Inventory of American Eels in selected El Yunque National Forest streams

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Introduction

The American Eel (*Anguilla rostrata*) is found in freshwater, estuarine, and marine habitats throughout a large part of the Atlantic basin, including Greenland, North America, the Caribbean, and northern South America. It has a catadromous life cycle that includes 6 distinct life stages (ASMFC, 2012). All American Eels spawn in the Sargasso Sea, a large portion of the western Atlantic east of the Bahamas and south of Bermuda, between February and April. Eggs hatch within a week of spawning and larval eels (leptocephali) are distributed generally westward and northward to continental waters over a period of 8 to 15 months by the Florida, Caribbean, and Gulf currents. The leptocephali transform to glass eels as they near the continental shelf, typically 6 to 12 months post-hatch and begin active migration, towards coastal waters in late winter or early summer. Glass eels transform to pigmented elvers as they enter brackish or freshwaters. Elvers transform to yellow eels by age two and settle in a wide range of habitats from estuaries to freshwater streams hundreds of kilometers from the ocean. Yellow eels may occupy freshwater habitats from 3 to 30 years before entering the silver eel phase. Silver eels migrate downstream, eventually reaching the Sargasso Sea in the winter or early spring. Although spawning has never been observed, American Eels are presumed to spawn once and die.

This complex lifecycle exposes the American Eel to a variety of stressors that can impact local distribution and overall population health, including commercial fishing (several life stages), blockages to upstream and downstream movements by dams and associated hydroelectric turbines, freshwater habitat degradation, predation, non-native parasites, contaminant bioaccumulation, and changes in ocean currents (ASMFC, 2012). Chronic exposure to these stressors throughout its range resulted in a 2004 petition for listing under the Endangered Species Act. In 2007, the U. S. Fish and Wildlife Service (FWS) elected not to list the American Eel citing its wide distribution, total population size in the millions, continued access to habitat throughout most of its historical range, and the ability to occupy a wide range of habitats as mitigating factors. The species went under review again in 2010 with the FWS citing new evidence warranting a new review; ruling on the 'new' petition is expected in 2015. Regardless of their official status, a better understanding of each life stage across the broad geographic range is needed to protect and manage the species.

There is relatively little information available on the distribution, abundance, or ecology of American Eels in Puerto Rico streams (Crain and Gould, 2011). Prior to 2007, American Eels were considered to be "…present but generally quite scarce in Puerto Rico" (EOL, 2014). Surveys by Kwak et al. (2007, 2013) of aquatic communities in every major watershed in Puerto Rico revealed that American

Eels were much more widespread and abundant on the island than previously believed, and that some of the highest densities of American Eels were in watersheds in the northeast corner of the island, on or adjacent to El Yunque National Forest. However, with the exception of the Rio Mamayes watershed, sampling was limited to 3 or fewer low elevation sample sites per watershed (Figure 1).

American Eels are known to occupy streams in El Yunque (Nuckols and Roghair, 2005) but information on their upstream extent and relative abundance is lacking. In 2014, El Yunque National Forest partnered with the USDA Forest Service, Southern Research Station, Center for Aquatic Technology Transfer (CATT) to complete additional surveys in 5 watersheds known to contain American Eels. We applied the 3-pass depletion sampling methods outlined in Kwak et al. (2007) to: 1) further describe eel distribution, and 2) quantify relative abundance in watersheds known to contain American Eels. In total, 4 CATT Biologists and 1 Regional Office Biologist joined with El Yunque's Forest Biologist and 2 Biological Technicians to complete American Eel surveys from April 15 - April 24, 2014.

Methods

Sample site selection

The topography in and around El Yunque National Forest is quite steep, the rainforest vegetation is thick, and the streams are prone to flash flooding, thus sample sites were limited to areas with reasonable and safe access via road or trail. All sample sites were located upstream of existing mainstem sample sites or in tributaries with no prior history of sampling. Based on surveys completed by Kwak et al. (2007, 2013), we selected a total of 14 sites from 5 watersheds known to contain American Eels (Table 1, Figure 1).

