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Evaluating Recruitment of American Eel, *Anguilla rostrata*, in the Potomac River (Spring 2009)

January 2009 – September 2009

By

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Submitted to Potomac River Fisheries Commission

September 2009

Acknowledgments

We thank the individuals that participated in field sampling including Hank Brooks, Wendy Lowery, Aimee Halvorson, Jennifer Conwell, Ashleigh Rhea, and Leonard Machut. We also thank the Virginia Marine Resources Commission (VMRC) law enforcement officers who kept the survey gear from being vandalized during the study. A special thanks to Mr. James Hess (Clark's Millpond) and Ms. Joanne Northern and family (Gardy's Millpond), who granted permission to sample on their properties. This project was funded by the Potomac River Fisheries Commission.

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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. Landings from Chesapeake Bay typically represent 63% of the annual United States commercial harvest (ASMFC 2000). In 2007, Virginia commercial landings (196,853 lbs) were 70% of the average annual landings in VA since mandatory reporting began (1993) and 23.6% of the US landings (ASMFC 2008; VMRC 2008). Since the 1980s, however, harvest along the U.S. Atlantic Coast has declined, with similar patterns occurring in the Canadian Maritime Provinces (Meister and Flagg 1997).

Hypotheses for the decline in abundance of American eel in recent years include locational shifts in the Gulf Stream, pollution, overfishing, parasites, and barriers to fish passage (Castonguay et al. 1994; Haro et al. 2000). The decline in abundance may or may not exhibit spatial synchrony (Richkus and Whalen 1999; Sullivan et al. 2006); 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). Limited knowledge about fundamental biological characteristics of juvenile American eel has complicated interpretation of juvenile abundance trends (Sullivan et al. 2006).

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 for providing data useful in calculating an index of recruitment over the historical coastal range and for serving as an early warning of potential range contraction of the species. Funding for the Virginia Institute of Marine Science's spring survey in the Potomac River was provided by the Potomac River Fisheries Commission, thereby ensuring compliance with the 1999 ASMFC Interstate Fishery Management Plan for American Eels.

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 (for 9-12 months) in a generally northwesterly direction and can grow to 85 mm TL (Jenkins and Burkhead 1993). Within one 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 rivers and estuaries from February to June (Able and Fahay 1998). Ciccotti et al. (1995) suggested that glass eel migration occurs as waves of invasion with perhaps a fortnightly periodicity related to tidal currents and stratification of the water column. Alterations in the timing and magnitude of freshwater flow to bays and estuaries may affect the magnitude, timing, and spatial patterns of upstream migration of glass eels (Facey and Van Den Avyle 1987). YOY eel may use freshwater "signals" to enhance recruitment to local estuaries, thereby influencing year-class strength in a particular estuary (Sullivan et al. 2006).

As glass eels grow, they become pigmented (elver stage) and within 12 to14 months eels acquire a dark color with underlying yellow (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, mature eels range from 8 to 24 years, with most being less than 10 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 to the Sargasso Sea to spawn and die (Haro et al. 2000).

Objectives

The objectives of our study in the Potomac River were to:

1. monitor the young of the year (glass eel) migration into the Potomac River watershed to determine spatial and temporal components of American eel recruitment;

2. examine the tidal, lunar, and hydrographic factors that may influence young of year eel recruitment; and

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

Methods

Minimum criteria for YOY American eel sampling were established in the ASMFC American Eel FMP and used in our survey. Specifically, the timing and placement of gear must coincide with periods of peak YOY onshore migration. At a minimum, the gear must be deployed during nighttime flood tides. 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 and the Potomac River, 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 in both Virginia and Maryland were evaluated previously (Geer 2001). Final site selection was based on known areas of glass eel concentrations, accessibility, and specific physical criteria (e.g., appropriate habitat) suitable for glass eel recruitment to the sampling gear. The Maryland sampling of the Potomac River (northern shore site) was discontinued in 2001, due in part to the low catch rates in 2000 (Geer 2001). At the request of PRFC, the Virginia Institute of Marine Science (VIMS) began sampling two sites on the southern shore of the Potomac River (Gardy's Millpond and Clark's Millpond; Figure 1) in 2000.

