Estimating Relative Abundance of Young-of-Year American Eel, *Anguilla rostrata,* in the Virginia Tributaries of Chesapeake Bay (Spring 2009)

Final Report

Submitted by

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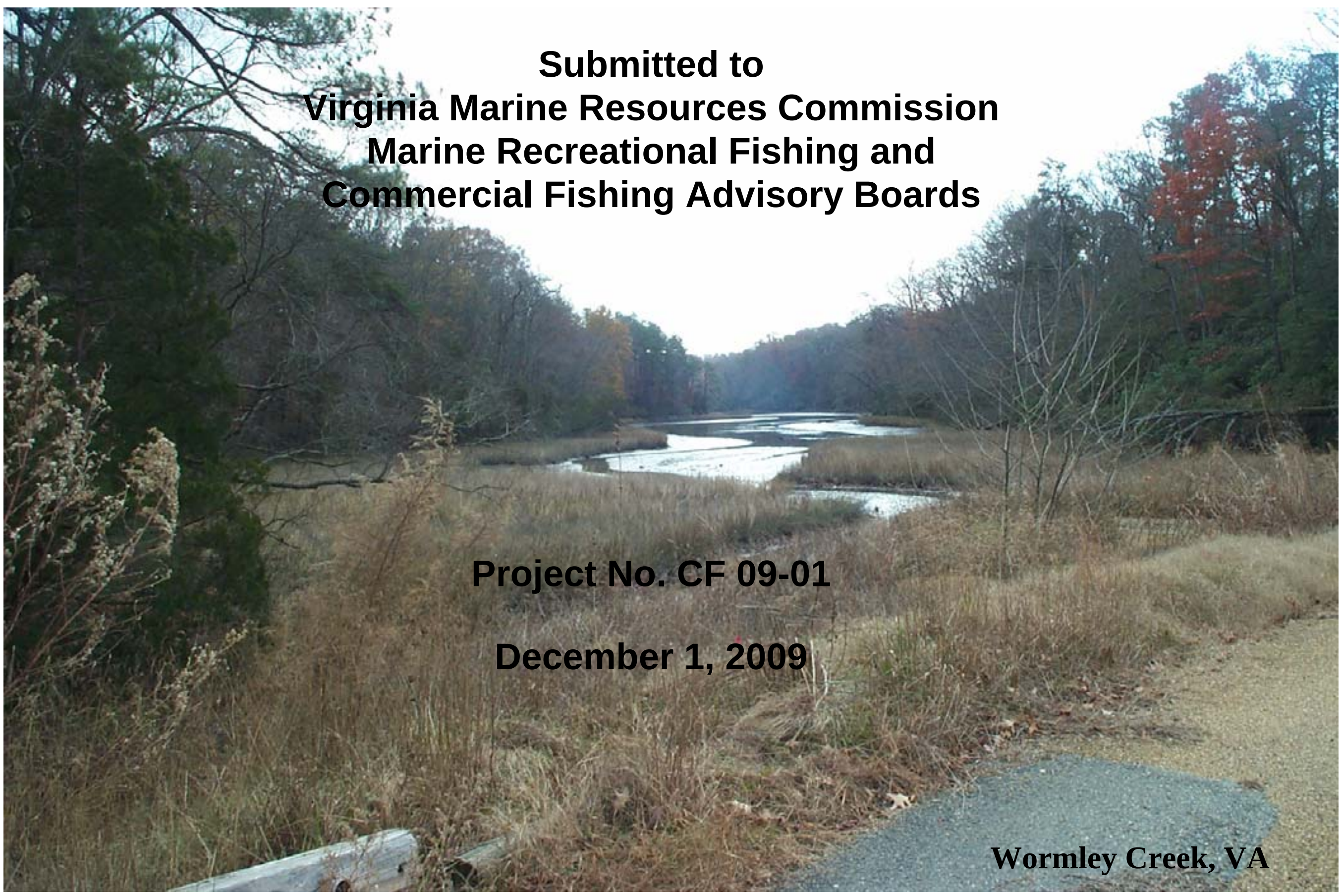

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Introduction

American eel (*Anguilla rostrata*) is a valuable commercial species along the Atlantic coast of North America from New Brunswick to Florida. In recent years, US coastal harvests have declined, with similar patterns occurring in the Canadian Maritime Provinces (Meister and Flagg 1997). Landings from Chesapeake Bay typically represent 63% of the annual US commercial harvest (ASMFC 2000). In 2008, Virginia commercial landings were 154,451 lbs; since mandatory reporting began in 1993, the average annual landings have been 218,037 lbs (VMRC 2008).

A decline in abundance of American eel has been observed in recent years with conflicting evidence regarding spatial synchrony throughout their range (Richkus and Whalen 1999; Sullivan et al. 2006). Limited knowledge about fundamental biological characteristics of glass eels has complicated interpretation of juvenile abundance trends (Sullivan et al. 2006). Hypotheses for the decline in abundance include shifts in location of the Gulf Stream, pollution, overfishing, parasites, altered oceanic conditions, and barriers to fish passage (Castonguay et al. 1994; Haro et al. 2000; Knights 2003). Additionally, factors such as unfavorable wind-driven currents may affect glass eel recruitment on the continental shelf and may have a greater impact than fishing mortality or continental climate change (Knights 2003).

The Atlantic States Marine Fisheries Commission (ASMFC) adopted the Interstate Fishery Management Plan (FMP) for the American eel in November 1999. The FMP focuses on increasing coastal states' efforts to collect American eel data through both fishery-dependent and fishery-independent studies. Consequently, member jurisdictions agreed to implement an annual survey for young-of-year (YOY) American eels. The survey is intended to "…characterize trends in annual recruitment of the YOY eels over time [to produce a] qualitative appraisal of the annual recruitment of American eel to the U.S. Atlantic Coast" (ASMFC 2000). The development of these surveys began in 2000 with full implementation by 2001. Survey results should provide necessary data on coastal recruitment success and further understanding of American eel population dynamics. A recent American eel stock assessment report (ASMFC 2006) emphasized the importance of the coast-wide survey as an index of sustained recruitment over the historical coastal range and an early warning of potential range contraction of the species. In 2009, the Virginia Institute of Marine Science continued its spring sampling to estimate relative abundance of YOY American eels in Virginia tributaries of Chesapeake Bay.

Life History

The American eel is a catadromous species that occurs along the Atlantic and Gulf coasts of North America and inland in the St. Lawrence Seaway and Great Lakes (Murdy et al. 1997). The species is panmictic and supported throughout its range by a single spawning population (Haro et al. 2000; Meister and Flagg 1997). Spawning takes place during winter to early spring in the Sargasso Sea. Eggs hatch into leaf-shaped transparent ribbon-like larvae called leptocephali, which are transported by ocean currents (over 9-12 months) in a generally northwesterly direction and can grow to 85 mm TL (Jenkins and Burkhead 1993). Within a year, metamorphosis into the next life stage (glass eel) occurs in the Western Atlantic near the east coast of North America. A reduction in length to about 50 mm TL occurs prior to reaching the continental shelf (Jenkins and Burkhead 1993). Coastal currents and active migration transport the glass eels (= YOY) into Maryland and Virginia estuaries from February to June (Able and Fahay 1998). As growth continues, the glass eel becomes pigmented (elver stage) and within 12 to14 months acquires a dark color with an underlying yellow hue (yellow eel stage). Many eels migrate upriver into freshwater rivers, streams, lakes, and ponds, while others remain in estuaries. Most of the eel's life is spent in these habitats as a yellow eel. Metamorphosis into the silver eel stage occurs during the seaward migration that takes place from late summer through autumn. Age at maturity varies greatly with location and latitude and in Chesapeake Bay may range from 2 to 18 years, with most eels between 2 and 6 years old (Owens and Geer 2003). American eel from Chesapeake Bay mature and migrate at an earlier age than eels from northern areas (Hedgepeth 1983). Upon maturity, eels migrate back to the Sargasso Sea to spawn and die (Haro et al. 2000).

It has been suggested that glass eel migration has a fortnightly periodicity related to tidal currents and stratification of the water column (Ciccotti et al. 1995). Additionally, alterations in freshwater flow (timing and magnitude) to bays and estuaries may affect the size, timing, and spatial patterns of upstream migration of glass eels and elvers (Facey and Van Den Avyle 1987). YOY eel may use freshwater “signals” to enhance recruitment to local estuaries, thereby influencing measures of year-class strength (Sullivan et al. 2006).

Objectives

1. Monitor the glass eel migration, or run, into the Virginia Chesapeake Bay tributaries to determine the spatial and temporal components of recruitment.

2. Examine environmental factors, which may influence young-of-year eel recruitment.

3. Collect basic biological information on recruiting eels, including length, weight, and pigment stage.

Methods

Field Methods

Minimum criteria for YOY American eel sampling were established in the ASMFC American Eel FMP, with the Technical Committee approving sampling gear and methods. The timing and placement of gear must coincide with periods of peak YOY shoreward migration. At a minimum, the gear must fish during flood tides during nighttime hours. The sampling season is designated as a minimum of four days per week for at least six weeks or for the duration of the run. At least one site must be sampled in each jurisdiction. The entire catch of YOY eels must be counted from each sampling event and a minimum of 60 glass eels (if present per system) must be examined for length, weight, and pigmentation stage weekly.

Due to the importance of the eel fishery in Virginia, the methods used must ensure proper temporal and spatial sampling coverage, and provide reliable recruitment estimates. To provide the necessary spatial coverage and to assess suitable locations, numerous sites were evaluated previously (Geer 2001). Final site selection was based on known areas of glass eel concentrations, accessibility, and specific physical criteria (e.g., proper habitat) suitable for glass eel recruitment to the sampling gear. Four sites were selected: two on the York River and one each on the Rappahannock and James rivers. The two sites on the York River are Bracken's Pond and Wormley Pond (Figure 1). Bracken's Pond is located along the Colonial Parkway at the base of the Yorktown Naval Weapons Station Pier and is less than 100 m from the York River; the tide often reaches the spillway. This site was chosen as a primary site in 2000 with gear comparisons performed throughout the sampling season. Wormley Pond is located on the Yorktown Battlefield and drains into Wormley Creek, which has a tidal range that routinely reaches 50 cm depth at the spillway. This site was not sampled in spring 2000. Kamp's Millpond drains into the eastern branch of the Corrotoman River, a tributary to the Rappahannock River (Figure 1). Kamp's Millpond covers approximately 80 acres and is located upstream of Route 790, just north of Kilmarnock. The final collection site on the James River is Wareham's Pond, which is located in the Kingsmill area of James City County. Wareham's Pond drains directly into the James River, which is about 100 m away, though high tides may reach the end of the spillway (Figure 1).