Sampling methods

We based our sampling methods on those described in Kwak et al. (2007) for quantifying fish populations in Puerto Rico streams. At each sample site we established a sampling reach consisting of at least 1 pool-riffle sequence with start and end points at habitat unit breaks. Our target reach length was 100 m, but because of variation in habitat unit length reaches ranged from 90 m – 130 m (Table 1). Blocknets were placed at the downstream and upstream end of each sample reach, unless a natural barrier or dam was located at the upstream end of the reach. We measured wetted stream width at a minimum of 3 locations spread throughout the length of the reach and calculated the average wetted width. We completed 3 passes through each sample reach using a DC backpack electrofisher. Where the sample reach wetted width exceeded 5 m we used 2 backpack electrofishers. After the first pass we recorded the total shock time from the shocker's timer and attempted to keep effort equal on the subsequent 2 passes. When no eels were collected on both passes 1 and 2 we omitted the third pass. After each pass we divided the eels into 4 size classes (<200 mm, 200-400 mm, 401-600 mm, >600 mm) and recorded the total number of eels in each size class. We measured the total length of the largest and smallest eel collected at each site. Eels were returned to the location of capture following the third pass. We also noted the fish, shrimp, and crab species collected at each sample site (Appendix A).

Data analysis

We used the 3-pass depletion formulas found in Kwak (1991) to calculate population abundance at each site. We multiplied the sample reach length by its average wetted width to calculate reach area. The population density for each site was calculated as the population abundance divided by the reach area and is reported as the number of American Eels per hectare (eels per ha). The 3-pass depletion formulas fail for sites where we did not capture fewer fish on each successive pass. For these sites we simply summed the three passes to provide a conservative estimate of population abundance for calculating density.

Results

We collected American Eels from all 5 watersheds and from 9 of 14 sample sites (Table 1, Figure 1). Total density ranged from 0 to 1,984 eels per ha, and size ranged from 100 mm to 920 mm (Table 2). We successfully depleted (i.e. captured fewer total eels on each successive pass) eels at 3 of the 9 sites where they were present (Table 2). Grouping eels by 4 size classes revealed that we collected eels from 22 of the 36 possible (9 sites where eels were present * 4 size classes per site) size class groups and had successful depletions for 4 of the 22 size class groups (Table 2).

Rio Fajardo

We collected eels at 4 sample sites in the Rio Fajardo watershed, with the highest density of eels (906 eels per ha) at the furthest downstream site (F17.2) (Figure 1, Table 2). Kwak et al. (2007) found similar eel density in tributaries to Rio Fajardo that join the mainstem between river km 13 and 14 (Figure 1). The upstream end of site F17.2 is marked by a lowhead dam. Total eel density, and most notably the density of eels less than 200 mm dropped sharply at site F18.0, 0.8 km upstream of the lowhead dam (Figure 2). We encountered a series of steep cascades and small waterfalls at the upstream end of site F19.6, a popular privately-owned recreation area known locally as Las Tinajas. We saw only a single eel at site F19.8, upstream of the cascades and falls. We failed to net the eel, but it was one of the largest we encountered at any of the sites we sampled.

Rio Juan Martin

We had 1 sample site in the Rio Juan Martin watershed. Site J3.7 was unique among the sites we sampled in that it was close to the ocean (3.7 river km), small (2.4 m average wetted width), and flowed through a mixed residential and agricultural area. At 1,984 eels per ha, sample site J3.7 had the highest density of eels of any site we sampled (Figure 2, Table 2). We failed to collect any eels over 400 mm and the sample was dominated by eels less than 200 mm. Kwak et al. (2007) found over 1,700 eels per ha at a sample site dominated by small juvenile eels approximately 1 river km downstream (Figure 1).

Rio Pitahaya

We sampled 3 sites in the Rio Pitahaya watershed and found eels only at the furthest downstream site, P8.2. We collected a total of 7 eels (109 eels per ha) at site P8.2, with the majority in the 400 mm – 600 mm size class (Figure 2, Table 2). We did not collect any eels from two sites on headwater tributaries to Rio Pitahaya. Stream gradient increases significantly between site P8.2 and the tributary sites. The elevation of site P8.2 is approximately 60 m. The elevation increases to 130 m and 160 m at sites Pt9.3 and Pt10.1, respectively. Kwak et al. (2007) found a density of eels in excess of 2,000 eels per ha at a sample site near river km 5.3 (Figure 1).