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, which was accomplished through a gravity feed. Hoses were attached to the ramp and collection buckets with adapters to allow for quick removal for sampling. Enkamat™ erosion control material on the ramp floor provided a textured climbing surface and extended into the water below the trap. The ramps were placed on an incline (15-45^{o}), often on land, with the ramp entrance and textured mat extending into the water. The ramp entrance was placed in shallow water (< 25 cm) to prevent submersion. 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.

Sampling on the Potomac River (Clark's Millpond and Gardy's Millpond) was conducted from 25 March to 18 June 2009. Clark's Millpond (Coan River – Northumberland County) spillway is situated approximately one meter above the creek with a steady stream flow that requires a modified ramp extension to allow eels access to the spillway. Gardy's Millpond (Yeocomico River – Northumberland County) contains a spillway that drains through four box culverts, across a riffle constructed of riprap and into a lotic area of the Yeocomico River.

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, wind direction and speed, and precipitation were recorded during most site visits. All eels were counted 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 greater than 85 mm TL 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). Individual length, weight, and pigmentation stage information (see Haro and Krueger 1988) from 60 eels was collected weekly. Daily catch (raw number of eels caught per day) and annual geometric mean catch per unit effort (CPUE) were calculated for each site. Annual CPUE at each site was standardized to a 24-hour soak time and geometric means were calculated from samples captured in the time period during which 95% of the cumulative total catch occurred (i.e., dates in which 0%-2.5% and 97.5%-100% of the cumulative total catch were collected were excluded). We used this modification to reduce variability in catch rates associated with the interannual variability in the period of maximum recruitment.

Results and Discussion

Glass eels were first observed at Gardy's Millpond on 27 March and at Clark's Millpond on 6 April (Figure 2). Peak collections of glass eels occurred one month earlier in Gardy's Millpond than in Clark's Millpond and glass eels continued to be captured in low numbers through the end of sampling (18 June) at both sites. The capture of glass eels at Gardy's Millpond exhibited an episodic pattern with three peaks, whereas a single peak in abundance was observed for

Clark's Millpond in 2009. Timing of glass eel recruitment to rivers in Chesapeake Bay follows a pattern related to the proximity of the sampling locations to the Atlantic Ocean. Stations in Virginia tributaries nearer the mouth of Chesapeake Bay show recruitment peaks earlier in the year compared with sites from the Potomac River (Tuckey and Fabrizio 2009).

Elvers were captured in greatest numbers early in the sampling period at both sites and catches decreased towards the end of the survey (Figure 3). As in previous years, more elvers were observed at Gardy's Millpond than at Clark's Millpond (Table 2). Initial arrival and migration of elvers may be correlated with increases in water temperature, however elver migration may be delayed at freshwater interfaces until certain behavioral and physiological changes have occurred (Sorensen and Bianchini 1986).

The index of abundance for glass eels in Clark's Millpond continues to be low compared with indices in previous years, but the glass eel index at Gardy's Millpond has increased slightly in recent years (Figure 4). Elver indices at both sites were below values observed in 2008 (Figure 5).

Glass eels with pigmentation stages 1 through 7 were collected, and more developed stages were encountered later in the survey (Figure 6). Pigmentation stages for Potomac River sites were, in general, more advanced than those for YOY eels collected from the James and York River sites (VIMS American Eel Survey, unpublished data) possibly as a result of the greater distance and longer migration period necessary to reach the middle Chesapeake Bay. Similar to previous years, glass eel weight increased with glass eel length, with and average length of 57.9 mm TL and an average weight of 0.14 g (Figure 7).

<u>Index calculation procedure</u>

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 the data reported in Table 1. In 2000, at Gardy's

Millpond, 291 glass eels were collected and 262 glass eels were used to calculate the 95% geometric mean index (18.3), whereas in 2009, 231 glass eels were collected and 223 glass eels 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 is 11 times greater in 2000. 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 8). During 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 captured and the 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 are very different 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 within a year change 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 constant.

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.

Interpreting area-under-the-curve index results

Average recruitment of glass eels from 2001 to 2009 is similar for Clark's (AUC mean = 156.18) and Gardy's Millponds (AUC mean = 196.19), but recent recruitment patterns in these two millponds are divergent (Figure 9). Recruitment to Gardy's Millpond has been near or above the historic nine-year average for the past three years, whereas recruitment to Clark's Millpond has been more variable and below average for the past two years.

Elver migration patterns at each site show similar patterns with consistently greater numbers of elvers captured at Gardy's Millpond compared with Clark's Millpond (Figure 10). The time series average number of elvers at Gardy's Millpond is greater than twice that observed at Clark's Millpond.