Irish eel ramps were used to collect eels at all sites. The ramp configuration successfully attracts and captures small eels in tidal waters of Chesapeake Bay. Ramp operation requires a continuous flow of water over the climbing substrate and the collection device; continuous flow was accomplished through a gravity feed. Hoses were attached to the ramp and collection buckets to allow for quick removal of eels for sampling. Enkamat™ erosion control material on the ramp floor provided a textured climbing surface. The ramps were placed on an incline (15-45^o) with the ramp entrance and textured mat extending into the water. The ramp entrance was placed in shallow water (< 25 cm) to prevent submersion of the entire ramp. The inclined ramp and an additional 4^o incline of the substrate inside the ramp provided sufficient slope to create attractant flow. A hinged lid provided access for cleaning and flow adjustments.

Only eels in the ramp's collection bucket (not on the climbing surface) were recorded. Trap performance was rated on a scale of 0 to 3 (0 = new set; 1 = gear fishing; 2 = gear fishing, but not efficiently; 3 = gear not fishing). Water temperature, air temperature, and precipitation were recorded during most site visits. All eels were enumerated and placed above the impediment, with any subsample information recorded, if applicable. Specimens less than or equal to ~ 85 mm total length (TL) were classified as YOY, while those > 85 were considered elvers. These lengths correspond to the two distinct length-frequency modes observed in the 2000 survey, which likely reflects differing year classes (Geer 2001; note: eels longer than 254 mm TL are considered yellow phase eels, although this is not explicitly stated in Geer 2001). Length, weight, and pigmentation stage (see Haro and Krueger 1988) were recorded from 60 eels weekly.

Index Calculation Procedure

A review of the index calculation procedure was undertaken in 2009 to investigate the use of the geometric mean catch for days during which 95% of the glass eels were captured. The rationale for the review was based on an observation concerning data from a glass eel monitoring site on the Potomac River (Gardy's Millpond; Tuckey and Fabrizio 2009). In 2000, at Gardy's Millpond, 291 glass eels were collected, of which 262 were used to calculate the 95% geometric mean index (18.3); in 2009, 231 glass eels were collected, of which 223 were used to calculate the 95% geometric mean index (1.6). The actual difference in numbers of glass eels used in the calculation is 39 (counting only those eels captured during the 95% recruitment window) and a difference of 54 days of effort, but the index in 2000 is 11 times greater than that in 2009. Is the index obtained by the 95% geometric mean method affected by daily fluctuations in recruitment when effort is "adjusted" by the 95% cut-off value? To answer that question, a theoretical analysis was conducted for three possible recruitment patterns and resultant indices were compared for: (1) a single peak recruitment event, (2) constant recruitment throughout the sampling period, and (3) episodic recruitment exhibiting multiple peaks during the sampling period (Figure 2). For this analysis, effort was constant and equal to 30 trap days and the total number of eels arriving during the recruitment period was 1,000 glass eels for each recruitment scenario. Three recruitment indices were calculated: (1) the simple, arithmetic average over the time period sampled, (2) the geometric mean using the 95% cut-off, and (3) the area-under-the-curve (AUC; Olney and Hoenig 2001).

If the arithmetic average is used to calculate the index, all three recruitment patterns yield the same index value -- 33.3 because the total number of glass eels captured and total effort are the same. One problem with using the average as an index of abundance for glass eels is that catches do not follow a normal distribution (a necessary assumption), and thus, this measure of central tendency may not accurately reflect 'average' conditions during the recruitment period. Furthermore, this approach requires adoption of constant effort year after year; if effort changes, then the index value may change as well. For example, adding a single week of sampling during which no eels are captured will reduce the average (index) to 27.0 in this example. Targeting the timing of sampling to coincide with recruitment for a species that migrates from the continental shelf and exhibits yearly fluctuations in timing is difficult, if not impossible. Timing of recruitment may vary due to water temperature, wind patterns or other factors that are not predictable and a fixed period of sampling may miss recruitment of glass eels if ingress occurs earlier or later than expected.

Indices based on the 95% geometric mean differ markedly for the three recruitment scenarios and range from 29.4 (episodic pattern) to 300.0 (peak pattern). The reason for this variation is that the number of zero catches included in the calculation depends on the recruitment pattern even though eliminating 5% of the low catches attempts to reduce that influence. If daily recruitment patterns do not change appreciably among years, then the 95% method for index calculation will work as expected. However, if recruitment patterns change each year such that in one year, glass eels arrive in a single week but the following year, eels trickle in over a period of two months, then the 95% geometric mean will produce incomparable results. The 95% geometric mean method is highly dependent on the underlying daily recruitment pattern, and appears to work best when ingress during the sampling period is fairly consistent.

The last index calculation method examined was the AUC; values resulting from this method were equal (1000.0). The AUC method is not sensitive to differences in annual sampling effort that may result in additional days with zero catches. More importantly, the index can easily accommodate variations in daily recruitment patterns that may be environmentally driven and vary from year to year.

One goal of recruitment monitoring is to allow comparison of relative recruitment between years with the underlying assumption that a constant relationship exists between the observed (calculated) index and the actual abundance of recruits. The index should be free from the influence of sampling variations that occur from year to year and should be invariant to within-year fluctuations in recruitment. The periodicity in recruitment that occurs within a single year is certainly of interest and may lead to insights into factors affecting recruitment variability, but the calculation of the index should not be affected by that pattern. A census that counts 500 eels recruiting to a pond in two days and no eels for the remaining 48 days of sampling compared with a census that counts 20 eels per day for 50 days should both result in a tally of 1,000 eels or an equivalent index. The current approach for calculating a recruitment index (based on the 95% geometric mean) appears to fall short of this goal. Results from this analysis were presented to the ASMFC American Eel Technical Committee and Stock Assessment Subcommittee meeting in Annapolis, MD September 14 – 16, 2009. A comparison between the 95% geometric mean index and the AUC index for all years including the 2009 survey is presented and discussed below.

Results

In 2009, eel traps were deployed from 2 February to 27 May at Wormley Pond, and from 19 February to 27 May at Bracken's Pond. Traps were deployed at Wareham's Pond on the James River from 24 February to 27 May and at Kamp's Millpond on the Rappahannock from 25 March to 18 June. Counts of glass eels at Wormley Pond (n = 8,367 glass eels) and Bracken's Pond (n = 69 glass eels) in 2009 were the lowest number recorded since collections began at these sites (Table 1). Counts of glass eels captured at Wareham's Pond were the highest observed (n = 5,322 glass eels), while counts at Kamp's Millpond (n = 182 glass eels) were the second lowest for the time series (Table 1).

The two methods of calculating glass eel indices of abundance from the York River sites showed different patterns with the area-under-the-curve method providing more comparable indices through time compared with the 95% geometric mean (Figure 3). For example, 78,258 glass eels were observed at Wormley Pond in 2004; 77,592 glass eels were observed at Bracken's Pond in 2003 (Table 1). The index resulting from the 95% geometric mean for Wormley Pond was more than eight times higher than the index for Bracken's Pond despite a less than 1% difference in the number of eels captured. The AUC index produced similar values for these two years and as a result, indices from theses two sites are more similar in magnitude than previously thought. Patterns observed in the James and Rappahannock rivers have not changed much with the new index calculation procedure (Figure 4). In the James River, recent glass eel abundance estimates have been increasing, whereas those from the Rappahannock River remain low (Figure 4).

The number of elvers captured at each site was below the historic average (Table 2). As elver catches are more consistent from year to year, the two index calculation methods do not differ greatly (Figure 5). Abundance estimates of elvers from Wormley Pond and Bracken's Pond in the York River exhibit similar patterns in recent years with a peak in 2007 and a dramatic decline in 2009 (Figure 5). Abundance indices of elvers in the James and Rappahannock rivers have been low aside from the peak observed in 2003 in the Rappahannock River (Figure 6).

A total of 564 glass eels from Wormley and Bracken's Ponds was returned to the lab for length and pigment stage and 478 glass eels were weighed. Total length (TL) of glass eels ranged from 48.4 to 66.7 mm, with a mean length of 57.8 mm (2.99 standard deviation, SD). Weights of individual glass eels ranged from 0.073 to 0.268 g and averaged 0.158 g (0.034 SD; Figure 7). Mean TL of glass eels recruiting to Wormley Pond and Bracken's Pond on the York River has remained consistent since 2001 (Figure 8). The pigmentation stage of glass eels increased each month from February to April (Figure 9).

Water temperature increased throughout the study period in 2009 and peak counts of glass eels occurred in late February at Bracken's Pond, late March at Wormley Pond, and late April in the James and Rappahannock rivers (Figure 10). Catches of elver eels were more variable and occurred throughout the monitoring period (Figure 11). Peak counts of glass eels tend to occur first in the York River, followed by the James, Rappahannock and Potomac rivers (Figure 12).

Discussion

The area-under-the-curve method is preferred to the 95% geometric mean index method because glass eel recruitment patterns vary in timing and magnitude and the 95% geometric mean is sensitive to those annual changes. Because elvers are captured throughout the monitoring period with no readily identifiable pattern, the elver index calculation method was less affected and comparisons between index methods showed similar results. Therefore, all future indices will be based on the AUC method to provide a more comparable index among years.

Overall, the time series shows that the total number of glass eels captured among all sites differs by several orders of magnitude with most caught at the two sites in the York River. The greatest number of glass eels captured in the York River peaked at nearly 91,000 glass eels in 2007, while the lowest number caught was 69 glass eels in 2009. Out of ten years of eel collections at Bracken’s Pond, the fewest number of glass eels were captured during 2009, representing a two orders-of-magnitude decrease from the previous year. Although fewer glass eels are typically captured on the James and Rappahannock rivers compared with the York River, 2009 ranked as the highest catch for the James River site. Catches of glass eels from the Rappahannock River in 2009 were the second lowest out of 10 years of survey data. Variability of glass eel catches has been found in other systems with no clear pattern related to water temperature or lunar phase, and conflicting results related to water flow or precipitation (Overton and Rulifson 2009).