Rio Sabana

We sampled 4 sites in the Rio Sabana watershed. The highest density of eels was at the furthest downstream site, S5.0. Density was 345 eels per ha at site S5.0 and eels less than 200 mm were the most abundant size class (Figure 2, Table 2). Between S5.0 and S7.5 there is a series of cascades used as a local private recreation area. At site S7.5, near the International Institute of Tropical Forestry work center, we collected only 1 eel, but it was the largest eel we netted at any sample site (920 mm) (Table 1). We did not collect any eels from the unnamed tributary entering the mainstem just upstream of site S7.5, nor did we collect any eels from site S9.2. Kwak et al. (2007) reported eel density of over 2,700 eels per ha near river km 4.1.

Rio Mamayes

The lower Rio Mamayes watershed has been the focus of extensive sampling by Kwak et al. (2007, 2013) (Figure 1). We added 2 sites in the Rio Mamayes watershed: Mt 10.1 is in an unnamed tributary near the upstream extent of Kwak et al.'s sampling; M12.7 is on the mainstem upstream of a high gradient section of Rio Mamayes that begins near the confluence with Quebrada La Coca . A previous inventory by the CATT documented the presence of eels as far upstream as the confluence with Quebrada La Coca (Nuckols and Roghair, 2005). We found low eel density (146 eels per ha) at the tributary site and failed to collect eels at site M12.7 (Figure 2, Table 2). Kwak et al. generally found the highest density of eels at sample sites downstream of river km 4.5.

Discussion

Fish intent on swimming from Puerto Rico's low gradient coastal rivers to the steep headwater streams of El Yunque National Forest encounter a variety of obstacles. The negative effects of man-made barriers such as dams on upstream eel passage are well documented (Cooney and Kwak, 2013), and we observed their effect firsthand on Rio Fajardo. As we sampled site F17.2, small eels probed the lowhead dam and unsuccessfully attempted to scale it. Eels in the smallest size class were nearly absent from sample sites upstream of the dam. Natural barriers such as waterfalls and cascades also play a significant role in limiting the upstream movement of American Eels (Cooney and Kwak, 2013). We saw a sharp decrease in density or an absence of eels upstream of waterfalls and/or cascades on Rio Fajardo, Rio Sabana, and Rio Mamayes. Eels were also absent upstream of high gradient reaches in the Rio Pitahaya watershed. The cumulative effect of these barriers is a general decrease in the density of eels, particularly eels in the smallest size classes, as they approach El Yunque National Forest.

Our inability to consistently complete successful 3-pass depletions was likely the result of 2 factors: 1) American Eels are a cryptic species that is challenging to collect with backpack electrofishers in complex habitats, and 2) many of our sample sites were in areas of relatively low population density. Our depletion success rate was similar to that of Kwak (2007), but our results highlight some of the limitations of the 3-pass approach for providing abundance estimates for American Eels. A benefit of completing multiple passes is the opportunity to detect rare species or size classes missed in the first pass. We collected additional size classes on the second or third pass at several sites, and at both Rio Sabana S7.5 and at Rio Fajardo F19.8 we would have failed to detect eels altogether had we not completed a second pass.

Continued use of the 3-pass approach adopted from Kwak et al. (2007) for future eel inventories will allow comparisons among datasets, but new approaches for detecting rare or cryptic species are needed to fully describe the distribution of American Eels in Puerto Rico. Environmental DNA (eDNA) is an emerging technology that may be useful for detecting the presence of American Eels, even when they are present in low densities (Olsen, 2012; Tomsen 2012; Bohmann, 2014). Collection of eDNA samples is relatively simple and may be a cost-effective alternative to electrofishing in the difficult terrain of El Yunque National Forest. Regardless of the methods used, collecting information on the distribution and abundance of American Eels is just the first step in developing strategies to better protect and manage this species in Puerto Rico. Additional information such as diet, growth rate, sex ratio, home range, length of stay in freshwater, and timing of seaward migration would allow for the development of more effective management plans.

