and riparian habitat surveys, measured water quality characteristics, and calculated relevant watershed and riparian characteristics for each sampling site to incorporate into exploratory models to explain patterns in fish community structure. Even after careful scrutiny of which variables to measure in the field or to delineate from digital mapping data bases, we measured and compiled data for 43 parameters that describe the physical environment that presumably shapes fish community structure (Table 4). However, many of these parameters were correlated among sites and are redundant in their description of fish habitat conditions (i.e., multicollinearity; Zar 1999). For example, we quantified the ionic content of stream water by six different measures (conductivity, total dissolved solids, salinity, alkalinity, hardness, and pH). And as expected, five of these six variables were highly correlated among sampling sites (Table 4).

To reduce the number of total parameters to be included in model development and to eliminate redundant parameters, we developed a simple linear correlation matrix of all 43 variables to examine relationships among them. Then based on patterns in numeric correlation (correlation coefficient, r) and related ecological functions among them, we selected 13 primary variables that represented a suite of environmental conditions that we deemed potentially influential to fish communities; we were also guided in variable selection by existing literature, knowledge, and experience. Thus, only these 13 primary representative variables were included in analyses to develop and select models describing patterns in fish community structure (Table 4).

Hierarchical Models

Little is known about Puerto Rico stream fish assemblages and their relationships with physical, chemical, and geographical variables. To better understand these relationships, we initiated exploratory investigations to determine which variables best explained the abundance and distribution of native and introduced fish communities sampled at the 81 sampling reaches.

We developed hierarchical regression models using Proc Mixed within SAS 9.1 software (SAS 1996; Singer 1998) to investigate the relationships between fish community variables (richness, diversity, density and biomass) and physical (stream width, percent cover, water temperature, and turbidity), chemical (conductivity and nitrate concentration) and geographical variables (watershed area, river km, presence of downstream reservoir, road density, percent forest concentration of upstream 30-m riparian buffer, percent forest of watershed, and percent publicly owned of watershed). Examination of resulting regression residuals revealed heteroscedasticity, and thus, we $\log_e(x+1)$ transformed all fish community variables, which remedied the condition.

Twelve of the sampling sites were sampled on more than one occasion, 14 of the 34 sampled drainage basins contained multiple sampling sites, and sites were sampled over three different seasons, creating dependency among sampling events. We investigated and quantified dependence among sampling sites and seasons for each of the fish community variables using nested all-subsets regression within SAS Proc Mixed.

To account for dependence of location within drainage and season, hierarchical models were constructed with the subject option as location, nested within drainage for all models. For those where seasonal effects created dependence, season was used as a group option within either the random statement or a repeated measures statement. Variance structure and Akaike's Information Criterion (AIC; Akaike 1973) values were examined for each of these structures, and the most favorable for each community variable was selected.

The selected hierarchical model structure for each dependent fish community variable was used to evaluate all-subsets regression of the 13 independent variables determined from the correlation analysis to develop suites of models. AIC model selection, based on AICc (AIC value with a second-order bias correction) and w_i (model weight or probability that a model is the best among all considered), was used to evaluate the relative fit of resulting models and to identify the most parsimonious models for each fish community variable (Burnham and Anderson 2002).

Results

Sampling Site Attributes

The 81 sampling reaches ranged in elevation from 4.6 m to 702.4 m above sea level, with a mean of 166.5 m, and the distance to the mouth of the river ranged from 2.6 km to 84.2 km, with a mean of 28.0 km (Table 6). A majority of sites were 150 m in length; however they ranged from 100 m to 155 m (Table 5). A single site, 28A (Figure 1), had a high gradient of 23.45%, explained by the presence of a 30-m waterfall immediately downstream of the site, whereas the remainder of sites had gradients ranging from 0.04 to 10.17%, with an average of 2.45%, or a decline of 3.75 m over a 150-m reach (Table 6). The mean upstream watershed area for each site was 18.3 km^2, and ranged from 1.070 km^2 to 95.483 km^2 (Table 6). All but 12 of the 46 major river drainages of Puerto Rico were sampled during our study (Figure 1). Several of the unsampled drainages had access only to sites that were not wadeable, others were dry, and most had limited access, if any.

Among the 81 sites we sampled, 10 were located upstream of large reservoirs and dams (Table 6); however, other sites among most drainages were located upstream of various observed natural and unnatural barriers to fish passage. The occurrence of these other barriers, including road crossings, culverts, small dams, subterranean river reaches, and waterfalls, were not as easily documented as large dams and reservoirs, but were present. For example, a 30-m waterfall was observed on Río Cañas within the Río Matilde drainage, between sites 28A and 28B, and a small dam at an old coffee plantation was located on Río Rosario, within the Río Guanajibo drainage, halfway between 35A and 35B.

The greater depths and widths of rivers along the coastal plain in northern Puerto Rico, between the cities of Aguadilla and Río Grande, made it difficult to locate wadeable reaches within close proximity to the coast. Therefore, a majority of sampling sites in the north were in the mountains at higher elevations. Similarly, river reaches downstream of reservoirs tended to be deep and wide, precluding most from being sampled. The greater density of drainages and tributaries, and corresponding smaller drainage areas and reaches, along the eastern, southern, and western coasts allowed for more favorable sampling conditions, and more stratified characteristics from the coast to the mountains within these drainages.

We sampled multiple sites within six river drainages that represent gradients from headwaters to river mouth. These examples include the two sites in Río Mameyes, sites A through D for three seasons in the Río Matilde drainage, sites B and C in Río Yauco, sites C through F and sites A, B, and H for three seasons in the Río Guanajibo drainage, and sites F, G, I, and J in the Río Manatí drainage. The only other examples of successional sampling occurred upstream of reservoirs in Río Yauco and in the Río Arecibo drainage.

Figures 2 through 28 display species richness, diversity, density and biomass from the spring 2006 sampling events at the 12 sites that were sampled during multiple seasons in conjunction with Chapter 1 (27A-27D and 35A-35H). All other sites were only sampled once, and values are displayed accordingly.

Fish Communities and Populations

Fish were present at each site, with a total of 25 fish species from 14 families collected from the 81 stream sampling reaches (Table 7). Of these, 10 species from seven families were native to Puerto Rico, and 15 species from seven families were introduced.

Previous accounts of freshwater Puerto Rico fishes (Hildebrand 1935; Erdman 1961, 1986) reported the presence of only one species of *Sicydium,* the sirajo goby, *Sicydium plumieri*; however, Watson (2000) recently examined fish holdings of a number of museums and other collections from Puerto Rico and determined that four species of *Sicydium* occur in the streams of Puerto Rico (*S. buski*, *S. gilberti*, *S. plumieri* and *S. punctatum*). Due to the minute physical distinctions between species that are difficult to distinguish in the field, we considered all four species one taxon, the sirajo goby *Sicydium plumieri*, for this study. A limited number of fish specimens that we vouchered (NC State Museum of Natural Sciences, Raleigh, North Carolina) from several of our 81 sampling sites included three of the four *Sicydium* species (*S. buski*, *S. plumieri* and *S. punctatum*).

We collected six of the seven predominant freshwater fish species native to Puerto Rico rivers (Table 7; Figures 11-28). The fat sleeper was not collected at any of the 81 sampling sites, possibly due to its association with brackish water. The six native freshwater species collected were found at a greater number of stations and were more numerous than the four native estuarine species; burro grunt *Pomadasys crocro* was found at eight locations, and fat snook *Centropomus parallelus*, gray snapper *Lutjanus griseus*, and white mullet *Mugil curema* were each collected at one location (Table 7). Of all fish species, the river goby was the most ubiquitous, found at 54 of 81 locations (Figures 11-13). Of the other sampled species, sirajo goby was the second most common native fish species, found at 50 stations, followed by mountain mullet at 41 sites, bigmouth sleeper at 35 sites, American eel at 32 sites, and smallscaled spinycheek sleeper at 26 sites (Table 7; Figures 14-28).

Introduced fishes were widespread among sampling sites (Figure 4). The three introduced species detected at the most sites were from the Poeciliidae family, and included guppy *Poecilia reticulata* found at 50 sites, green swordtail *Xiphophorus hellerii* at 35 locations, and Mexican molly *Poecilia sphenops* at 28 sites (Table 7). Mozambique tilapia *Oreochromis mossambicus* was the fourth most ubiquitous introduced species, found at 27 locations, followed by rosy barb *Puntius conchonius* at eight sites, channel catfish *Ictalurus punctatus* at six sites, Amazon sailfin catfish *Pterygoplicthys pardalis* at five sites, redbreast sunfish *Lepomis auritus* and largemouth bass *Micropterus salmoides* at four sites each, convict cichlid *Archocentrus nigrofasciatus* and sailfin molly *Poecilia latipinna* at two sites each, and finally, bluegill *Lepomis macrochirus*, Chinese algae-eater *Gyrinocheilus aymonieri*, Nile tilapia *Oreochromis niloticus*, and redbreast tilapia *Tilapia rendalli*, each found at one location.

Mean fish species richness for all sites was 5.16 species, ranging from one to 11 species (Table 8; Figure 2). The sample reach on Río Cañas (1C), just upstream of Lago Carraizo within the Río Grande de Loíza river drainage, yielded 11 fish species, the highest of all sites (Table 9; Figure 2). These were all introduced species of fish (Table 8). Three sites (37A, 37B, and 46B) yielded species richness of 10 (Figure 2), each comprised of six native and four introduced species (Table 8). Three sites (3A, 37D, and 42E) yielded only one fish species (Figure 2), the sirajo goby (Table 8).

Native fish species richness ranged from zero to seven species, with a mean richness of 3.34 species (Table 10; Figure 3). Native fish were sampled in 65 of the 81 stream reaches, and the fish community at 20 sites was comprised entirely of native fishes (Table 8). Of these 20 locations, five or more native species occurred at 12 of them. No native fish species were found at any of the 10 sites upstream of a large reservoir. There were six additional sites where native fish species were not detected, yet no large reservoir was present downstream of these sites, suggesting the presence of another type of barrier to fish movement or other influential factor. Twelve sites had all six of the predominant freshwater fish species sampled (4A, 5A, 6A, 7A, 28D, 31A, 35E, 35F, 35G, 36A, 42J, and 46A). The 23 sites with one or two native species were primarily situated at higher elevations and greater distances from the river mouth, and were represented by river gobies or sirajo gobies; whereas the 29 sites with five or more native species were generally situated at lower elevations and shorter distances from the river mouth (Table 10; Figure 3). Thirteen sites had three or four species of native fishes and were generally moderate in elevation and distance from the river mouth. Only two of the 29 sites with five or more native species (32B and 35E) had three or four introduced fish species, whereas all others contained two or less introduced species (Table 8).

Introduced fish species richness ranged from zero to 11, with a mean species richness of 1.82 species (Table 11; Figure 4). Introduced fishes were collected at 61 of the 81 stream sampling reaches, with communities at 16 composed of strictly introduced fishes (Table 8). Introduced fish species were found at all sites upstream of reservoirs, and six of the seven locations with five or more introduced species were either upstream or immediately downstream of a large reservoir. The 33 sites with one or two introduced species were primarily represented by guppy or green swordtail and were found in closer proximity to the coast, and the 21 sites with three or four species often also included Mexican molly or Mozambique tilapia. Only one of the seven sites with five or more introduced species (42A) had the presence of any native fish species, which was represented by the sirajo goby (Table 8).

Fish species diversity averaged 0.84 among sites, ranging from 0 to 1.69 (Table 9), with higher values associated with coastal areas and at sites with relatively high native fish species richness. Sites with high native species richness generally showed greater evenness among species. The abundance of fishes at sites with relatively high introduced species richness or lower native species richness tended to be dominated by fewer species, skewing the evenness of the distribution and reducing species diversity.

Total fish community density among sampling sites and events varied greatly, ranging from about 200 fish/ha at site 42D to over 83,000 fish/ha at site 44A, with an overall mean of 9,640 fish/ha (Table 9; Figure 5). For each sampling event, community density was usually dominated by either native or introduced individuals. During 61 of the sampling events, native fish density was more than eight times greater than introduced fish density (Tables 10 and 11). Conversely, 27 of the sampling events yielded introduced fish densities more than eight times greater than native fish populations. Only 17 of the sampling events yielded introduced and native fish densities of similar magnitude, and those were almost all comprised of low densities for each. The sample of Río Guanajibo, 35G, during spring of 2006 was the only event to have fish densities of greater than 5,000 fish/ha for both native and introduced fish (Tables 10 and 11).

Total fish community biomass estimates for each sampling site and event also varied greatly, ranging from 0.3 kg/ha at site 42D to over 622.2 kg/ha at site 28D (Table 9; Figure 8), with an overall mean of 88.3 kg/ha. Similar to community density, community biomass was almost always dominated by biomass from either native or introduced fish. During 64 of the sampling events, native fish biomass estimates were more than 10 times greater than introduced fish biomass (Tables 10 and 11). Conversely, 21 of the sampling events yielded biomass estimates of introduced fish more than 15 times greater than that for native fish populations. Only 20 of the sampling events yielded introduced and native fish biomass of similar magnitude, and were almost entirely comprised of low biomass for each. The samples of Río Yauco during fall of 2006 (site 32B) and Río Piedras during spring of 2007 (site 46A) were the only sampling events to yield fish biomass greater than 50 kg/ha for both native and introduced fish (Tables 10 and 11).

Results of the eight sampling events yielding the highest density of fishes were dominated almost entirely by introduced fish, with six of the eight occurring upstream of reservoirs where native fish were not present. The density of native fishes from the two sites where native fishes were present (38E and 42A) represented less than one percent of the total fish density. On average, introduced fish density was twice as high as native fish density; however, the higher densities of introduced fish occurred at sites without native fishes present.

Native fish density was highest in eastern, southern, and western rivers in close proximity to coastal regions (Figure 6), where all sites with native fish density exceeding 10,000 fish/ha were free of introduced species, and 10 of 16 sites with native fish density greater than 5,000 fish/ha were free of introduced fish (Tables 10 and 11). Conversely, introduced fish density was much higher among northern sampling sites in closer proximity to mountain regions (Figure 7). Sixteen of the 20 sampling events with more than 10,000 introduced fish/ha were from northern rivers.

In contrast to community density estimates, the seven sampling events with the highest fish biomass estimate were dominated entirely by native fish, with four of the seven occurring where introduced fishes were not present. On average, native fish biomass estimates were 3.5 times as high as those for introduced fish biomass. Similar to the trend associated with native fish density, native fish biomass estimates were higher at sites in proximity to the coast (Figure 9). Higher introduced fish biomass estimates were in proximity to mountain regions (Figure 10); however, a majority of introduced fish biomass estimates were low (Table 11), even at some sites with relatively high density estimates. Only three sites yielded introduced fish biomass estimates of higher than 150 kg/ha (Table 11), owing to the presence of larger-bodied species, including channel catfish and cichlids at site 1A, channel catfish at site 31A, and largemouth bass and redbreast sunfish at site 42A (Table 8).

Total fish density estimates for individual species summed for all sites varied greatly, with a mean of 40,458 fish/ha and a range of 7.5 to 364,840 fish/ha (Table 7). The most abundant species was Mexican molly with a total density among all sites of 364,840 fish/ha, followed by mountain mullet with total species density exceeding 155,000 fish/ha (Table 7). Mexican molly was also the species with the highest abundance at each site where it was detected, with a mean density of 13,030 fish/ha among 28 sites, followed by convict cichlid, with an average of 12,113 fish/ha at 2 sites, 1C and 41D (Table 8). The two native fish species with the highest mean biomass per site were mountain mullet and sirajo goby, with 3,781 and 2,083 fish/ha, respectively (Table 7).

Total fish biomass estimates for individual species summed for all sites also varied greatly, with a mean of 364.4 kg/ha and a range of 0.03 to 3,289.1 kg/ha (Table 7). Five of the six species with the highest total biomass estimates were native species, with mountain mullet having the highest biomass (3,289.1 kg/ha), followed by bigmouth sleeper with 1,761.3 kg/ha

(Table 7). Mexican molly represented the introduced species with the highest total biomass estimate from all sites, with an average of 658.3 kg/ha. Convict cichlid was the species with the highest mean biomass at each site where it was detected with 93.4 kg /ha, followed by mountain mullet with a mean of 80.2 kg/ha (Table 7).

Amazon sailfin catfish was the species with the highest average weight, 442.7 g, whereas, the four Poeciliidae had the smallest average weights (Table 7). The four native species with the highest average individual weight were white mullet, burro grunt, gray snapper, and fat snook, and were rarely collected because they are more commonly associated with brackish water conditions.

In summary, native fish species richness, density, biomass and total species diversity index values were highest in association with coastal regions. Conversely, introduced species richness, density, and biomass were highest in proximity to mountain regions. Total fish density was lower for native species and higher for introduced species, whereas total fish biomass was higher for native species and lower for introduced species. Thus, a majority of native fish species were represented by a smaller number of more evenly distributed larger bodied fish, in proximity to coastal regions, whereas a majority of introduced fish species were represented by a larger number, dominated by few species of smaller bodied fish, in proximity to mountain regions.

Native Fish Species

River Goby.—The river goby was sampled at 54 stream sampling reaches (Table 8; Figures 11-13), with a mean density of 555.0 fish/ha, mean biomass of 9.2 kg/ha, and mean individual weight of 16.6 g (Table 7). River goby was the only native fish detected at sites 38B and 45B (Table 8). Of all species, river goby composed the highest density and biomass at four and five sites, respectively (Table 12), a majority of which had sand or very coarse sand as the dominant substrate. Over 600 fish/ha and more than 12.0 kg/ha of river goby occurred at 10 and nine sites, respectively, with six sites exhibiting both characteristics (Figures 11 and 12). The specialized pelvic fins of the river goby and sirajo goby enable them to ascend barriers that other native species were unable to navigate, and ascend to higher elevations (Watson 1996, 2000). The largest river goby that we sampled, at 303 mm TL and 309.4 g, was collected on June 15, 2005, in Río Maricao within the Río Guanajibo drainage, at site 35A, and the smallest, at 37 mm

TL and 0.5 g, was collected on November 10, 2006, at site 36A, in Río Yagüez. The highest abundance of juvenile river goby was sampled during the spring.

Sirajo Goby.—The sirajo goby was collected at 50 stream sampling reaches (Table 8; Figures 14-16); mean parameter estimates were 2,082.9 fish/ha density, 6.4 kg/ha biomass, and 3.1 g individual weight (Table 7). Of all native species, sirajo goby was sampled at the highest overall and mean elevation, gradient, and distance to river mouth, and in the smallest watersheds with the lowest road density (Table 13). Sirajo goby was the only native species detected at 10 sites, with seven of them occurring in the Río Manatí drainage (Table 8). Additionally, sirajo goby was the only fish species present at three sites, 3A, 37D and 42E. Of all fishes, sirajo goby had the highest density and biomass at 11 and eight sites, respectively (Table 12), most often in locations with relatively high mean water velocities and larger substrate materials. Over 4,000 fish/ha and more than 9.0 kg of fish/ha of sirajo goby occurred at four and 11 sites, respectively, with three sites exceeding both parameter levels (Figured 14 and 15). Sirajo gobies were generally found in higher abundance at sites with moderate to high elevations and steep gradients. The site with the highest density and biomass estimate of sirajo goby was 1E (Table 12), where sirajo goby of all sizes were detected in large numbers among the predominant substrate of large cobble. In contrast to river goby, the sirajo goby was generally not found at sites with abundant fine substrate, and not often in coastal river reaches. The largest sirajo goby collected during our study was 188 mm TL and 37.9 g and was collected on June 14, 2006, in Río Cialito within the Río Manatí drainage, at site 42G. A large number of juveniles of 18 mm TL and 0.5 g were collected on March 15 and 16, 2006, at sites 21A and 21B, respectively, on Río Cañas in the Río Matilde drainage.

Juvenile sirajo gobies were collected in highest abundance during the fall and spring. We observed a large school of juvenile sirajo gobies (or seti) exceeding 1,000 individuals ascending the face of a 30-m waterfall, using their modified pelvic fins for suction, on Río Cañas in the Río Matilde drainage on November 20, 2006, between sites 28A and 28B.

Mountain Mullet.—The mountain mullet was collected at 41 stream sample reaches (Table 8; Figures 17-19), with means of 3,781.5 fish/ha density, 80.2 kg/ha biomass, and 21.2 g individual weight (Table 7). River goby was also collected at all sites where mountain mullet were collected (Table 8). Of all fish species, mountain mullet yielded the highest density and biomass estimates at 26 and 23 sites, respectively (Table 12). Over 3,000 fish/ha and more than

75.0 kg/ha of mountain mullet occurred at nine sites each, with four sites exceeding both parameter trends (Figures 17 and 18). Mountain mullet was generally found within or at the downstream end of riffles in sites of low elevation and low gradient; however, several large individuals occurred in a high gradient site (11A) on Río Blanco, near the southern boundary of the El Yunque National Forest. Large schools of large individuals were also observed within pools downstream of high, unscalable waterfalls at several locations in Puerto Rico, including the 30-m waterfall between sites 28A and 28B on Río Cañas in the Río Matilde drainage. The highest abundance of large mountain mullet was consistently collected within the same river, at site 28C, for all three sampling events that occurred at this site. The largest individual mountain mullet we sampled was 345 mm TL and 446.9 g, and was collected on June 21, 2005, at this site, and the smallest, 30 mm TL and 0.3 g, was collected on November 15, 2006, at site 31A, in Río Guayanilla.

Juvenile mountain mullet (<100 mm TL) were collected in highest abundance during the spring. We also observed them ascending the face of a 2-m low-head dam on Río Toro Negro within the Río Manatí drainage, approximately 1-km downstream of site 42H on June 6, 2006, by jumping into the air from the downstream pool and landing in the upstream pool.

Bigmouth Sleeper.—The bigmouth sleeper was sampled at 35 stream reaches (Table 8; Figures 20-22); its mean parameters were 756.6 fish/ha density, 50.3 kg/ha biomass, and 66.5 g individual weight (Table 7). River gobies were collected at all sites where bigmouth sleeper was collected, and mountain mullet was collected at all but two of these sites, 14A and 15A (Table 8). Of all fishes, bigmouth sleeper had the highest density and biomass estimate at one (site 7B) and nine sites, respectively (Table 12). Over 1,000 fish/ha and more than 45.0 kg/ha of bigmouth sleeper occurred at five sites and seven sites, respectively, with four sites exceeding both measures of abundance (Figures 20 and 21). Bigmouth sleeper was generally found in riffles with medium-sized substrate and under rock ledges and undercut banks at sites at low elevations and low gradients. The largest individual bigmouth sleeper we sampled was 441 mm TL and 808.3 g and was collected on March 24, 2006, in Río Nueve Pasos within Río Guanajibo drainage, at site 35D, and the smallest, 37 mm TL and 0.5 g, was collected on November 15, 2006, at site 31A, in Río Guayanilla. The highest abundance of juvenile bigmouth sleeper was sampled during spring.

American Eel.—American eel was collected at 32 stream sampling reaches (Table 8; Figures 23-25), with a mean density of 62.0 fish/ha, mean biomass of 27.4 kg/ha, and mean individual weight of 442.7 g (Table 7). River goby, bigmouth sleeper, and mountain mullet were collected at all but four sites (14A, 15A, 33A and 34A) where American eel was collected (Table 8). Of all species, American eel yielded the highest biomass estimate at five sites, but never produced the highest density estimate (Table 12). Conversely, American eel was the lowest in density and biomass at one (15A) and 10 sites, respectively, of all fishes (Table 12). Over 1,000 fish/ha and more than 24.0 kg/ha of American eel occurred at four sites and 11 sites, respectively, with four sites exceeding both abundances (Figures 23 and 24). American eel was generally found associated with overhanging vegetation and rootwads as cover along stream banks in sites with low elevations and low gradients. The largest individual American eel we sampled was 885 mm TL and 1,299.4 g and was collected on June 17, 2005, in Río Cañas in the Río Matilde drainage, at site 28D, and the smallest, 87 mm TL and 1.0 g, was collected on March 12, 2007, at site 6A, in Río Juan Martín. The highest abundance of juvenile American eel was detected in spring samples, especially in the Sabana, Juan Martín, and Fajardo river drainages.

Smallscaled Spinycheek Sleeper.—Smallscaled spinycheek sleeper was the least ubiquitous of the predominant native freshwater fish species and was collected at 25 stream sampling reaches (Table 8; Figures 26-28). Its parameter mean values were 464.2 fish/ha density, 6.7 kg/ha biomass, and 14.4 g individual weight (Table 7). River goby and bigmouth sleeper were collected at all but one site (34A) where smallscaled spinycheek sleeper were sampled, whereas mountain mullet and American eel were found at all but three sites each (Table 8). Of all native species, smallscaled spinycheek sleeper was the most restricted in elevation, gradient, and distance to river mouth, and had the lowest mean values of these variables among all sites where it was sampled (Table 13). Of all fishes, smallscaled spinycheek sleeper yielded the highest density and biomass estimates at two (35H and 38 D) and four sites (4A, 34A, 38C and 38 D), respectively (Table 12). However, smallscaled spinycheek sleeper was lowest in density and biomass of all fish species detected at five sites each (Table 12). Over 800 fish/ha and more than 6.0 kg/ha of smallscaled spinycheek sleeper occurred at three sites and four sites, respectively, with three sites exhibiting both characteristics (Figures 26 and 27). Smallscaled spinycheek sleeper was generally found associated with rootwads and undercut banks as cover in areas of low flow in coastal plain sites. The largest individual smallscaled spinycheek sleeper that we sampled was 197 mm TL and 88.0 g and was collected on November 3, 2006, in Quebrada Salada in the Río Culebrinas drainage at site 38C, and the smallest, 20 mm TL and 0.1 g, was collected on March 10, 2007, at site 16A in Río Maunabo.

Macroinvertebrates

Eleven species of freshwater shrimp, three species of crab, and one introduced species of crayfish were collected from the 81 stream sampling reaches in association with fish sampling (Table 14). Shrimp were found at 75 of the sites, crabs at 58, and the crayfish at one (Table 15; Figures 29 and 30). Site 46B was the only site where no decapods were found.

Carrot nose river shrimp *Xiphocaris elongata*, found at 64 sites, was the most ubiquitous species, followed by bigarm river shrimp *Macrobrachium faustinum* at 58 sites, basket shrimp *Atya innocous* at 48 sites, roughback shrimp *Atya scabra* at 44 sites, bigclaw river shrimp *Macrobrachium carcinus* and cascade river shrimp *Macrobrachium heterochirus* at 34 sites each, tiny basket shrimp *Micratya poeyi* at 32 sites, spinning shrimp *Atya lanipes* at 26 sites, striped river shrimp *Macrobrachium crenulatum* at 22 sites, smooth potimirim *Potimirim glabra* at 18 sites, and cinnamon river shrimp *Macrobrachium acanthurus* at 10 sites (Table 15).

Eighteen of the 75 sites with shrimp yielded seven or more species, whereas, a majority, 42 sites, contained four to six species (Figure 29). Most sites produced a moderate number of species, with only four sites, 1A, 41A, 41B and 45A, where one species of shrimp was detected, and three sites, 10A, 35B, and 35H with nine collected species (Table 15).

Four of the six sites where shrimp were not detected were upstream of large reservoirs, and one of the remaining two sites was also absent of native fish species indicating a limiting influence at this site (43B). The one remaining site that was void of shrimp contained sirajo goby, along with several introduced fish species, including many large redbreast sunfish and largemouth bass that may have prevented the establishment of shrimp species at this site (42A). Shrimp were detected at six other sites situated upstream of large reservoirs, with a total of five species detected among five sites upstream of Lago Dos Bocas in the Río Arecibo drainage, and one species, carrot nose river shrimp, detected at one site (1A) upstream of Lago Carraizo in the Río Grande de Loíza drainage.

The Puerto Rican freshwater crab *Epilobocera sinuatifrons* was sampled at 57 sites (Table 14; Figure 30). It was found at all but one of the 10 sites located upstream of large reservoirs. Blue crab *Callinectes sapidus* and wetland crab *Armases roberti* are commonly associated with brackish water, and were collected in river reaches along the coastal plain. Blue crab and wetland crab were found at only one site each, 16A and 35H, respectively (Table 14). The Australian red-claw crayfish *Cherax quadricarinatus* was only found at site 1E, within the Río Grande de Loíza drainage.

Instream Habitat Characteristics

The average mean width among all 81 sites was 5.92 m, and mean width ranged from 1.58 m to 15.08 m among sites (Table 5). Sampling reach area averaged 836.55 m^2 and ranged from 237.15 m^2 to 2,262.00 m^2. Average mean depth was 15.10 cm, ranging from 2.43 cm to 47.60 cm. Mean column velocity averaged 0.178 m/s and ranged from 0.014 m/s to 1.031 m/s. Mean bank angle was 135.4^o and ranged from 92.3^o to 171.3^o. Percent cover varied among sites from 16% to 98% with an average of 54%. The most frequently encountered substrate material was small cobble, with an average diameter of about 0.1 m.

Water Quality

Among all 81 sampling sites, water quality parameter means (and ranges) were 3.65 mg/L (0 to 25.8mg/L) nitrate concentration (mg/L NO_3^-), 0.076 mg/L (0 to 0.910 mg/L) nitrite concentration (mg/L NO_2^-), 0.08 mg/L (0 to 0.60 mg/L) ammonia concentration (mg/L NH_3), 0.65 mg/L (0 to 2.75 mg/L) phosphorus concentration (mg/L PO_4), 6.6 FAU (0 to 52 FAU) turbidity, 130 mg/L (17 to 277 mg/L) alkalinity (mg/L $CaCO_3$), 135 mg/L (14 to 280 mg/L) hardness (mg/L $CaCO_3$), and 8.29 (7.05 to 9.21) pH. Water temperature during sampling averaged 24.32 ºC (20.27 to 30.20 ºC), conductivity averaged 322 µS/cm (59 to 780 µS/cm), salinity concentration averaged 0.15 ppt (0.03 to 0.38 ppt), total dissolved solids (TDS) averaged 0.209 g/L (0.038 to 0.507 g/L), and dissolved oxygen averaged 8.19 mg/L (4.12 to 11.11 mg/L; Table 16).

Land Cover and Ownership

Within the upstream 30-m and 100-m buffers of the stream, as well as within the entire upstream watershed, forest was the most predominant land cover, followed by agriculture, shrub and woodland, then urban when averaged among all sites (Table 17). Within the 100-m buffer, forest comprised 56.9% of the land cover for all sites combined and decreased to 43.9% within the 30-m buffer, while agriculture increased from 25.3% at the 100-m level to 37.4% at the 30-m level, indicating that in upstream regions the immediate riparian zone was used for agriculture. Slope of the riparian zone is a likely factor influencing agricultural land use. At the watershed level, the percent of agriculture land cover was 40.1% and was similar to that of forest (42.1%).

A majority of sites with high proportions of agriculture land cover at all three scales of analysis (30-m riparian, 100-m riparian, and watershed) were in northern and northwestern river drainages. Conversely, a majority of sites with higher forest land cover percentages were located in the northeast, downstream of the El Yunque National Forest. Mean land cover proportions of urban (3.5%, 4.0% and 4.2%) and shrub and woodland (14.8%, 13.6% and 13.4%) were fairly constant among the 30-m riparian buffer, 100-m riparian buffer and entire watershed levels of analysis; however, shrub and woodland decreased slightly, whereas urban increased slightly as more area was incorporated into the analysis.

The average percentage of ownership for 100-m upstream riparian buffer and the entire watershed for all sites were almost identical, with private ownership representing 88.5% of the riparian zone and 88.0% of the watershed, 11.2% public riparian ownership and 11.9% public watershed ownership, and utility and NGO ownership covering 0.2% for both riparian and watershed scales (Table 18). A majority of sites had 100% of upstream land privately owned, and the watersheds of only two sites (3A and 42F) were completely owned by public entities.

Correlation Among Environmental Variables

The degree of correlation among the 43 instream habitat and watershed and riparian variables that we measured and delineated was significant for those variables that were of similar ecological function (Table 4). We were able to reduce the number of environmental variables to include in hierarchical model development from 43 to 13 primary representative variables without notable loss of information. Primary instream habitat variables described instream geomorphology (width and cover) and the physicochemical properties of water (temperature, conductivity, nitrate concentration, and turbidity). Primary watershed and riparian variables represented position of the sampling site on the watershed (watershed area, river km), occurrence of human structures (downstream reservoir, road density), and land cover and ownership (watershed forest, 30-m riparian forest, watershed public ownership).

Hierarchical Models

The physical, independent variables that most parsimoniously explained variance in each of the 11 fish community parameters among the 81 sites were (1) river-kilometer of the sampling site, (2) the presence of a large downstream reservoir (and dam), (3) area of the watershed above the site, and (4) density of roads in the upstream watershed (Tables 19-21).

River km of the sample site, a measure of distance from the Atlantic Ocean, was included in nine of the 11 most parsimonious hierarchical regression models, and was negatively correlated to total community biomass, community diversity, and each of the native species parameters, indicating a decrease in community biomass and diversity, and native species richness, density, biomass and diversity as rivers proceeded upstream. Conversely, river km was positively correlated with each of the introduced fish variables, indicating an increase in introduced species richness, density and biomass at greater distances from the river mouth (Tables 19-21).

The presence of a large downstream reservoir was included in eight of the models, and similar to river km, the presence of a large downstream reservoir was negatively correlated with each of the native fish variables, and positively correlated with each of the introduced fish variables, as well as the total density of the community. With the absence of native fish species above reservoirs and the highest abundances of introduced fish above reservoirs, this variable was highly significant in explaining the variance in these biotic parameters (Tables 19-21).

The area of the upstream watershed at each site was positively correlated in models explaining seven biotic variables, including community and native species richness, biomass and diversity, and introduced biomass, and was not negatively correlated to any variable. Therefore, the number of species, biomass and diversity at each site generally increased with an increase in watershed area.

Road density, considered an indication of human population density, was positively correlated in models explaining variance in five biotic parameters, including community species richness and density, and each of the introduced variables, indicating that as the human population density increased upstream of the sites, higher abundances of introduced fish species richness, density and biomass were found. Conversely, road density was negatively correlated to native biomass, indicating lower native biomass in areas downstream of areas with higher human population densities (Tables 19-21).

In addition to the most prevalent variables contained within the models, percent cover was positively related in the density models for the whole community of fish and the native fish (Tables 19 and 20). Stream width, water temperature and nitrate concentration were also positively related to native fish density (Table 20).

The hierarchical models we developed to explain trends in native fish variables from only the 65 sites where native fish were collected produced similar models to those from all sites (Table 22). The presence of a downstream reservoir no longer contributed to the models, as that independent variable was excluded from the analysis since no native fish were found above large reservoirs. This reduced the K value (number of parameters) for most models by one (Table 22).

Discussion

Previous research has demonstrated the influence of dams on fish community distribution in Puerto Rico (Holmquist et al. 1998; Greathouse et al. 2006), but the effect of other variables on fish distribution across the island has received little attention. Our results demonstrate and strengthen existing evidence on the influence of dams; however, we also examined and quantified insightful relationships on the effects of other physical, chemical and geographic elements on fish community parameters and on the abundance of individual fish populations.

Two of the four most prevalent explanatory variables included in the most parsimonious hierarchical models, river km and watershed area, are static measures and could be interpreted as factors inherently affecting the longitudinal distribution of fish communities of Puerto Rico; whereas, the other two most prevalent variables, presence or absence of a downstream reservoir and dam, and density of roads in the upstream watershed, are anthropogenic and suggest strong human influences. All four explanatory variables of fish community parameters emphasize the landscape-level influence on stream ecosystems. While stream ecologists have recognized the importance of landscape influences conceptually for some time (Hynes 1975; Vannote et al.

1980), only recently has it been quantitatively described as we have done here (e.g., Roth et al. 1996). Puerto Rico has experienced rapid development over the last 60 years, and the human population density represents one of the highest in the world (Hunter and Arbona 1995). Human alteration of stream watersheds appears to be closely tied to fish communities in those systems. Our research suggests that strategic planning for stream fish and ecosystem management should include considerations at the watershed scale.

Similar to previous research (Holmquist et al. 1998; Greathouse et al. 2006), no native fish species were found upstream of any large dam and reservoir in our study (Figure 3); however, we found *Macrobrachium faustinum*, *Xiphocaris elongata*, the three *Atya* shrimp species, and the Puerto Rican freshwater crab *Epilobocera sinuatifrons* upstream of several reservoirs, although no single site upstream of a reservoir contained all of these crustacean taxa (Table 15). Contrary to our findings for fish distribution and abundance, the abundance of freshwater shrimp in streams is directly related to flow (Scatena and Johnson 2001). We collected no native fish on Río Camuy (site 40A), situated upstream of a large subterranean river reach. However, we found carrot nose river shrimp and all three *Atya* shrimp species at this site, suggesting that these shrimp species are able to navigate the underground cave system, or they were introduced, like the three Poeciliidae species of fish found at that location. The remaining four sites where we did not find native fish, one of which was also absent of shrimp (site 43B), should be further explored for downstream barriers to migration or local stream impacts to determine the cause of native species extirpation.

The sites where we found all six native freshwater fish species occurring sympatrically were at low elevations, with short distances to the river mouth, and large watershed areas (Table 13). The amphidromous life cycles of these fishes indicate that they all begin their lives as larvae in saltwater and migrate upstream from the mouth of the river, explaining the relatively higher density and biomass of native fishes in proximity to coastal areas (Table 10). Conversely, not all of these native fish were present in our sampling at sites with higher elevations and greater distances from the river mouth where watershed area is at its lowest (Table 13), explaining the lower density and biomass of native fish species at these locations (Table 10). Only the two Gobiidae species, with specialized pelvic fins, were found among the 16 sites with elevations over 210 m and no large downstream reservoirs. They were also the only native fishes found among the seven sites over 57 km from the river mouth without large downstream reservoirs (Table 13), demonstrating that factors in addition to the occurrence of artificial dams determine the distribution of native fishes.

We sampled multiple sites within six river basins that represent the longitudinal stream gradient from headwaters to the river mouth. In all of those six basins, fish species richness remained constant or decreased as sites progressed upstream, including those that were sampled during multiple seasons (Table 10; Figure 3). Using Río Cañas as an example, where elevation decreased 190 m over a 10.5-km reach between sites 28D and 28A, all six native species were collected during each season at the most downstream site. The next two upstream sites (28C and 28B) contained five of the native species, with the loss of smallscaled spinycheek sleeper. Finally, only the two Gobiidae species were collected at the most upstream site (28A). In the Río Guanajibo drainage, where elevation decreased 160 m over a 9.8-km distance between sites 35F and 35C, we detected an almost identical trend as that detected in Río Cañas for all seasons, with six native species collected at site 35F, the most downstream site of the group. Smallscaled spinycheek sleepers and American eel were absent from mid-elevation sites (35E and 35D), and only the two Gobiidae species remained at the most upstream site of the group (35C). Similar patterns are reflected in the mean and ranges of elevation, river km, and watershed area for the sites where each native species was collected (Table 13).

Geomorphic factors that most likely contribute to the reduction in native fish species richness and abundance as the sites increase in distance from the river mouth and decrease in watershed area are sharp increases in gradient, decreases or loss of suitable habitat, and inconsistent water supply. Similar to the effect of dams, sharp changes in gradient can create waterfalls and spill-pool sequences that are difficult for fish to navigate. Those species more suited to navigation of these natural gradients were more frequently sampled upstream. We anecdotally observed several waterfalls and steep gradient river runs blocking mountain mullet upstream migration. Other observed barriers, including some culverts and road crossings, functioned similarly, limiting the passage, distribution, and abundance of native fishes.

Habitat and cover associations at finer scales were also probably reflected in our model results explaining the distribution of native fish species. The diversity of habitat and substrate was greatest at lower elevations, where riffles, runs, and pools, flowing over sand, gravel, cobble, and boulders dominated stream channels. At sites with higher elevation and gradient, habitat and substrate generally consisted of spill-pools and cascades pouring over cobble and boulders. American eel and smallscaled spinycheek sleeper were most commonly found in reaches with overhanging vegetation and among undercut banks in areas of low water velocity, which are not commonly found at higher elevations. Conversely, sirajo gobies are algal scrapers (Watson 2000), and are most commonly associated with larger substrates, explaining their presence in higher gradient locations that offer large surface areas for algae and biofilm growth. Sirajo gobies also have modified pelvic fins that function as suction discs, allowing them greatest access to habitat at higher elevations and gradients, where they are released from predation pressure by other predatory native fish (Fraser et al. 1995). River gobies are often found in sandy habitat, where they burrow under the sand to avoid predation. Similar to sirajo gobies, they also have suction discs, enabling them access to higher gradient streams where sand is not as prevalent, explaining this fish's presence at most sampling sites, and its generalist association with habitat.