The extremely low catch of glass eels and elvers at Bracken’s Pond may be the result of changes to flow dynamics at the site. The Irish eel ramp at Bracken’s Pond was submerged during the entire sampling period, a pattern that is different from other years. This may have resulted in an altered freshwater signal that reached glass eels in the main portion of the York River. The change in hydrology at this site will require alteration of the Irish ramp deployment methodology and an evaluation of its continued use as a monitoring location. The fact that Wormley pond shows a similar declining index in recent years suggests that the data from Bracken’s Pond may still be of value.

Throughout the duration of the survey, the number of elvers captured with Irish eel ramps was well below that of glass eels and ranged from as few as 3 elvers (Bracken's Pond, 2009) to as many as 1,968 elvers per year (Kamp's Millpond, 2003). Peak collections of elvers occurred during 2007 at both sites in the York River and the James River, but in the Rappahannock River 2007 ranked second lowest. The number of elvers captured during 2009 was extremely low in the Rappahannock and York rivers and below average in the James River compared with historic averages for these systems.

The timing of recruitment of glass eels in each pond appears to be related to the distance between the sampling site and the mouth of Chesapeake Bay. Earliest recruitment is observed at Wormley Pond on the York River (55.7 km from the mouth of the Bay), followed by Bracken's Pond (59.4 km), Wareham's Pond in the James River (77.8 km), and finally Kamp's Millpond on the Rappahannock River (101 km). Additionally, two sites located on the Virginia side of the Potomac River (> 101 km from the mouth of the bay) show much later recruitment peaks compared with other Virginia locations.

Conclusions and Recommendations

1. The area-under-the-curve index calculation procedure will be adopted for future monitoring and reports. Additional changes to index calculations may include variables such as pond drainage area, distance from the ocean, discharge, and other physical characteristics. These values may then be used to weight the catch rates at each site to provide an overall estimate of juvenile eel recruitment to Virginia waters.

2. Irish eel ramps are an effective, passive gear for sampling YOY American eel in coastal Virginia. The traps fish continuously meeting the ASMFC mandates for sample collections during peak recruitment.

3. Sampling should continue at the primary sites on the York, James and Rappahannock rivers and should start at least as early as the previous year and continue later, if necessary. If sampling is to continue at Bracken's Pond a reconfiguration to a floating trap may be necessary to create attractant flow. Given the great variability associated with spring temperatures in the Chesapeake Bay region, monitoring must occur over a wide range of water temperatures to ensure sampling during the peak migration of YOY eels.

4. Additional years of data are necessary to solve the American eel recruitment puzzle. Anomalies that occur offshore (e.g., Gulf Stream changes) should also be investigated.
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Table 1. Total number of glass eels collected, the number of glass eels used for 95% index calculations, dates corresponding to 95% index period, the number of days of the index period, and the geometric mean and standard error by site and year.

Site	Year	Total Caught	Total Used	Start Date	End Date	Days	GEOMEAN	STDERR
Wormley Pond	2001	82267	79485	15-Mar	13-Apr	30	737.125	0.464
	2002	31518	30299	24-Feb	9-Apr	45	272.130	0.292
	2003	14385	13678	14-Mar	15-Apr	33	95.949	0.399
	2004	78258	73834	1-Mar	19-Apr	50	980.639	0.161
	2005	56259	53378	23-Feb	19-Apr	56	172.220	0.306
	2006	61211	57698	8-Mar	12-Apr	36	841.993	0.239
	2007	90988	85414	5-Mar	23-Apr	50	184.356	0.499
	2008	9012	8705	4-Mar	17-Apr	45	86.918	0.256
	2009	8367	7996	16-Feb	29-Mar	42	60.939	0.289
Bracken's Pond	2000	61228	58288	27-Mar	2-May	36	482.177	0.381
	2001	52838	50146	14-Mar	5-Jun	84	261.503	0.156
	2002	7413	7000	8-Mar	20-Apr	44	106.465	0.169
	2003	77592	73431	11-Mar	12-May	63	119.631	0.340
	2004	29914	28403	6-Mar	12-May	68	173.152	0.207
	2005	65983	63009	13-Mar	14-May	63	188.142	0.283
	2006	45738	43268	27-Feb	5-May	68	297.585	0.201
	2007	46758	44637	12-Mar	10-May	60	211.588	0.227
	2008	1165	1113	5-Mar	26-May	83	4.560	0.145
	2009	69	67	20-Feb	21-May	91	0.400	0.059
Wareham's Pond	2003	2230	2150	19-Mar	29-Apr	37	12.819	0.244
	2004	158	154	8-Mar	16-May	69	1.032	0.113
	2005	225	214	21-Mar	8-Apr	19	6.312	0.300
	2006	3280	3145	3-Mar	19-Apr	48	29.770	0.216
	2007	953	920	5-Mar	3-May	60	7.547	0.158
	2008	2456	2333	17-Mar	17-Apr	32	32.615	0.259
	2009	5322	5010	13-Mar	30-Apr	49	35.030	0.216
Kamp's Millpond	2000	139	134	16-Apr	12-May	27	1.531	0.185
	2001	3956	3788	6-Apr	3-May	28	31.468	0.281
	2002	11217	10589	17-Mar	16-Apr	31	136.605	0.251
	2003	2387	2254	26-Mar	8-May	44	28.606	0.222
	2004	524	497	13-Apr	23-May	41	4.993	0.210
	2005	2084	2016	30-Mar	3-May	35	14.942	0.289
	2006	302	283	10-Mar	24-May	76	1.806	0.112
	2007	313	299	30-Mar	1-Jul	94	2.201	0.077
	2008	481	459	31-Mar	4-Jun	62	3.938	0.129
	2009	182	170	27-Mar	2-Jun	68	1.778	0.082

Table 2. Total number of elver eels collected, the number of elver eels used for 95% index calculations, dates corresponding to the index period, the number of days of the index period, and the geometric mean and standard error by site and year.

Site	Year	Total Caught	Total Used	Start Date	End Date	Days	GEOMEAN	STDERR
Wormley Pond	2001	171	162	12-Mar	4-May	54	1.564	0.129
	2002	315	298	22-Feb	17-Apr	55	3.279	0.135
	2003	138	130	4-Mar	12-May	70	1.099	0.093
	2004	257	239	24-Feb	16-May	83	1.631	0.101
	2005	105	100	22-Feb	19-May	87	0.715	0.073
	2006	160	156	20-Feb	6-May	76	0.985	0.094
	2007	619	559	26-Feb	14-May	78	3.704	0.102
	2008	139	135	2-Mar	28-May	88	0.715	0.081
	2009	31	30	13-Feb	20-May	96	0.207	0.036
Bracken's Pond	2000	528	481	28-Mar	9-May	42	2.811	0.253
	2001	334	314	4-Mar	17-Jun	106	1.119	0.099
	2002	52	49	16-Mar	28-Apr	44	0.673	0.102
	2003	411	399	6-Mar	12-May	68	2.263	0.145
	2004	171	158	22-Feb	13-May	82	1.022	0.098
	2005	231	224	23-Feb	15-May	82	1.525	0.099
	2006	166	152	23-Feb	6-May	73	1.305	0.092
	2007	723	692	23-Feb	13-May	80	5.389	0.116
	2008	262	247	4-Mar	26-May	84	1.354	0.105
	2009	3	2	3-Apr	25-May	53	0.038	0.014
Wareham's Pond	2003	84	79	19-Mar	24-Apr	32	1.296	0.156
	2004	260	252	8-Mar	9-May	62	1.839	0.131
	2005	148	137	20-Mar	12-May	54	1.791	0.101
	2006	469	442	24-Feb	17-May	83	2.134	0.132
	2007	682	641	15-Mar	17-May	64	5.207	0.150
	2008	511	487	12-Mar	18-May	67	3.261	0.156
	2009	275	235	11-Mar	25-May	76	1.769	0.104
Kamp's Millpond	2000	5	4	16-Apr	25-Apr	10	0.390	0.039
	2001	222	215	16-Mar	8-May	54	2.415	0.125
	2002	224	216	13-Mar	19-Apr	38	4.387	0.117
	2003	1968	1907	13-Mar	9-May	58	13.669	0.200
	2004	250	230	10-Mar	20-May	72	2.023	0.094
	2005	196	188	23-Mar	17-May	56	2.331	0.087
	2006	312	301	10-Mar	14-May	66	2.478	0.112
	2007	32	25	15-Mar	27-Jun	105	0.209	0.029
	2008	37	33	24-Mar	8-Jun	73	0.424	0.037
	2009	33	32	30-Mar	17-Jun	80	0.327	0.037