Conclusions and Recommendations

1. Peak recruitment of glass eels in 2009 occurred earlier at Gardy's Millpond and was nearly one month later at Clark's Millpond.

2. Recruitment of elvers occurred early in the 2009 sampling season and decreased as sampling progressed at each site.

3. The geometric mean index of abundance that uses data from sampling dates during which 95% of the catch is obtained may bias index values depending on the recruitment pattern observed within the year. An alternative index calculation method that is unaffected by fluctuations in the daily recruitment pattern is the area-under-the-curve method, and results obtained from this method indicate relatively stable recruitment in the time series for glass eels at each site.

4. The ultimate goal of this survey is to provide estimates of recruitment for glass eel and elver stage American eels in the Potomac River. Considering the unique nature of each site and the performance variability of the sampling gear at each site, it may be necessary to develop an index for each sampling site. Drainage area, distance from the ocean, discharge, and other physical variables should be evaluated in an attempt to provide a relative value for each site. This value could then be used to weight the catch rates at each site to provide a more reliable abundance estimate for the Potomac River.

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Table 1. Summary of glass eel collections on the Potomac River at Clark’s Millpond, Gardy’s Millpond, and for the combined sites (2000 – 2009). CPUE is calculated as the standardized 95% geometric mean catch.

Source	Year	Start Date	End Date	Total Catch	Number Used	Trap Days	CPUE	Standard Error
Clark's Millpond	2000	28-Apr	15-May	15	12	18	0.650	0.088
	2001	9-Apr	22-Apr	4	3	14	0.186	0.069
	2002	1-Apr	27-Apr	115	109	27	3.387	0.115
	2003	25-Apr	15-May	24	22	21	0.902	0.090
	2004	21-Apr	27-May	447	430	37	6.006	0.179
	2005	13-Apr	26-May	223	213	44	3.311	0.128
	2006	6-Apr	22-May	80	77	47	1.311	0.079
	2007	26-Apr	1-Jul	435	379	67	3.934	0.122
	2008	14-Apr	19-Jun	22	20	63	0.208	0.041
	2009	6-Apr	11-Jun	42	40	67	0.420	0.051
Gardy's Millpond	2000	16-Apr	27-Apr	291	262	12	18.266	0.183
	2001	8-Apr	24-Apr	729	707	17	10.956	0.471
	2002	29-Mar	25-Apr	129	122	28	2.281	0.190
	2003	7-Apr	13-May	71	68	37	1.407	0.103
	2004	2-Apr	18-May	39	38	47	0.612	0.071
	2005	28-Mar	5-May	94	89	39	1.462	0.126
	2006	17-Mar	11-May	46	39	56	0.419	0.066
	2007	23-Apr	27-Jun	248	237	66	1.590	0.120
	2008	20-Mar	11-Jun	187	180	80	1.516	0.078
	2009	30-Mar	3-Jun	231	223	66	1.554	0.106
Combined	2000	16-Apr	12-May	306	295	27	4.510	0.280
	2001	8-Apr	24-Apr	733	711	17	11.223	0.467
	2002	29-Mar	27-Apr	244	233	30	5.649	0.138
	2003	9-Apr	13-May	95	87	35	1.886	0.114
	2004	13-Apr	27-May	486	461	45	5.712	0.164
	2005	30-Mar	26-May	317	305	58	4.000	0.095
	2006	20-Mar	21-May	126	119	63	1.373	0.083
	2007	23-Apr	1-Jul	683	619	70	5.877	0.123
	2008	20-Mar	11-Jun	209	199	84	1.604	0.077
	2009	30-Mar	7-Jun	273	263	70	1.994	0.099

Table 2. Summary of elver collections on the Potomac River at Clark's Millpond, Gardy's Millpond, and for the combined sites (2000 – 2009). CPUE is calculated as the standardized 95% geometric mean catch.