Another important contributor to Puerto Rico native fish distribution and the decrease in native species richness and abundance as river km increases and watershed area decreases is a consistent supply of water. Several rivers, especially in the southeastern region of the island, were completely dry, including Río Jueyes, where others, including Río Coama, consisted of disconnected pools of trapped water (Figure 1). Without a continuous upstream supply of water, amphidromous fish are unable to persist in these rivers. Similarly, streams and rivers at high altitudes have reduced catchments to capture rain, and many rivers undergo water extraction for human uses, limiting the consistency of water levels (Erdman 1984). During the dry season, river reaches at high altitudes may desiccate or reduce to a small or intermittent channel, limiting habitat and support functions for fish and invertebrate. We found exceptions to this conclusion, however, where we sampled reaches with relatively small watersheds that yielded many native freshwater fishes; these were sites downstream of El Yunque, a rainforest receiving high volumes of annual rainfall (García-Martinó et al. 1996). Overall, our results indicate that stream reaches with few downstream gradient limitations, abundant and diverse suitable habitats, and a consistent supply of water, generally associated with relatively larger watershed areas, tend to support a greater diversity of fish with high abundance.

Mountain mullet was the most densely populated native fish species and contributed the highest proportion of biomass at each site where it was found (Table 7). Bigmouth sleeper and American eel also contributed a large proportion of biomass at each site where they occurred, explaining the higher biomass and density estimates at sites in proximity to the river mouth. The high abundance of these three native species at select sites has implications that may facilitate native sport fisheries in stream habitats. The two goby species were two of the three native fishes with the smallest average individual weight and contributed relatively little biomass at the sites where they were present (Table 7), further explaining the lower density and biomass of native fish at higher elevations, where the few native species that occurred were small-bodied.

Similar to models for native fish community variables, the most explanatory hierarchical models for introduced fish species parameters included the presence or absence of a downstream reservoir and the distance to the river mouth; however, their relationship is opposite that of native fishes, as introduced fish were more ubiquitous upstream of reservoirs at greater distances from the river mouth. All of the most parsimonious models for introduced fish parameters included road density as an explanatory factor, indicating that introduced fish were more likely to be in areas downstream of higher density human populations. This is in agreement with the finding by Holmquist et al. (1998) where the highest abundance of introduced fish was found upstream of dams, and the fewest in streams without dams. With a complete void of native fish species, and the purposeful introduction of non-native fish species in reservoirs (Neal et al. 2004), these confirming relationships strengthen the validity of our models and their ability to explain fish distribution and abundance patterns.

The fish communities of Puerto Rico are comprised of two complementary and diametric groups of fish. We found stream reaches usually dominated by either native or introduced species, with only a few sites at intermediate elevations and others downstream of reservoirs that supported similarly represented native and introduced fish components. We demonstrated that native and introduced fish community components exhibit opposing trends, and when modeled as a single community, the two diametric groups represent conflicting relationships that offset each other, rendering models that explain little ecologically. The most obvious trend from these models is the occurrence of greater total fish species richness, biomass and diversity at sites with larger watershed areas, demonstrating greater occurrences of native fishes in proximity to river mouths and greater abundances of introduced fishes in proximity to the reservoir. Thus, we emphasize the relevance of our model sets for native and introduced components of the fish community as most ecologically informative.

No estuarine environments were sampled during our study, limiting the ability to extrapolate our findings to claim that native fish occurrences would be greatest at the river mouth. We can only interpret our data within the limits at which they were collected. Further, while our results suggest that native fish species do not occur upstream of large dams and reservoirs, as none did in our sampling effort, exceptions may exist, which is the case for the bigmouth sleeper population that persists upstream of Carite Reservoir (Bacheler et al. 2004).

Ecological and Management Implications

Our findings confirm some findings of previous investigations on the ecology of Puerto Rico stream fishes [e.g., Holmquist et al. (1998) on dam effects], but they also reveal new information on factors influencing fish community structure (e.g., watershed attributes). The presentation of our results in map form reveals trends in fish occurrence that were heretofore undetected. We identified stream sites where native fishes may be impacted by introduced species, such as tilapia species or the Australian red claw crayfish, both known to exert negative impacts on native fauna where they are introduced (Fuller et al. 1999; Lodge et al. 2000). And we collected one new introduced species with an established population that was not previously known to exist on the island (the Chinese algae-eater).

Our sampling results and analyses represent the most comprehensive increase in knowledge of Puerto Rico stream fish distributions and ecology, since the work of Donald Erdman in the 1960–80s, and yet, it leaves many topics on the subject unaddressed. Our hierarchical models were exploratory by design, and we included a suite of independent variables to identify general relationships among fish community parameters and environmental influences. While we present multivariable regression models with exact coefficients and intercepts, the models are not meant to imply direct cause-and-effect of the measured variables on fish, but rather to describe ecological patterns for further investigation.

Our findings and data compilation may serve as the basis for stream fisheries and ecosystem management. Knowledge of the current distribution and abundance of fish populations and their relationship with their environment is critical for management planning and to discern trends over time. Our results may guide specific protection of unique stream resources or assist commonwealth and federal agency personnel in evaluating impacts of specific construction project proposals that may affect stream resources and associated permitting and mitigation decisions. Freshwater is a limited resource in Puerto Rico, and our data on stream fish and their habitats can be applied to water impoundment, withdrawal, and flow regulation decisions. The information that we provide on the abundance and distribution of stream sport fishes may enhance the ability of agencies to further develop the potential of these sport fisheries. Knowing where and at what density and biomass introduced fishes occur can also direct effort toward limiting their spread or impact on native fauna. Finally, our intention is that these results become the initiation of a stream fish data base that will be useful to a number of agencies, educational institutions, private entities, and the public to manage, conserve, and appreciate the freshwater fish resources of Puerto Rico.

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Table 1. Site number, drainage basin, river, municipality, location, number of closest route, and GPS coordinates of 81 freshwater fish sampling sites in Puerto Rico. Site numbers in parentheses correspond to those in Chapter 1 for Río Matilde and Río Guanajibo drainage basins.

Site number	Drainage basin	River name	Municipality	Location	Route number	Latitude (N)	Longitude (W)
1A	Río Grande de Loíza	Río Cagüitas	Aguas Buenas	1.5 km S of Aguas Buenas	794	18° 14' 38.90"	66° 06' 18.79"
1B	Río Grande de Loíza	Tributary to Río Loíza	San Lorenzo	0.7 km E of San Lorenzo	916	18° 11' 16.15"	65° 57' 31.75"
1C	Río Grande de Loíza	Río Cañas	Caguas/San Juan	5.1 km NNE of Bairoa	175	18° 17' 50.42"	66° 02' 54.13"
1D	Río Grande de Loíza	Río Canovanillas	Canóvanas/Carolina	3.8 km SSW of Campo Rico	185	18° 18' 18.54"	65° 54' 36.94"
1E	Río Grande de Loíza	Río Canóvanas	Canóvanas	3.8 km SSW of Campo Rico	185	18° 19' 00.59"	65° 53' 18.46"
2A	Río Herrera	Río Herrera	Río Grande	3.2 km E of Campo Rico	958	18° 20' 21.70"	65° 52' 03.29"
3A	Río Espíritu Santo	Río Espíritu Santo	Río Grande	5.8 km SSE of Bartolo	186	18° 18' 43.63"	65° 49' 20.14"
4A	Río Mameyes	Quebrada Tabonuco	Río Grande/Luquillo	1.4 km S of Palmer	191	18° 21' 35.35"	65° 46' 08.80"
4B	Río Mameyes	Río Mameyes	Río Grande/Luquillo	0.6 km SE of Palmer	191	18° 21' 58.14"	65° 46' 12.11"
5A	Río Sabana	Río Sabana	Luquillo	1.9 km NW of Ramos	983	18° 21' 02.27"	65° 43' 32.23"
5B	Río Sabana	Río Pitahaya	Luquillo	1.0 km N of Ramos	983	18° 20' 52.30"	65° 42' 34.38"
6A	Río Juan Martín	Río Juan Martín	Luquillo	3.1 km ENE of Ramos	940	18° 21' 01.73"	65° 41' 09.20"
7A	Río Fajardo	Quebrada Juan Diego	Fajardo	5.2 km NW of Duque	976	18° 16' 35.44"	65° 42' 59.29"
7B	Río Fajardo	Quebrada Rincón	Fajardo/Ceiba	4.6 km NW of Aguas Claras	977	18° 16' 54.59"	65° 41' 23.86"
10A	Río Santiago	Quebrada Grande	Naguabo	0.3 km S of Duque	970	18° 14' 06.18"	65° 44' 35.20"
11A	Río Blanco	Tributary to Río Blanco	Naguabo	3.7 km N of Río Blanco	191	18° 14' 42.65"	65° 47' 59.28"
13A	Río Humacao	Río Humacao	Las Piedras	2.9 km SSE of Las Piedras	9921	18° 09' 08.42"	65° 52' 02.06"
14A	Río Guayanés	Río Guayanés	Yabucoa	1.5 km E of Raso Sanchez	182	18° 03' 23.98"	65° 53' 58.78"
15A	Caño de Santiago	Caño de Santiago	Yabucoa	0.7 km NNE of Yabucoa	901	18° 03' 10.73"	65° 52' 33.82"
16A	Río Maunabo	Río Maunabo	Maunabo	0.5 km SW of Maunabo	3	18° 00' 18.61"	65° 54' 16.34"
19A	Río Salinas	Río Majada	Salinas	2.9 km S of La Plena	712	18° 00' 56.56"	66° 12' 27.50"
22A	Río Descalabrado	Río Descalabrado	Coamo	4.0 km N of Los Llanos	553	18° 05' 30.23"	66° 24' 24.77"
22B	Río Descalabrado	Río Descalabrado	Coamo/Juana Díaz	1.8 km WSW of Los Llanos	14	18° 03' 00.61"	66° 25' 29.39"
23A	Río Cañas	Río Cañas	Juana Díaz	1.2 km W of Río Cañas Abajo	14	18° 02' 34.58"	66° 27' 25.02"
28A (C1)	Río Matilde	Río Cañas	Ponce	5.6 km NNW of Ponce	123	18° 05' 10.25"	66° 39' 22.61"
28B (C2)	Río Matilde	Río Cañas	Ponce	5.0 km NNW of Ponce	123	18° 05' 00.49"	66° 39' 19.22"
28C (C3)	Río Matilde	Río Cañas	Ponce	3.1 km NW of Ponce	501	18° 02' 43.94"	66° 38' 41.64"
28D (C4)	Río Matilde	Río Cañas	Ponce	2.0 km NW of Ponce	123	18° 01' 29.14"	66° 38' 24.54"
28E	Río Matilde	Río Pastillo	Ponce	0.3 km W of Pastillo	502	18° 02' 11.33"	66° 39' 46.19"

Table 1 continued.

Site number	Drainage basin	River name	Municipality	Location	Route number	Latitude (N)	Longitude (W)
29A	Río Tallaboa	Río Tallaboa	Peñuelas	0.4 km N of Tallaboa Alta	132	18° 03' 12.96"	66° 42' 15.88"
30A	Río Macaná	Río Macaná	Peñuelas/Guayanilla	2.5 km SW of Santo Domingo	382	18° 03' 02.84"	66° 46' 00.30"
31A	Río Guayanilla	Río Guayanilla	Guayanilla	1.3 km NW of Guayanilla	127	18° 01' 54.30"	66° 47' 55.75"
32A	Río Yauco	Río Yauco	Yauco	8.4 km N of Yauco	128	18° 06' 33.44"	66° 52' 31.84"
32B	Río Yauco	Río Yauco	Yauco	3.0 km N of Yauco	128	18° 03' 41.22"	66° 51' 30.20"
32C	Río Yauco	Río Yauco	Yauco	2.3 km NNE of Yauco	372	18° 03' 08.75"	66° 51' 02.92"
33A	Río Loco	Río Loco	Yauco	1.9 km E of Lluveras	368	18° 02' 09.89"	66° 53' 15.40"
34A	Río Cartagena	Quebrada los Llanos	Cabo Rojo/Lajas	2.0 km E of Betances	101	18° 01' 44.72"	67° 06' 51.30"
35A (G1)	Río Guanajibo	Río Maricao	Maricao	0.3 km S of Maricao	410	18° 10' 36.44"	66° 58' 46.78"
35B (G2)	Río Guanajibo	Río Rosario	San Germán/Mayagüez	4.5 km SW of Rosario	345	18° 09' 26.93"	67° 05' 07.62"
35C (G3)	Río Guanajibo	Río Nueve Pasos	San Germán	2.9 km ESE of Rosario	119	18° 08' 42.04"	67° 01' 53.51"
35D (G4)	Río Guanajibo	Río Nueve Pasos	San Germán	1.3 km SE of Rosario	348	18° 08' 54.71"	67° 03' 42.44"
35E (G5)	Río Guanajibo	Río Duey	San Germán	1.5 km SE of Rosario	330	18° 08' 14.17"	67° 04' 16.61"
35F (G6)	Río Guanajibo	Río Duey	San Germán	2.0 km SSE of Rosario	330	18° 07' 36.52"	67° 04' 22.98"
35G (G7)	Río Guanajibo	Río Hoconuco	San Germán	2.6 km SSE of Rosario	358	18° 07' 04.12"	67° 03' 45.43"
35H (G8)	Río Guanajibo	Río Rosario	Hormigueros	1.5 km SE of Hormigueros	319	18° 07' 32.63"	67° 07' 23.27"
36A	Río Yagüez	Río Yagüez	Mayagüez	3.1 km E of Mayagüez	106	18° 12' 35.21"	67° 06' 53.82"
37A	Río Añasco	Río Blanco	Lares	5.0 km S of Lares	431	18° 14' 54.24"	66° 53' 13.96"
37B	Río Añasco	Río Prieto	Lares	5.1 km S of Lares	431	18° 14' 50.96"	66° 53' 27.56"
37C	Río Añasco	Tributary to Río Añasco	Las Marías/San Sebastián	5.7 km SE of Lares	124	18° 15' 16.78"	66° 54' 59.54"
37D	Río Añasco	Quebrada Fría	Las Marías	1.4 km SE of Las Marías	124	18° 14' 37.14"	66° 58' 40.69"
37E	Río Añasco	Río Casey	Las Marías	6.6 km WSW of Las Marías	397	18° 14' 16.87"	67° 02' 45.71"
37F	Río Añasco	Río Cañas	Mayagüez	8.5 km ENE of Mayagüez	354	18° 13' 31.12"	67° 04' 00.44"
38A	Río Culebrinas	Río Juncal	Lares	1.4 km E of Lares	436	18° 17' 23.82"	66° 53' 41.60"
38B	Río Culebrinas	Río Guatemala	San Sebastián	5.8 km NE of San Sebastián	447	18° 22' 06.24"	66° 57' 10.12"
38C	Río Culebrinas	Quebrada Salada	San Sebastián	3.7 km NW of San Sebastián	111	18° 21' 06.95"	67° 01' 32.23"
38D	Río Culebrinas	Quebrada Dulce	Moca	1.9 km SE of Moca	125	18° 22' 46.85"	67° 06' 15.34"
38E	Río Culebrinas	Tributary to Río Culebrinas	Moca	0.5 km E of Moca	110	18° 23' 35.56"	67° 06' 32.54"
40A	Río Camuy	Río Camuy	Utuado	6.3 km E of Lares	111	18° 17' 50.39"	66° 49' 22.87"
41A	Río Grande de Arecibo	Río Naranjito	Utuado/Jayuya	7.3 km N of Jayuya	613	18° 17' 02.80"	66° 35' 28.61"
41B	Río Grande de Arecibo	Río Limón	Utuado/Jayuya	6.9 km N of Jayuya	613	18° 16' 53.04"	66° 35' 49.02"

Table 1 continued.

Site number	Drainage basin	River name	Municipality	Location	Route number	Latitude (N)	Longitude (W)
41C	Río Grande de Arecibo	Río La Venta	Utuado	7.8 km SW of Florida	141	18° 17' 48.34"	66° 35' 18.42"
41D	Río Grande de Arecibo	Río Yunes	Utuado/Ciales	5.0 km SW of Florida	146	18° 19' 22.69"	66° 35' 04.88"
41E	Río Grande de Arecibo	Río Tanamá	Utuado	5.0 km W of Cayuco	111	18° 17' 53.95"	66° 46' 56.46"
41F	Río Grande de Arecibo	Quebrada Jobos	Utuado/Arecibo	6.9 km NE of Utuado	123	18° 19' 25.61"	66° 40' 25.11"
42A	Río Grande de Manatí	Río Grande de Manatí	Barranquitas	4.3 km N of Barranquitas	771	18° 13' 25.00"	66° 19' 01.34"
42B	Río Grande de Manatí	Río Cañabon	Barranquitas	5.3 km E of Orocovis	770	18° 13' 38.06"	66° 20' 33.25"
42C	Río Grande de Manatí	Río Bauta	Orocovis	5.3 km SSW of Orocovis	155	18° 10' 26.22"	66° 24' 24.73"
42D	Río Grande de Manatí	Río Sana Muerto	Orocovis	2.6 km NW of Orocovis	157	18° 14' 23.68"	66° 24' 34.88"
42E	Río Grande de Manatí	Tributary to Río Bauta	Orocovis	5.8 km W of Orocovis	157	18° 13' 57.65"	66° 26' 47.65"
42F	Río Grande de Manatí	Río Cialitos	Ciales	6.5 km E of Jayuya	533	18° 13' 47.78"	66° 32' 11.00"
42G	Río Grande de Manatí	Río Cialitos	Ciales	7.8 km NE of Jayuya	608	18° 14' 13.81"	66° 31' 33.56"
42H	Río Grande de Manatí	Río Toro Negro	Ciales	5.8 km SW of Ciales	615	18° 17' 09.53"	66° 29' 27.71"
42I	Río Grande de Manatí	Río Cialitos	Ciales	7.1 km SW of Ciales	614	18° 17' 06.22"	66° 30' 52.81"
42J	Río Grande de Manatí	Río Cialitos	Ciales	0.9 km N of Ciales	146	18° 20' 34.44"	66° 28' 12.83"
43A	Río Cibuco	Río Mavilla	Corozal	3.7 km SE of Corozal	164	18° 18' 59.94"	66° 17' 22.38"
43B	Río Cibuco	Río Morovis	Morovis	1.0 km E of Franquez	155	18° 20' 14.93"	66° 25' 08.90"
43C	Río Cibuco	Río Unibón	Morovis/Vega Alta	3.8 km NE of Morovis	160	18° 20' 37.68"	66° 22' 32.23"
44A	Río La Plata	Río Barranquitas	Barranquitas	0.5 km W of Barranquitas	156	18° 11' 11.62"	66° 18' 51.23"
45A	Río Bayamón	Quebrada La Zapera	Aguas Buenas/Cidra	0.8 km SW of Sumidero	173	18° 12' 19.26"	66° 08' 21.59"
45B	Río Bayamón	Río Guaynabo	Guaynabo	6.0 km S of Guanabo	169	18° 19' 51.13"	66° 06' 01.19"
46A	Río Piedras	Río Piedras	San Juan	2.5 km SSE of San Juan	176	18° 23' 02.76"	66° 03' 30.92"

Table 2. Season, date and electrofishing technique for 81 Puerto Rico stream sampling sites. Site numbers in parentheses correspond to those in Chapter 1 for Río Matilde and Río Guanajibo drainage basins.

Site Number	Season	Date (month/day/year)			Technique
1A	Spring	3	17	2007	Backpack
1B	Spring	3	20	2007	Backpack
1C	Spring	4	1	2007	Backpack
1D	Spring	3	26	2007	Backpack
1E	Spring	3	21	2007	Backpack
2A	Spring	3	22	2007	Backpack
3A	Spring	3	23	2007	Backpack
4A	Spring	3	14	2007	Backpack
4B	Spring	4	3	2007	Barge
5A	Spring	3	8	2007	Backpack
5B	Spring	3	13	2007	Backpack
6A	Spring	3	12	2007	Backpack
7A	Spring	3	9	2007	Backpack
7B	Spring	3	11	2007	Backpack
10A	Spring	3	12	2007	Backpack
11A	Spring	3	9	2007	Backpack
13A	Spring	3	20	2007	Backpack
14A	Spring	3	24	2007	Barge
15A	Spring	3	10	2007	Backpack
16A	Spring	3	10	2007	Backpack
19A	Spring	3	15	2007	Backpack
22A	Fall	11	19	2006	Backpack
22B	Fall	11	18	2006	Backpack
23A	Fall	11	18	2006	Backpack
28A (C1)	Summer	6	16	2005	Backpack
28A (C1)	Fall	11	21	2005	Backpack
28A (C1)	Spring	3	14	2006	Backpack
28B (C2)	Summer	6	14	2005	Backpack
28B (C2)	Fall	11	23	2005	Backpack
28B (C2)	Spring	3	17	2006	Backpack
28C (C3)	Summer	6	21	2005	Barge
28C (C3)	Fall	12	8	2005	Barge
28C (C3)	Spring	3	16	2006	Barge
28D (C4)	Summer	6	17	2005	Barge
28D (C4)	Fall	12	7	2005	Barge
28D (C4)	Spring	3	10	2006	Barge
28E	Fall	11	13	2006	Backpack
29A	Fall	11	27	2006	Backpack
30A	Fall	11	13	2006	Backpack
31A	Fall	11	15	2006	Barge
32A	Fall	11	21	2006	Backpack
32B	Fall	11	30	2006	Backpack
32C	Fall	11	22	2006	Backpack
33A	Fall	11	12	2006	Backpack
34A	Fall	11	19	2006	Backpack

Table 2 continued.

Site Number	Season	Date (month/day/year)			Technique
35A (G1)	Summer	6	15	2005	Backpack
35A (G1)	Fall	11	16	2005	Backpack
35A (G1)	Spring	3	22	2006	Backpack
35B (G2)	Summer	6	13	2005	Barge
35B (G2)	Fall	11	28	2005	Barge
35B (G2)	Spring	4	4	2006	Barge
35C (G3)	Summer	6	24	2005	Backpack
35C (G3)	Fall	11	15	2005	Backpack
35C (G3)	Spring	3	20	2006	Backpack
35D (G4)	Summer	6	28	2005	Backpack
35D (G4)	Fall	11	17	2005	Backpack
35D (G4)	Spring	3	24	2006	Backpack
35E (G5)	Summer	7	7	2005	Barge
35E (G5)	Fall	11	12	2005	Barge
35E (G5)	Spring	3	11	2006	Barge
35F (G6)	Summer	6	29	2005	Backpack
35F (G6)	Fall	11	14	2005	Barge
35F (G6)	Spring	3	12	2006	Backpack
35G (G7)	Summer	6	27	2005	Backpack
35G (G7)	Fall	11	18	2005	Barge
35G (G7)	Spring	3	26	2006	Backpack
35H (G8)	Summer	6	9	2005	Barge
35H (G8)	Fall	11	29	2005	Barge
35H (G8)	Spring	3	29	2006	Barge
36A	Fall	11	10	2006	Backpack
37A	Fall	11	6	2006	Barge
37B	Fall	11	20	2006	Barge
37C	Fall	11	4	2006	Backpack
37D	Fall	11	10	2006	Backpack
37E	Fall	11	11	2006	Backpack
37F	Fall	11	7	2006	Backpack
38A	Fall	11	4	2006	Backpack
38B	Fall	11	5	2006	Backpack
38C	Fall	11	3	2006	Backpack
38D	Fall	11	3	2006	Backpack
38E	Fall	11	2	2006	Backpack
40A	Summer	7	9	2006	Backpack
41A	Summer	6	10	2006	Backpack
41B	Summer	6	11	2006	Backpack
41C	Summer	6	9	2006	Backpack
41D	Summer	6	8	2006	Backpack
41E	Summer	7	1	2006	Barge
41F	Summer	6	19	2006	Backpack
42A	Summer	7	6	2006	Backpack
42B	Summer	7	7	2006	Backpack
42C	Summer	6	17	2006	Backpack
42D	Summer	6	20	2006	Backpack

Table 2 continued.

Site Number	Season	Date (month/day/year)			Technique
42E	Summer	6	20	2006	Backpack
42F	Summer	6	12	2006	Backpack
42G	Summer	6	14	2006	Backpack
42H	Summer	6	29	2006	Barge
42I	Summer	6	15	2006	Backpack
42J	Summer	6	28	2006	Barge
43A	Summer	7	5	2006	Backpack
43B	Summer	7	10	2006	Backpack
43C	Summer	7	8	2006	Backpack
44A	Summer	7	7	2006	Backpack
45A	Spring	3	17	2007	Backpack
45B	Spring	4	2	2007	Backpack
46A	Spring	3	25	2007	Backpack

Table 3. Original data sources and original and modified categories used in geographical analysis of watershed attributes. Data were derived from Puerto Rico Gap Analysis Project (PRGAP) and United States Geological Survey (USGS) database.

Mapping	Data Source	Categories
Watershed delineation	USGS, EROS Data Center 7.5 minute 30-m National Elevation Dataset (NED)	
Streams	USGS, National Hydrography Dataset (NHD), 2000	
Land cover	PRGAP 1_Land_cover_grid 2006	Agricultural, forested, freshwater, nonsaline wetlands, shrubland and woodland, urban, other.
Land ownership	PRGAP 3_Land_ownership 2006	Autoridad de Energia Electrica, Conservation Trust of Puerto Rico, Puerto Rico Department of Natural and Environmental Resources, Land Administration, Private, United States Forest Service
Roads	Topologically Integrated Geographic Encoding and Referencing System (TIGER/line), 2000. U.S. Department of Commerce, Bureau of the Census, 1:100,000 scale topographic map	

Table 4. Instream habitat, watershed, and riparian attribute variables for 81 Puerto Rico stream sampling sites. Forty-three variables (19 instream habitat, 24 watershed and riparian) were reduced to 13 primary variables for hierarchical modeling (six instream habitat, seven watershed and riparian) based on correlation coefficients (*r*) and related ecological functions. Bold *r*-values denote significant correlations between primary and secondary variables ($P < 0.05$). Critical absolute *r*-values are 0.190 for instream habitat correlations and 0.216 for watershed and riparian correlations.

Primary representative variable	*r*	Correlated secondary variable
Instream habitat		
Mean stream width (m)		
	0.4185	Mean depth (cm)
	0.1818	Mean velocity (m/s)
	-0.1837	Mean bank angle (º)
	-0.2463	Mean substrate diameter (mm)
Percent cover		
Water temperature (ºC)		
	-0.0553	Dissolved oxygen concentration (mg/L)
Conductivity (µS/cm)		
	0.9996	Total dissolved solids (g/L)
	0.9868	Salinity (ppt)
	0.7919	Alkalinity (mg/L $CaCO_3$)
	0.8039	Hardness (mg/L $CaCO_3$)
	0.0879	pH
Nitrate concentration (mg/L NO_3^-)		
	0.1189	Nitrite concentration (mg/L NO_2^-)
	0.1047	Ammonia concentration (mg/L NH_3)
	0.2521	Phosphorus concentration (mg/L PO_4)
Turbidity (FAU)		

Table 4 continued.

Primary representative variable	*r*	Correlated secondary variable
Watershed and riparian attributes		
Watershed area (km^2)		
	-0.3258	Elevation (m)
	-0.2415	Gradient (%)
River km (km)		
Reservoir downstream of site (presence/absence)		
Road density (km/ha)		
Watershed forest (%)		
	-0.9145	Watershed agriculture (%)
	0.5141	Watershed shrub and woodland (%)
	-0.2716	Watershed urban (%)
30-m Riparian forest (%)		
	-0.8764	30-m Riparian agriculture (%)
	-0.3974	30-m Riparian shrub and woodland (%)
	-0.2118	30-m Riparian urban (%)
	0.4807	100-m Riparian forest (%)
	-0.3415	100-m Riparian agriculture (%)
	-0.4638	100-m Riparian shrub and woodland (%)
	-0.1491	100-m Riparian urban (%)
Watershed public ownership (%)		
	-0.9997	Watershed private ownership (%)
	-0.1404	Watershed utility and NGO ownership (%)
	0.9952	100-m Riparian public ownership (%)
	-0.9943	100-m Riparian private ownership (%)
	-0.1437	100-m Riparian utility and NGO ownership (%)

Table 5. Instream habitat and sampling reach characteristics from 81 Puerto Rico river locations during 2005-2007 surveys.

Site number	Season	Year	Reach length (m)	Mean width (m)	Area (m^2)	Mean depth (cm)	Mean velocity (m/s)	Dominant substrate	Mean bank angle (º)	% Cover
1A	Spring	2007	150	2.31	346	8.9	0.050	Coarse gravel	137.3	47
1B	Spring	2007	150	2.43	670	3.4	0.128	Pea gravel	171.3	41
1C	Spring	2007	150	6.41	962	14.0	0.061	Sand	141.3	24
1D	Spring	2007	150	5.86	878	13.3	0.032	Fine gravel	143.3	75
1E	Spring	2007	150	9.22	1,382	12.1	0.098	Large cobble	160.5	76
2A	Spring	2007	150	4.94	741	22.5	0.036	Silt	123.8	68
3A	Spring	2007	150	15.08	2,262	15.6	0.196	Medium boulder	129.5	40
4A	Spring	2007	150	5.32	797	10.6	0.058	Silt	124.0	67
4B	Spring	2007	150	10.05	1,508	35.4	0.066	Small cobble	133.0	82
5A	Spring	2007	150	7.64	1,146	8.9	0.073	Medium gravel	154.5	49
5B	Spring	2007	150	4.64	696	18.2	0.090	Coarse gravel	131.8	41
6A	Spring	2007	150	2.79	418	8.6	0.015	Medium gravel	161.3	75
7A	Spring	2007	150	3.66	549	12.6	0.060	Coarse gravel	139.7	63
7B	Spring	2007	150	2.61	392	11.5	0.057	Small cobble	133.8	62
10A	Spring	2007	150	4.24	636	5.2	0.044	Small boulder	149.0	58
11A	Spring	2007	150	2.94	440	11.4	0.039	Large boulder	146.0	44
13A	Spring	2007	150	4.47	365	8.5	0.253	Sand	154.0	21
14A	Spring	2007	150	9.16	1,373	27.3	0.127	Sand	135.8	42
15A	Spring	2007	150	4.20	630	8.5	0.154	Very coarse sand	130.5	34
16A	Spring	2007	150	6.74	1,011	8.2	0.193	Very coarse sand	149.1	16
19A	Spring	2007	150	4.24	635	9.5	0.021	Pea gravel	163.5	86
22A	Spring	2006	150	6.43	965	11.7	0.255	Medium gravel	139.3	53
22B	Spring	2006	150	8.02	1,203	7.9	0.255	Sand	127.8	16
23A	Spring	2006	150	3.59	538	2.4	0.056	Medium gravel	154.8	26
28A	Summer	2005	112	4.35	487	14.4	0.452	Medium boulder	117.1	95
28A	Fall	2005	112	5.16	578	18.9	0.500	Medium boulder	131.5	86
28A	Spring	2006	112	3.84	430	14.9	0.081	Medium boulder	136.8	59
28B	Summer	2005	118	4.97	586	17.1	0.140	Medium boulder	110.5	98
28B	Fall	2005	118	6.53	771	17.7	0.105	Medium boulder	126.0	80
28B	Spring	2006	118	4.64	548	12.2	0.048	Medium boulder	136.3	67

Table 5 continued.

Site number	Season	Year	Reach length (m)	Mean width (m)	Area (m^2)	Mean depth (cm)	Mean velocity (m/s)	Dominant substrate	Mean bank angle (º)	% Cover
28C	Summer	2005	108	5.01	541	26.0	0.217	Very coarse gravel	137.5	56
28C	Fall	2005	108	6.03	651	29.2	0.106	Very coarse gravel	138.3	51
28C	Spring	2006	108	4.61	498	30.9	0.026	Very coarse gravel	141.5	54
28D	Summer	2005	118	5.12	604	21.7	0.450	Sand	128.3	65
28D	Fall	2005	118	8.16	963	14.3	0.217	Sand	114.0	34
28D	Spring	2006	118	8.17	964	14.5	0.202	Sand	131.3	54
28E	Fall	2006	150	6.22	933	8.3	0.114	Medium gravel	141.3	45
29A	Fall	2006	150	6.19	929	14.4	0.213	Medium gravel	152.8	82
30A	Fall	2006	150	5.66	849	8.8	0.078	Medium gravel	135.3	48
31A	Fall	2006	150	10.22	1,533	20.7	0.172	Very coarse gravel	100.8	27
32A	Fall	2006	150	6.04	905	20.2	0.160	Medium gravel	130.8	46
32B	Fall	2006	150	7.08	1,062	21.8	0.014	Medium gravel	124.8	49
32C	Fall	2006	150	6.21	932	20.4	0.109	Small boulder	135.7	69
33A	Fall	2006	150	8.05	1,208	17.5	0.055	Very coarse gravel	129.8	60
34A	Fall	2006	150	3.02	452	8.9	0.017	Sand	143.3	25
35A	Summer	2005	118	3.70	437	15.0	0.115	Small cobble	133.3	60
35A	Fall	2005	118	5.63	664	12.9	0.199	Small cobble	135.3	57
35A	Spring	2006	118	3.75	442	9.6	0.055	Small cobble	147.4	75
35B	Summer	2005	130	10.30	1,339	26.7	0.362	Small cobble	117.8	38
35B	Fall	2005	130	11.14	1,448	25.3	0.379	Small cobble	113.3	40
35B	Spring	2006	130	10.75	1,397	18.4	0.236	Small cobble	118.8	51
35C	Summer	2005	134	3.94	527	12.1	0.720	Very coarse gravel	131.8	84
35C	Fall	2005	134	4.02	538	12.4	0.232	Very coarse gravel	116.8	35
35C	Spring	2006	134	2.94	394	6.7	0.057	Very coarse gravel	145.8	66
35D	Summer	2005	124	5.26	652	15.0	0.619	Very coarse gravel	138.5	71
35D	Fall	2005	124	6.13	760	12.8	0.273	Very coarse gravel	148.0	61
35D	Spring	2006	124	3.98	493	10.5	0.083	Very coarse gravel	156.5	75
35E	Summer	2005	144	4.99	718	19.6	0.377	Small cobble	124.0	46
35E	Fall	2005	144	7.31	1,053	19.2	0.939	Small cobble	137.3	53
35E	Spring	2006	144	4.54	654	17.8	0.073	Small cobble	149.3	78
35F	Summer	2005	144	7.50	1,080	11.7	0.435	Very coarse sand	119.0	38

Table 5 continued.

Site number	Season	Year	Reach length (m)	Mean width (m)	Area (m^2)	Mean depth (cm)	Mean velocity (m/s)	Dominant substrate	Mean bank angle (º)	% Cover
35F	Fall	2005	144	7.71	1,110	16.8	1.031	Very coarse sand	114.5	23
35F	Spring	2006	144	6.90	994	9.4	0.041	Very coarse sand	125.3	56
35G	Summer	2005	144	4.71	678	10.1	0.592	Small cobble	145.8	66
35G	Fall	2005	144	5.16	742	18.5	0.259	Small cobble	145.8	37
35G	Spring	2006	144	2.43	350	7.9	0.079	Small cobble	163.3	60
35H	Summer	2005	114	7.64	871	39.6	0.405	Clay	108.3	27
35H	Fall	2005	114	7.11	811	47.6	0.341	Clay	96.3	24
35H	Spring	2006	114	6.71	764	35.9	0.189	Clay	116.0	44
36A	Fall	2006	150	4.16	624	13.0	0.099	Coarse gravel	134.8	32
37A	Fall	2006	150	13.55	2,033	17.7	0.156	Coarse gravel	134.5	40
37B	Fall	2006	150	11.33	1,700	28.6	0.105	Medium gravel	140.5	56
37C	Fall	2006	150	1.73	260	6.3	0.104	Mammoth boulder	117.3	45
37D	Fall	2006	150	2.84	426	6.9	0.072	Silt	135.8	55
37E	Fall	2006	150	5.06	759	16.8	0.165	Coarse gravel	140.0	53
37F	Fall	2006	150	5.74	861	13.7	0.159	Very coarse gravel	124.5	67
38A	Fall	2006	150	2.74	410	15.7	0.086	Mammoth boulder	116.5	60
38B	Fall	2006	150	3.59	539	14.5	0.041	Small cobble	117.3	67
38C	Fall	2006	150	6.85	1,027	15.5	0.090	Medium gravel	123.3	29
38D	Fall	2006	150	7.21	1,082	16.7	0.064	Large cobble	119.3	60
38E	Fall	2006	150	1.58	237	13.6	0.110	Sand	119.5	26
40A	Summer	2006	150	7.69	1,153	13.9	0.136	Sand	123.3	72
41A	Summer	2006	150	4.23	635	11.2	0.137	Coarse gravel	146.8	65
41B	Summer	2006	150	6.01	902	18.3	0.209	Coarse gravel	157.5	51
41C	Summer	2006	155	3.04	471	10.4	0.111	Very coarse gravel	143.3	36
41D	Summer	2006	150	11.95	1,793	14.5	0.190	Small cobble	140.3	84
41E	Summer	2006	150	8.04	1,205	20.0	0.287	Very coarse sand	147.5	86
41F	Summer	2006	121	3.01	364	9.2	0.353	Mammoth boulder	130.8	50
42A	Summer	2006	150	3.71	557	10.2	0.152	Very coarse sand	115.0	42
42B	Summer	2006	150	5.25	788	10.4	0.041	Fine gravel	144.5	57
42C	Summer	2006	150	3.82	573	10.1	0.081	Sand	142.4	47
42D	Summer	2006	100	3.04	304	11.1	0.074	Mammoth boulder	129.5	62

Table 5 continued.

Site number	Season	Year	Reach length (m)	Mean width (m)	Area (m^2)	Mean depth (cm)	Mean velocity (m/s)	Dominant substrate	Mean bank angle (º)	% Cover
42E	Summer	2006	138	6.22	858	17.6	0.157	Large boulder	119.3	57
42F	Summer	2006	150	3.09	464	10.8	0.066	Small boulder	144.8	76
42G	Summer	2006	155	8.30	1,287	11.8	0.077	Coarse gravel	137.5	52
42H	Summer	2006	150	13.53	2,029	19.3	0.167	Very coarse sand	140.3	79
42I	Summer	2006	150	8.74	1,311	13.7	0.144	Medium gravel	147.0	71
42J	Summer	2006	150	12.14	1,821	14.3	0.181	Very coarse sand	148.3	76
43A	Summer	2006	150	6.79	1,019	11.3	0.160	Fine gravel	144.0	55
43B	Summer	2006	150	4.71	707	10.5	0.224	Very coarse sand	130.3	20
43C	Summer	2006	140	5.66	792	10.0	0.115	Sand	147.5	54
44A	Summer	2006	150	3.61	541	8.6	0.096	Very coarse sand	138.7	76
45A	Spring	2007	150	3.16	474	10.0	0.023	Silt	145.3	58
45B	Spring	2007	150	6.48	971	9.5	0.160	Medium gravel	152.5	41
46A	Spring	2007	150	6.59	988	19.1	0.167	Coarse gravel	152.8	35
Mean			140.8	5.92	836.6	15.1	0.178	Small cobble	135.4	54

Table 6. Geographic characteristics of 81 Puerto Rico stream sampling reaches.