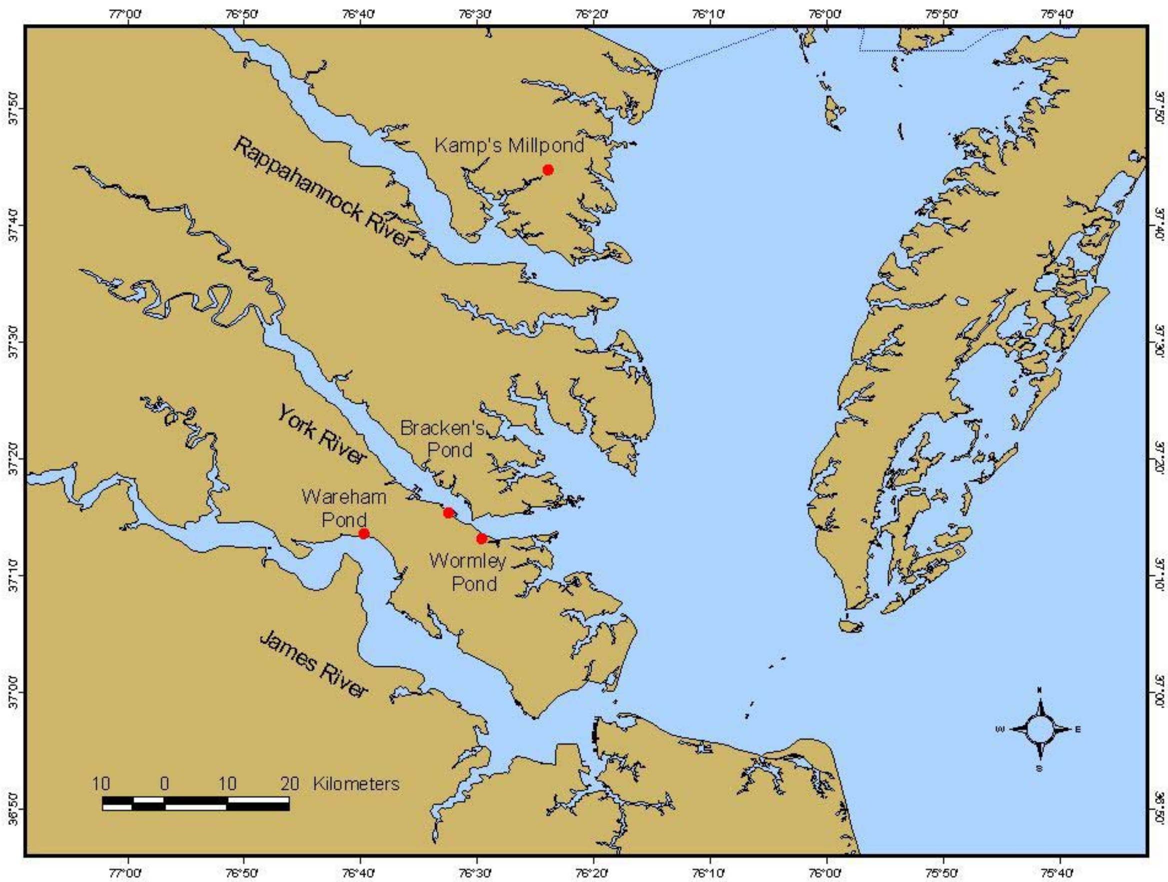


Figure 1. American eel sampling sites in the Rappahannock (Kamp's Millpond), York (Wormley Pond and Bracken's Pond), and James (Wareham's Pond) rivers, Virginia, 2009.

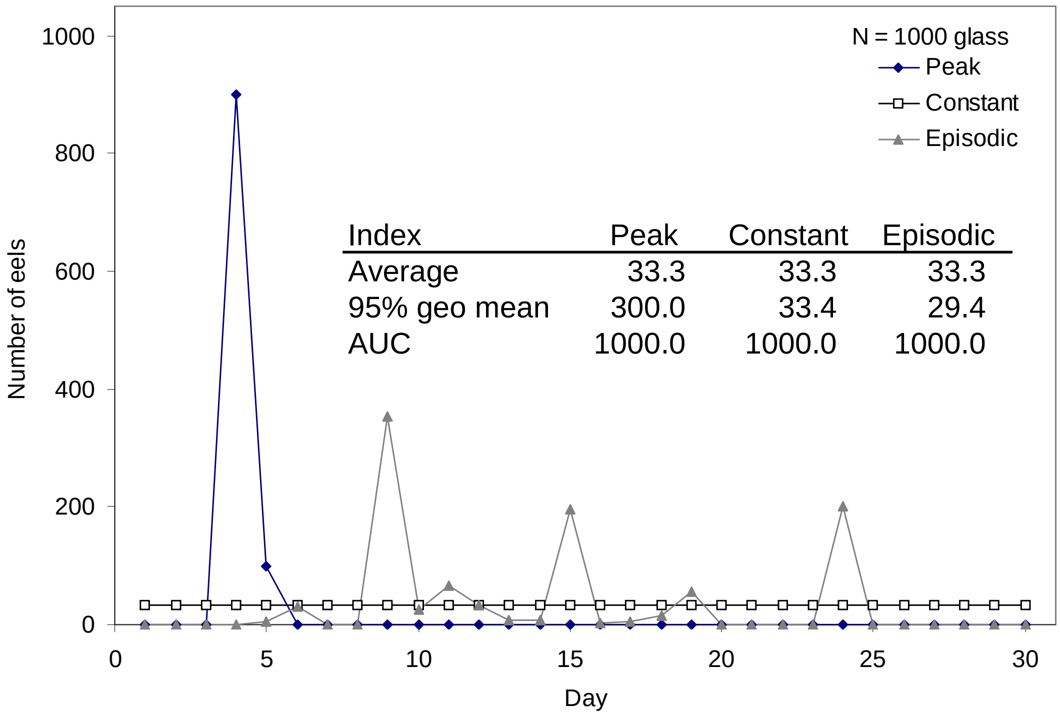


Figure 2. The potential influence of three glass eel recruitment patterns -- a single peak event (Peak), constant recruitment throughout the survey period (Constant), and periodic peaks in abundance (Episodic) -- on the value of three methods for calculating the index of abundance: arithmetic average, 95% geometric mean, and area under the curve (AUC). The 95% geometric mean eliminates the lowest 2.5% of the catch from each end of the sampling period and uses the geometric mean to reduce the influence of large catches. The sampling period (30 days) and catch (N = 1,000 glass eels) for all three recruitment pattern scenarios were constant.

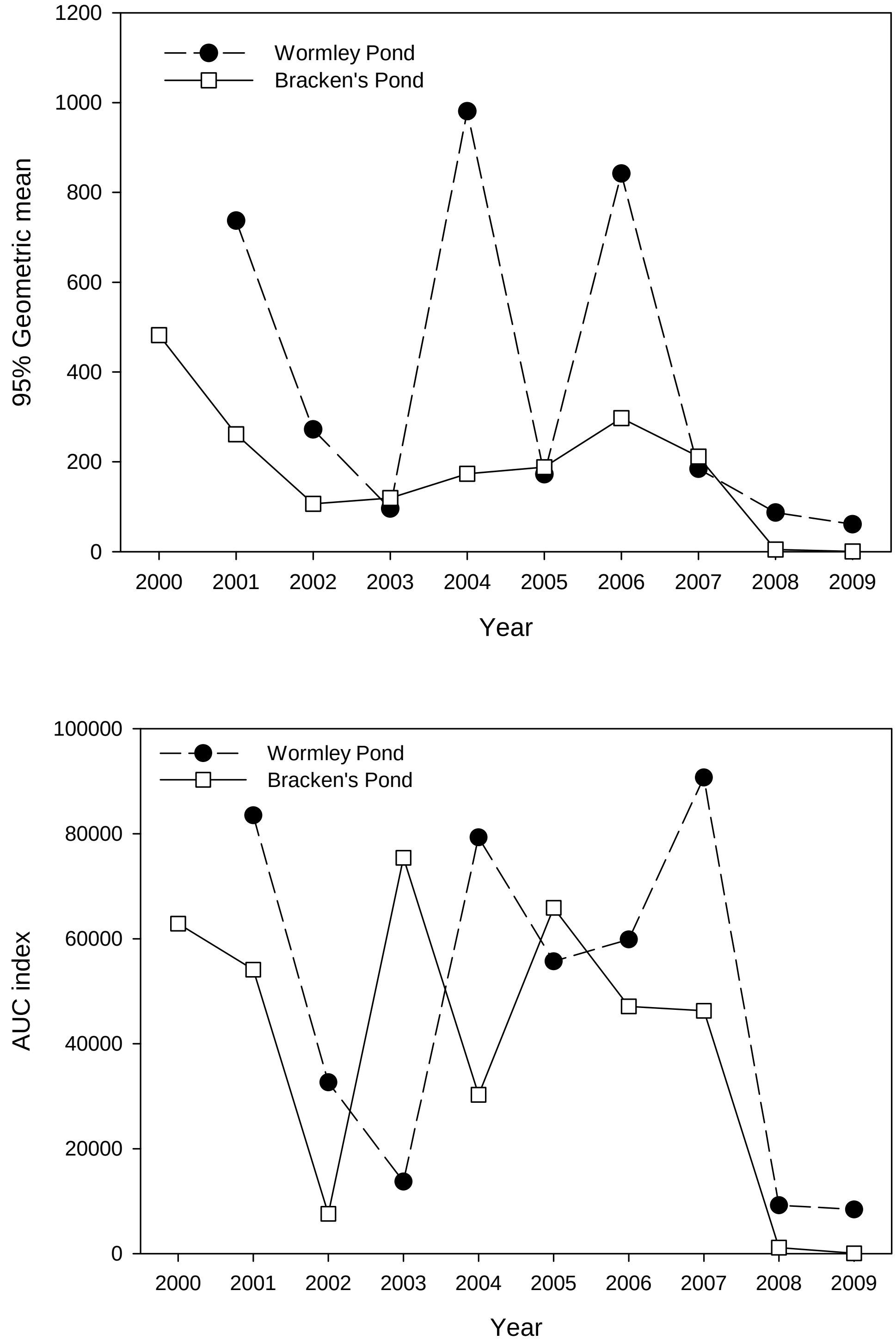
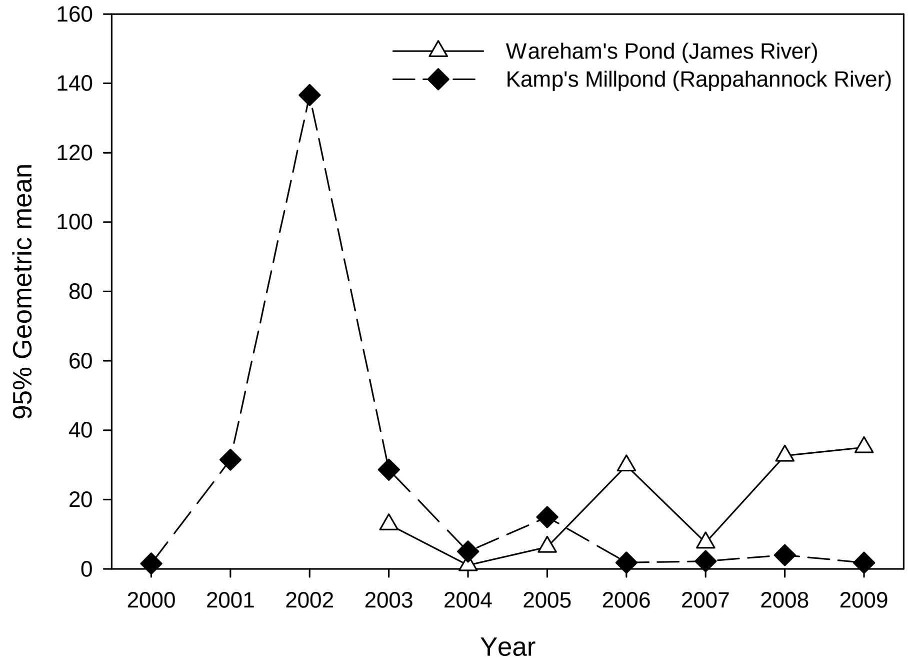


Figure 3. Comparison of abundance indices calculated by the 95% geometric mean (Top) and area-under-the-curve (AUC, Bottom) methods for glass eels from Wormley Pond and Bracken's Pond.