A number of recommendations have been developed by the Atlantic States Marine Fisheries Commission (ASMFC) for the improvement of freshwater habitat quality for American Eels, including:

1) identify and remediate hazards to upstream migration, report changes in size class distributions following blockage remediation projects,
2) consider eel habitat in watershed development and restoration plans,
3) explore and pursue acquisition, deed restrictions, or conservation easements along migration corridors, and
4) establish windows of compatibility for activities that may adversely affect eels (e.g. dredging, filling, aquatic construction, water diversions/withdrawal) (ASMFC, 2014).

The most obvious management action to improve eel habitat in the watersheds we sampled is to breach or remove the lowhead dam on Rio Fajardo. Allowing eels to more easily pass through the site should result in an increase in eel density, particularly for the smallest size classes in the 2.5 km reach between the lowhead dam and the series of cascades and falls at river km 19.7, Las Tinajas. A large tributary entering Rio Fajardo just upstream of the dam could also see increases in eel density, though the use of the tributary by eels is currently unknown.

The relative rarity of American Eels in streams flowing through El Yunque National Forest managed lands should not preclude the Forest from taking a lead role in development of American Eel management strategies. The Forest Service has often taken the lead in securing sufficient flows of high quality water to improve native fisheries downstream of National Forest managed lands. Forest leaders may facilitate management action through partnerships or collaboration with various local government or Commonwealth agencies as well as local stakeholder groups to address several of the ASMFC recommendations listed above. In addition, El Yunque National Forest is uniquely positioned to lead a public education campaign to raise awareness of the American Eel in Puerto Rico and to improve native fisheries sustainability through continued leadership in eliminating rapacious fish collection methods within El Yunque's boundaries and beyond. We encourage El Yunque National Forest to continue its efforts to better protect and manage the American Eel.