Site number	Elevation (m)	Gradient %	Distance to river mouth (km)	Road density (km/ha)	Watershed area (km^2)	Downstream reservoir
1A	186.1	1.39	56.260	0.055	3.036	Yes
1B	78.3	0.78	52.908	0.057	8.755	Yes
1C	48.5	0.94	35.184	0.057	9.756	Yes
1D	106.1	0.58	23.455	0.060	19.448	No
1E	69.1	1.11	21.972	0.041	26.464	No
2A	80.2	1.61	13.031	0.069	5.345	No
3A	517.0	4.09	15.396	0.011	5.541	No
4A	11.3	0.85	3.812	0.050	1.719	No
4B	8.6	1.10	3.184	0.023	30.922	No
5A	18.8	0.41	4.109	0.020	14.052	No
5B	20.3	1.56	3.993	0.032	8.117	No
6A	19.8	0.40	2.577	0.028	3.796	No
7A	110.6	5.17	16.048	0.029	2.550	No
7B	70.5	2.35	14.662	0.028	2.605	No
10A	65.4	2.81	5.913	0.014	3.791	No
11A	159.9	7.85	15.687	0.009	2.426	No
13A	116.7	0.19	18.169	0.053	9.828	No
14A	16.0	0.15	12.500	0.047	31.246	No
15A	9.8	0.27	6.242	0.044	56.259	No
16A	4.6	0.10	2.715	0.038	32.075	No
19A	128.8	0.96	17.637	0.026	42.671	No
22A	185.1	2.03	20.411	0.029	9.847	No
22B	69.9	1.53	12.150	0.033	33.316	No
23A	79.0	0.07	8.466	0.035	7.340	No
28A	220.8	23.45	15.450	0.038	7.848	No
28B	164.2	3.88	15.130	0.037	8.686	No
28C	57.7	1.17	10.480	0.033	14.896	No
28D	30.0	0.25	4.990	0.043	20.066	No
28E	45.2	3.22	8.126	0.033	19.252	No
29A	58.0	3.18	10.580	0.036	27.305	No
30A	60.1	4.05	8.035	0.050	8.742	No
31A	20.0	1.93	5.544	0.046	54.062	No
32A	180.2	3.23	31.663	0.036	21.221	Yes
32B	62.1	1.81	19.525	0.036	53.684	No
32C	49.0	0.04	14.497	0.037	77.333	No
33A	48.9	1.70	13.321	0.033	29.936	No
34A	20.0	0.25	7.063	0.039	10.577	No
35A	426.2	2.75	44.340	0.014	5.051	No
35B	48.8	1.99	23.643	0.034	48.194	No
35C	199.3	0.98	31.462	0.018	4.391	No
35D	61.4	2.83	26.423	0.030	11.313	No
35E	47.7	0.33	23.465	0.033	17.065	No
35F	39.2	1.85	21.693	0.034	19.523	No
35G	41.6	2.80	21.935	0.038	12.785	No
35H	10.2	0.12	11.621	0.036	60.856	No
36A	27.5	0.34	5.987	0.051	4.702	No

Table 6 continued

Site number	Elevation (m)	Gradient %	Distance to river mouth (km)	Road density (km/ha)	Watershed area (km^2)	Downstream reservoir
37A	200.0	1.76	56.745	0.041	95.483	No
37B	179.8	5.19	55.991	0.033	63.100	No
37C	154.8	7.59	53.897	0.042	1.070	No
37D	220.1	2.54	51.694	0.049	1.160	No
37E	207.6	1.34	25.650	0.037	9.210	No
37F	186.6	2.43	26.264	0.043	9.266	No
38A	363.4	8.06	56.366	0.056	1.949	No
38B	171.4	0.17	57.872	0.047	3.010	No
38C	44.6	1.57	42.444	0.035	13.521	No
38D	20.1	0.06	15.817	0.065	13.961	No
38E	29.3	0.05	12.837	0.060	2.300	No
40A	289.7	5.06	26.910	0.046	11.524	No
41A	380.9	0.31	42.698	0.031	6.731	Yes
41B	358.3	0.34	40.267	0.030	14.190	Yes
41C	309.7	4.77	37.585	0.037	2.855	Yes
41D	147.1	0.89	36.993	0.025	40.804	Yes
41E	291.5	0.65	28.285	0.055	5.801	No
41F	117.0	6.29	24.032	0.021	5.112	Yes
42A	586.4	0.51	84.201	0.056	6.723	No
42B	508.5	7.25	72.001	0.056	5.330	No
42C	702.4	3.90	66.207	0.048	5.718	No
42D	610.5	9.70	57.811	0.026	2.334	No
42E	305.9	10.17	57.573	0.032	2.581	No
42F	599.5	4.28	57.544	0.001	1.301	No
42G	515.3	1.53	56.567	0.013	8.013	No
42H	117.8	0.16	49.414	0.027	78.068	No
42I	267.2	0.82	47.260	0.026	17.607	No
42J	36.8	0.40	31.265	0.029	45.847	No
43A	158.8	1.06	42.268	0.056	19.843	No
43B	129.2	0.47	30.200	0.079	7.965	No
43C	136.2	1.83	24.411	0.050	15.423	No
44A	583.3	3.32	68.224	0.049	6.635	Yes
45A	385.0	1.85	38.528	0.056	1.576	No
45B	59.0	1.50	19.072	0.059	22.109	No
46A	13.3	0.18	8.644	0.098	23.203	No
Mean	166.5	2.45	27.963	0.039	18.268	

Table 7. Fish sampled at 81 Puerto Rico stream sites include 25 species from 14 families. Variables include number of sites where sampled, total density summed for all sites sampled, mean density among sites, total biomass for all sites, mean biomass among sites and mean individual weight of each species. Fish species with an asterisk (*) are not native to Puerto Rico.

Family	Scientific name	English common name	Spanish common name	Number of sites	Total density (fish/ha)	Mean density (fish/ha)	Total biomass (kg/ha)	Mean biomass (kg/ha)	Average weight (g/fish)
Anguillidae	*Anguilla rostrata*	American eel	Anguila	32	14,797.6	462.4	1,063.0	33.2	71.8
Centrarchidae	*Lepomis auritus**	Redbreast sunfish	Chopa pechicolorado, chopo	4	2,606.7	651.7	120.5	30.1	46.2
Centrarchidae	*Lepomis macrochirus**	Bluegill	Chopa criolla	1	7.5	7.5	1.0	1.0	126.7
Centrarchidae	*Micropterus salmoides**	Largemouth bass	Lobina	4	1,784.3	446.1	191.2	47.8	107.1
Centropomidae	*Centropomus parallelus*	Fat snook	Robalo blanco	1	25.0	25.0	2.1	2.1	85.5
Cichlidae	*Archocentrus nigrofasciatus**	Convict cichlid	Convicto, Cebra	2	24,226.3	12,113.1	186.9	93.4	7.7
Cichlidae	*Oreochromis mossambicus**	Mozambique tilapia	Tilapia mosambica	27	36,331.7	1,345.6	260.7	9.7	7.2
Cichlidae	*Oreochromis niloticus**	Nile tilapia	Tilipia del nilótica	1	9.8	9.8	2.8	2.8	284.0
Cichlidae	*Tilapia rendalli**	Redbreast tilapia	Tilapia moteado	1	52.8	52.8	3.7	3.7	70.4
Cyprinidae	*Puntius conchonius**	Rosy barb	Minó rosado	8	7,021.2	877.6	13.3	1.7	1.9
Eleotridae	*Eleotris perniger*	Smallscaled spinycheek sleeper	Morón	25	11,604.4	464.2	167.0	6.7	14.4
Eleotridae	*Gobiomorus dormitor*	Bigmouth sleeper	Guavina	35	26,480.5	756.6	1,761.3	50.3	66.5
Gobiidae	*Awaous banana*	River goby	Saga	54	29,972.5	555.0	496.4	9.2	16.6
Gobiidae	*Sicydium plumieri*[a]	Sirajo goby	Olivo, chupapiedra	50	104,145.6	2,082.9	319.2	6.4	3.1
Gyrinocheilidae	*Gyrinocheilus aymonieri**	Chinese algae-eater	Pez ventosa	1	72.8	72.8	3.0	3.0	41.6
Haemulidae	*Pomadasys crocro*	Burro grunt	Viejo, ronco blanco, burro	8	533.2	66.7	66.6	8.3	124.9
Ictaluridae	*Ictalurus punctatus**	Channel catfish	Barbudo de canal	6	3,384.5	564.1	249.7	41.6	73.8
Loricariidae	*Pterygoplicthys pardalis**	Amazon sailfin catfish	Corroncho de América del Sur	5	309.9	62.0	137.2	27.4	442.7
Lutjanidae	*Lutjanus griseus*	Gray snapper	Pargo prieto	1	25.0	25.0	2.7	2.7	106.8
Mugilidae	*Agonostomus monticola*	Mountain mullet	Dajao, lisa de río	41	155,043.4	3,781.5	3,289.1	80.2	21.2
Mugilidae	*Mugil curema*	White mullet	Jarea, lisa blanca	1	18.8	18.8	4.8	4.8	253.8
Poeciliidae	*Poecilia latipinna**	Sailfin molly	Gupí	2	34.6	17.3	0.0	0.0	0.9
Poeciliidae	*Poecilia reticulata**	Guppy	Gupí	50	145,573.7	2,911.5	32.5	0.7	0.2
Poeciliidae	*Poecilia sphenops**	Mexican molly	Gupí	28	364,839.8	13,030.0	658.3	23.5	1.8
Poeciliidae	*Xiphophorus hellerii**	Green swordtail	Pez cola de espada	35	82,557.4	2,358.8	76.3	2.2	0.9

[a] Four species of *Sicydium* occur in Puerto Rico, combined here.

Table 8. Fish detected (X) during 105 sampling events during three seasons at 81 sites in Puerto Rico stream reaches, including 25 species from 14 families. Samples were collected from summer 2005 to Spring 2007. Fish species with an asterisk (*) are not native to Puerto Rico.

Family	Scientific name	Spring 2007 1A	Spring 2007 1B	Spring 2007 1C	Spring 2007 1D	Spring 2007 1E	Spring 2007 2A	Spring 2007 3A	Spring 2007 4A	Spring 2007 4B	Spring 2007 5A	Spring 2007 5B
Anguillidae	*Anguilla rostrata*					X	X		X	X	X	X
Centrarchidae	*Lepomis auritus**			X								
Centrarchidae	*Lepomis macrochirus**											
Centrarchidae	*Micropterus salmoides**											
Centropomidae	*Centropomus parallelus*											
Cichlidae	*Archocentrus nigrofasciatus**			X								
Cichlidae	*Oreochromis mossambicus**		X	X	X							
Cichlidae	*Oreochromis niloticus**											
Cichlidae	*Tilapia rendalli**			X								
Cyprinidae	*Puntius conchonius**	X	X	X	X							
Eleotridae	*Eleotris perniger*								X	X	X	X
Eleotridae	*Gobiomorus dormitor*					X	X		X	X	X	X
Gobiidae	*Awaous banana*				X	X	X		X	X	X	X
Gobiidae	*Sicydium plumieri*[a]				X	X	X	X	X		X	
Gyrinocheilidae	*Gyrinocheilus aymonieri**			X								
Haemulidae	*Pomadasys crocro*											X
Ictaluridae	*Ictalurus punctatus**			X								
Loricariidae	*Pterygoplicthys pardalis**		X	X								
Lutjanidae	*Lutjanus griseus*									X		
Mugilidae	*Agonostomus monticola*					X	X		X	X	X	X
Mugilidae	*Mugil curema*											
Poeciliidae	*Poecilia latipinna**		X			X						
Poeciliidae	*Poecilia reticulata**	X	X	X	X	X	X					
Poeciliidae	*Poecilia sphenops**	X	X	X	X	X						
Poeciliidae	*Xiphophorus hellerii**		X	X								
Total species		3	7	11	6	8	6	1	6	6	6	6

Table 8 continued.

Scientific name	Spring 2007 6A	Spring 2007 7A	Spring 2007 7B	Spring 2007 10A	Spring 2007 11A	Spring 2007 13A	Spring 2007 14A	Spring 2007 15A	Spring 2007 16A	Spring 2007 19A	Fall 2006 22A	Fall 2006 22B	Fall 2006 23A
Anguilla rostrata	X	X	X				X	X	X				
*Lepomis auritus**													
*Lepomis macrochirus**													
*Micropterus salmoides**													
Centropomus parallelus													
*Archocentrus nigrofasciatus**													
*Oreochromis mossambicus**	X						X	X		X			
*Oreochromis niloticus**													
*Tilapia rendalli**													
*Puntius conchonius**										X			
Eleotris perniger	X	X	X				X	X	X				
Gobiomorus dormitor	X	X	X				X	X	X	X			
Awaous banana	X	X	X	X	X	X	X	X	X	X	X	X	X
Sicydium plumieri[a]	X	X		X	X					X	X	X	X
*Gyrinocheilus aymonieri**													
Pomadasys crocro													
*Ictalurus punctatus**													
*Pterygoplicthys pardalis**	X												
Lutjanus griseus													
Agonostomus monticola	X	X	X	X	X	X			X	X			X
Mugil curema													
*Poecilia latipinna**													
*Poecilia reticulata**				X		X	X			X		X	X
*Poecilia sphenops**										X	X	X	X
*Xiphophorus hellerii**						X							
Total species	8	6	5	4	3	4	6	5	5	8	3	4	5

Table 8 continued.

Scientific name	Summer 2005 28A	Fall 2005 28A	Spring 2006 28A	Summer 2005 28B	Fall 2005 28B	Spring 2006 28B	Summer 2005 28C	Fall 2005 28C	Spring 2006 28C	Summer 2005 28D	Fall 2005 28D	Spring 2006 28D	Fall 2006 28E
Anguilla rostrata				X	X	X	X	X	X	X	X	X	
*Lepomis auritus**													
*Lepomis macrochirus**													
*Micropterus salmoides**													
Centropomus parallelus													
*Archocentrus nigrofasciatus**													
*Oreochromis mossambicus**													
*Oreochromis niloticus**													
*Tilapia rendalli**													
*Puntius conchonius**													
Eleotris perniger										X	X	X	
Gobiomorus dormitor				X	X	X	X	X	X	X	X	X	X
Awaous banana	X	X	X	X	X	X	X	X	X	X	X	X	X
Sicydium plumieri[a]	X	X	X	X	X	X	X	X	X	X	X	X	X
*Gyrinocheilus aymonieri**													
Pomadasys crocro													
*Ictalurus punctatus**													
*Pterygoplicthys pardalis**													
Lutjanus griseus													
Agonostomus monticola				X	X	X	X	X	X	X	X	X	X
Mugil curema													
*Poecilia latipinna**													
*Poecilia reticulata**	X		X										
*Poecilia sphenops**													
*Xiphophorus hellerii**			X										
Total species	3	2	4	5	5	5	5	5	5	6	6	6	4

Table 8 continued.

Scientific name	Fall 2006 29A	Fall 2006 30A	Fall 2006 31A	Fall 2006 32A	Fall 2006 32B	Fall 2006 32C	Fall 2006 33A	Fall 2006 34A	Summer 2005 35A	Fall 2005 35A	Spring 2006 35A	Summer 2005 35B	Fall 2005 35B
Anguilla rostrata	X		X			X	X	X				X	X
*Lepomis auritus**													
*Lepomis macrochirus**												X	
*Micropterus salmoides**					X				X	X	X		
Centropomus parallelus													
*Archocentrus nigrofasciatus**													
*Oreochromis mossambicus**			X	X	X	X	X				X		X
*Oreochromis niloticus**													
*Tilapia rendalli**													
*Puntius conchonius**													
Eleotris perniger			X		X	X		X					X
Gobiomorus dormitor	X		X		X	X						X	X
Awaous banana	X	X	X		X	X	X		X	X	X	X	X
Sicydium plumieri[a]	X	X	X				X		X	X	X		
*Gyrinocheilus aymonieri**													
Pomadasys crocro	X		X										X
*Ictalurus punctatus**				X			X						
*Pterygoplicthys pardalis**					X								
Lutjanus griseus													
Agonostomus monticola	X	X	X		X	X						X	X
Mugil curema					X								
*Poecilia latipinna**													
*Poecilia reticulata**		X		X	X			X			X		
*Poecilia sphenops**				X									
*Xiphophorus hellerii**				X				X			X		X
Total species	6	4	8	5	9	6	5	4	3	3	6	5	8

Table 8 continued.

Scientific name	Spring 2006 35B	Summer 2005 35C	Fall 2005 35C	Spring 2006 35C	Summer 2005 35D	Fall 2005 35D	Spring 2006 35D	Summer 2005 35E	Fall 2005 35E	Spring 2006 35E	Summer 2005 35F	Fall 2005 35F	Spring 2006 35F
Anguilla rostrata	X				X			X	X	X	X	X	X
*Lepomis auritus**													
*Lepomis macrochirus**													
*Micropterus salmoides**													
Centropomus parallelus													
*Archocentrus nigrofasciatus**													
*Oreochromis mossambicus**	X							X	X	X	X	X	
*Oreochromis niloticus**													
*Tilapia rendalli**													
*Puntius conchonius**													
Eleotris perniger										X	X	X	X
Gobiomorus dormitor	X				X	X	X	X	X	X	X	X	X
Awaous banana	X			X	X	X	X	X	X	X	X	X	X
Sicydium plumieri[a]	X	X	X	X	X	X	X	X	X	X	X	X	X
*Gyrinocheilus aymonieri**													
Pomadasys crocro	X												
*Ictalurus punctatus**													
*Pterygoplicthys pardalis**													
Lutjanus griseus													
Agonostomus monticola	X				X	X	X	X	X	X	X	X	X
Mugil curema													
*Poecilia latipinna**													
*Poecilia reticulata**		X	X	X						X			X
*Poecilia sphenops**													
*Xiphophorus hellerii**	X	X	X	X	X		X		X	X			X
Total species	8	3	3	4	6	4	5	6	7	9	7	7	8

Table 8 continued.

Scientific name	Summer 2005 35G	Fall 2005 35G	Spring 2006 35G	Summer 2005 35H	Fall 2005 35H	Spring 2006 35H	Fall 2006 36A	Fall 2006 37A	Fall 2006 37B	Fall 2006 37C	Fall 2006 37D	Fall 2006 37E	Fall 2006 37F
Anguilla rostrata	X	X	X	X	X	X	X	X	X				
*Lepomis auritus**													
*Lepomis macrochirus**													
*Micropterus salmoides**													
Centropomus parallelus					X	X							
*Archocentrus nigrofasciatus**													
*Oreochromis mossambicus**									X				
*Oreochromis niloticus**								X					
*Tilapia rendalli**													
*Puntius conchonius**													
Eleotris perniger		X	X	X	X	X	X						
Gobiomorus dormitor	X	X	X	X	X	X	X	X	X				
Awaous banana	X	X	X		X	X	X	X	X	X		X	X
Sicydium plumieri[a]	X	X	X				X	X	X	X	X	X	X
*Gyrinocheilus aymonieri**													
Pomadasys crocro				X		X	X	X	X				
*Ictalurus punctatus**								X	X				
*Pterygoplicthys pardalis**													
Lutjanus griseus													
Agonostomus monticola	X	X	X	X	X	X	X	X	X	X		X	
Mugil curema													
*Poecilia latipinna**													
*Poecilia reticulata**		X	X					X	X				X
*Poecilia sphenops**													
*Xiphophorus hellerii**		X	X					X	X				
Total species	5	8	8	5	6	7	7	10	10	3	1	3	3

Table 8 continued.

Scientific name	Fall 2006 38A	Fall 2006 38B	Fall 2006 38C	Fall 2006 38D	Fall 2006 38E	Summer 2006 40A	Summer 2006 41A	Summer 2006 41B	Summer 2006 41C	Summer 2006 41D	Summer 2006 41E	Summer 2006 41F	Summer 2006 42A
Anguilla rostrata													
*Lepomis auritus**													X
*Lepomis macrochirus**													
*Micropterus salmoides**				X									X
Centropomus parallelus													
*Archocentrus nigrofasciatus**										X			
*Oreochromis mossambicus**		X											
*Oreochromis niloticus**													
*Tilapia rendalli**													
*Puntius conchonius**										X			
Eleotris perniger			X	X									
Gobiomorus dormitor			X	X									
Awaous banana		X	X	X	X								
Sicydium plumieri[a]				X							X		X
*Gyrinocheilus aymonieri**													
Pomadasys crocro													
*Ictalurus punctatus**													
*Pterygoplicthys pardalis**													
Lutjanus griseus													
Agonostomus monticola			X	X	X								
Mugil curema													
*Poecilia latipinna**													
*Poecilia reticulata**	X	X	X		X	X	X	X	X	X	X	X	X
*Poecilia sphenops**		X			X	X	X	X	X	X	X		X
*Xiphophorus hellerii**	X	X				X	X	X	X	X	X	X	X
Total species	2	5	5	6	4	3	3	3	3	5	4	2	6

Table 8 continued.

Scientific name	Summer 2006 42B	Summer 2006 42C	Summer 2006 42D	Summer 2006 42E	Summer 2006 42F	Summer 2006 42G	Summer 2006 42H	Summer 2006 42I	Summer 2006 42J	Summer 2006 43A	Summer 2006 43B	Summer 2006 43C
Anguilla rostrata							X		X			
*Lepomis auritus**												
*Lepomis macrochirus**												
*Micropterus salmoides**												
Centropomus parallelus												
*Archocentrus nigrofasciatus**												
*Oreochromis mossambicus**						X		X		X	X	X
*Oreochromis niloticus**												
*Tilapia rendalli**												
*Puntius conchonius**												
Eleotris perniger									X			
Gobiomorus dormitor							X		X			
Awaous banana							X		X			X
Sicydium plumieri[a]	X	X		X	X	X	X	X	X			X
*Gyrinocheilus aymonieri**												
Pomadasys crocro												
*Ictalurus punctatus**												
*Pterygoplicthys pardalis**												
Lutjanus griseus												
Agonostomus monticola							X		X			
Mugil curema												
*Poecilia latipinna**												
*Poecilia reticulata**	X	X	X		X	X		X		X	X	X
*Poecilia sphenops**	X		X				X	X		X		X
*Xiphophorus hellerii**	X	X						X	X	X		X
Total species	4	3	2	1	2	3	6	5	7	4	2	6

Table 8 continued.

Scientific name	Summer 2006 44A	Spring 2007 45A	Spring 2007 45B	Spring 2007 46A
Anguilla rostrata				X
*Lepomis auritus**	X	X		
*Lepomis macrochirus**				
*Micropterus salmoides**				
Centropomus parallelus				
*Archocentrus nigrofasciatus**				
*Oreochromis mossambicus**	X	X	X	X
*Oreochromis niloticus**				
*Tilapia rendalli**				
*Puntius conchonius**	X	X		
Eleotris perniger				X
Gobiomorus dormitor				X
Awaous banana			X	X
Sicydium plumieri[a]				X
*Gyrinocheilus aymonieri**				
Pomadasys crocro				
*Ictalurus punctatus**		X		
*Pterygoplicthys pardalis**				X
Lutjanus griseus				
Agonostomus monticola				X
Mugil curema				
*Poecilia latipinna**				
*Poecilia reticulata**	X	X	X	X
*Poecilia sphenops**	X	X	X	
*Xiphophorus hellerii**	X	X	X	X
Total species	6	7	5	10

[a] Four species of *Sicydium* occur in Puerto Rico, combined here.

Table 9. Community variables for all species of fish collected among 81 Puerto Rico stream sampling reaches. Density and biomass were estimated according to species and then summed for totals presented here.

Site number	Season	Year	Species richness	Diversity (H')	Density (fish/ha)	Density SE (fish/ha)	Biomass (kg/ha)	Biomass SE (kg/ha)
1A	Spring	2007	3	0.93	15,883.8	837.2	11.6	1.1
1B	Spring	2007	7	0.75	43,354.5	265.3	12.6	0.3
1C	Spring	2007	11	1.29	56,210.2	87,637.9	235.1	545.6
1D	Spring	2007	6	1.37	916.2	648.1	6.6	3.1
1E	Spring	2007	8	0.47	10,691.2	6,985.5	116.2	10.6
2A	Spring	2007	6	1.02	2,911.8	227.0	130.9	7.8
3A	Spring	2007	1	0.00	2,463.8	352.1	9.9	1.8
4A	Spring	2007	6	1.26	7,552.7	3,094.3	92.5	59.3
4B	Spring	2007	6	1.37	5,850.7	803.9	81.1	8.9
5A	Spring	2007	6	1.31	16,865.4	2,889.7	167.9	44.9
5B	Spring	2007	6	1.13	9,172.6	273.6	106.2	9.3
6A	Spring	2007	8	1.68	9,501.7	952.6	169.0	13.3
7A	Spring	2007	6	1.25	6,205.5	190.5	172.2	6.7
7B	Spring	2007	5	1.36	2,956.1	98.0	97.0	6.2
10A	Spring	2007	4	0.75	4,940.2	1,173.5	22.4	5.6
11A	Spring	2007	3	0.50	799.8	63.2	42.5	3.0
13A	Spring	2007	4	0.56	2,027.3	486.6	5.3	0.8
14A	Spring	2007	6	0.67	1,106.5	775.2	23.1	6.5
15A	Spring	2007	5	1.04	3,726.8	50.2	94.4	2.8
16A	Spring	2007	5	1.01	16,940.8	1,088.0	73.2	10.3
19A	Spring	2007	8	1.45	5,374.8	267.4	51.6	9.6
22A	Fall	2006	3	0.21	2,234.8	311.0	2.6	0.8
22B	Fall	2006	4	0.85	1,971.0	158.4	4.1	0.5
23A	Fall	2006	5	1.57	1,230.0	323.0	10.8	3.5
28A	Summer	2005	3	0.14	3,095.2	336.1	13.1	1.2
28A	Fall	2005	2	0.06	2,189.5	674.9	13.3	1.1
28A	Spring	2006	4	0.12	11,718.2	374.6	17.2	1.5
28B	Summer	2005	5	0.70	4,952.8	678.7	121.9	18.8
28B	Fall	2005	5	0.86	2,999.7	198.7	118.6	12.6
28B	Spring	2006	5	1.03	6,885.7	306.7	142.1	30.5
28C	Summer	2005	5	1.05	4,896.5	1,838.2	521.0	384.9
28C	Fall	2005	5	1.07	4,609.3	186.4	229.2	7.6
28C	Spring	2006	5	1.27	11,672.1	121.8	455.3	17.4
28D	Summer	2005	6	1.21	8,078.4	3,621.6	621.9	396.5
28D	Fall	2005	6	1.48	4,556.8	119.7	103.2	7.1
28D	Spring	2006	6	0.86	27,492.8	369.3	168.5	9.5
28E	Fall	2006	4	1.10	2,454.7	117.7	26.9	5.5
29A	Fall	2006	6	1.18	14,245.4	892.2	220.6	21.5
30A	Fall	2006	4	0.86	769.8	725.7	20.2	25.1
31A	Fall	2006	8	1.17	3,978.1	503.5	74.7	5.1
32A	Fall	2006	5	0.90	35,955.0	175,111.8	211.9	39.4
32B	Fall	2006	9	0.62	4,947.0	18,357.7	248.6	545.7
32C	Fall	2006	6	1.03	3,292.0	377.4	174.6	22.7
33A	Fall	2006	5	0.31	3,189.1	14,295.6	57.3	72.2
34A	Fall	2006	4	0.87	1,637.2	230.1	9.2	4.2
35A	Summer	2005	3	0.79	648.7	395.2	24.9	19.7

Table 9 continued.

Site number	Season	Year	Species richness	Diversity (H')	Density (fish/ha)	Density SE (fish/ha)	Biomass (kg/ha)	Biomass SE (kg/ha)
35A	Fall	2005	3	0.84	757.6	203.8	31.1	6.1
35A	Spring	2006	6	0.99	1,173.4	57.8	101.8	4.3
35B	Summer	2005	5	0.97	1,096.2	147.1	75.9	43.5
35B	Fall	2005	8	1.25	956.9	180.1	72.3	20.4
35B	Spring	2006	8	1.12	3,478.7	187.4	133.6	29.3
35C	Summer	2005	3	0.38	1,137.8	1,050.7	2.1	0.7
35C	Fall	2005	3	0.87	209.4	64.8	1.6	1.5
35C	Spring	2006	4	0.73	2,184.5	177.2	8.9	0.2
35D	Summer	2005	6	0.34	5,101.6	827.3	178.3	82.6
35D	Fall	2005	4	0.85	2,103.1	96.6	78.4	5.3
35D	Spring	2006	5	0.60	3,314.9	56.2	87.8	24.6
35E	Summer	2005	6	0.56	4,954.7	1,042.6	303.6	40.7
35E	Fall	2005	7	0.70	3,500.0	322.1	114.4	14.9
35E	Spring	2006	9	0.81	13,459.7	67.5	267.9	6.8
35F	Summer	2005	7	0.75	2,803.0	255.2	117.7	20.3
35F	Fall	2005	7	0.99	3,399.9	375.2	134.0	19.1
35F	Spring	2006	8	0.99	2,883.8	183.9	59.8	8.2
35G	Summer	2005	5	0.73	2,588.5	206.8	56.1	20.4
35G	Fall	2005	8	1.18	2,492.8	275.7	66.4	12.2
35G	Spring	2006	8	0.80	23,459.8	73,886.2	114.9	84.0
35H	Summer	2005	5	0.55	753.7	1,825.0	30.1	20.9
35H	Fall	2005	6	1.57	414.0	38.3	14.0	2.6
35H	Spring	2006	7	1.65	301.0	196.1	10.9	16.5
36A	Fall	2006	7	1.40	4,204.5	1,897.0	61.9	35.4
37A	Fall	2006	10	1.42	1,443.0	88.0	35.9	5.6
37B	Fall	2006	10	1.33	1,804.7	438.7	59.6	10.1
37C	Fall	2006	3	0.74	3,902.6	304.6	26.5	3.5
37D	Fall	2006	1	0.00	2,982.1	199.7	21.1	1.3
37E	Fall	2006	3	0.43	28,139.7	37,581.4	156.4	30.1
37F	Fall	2006	3	0.49	690.6	14.9	3.0	0.0
38A	Fall	2006	2	0.69	6,551.2	528.8	2.8	0.4
38B	Fall	2006	5	0.76	3,286.0	4,866.0	15.8	4.1
38C	Fall	2006	5	1.44	270.0	53.0	9.2	2.9
38D	Fall	2006	6	0.95	714.8	367.1	23.7	8.9
38E	Fall	2006	4	0.07	60,357.0	42,764.5	120.1	153.4
40A	Summer	2006	3	0.78	24,949.8	4,894.2	28.0	5.4
41A	Summer	2006	3	0.16	51,056.7	927.1	117.9	2.2
41B	Summer	2006	3	0.19	10,409.4	1,401.9	28.1	3.9
41C	Summer	2006	3	0.66	20,026.5	740.5	26.4	1.3
41D	Summer	2006	5	0.68	21,857.2	1,428.3	132.8	14.8
41E	Summer	2006	4	0.62	9,144.6	3,757.5	18.8	24.4
41F	Summer	2006	2	0.13	10,310.0	27,939.2	4.2	9.9
42A	Summer	2006	6	0.91	50,323.9	1,406.7	172.1	21.1
42B	Summer	2006	4	0.77	6,681.4	4,957.7	9.2	6.2
42C	Summer	2006	3	0.38	12,325.5	316.6	6.1	0.3
42D	Summer	2006	2	0.45	198.3	6.2	0.3	0.0
42E	Summer	2006	1	0.00	1,490.9	425.0	2.7	0.8

Table 9 continued.

Site number	Season	Year	Species richness	Diversity (H')	Density (fish/ha)	Density SE (fish/ha)	Biomass (kg/ha)	Biomass SE (kg/ha)
42F	Summer	2006	2	0.66	1,339.8	264.3	6.2	4.8
42G	Summer	2006	3	0.51	2,888.5	207.7	4.5	1.2
42H	Summer	2006	6	1.28	3,551.1	1,266.4	81.2	7.0
42I	Summer	2006	5	0.43	24,242.4	3,769.1	64.5	1.7
42J	Summer	2006	7	1.58	2,598.9	341.2	86.8	26.9
43A	Summer	2006	4	0.25	39,815.4	124,931.0	127.0	340.7
43B	Summer	2006	2	0.65	1,868.3	1,027.2	25.3	16.0
43C	Summer	2006	6	0.63	12,504.7	474.9	25.8	13.4
44A	Summer	2006	6	0.62	83,100.7	1,092.6	63.7	1.1
45A	Spring	2007	7	1.01	20,937.5	340.4	24.6	2.1
45B	Spring	2007	5	0.93	5,906.1	2,562.1	9.9	2.2
46A	Spring	2007	10	1.69	1,907.9	106.8	113.1	12.8

Table 10. Community variables for all native fish species collected among 81 Puerto Rico stream sampling reaches. Density and biomass were estimated according to species and then summed for totals presented here. Standard error (SE) estimates with an asterisk indicate species for which the removal criteria failed; density and biomass estimates represent actual capture converted to the standardized area (ha).

Site number	Season	Year	Species richness	Diversity (H')	Density (fish/ha)	Density SE (fish/ha)	Biomass (kg/ha)	Biomass SE (kg/ha)
1A	Spring	2007	0	.	0	.	0	.
1B	Spring	2007	0	.	0	.	0	.
1C	Spring	2007	0	.	0	.	0	.
1D	Spring	2007	2	0.52	161.6	25.1	2.8	0.6
1E	Spring	2007	5	0.43	10,629.7	6,985.5	116.2	10.6
2A	Spring	2007	5	0.91	2,817.3	227.0	130.9	7.8
3A	Spring	2007	1	0	2,463.8	352.1	9.9	1.8
4A	Spring	2007	6	1.26	7,552.7	3,094.3	92.5	59.3
4B	Spring	2007	6	1.37	5,850.7	803.9	81.1	8.9
5A	Spring	2007	6	1.31	16,865.4	2,889.7	167.9	44.9
5B	Spring	2007	6	1.13	9,172.6	273.6	106.2	9.3
6A	Spring	2007	6	1.63	9,382.2	952.6	154.0	13.3
7A	Spring	2007	6	1.25	6,205.5	190.5	172.2	6.7
7B	Spring	2007	5	1.36	2,956.1	98.0	97.0	6.2
10A	Spring	2007	3	0.35	1,649.0	453.9	21.9	5.6
11A	Spring	2007	3	0.50	799.8	63.2	42.5	3.0
13A	Spring	2007	2	0.49	290.7	41.9	5.0	0.8
14A	Spring	2007	4	0.43	1,033.5	775.2	22.2	6.5
15A	Spring	2007	4	0.89	3,550.2	49.8	68.9	2.5
16A	Spring	2007	5	1.01	16,940.8	1,088.0	73.2	10.3
19A	Spring	2007	4	0.88	1,661.6	182.8	45.4	9.6
22A	Fall	2006	2	0.67	100.2	61.8	1.2	0.7
22B	Fall	2006	2	0.52	521.7	39.8	10.3	3.5
23A	Fall	2006	3	1.04	861.4	313.0	3.3	0.5
28A	Summer	2005	2	0.04	3,032.2	336.0	13.0	1.2
28A	Fall	2005	2	0.06	2,189.5	674.9	13.3	1.1
28A	Spring	2006	2	0.03	11,531.8	374.6	17.1	1.5
28B	Summer	2005	5	0.70	4,952.8	678.7	121.9	18.8
28B	Fall	2005	5	0.86	2,999.7	198.7	118.6	12.6
28B	Spring	2006	5	1.03	6,885.7	306.7	142.1	30.5
28C	Summer	2005	5	1.05	4,896.5	1,838.2	521.0	384.9
28C	Fall	2005	5	1.07	4,609.3	186.4	229.2	7.6
28C	Spring	2006	5	1.27	11,672.1	121.8	455.3	17.4
28D	Summer	2005	6	1.21	8,078.4	3,621.6	621.9	396.5
28D	Fall	2005	6	1.48	4,556.8	119.7	103.2	7.1
28D	Spring	2006	6	0.86	27,492.8	369.3	168.5	9.5
28E	Fall	2006	4	1.10	2,454.7	117.7	26.9	5.5
29A	Fall	2006	6	1.18	14,245.4	892.2	220.6	21.5
30A	Fall	2006	3	0.79	758.0	725.7	20.2	25.1
31A	Fall	2006	7	1.13	3,943.3	503.5	71.2	5.0
32A	Fall	2006	0	.	0	.	0	.
32B	Fall	2006	5	0.55	4,428.5	18,357.7	151.9	545.3
32C	Fall	2006	5	0.80	2,992.4	377.4	144.7	22.7

Table 10 continued.

Site number	Season	Year	Species richness	Diversity (H')	Density (fish/ha)	Density SE (fish/ha)	Biomass (kg/ha)	Biomass SE (kg/ha)
33A	Fall	2006	3	0.18	3,106.1	14,295.6	34.3	72.2
34A	Fall	2006	2	0.24	333.3	230.1	7.9	4.2
35A	Summer	2005	2	0.19	195.9	10.4	4.1	0.2
35A	Fall	2005	2	0.33	359.7	174.8	7.0	4.6
35A	Spring	2006	2	0.61	298.5	51.1	14.2	1.7
35B	Summer	2005	4	0.93	1,088.7	147.1	74.9	43.5
35B	Fall	2005	6	1.16	936.2	180.1	70.3	20.4
35B	Spring	2006	6	1.10	3,465.1	187.4	132.5	29.3
35C	Summer	2005	1	0	37.5	0.0	1.5	0.3
35C	Fall	2005	1	0	74.8	64.8	1.5	1.5
35C	Spring	2006	2	0.56	101.5	0.0	8.3	0.0
35D	Summer	2005	5	0.31	5,082.8	827.3	178.3	82.6
35D	Fall	2005	4	0.85	2,103.1	96.6	78.4	5.3
35D	Spring	2006	4	0.57	3,294.4	56.2	87.7	24.6
35E	Summer	2005	5	0.52	4,917.1	1,042.1	293.0	39.3
35E	Fall	2005	5	0.57	3,398.0	320.9	113.6	14.9
35E	Spring	2006	6	0.56	12,531.7	58.1	262.9	6.8
35F	Summer	2005	6	0.68	2,761.3	255.2	114.5	20.3
35F	Fall	2005	6	0.90	3,291.7	373.1	125.7	19.0
35F	Spring	2006	6	0.86	2,783.7	183.9	59.6	8.2
35G	Summer	2005	5	0.73	2,588.5	206.8	56.1	20.4
35G	Fall	2005	6	1.02	2,375.0	275.7	66.3	12.2
35G	Spring	2006	6	1.06	5,355.6	400.1	95.4	26.4
35H	Summer	2005	5	0.55	753.7	1,825.0	30.1	20.9
35H	Fall	2005	6	1.57	414.0	38.3	14.0	2.6
35H	Spring	2006	7	1.65	301.0	196.1	10.9	16.5
36A	Fall	2006	7	1.40	4,204.5	1,897.0	61.9	35.4
37A	Fall	2006	6	1.25	1,384.2	88.0	33.1	5.6
37B	Fall	2006	6	1.13	1,708.5	429.1	55.8	10.1
37C	Fall	2006	3	0.74	3,902.6	304.6	26.5	3.5
37D	Fall	2006	1	0	2,982.1	199.7	21.1	1.3
37E	Fall	2006	3	0.43	28,139.7	37,581.4	156.4	30.1
37F	Fall	2006	2	0.54	99.0	14.9	2.9	0
38A	Fall	2006	0	.	0	.	0	.
38B	Fall	2006	1	0	74.4	0*	2.8	0*
38C	Fall	2006	4	1.27	248.9	52.5	9.2	2.9
38D	Fall	2006	5	0.89	705.6	367.1	21.4	8.9
38E	Fall	2006	2	0.56	172.0	15.1	3.2	1.1
40A	Summer	2006	0	.	0	.	0	.
41A	Summer	2006	0	.	0	.	0	.
41B	Summer	2006	0	.	0	.	0	.
41C	Summer	2006	0	.	0	.	0	.
41D	Summer	2006	0	.	0	.	0	.
41E	Summer	2006	1	0	986.4	3,410.6	7.0	24.3
41F	Summer	2006	0	.	0	.	0	.
42A	Summer	2006	1	0	252.0	0*	0.3	0*
42B	Summer	2006	1	0	2,043.9	325.1	4.3	0.8

Table 10 continued.

Site number	Season	Year	Species richness	Diversity (H')	Density (fish/ha)	Density SE (fish/ha)	Biomass (kg/ha)	Biomass SE (kg/ha)
42C	Summer	2006	1	0	343.1	38.8	0.9	0.1
42D	Summer	2006	0	.	0	.	0	.
42E	Summer	2006	1	0	1,490.9	425.0	2.7	0.8
42F	Summer	2006	1	0	837.0	264.0	5.9	4.8
42G	Summer	2006	1	0	565.2	154.0	3.6	1.2
42H	Summer	2006	5	0.96	2,736.3	106.4	79.3	6.4
42I	Summer	2006	1	0	325.1	43.4	0.9	0.2
42J	Summer	2006	6	1.57	2,593.4	341.2	86.8	26.9
43A	Summer	2006	0	.	0	.	0	.
43B	Summer	2006	0	.	0	.	0	.
43C	Summer	2006	2	0.48	67.5	13.2	1.6	0
44A	Summer	2006	0	.	0	.	0	.
45A	Spring	2007	0	.	0	.	0	.
45B	Spring	2007	1	0	10.3	0	0.4	0
46A	Spring	2007	6	1.27	1,637.9	105.8	56.2	5.5

Table 11. Community variables for all introduced fish species collected among 81 Puerto Rico stream sampling reaches. Density and biomass were estimated according to species and then summed for totals presented here. Standard error (SE) estimates with an asterisk indicate species for which the removal criteria failed; density and biomass estimates for those populations represent actual capture converted to the standardized area (ha).

Site number	Season	Year	Species richness	Density (fish/ha)	Density SE (fish/ha)	Biomass (kg/ha)	Biomass SE (kg/ha)
1A	Spring	2007	3	15,883.8	837.2	11.6	1.1
1B	Spring	2007	7	43,354.5	265.3	12.6	0.3
1C	Spring	2007	11	56,210.2	87,637.9	235.1	545.6
1D	Spring	2007	4	754.6	647.6	3.8	3.0
1E	Spring	2007	3	61.5	9.2	0.0	0.0
2A	Spring	2007	1	94.5	0	0.0	0.0
3A	Spring	2007	0	0	.	0	.
4A	Spring	2007	0	0	.	0	.
4B	Spring	2007	0	0	.	0	.
5A	Spring	2007	0	0	.	0	.
5B	Spring	2007	0	0	.	0	.
6A	Spring	2007	2	119.5	0	15.1	0.8
7A	Spring	2007	0	0	.	0	.
7B	Spring	2007	0	0	.	0	.
10A	Spring	2007	1	3,291.2	1,082.2	0.5	0.2
11A	Spring	2007	0	0	.	0	.
13A	Spring	2007	2	1,736.6	484.8	0.3	0.1
14A	Spring	2007	2	73.0	0	0.9	0.0
15A	Spring	2007	1	176.7	6.5	25.5	1.3
16A	Spring	2007	0	0	.	0	.
19A	Spring	2007	4	3,713.2	195.2	6.2	0.7
22A	Fall	2006	1	2,134.5	304.8	1.3	0.2
22B	Fall	2006	2	471.9	79.8	0.3	0.0
23A	Fall	2006	2	1,345.9	153.3	1.1	0.1
28A	Summer	2005	1	63.0	7.3	0.0	0.0
28A	Fall	2005	0	0	.	0	.
28A	Spring	2006	2	186.4	0*	0.1	0*
28B	Summer	2005	0	0	.	0	.
28B	Fall	2005	0	0	.	0	.
28B	Spring	2006	0	0	.	0	.
28C	Summer	2005	0	0	.	0	.
28C	Fall	2005	0	0	.	0	.
28C	Spring	2006	0	0	.	0	.
28D	Summer	2005	0	0	.	0	.
28D	Fall	2005	0	0	.	0	.
28D	Spring	2006	0	0	.	0	.
28E	Fall	2006	0	0	.	0	.
29A	Fall	2006	0	0	.	0	.
30A	Fall	2006	1	11.8	0*	0.0	0*
31A	Fall	2006	1	34.8	6.8	3.5	0.6
32A	Fall	2006	5	35,955.0	175,111.8	211.9	39.4
32B	Fall	2006	4	518.4	36.0	96.8	18.5

Table 11 continued.