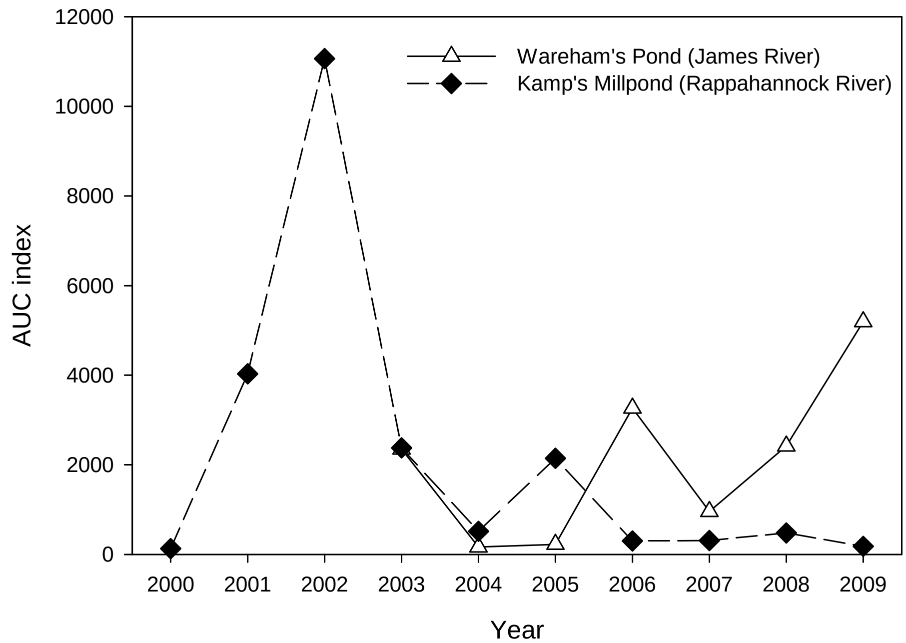


Figure 4. Comparison of abundance indices calculated by the 95% geometric mean (Top) and area-under-the-curve (AUC, Bottom) methods for glass eels from Wareham's Pond and Kamp's Millpond.

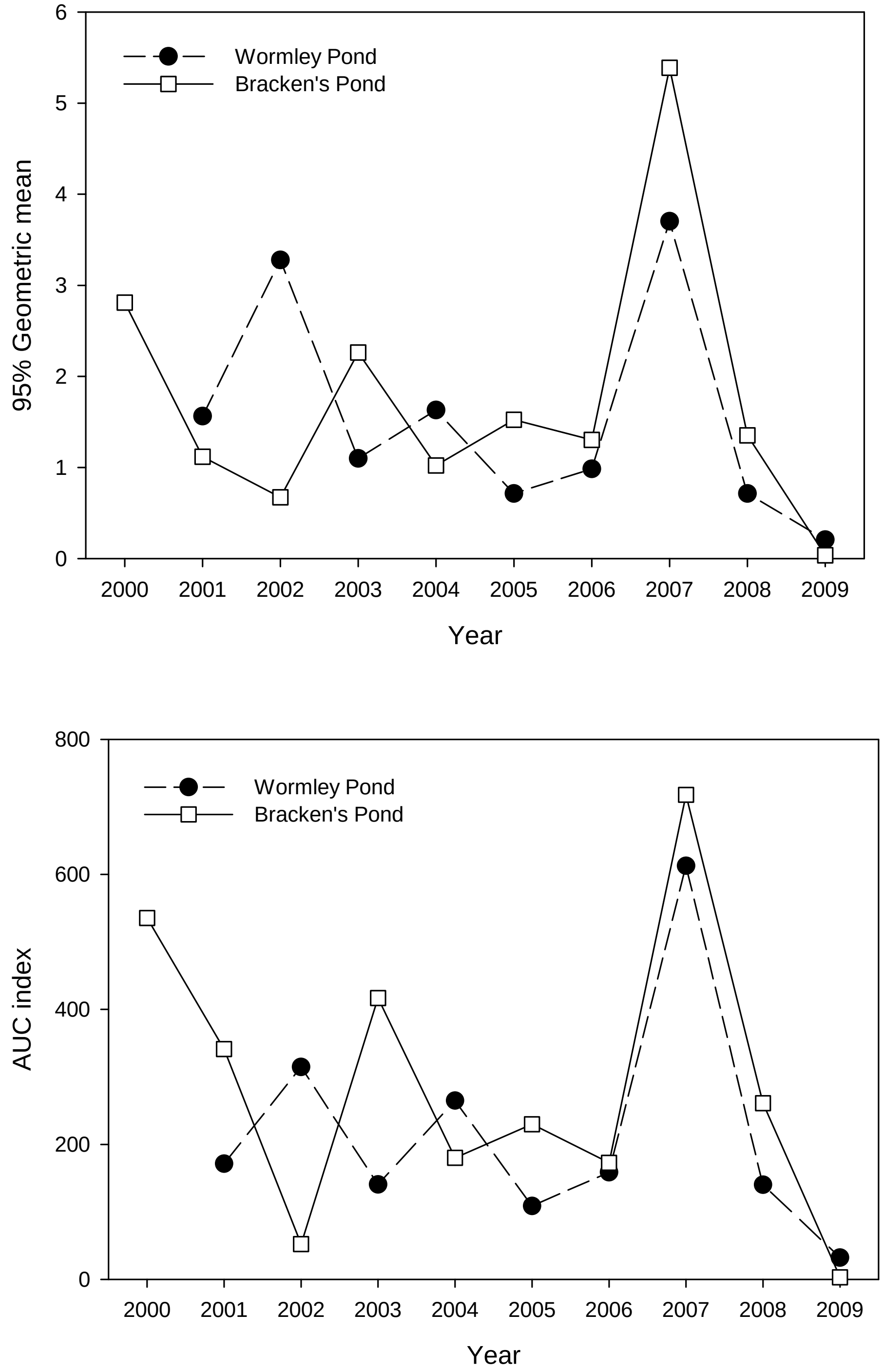


Figure 5. Comparison of abundance indices calculated by the 95% geometric mean (Top) and area-under-the-curve (AUC, Bottom) methods for elvers from Wormley Pond and Bracken's Pond.

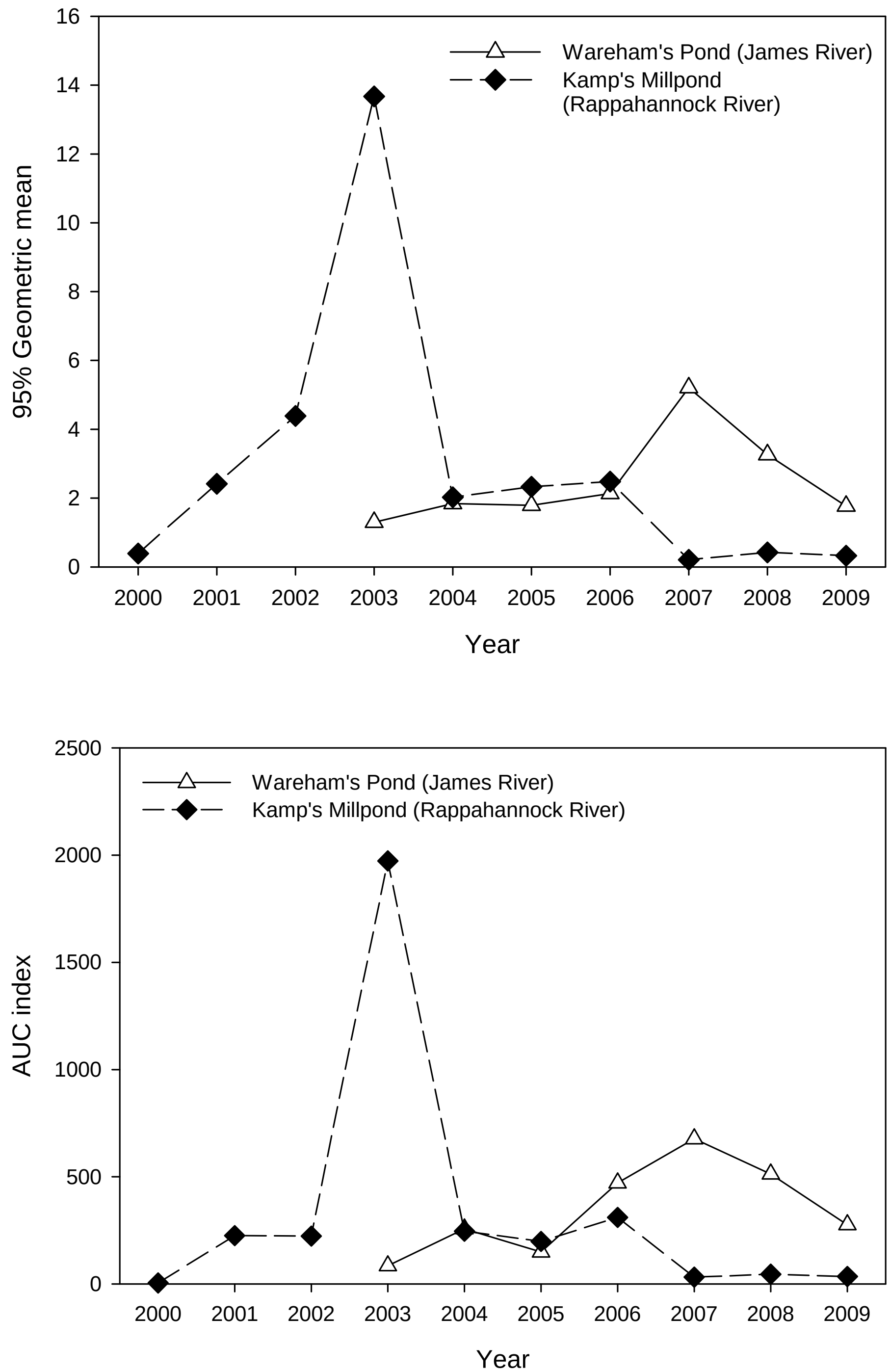


Figure 6. Comparison of abundance indices calculated by the 95% geometric mean (Top) and area-under-the-curve (AUC, Bottom) methods for elvers from Wareham's Pond and Kamp's Millpond.