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Figures

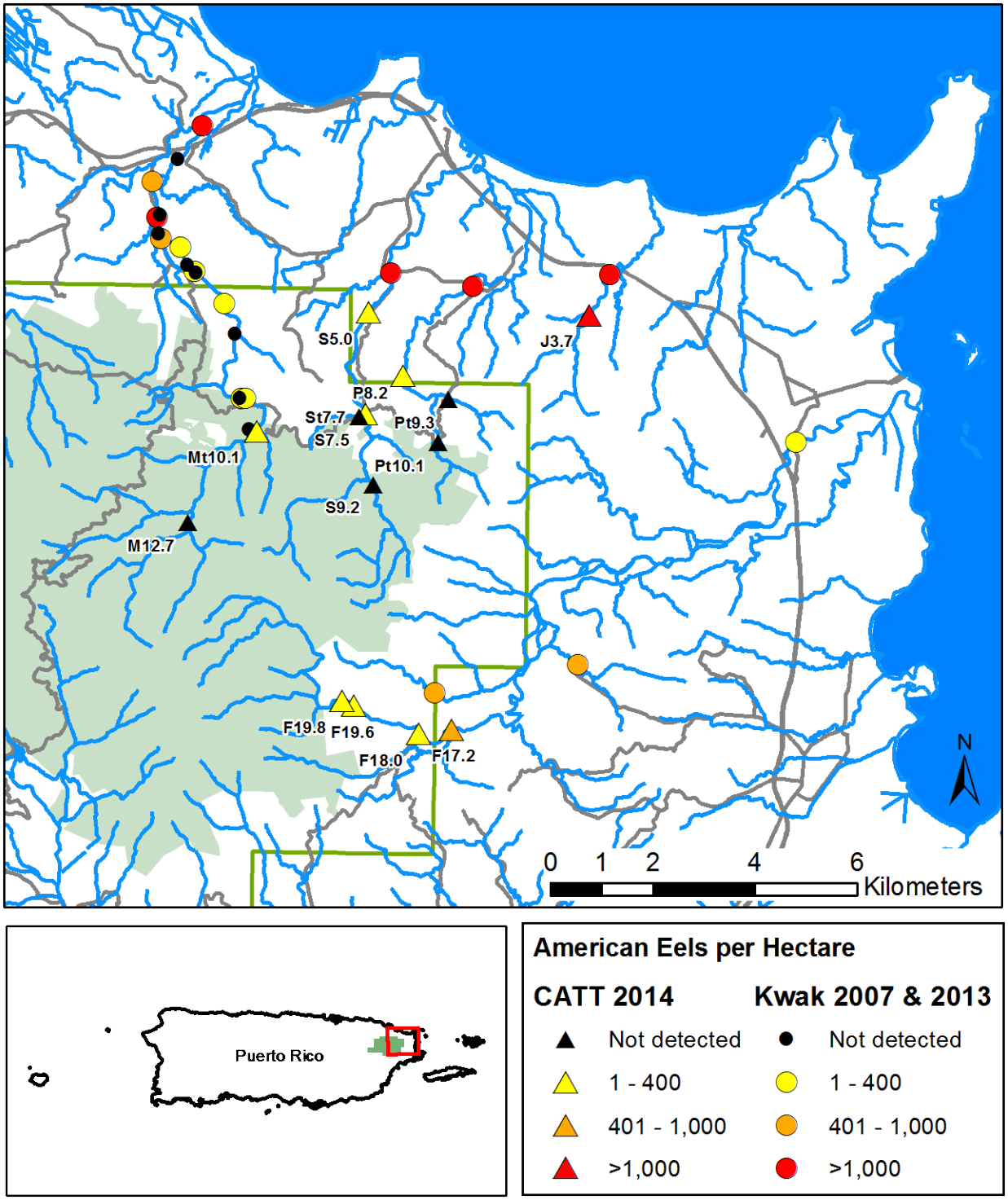

Figure 1. Density of American Eels collected from Puerto Rico streams by Kwak (2007, 2013) and in 2014 by the CATT. Green line indicates El Yunque National Forest Proclamation boundary; green shading is National Forest managed lands.