Site number	Season	Year	Species richness	Density (fish/ha)	Density SE (fish/ha)	Biomass (kg/ha)	Biomass SE (kg/ha)
32C	Fall	2006	1	299.6	0*	29.8	0*
33A	Fall	2006	2	83.0	0	23.0	0.0
34A	Fall	2006	2	1,303.9	0*	1.3	0*
35A	Summer	2005	1	452.8	395.0	20.8	19.7
35A	Fall	2005	1	397.9	104.9	24.1	4.0
35A	Spring	2006	4	874.9	26.9	87.6	3.9
35B	Summer	2005	1	7.5	0*	0.9	0*
35B	Fall	2005	2	20.7	0.0	2.0	0.0
35B	Spring	2006	2	13.6	0.0	1.1	0.0
35C	Summer	2005	2	1,100.3	1,050.7	0.6	0.7
35C	Fall	2005	2	134.7	0.0	0.1	0.0
35C	Spring	2006	2	2,083.0	177.2	0.6	0.2
35D	Summer	2005	1	18.8	0.0	0.0	0.0
35D	Fall	2005	0	0	.	0	.
35D	Spring	2006	1	20.5	0.0	0.0	0.0
35E	Summer	2005	1	37.6	32.6	10.6	10.4
35E	Fall	2005	2	102.0	27.0	0.8	0.9
35E	Spring	2006	3	928.1	34.5	5.0	0.1
35F	Summer	2005	1	41.7	0*	3.2	0*
35F	Fall	2005	1	108.2	39.6	8.3	2.6
35F	Spring	2006	2	100.1	0.0	0.2	0.0
35G	Summer	2005	0	0	.	0	.
35G	Fall	2005	2	117.8	0*	0.1	0*
35G	Spring	2006	2	18,104.2	73,885.2	19.5	79.8
35H	Summer	2005	0	0	.	0	.
35H	Fall	2005	0	0	.	0	.
35H	Spring	2006	0	0	.	0	.
36A	Fall	2006	0	0	.	0	.
37A	Fall	2006	4	58.8	0	2.8	0.0
37B	Fall	2006	4	96.1	91.5	3.8	0.0
37C	Fall	2006	0	0	.	0	.
37D	Fall	2006	0	0	.	0	.
37E	Fall	2006	0	0	.	0	.
37F	Fall	2006	1	591.6	0*	0.1	0*
38A	Fall	2006	2	6,551.2	528.8	2.8	0.4
38B	Fall	2006	4	3,211.6	4,866.0	13.0	4.1
38C	Fall	2006	1	21.1	7.2	0.0	0.0
38D	Fall	2006	1	9.2	0*	2.3	0*
38E	Fall	2006	2	60,185.1	42,764.5	116.9	153.4
40A	Summer	2006	3	24,949.8	4,894.2	28.0	5.4
41A	Summer	2006	3	51,056.7	927.1	117.9	2.2
41B	Summer	2006	3	10,409.4	1,401.9	28.1	3.9
41C	Summer	2006	3	20,026.5	740.5	26.4	1.3
41D	Summer	2006	5	21,857.2	1,428.3	132.8	14.8
41E	Summer	2006	3	8,158.2	1,576.7	11.8	2.4
41F	Summer	2006	2	10,310.0	27,939.2	4.2	9.9
42A	Summer	2006	5	50,071.9	1,406.7	171.8	21.1

Table 11 continued.

Site number	Season	Year	Species richness	Density (fish/ha)	Density SE (fish/ha)	Biomass (kg/ha)	Biomass SE (kg/ha)
42B	Summer	2006	3	4,637.5	4,947.0	4.9	6.2
42C	Summer	2006	2	11,982.4	314.2	5.2	0.3
42D	Summer	2006	2	198.3	6.2	0.3	0.0
42E	Summer	2006	0	0	.	0	.
42F	Summer	2006	1	502.9	13.6	0.2	0.0
42G	Summer	2006	2	2,323.3	139.3	0.9	0.0
42H	Summer	2006	1	814.8	1,261.9	1.8	2.8
42I	Summer	2006	4	23,917.3	3,768.9	63.6	1.7
42J	Summer	2006	1	5.5	0	0.0	0.0
43A	Summer	2006	4	39,815.4	124,931.0	127.0	340.7
43B	Summer	2006	2	1,868.3	1,027.2	25.3	16.0
43C	Summer	2006	4	12,437.2	474.8	24.2	13.4
44A	Summer	2006	6	83,100.7	1,092.6	63.7	1.1
45A	Spring	2007	7	20,937.5	340.4	24.6	2.1
45B	Spring	2007	4	5,895.8	2,562.1	9.6	2.2
46A	Spring	2007	4	270.0	15.0	57.0	11.6

Table 12. Density and biomass estimates of all fish species sampled among 81 Puerto Rico stream reaches from summer 2005 to spring 2007. Standard error (SE) estimates with an asterisk indicate species for which the removal criteria failed; density and biomass estimates for those populations represent actual capture converted to the standardized area (ha).

Site Number	Season	Year	Species	Density (fish/ha)	Density SE (fish/ha)	Biomass (kg/ha)	Biomass SE (kg/ha)
1A	Spring	2007	Guppy	8,408.7	230.6	1.7	0.1
			Mexican molly	5,886.2	802.7	6.4	1.0
			Rosy barb	1,589.0	57.9	3.4	0.4
1B	Spring	2007	Amazon sailfin catfish	27.4	0	0.2	0
			Green swordtail	54.8	0	0.01	0
			Guppy	11,723.5	96.4	1.2	0
			Mexican molly	1,652.3	114.4	1.3	0.2
			Mozambique tilapia	29,841.7	219.1	9.8	0.2
			Rosy barb	27.4	0	0.1	0
			Sailfin molly	27.4	0*	0.02	0*
1C	Spring	2007	Amazon sailfin catfish	62.4	0*	8.6	0*
			Channel catfish	534.7	258.0	52.1	5.6
			Chinese algae eater	72.8	0*	3.0	0*
			Convict cichlid	19,604.3	87,402.8	122.3	545.5
			Green swordtail	24,983.1	6,368.3	23.7	6.1
			Guppy	2,716.9	185.4	0.5	0
			Mexican molly	7,028.5	503.2	7.4	0.5
			Mozambique tilapia	172.5	11.2	8.8	1.0
			Redbreast sunfish	53.9	7.7	2.8	1.0
			Redbreast tilapia	52.8	3.7	3.7	0.6
			Rosy barb	928.4	482.1	2.1	1.4
1D	Spring	2007	Guppy	372.5	32.6	0.05	0
			Mexican molly	45.6	0*	0.02	0*
			Mozambique tilapia	22.8	0*	2.3	0*
			River goby	127.4	25.1	2.7	0.6
			Rosy barb	313.7	646.7	1.5	3.0
			Sirajo goby	34.2	0	0.1	0
1E	Spring	2007	American eel	259.6	65.7	25.3	6.9
			Bigmouth sleeper	127.3	9.9	28.5	2.8
			Guppy	47.1	9.2	0.01	0
			Mexican molly	7.2	0*	0.01	0*
			Mountain mullet	488.0	28.4	20.8	1.8
			River goby	138.9	27.4	5.4	2.5
			Sailfin molly	7.2	0*	0.01	0*
			Sirajo goby	9,615.9	6,985.0	36.2	6.8
2A	Spring	2007	American eel	13.5	0*	6.0	0*
			Bigmouth sleeper	58.8	14.1	23.9	6.1
			Guppy	94.5	0	0.01	0
			Mountain mullet	1,697.0	99.4	88.8	4.6
			River goby	112.4	12.1	0.6	0.1
			Sirajo goby	935.5	203.2	11.6	1.6
3A	Spring	2007	Sirajo goby	2,463.8	352.1	9.9	1.8
4A	Spring	2007	American eel	770.2	1,125.4	13.2	19.7
			Bigmouth sleeper	936.8	64.3	26.5	2.3

Table 12 continued

Site Number	Season	Year	Species	Density (fish/ha)	Density SE (fish/ha)	Biomass (kg/ha)	Biomass SE (kg/ha)
4A	Spring	2007	American eel	3,124.5	100.3	12.1	0.6
			River goby	25.0	0	3.1	0
			Sirajo goby	25.0	0*	0.1	0*
			Smallscaled spinycheek sleeper	2,671.2	2,879.9	37.5	55.9
4B	Spring	2007	American eel	661.3	74.5	16.8	1.1
			Bigmouth sleeper	1,230.1	38.0	32.6	2.3
			Gray snapper	25.0	16.3	2.7	1.8
			Mountain mullet	2,121.0	99.3	8.8	0.4
			River goby	52.8	0*	2.9	0*
			Smallscaled spinycheek sleeper	1,760.5	793.1	17.3	8.3
5A	Spring	2007	American eel	2,781.4	2,118.2	34.0	22.0
			Bigmouth sleeper	2,066.8	1,082.6	55.7	38.1
			Mountain mullet	8,723.5	289.2	62.5	2.6
			River goby	19.0	6.5	0.1	0
			Sirajo goby	2,705.7	0*	12.5	0*
			Smallscaled spinycheek sleeper	569.0	1,614.9	3.1	8.7
5B	Spring	2007	American eel	2,269.2	162.8	35.5	8.0
			Bigmouth sleeper	781.1	136.7	34.1	4.2
			Burro grunt	14.4	0	4.5	0
			Mountain mullet	5,298.5	69.6	26.5	1.8
			River goby	120.2	139.5	0.7	1.0
			Smallscaled spinycheek sleeper	689.2	73.2	4.9	0.9
6A	Spring	2007	Amazon sailfin catfish	23.9	0	3.4	0
			American eel	1,713.2	97.9	35.8	3.3
			Bigmouth sleeper	2,385.6	513.6	75.0	12.3
			Mountain mullet	2,690.7	43.8	24.3	2.0
			Mozambique tilapia	95.6	0	11.7	0.8
			River goby	349.2	28.8	5.0	2.3
			Sirajo goby	701.7	776.8	2.0	2.2
			Smallscaled spinycheek sleeper	1,541.8	167.2	11.9	1.6
7A	Spring	2007	American eel	634.4	25.6	39.1	4.7
			Bigmouth sleeper	546.7	3.8	40.5	1.3
			Mountain mullet	3,347.2	46.3	71.5	2.5
			River goby	203.0	8.6	10.1	3.6
			Sirajo goby	1,456.1	182.8	10.3	1.4
			Smallscaled spinycheek sleeper	18.2	0*	0.6	0*
7B	Spring	2007	American eel	431.5	53.6	17.1	3.9
			Bigmouth sleeper	1,444.9	34.4	48.0	3.6
			Mountain mullet	617.9	47.9	18.5	2.7
			River goby	256.9	9.1	7.8	0.5
			Smallscaled spinycheek sleeper	204.9	56.3	5.6	1.7
10A	Spring	2007	Guppy	3,291.2	1,082.2	0.5	0.2
			Mountain mullet	119.0	55.0	6.4	3.9
			River goby	31.4	0	3.2	0.4
			Sirajo goby	1,498.6	450.5	12.4	3.9
11A	Spring	2007	Mountain mullet	686.3	63.2	40.6	3.0
			River goby	45.4	0	1.0	0

Table 12 continued

Site Number	Season	Year	Species	Density (fish/ha)	Density SE (fish/ha)	Biomass (kg/ha)	Biomass SE (kg/ha)
11A	Spring	2007	Sirajo goby	68.1	0	1.0	0.1
13A	Spring	2007	Green swordtail	29.8	0	0.03	0
			Guppy	1,706.8	484.8	0.2	0.1
			Mountain mullet	56.5	36.9	0.5	0.4
			River goby	234.2	19.8	4.5	0.8
14A	Spring	2007	American eel	31.8	7.6	8.2	3.5
			Bigmouth sleeper	7.3	0	3.7	0
			Guppy	58.4	0*	0.01	0*
			Mozambique tilapia	14.6	0	0.9	0
			River goby	924.1	773.9	6.5	4.8
			Smallscaled spinycheek sleeper	70.4	43.4	3.8	2.8
15A	Spring	2007	American eel	83.0	10.7	1.2	0.4
			Bigmouth sleeper	534.4	17.5	46.7	2.2
			Mozambique tilapia	176.7	6.5	25.5	1.3
			River goby	2,471.7	45.4	16.1	0.9
			Smallscaled spinycheek sleeper	461.1	0*	4.9	0*
16A	Spring	2007	American eel	440.6	237.4	16.9	9.5
			Bigmouth sleeper	492.4	32.9	27.8	3.5
			Mountain mullet	7,737.3	605.2	11.4	0.9
			River goby	7,785.4	871.9	15.2	1.9
			Smallscaled spinycheek sleeper	485.1	0*	2.0	0*
19A	Spring	2007	Bigmouth sleeper	15.7	0*	1.8	0*
			Guppy	94.2	0*	0.01	0*
			Mexican molly	2,738.1	188.0	2.1	0.7
			Mountain mullet	1,043.2	36.2	27.8	1.7
			Mozambique tilapia	314.0	0*	3.6	0*
			River goby	483.7	170.5	15.5	9.4
			Rosy barb	566.9	52.3	0.4	0.1
			Sirajo goby	119.0	55.0	0.3	0.1
22A	Fall	2006	Mexican molly	2,134.5	304.8	1.3	0.2
			River goby	39.4	25.7	1.1	0.7
			Sirajo goby	60.8	56.1	0.2	0.1
22B	Fall	2006	Guppy	211.5	79.8	0.03	0
			Mexican molly	260.4	0*	0.2	0*
			Mountain mullet	366.5	180.8	8.3	2.6
			River goby	155.3	180.2	2.0	2.4
23A	Fall	2006	Guppy	24.9	0	0.004	0
			Mexican molly	1,321.0	153.3	1.1	0.1
			River goby	492.3	39.8	2.9	0.5
			Sirajo goby	369.1	181.2	0.4	0.1
28A	Summer	2005	Guppy	63.0	7.3	0.03	0
			River goby	20.5	0*	0.9	0*
			Sirajo goby	3,011.7	336.0	12.1	1.2
28A	Fall	2005	River goby	23.5	0	1.2	0
			Sirajo goby	2,166.0	674.9	12.1	1.1
28A	Spring	2006	Green swordtail	116.5	0*	0.1	0*
			Guppy	69.9	0*	0.001	0*

Table 12 continued

Site Number	Season	Year	Species	Density (fish/ha)	Density SE (fish/ha)	Biomass (kg/ha)	Biomass SE (kg/ha)
28A	Spring	2006	River goby	56.8	9.6	2.3	0.5
			Sirajo goby	11,475.0	374.5	14.8	1.4
28B	Summer	2005	American eel	79.4	40.8	12.5	5.2
			Bigmouth sleeper	134.4	44.3	9.3	2.6
			Mountain mullet	4,015.0	676.0	94.0	17.9
			River goby	329.0	0*	3.3	0*
			Sirajo goby	395.0	0*	2.8	0*
28B	Fall	2005	American eel	95.4	40.8	22.2	12.1
			Bigmouth sleeper	233.0	10.0	20.5	2.1
			Mountain mullet	2,231.0	11.3	70.4	1.5
			River goby	62.3	22.8	3.5	2.3
			Sirajo goby	378.0	192.6	2.0	1.2
28B	Spring	2006	American eel	55.2	0	6.8	0.4
			Bigmouth sleeper	294.5	145.7	30.6	30.2
			Mountain mullet	3,212.0	15.3	95.6	2.6
			River goby	295.0	132.7	7.0	3.2
			Sirajo goby	3,029.0	234.5	2.1	0.2
28C	Summer	2005	American eel	462.0	1,110.0	151.1	365.5
			Bigmouth sleeper	759.0	1,346.5	113.0	116.4
			Mountain mullet	3,159.0	477.9	225.5	30.7
			River goby	498.0	324.8	31.1	10.0
			Sirajo goby	18.5	0	0.3	0
28C	Fall	2005	American eel	188.3	50.8	21.7	4.4
			Bigmouth sleeper	736.0	63.3	62.3	4.2
			Mountain mullet	2,746.0	56.3	142.6	3.7
			River goby	758.0	158.1	1.4	2.6
			Sirajo goby	181.0	0*	1.2	0*
28C	Spring	2006	American eel	246.4	17.4	48.4	4.5
			Bigmouth sleeper	1,710.0	46.5	100.2	13.7
			Mountain mullet	5,083.8	22.1	286.0	8.6
			River goby	787.9	103.0	19.3	4.6
			Sirajo goby	3,844.0	35.5	1.4	0.1
28D	Summer	2005	American eel	388.9	236.1	182.9	139.8
			Bigmouth sleeper	2,681.0	3,580.5	250.7	369.9
			Mountain mullet	4,026.5	488.6	177.6	28.7
			River goby	307.6	21.3	6.9	0.6
			Sirajo goby	624.7	32.3	1.6	0.2
			Smallscaled spinycheek sleeper	49.7	0*	2.2	0*
28D	Fall	2005	American eel	60.9	29.1	12.7	6.8
			Bigmouth sleeper	962.0	19.6	38.5	1.3
			Mountain mullet	1,968.0	20.4	38.6	1.3
			River goby	705.0	22.2	5.9	0.4
			Sirajo goby	770.0	110.1	3.3	0.5
			Smallscaled spinycheek sleeper	90.9	8.3	4.2	0.7
28D	Spring	2006	American eel	53.5	5.1	4.0	0.8
			Bigmouth sleeper	466.6	33.3	28.4	2.5
			Mountain mullet	17,087.0	255.4	118.4	3.2

Table 12 continued

Site Number	Season	Year	Species	Density (fish/ha)	Density SE (fish/ha)	Biomass (kg/ha)	Biomass SE (kg/ha)
28D	Spring	2006	River goby	592.7	28.8	3.8	0.3
			Sirajo goby	9,080.9	55.2	6.9	0.2
			Smallscaled spinycheek sleeper	212.1	257.2	7.0	8.5
28E	Fall	2006	Bigmouth sleeper	112.6	104.0	7.9	5.4
			Mountain mullet	1,127.8	15.7	13.5	0.7
			River goby	955.0	52.6	5.1	0.4
			Sirajo goby	259.3	6.2	0.4	0
29A	Fall	2006	American eel	251.4	90.7	19.0	4.7
			Bigmouth sleeper	903.5	58.3	46.3	1.9
			Burro grunt	379.1	66.1	16.3	2.4
			Mountain mullet	8,426.7	856.5	113.5	20.7
			River goby	1,046.6	125.4	9.8	1.1
			Sirajo goby	3,238.1	175.4	15.7	1.0
30A	Fall	2006	Guppy	11.8	0*	0.005	0*
			Mountain mullet	537.9	725.6	18.4	25.1
			River goby	75.0	12.3	1.4	0.3
			Sirajo goby	145.1	8.4	0.4	0.1
31A	Fall	2006	American eel	64.1	16.3	9.7	1.0
			Bigmouth sleeper	477.8	61.6	29.9	2.9
			Burro grunt	26.0	0	1.9	0.1
			Mountain mullet	2,622.4	404.2	22.6	1.8
			Mozambique tilapia	34.8	6.8	3.5	0.6
			River goby	324.4	291.3	4.3	3.6
			Sirajo goby	350.6	34.0	1.9	0.2
			Smallscaled spinycheek sleeper	78.0	0*	0.9	0*
32A	Fall	2006	Channel catfish	2,693.9	795.8	187.1	28.1
			Green swordtail	22.0	0*	0.02	0*
			Guppy	22,586.8	175,045.2	3.1	24.3
			Mexican molly	10,237.3	4,698.1	16.5	11.3
			Mozambique tilapia	415.0	793.5	5.1	6.3
32B	Fall	2006	Amazon sailfin catfish	130.2	27.4	75.0	18.5
			Bigmouth sleeper	308.6	159.4	22.9	11.0
			Guppy	322.4	23.4	0.1	0
			Largemouth bass	9.4	0*	15.5	0*
			Mountain mullet	3,796.9	18,354.5	117.7	545.2
			Mozambique tilapia	56.4	0*	6.2	0*
			River goby	28.2	0*	1.1	0*
			Smallscaled spinycheek sleeper	276.0	305.5	5.4	6.0
			White mullet	18.8	0	4.8	0.3
32C	Fall	2006	American eel	32.9	3.8	3.4	0.5
			Bigmouth sleeper	374.7	32.4	49.2	11.7
			Mountain mullet	2,299.4	284.4	83.9	17.0
			Mozambique tilapia	299.6	0*	29.8	0*
			River goby	157.1	245.9	5.9	9.5
			Smallscaled spinycheek sleeper	128.4	0*	2.4	0*
33A	Fall	2006	American eel	67.9	6.1	18.6	1.2
			Channel catfish	16.6	0	9.1	0

Table 12 continued

Site Number	Season	Year	Species	Density (fish/ha)	Density SE (fish/ha)	Biomass (kg/ha)	Biomass SE (kg/ha)
33A	Fall	2006	Mozambique tilapia	66.4	0*	13.9	0*
			River goby	43.6	6.8	0.6	0.3
			Sirajo goby	2,994.6	14,295.6	15.0	72.2
34A	Fall	2006	American eel	22.1	0	2.4	0
			Green swordtail	1,127.1	0*	1.2	0*
			Guppy	176.8	0*	0.04	0*
			Smallscaled spinycheek sleeper	311.2	230.1	5.4	4.2
35A	Summer	2005	Largemouth bass	452.8	395.0	20.8	19.7
			River goby	15.3	0	1.0	0
			Sirajo goby	180.6	10.4	3.1	0.2
35A	Fall	2005	Largemouth bass	397.9	104.9	24.1	4.0
			River goby	50.8	0	2.7	1.7
			Sirajo goby	308.9	174.8	4.3	4.3
35A	Spring	2006	Green swordtail	22.6	0	0.01	0
			Guppy	22.6	0	0.001	0
			Largemouth bass	807.0	26.9	83.9	3.9
			Mozambique tilapia	22.6	0	3.7	0
			River goby	90.5	0*	10.0	0*
			Sirajo goby	208.0	51.1	4.2	1.7
35B	Summer	2005	American eel	157.0	142.3	44.1	43.4
			Bigmouth sleeper	90.6	19.2	8.6	1.1
			Bluegill	7.5	0*	1.0	0*
			Mountain mullet	758.5	25.9	20.1	2.4
			River goby	82.6	18.7	2.1	0.8
35B	Fall	2005	American eel	70.1	14.8	10.3	3.4
			Bigmouth sleeper	287.0	141.9	29.2	19.5
			Burro grunt	6.9	0	10.3	0
			Green swordtail	13.8	0*	0.02	0*
			Mountain mullet	474.6	103.3	18.3	4.9
			Mozambique tilapia	6.9	0	2.0	0
			River goby	90.1	37.5	1.9	0.2
			Smallscaled spinycheek sleeper	7.5	0	0.3	0
35B	Spring	2006	American eel	169.0	119.4	32.0	28.6
			Bigmouth sleeper	347.0	25.1	26.6	2.9
			Burro grunt	6.8	0	10.1	0
			Green swordtail	6.8	0	0.003	0
			Mountain mullet	1,947.9	88.0	48.4	2.4
			Mozambique tilapia	6.8	0	1.1	0
			River goby	974.0	111.8	15.3	5.0
			Sirajo goby	20.4	0*	0.1	0*
35C	Summer	2005	Green swordtail	1,044.0	1,050.7	0.6	0.7
			Guppy	56.3	0*	0.01	0*
			Sirajo goby	37.5	0	1.5	0.3
35C	Fall	2005	Green swordtail	117.8	0*	0.1	0*
			Guppy	16.8	0	0.003	0
			Sirajo goby	74.8	64.8	1.5	1.5
35C	Spring	2006	Green swordtail	1,599.0	144.5	0.6	0.2

Table 12 continued

Site Number	Season	Year	Species	Density (fish/ha)	Density SE (fish/ha)	Biomass (kg/ha)	Biomass SE (kg/ha)
35C	Spring	2006	Guppy	484.0	102.6	0.1	0
			River goby	25.4	0	5.8	0
			Sirajo goby	76.1	0*	2.5	0*
35D	Summer	2005	American eel	15.3	0	1.9	0
			Bigmouth sleeper	107.0	0*	13.1	0*
			Green swordtail	18.8	0	0.002	0
			Mountain mullet	4,761.7	827.3	158.4	82.6
			River goby	122.3	0*	3.1	0*
			Sirajo goby	76.5	0*	1.8	0*
35D	Fall	2005	Bigmouth sleeper	261.0	19.0	27.7	1.6
			Mountain mullet	1,565.7	84.7	46.5	5.0
			River goby	86.8	24.6	1.9	0.8
			Sirajo goby	189.6	34.7	2.3	0.6
35D	Spring	2006	Bigmouth sleeper	139.4	50.8	37.5	24.3
			Green swordtail	20.5	0	0.02	0
			Mountain mullet	2,807.0	23.5	44.5	3.6
			River goby	265.6	3.1	4.1	0.3
			Sirajo goby	82.4	4.8	1.6	0.4
35E	Summer	2005	American eel	63.8	23.3	16.3	2.6
			Bigmouth sleeper	324.6	174.2	41.4	18.8
			Mountain mullet	4,289.9	1,027.2	172.7	34.4
			Mozambique tilapia	37.6	32.6	10.6	10.4
			River goby	224.9	0*	62.5	0*
			Sirajo goby	13.9	4.7	0.1	0.1
35E	Fall	2005	American eel	9.5	0	5.4	0
			Bigmouth sleeper	186.2	38.8	34.1	13.7
			Green swordtail	75.9	0*	0.1	0*
			Mountain mullet	2,896.0	296.0	66.3	4.7
			Mozambique tilapia	26.1	27.0	0.7	0.9
			River goby	248.9	91.2	6.6	2.9
			Sirajo goby	57.4	74.6	1.2	1.7
35E	Spring	2006	American eel	45.9	0	11.1	0.7
			Bigmouth sleeper	287.9	25.0	30.0	4.8
			Green swordtail	775.1	34.5	1.1	0.1
			Guppy	76.5	0	0.01	0
			Mountain mullet	10,544.0	48.4	183.0	4.3
			Mozambique tilapia	76.5	0*	3.9	0*
			River goby	1,544.0	17.6	37.0	2.1
			Sirajo goby	94.6	10.0	0.8	0.1
			Smallscaled spinycheek sleeper	15.3	0*	1.1	0*
35F	Summer	2005	American eel	55.6	48.2	10.0	8.7
			Bigmouth sleeper	141.1	37.4	14.8	2.2
			Mountain mullet	2,314.4	247.8	82.6	18.2
			Mozambique tilapia	41.7	0*	3.2	0*
			River goby	69.5	0*	1.2	0*
			Sirajo goby	13.9	0	0.2	0
			Smallscaled spinycheek sleeper	166.8	0*	5.7	0*

Table 12 continued

Site Number	Season	Year	Species	Density (fish/ha)	Density SE (fish/ha)	Biomass (kg/ha)	Biomass SE (kg/ha)
35F	Fall	2005	American eel	220.8	83.9	26.1	15.4
			Bigmouth sleeper	339.0	72.1	33.1	9.8
			Mountain mullet	2,379.0	355.1	54.5	5.0
			Mozambique tilapia	108.2	39.6	8.3	2.6
			River goby	153.4	0*	4.9	0*
			Sirajo goby	13.9	0	0.3	0
			Smallscaled spinycheek sleeper	185.6	29.6	6.8	1.3
35F	Spring	2006	American eel	37.8	28.7	4.5	2.2
			Bigmouth sleeper	305.5	57.3	17.6	4.9
			Green swordtail	90.0	0*	0.2	0*
			Guppy	10.1	0	0.001	0
			Mountain mullet	2,117.9	51.7	28.8	1.3
			River goby	197.4	22.3	4.4	0.9
			Sirajo goby	20.2	0	0.5	0
			Smallscaled spinycheek sleeper	104.9	162.9	3.8	6.0
35G	Summer	2005	American eel	13.9	0	1.1	0
			Bigmouth sleeper	137.4	142.4	15.9	20.2
			Mountain mullet	2,074.3	121.9	34.6	2.5
			River goby	167.1	12.4	1.8	0.2
			Sirajo goby	195.8	86.5	2.7	1.3
35G	Fall	2005	American eel	59.7	0	13.3	2.6
			Bigmouth sleeper	347.0	87.6	17.4	1.5
			Green swordtail	106.0	0*	0.1	0*
			Guppy	11.8	0*	0.001	0*
			Mountain mullet	1,612.0	182.9	22.1	1.1
			River goby	180.9	182.9	9.4	11.7
			Sirajo goby	149.7	36.5	1.9	0.6
			Smallscaled spinycheek sleeper	25.7	8.7	2.2	0.8
35G	Spring	2006	American eel	57.5	0*	6.3	0*
			Bigmouth sleeper	734.1	332.2	26.7	25.0
			Green swordtail	18,018.0	73,885.2	19.5	79.8
			Guppy	86.2	0	0.01	0
			Mountain mullet	3,537.0	22.5	38.9	1.8
			River goby	544.5	83.4	14.4	7.6
			Sirajo goby	453.8	205.6	7.6	2.6
			Smallscaled spinycheek sleeper	28.7	0*	1.5	0*
35H	Summer	2005	American eel	11.6	0	0.5	0
			Bigmouth sleeper	25.3	8.6	4.1	1.7
			Burro grunt	11.6	0	17.4	0
			Mountain mullet	670.4	1,825.0	7.5	20.8
			Smallscaled spinycheek sleeper	34.8	0*	0.7	0*
35H	Fall	2005	American eel	47.6	0	2.5	0.7
			Bigmouth sleeper	95.2	24.5	5.4	2.5
			Fat snook	11.9	0*	1.9	0*
			Mountain mullet	57.0	29.5	1.2	0.4
			River goby	47.6	0*	0.3	0*
			Smallscaled spinycheek sleeper	154.7	0*	2.7	0*

Table 12 continued

Site Number	Season	Year	Species	Density (fish/ha)	Density SE (fish/ha)	Biomass (kg/ha)	Biomass SE (kg/ha)
35H	Spring	2006	American eel	11.6	0*	0.3	0*
			Bigmouth sleeper	86.9	172.5	7.7	16.4
			Burro grunt	13.1	0	0.3	0
			Fat snook	13.1	0	0.2	0
			Mountain mullet	24.6	6.1	0.2	0.1
			River goby	59.9	93.1	1.0	1.7
			Smallscaled spinycheek sleeper	91.7	0*	1.2	0*
36A	Fall	2006	American eel	1,138.7	1,764.1	31.2	34.4
			Bigmouth sleeper	204.8	57.0	10.0	4.2
			Burro grunt	34.9	11.8	0.9	0.3
			Mountain mullet	2,000.5	510.7	13.7	4.3
			River goby	133.6	155.0	0.5	0.6
			Sirajo goby	180.7	248.0	0.8	1.1
			Smallscaled spinycheek sleeper	511.5	370.2	4.8	6.0
37A	Fall	2006	American eel	40.1	3.6	5.6	0.3
			Bigmouth sleeper	47.1	15.1	8.1	4.5
			Burro grunt	28.6	26.5	3.2	3.0
			Channel catfish	9.8	0*	0.01	0*
			Green swordtail	9.8	0	0.003	0
			Guppy	29.4	0	0.003	0
			Mountain mullet	677.5	42.5	10.4	0.6
			Nile tilapia	9.8	0*	2.8	0*
			River goby	447.4	63.8	5.4	1.3
			Sirajo goby	143.5	30.4	0.4	0.2
37B	Fall	2006	American eel	50.6	20.7	18.4	9.3
			Bigmouth sleeper	34.2	14.6	9.2	3.0
			Burro grunt	11.8	0	1.7	0.1
			Channel catfish	5.9	0*	0.04	0*
			Green swordtail	5.9	0	0.01	0
			Guppy	66.6	91.5	0.01	0
			Mountain mullet	1,004.2	38.5	19.6	1.4
			Mozambique tilapia	17.7	0*	3.7	0*
			River goby	371.4	28.9	5.2	0.7
			Sirajo goby	236.3	425.6	1.7	2.2
37C	Fall	2006	Mountain mullet	1,758.8	178.8	18.0	2.4
			River goby	38.5	0	0.5	0
			Sirajo goby	2,105.3	246.6	7.9	2.4
37D	Fall	2006	Sirajo goby	2,982.1	199.7	21.1	1.3
37E	Fall	2006	Mountain mullet	2,826.8	42.1	109.9	6.2
			River goby	650.2	525.5	21.0	12.8
			Sirajo goby	24,662.7	37,577.7	25.5	26.6
37F	Fall	2006	Guppy	591.6	0*	0.1	0*
			River goby	23.2	0*	2.7	0*
			Sirajo goby	75.8	14.9	0.1	0
38A	Fall	2006	Green swordtail	2,866.8	528.8	2.0	0.4
			Guppy	3,684.4	0*	0.8	0*
38B	Fall	2006	Green swordtail	2,495.2	4,866.0	2.2	4.1

Table 12 continued

Site Number	Season	Year	Species	Density (fish/ha)	Density SE (fish/ha)	Biomass (kg/ha)	Biomass SE (kg/ha)
38B	Fall	2006	Guppy	586.2	16.5	0.1	0
			Mexican molly	74.4	0*	0.2	0*
			Mozambique tilapia	55.8	0	10.5	0
			River goby	74.4	0*	2.8	0*
38C	Fall	2006	Bigmouth sleeper	19.4	0	0.6	0
			Guppy	21.1	7.2	0.002	0
			Mountain mullet	94.1	0*	1.2	0*
			River goby	56.7	52.4	2.9	2.8
			Smallscaled spinycheek sleeper	78.7	4.0	4.6	0.6
38D	Fall	2006	Bigmouth sleeper	18.4	0	4.1	0
			Largemouth bass	9.2	0*	2.3	0*
			Mountain mullet	119.6	0*	5.1	0*
			River goby	9.2	0*	0.4	0*
			Sirajo goby	53.8	49.7	0.1	0.1
			Smallscaled spinycheek sleeper	504.6	363.7	11.7	8.9
38E	Fall	2006	Guppy	511.9	17.9	0.1	0
			Mexican molly	59,673.2	42,764.5	116.7	153.4
			Mountain mullet	129.8	15.1	2.5	1.1
			River goby	42.2	0*	0.7	0*
40A	Summer	2006	Green swordtail	5,192.1	3,868.9	3.5	2.6
			Guppy	2,101.6	2,050.3	0.3	0.3
			Mexican molly	17,656.1	2,186.6	24.1	4.7
41A	Summer	2006	Green swordtail	1,777.2	277.7	1.8	0.3
			Guppy	94.8	0*	0.01	0*
			Mexican molly	49,184.7	884.5	116.1	2.2
41B	Summer	2006	Green swordtail	166.5	0*	0.3	0*
			Guppy	236.8	177.9	0.04	0
			Mexican molly	10,006.1	1,390.6	27.7	3.9
41C	Summer	2006	Green swordtail	4,215.8	188.4	4.0	0.3
			Guppy	735.3	120.7	0.1	0
			Mexican molly	15,075.4	705.9	22.3	1.3
41D	Summer	2006	Convict cichlid	4,622.0	1,028.3	64.5	14.1
			Green swordtail	271.2	111.7	0.4	0.2
			Guppy	138.1	17.7	0.03	0
			Mexican molly	16,570.7	922.7	66.5	4.4
			Rosy barb	255.3	344.3	1.3	1.7
41E	Summer	2006	Green swordtail	282.2	0*	0.3	0*
			Guppy	322.8	46.0	0.1	0
			Mexican molly	7,553.2	1,576.1	11.4	2.4
			Sirajo goby	986.4	3,410.6	7.0	24.3
41F	Summer	2006	Green swordtail	294.6	40.7	0.6	0.2
			Guppy	10,015.3	27,939.2	3.6	9.9
42A	Summer	2006	Green swordtail	2,653.1	763.6	2.7	0.8
			Guppy	34,610.2	654.0	9.4	0.2
			Largemouth bass	108.0	0	44.6	2.5
			Mexican molly	10,827.0	750.7	16.6	1.5
			Redbreast sunfish	1,873.7	635.9	98.5	20.8

Table 12 continued

Site Number	Season	Year	Species	Density (fish/ha)	Density SE (fish/ha)	Biomass (kg/ha)	Biomass SE (kg/ha)
42A	Summer	2006	Sirajo goby	252.0	0*	0.3	0*
42B	Summer	2006	Green swordtail	96.3	44.5	0.04	0
			Guppy	129.0	27.3	0.03	0
			Mexican molly	4,412.2	4,946.7	4.8	6.2
			Sirajo goby	2,043.9	325.1	4.3	0.8
42C	Summer	2006	Green swordtail	848.2	211.5	1.3	0.2
			Guppy	11,134.2	232.4	3.9	0.1
			Sirajo goby	343.1	38.8	0.9	0.1
42D	Summer	2006	Guppy	165.4	6.2	0.02	0
			Mexican molly	32.9	0	0.3	0
42E	Summer	2006	Sirajo goby	1,490.9	425.0	2.7	0.8
42F	Summer	2006	Guppy	502.9	13.6	0.2	0
			Sirajo goby	837.0	264.0	5.9	4.8
42G	Summer	2006	Guppy	2,315.5	139.3	0.6	0
			Mozambique tilapia	7.8	0*	0.3	0*
			Sirajo goby	565.2	154.0	3.6	1.2
42H	Summer	2006	American eel	72.3	17.5	27.7	6.0
			Bigmouth sleeper	29.4	0*	8.1	0*
			Mexican molly	814.8	1,261.9	1.8	2.8
			Mountain mullet	279.3	6.7	16.8	0.8
			River goby	509.4	46.5	21.4	1.9
			Sirajo goby	1,845.9	93.8	5.4	0.4
42I	Summer	2006	Green swordtail	281.2	0*	0.5	0*
			Guppy	2,052.3	3,746.8	0.7	1.3
			Mexican molly	21,568.6	406.8	59.4	1.2
			Mozambique tilapia	15.2	0*	3.0	0*
			Sirajo goby	325.1	43.4	0.9	0.2
42J	Summer	2006	American eel	230.7	64.0	26.4	12.2
			Bigmouth sleeper	574.0	134.3	39.8	23.8
			Green swordtail	5.5	0	0.01	0
			Mountain mullet	659.1	9.9	10.7	0.4
			River goby	456.1	129.9	8.4	2.9
			Sirajo goby	667.9	278.1	1.3	0.3
			Smallscaled spinycheek sleeper	5.5	0	0.3	0
43A	Summer	2006	Green swordtail	621.3	60.6	0.5	0.1
			Guppy	715.5	2,110.6	0.3	0.8
			Mexican molly	37,861.4	124,912.5	96.1	340.0
			Mozambique tilapia	617.1	400.7	30.1	21.7
43B	Summer	2006	Guppy	1,221.2	0*	0.5	0*
			Mozambique tilapia	647.1	1,027.2	24.8	16.0
43C	Summer	2006	Green swordtail	12.6	0*	0.03	0*
			Guppy	63.4	2.4	0.01	0
			Mexican molly	9,330.9	370.9	6.7	0.6
			Mozambique tilapia	3,030.4	296.4	17.5	13.4
			River goby	12.6	0	1.5	0
			Sirajo goby	54.9	13.2	0.1	0
44A	Summer	2006	Green swordtail	8,085.2	559.2	4.7	0.4

Table 12 continued

Site Number	Season	Year	Species	Density (fish/ha)	Density SE (fish/ha)	Biomass (kg/ha)	Biomass SE (kg/ha)
44A	Summer	2006	Guppy	5,024.9	176.8	1.0	0.1
			Mexican molly	68,682.0	897.9	46.6	1.0
			Mozambique tilapia	18.5	0	4.4	0
			Redbreast sunfish	18.5	0	5.8	0
			Rosy barb	1,271.6	208.8	1.2	0.2
45A	Spring	2007	Channel catfish	123.6	43.9	1.4	0.5
			Green swordtail	3,196.7	158.1	3.3	0.4
			Guppy	14,392.0	227.8	2.8	0.1
			Mexican molly	474.5	65.4	0.4	0.1
			Mozambique tilapia	21.1	0	0.03	0
			Redbreast sunfish	660.7	9.5	13.3	1.9
			Rosy barb	2,069.0	180.9	3.3	0.3
45B	Spring	2007	Green swordtail	837.3	2,560.0	0.3	1.0
			Guppy	1,305.2	31.6	0.2	0
			Mexican molly	3,730.9	99.8	4.0	0.1
			Mozambique tilapia	22.4	7.6	5.0	2.0
			River goby	10.3	0	0.4	0
46A	Spring	2007	Amazon sailfin catfish	66.0	12.9	50.0	11.2
			American eel	60.6	0	3.5	0.3
			Bigmouth sleeper	529.3	16.5	36.1	2.4
			Green swordtail	101.0	0*	0.2	0*
			Guppy	60.8	1.6	0.01	0
			Mountain mullet	205.3	22.4	5.8	0.7
			Mozambique tilapia	42.2	7.5	6.8	3.2
			River goby	761.9	102.0	10.0	4.9
			Sirajo goby	10.1	0	0.1	0
			Smallscaled spinycheek sleeper	70.7	0*	0.6	0*

Table 13. Geographic characteristics of sites where the six native predominantly freshwater fish species of Puerto Rico were sampled from 81 sampling sites during summer 2005 through spring 2007.