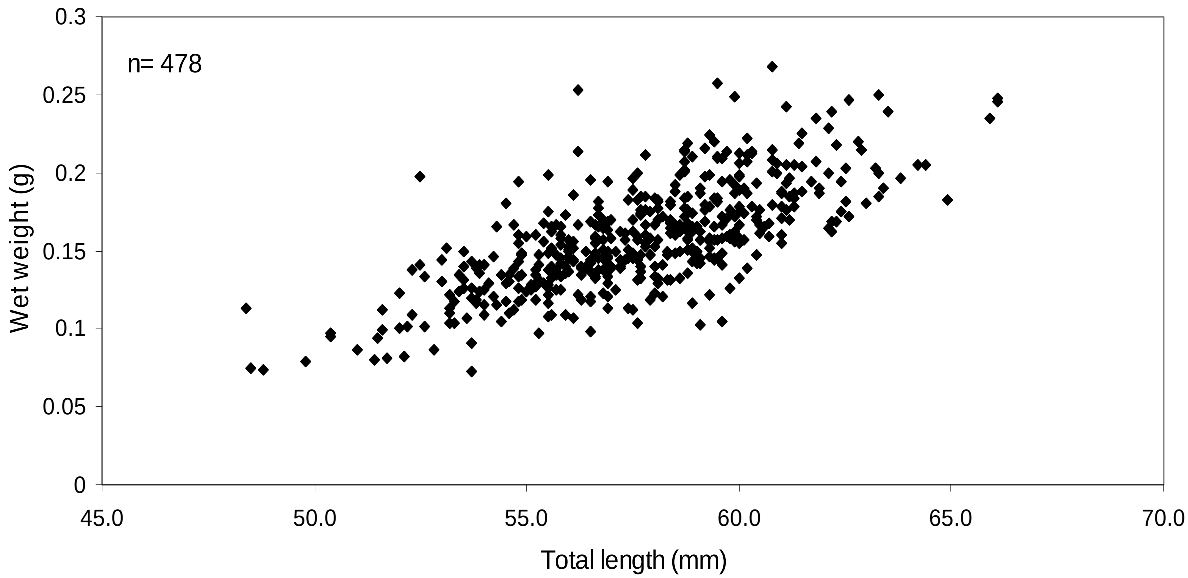


Figure 7. American eel total length and wet weight from the York River, 2009.

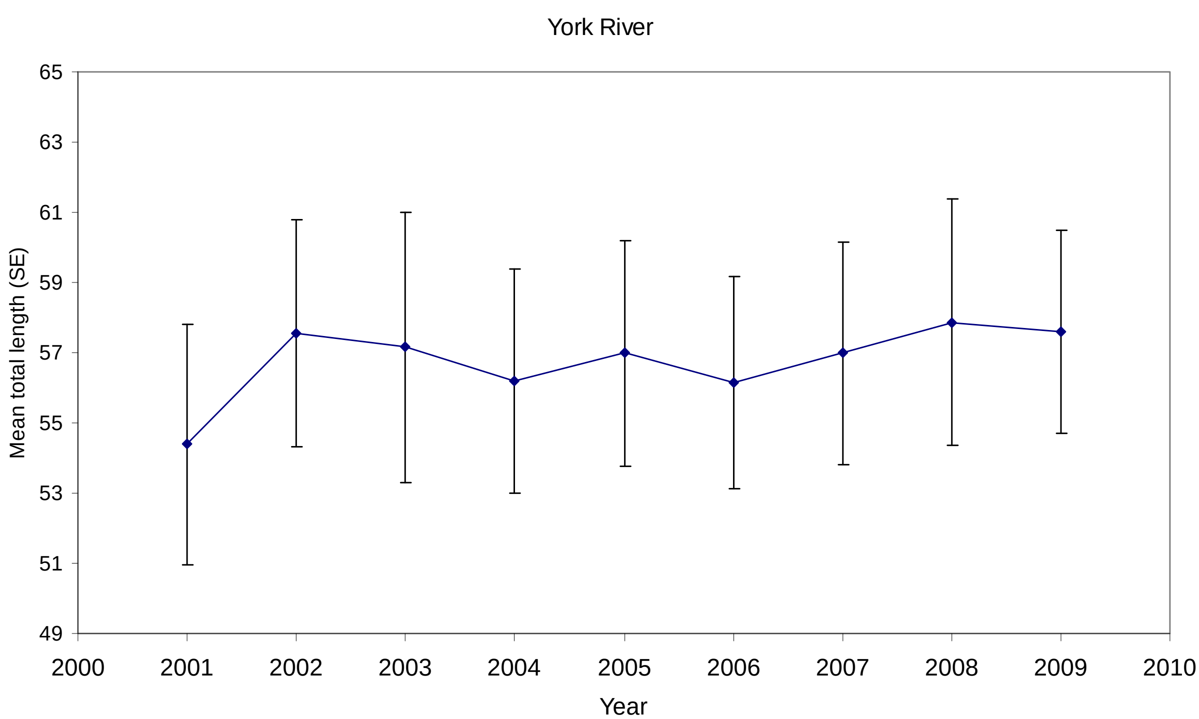


Figure 8. Mean total length (mm; SD) of glass eels collected with Irish eel ramps from 2001 to 2009 from two sites combined (Wormley and Bracken's Ponds) in the York River, Virginia.

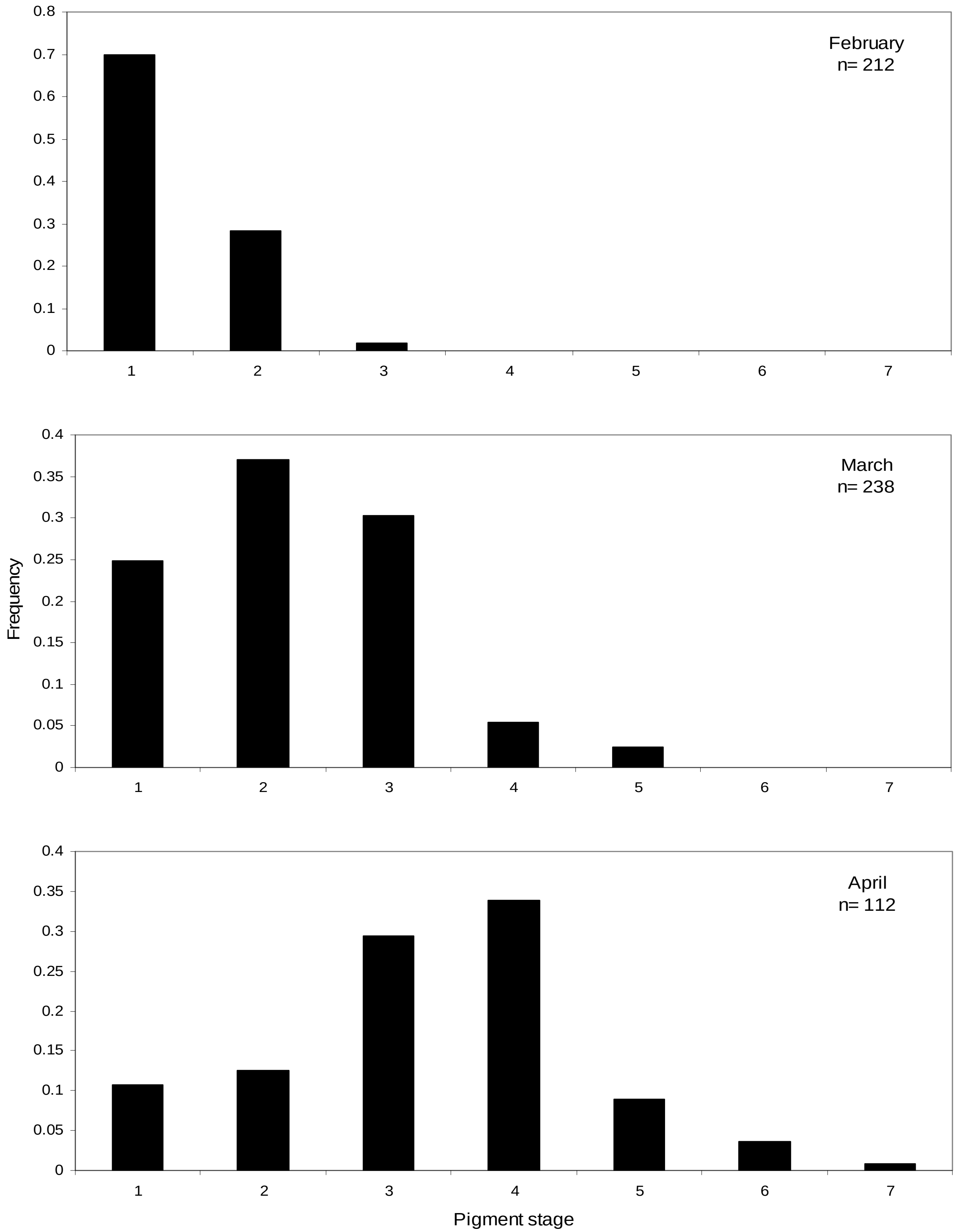


Figure 9. Frequency of glass eel pigment stages by month for the York River system, 2009.