Source	Year	Start Date	End Date	Total Catch	Number Used	Trap Days	CPUE	Standard Error
Clark's Millpond	2000	5-Apr	15-May	5	3	41	0.078	0.022
	2001	19-Mar	10-May	205	196	53	2.711	0.099
	2002	13-Mar	21-Apr	90	83	40	1.810	0.071
	2003	17-Mar	8-May	225	213	53	2.165	0.140
	2004	2-Apr	23-May	314	299	52	3.029	0.153
	2005	28-Mar	24-May	62	59	58	0.773	0.068
	2006	15-Mar	24-May	153	146	71	1.351	0.081
	2007	15-Mar	27-Jun	90	85	105	0.646	0.045
	2008	24-Mar	15-Jun	276	258	80	2.209	0.068
	2009	30-Mar	31-May	90	82	63	0.761	0.083
Gardy's Millpond	2000	16-Apr	15-May	15	14	30	0.232	0.065
	2001	16-Mar	1-May	624	605	47	7.887	0.135
	2002	15-Mar	27-Apr	273	261	44	3.682	0.154
	2003	19-Mar	6-May	300	280	49	4.248	0.109
	2004	10-Mar	11-May	483	470	63	4.663	0.109
	2005	23-Mar	17-May	313	304	56	4.540	0.072
	2006	10-Mar	14-May	692	672	66	5.300	0.129
	2007	15-Mar	27-Jun	198	190	105	1.320	0.059
	2008	20-Mar	11-Jun	393	380	80	3.714	0.076
	2009	30-Mar	2-Jun	360	348	65	2.811	0.120
Combined	2000	5-Apr	15-May	20	17	41	0.318	0.062
	2001	16-Mar	8-May	829	801	54	9.942	0.114
	2002	15-Mar	27-Apr	363	346	44	5.614	0.127
	2003	17-Mar	8-May	525	503	53	6.868	0.114
	2004	10-Mar	20-May	797	740	72	6.558	0.107
	2005	23-Mar	19-May	375	365	58	5.266	0.073
	2006	10-Mar	21-May	845	821	73	6.367	0.118
	2007	15-Mar	27-Jun	288	275	105	2.030	0.059
	2008	20-Mar	15-Jun	669	651	88	5.564	0.080
	2009	30-Mar	2-Jun	450	436	65	3.539	0.124

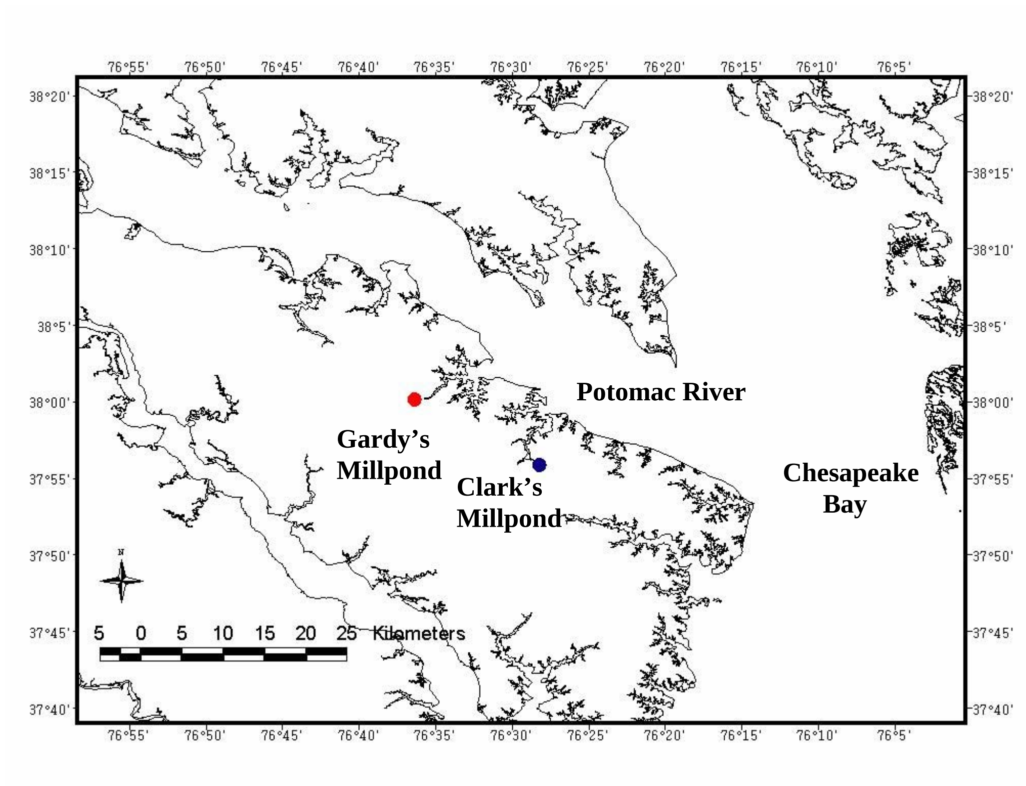

Figure 1. Sampling sites in the Potomac River.