Characteristic	American eel	Bigmouth sleeper	Mountain mullet	River goby	Sirajo goby	Smallscaled spinycheek sleeper
Number of sites	32	35	41	54	50	25
Elevation (m)						
Mean	54.0	55.6	64.3	92.2	157.8	31.3
SE	48.2	47.0	51.8	92.5	162.7	22.0
Min.–max.	4.6–200.0	4.6–200.0	4.6–207.6	4.6–426.2	11.3–702.4	4.6–110.6
Gradient (%)						
Mean	1.5	1.5	1.8	2.6	3.1	1.0
SE	1.4	1.4	1.8	4.6	4.8	1.2
Min.–max.	0.1–5.2	0.1–5.2	0.1–7.8	0.1–23.4	0.1–23.4	0.1–5.2
Distance to river mouth (m)						
Mean	16.4	17.5	17.9	19.6	25.3	13.3
SE	12.4	12.5	12.9	13.6	18.5	9.6
Min.–max.	2.5–56.7	2.5–56.7	2.5–56.0	2.5–57.9	2.5–84.2	2.5–42.4
Road density (km/ha)						
Mean	0.038	0.038	0.037	0.037	0.036	0.039
SE	0.012	0.012	0.013	0.013	0.015	0.014
Min.–max.	0.020–0.098	0.020–0.098	0.009–0.098	0.009–0.098	0.001–0.098	0.020–0.098
Watershed area (km^2)						
Mean	27.96	27.69	24.15	21.82	16.35	27.26
SE	23.04	22.59	22.35	20.69	17.61	21.23
Min.–max.	1.72–95.48	1.72–95.48	1.07–78.07	1.07–95.48	1.07–95.48	1.72–77.33

Table 14. Macroinvertebrates sampled at 81 Puerto Rico stream sites from summer 2005 to spring 2007. All species are native to Puerto Rico, except the Australian red-claw crayfish.

Taxonomic group	Scientific name	English common name	Spanish common name	Number of sites
Shrimp	*Atya innocous*	Basket shrimp	Gata chica, chágara	48
	Atya lanipes	Spinning shrimp	Chágara giradora	26
	Atya scabra	Roughback shrimp	Gata grande, guábara	44
	Macrobrachium acanthurus	Cinnamon river shrimp	Camarón de pollar	10
	Macrobrachium carcinus	Bigclaw river shrimp	Camarón de años, viejo	34
	Macrobrachium crenulatum	Striped river shrimp	Coyuntero del Verde, rayao	22
	Macrobrachium faustinum	Bigarm river shrimp	Coyuntero, pelú, popeye	58
	Macrobrachium heterochirus	Cascade river shrimp	Camarón tigre, leopardo	34
	Micratya poeyi	Tiny basket shrimp	Chagarita	32
	Potimirim glabra	Smooth potimirim	Potimirim calva	18
	Xiphocaris elongata	Carrot nose river shrimp	Chirpi, chirpe, salpiche	64
Crab	*Epilobocera sinuatifrones*	Puerto Rican freshwater crab	Buruquena, bruquena	57
	Callinectes sapidus	Blue crab	Cocolía azul, jaiba	1
	Armases roberti	Wetland crab	Juey de humedales, juey de río	1
Crayfish	*Cherax quadricarinatus*	Australian red-claw crayfish	Langostino azul australiano	1

Table 15. Shrimp, crab, and crayfish species sampled at 81 Puerto Rico stream reaches. Sites were sampled from summer 2005 to spring 2007.

	Shrimp											Crab		
Site	*Atya*			*Macrobrachium*					*Micratya*	*Potimirim*	*Xiphocaris*	*Epilobocera*		
number	*innocous*	*lanipes*	*scabra*	*acanthurus*	*carcinus*	*crenulatum*	*faustinum*	*heterochirus*	*poeyi*	*glabra*	*elongata*	*sinuatifrons*	Other	Total
1A											X	X		2
1B														0
1C												X		1
1D	X	X	X				X	X			X	X		7
1E	X		X		X	X	X	X	X	X		X	X[a]	10
2A	X		X		X	X		X	X	X	X	X		9
3A	X	X			X			X			X	X		6
4A					X	X	X	X			X	X		6
4B							X		X		X			3
5A	X				X	X	X	X			X			6
5B				X		X				X	X	X		5
6A	X			X	X	X		X			X	X		7
7A	X		X		X	X	X	X	X		X	X		9
7B			X			X	X		X	X	X	X		7
10A	X	X	X		X	X	X	X		X	X	X		10
11A			X		X		X	X	X	X	X	X		8
13A	X		X				X		X	X	X	X		7
14A				X	X	X	X		X	X	X			7
15A				X		X	X			X				4
16A					X	X	X		X		X		X[b]	6
19A	X		X		X	X	X		X	X		X		8
22A	X	X	X				X				X	X		6
22B	X	X	X		X	X	X		X		X	X		9
23A	X		X		X		X		X		X	X		7
28A	X		X		X		X	X			X	X		7
28B	X		X		X		X	X			X	X		7
28C							X	X			X	X		4
28D					X	X	X	X			X	X		6

Table 15 continued.

Site	Shrimp											Crab		
	Atya			*Macrobrachium*					*Micratya*	*Potimirim*	*Xiphocaris*	*Epilobocera*		
number	*innocous*	*lanipes*	*scabra*	*acanthurus*	*carcinus*	*crenulatum*	*faustinum*	*heterochirus*	*poeyi*	*glabra*	*elongata*	*sinuatifrons*	Other	Total
28E	X		X				X		X		X			5
29A	X						X	X	X	X	X			6
30A	X	X	X		X		X				X	X		7
31A				X	X		X		X	X	X			6
32A												X		1
32B							X				X			2
32C	X			X	X		X	X			X			6
33A	X		X	X	X		X	X	X		X	X		9
34A		X					X					X		3
35A	X	X	X		X		X	X	X		X	X		9
35B		X	X		X	X	X	X	X	X	X	X		10
35C	X	X	X					X			X	X		6
35D	X		X		X	X	X		X	X	X	X		9
35E	X				X				X	X	X	X		6
35F	X		X		X		X	X	X		X	X		8
35G	X		X			X	X	X	X	X	X	X		9
35H	X			X	X	X	X	X	X	X	X	X	X^c	11
36A	X				X		X		X		X	X		6
37A					X		X		X		X			4
37B							X				X			2
37C	X	X	X		X		X				X			6
37D		X	X								X	X		4
37E	X	X	X					X	X		X	X		7
37F	X	X	X		X		X		X		X	X		8
38A	X	X	X					X			X	X		6
38B	X	X	X		X		X				X	X		7
38C			X	X		X	X		X					5
38D	X			X	X		X	X	X			X		7
38E	X						X			X		X		4

Table 15 continued.

	Shrimp											Crab		
Site	*Atya*			*Macrobrachium*					*Micratya*	*Potimirim*	*Xiphocaris*	*Epilobocera*		
number	*innocous*	*lanipes*	*scabra*	*acanthurus*	*carcinus*	*crenulatum*	*faustinum*	*heterochirus*	*poeyi*	*glabra*	*elongata*	*sinuatifrons*	Other	Total
40A	X	X	X								X			4
41A											X	X		2
41B											X	X		2
41C	X	X									X	X		4
41D	X		X				X					X		4
41E	X	X	X				X				X			5
41F	X						X					X		3
42A												X		1
42B	X	X	X					X			X	X		6
42C		X	X				X	X			X	X		6
42D	X	X	X								X	X		5
42E	X	X	X				X	X			X			6
42F		X	X					X			X			4
42G	X	X	X				X	X	X		X	X		8
42H			X				X		X		X			4
42I	X		X				X				X			4
42J							X	X	X		X			4
43A	X	X	X				X				X	X		6
43B												X		1
43C	X		X				X	X			X	X		6
44A												X		1
45A							X					X		2
45B	X		X		X	X	X	X			X			7
46A						X	X							2
Total	48	26	44	10	34	22	58	34	32	18	64	57	3	

[a] *Cherax quadricarinatus*; non-native Australian red-claw crayfish

[b] *Callinectes sapidus*; blue crab, cocolía azul; more commonly found in brackish environments

[c] *Armases roberti*; a semiterrestrial crab, found along steep river banks

Table 16. Water quality analyses from 81 Puerto Rico river sampling sites during 2005-2007 surveys.

Site	Season	Year	Water temperature (°C)	Total dissolved solids (g/L)	Conduct-ivity (µS/cm)	Salinity (ppt)	Nitrate (mg/L as NO_3^-)	Nitrite (mg/L as NO_2^-)	Ammonia (NH_3)	Phos-phorous (mg/L as PO_4^-)	Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Turbidity (FAU)	pH	Dissolved oxygen (mg/L)
1A	Spring	2007	23.06	0.260	400	0.19	1.9	0.028	0.11	0.11	163	170	5	8.24	7.89
1B	Spring	2007	25.99	0.320	492	0.24	5.3	0.910	0.02	1.21	201	159	11	7.85	5.47
1C	Spring	2007	22.03	0.311	478	0.23	2.1	0.101	0.02	0.21	170	191	7	7.71	8.43
1D	Spring	2007	23.41	0.384	590	0.29	0.1	0.034	0.00	0.12	44	45	6	7.72	6.21
1E	Spring	2007	22.76	0.161	248	0.12	1.0	0.000	0.09	0.29	90	90	5	8.20	8.01
2A	Spring	2007	23.18	0.146	224	0.11	0.6	0.001	0.01	0.25	85	78	14	8.08	7.58
3A	Spring	2007	20.27	0.038	59	0.03	0.7	0.010	0.01	0.33	17	14	8	7.68	11.11
4A	Spring	2007	23.41	0.192	296	0.14	2.5	0.009	0.10	0.07	118	118	3	8.28	6.88
4B	Spring	2007	21.68	0.083	129	0.06	0.1	0.000	0.00	0.94	248	237	7	7.70	7.87
5A	Spring	2007	23.66	0.115	177	0.08	5.2	0.130	0.03	0.47	68	64	0	8.80	8.08
5B	Spring	2007	24.09	0.113	173	0.08	4.7	0.001	0.50	0.13	54	46	0	7.55	6.84
6A	Spring	2007	23.54	0.300	432	0.21	2.4	0.027	0.02	0.20	155	130	0	7.82	5.07
7A	Spring	2007	23.24	0.090	138	0.06	9.0	0.015	0.50	0.39	58	44	0	7.87	8.49
7B	Spring	2007	22.80	0.094	144	0.07	9.3	0.025	0.01	0.30	43	39	0	7.79	7.01
10A	Spring	2007	25.90	0.103	159	0.07	0.8	0.000	0.10	0.44	32	42	0	7.68	7.10
11A	Spring	2007	23.66	0.189	291	0.14	8.5	0.022	0.50	1.98	120	114	0	8.50	8.80
13A	Spring	2007	22.73	0.105	169	0.08	3.3	0.011	0.10	0.37	50	41	4	8.19	8.06
14A	Spring	2007	24.23	0.120	185	0.09	0.9	0.003	0.00	0.37	64	51	3	7.47	8.01
15A	Spring	2007	24.68	0.188	290	0.14	1.5	0.223	0.50	1.32	97	93	3	8.02	6.14
16A	Spring	2007	29.23	0.177	272	0.13	5.8	0.023	0.02	0.21	90	81	0	7.89	7.40
19A	Spring	2007	23.27	0.383	589	0.29	2.9	0.000	0.13	0.25	232	228	8	8.18	6.23
22A	Fall	2006	22.37	0.260	400	0.19	0.0	0.019	0.00	2.75	195	192	10	8.72	8.62
22B	Fall	2006	26.74	0.304	468	0.22	0.0	0.035	0.02	0.85	204	205	14	8.67	7.85
23A	Fall	2006	24.08	0.507	780	0.38	6.0	0.020	0.00	2.75	277	280	6	8.77	7.70
28A	Summer	2005	25.95	0.198	305	0.14	1.4	0.007	0.01	0.17	140	158	9	7.95	8.00
28A	Fall	2005	22.72	0.228	351	0.17	1.8	0.000	0.00	0.09	163	182	7	8.46	8.95
28A	Spring	2006	24.60	0.245	377	0.18	1.7	0.048	0.13	0.07	142	156	10	8.86	8.53

Table 16 continued.

Site	Season	Year	Water temperature (°C)	Total dissolved solids (g/L)	Conduct-ivity (µS/cm)	Salinity (ppt)	Nitrate (mg/L as NO_3^-)	Nitrite (mg/L as NO_2^-)	Ammonia (NH_3)	Phos-phorous (mg/L as PO_4^-)	Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Turbidity (FAU)	pH	Dissolved oxygen (mg/L)
28B	Summer	2005	25.49	0.198	295	0.14	1.6	0.004	0.04	0.05	129	135	6	8.41	7.60
28B	Fall	2005	23.37	0.239	368	0.18	0.4	0.012	0.00	0.34	157	163	15	8.05	8.65
28B	Spring	2006	22.44	0.245	377	0.18	1.6	0.068	0.04	0.16	164	172	3	8.47	8.92
28C	Summer	2005	26.54	0.244	376	0.18	1.9	0.016	0.04	0.32	160	164	13	8.19	7.93
28C	Fall	2005	24.56	0.327	503	0.24	5.8	0.092	0.12	0.13	160	172	9	8.25	7.67
28C	Spring	2006	25.69	0.294	453	0.22	2.2	0.152	0.00	0.43	187	204	7	8.64	6.80
28D	Summer	2005	27.07	0.294	452	0.22	0.1	0.002	0.00	0.03	149	172	4	8.11	8.12
28D	Fall	2005	25.63	0.364	560	0.27	0.4	0.000	0.18	0.00	147	163	17	8.11	8.99
28D	Spring	2006	20.51	0.240	369	0.18	3.6	0.000	0.00	0.54	164	176	6	8.56	9.28
28E	Fall	2006	25.60	0.378	582	0.28	0.0	0.890	0.04	0.68	251	253	3	8.81	8.81
29A	Fall	2006	22.74	0.237	365	0.17	11.0	0.053	0.01	2.75	170	171	7	8.66	9.41
30A	Fall	2006	23.35	0.323	496	0.24	0.0	0.000	0.03	2.75	213	230	6	8.81	8.10
31A	Fall	2006	29.97	0.264	407	0.19	0.0	0.073	0.01	0.23	137	165	10	9.18	10.98
32A	Fall	2006	23.69	0.228	351	0.17	4.0	0.039	0.05	0.04	152	158	5	8.89	8.55
32B	Fall	2006	24.53	0.333	512	0.25	4.4	0.037	0.00	0.51	200	170	4	8.81	5.98
32C	Fall	2006	24.88	0.265	408	0.19	0.0	0.030	0.04	0.36	181	187	3	8.72	7.60
33A	Fall	2006	24.95	0.191	294	0.14	0.0	0.048	0.10	0.34	127	131	4	8.48	4.12
34A	Fall	2006	26.01	0.433	668	0.32	0.0	0.022	0.02	0.77	223	248	8	8.25	5.00
35A	Summer	2005	23.26	0.147	226	0.11	0.4	0.021	0.19	0.90	109	112	5	8.00	7.96
35A	Fall	2005	21.11	0.137	211	0.11	4.0	0.018	0.00	0.42	103	107	0	8.53	8.07
35A	Spring	2006	23.79	0.147	225	0.11	12.6	0.007	0.00	0.05	94	110	5	9.21	9.25
35B	Summer	2005	24.84	0.181	278	0.13	0.8	0.003	0.01	0.40	135	134	2	8.29	8.51
35B	Fall	2005	23.80	0.176	271	0.13	1.6	0.058	0.01	2.16	137	148	3	8.20	10.82
35B	Spring	2006	27.16	0.157	241	0.11	3.8	0.042	0.04	2.75	107	109	17	8.68	7.86
35C	Summer	2005	24.86	0.165	253	0.12	1.4	0.049	0.01	0.40	136	143	8	8.26	9.24
35C	Fall	2005	23.36	0.173	266	0.13	3.6	0.009	0.00	0.26	126	133	0	8.60	8.92
35C	Spring	2006	22.69	0.191	294	0.14	0.7	0.053	0.04	0.44	141	153	8	8.42	8.42
35D	Summer	2005	25.12	0.214	329	0.16	1.7	0.053	0.02	1.33	158	162	0	8.30	9.11

Table 16 continued.

Site	Season	Year	Water temperature (°C)	Total dissolved solids (g/L)	Conduct-ivity (µS/cm)	Salinity (ppt)	Nitrate (mg/L as NO_3^-)	Nitrite (mg/L as NO_2^-)	Ammonia (NH_3)	Phos-phorous (mg/L as PO_4^-)	Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Turbidity (FAU)	pH	Dissolved oxygen (mg/L)
35D	Fall	2005	23.89	0.229	353	0.17	2.9	0.022	0.00	0.99	168	181	4	8.62	9.14
35D	Spring	2006	24.45	0.264	406	0.19	7.8	0.132	0.02	1.34	174	204	1	8.81	10.61
35E	Summer	2005	24.42	0.257	395	0.19	1.7	0.005	0.00	0.13	185	207	10	8.19	8.17
35E	Fall	2005	23.90	0.233	343	0.16	2.3	0.028	0.00	0.07	264	173	7	8.52	9.24
35E	Spring	2006	24.39	0.264	406	0.19	6.2	0.031	0.13	0.57	187	242	6	8.81	7.42
35F	Summer	2005	25.80	0.253	390	0.19	1.1	0.011	0.00	0.45	183	202	5	8.20	8.23
35F	Fall	2005	23.58	0.224	345	0.16	2.8	0.012	0.01	0.24	128	177	2	8.50	9.18
35F	Spring	2006	24.56	0.274	421	0.20	8.4	0.028	0.11	0.63	177	206	8	8.70	9.71
35G	Summer	2005	29.35	0.236	363	0.17	2.0	0.012	0.00	0.05	170	178	0	8.27	8.27
35G	Fall	2005	25.90	0.235	362	0.17	1.8	0.000	0.00	0.09	164	179	7	8.58	9.57
35G	Spring	2006	30.20	0.264	406	0.19	1.8	0.076	0.01	2.67	178	202	3	8.72	9.69
35H	Summer	2005	26.50	0.199	306	0.14	1.1	0.008	0.02	0.65	138	149	8	7.71	7.92
35H	Fall	2005	22.30	0.205	315	0.15	1.7	0.026	0.03	1.46	156	161	10	8.14	8.30
35H	Spring	2006	24.88	0.183	283	0.13	0.4	0.023	0.10	0.28	125	129	23	8.71	7.78
36A	Fall	2006	23.12	0.210	322	0.15	6.2	0.013	0.12	0.40	129	133	2	7.05	8.36
37A	Fall	2006	24.84	0.158	244	0.11	14.4	0.026	0.12	0.28	79	88	11	7.64	9.75
37B	Fall	2006	22.10	0.183	282	0.13	4.5	0.043	0.00	0.55	115	125	7	8.61	8.29
37C	Fall	2006	24.11	0.131	202	0.09	1.7	0.029	0.14	0.22	71	79	2	8.24	8.24
37D	Fall	2006	24.11	0.177	272	0.13	11.6	0.036	0.11	0.31	108	117	3	8.36	8.67
37E	Fall	2006	21.52	0.117	181	0.08	11.7	0.004	0.11	0.43	70	77	1	8.25	8.23
37F	Fall	2006	21.35	0.161	248	0.12	8.7	0.060	0.14	0.21	100	114	5	7.74	8.71
38A	Fall	2006	22.37	0.111	170	0.08	2.5	0.106	0.18	0.36	50	55	15	7.73	8.20
38B	Fall	2006	23.68	0.302	465	0.22	7.8	0.019	0.11	0.32	198	220	5	7.55	7.07
38C	Fall	2006	25.67	0.284	437	0.21	1.9	0.015	0.12	0.24	156	160	9	8.05	7.95
38D	Fall	2006	24.72	0.289	444	0.21	0.3	0.001	0.10	0.14	169	180	1	7.70	7.98
38E	Fall	2006	26.18	0.342	528	0.25	3.4	0.035	0.14	0.10	202	218	0	7.99	7.64
40A	Summer	2006	21.97	0.084	129	0.06	8.6	0.035	0.11	2.75	40	42	4	8.34	8.69
41A	Summer	2006	27.63	0.112	173	0.08	6.2	0.174	0.60	1.92	60	64	4	8.95	8.01

Table 16 continued.

Site	Season	Year	Water temperature (°C)	Total dissolved solids (g/L)	Conduct-ivity (µS/cm)	Salinity (ppt)	Nitrate (mg/L as NO_3^-)	Nitrite (mg/L as NO_2^-)	Ammonia (NH_3)	Phos-phorous (mg/L as PO_4^-)	Alkalinity (mg/L as $CaCO_3$)	Hardness (mg/L as $CaCO_3$)	Turbidity (FAU)	pH	Dissolved oxygen (mg/L)
41B	Summer	2006	23.85	0.094	145	0.07	8.5	0.015	0.03	1.94	56	48	5	8.30	8.72
41C	Summer	2006	26.39	0.103	158	0.07	5.9	0.515	0.00	0.11	53	49	4	9.14	7.90
41D	Summer	2006	27.06	0.126	194	0.09	5.7	0.105	0.00	1.64	78	82	6	9.15	6.88
41E	Summer	2006	24.36	0.103	159	0.07	14.7	0.223	0.02	0.20	58	55	12	8.39	8.80
41F	Summer	2006	25.19	0.183	281	0.03	3.2	0.008	0.04	0.10	126	144	2	8.72	8.15
42A	Summer	2006	23.86	0.189	291	0.14	1.7	0.057	0.12	0.21	104	122	19	7.79	8.40
42B	Summer	2006	22.72	0.213	327	0.16	25.8	0.395	0.04	2.75	125	132	33	8.52	8.68
42C	Summer	2006	25.41	0.140	214	0.10	3.6	0.096	0.05	0.07	83	81	6	7.68	8.95
42D	Summer	2006	23.18	0.123	189	0.09	4.5	0.058	0.11	0.30	81	76	3	7.65	8.82
42E	Summer	2006	24.65	0.141	217	0.10	1.4	0.129	0.11	0.17	74	89	5	8.27	8.97
42F	Summer	2006	21.10	0.073	112	0.05	3.1	0.019	0.03	0.18	46	43	1	8.54	8.61
42G	Summer	2006	23.04	0.086	133	0.06	4.2	0.082	0.13	1.48	50	52	9	8.49	9.18
42H	Summer	2006	25.33	0.119	183	0.09	1.3	0.456	0.01	0.25	73	73	2	8.36	8.81
42I	Summer	2006	26.40	0.114	175	0.08	3.8	0.004	0.00	0.09	65	67	8	8.75	10.45
42J	Summer	2006	28.20	0.172	264	0.12	1.6	0.262	0.01	0.46	106	108	7	8.38	8.47
43A	Summer	2006	24.80	0.172	267	0.12	2.3	0.096	0.00	1.12	99	104	11	8.42	8.44
43B	Summer	2006	24.48	0.252	388	0.18	0.0	0.416	0.60	0.50	112	111	52	8.09	4.96
43C	Summer	2006	24.92	0.221	341	0.16	4.5	0.210	0.12	1.20	130	138	6	8.38	8.33
44A	Summer	2006	24.93	0.250	385	0.18	2.1	0.123	0.05	0.31	141	156	0	8.33	8.41
45A	Spring	2007	20.31	0.148	228	0.11	4.5	0.014	0.16	0.09	78	79	8	8.16	7.80
45B	Spring	2007	21.66	0.278	427	0.20	2.2	0.038	0.07	0.55	148	155	8	7.80	8.20
46A	Spring	2007	23.85	0.294	452	0.22	0.2	0.062	0.12	0.49	169	168	5	7.50	7.49
Mean			24.32	0.209	322	0.15	3.7	0.076	0.08	0.65	130	135	6.6	8.29	8.19

Table 17. Land cover composition for 81 Puerto Rico stream sampling sites. Riparian and watershed percentages were calculated for the entire riparian zone and watershed upstream of each site.

	30-m riparian buffer land cover (%)				100-m riparian buffer land cover (%)				Watershed land cover (%)				
Site	Agriculture	Forest	Shrub and woodland	Urban	Agriculture	Forest	Shrub and woodland	Urban	Agriculture	Forest	Freshwater	Shrub and woodland	Urban
1A	0	78.6	21.4	0	28.5	55.5	16.0	0	36.6	42.3	0	15.4	5.7
1B	59.5	28.3	8.8	2.7	63.4	23.1	6.5	6.5	63.3	22.0	0.3	5.6	8.8
1C	41.8	28.7	14.2	15.3	35.2	31.0	13.0	20.8	34.4	32.0	0	12.8	20.9
1D	52.7	36.5	7.5	3.4	53.9	35.6	6.5	4.0	51.0	38.2	0	6.6	4.2
1E	22.0	70.8	5.1	2.1	24.8	68.7	4.1	2.4	26.0	67.6	0	3.8	2.6
2A	44.9	45.3	5.4	4.3	52.9	37.3	4.6	5.2	55.0	33.4	0	4.8	6.8
3A	0.1	99.4	0.5	0	0.1	99.7	0.2	0	0.1	99.8	0	0.2	0
4A	30.7	53.5	6.9	8.9	35.0	46.7	7.7	10.5	33.0	51.6	0	7.0	8.4
4B	8.1	87.4	1.8	0.5	8.4	87.9	1.8	0.9	7.7	89.2	0.2	1.7	0.9
5A	11.2	82.8	3.8	1.6	10.1	84.1	3.9	1.4	10.3	84.0	0	4.1	1.2
5B	20.7	62.3	11.9	3.4	17.9	65.5	10.8	4.0	18.4	67.0	0	10.4	3.3
6A	37.0	50.2	6.8	5.6	35.2	52.4	7.5	4.6	32.0	55.2	0	9.0	3.6
7A	10.0	83.9	6.1	0.1	8.5	86.3	5.1	0.1	6.8	89.5	0	3.7	0.1
7B	25.3	64.7	9.8	0.2	26.2	61.8	10.8	1.1	22.6	66.8	0	9.4	1.1
10A	12.4	79.4	5.6	2.6	11.7	81.5	3.5	3.3	8.3	87.4	0	2.0	2.3
11A	6.4	88.7	4.7	0.2	8.0	87.9	3.8	0.2	4.4	92.2	0	3.1	0.2
13A	37.7	55.9	5.9	0.5	46.3	46.0	5.4	2.3	50.2	41.1	0	5.1	3.6
14A	38.2	53.8	6.7	0	3.9	87.5	7.0	0	39.3	51.5	0	7.3	0
15A	35.4	45.3	8.8	3.8	34.3	46.7	9.6	3.9	33.9	48.1	0	10.4	3.6
16A	24.8	59.0	12.5	2.4	24.4	59.7	12.1	3.1	20.5	64.9	0.1	11.6	2.7
19A	22.0	56.3	20.8	0.9	20.9	59.1	18.7	1.3	22.1	58.6	0	18.1	1.3
22A	22.1	25.5	51.9	0.5	35.3	21.1	42.8	0.8	38.1	23.6	0	37.8	0.5
22B	27.4	24.6	46.7	1.1	42.9	18.0	37.3	1.8	47.1	17.3	0	33.6	2.0
23A	16.6	46.9	32.4	4.1	25.8	36.3	30.2	7.6	22.2	38.1	0	34.1	5.6
28A	52.5	31.7	14.9	0.9	24.9	59.3	14.9	0.9	53.8	30.0	0	15.2	1.0
28B	53.1	30.9	15.3	0.6	29.4	54.2	15.6	0.8	55.2	27.2	0	16.7	0.9
28C	38.1	33.5	26.2	2.2	26.4	43.3	28.1	2.2	41.7	28.8	0	27.9	1.6

Table 17 continued.

	30-m riparian buffer land cover (%)				100-m riparian buffer land cover (%)				Watershed land cover (%)				
Site	Agriculture	Forest	Shrub and woodland	Urban	Agriculture	Forest	Shrub and woodland	Urban	Agriculture	Forest	Freshwater	Shrub and woodland	Urban
28D	31.1	30.1	22.5	16.0	23.5	37.8	24.2	14.3	35.8	28.3	0	26.5	9.2
28E	26.8	33.7	32.9	6.6	28.4	32.4	33.5	5.7	35.8	26.7	0	33.8	3.7
29A	23.9	44.4	29.6	2.1	20.8	51.6	25.0	2.6	29.3	44.8	0	23.6	2.2
30A	11.1	49.9	36.3	2.6	16.8	47.8	31.7	3.6	20.4	48.3	0	28.0	3.2
31A	33.8	35.0	28.0	3.0	26.1	45.2	24.9	3.7	38.3	34.6	0	23.8	3.3
32A	55.0	27.5	17.5	0	17.0	68.5	14.4	0.1	60.1	24.2	0	15.2	0.5
32B	45.0	15.3	18.7	20.6	21.9	54.7	20.1	0.5	47.9	29.8	1.5	20.1	0.8
32C	50.3	20.4	27.0	2.4	20.8	53.4	23.2	2.6	56.0	20.7	0	21.0	2.4
33A	5.1	81.4	10.6	1.3	6.4	78.2	12.6	1.5	10.5	71.6	0.7	15.1	2.2
34A	32.9	51.0	14.2	1.9	38.8	44.8	13.8	2.7	40.4	41.8	0	13.6	4.2
35A	42.6	53.2	4.1	0	1.2	95.9	2.9	0	34.5	62.5	0	3.0	0
35B	50.6	37.6	9.8	1.9	7.1	81.1	9.7	2.1	53.5	34.4	0	10.2	1.8
35C	2.9	89.7	7.4	0	2.4	91.6	6.0	0	3.9	89.1	0	6.9	0.1
35D	23.1	66.3	9.9	0.7	13.0	76.8	9.4	0.8	25.9	62.2	0	10.6	1.2
35E	30.3	59.1	10.0	0.6	22.7	66.1	9.8	1.3	32.2	55.5	0	10.6	1.6
35F	40.5	46.0	11.7	1.8	32.3	53.4	11.7	2.6	43.3	41.8	0	12.1	2.7
35G	27.2	61.1	9.8	1.9	18.7	70.3	9.3	1.7	29.6	60.2	0	8.6	1.7
35H	49.2	18.7	21.1	11.0	55.1	30.7	7.8	6.4	53.5	33.0	0	7.9	5.5
36A	65.0	11.4	3.4	20.2	16.3	61.5	16.2	6.0	63.3	12.4	0	16.0	8.3
37A	68.4	12.1	13.9	1.6	13.6	68.2	14.3	1.7	67.9	14.5	1.1	14.8	1.7
37B	58.8	26.6	13.9	0.4	9.9	75.8	13.7	0.5	58.2	26.6	0	14.5	0.7
37C	71.0	10.3	18.3	0	3.9	79.8	15.9	0.3	68.2	15.6	0	15.1	1.0
37D	13.2	67.0	16.6	3.2	6.0	77.8	15.2	1.0	14.7	66.3	0	16.6	2.4
37E	75.7	9.0	15.2	0.1	7.0	80.1	12.6	0.2	77.9	7.9	0	13.4	0.8
37F	49.9	29.8	19.5	0.9	11.7	71.8	16.5	0	58.1	23.8	0	15.7	2.3
38A	74.7	11.7	13.3	0.4	8.6	74.3	14.8	2.3	71.6	5.4	0	16.6	6.4
38B	74.5	12.3	12.1	1.1	81.5	7.7	8.3	2.5	82.3	7.5	0	6.5	3.6
38C	50.7	38.0	9.4	1.8	59.2	29.0	8.3	3.4	57.0	30.2	0	8.0	4.8
38D	53.2	32.5	7.3	7.0	53.7	29.3	7.1	9.9	48.9	31.6	0	7.8	11.7

Table 17 continued.

	30-m riparian buffer land cover (%)				100-m riparian buffer land cover (%)				Watershed land cover (%)				
Site	Agriculture	Forest	Shrub and woodland	Urban	Agriculture	Forest	Shrub and woodland	Urban	Agriculture	Forest	Freshwater	Shrub and woodland	Urban
38E	0	55.3	22.5	22.2	46.6	26.5	4.6	22.4	47.6	26.6	0	4.5	21.4
40A	70.7	11.6	17.5	0.2	25.3	55.4	18.0	1.3	62.5	15.8	0	18.4	3.3
41A	68.8	14.5	14.5	2.2	15.5	67.3	15.0	2.2	71.5	12.4	0	13.5	2.6
41B	66.7	18.4	14.6	0.3	19.4	65.6	14.3	0.7	60.8	22.8	0	15.3	1.0
41C	82.0	4.2	13.7	0.1	13.1	71.8	14.4	0.7	73.9	6.8	0	16.1	3.1
41D	52.5	37.9	9.3	0.3	10.4	79.7	9.3	0.6	49.8	39.2	0	9.9	1.1
41E	72.7	12.8	13.9	0.6	45.5	36.3	16.6	1.7	61.4	17.5	0	17.4	3.7
41F	3.4	88.2	7.5	0.8	2.4	91.1	5.9	0.5	2.5	92.6	0	4.5	0.4
42A	36.5	30.2	22.0	11.4	9.9	41.2	23.1	25.8	42.3	30.6	0	20.4	6.7
42B	41.6	35.8	21.2	1.4	52.0	27.0	18.0	3.0	57.5	22.7	0	15.8	3.9
42C	48.7	24.1	26.7	0.4	33.3	43.6	22.0	1.1	52.5	25.2	0	20.1	2.2
42D	35.3	41.9	22.4	0.4	35.5	45.1	18.9	0.5	46.3	35.1	0	17.3	1.3
42E	30.5	55.3	14.2	0	29.8	57.1	13.0	0.1	36.4	48.8	0	14.1	0.7
42F	4.2	94.8	1.0	0	0.1	99.2	0.7	0	1.5	96.9	0	1.6	0
42G	56.2	38.9	4.9	0	3.1	90.3	6.7	0	43.2	50.9	0	5.8	0
42H	17.1	65.1	13.8	0.3	22.5	62.8	12.4	0.6	27.3	59.4	0.9	11.6	0.8
42I	57.2	32.5	10.2	0.1	17.6	72.0	10.2	0.1	51.7	38.0	0	9.9	0.5
42J	50.9	31.8	15.8	1.1	34.3	48.2	15.2	2.2	49.5	32.3	0.1	14.8	3.2
43A	32.7	40.3	25.1	1.9	37.2	35.1	23.5	4.2	39.6	29.5	0	23.7	7.1
43B	27.5	50.9	12.2	9.5	34.7	36.7	13.4	15.2	36.5	30.5	0	12.4	20.6
43C	33.7	50.9	11.5	3.9	37.2	44.3	12.3	6.1	38.8	41.3	0	12.6	7.3
44A	40.0	26.6	23.1	10.3	43.5	25.5	18.8	12.2	46.1	25.5	0	18.1	10.3
45A	61.8	28.3	6.5	3.5	44.4	37.5	9.2	8.9	46.0	36.7	0	8.8	8.4
45B	24.7	51.3	15.2	8.5	23.3	50.9	13.4	12.3	25.0	50.0	0.1	13.4	11.6
46A	30.1	31.6	11.1	24.3	27.3	28.8	9.3	33.0	24.8	26.3	0.7	8.8	39.4
Mean	37.4	43.9	14.8	3.5	25.3	56.9	13.6	4.0	40.1	42.1	0.1	13.4	4.2

Table 18. Ownership of the upstream riparian zone and watershed for 81 Puerto Rico stream sampling reaches.

	100-m riparian buffer ownership (%)			Watershed ownership (%)		
Site	Private	Public	Utility and NGO	Private	Public	Utility and NGO
1A	100.0	0	0	98.7	1.3	0
1B	100.0	0	0	100.0	0	0
1C	100.0	0	0	100.0	0	0
1D	90.2	9.8	0	89.3	10.7	0
1E	78.1	21.9	0	76.7	23.3	0
2A	100.0	0	0	100.0	0	0
4A	92.5	7.5	0	94.6	5.4	0
4B	33.7	66.3	0	30.9	69.1	0
5A	44.4	55.6	0	45.0	55.0	0
5B	76.2	23.8	0	79.0	21.0	0
6A	100.0	0	0	100.0	0	0
7A	81.2	18.8	0	76.2	23.8	0
7B	100.0	0	0	100.0	0	0
10A	67.9	32.1	0	57.6	42.4	0
11A	98.4	1.6	0	83.8	16.2	0
13A	100.0	0	0	100.0	0	0
14A	100.0	0	0	100.0	0	0
15A	100.0	0	0	100.0	0	0
16A	100.0	0	0	100.0	0	0
19A	100.0	0	0	100.0	0	0
22A	100.0	0	0	100.0	0	0
22B	100.0	0	0	100.0	0	0
23A	100.0	0	0	100.0	0	0
28A	99.7	0	0.3	99.9	0	0.1
28B	95.3	0	4.7	96.6	0	3.4
28C	96.8	0	3.2	97.7	0	2.3
28D	97.6	0	2.4	98.3	0	1.7
28E	100.0	0	0	100.0	0	0
29A	100.0	0	0	99.7	0.3	0
30A	100.0	0	0	100.0	0	0
31A	100.0	0	0	99.8	0.2	0
32A	100.0	0	0	100.0	0	0
32B	96.8	0	3.2	98.2	0	1.7
32C	96.7	1.1	2.2	97.6	1.1	1.2
33A	62.1	37.9	0	61.7	38.3	0
34A	100.0	0	0	100.0	0	0
35A	41.2	58.8	0	35.5	64.5	0
35B	82.2	17.8	0	81.3	18.7	0
35C	50.0	50.0	0	48.5	51.5	0
35D	73.9	26.1	0	72.2	27.8	0
35E	79.5	20.5	0	78.2	21.8	0
35F	82.2	17.8	0	80.9	19.1	0
35G	82.4	17.6	0	81.4	18.6	0
35H	86.3	13.7	0	85.2	14.8	0

Table 18 continued.

	100-m riparian buffer ownership (%)			Watershed ownership (%)		
Site	Private	Public	Utility and NGO	Private	Public	Utility and NGO
36A	100.0	0	0	100.0	0	0
37A	97.2	2.8	0	95.8	4.2	0
37B	94.5	5.5	0	94.5	5.5	0
37C	100.0	0	0	100.0	0	0
37D	100.0	0	0	100.0	0	0
37E	100.0	0	0	100.0	0	0
37F	100.0	0	0	100.0	0	0
38A	100.0	0	0	100.0	0	0
38B	100.0	0	0	100.0	0	0
38C	100.0	0	0	100.0	0	0
38D	100.0	0	0	100.0	0	0
38E	100.0	0	0	100.0	0	0
3A	0	100.0	0	0	100.0	0
40A	100.0	0	0	100.0	0	0
41A	100.0	0	0	100.0	0	0
41B	100.0	0	0	100.0	0	0
41C	100.0	0	0	100.0	0	0
41D	96.9	0	3.1	97.6	0	2.4
41E	100.0	0	0	100.0	0	0
41F	23.7	76.3	0	27.0	73.0	0
42A	100.0	0	0	100.0	0	0
42B	100.0	0	0	100.0	0	0
42C	100.0	0	0	100.0	0	0
42D	100.0	0	0	100.0	0	0
42E	100.0	0	0	100.0	0	0
42F	0	100.0	0	0	100.0	0
42G	38.5	61.5	0	35.9	64.1	0
42H	76.5	23.5	0	74.6	25.4	0
42I	69.2	30.8	0	68.9	31.1	0
42J	88.5	11.5	0	88.1	11.9	0
43A	100.0	0	0	100.0	0	0
43B	100.0	0	0	100.0	0	0
43C	100.0	0	0	100.0	0	0
44A	100.0	0	0	100.0	0	0
45A	100.0	0	0	97.7	2.3	0
45B	100.0	0	0	100.0	0	0
46A	99.9	0	0.1	100.0	0	0
Mean	88.5	11.2	0.2	88.0	11.9	0.2

Table 19. Five most parsimonious models explaining variance in each of four fish community parameters among 81 Puerto Rican stream reaches. *K* is the number of model parameters; ΔAICc is the difference between successive model Akaike's Information Criterion values corrected for bias; and w_i is the Akaike weight, or probability that the model is the most informative model.