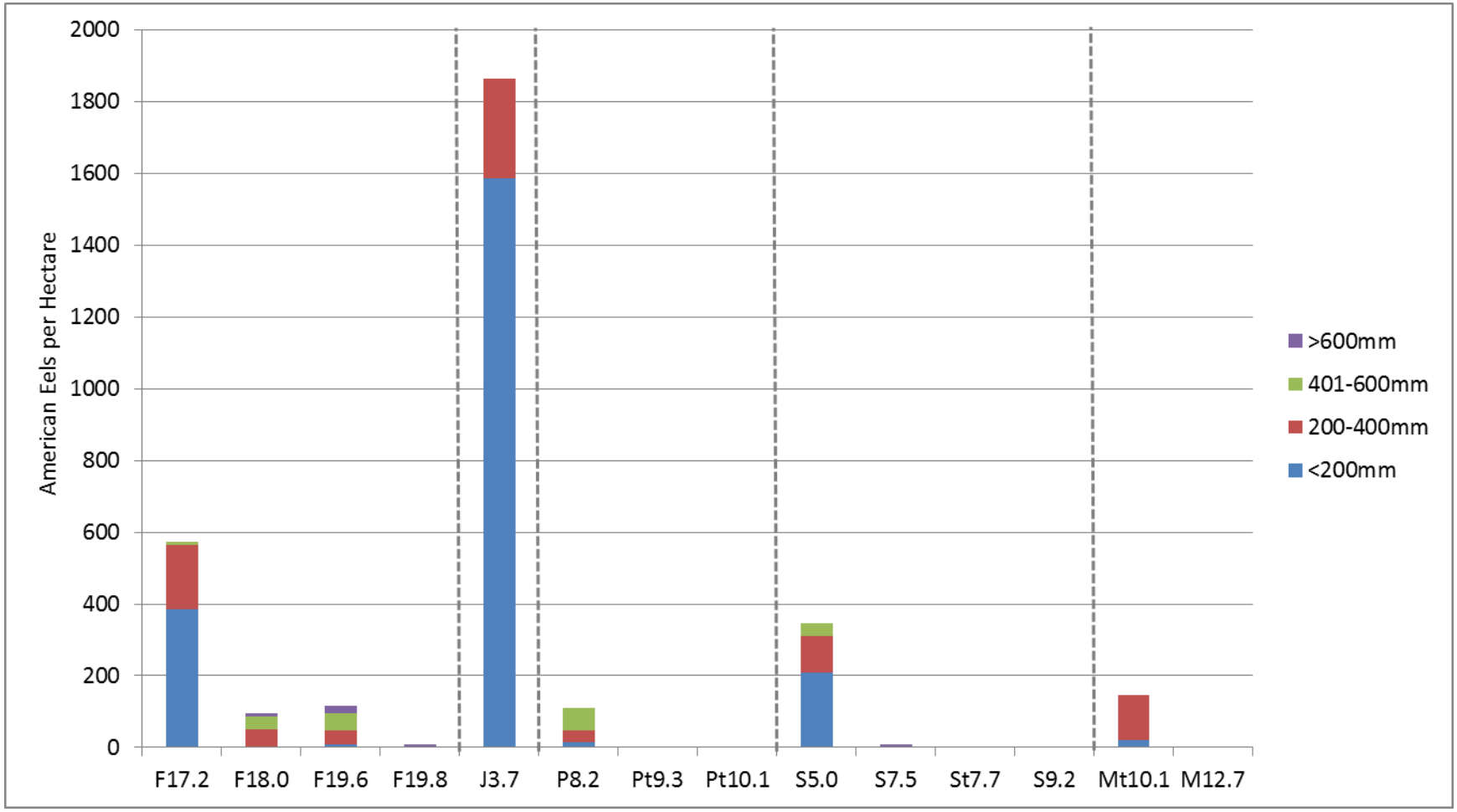

Figure 2. Number of American Eels per hectare by size class at sample sites on Rio Farjardo, PR, April 2014. Vertical lines separate major watersheds (F = Fajardo, J = Juan Martin, P = Pitahaya, S = Sabana, M = Mamayes, t = tributary). Sample site numbers correspond to river kilometers from the ocean.

Tables

Table 1. Location and description of American Eel sample sites grouped by major watershed, Puerto Rico, April 2014. Watersheds are arranged from furthest east to furthest west; within each watershed sites are arranged from furthest downstream to furthest upstream. OKM = river kilometers from the ocean. RKM = river kilometers from confluence with mainstem river (tributary sites only). GPS map datum = NAD83. Width is average wetted width.

River	OKM	RKM	SiteID	GPS	Comments	Date	Length (m)	Width (m)	Eel Present
Rio Fajardo									
Fajardo	17.2	--	F17.2	N18.27003 W65.71309	downstream of lowhead dam	4/15/14	90	13	Yes
Fajardo	18.0	--	F18.0	N18.26910 W65.71927	upstream of lowhead dam	4/15/14	130	9	Yes
Fajardo	19.6	--	F19.6	N18.27407 W65.73128	downstream of waterfall/cascade	4/18/14	95	11	Yes
Fajardo	19.8	--	F19.8	N18.27469 W65.73337	upstream of waterfall/cascade	4/18/14	100	11	Yes
Rio Juan Martin									
Juan Martin	3.7	--	J3.7	N18.34366 W65.68880	road 984 bridge 1km from road 940	4/24/14	105	2.4	Yes
Rio Pitahaya									
Pitahaya	8.2	--	P8.2	N18.33245 W65.72297	upstream of bridge on road 9983	4/19/14	119	5.4	Yes
Not named	9.3	0.2	Pt9.3	N18.32847 W65.71449	downstream of road 988 crossing	4/22/14	110	5	No
Chiquito	10.1	1.0	Pt10.1	N18.32081 W65.71650	downstream of road 988 crossing	4/21/14	118	6	No
Rio Sabana									
Sabana	5.0	--	S5.0	N18.34357 W65.72962	1 km upstream of road 991 crossing	4/17/14	100	11	Yes
Sabana	7.5	--	S7.5	N18.32587 W65.72989	downstream of bridge at IITF	4/16/14	120	10.3	Yes
Not named	7.7	0.2	St7.7	N18.32558 W65.73071	tributary to Rio Sabana near IITF	4/17/14	115	6	No
Sabana	9.2	--	S9.2	N18.31320 W65.72829	downstream of water intake dam	4/16/14	100	3.5	No
Rio Mamayes									
Not named	10.1	0.1	Mt10.1	N18.32260 W65.75007	upstream of Angelito trail crossing	4/22/14	100	4.8	Yes
Mamayes	12.7	--	M12.7	N18.30597 W65.76247	Bisley Trail crossing; had to clear trail	4/23/14	110	9	No