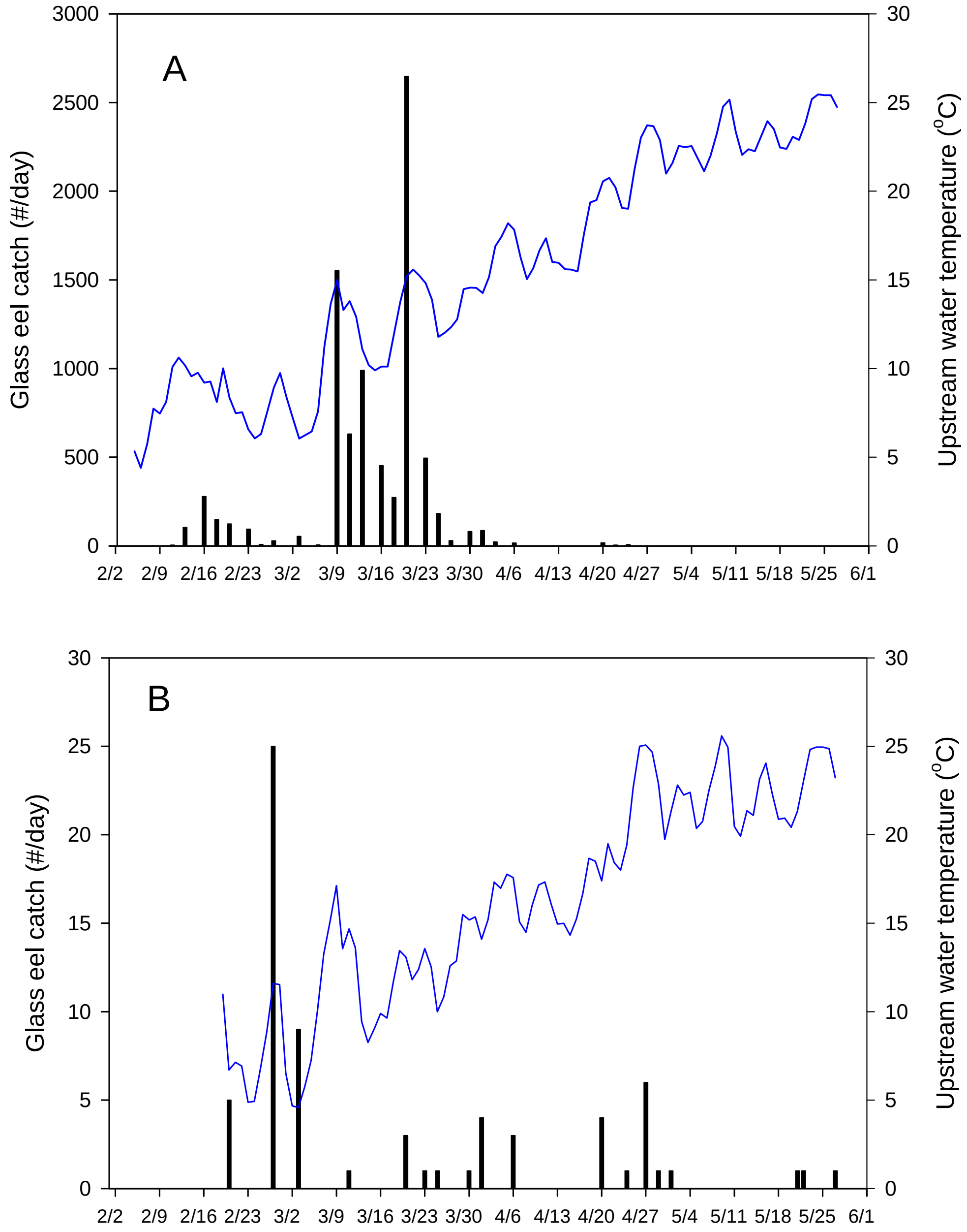


Figure 10. Glass eel catches (bars) and water temperature (line) during 2009 from A) Wormley Pond, B) Bracken's Pond, C) Wareham's Pond, and D) Kamp's Millpond. Note y-axis scale for glass eel catches are not uniform.

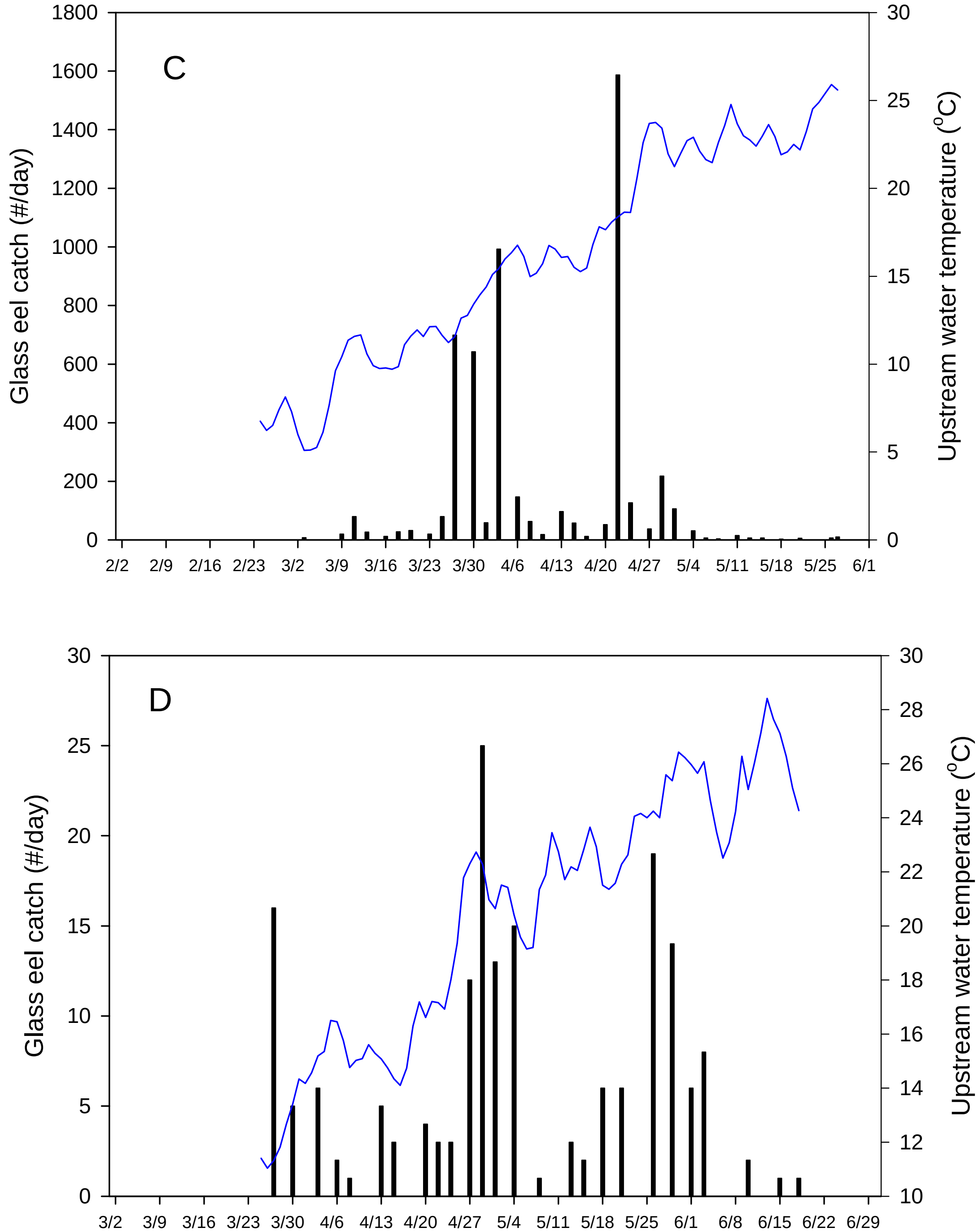
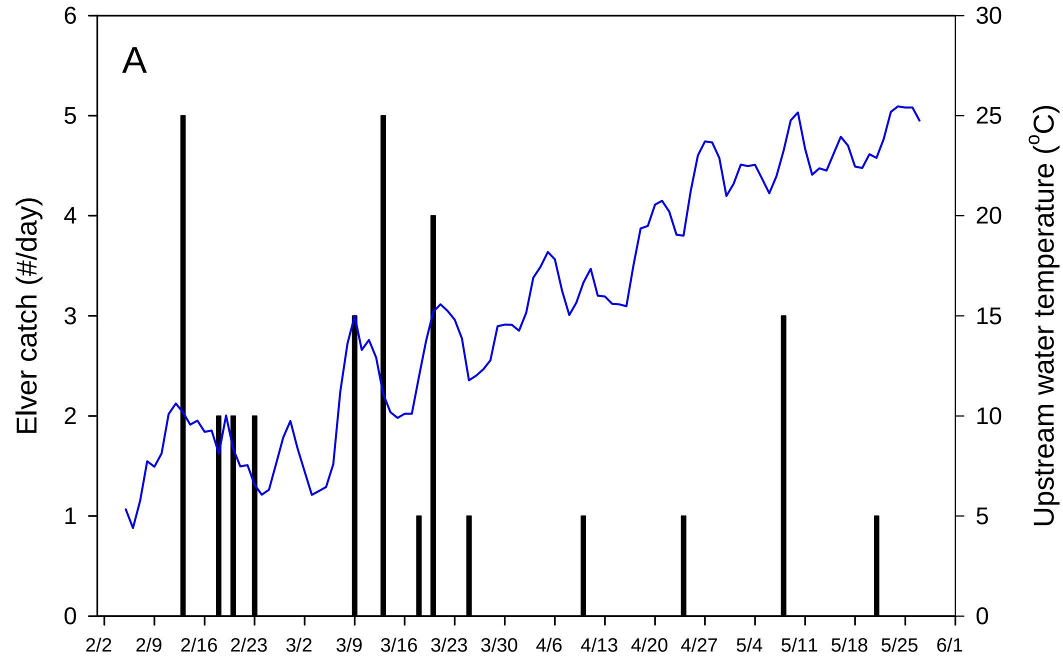


Figure 10 continued. Glass eel catches (bars) and water temperature (line) during 2009 from A) Wormley pond, B) Bracken's Pond, C) Wareham's Pond, and D) Kamp's Millpond. Note y-axis scale for glass eel catches are not uniform.