Model	*K*	ΔAICc	w_i
Fish community species richness (loge(x+1))			
0.0091(watershed area)+0.0008(conductivity)+8.1647(road density)+0.0157(watershed % forest)-0.0139(30-m % forest)+0.9369	7	0	0.027
0.0090(watershed area)+0.0009(conductivity)+8.7495(road density)+0.0158(watershed % forest)-0.0139(30-m % forest)+0.0023(% cover)+0.7581	8	0.275	0.023
0.0087(watershed area)+0.0008(conductivity)+8.3703(road density)+0.0141(watershed % forest)-0.0130(30-m % forest)+0.0025(% cover)-0.0026(river km)+0.0003	9	0.638	0.019
0.0088(watershed area)+0.0007(conductivity)+7.7847(road density)+0.0142(watershed % forest)-0.0131(30-m % forest)-0.0024(river km)+1.092	8	0.716	0.019
0.0092(watershed area)+0.0008(conductivity)+8.6905(road density)+0.0146(watershed % forest)-0.0130(30-m % forest)-0.0048(turbidity)+0.9489	8	1.254	0.014
Fish community density (loge(x+1))			
23.7596(road density)+2.0351(downstream reservoir)+0.0135(% cover)+6.5387	5	0	0.022
22.8014(road density)+2.0024(downstream reservoir)+0.0126(% cover)+0.0279(nitrate)+6.5258	6	1.157	0.012
26.3039(road density)+2.0029(downstream reservoir)+0.0119(% cover)-0.0010(conductivity)+6.8470	6	1.192	0.012
22.2452(road density)+1.9922(downstream reservoir)+0.0138(% cover)-0.0456(width)+6.8595	6	1.257	0.012
22.1962(road density)+2.0023(downstream reservoir)+0.0133(% cover)-0.0047(watershed area)+6.6619	6	1.820	0.009
Fish community biomass (loge(x+1))			
0.0267(watershed area)+0.0860(temperature)-0.0210(river km)-0.1218(width)-0.0015(conductivity)+1.2101	7	0	0.007
0.0147(watershed area)+0.0913(temperature)-0.0192(river km)+0.0082(% cover)+1.2669	6	0.298	0.006
0.0233(watershed area)+0.0844(temperature)-0.0182(river km)-0.0904(width)+2.2240	6	0.373	0.006
0.0227(watershed area)+0.0738(temperature)-0.0193(river km)-0.0820(width)+0.0074(% cover)+2.0759	7	0.416	0.006
0.0158(watershed area)+0.0814(temperature)-0.0221(river km)-0.0088(% cover)+0.6171(reservoir)+2.0759	7	0.467	0.006
Fish community diversity (loge(x+1))			
0.0041(watershed area)+0.0004(conductivity)-0.0025(river km)+0.4709	5	0	0.010
0.0045(watershed area)+0.0004(conductivity)-0.0024(river km)-0.0147(temp)+0.7997	6	0.691	0.007
0.0039(watershed area)+0.0003(conductivity)-0.0028(river km)+0.0032(turbidity)+0.4684	6	1.118	0.006
0.0043(watershed area)+0.0004(conductivity)+0.3811	4	1.176	0.006
0.0039(watershed area)+0.0005(conductivity)+0.0095(watershed % forest)-0.0082(30-m % forest)+0.1904	7	1.382	0.005

Table 20. Five most parsimonious models explaining variance in each of four native fish community parameters among 81 Puerto Rico stream sample reaches. *K* is the number of model parameters; ΔAICc is the difference between successive model Akaike's Information Criterion values corrected for bias; and w_i is the Akaike weight, or probability that the model is the most informative model.

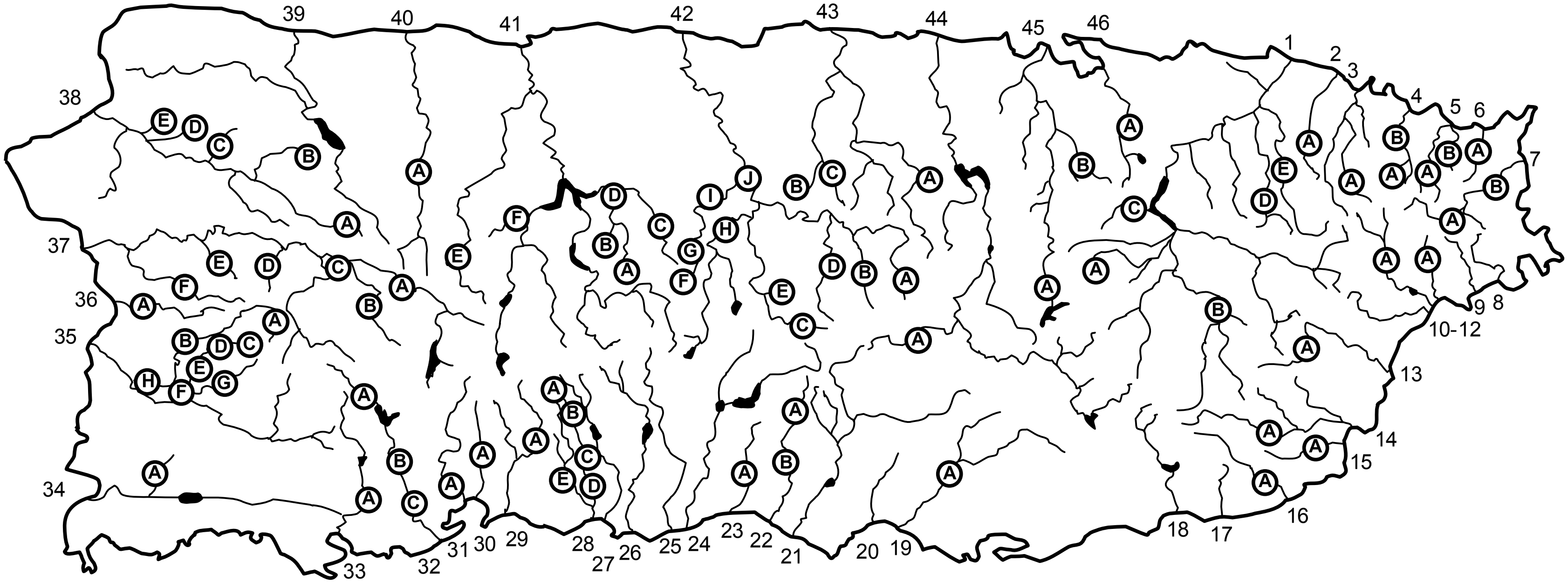
Model	*K*	ΔAICc	w_i
Native fish species richness (loge(x+1))			
-0.9959(downstream reservoir)-0.0152(river km)+0.0113(watershed area)+1.5091	5	0	0.032
-0.9884(downstream reservoir)-0.0155(river km)+0.0113(watershed area)+0.0016(% cover)+1.4280	6	0.734	0.022
-0.9966(downstream reservoir)-0.0151(river km)+0.0112(watershed area)-3.4197(road density)+1.6439	6	0.958	0.020
-1.0040(downstream reservoir)-0.0152(river km)+0.0128(watershed area)-0.0157(width)+1.5764	6	1.244	0.017
-0.9816(downstream reservoir)-0.0147(river km)+0.0117(watershed area)+0.0018(watershed % forest)+1.4081	6	1.536	0.015
Native fish density (loge(x+1))			
-5.6654(downstream reservoir)-0.0581(river km)+0.0227(% cover)+0.1913(width)+0.2686(temperature)+0.1371(nitrate)-0.0840(turbidity)+0.0003(conductivity)-0.5184	10	0	0.071
-5.6432(downstream reservoir)-0.0588(river km)+0.0224(% cover)+0.1855(width)+0.2745(temperature)+0.1367(nitrate)-0.0818(turbidity)+0.0010(watershed % public owned)-0.5087	10	0.041	0.069
-5.6476(downstream reservoir)-0.0587(river km)+0.0226(% cover)+0.1876(width)+0.2731(temperature)+0.1362(nitrate)-0.0827(turbidity)-0.4794	9	0.054	0.069
-5.6096(downstream reservoir)-0.0593(river km)+0.0210(% cover)+0.1749(width)+0.2662(temperature)+0.1312(nitrate)-0.0773(turbidity)+0.0034(watershed % forest)-0.5203	10	1.614	0.031
-5.6176(downstream reservoir)-0.0587(river km)+0.0207(% cover)+0.1745(width)+0.2673(temperature)+0.1317(nitrate)-0.0761(turbidity)+0.0019(30-m % forest)-0.3711	10	1.705	0.030
Native fish biomass (loge(x+1))			
-2.2128(downstream reservoir)-0.0440(river km)+0.0404(watershed area)-17.4683(road density)-0.1820(width)-0.0016(conductivity)+5.6852	8	0	0.013
-2.2383(downstream reservoir)-0.0409(river km)+0.0368(watershed area)-21.7121(road density)-0.1524(width)+5.1512	7	0.021	0.013
-2.2819(downstream reservoir)-0.0434(river km)+0.0369(watershed area)-16.9491(road density)-0.1619(width)-0.0017(conductivity)+0.0640(temperature)+4.0687	9	0.283	0.012
-2.1967(downstream reservoir)-0.0421(river km)+0.0355(watershed area)-19.2036(road density)-0.1361(width)+0.0073(% cover)+4.6198	8	0.390	0.011
-2.3069(downstream reservoir)-0.0401(river km)+0.0334(watershed area)-21.4013(road density)-0.1334(width)+0.6198(temperature)+3.5735	8	0.510	0.010
Native fish diversity (loge(x+1))			
-0.2715(downstream reservoir)-0.0082(river km)+0.0056(watershed area)+0.5489	5	0	0.035
-0.2801(downstream reservoir)-0.0081(river km)+0.0054(watershed area)-0.0001(watershed % public owned)+0.5564	6	0.976	0.021
-0.2741(downstream reservoir)-0.0082(river km)+0.0067(watershed area)-0.0129(width)+0.6072	6	1.258	0.018
-0.2715(downstream reservoir)-0.0078(river km)+0.0055(watershed area)+0.0002(conductivity)+0.4777	6	1.394	0.017
-0.2810(downstream reservoir)-0.0084(river km)+0.0053(watershed area)+0.0010(30-m % forest)+0.6048	6	1.667	0.015

Table 21. Five most parsimonious models explaining variance in each of three introduced fish community parameters among 81 Puerto Rico stream sample reaches. *K* is the number of model parameters; ΔAICc is the difference between successive model Akaike's Information Criterion values corrected for bias; and w_i is the Akaike weight, or probability that the model is the most informative model.

Model	*K*	ΔAICc	w_i
Introduced fish species richness (loge(x+1))			
0.7032(downstream reservoir)+0.0148(river km)+10.1432(road density)+0.0010(conductivity)+0.0370(width)-0.5561	7	0	0.027
0.7357(downstream reservoir)+0.0147(river km)+14.4387(road density)+0.0010(conductivity)+0.0056(watershed area)+0.0051(watershed % public owned)-0.6756	8	0.408	0.022
0.6937(downstream reservoir)+0.0145(river km)+10.1214(road density)+0.0009(conductivity)+0.0048(watershed area)-0.3587	7	0.645	0.019
0.7355(downstream reservoir)+0.0148(river km)+13.6274(road density)+0.0012(conductivity)+0.0381(width)+0.0040(watershed % public owned)-0.7975	8	0.693	0.019
0.6607(downstream reservoir)+0.0140(river km)+9.9318(road density)+0.0009(conductivity)-0.2455	6	1.447	0.013
Introduced fish density (loge(x+1))			
2.2589(downstream reservoir)+0.0167(river km)+31.9318(road density)-0.4268	5	0	0.012
2.2369(downstream reservoir)+0.0188(river km)+28.8619(road density)+0.0010(conductivity)-0.6875	6	0.066	0.012
2.2560(downstream reservoir)+0.0167(river km)+31.8575(road density)-0.0029(width)-0.4059	6	0.520	0.009
2.2596(downstream reservoir)+0.0189(river km)+32.7588(road density)+0.0012(conductivity)+0.0049(watershed % public owned)-0.9594	7	0.679	0.009
2.2605(downstream reservoir)+0.0165(river km)+31.5950(road density)+0.0014(turbidity)-0.0035(width)-0.3982	7	1.180	0.007
Introduced fish biomass (loge(x+1))			
2.2920(downstream reservoir)+0.0180(river km)+30.7970(road density)+0.0240(watershed area)-0.1011(width)-0.2601	7	0	0.018
2.3426(downstream reservoir)+0.0180(river km)+32.8550(road density)+0.0146(watershed area)-0.7773	6	0.230	0.016
2.3432(downstream reservoir)+0.0177(river km)+39.4136(road density)+0.0274(watershed area)-0.1222(width)-0.6537	7	1.056	0.011
2.2982(downstream reservoir)+0.0140(river km)+39.1286(road density)+0.0261(watershed area)-0.1345(width)-0.0132(30-m % forest)+0.0188(watershed % public owned)+0.0396	9	1.278	0.010
2.2589(downstream reservoir)+0.0167(river km)+31.9318(road density)-0.4268	5	1.769	0.008

Table 22. Five most parsimonious models explaining variance in each of four native fish community parameters among only the 65 Puerto Rico stream sample reaches where native fish were collected. *K* is the number of model parameters; ΔAICc is the difference between successive model Akaike's Information Criterion values corrected for bias; and w_i is the Akaike weight, or probability that the model is the most informative model.

Model	*K*	ΔAICc	w_i
Native fish species richness ($\log_e$(x+1))			
-0.0130(river km)+0.0098(watershed area)+1.5738	4	0	0.025
-0.0132(river km)+0.0099(watershed area)+0.0017(% cover)+1.4874	5	0.501	0.019
-0.0134(river km)+0.0097(watershed area)-0.0047(turbidity)+1.5592	5	0.961	0.015
-0.0129(river km)+0.0109(watershed area)-0.0126(width)+1.6278	5	1.511	0.012
-0.0128(river km)+0.0096(watershed area)-0.0016(watershed % public owned)+1.5948	5	1.544	0.011
Native fish density ($\log_e$(x+1))			
-0.0428(river km)+0.0157(% cover)+0.0860(nitrate)+0.1668(temperature)-0.0023(conductivity)+3.9143	7	0	0.014
-0.0381(river km)+0.0185(% cover)+0.0905(nitrate)+0.1313(temperature)+0.0871(width)+3.1860	7	0.943	0.009
-0.0367(river km)+0.0170(% cover)+0.0825(nitrate)+0.1301(temperature)+3.8254	6	0.986	0.009
-0.0430(river km)+0.0171(% cover)+0.0921(nitrate)+0.1638(temperature)+0.0673(width)-0.0020(conductivity)+3.3554	8	1.113	0.008
-0.0381(river km)+0.0164(% cover)+0.0759(nitrate)+0.0866(width)+6.5573	6	1.147	0.008
Native fish biomass ($\log_e$(x+1))			
-0.0421(river km)+0.0379(watershed area)-0.1923(width)-0.0031(conductivity)+5.7495	6	0	0.060
-0.0417(river km)+0.0349(watershed area)-0.1732(width)-0.0031(conductivity)+0.0592(temperature)+4.2643	7	0.634	0.044
-0.0426(river km)+0.0362(watershed area)-0.1700(width)-0.0028(conductivity)+0.5895(cover)+5.2454	7	1.225	0.033
-0.0420(river km)+0.0379(watershed area)-0.1933(width)-0.0029(conductivity)-8.6675(road density)+6.0069	7	1.712	0.026
-0.0414(river km)+0.0382(watershed area)-0.1976(width)-0.0031(conductivity)-0.0092(nitrate)+5.7989	7	2.291	0.019
Native fish diversity ($\log_e$(x+1))			
-0.0077(river km)+0.0051(watershed area)-0.0019(watershed % public owned)+0.5954	5	0	0.029
-0.0080(river km)+0.0053(watershed area)+0.5729	4	0.066	0.028
-0.2023(river km)+0.0047(watershed area)-0.0020(30-m % forest)+0.6871	5	0.223	0.026
-0.0082(river km)+0.0049(watershed area)-0.0017(watershed % forest)+0.6667	5	0.531	0.022
-0.0078(river km)+0.0055(watershed area)-0.0023(watershed % public owned)-0.0130(temperature)+0.9069	6	1.688	0.012



1. Loíza
2. Herrera
3. Espíritu Santo
4. Mameyes
5. Sabana
6. Juan Martín
7. Fajardo
8. Dagüao
9. Palma
10. Santiago
11. Blanco
12. Antón Ruiz
13. Humacao
14. Guayanés
15. Caño de Santiago
16. Maunabo
17. Jaraboa
18. Patillas
19. Salinas
20. Jueyes
21. Coama
22. Descalabrado
23. Cañas
24. Jacaguas
25. Inabón
26. Bucaná
27. Portugés
28. Matilde
29. Tallaboa
30. Macaná
31. Guayanilla
32. Yauco
33. Loco
34. Cartagena
35. Guanajibo
36. Yagüez
37. Añasco
38. Culebrinas
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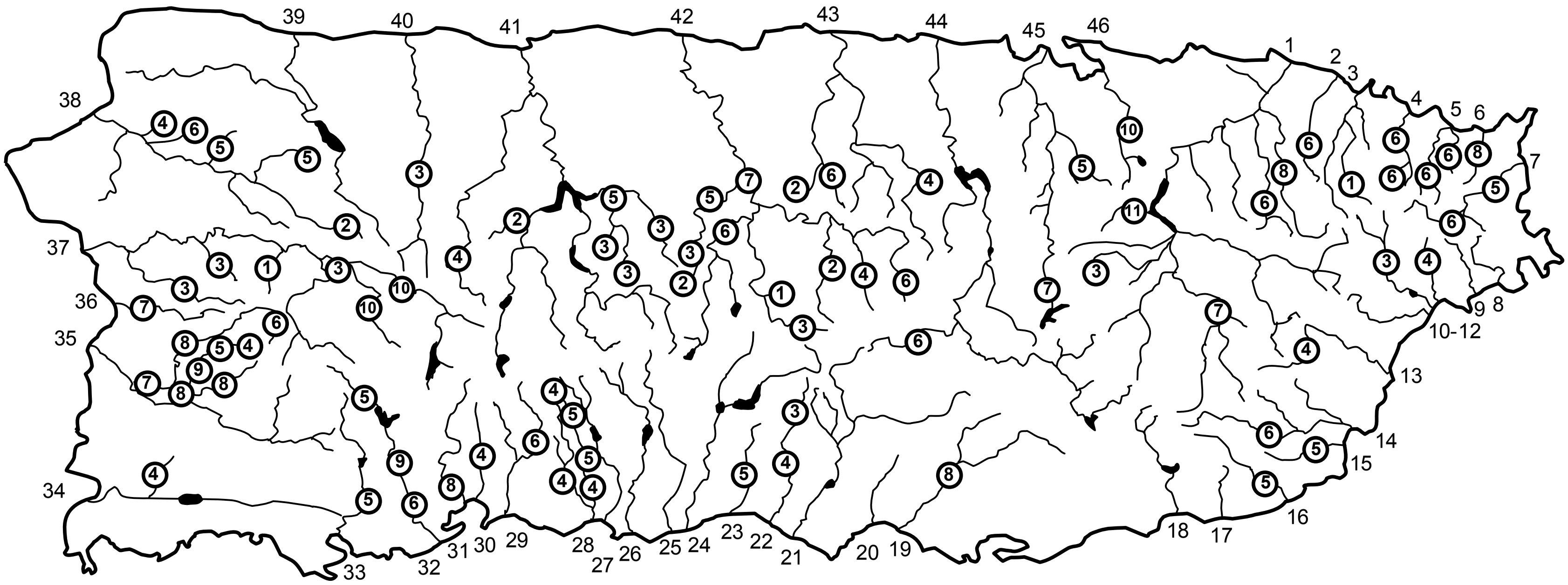
41. Arecibo
42. Manatí
43. Cibuco
44. La Plata
45. Bayamón
46. Piedras

Figure 1. Fish, instream habitat, and water quality sampling sites ($N = 81$) spanning 34 of 46 drainage basins in Puerto Rico.



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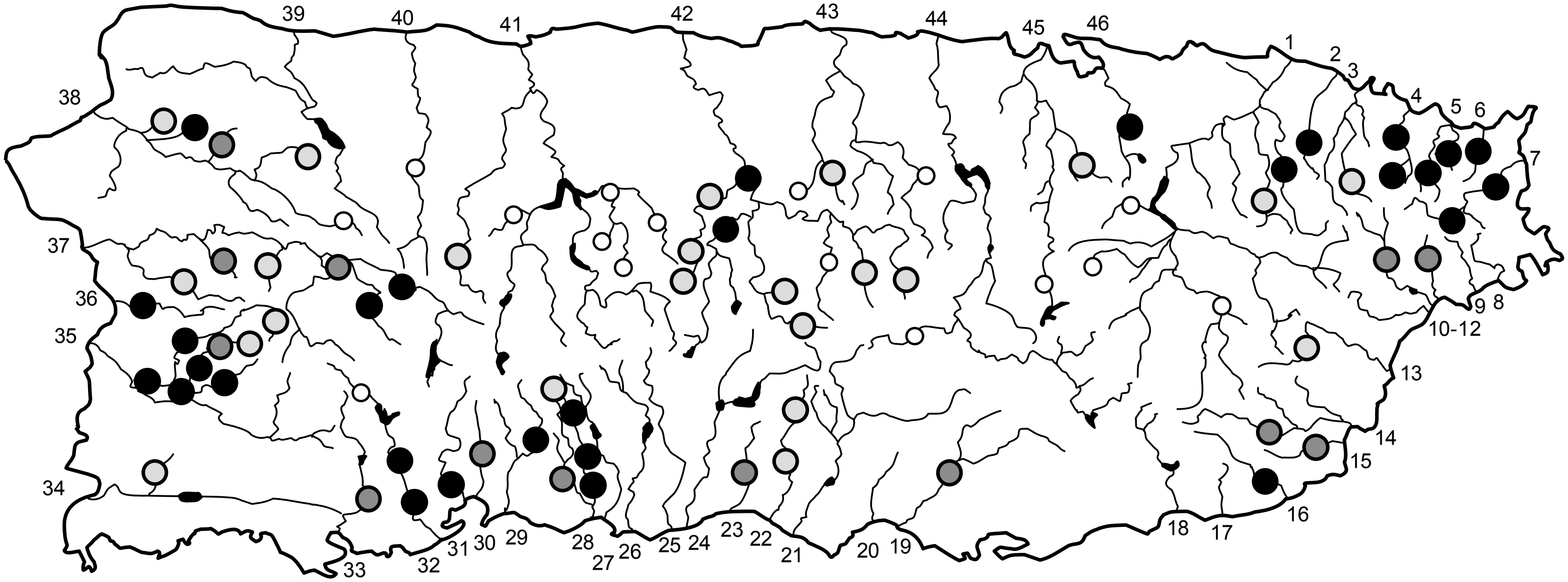
46. Piedras

Figure 2. Fish community species richness (native and introduced species) among 81 sites sampled during 2006–2007 spanning 34 of 46 drainage basins in Puerto Rico.



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45. Bayamón
46. Piedras

Native fish species richness

○ Not detected

◍ 1–2 species

◉ 3–4 species

● 5–7 species

Figure 3. Native fish species occurrence and richness among 81 sites sampled during 2006–2007 spanning 34 of 46 drainage basins in Puerto Rico.

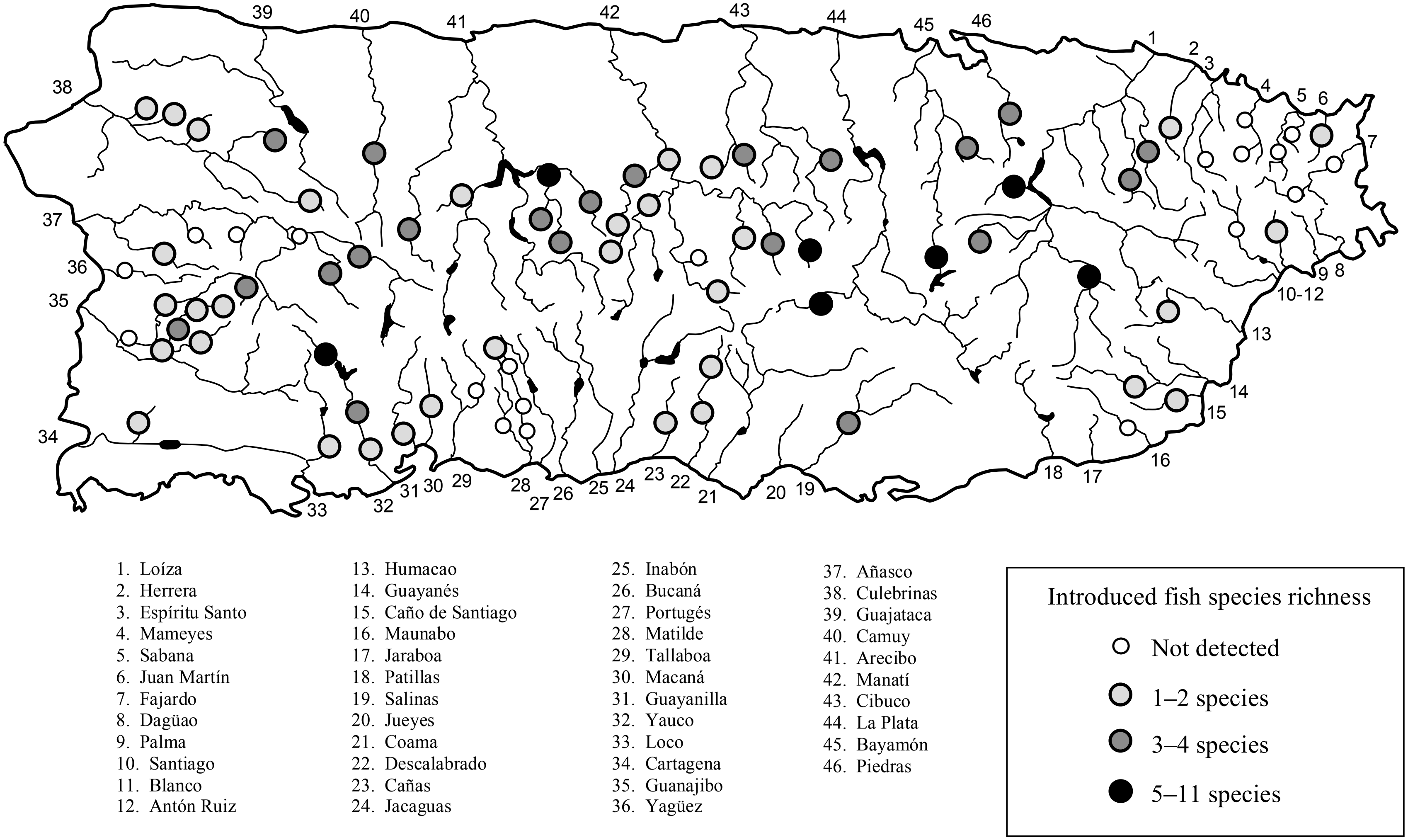
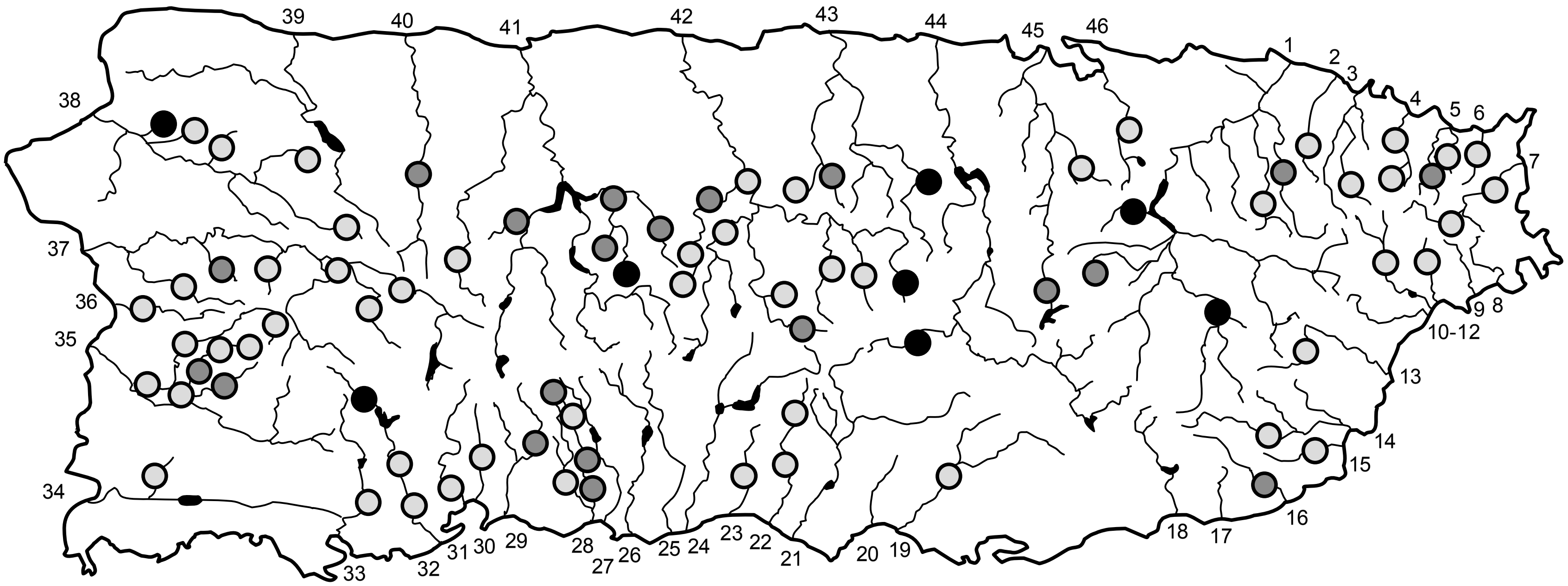


Figure 4. Introduced fish species occurrence and richness among 81 sites sampled during 2006–2007 spanning 34 of 46 drainage basins in Puerto Rico.



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45. Bayamón
46. Piedras

Total fish density
○ Not detected
◎ 1–10,000 fish/ha
◉ 10,001–30,000 fish/ha
● > 30,000 fish/ha

Figure 5. Density of all fish species among 81 sites sampled during 2006–2007 spanning 34 of 46 drainage basins in Puerto Rico.

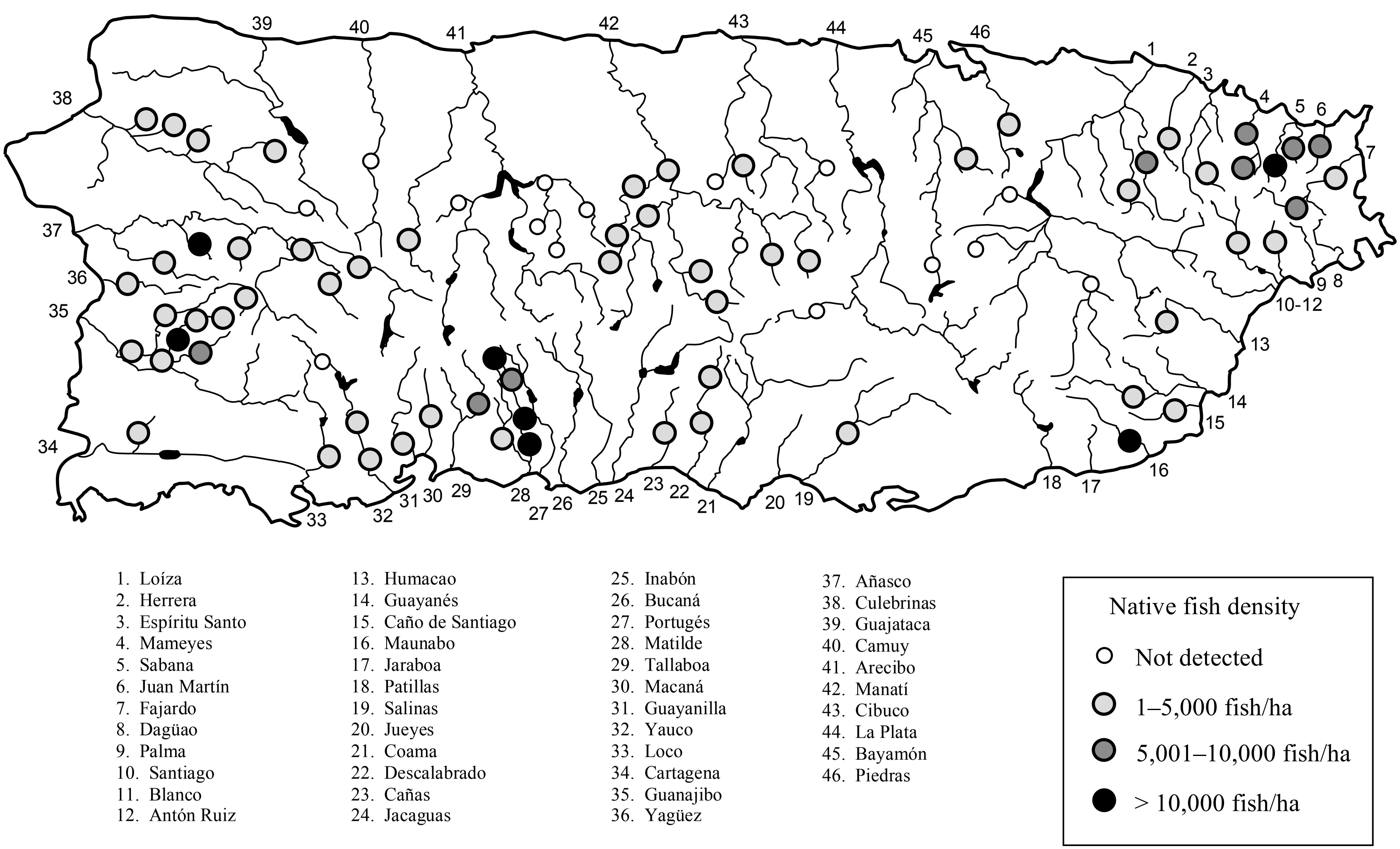

Figure 6. Occurrence and density of native fish species among 81 sites sampled during 2006–2007 spanning 34 of 46 drainage basins in Puerto Rico.

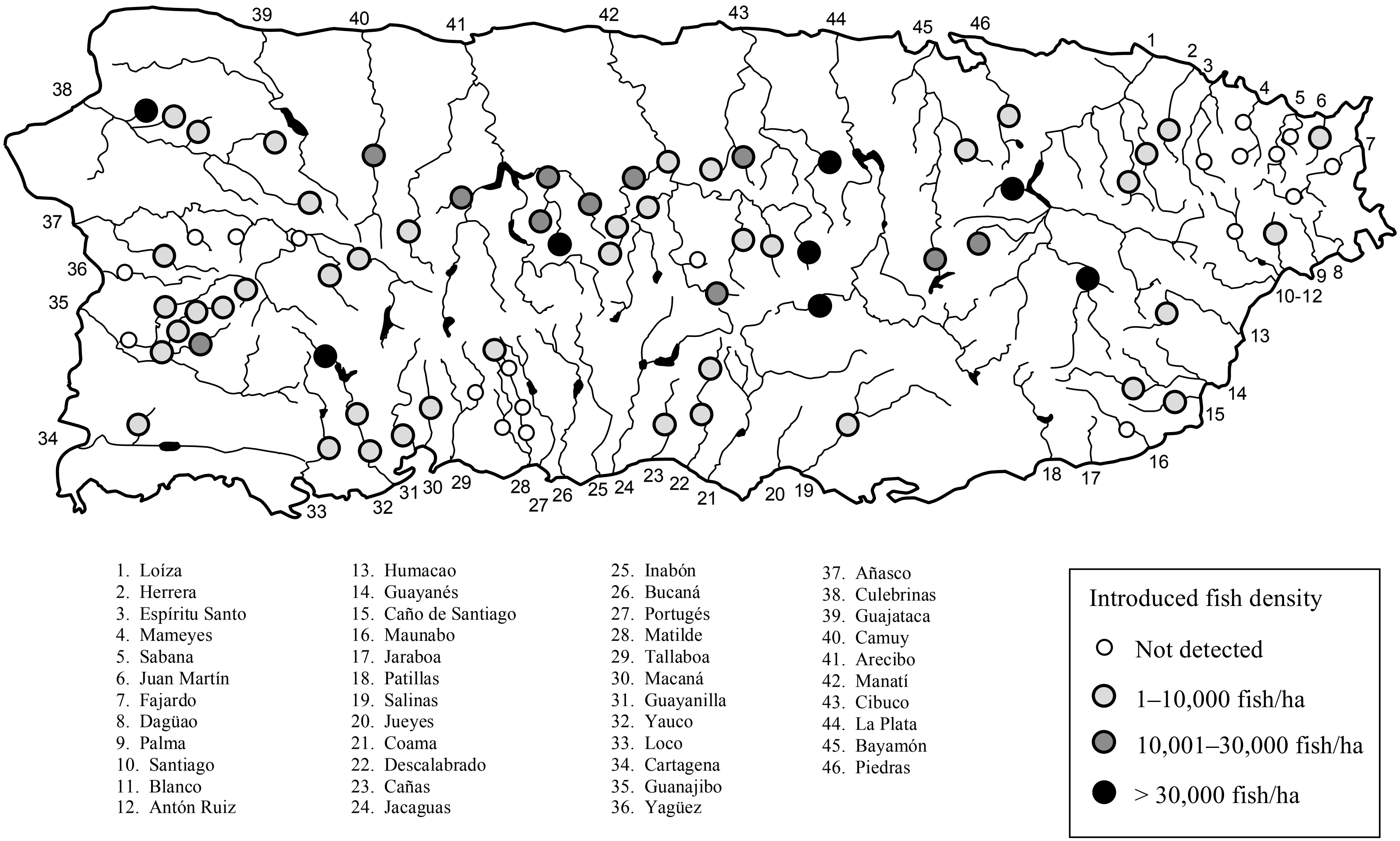

Figure 7. Occurrence and density of introduced fish species among 81 sites sampled during 2006–2007 spanning 34 of 46 drainage basins in Puerto Rico.

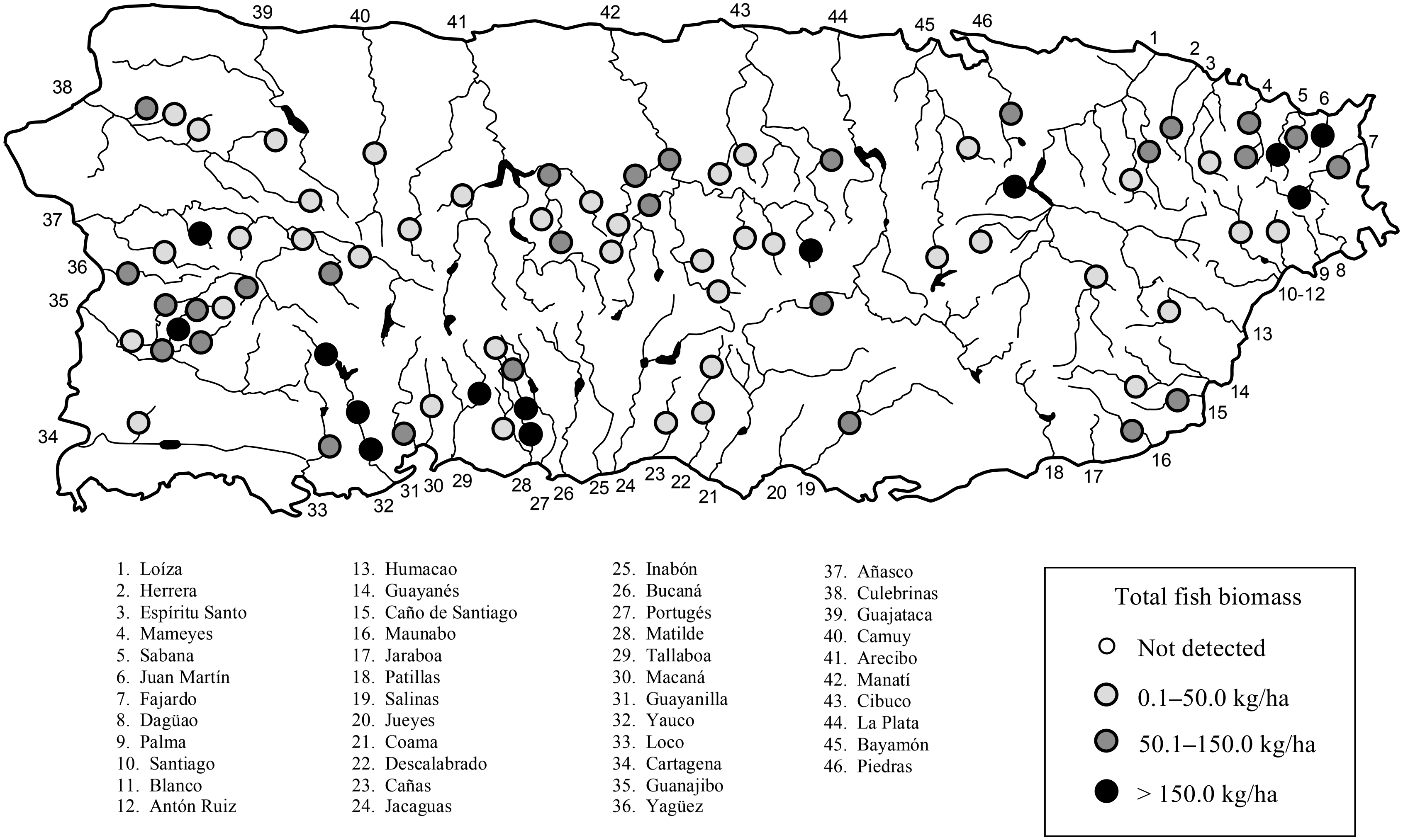

Figure 8. Biomass of all fish species among 81 sites sampled during 2006–2007 spanning 34 of 46 drainage basins in Puerto Rico.