Table 2. American Eel abundance, density, and size grouped by major watershed, Puerto Rico, April 2014. Boxed estimates indicate successful 3-pass depletions; abundance estimates were calculated using formulas from Kwak (1991). All remaining abundance estimates are simply the sum of the 3 passes. Hectares are calculated as (length x wetted width) / 10,000; see Table 1 for length and width. *At site F19.8 we failed to net the only American Eel we saw; it was a very large eel, well over 600 mm. We did not collect a maximum eel length at site F19.6.

	Abundance estimate (N)					**Density (N / hectare)**					**Total Length**	
	Size classes (mm)					Size classes (mm)					Min	Max
SiteID	<200	200-400	401-600	>600	All	<200	200-400	401-600	>600	All	(mm)	(mm)
Rio Fajardo												
F17.2	45	21	1	0	106	385	179	9	0	906	140	450
F18.0	0	6	4	1	12	0	51	34	9	103	240	750
F19.6	1	3	5	2	12	10	38	48	19	115	190	NA
F19.8	0	0	0	1	1	0	0	0	9	9	>600*	>600*
Rio Juan Martin												
J3.7	40	7	0	0	50	1587	278	0	0	1984	110	340
Rio Pitahaya												
P8.2	1	2	4	0	7	16	31	62	0	109	140	450
Pt9.3	0	0	0	0	0	0	0	0	0	0	--	--
Pt10.1	0	0	0	0	0	0	0	0	0	0	--	--
Rio Sabana												
S5.0	23	11	4	0	38	209	100	36	0	345	100	530
S7.5	0	0	0	1	1	0	0	0	8	8	920	920
St7.7	0	0	0	0	0	0	0	0	0	0	--	--
S9.2	0	0	0	0	0	0	0	0	0	0	--	--
Rio Mamayes												
Mt10.1	1	6	0	0	7	21	125	0	0	146	180	280
M12.7	0	0	0	0	0	0	0	0	0	0	--	--

Appendix – Other Species Observed

Table A1. Species observed while collecting American Eels in Puerto Rico, April 2014. The target species was American Eels; lack of detection for other species should not be interpreted as absence.

	Rio Fajardo				**Rio Juan Martin**	**Rio Pitahaya**			**Rio Sabana**				**Rio Mamayes**	
	F17.2	F18.0	F19.6	F19.8	J3.7	P8.2	Pt9.3	Pt10.1	S5.0	S7.5	St7.7	S9.2	Mt10.1	M12.7
Fish														
ANRO	x	x	x	x	x	x			x	x			x	
AGMO	x		x		x	x	x	x	x					
AWBA		x		x		x	x	x						
GODO	x		x	x	x				x				x	
ELPI					x									
SIPL	x			x		x	x	x	x	x	x	x	x	x
POCR									x					
Shrimp														
ATLA			x	x	x		x	x	x	x	x	x	x	x
ATSC				x		x		x		x	x			x
MIPO								x	x					
XIEL	x	x		x	x	x	x	x	x	x	x	x	x	x
MAFA	x	x	x		x		x	x	x	x		x		x
MAHE			x	x				x					x	x
MACR														x
MACA		x	x			x	x	x	x	x	x	x		x
Crab														
EPSI						x								x

Fish: ANRO = *Anguilla rostrata*; AGMO = *Agonostomus monticola*; AWBA = *Awous banana*; GODO = *Gobiomorus dormitor*; ELPI = *Eleotris pisonis*; SIPL = *Sicydium plumieri*; POCR = *Pomadasys crocro*

Shrimp: ATLA = *Atya lanipes*; ATSC = *Atya Scabra*; MIPO = *Micratya poeyi*; XIEL = *Xiphocaris elongata*; MAFA = *Macrbrachium faustinum*; MAHE = *Macrobrachium heterochirus*; MACR = *Macrobrachium crenulatum*; MACA = *Macrobrachium carcinus*

Crab: EPSI = *Epilobocera sinuatifrons*