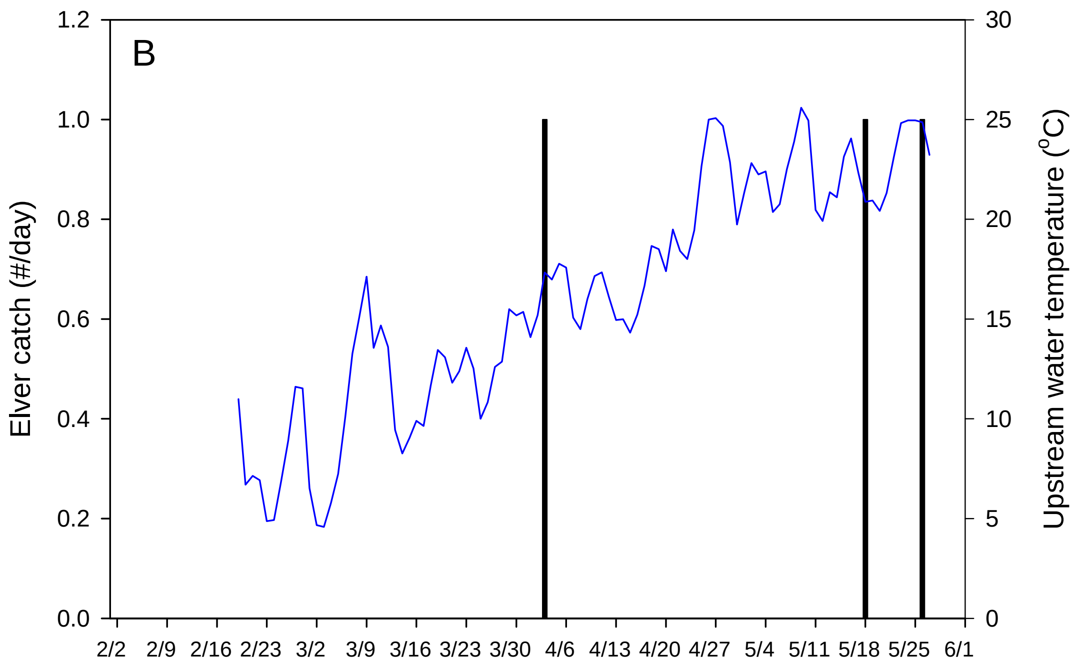
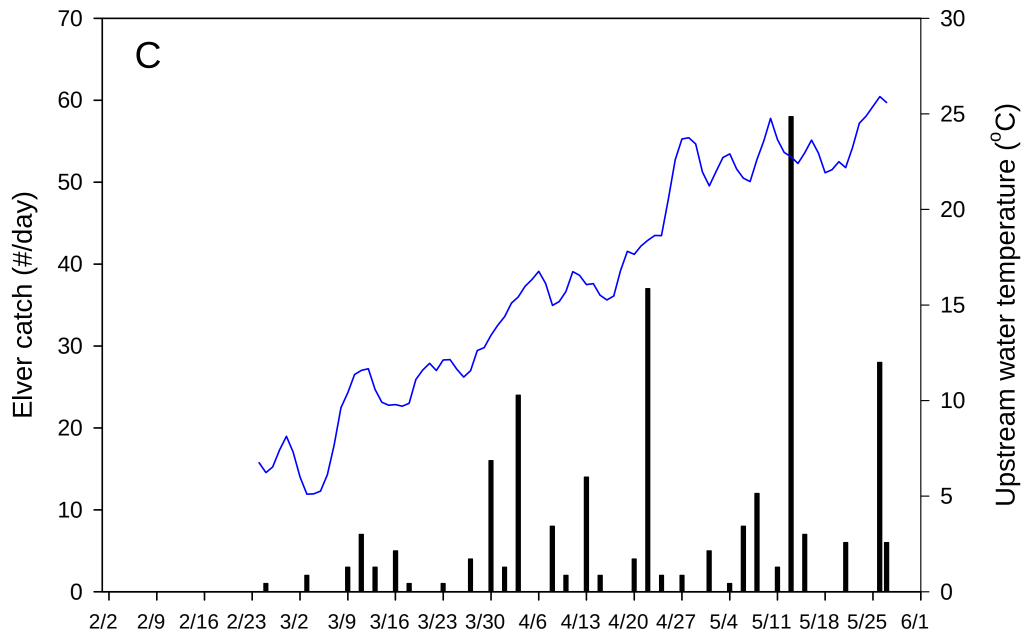


Figure 11. Elver catches (bars) and water temperature (line) during 2009 from A) Wormley pond, B) Bracken's Pond, C) Wareham's Pond, and D) Kamp's Millpond.



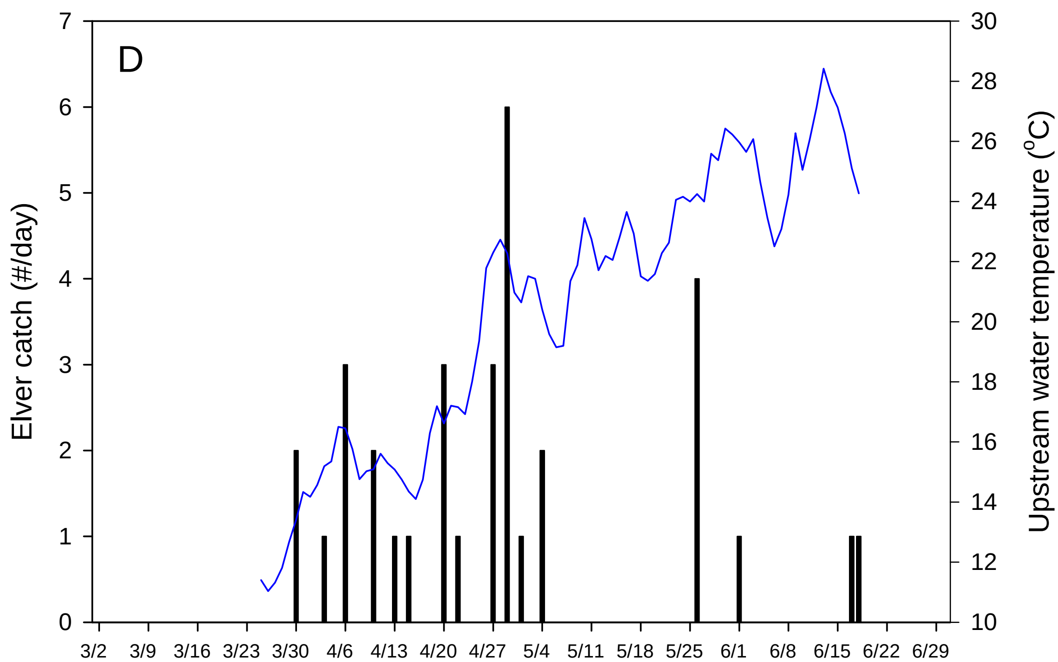


Figure 11 continued. Elver catches (bars) and water temperature (line) during 2009 from A) Wormley pond, B) Bracken's Pond, C) Wareham's Pond, and D) Kamp's Millpond.

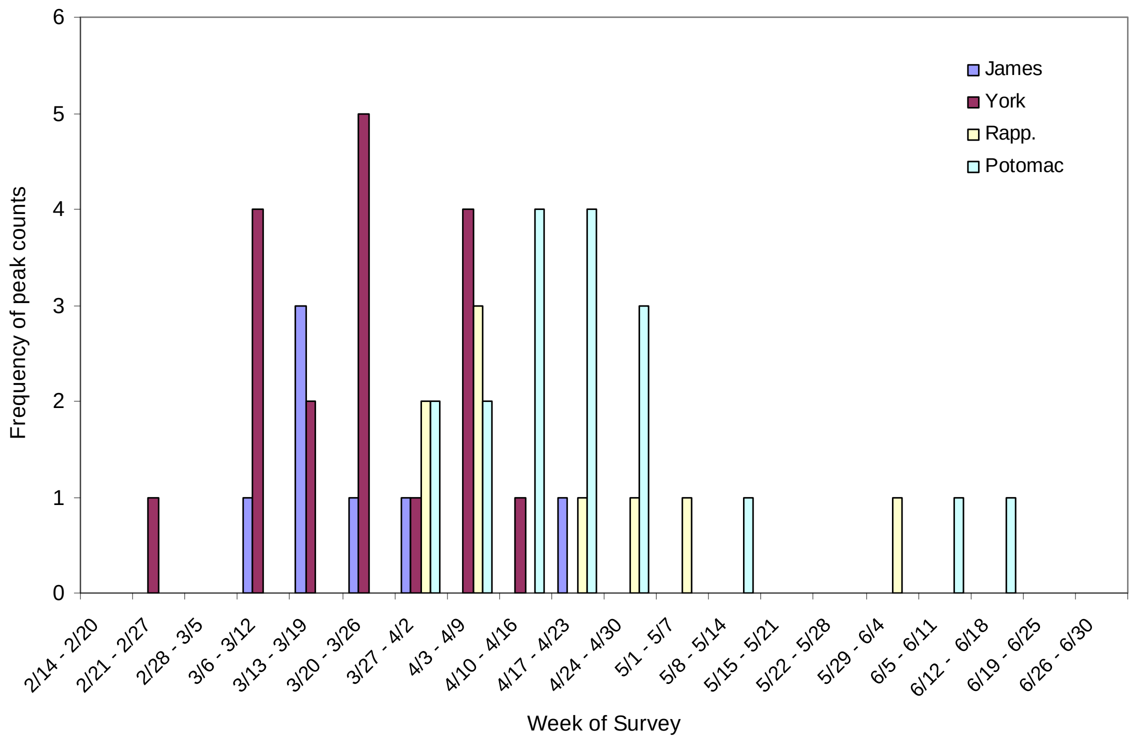


Figure 12. Week of survey when peak counts of glass eels were observed in each river from 2001 to 2009. Two sites are monitored in the York and Potomac rivers each year (n = 18 observations per river). In the James River, one site was monitored beginning in 2003 (n=7 observations). In the Rappahannock River, one site was monitored each year (n=9 observations). Potomac River data are from Tuckey and Fabrizio, 2009.