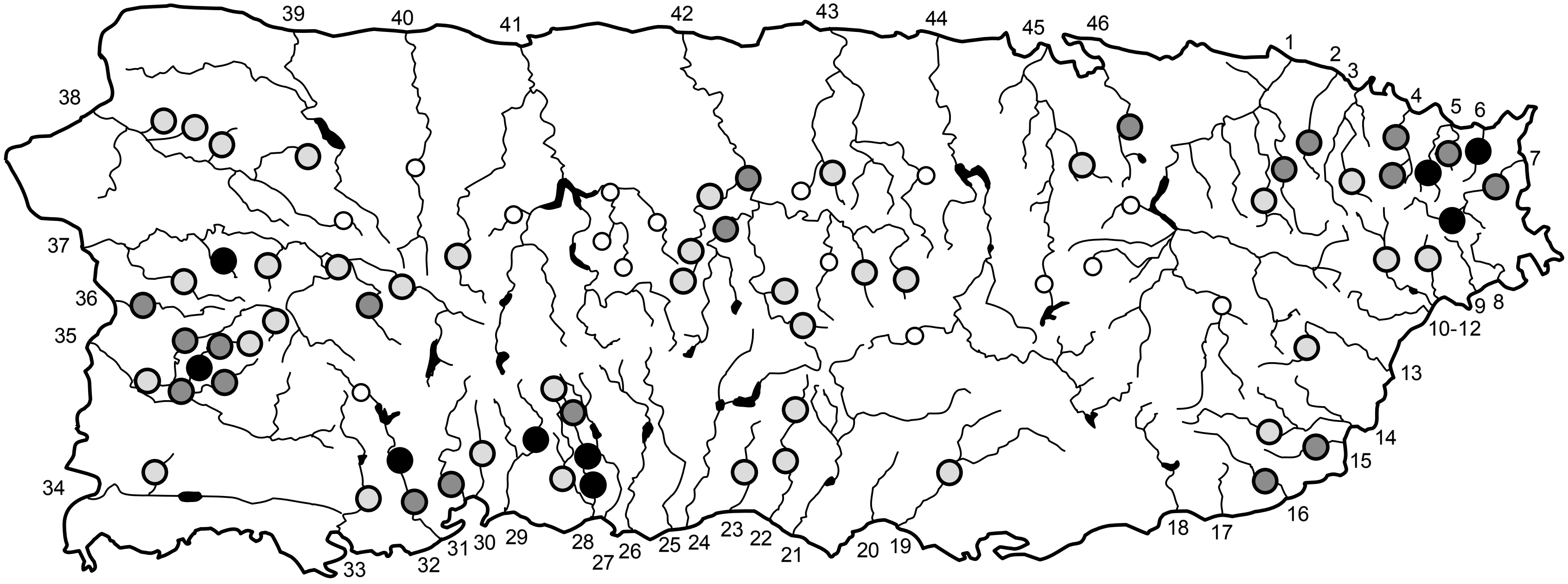

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Figure 9. Occurrence and biomass of native fish species among 81 sites sampled during 2006–2007 spanning 34 of 46 drainage basins in Puerto Rico.

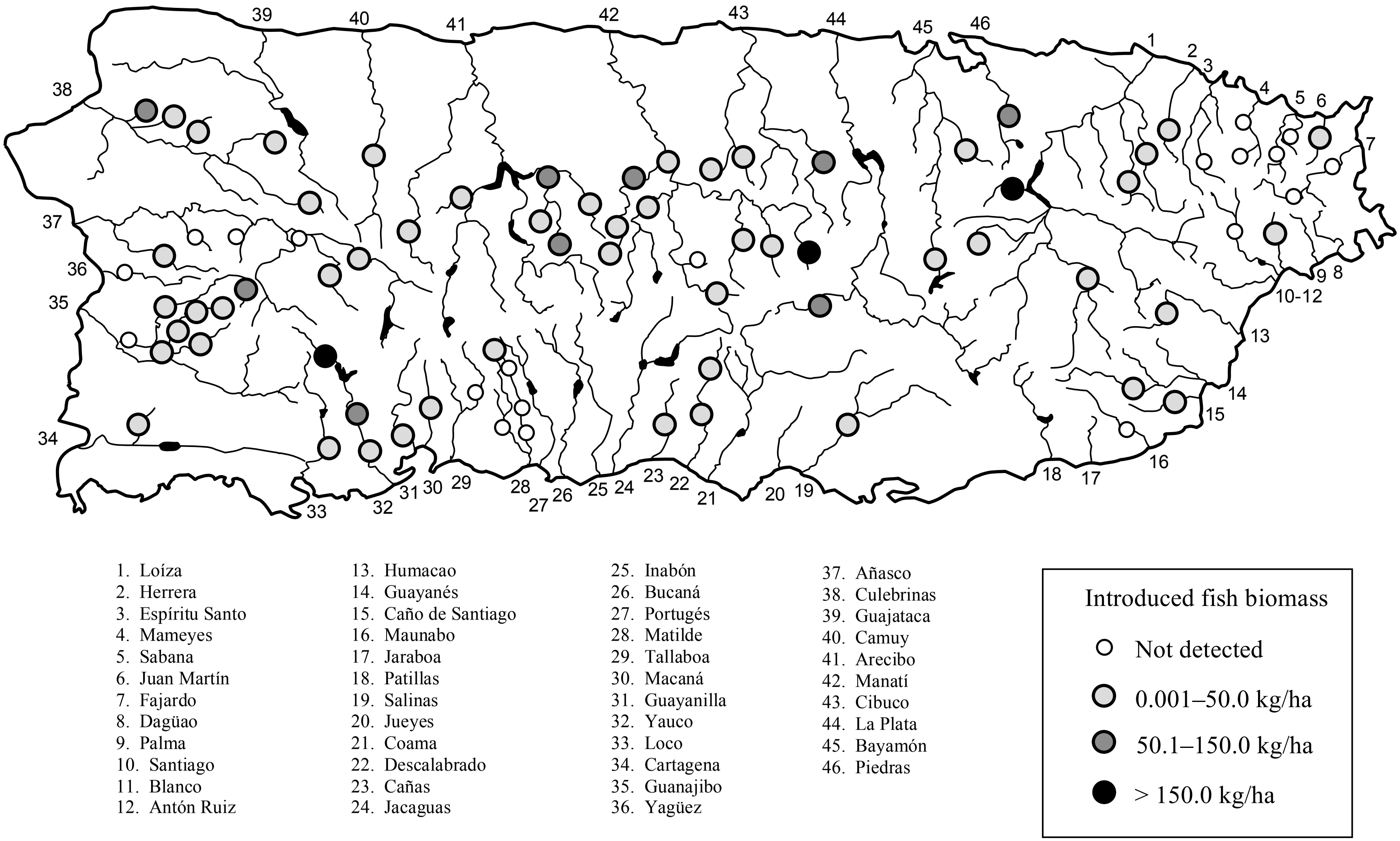

Figure 10. Occurrence and biomass of introduced fish species among 81 sites sampled during 2006–2007 spanning 34 of 46 drainage basins in Puerto Rico.

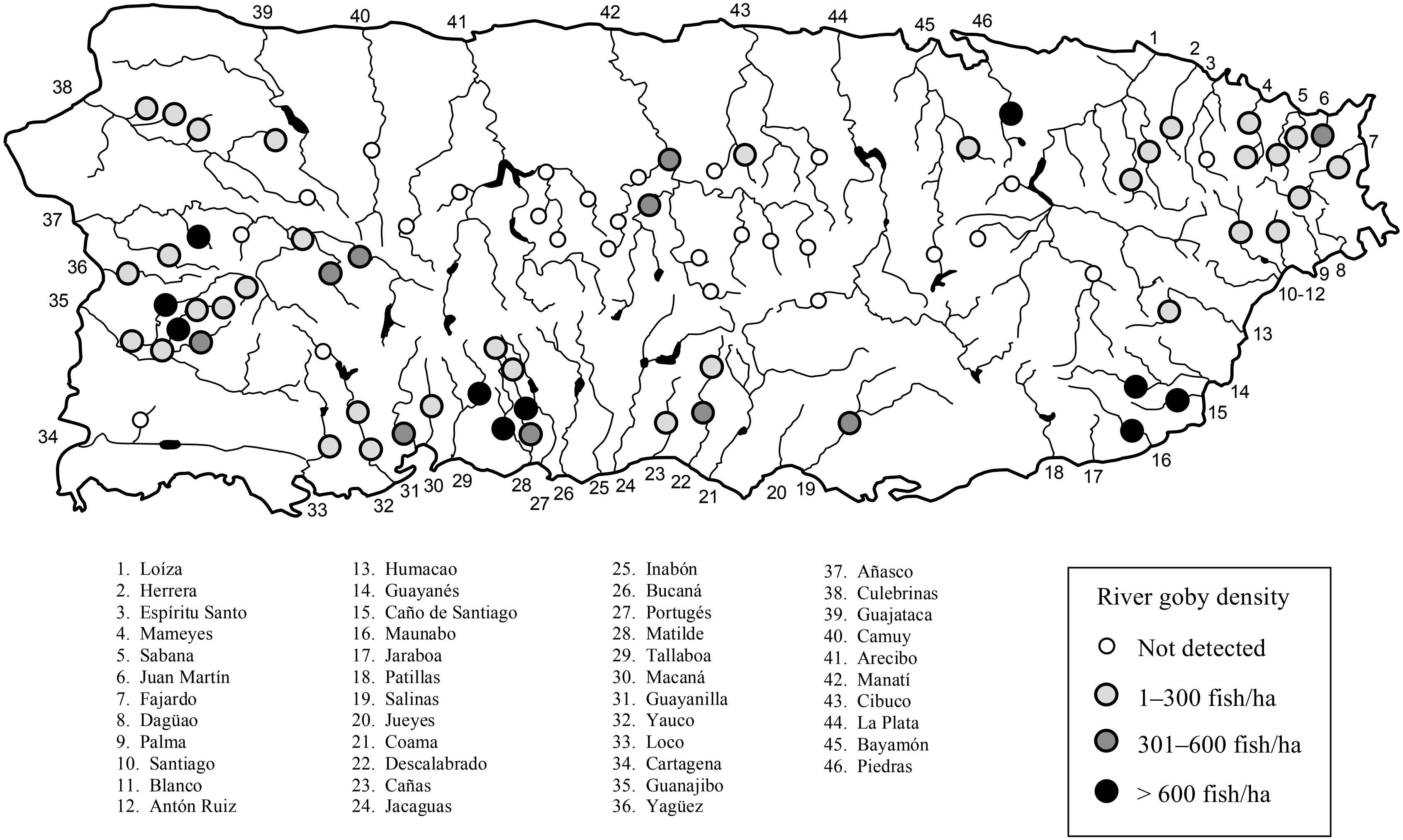

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Figure 11. Occurrence and density of river goby among 81 sites sampled during 2006–2007 spanning 34 of 46 drainage basins in Puerto Rico.

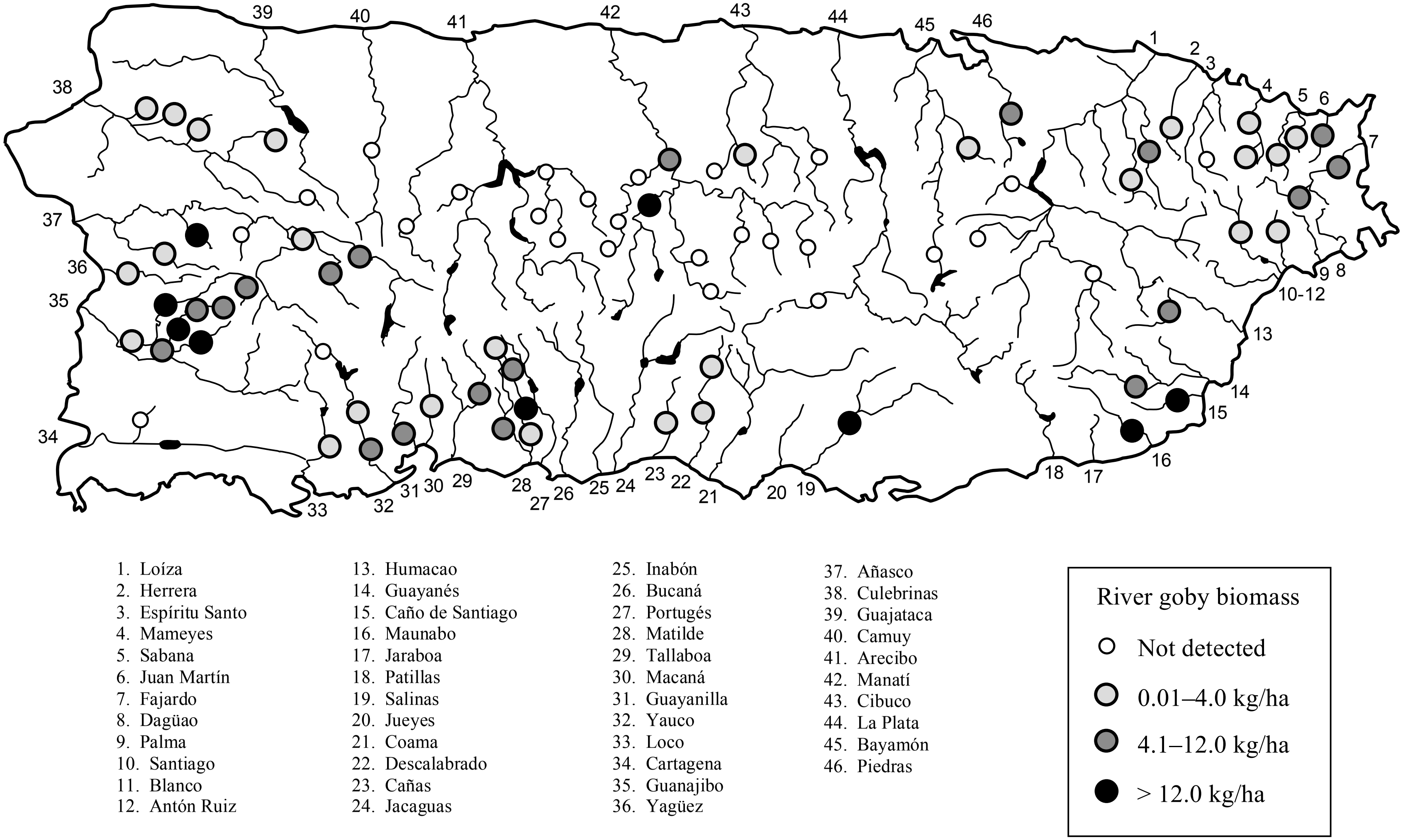


Figure 12. Occurrence and biomass of river goby among 81 sites sampled during 2006–2007 spanning 34 of 46 drainage basins in Puerto Rico.

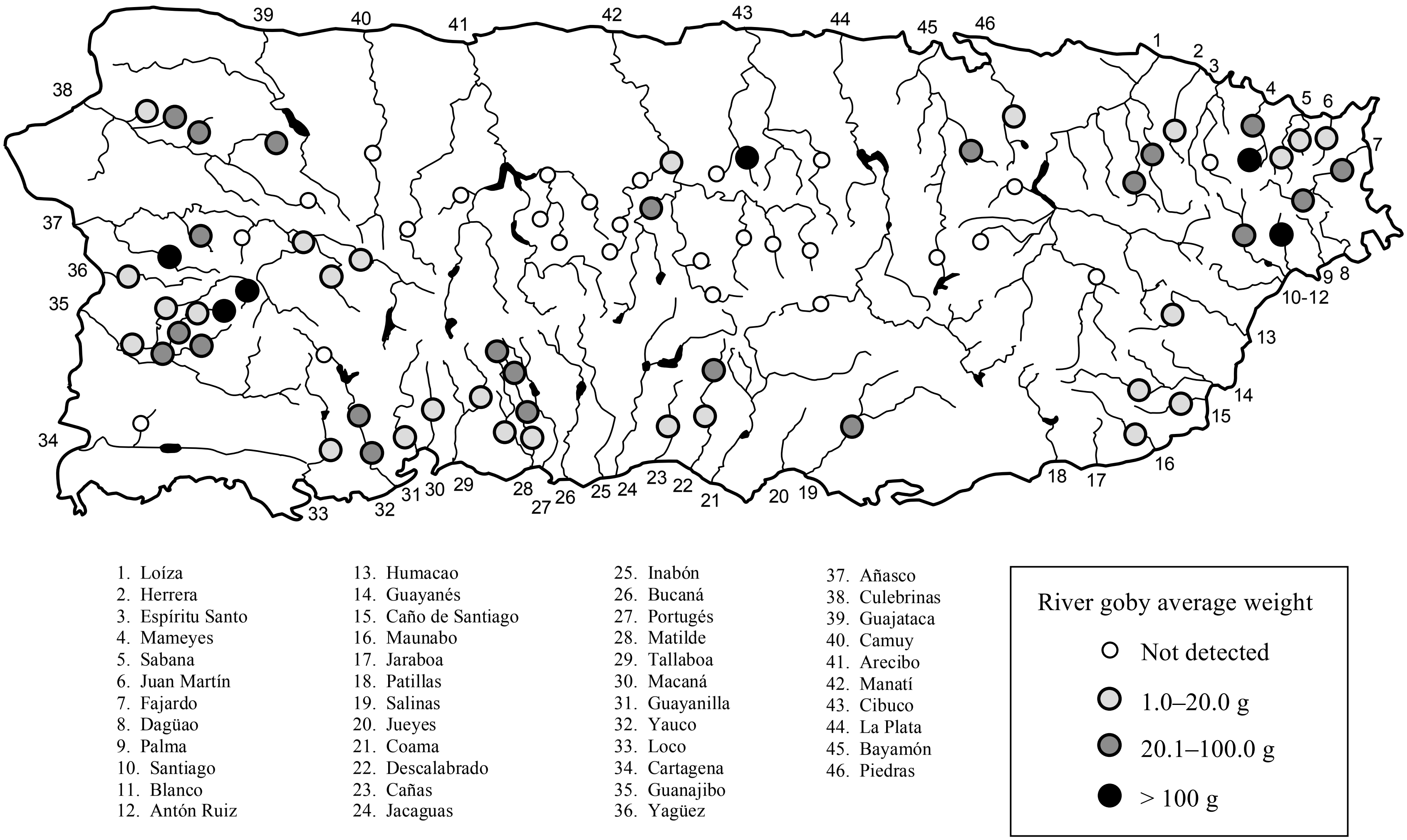
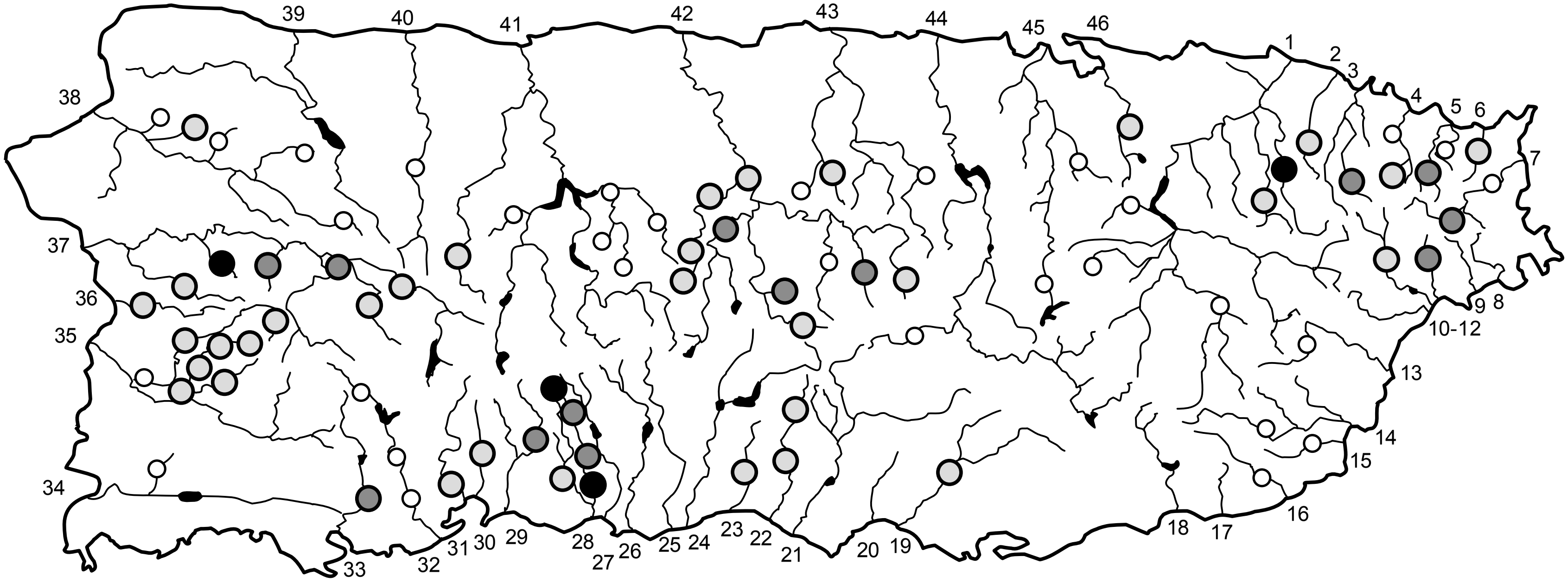


Figure 13. Occurrence and average weight of river goby among 81 sites sampled during 2006–2007 spanning 34 of 46 drainage basins in Puerto Rico.



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45. Bayamón
46. Piedras

Sirajo goby density

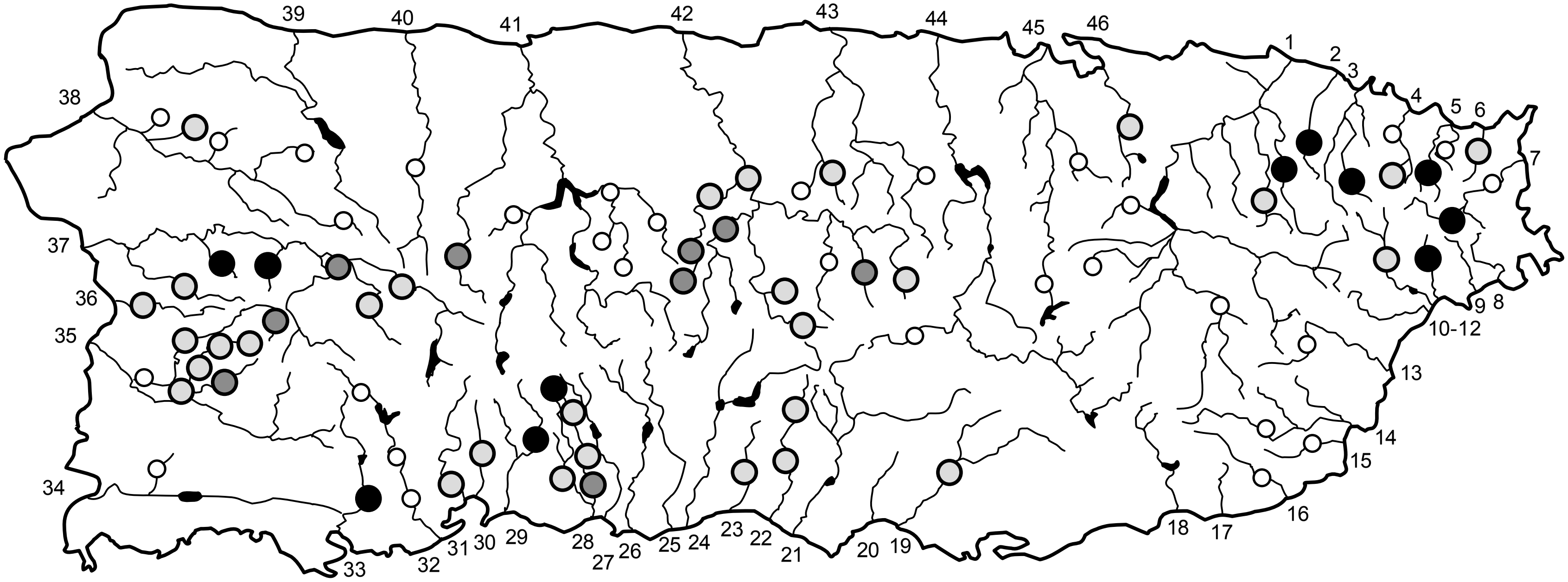
○ Not detected

● 1–1,000 fish/ha

● 1,001–4,000 fish/ha

● > 4,000 fish/ha

Figure 14. Occurrence and density of sirajo goby among 81 sites sampled during 2006–2007 spanning 34 of 46 drainage basins in Puerto Rico.



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46. Piedras

Sirajo goby biomass

○ Not detected

◍ 0.01–3.0 kg/ha

◉ 3.1–9.0 kg/ha

● > 9.0 kg/ha

Figure 15. Occurrence and biomass of sirajo goby among 81 sites sampled during 2006–2007 spanning 34 of 46 drainage basins in Puerto Rico.

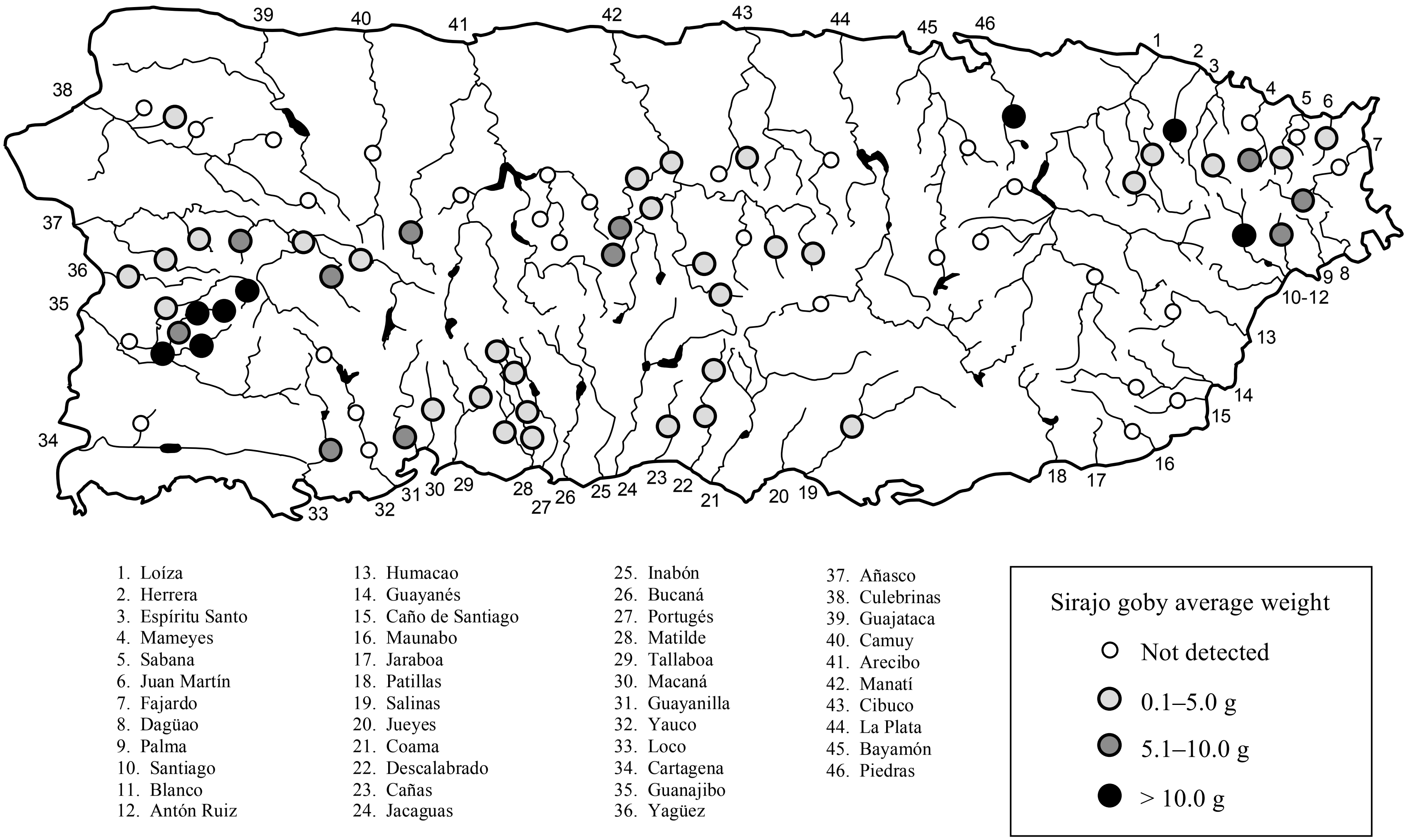

Figure 16. Occurrence and average weight of sirajo goby among 81 sites sampled during 2006–2007 spanning 34 of 46 drainage basins in Puerto Rico.

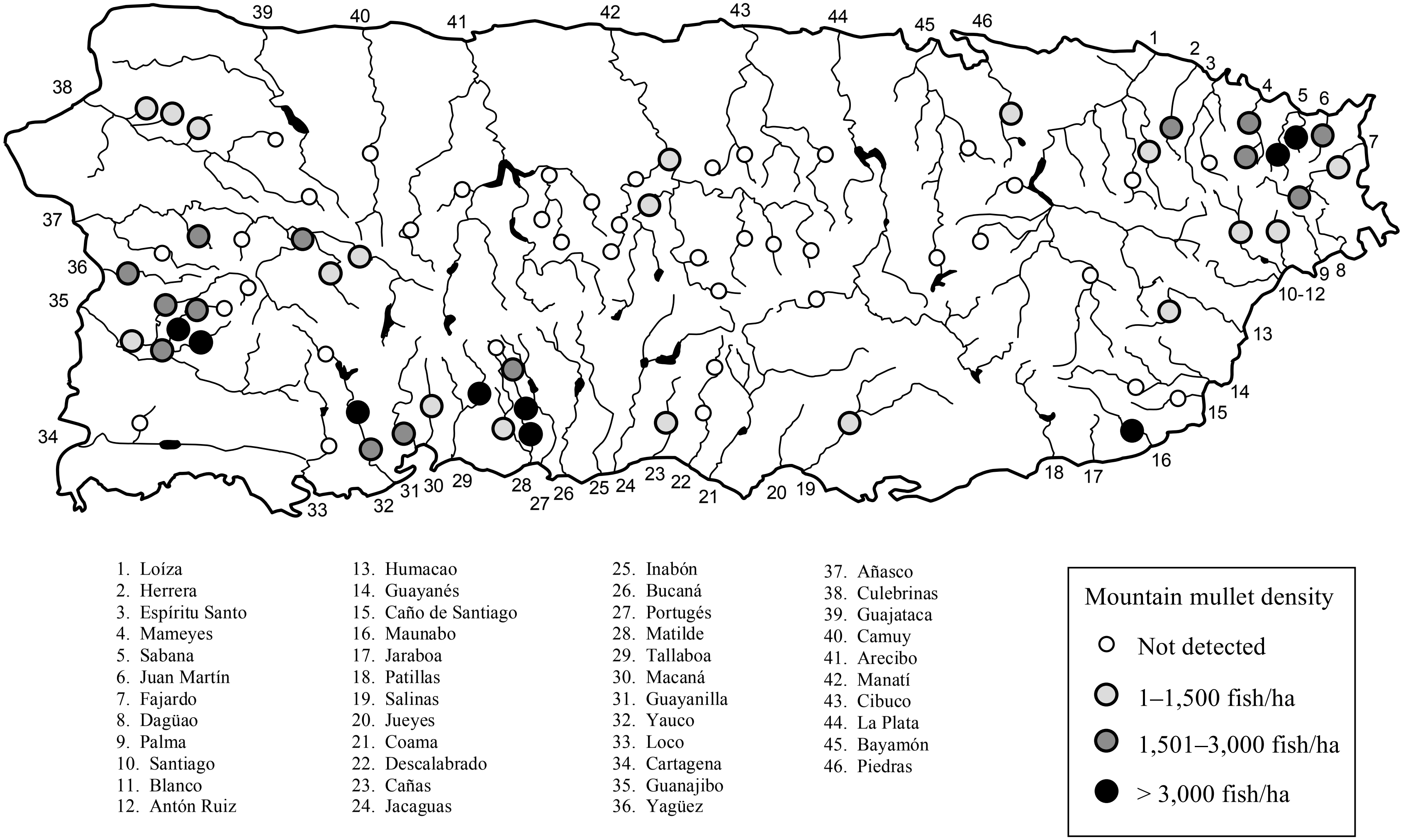

Figure 17. Occurrence and density of mountain mullet among 81 sites sampled during 2006–2007 spanning 34 of 46 drainage basins in Puerto Rico.

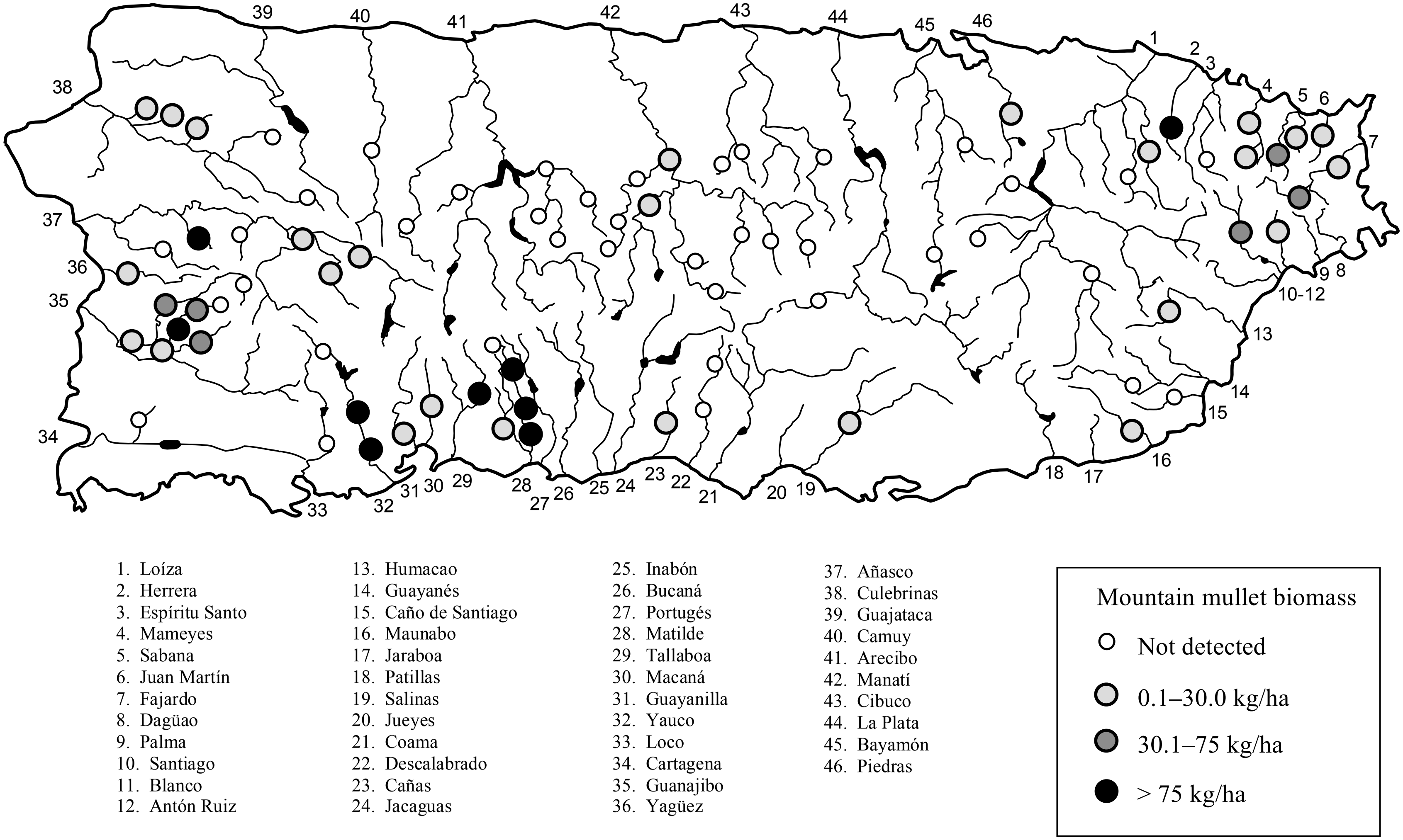

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Figure 18. Occurrence and biomass of mountain mullet among 81 sites sampled during 2006–2007 spanning 34 of 46 drainage basins in Puerto Rico.

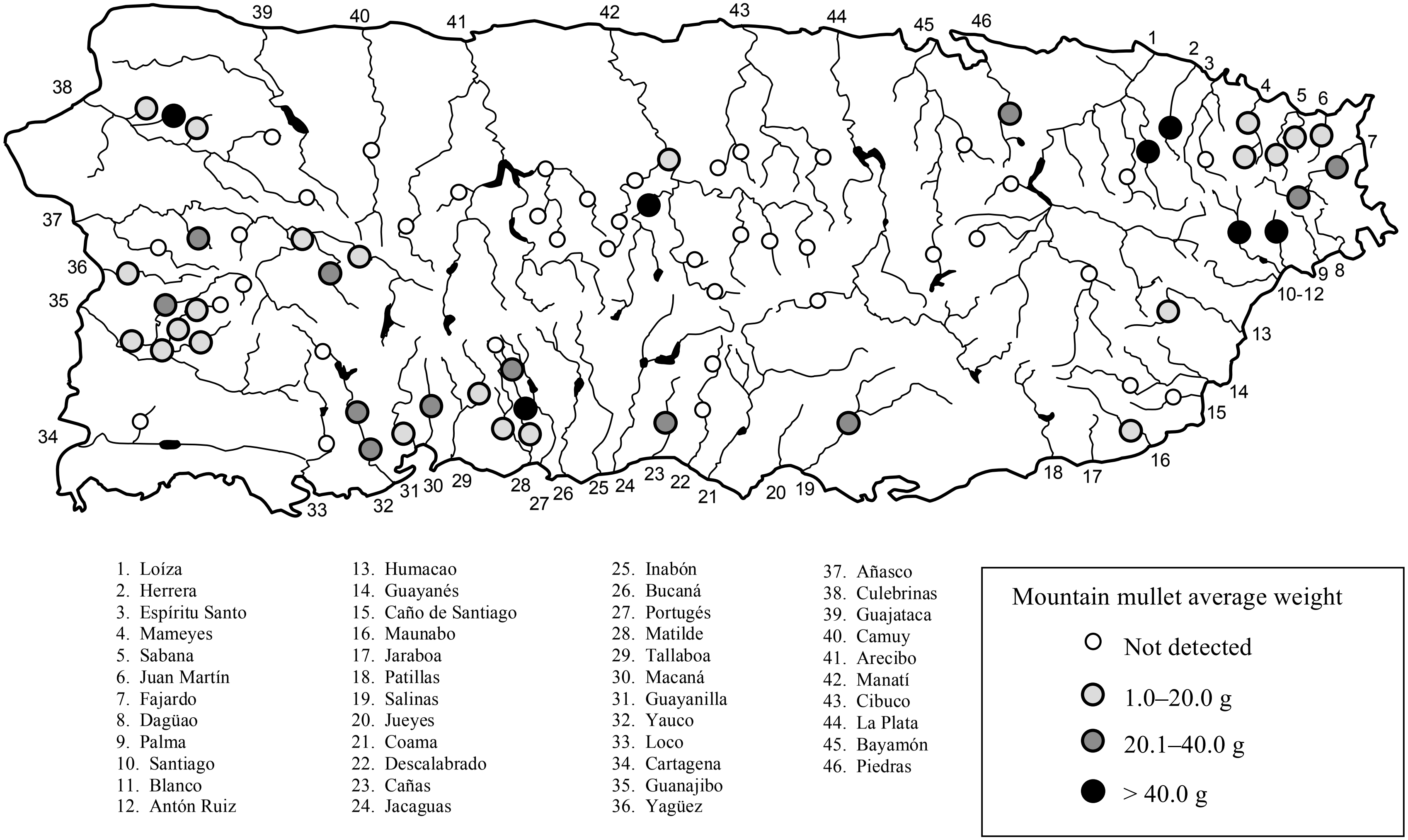

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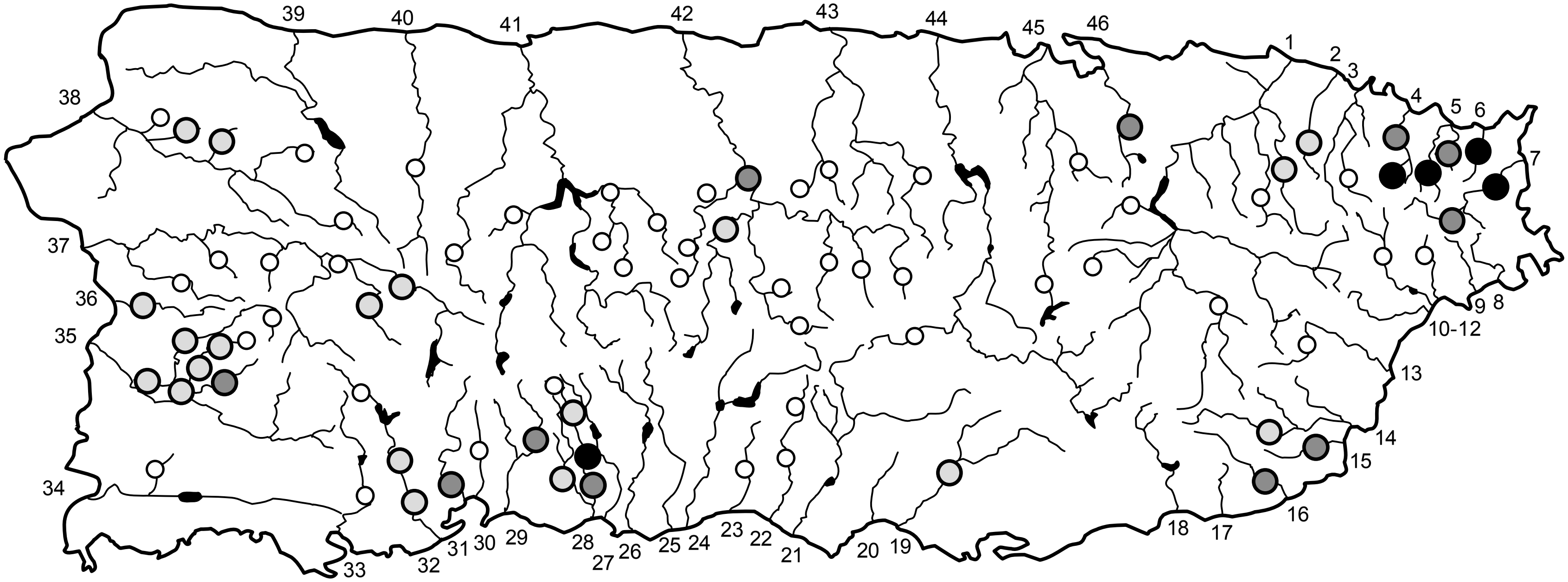
Figure 19. Occurrence and average weight of mountain mullet among 81 sites sampled during 2006–2007 spanning 34 of 46 drainage basins in Puerto Rico.



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45. Bayamón
46. Piedras

Bigmouth sleeper density

○ Not detected

◎ 1–400 fish/ha

◉ 401–1,000 fish/ha

● > 1,000 fish/ha

Figure 20. Occurrence and density of bigmouth sleeper among 81 sites sampled during 2006–2007 spanning 34 of 46 drainage basins in Puerto Rico.

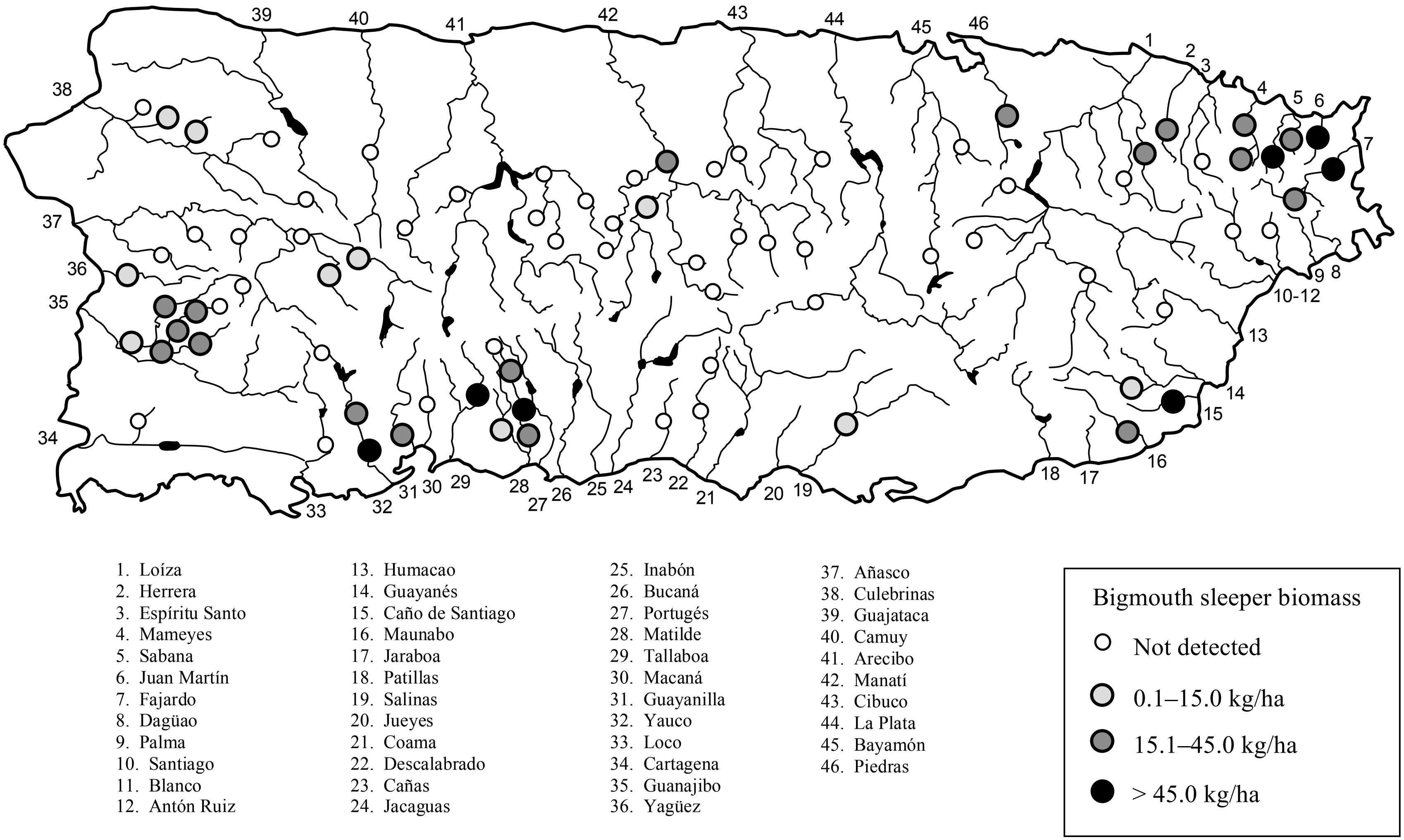

Figure 21. Occurrence and biomass of bigmouth sleeper among 81 sites sampled during 2006–2007 spanning 34 of 46 drainage basins in Puerto Rico.

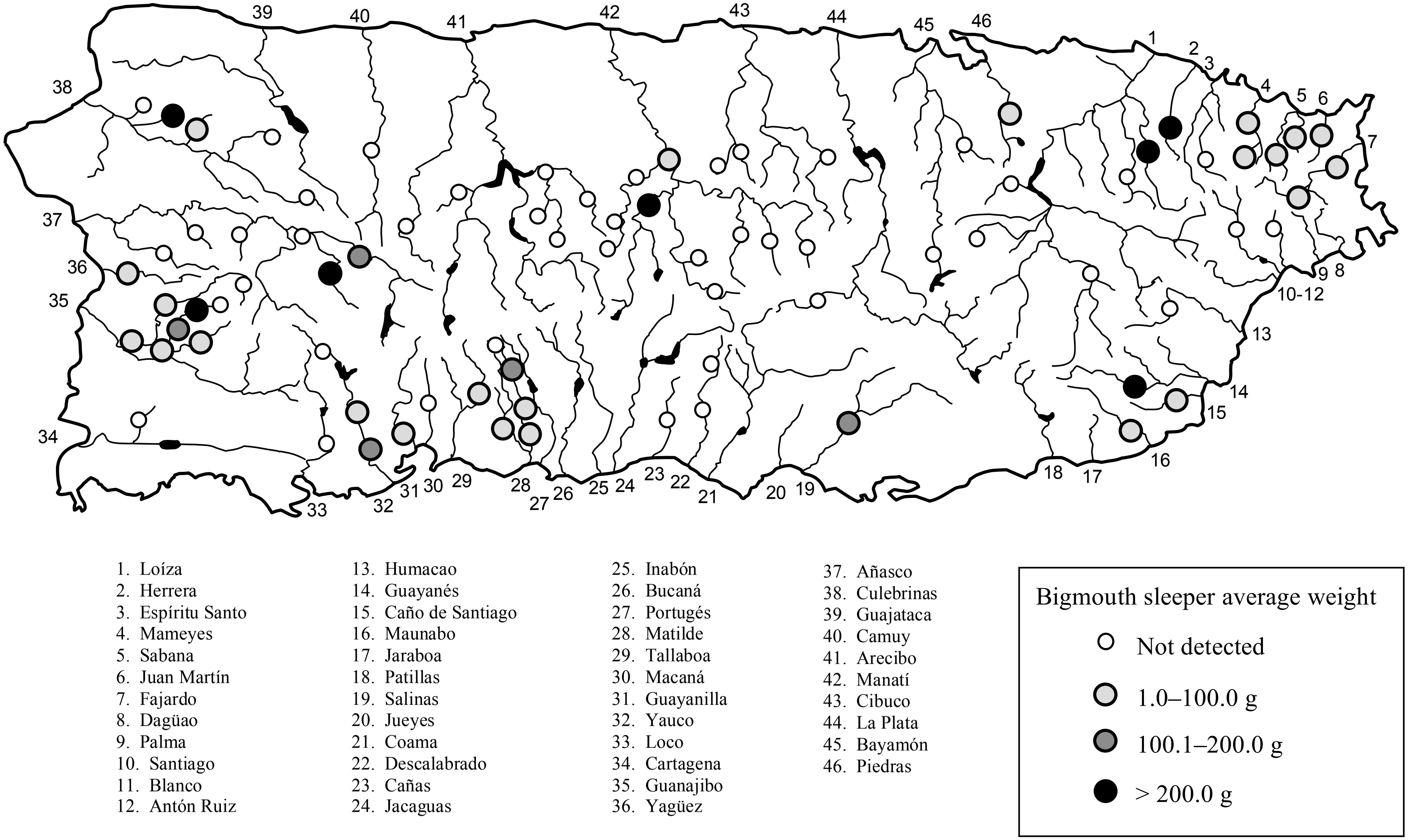

Figure 22. Occurrence and average weight of bigmouth sleeper among 81 sites sampled during 2006–2007 spanning 34 of 46 drainage basins in Puerto Rico.

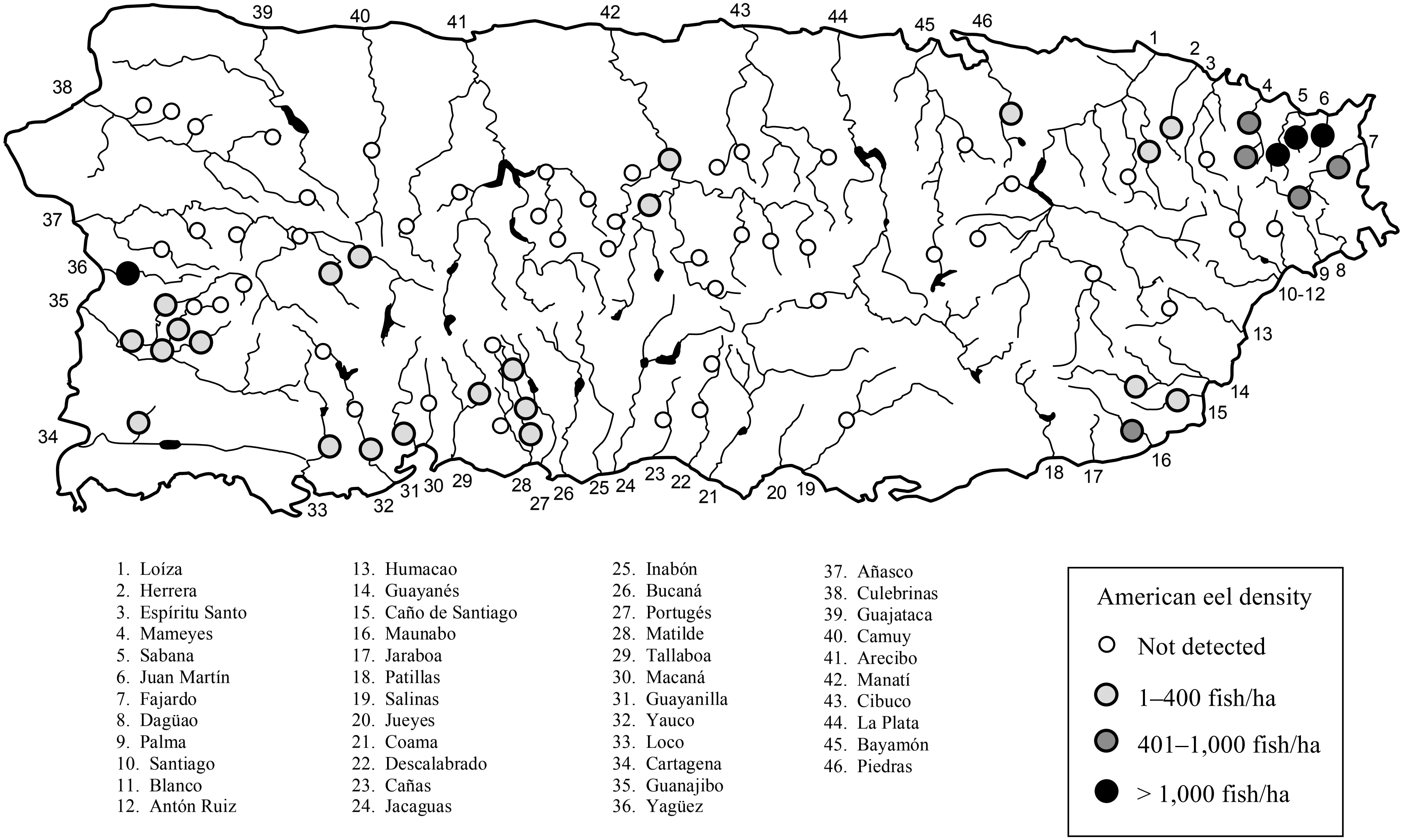

Figure 23. Occurrence and density of American eel among 81 sites sampled during 2006–2007 spanning 34 of 46 drainage basins in Puerto Rico.

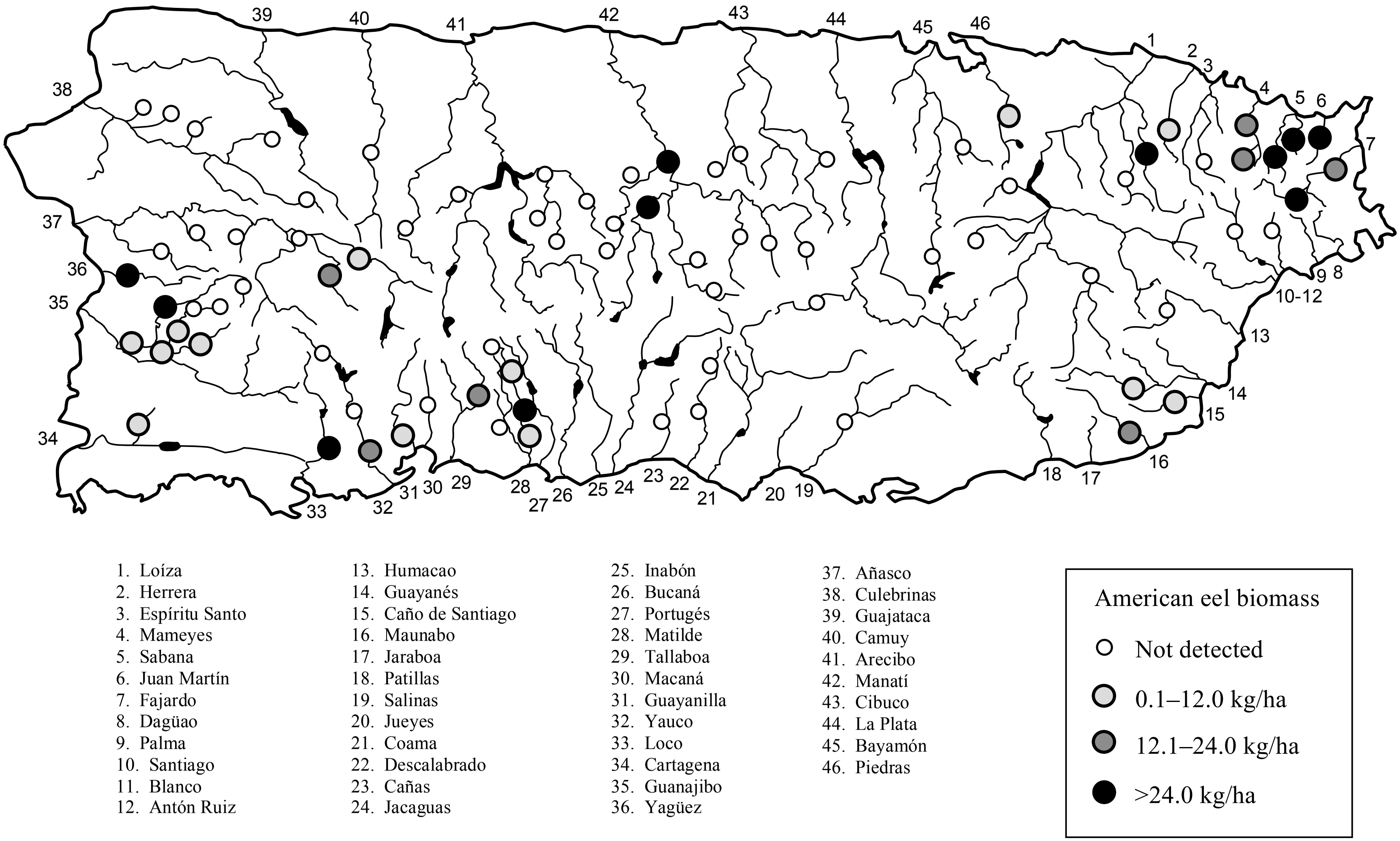

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Figure 24. Occurrence and biomass of American eel among 81 sites sampled during 2006–2007 spanning 34 of 46 drainage basins in Puerto Rico.

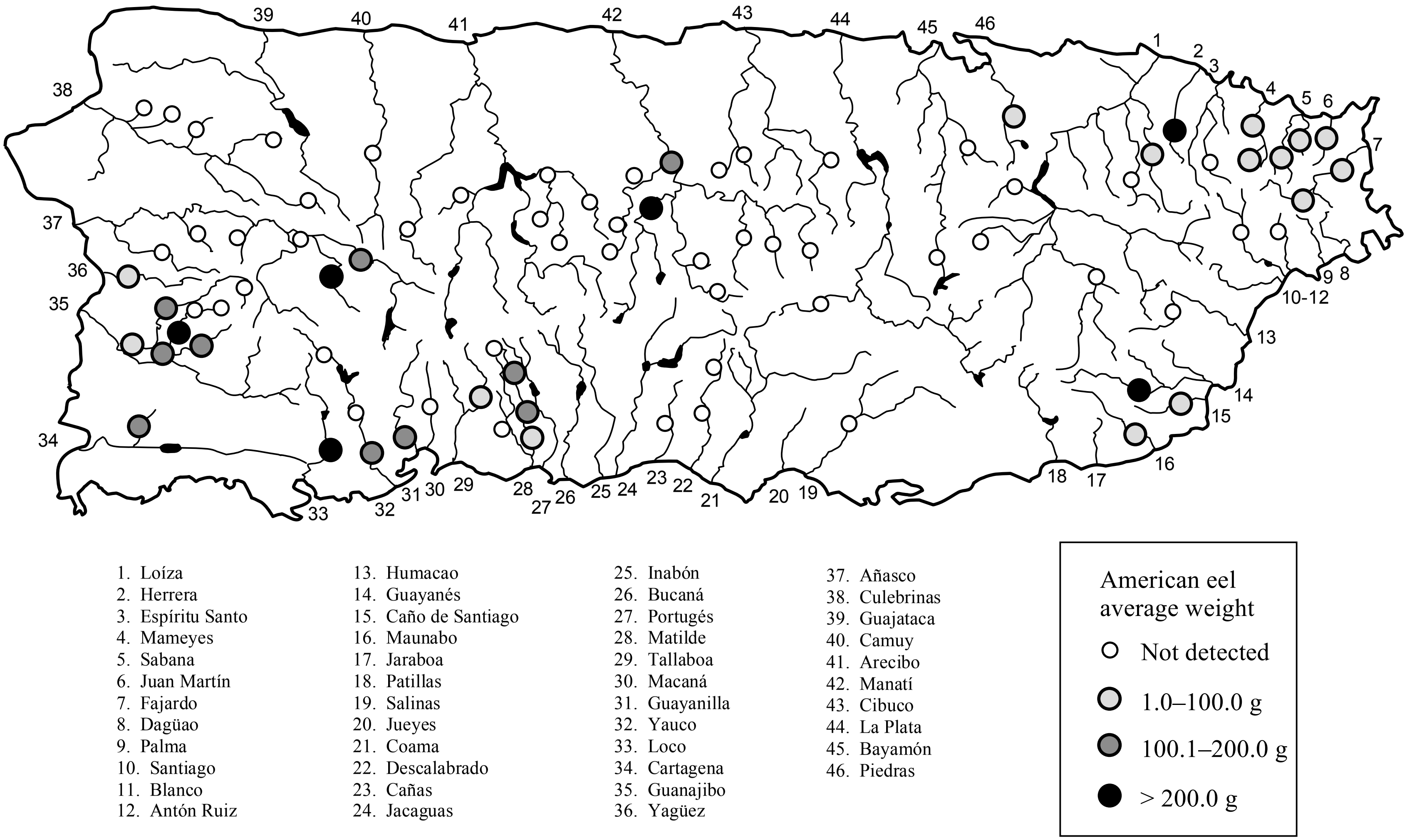

Figure 25. Occurrence and average weight of American eel among 81 sites sampled during 2006–2007 spanning 34 of 46 drainage basins in Puerto Rico.

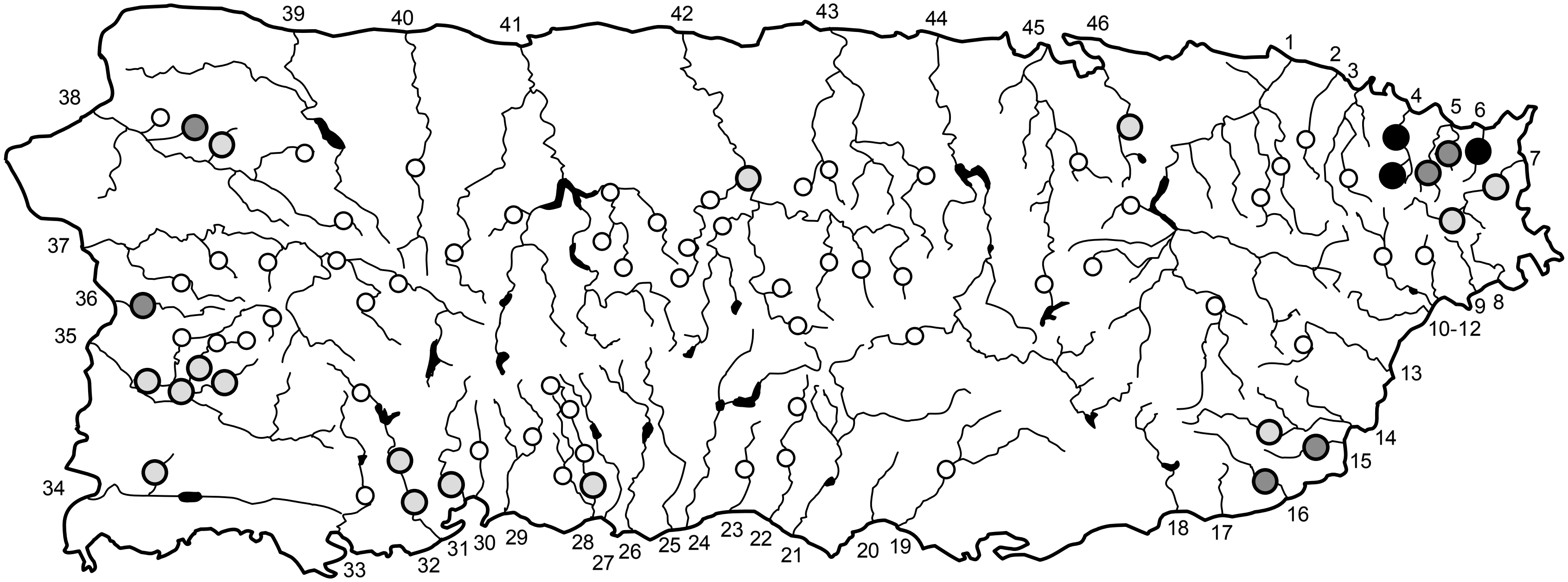

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Figure 26. Occurrence and density of smallscaled spinycheek sleeper among 81 sites sampled during 2006–2007 spanning 34 of 46 drainage basins in Puerto Rico.

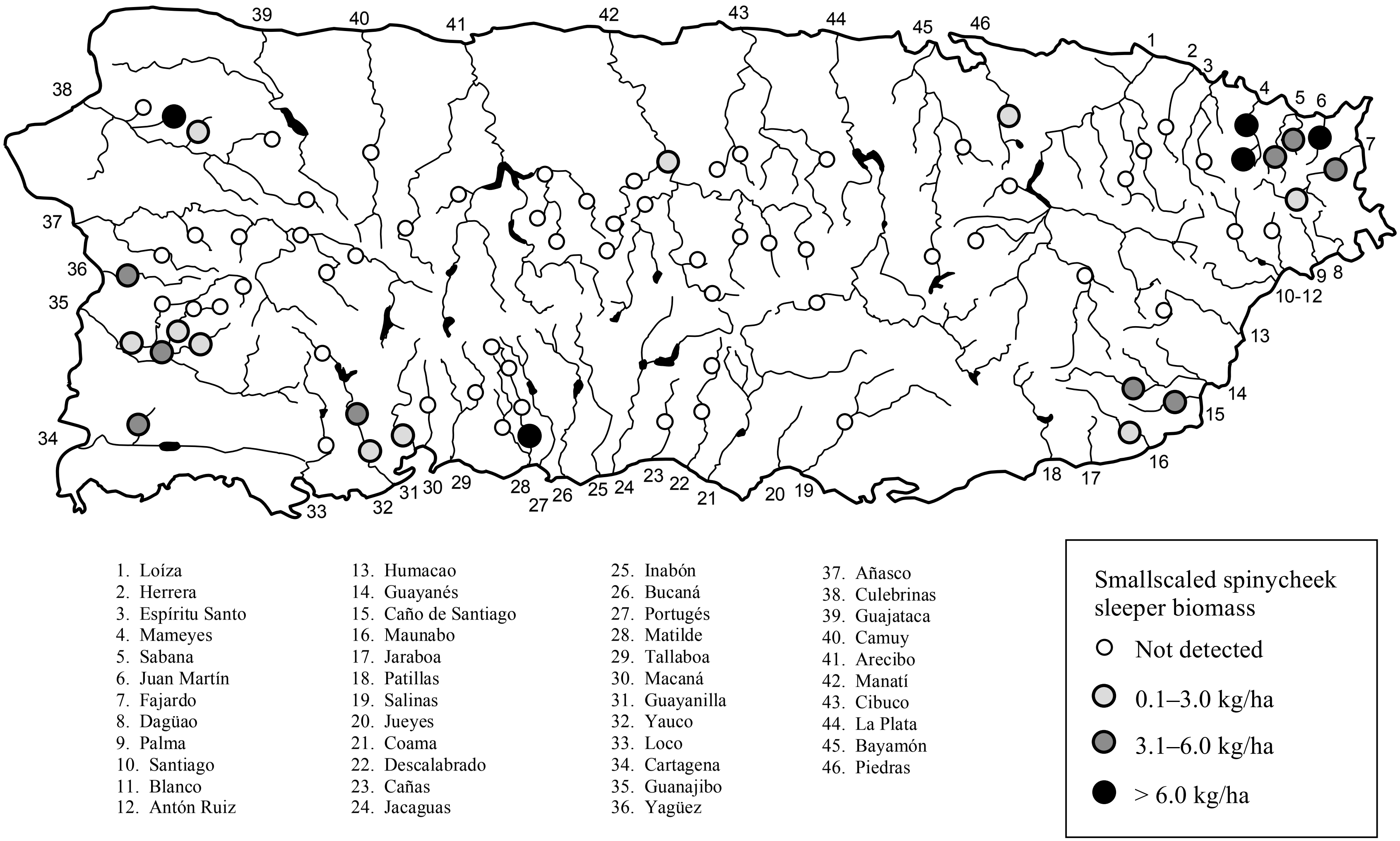


Figure 27. Occurrence and biomass of smallscaled spinycheek sleeper among 81 sites sampled during 2006–2007 spanning 34 of 46 drainage basins in Puerto Rico.

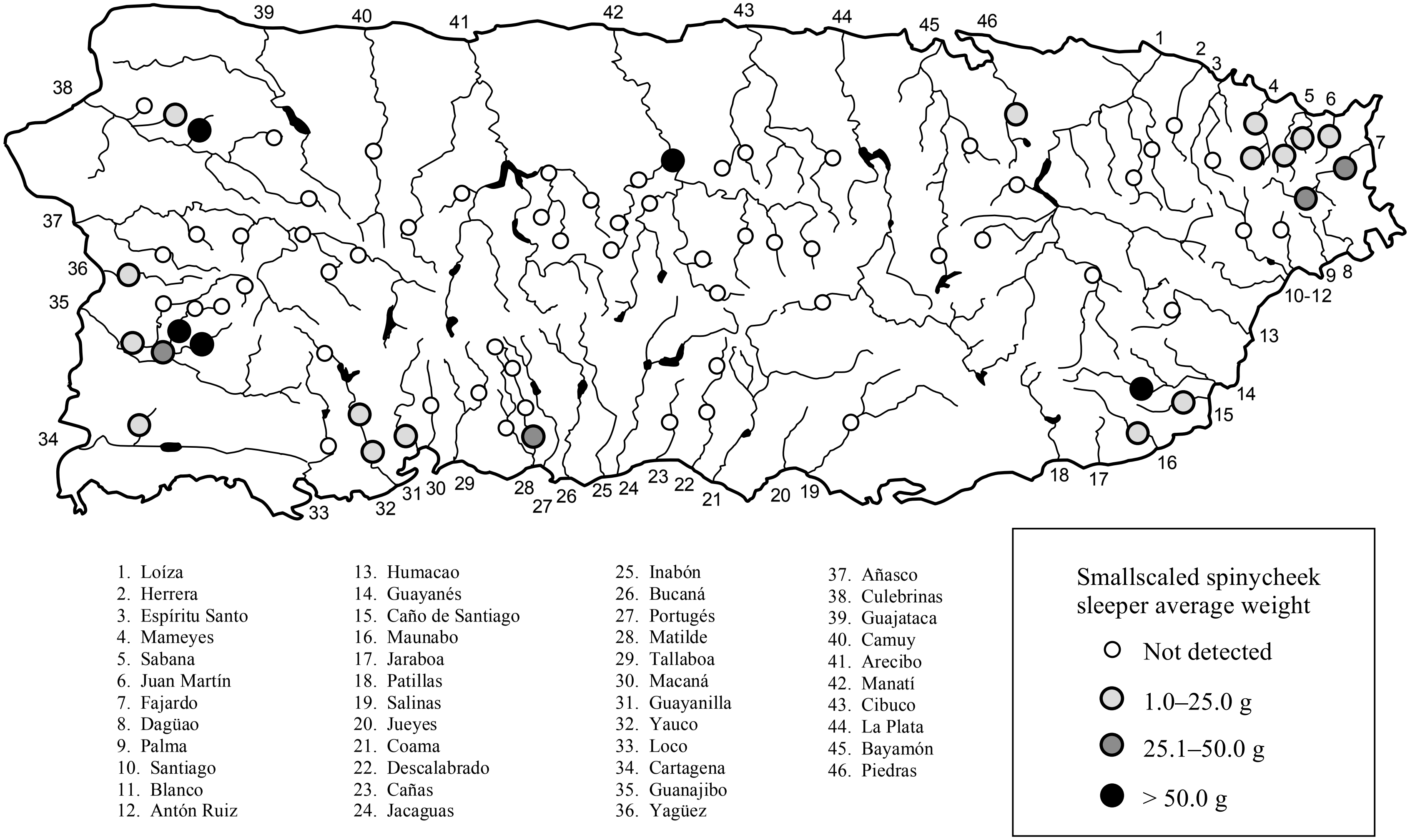
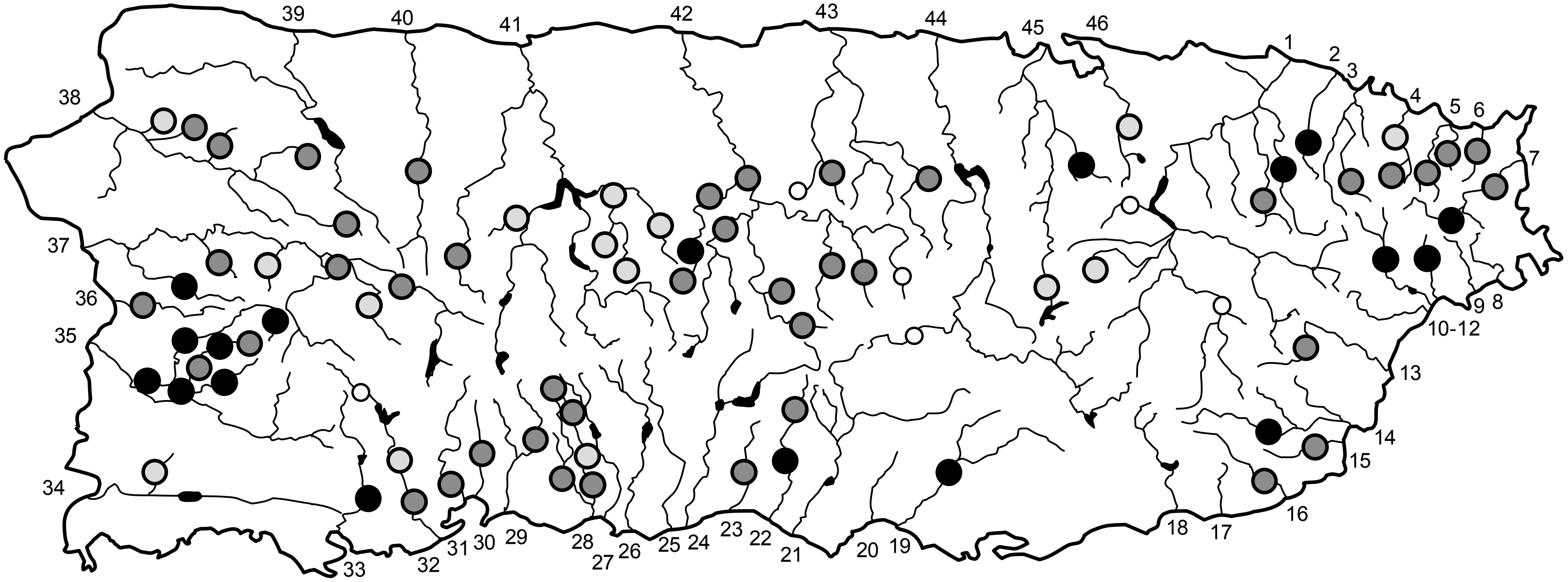


Figure 28. Occurrence and average weight of smallscaled spinycheek sleeper among 81 sites sampled during 2006–2007 spanning 34 of 46 drainage basins in Puerto Rico.



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15. Caño de Santiago
16. Maunabo
17. Jaraboa
18. Patillas
19. Salinas
20. Jueyes
21. Coama
22. Descalabrado
23. Cañas
24. Jacaguas
25. Inabón
26. Bucaná
27. Portugés
28. Matilde
29. Tallaboa
30. Macaná
31. Guayanilla
32. Yauco
33. Loco
34. Cartagena
35. Guanajibo
36. Yagüez
37. Añasco
38. Culebrinas
39. Guajataca
40. Camuy
41. Arecibo
42. Manatí
43. Cibuco
44. La Plata
45. Bayamón
46. Piedras

Native shrimp species richness

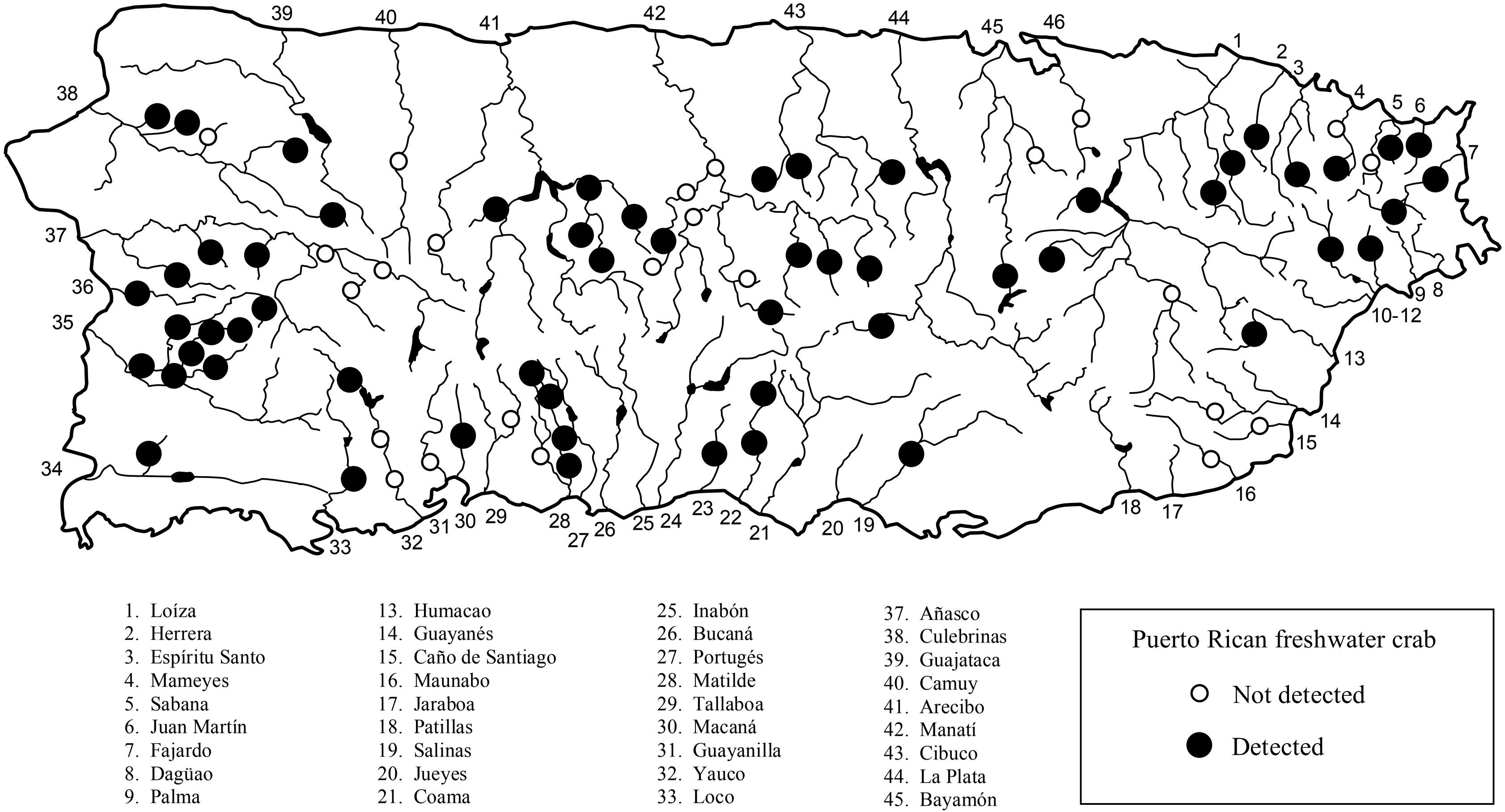
○ Not detected

● 1–3 species

● 4–6 species

● 7–9 species

Figure 29. Native shrimp species occurrence and richness among 81 sites sampled during 2005–2007 spanning 34 of 46 drainage basins in Puerto Rico.



1. Loíza
2. Herrera
3. Espíritu Santo
4. Mameyes
5. Sabana
6. Juan Martín
7. Fajardo
8. Dagüao
9. Palma
10. Santiago
11. Blanco
12. Antón Ruiz
13. Humacao
14. Guayanés
15. Caño de Santiago
16. Maunabo
17. Jaraboa
18. Patillas
19. Salinas
20. Jueyes
21. Coama
22. Descalabrado
23. Cañas
24. Jacaguas
25. Inabón
26. Bucaná
27. Portugés
28. Matilde
29. Tallaboa
30. Macaná
31. Guayanilla
32. Yauco
33. Loco
34. Cartagena
35. Guanajibo
36. Yagüez
37. Añasco
38. Culebrinas
39. Guajataca
40. Camuy
41. Arecibo
42. Manatí
43. Cibuco
44. La Plata
45. Bayamón
46. Piedras

Figure 30. Distribution of Puerto Rican freshwater crab *Epilobocera sinuatifrons* among 81 sites sampled during 2005–2007 spanning 34 of 46 drainage basins in Puerto Rico.