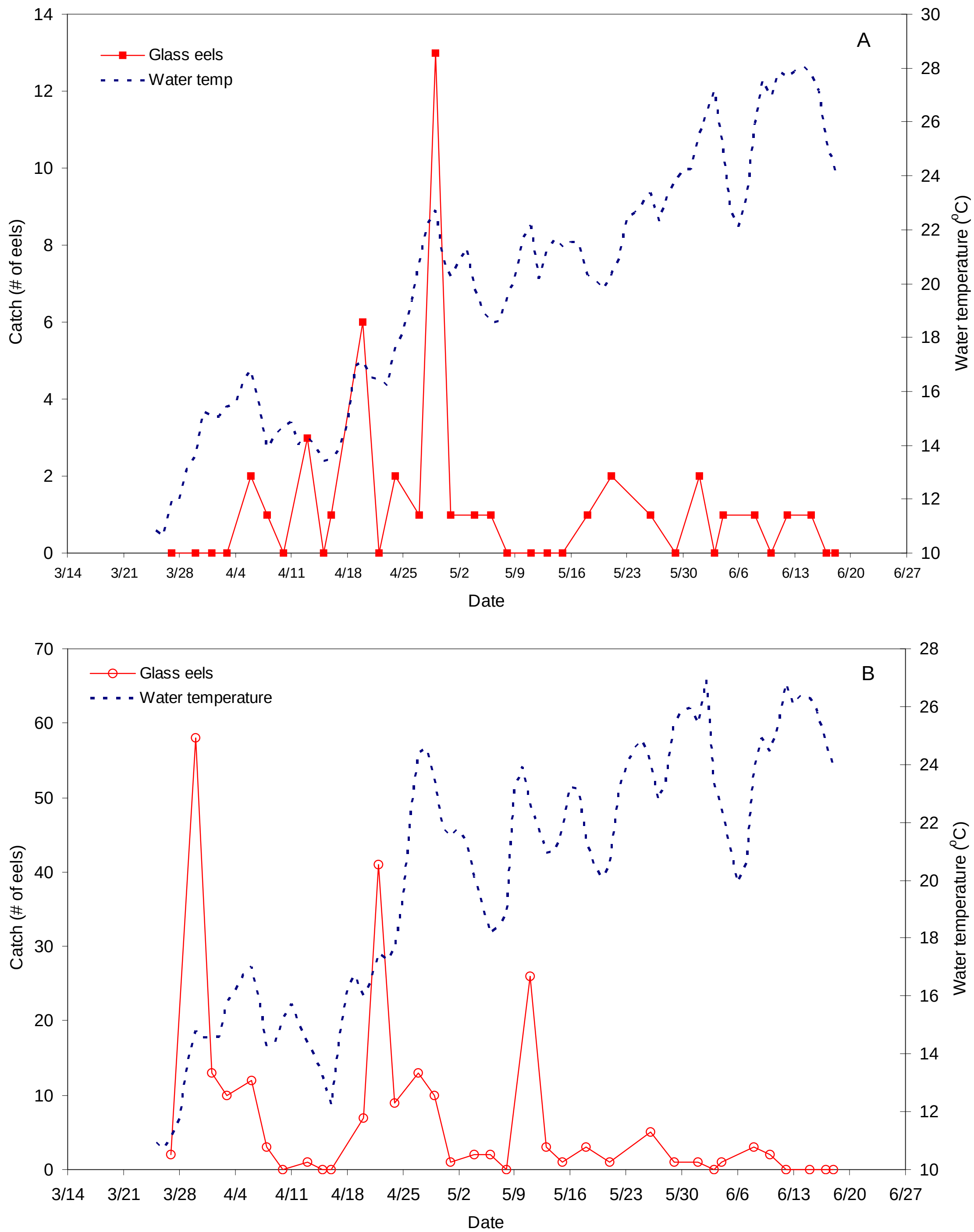

Figure 2. The total number of glass eels captured during each sampling event and water temperature at A) Clark's Millpond and B) Gardy's Millpond, 2009.

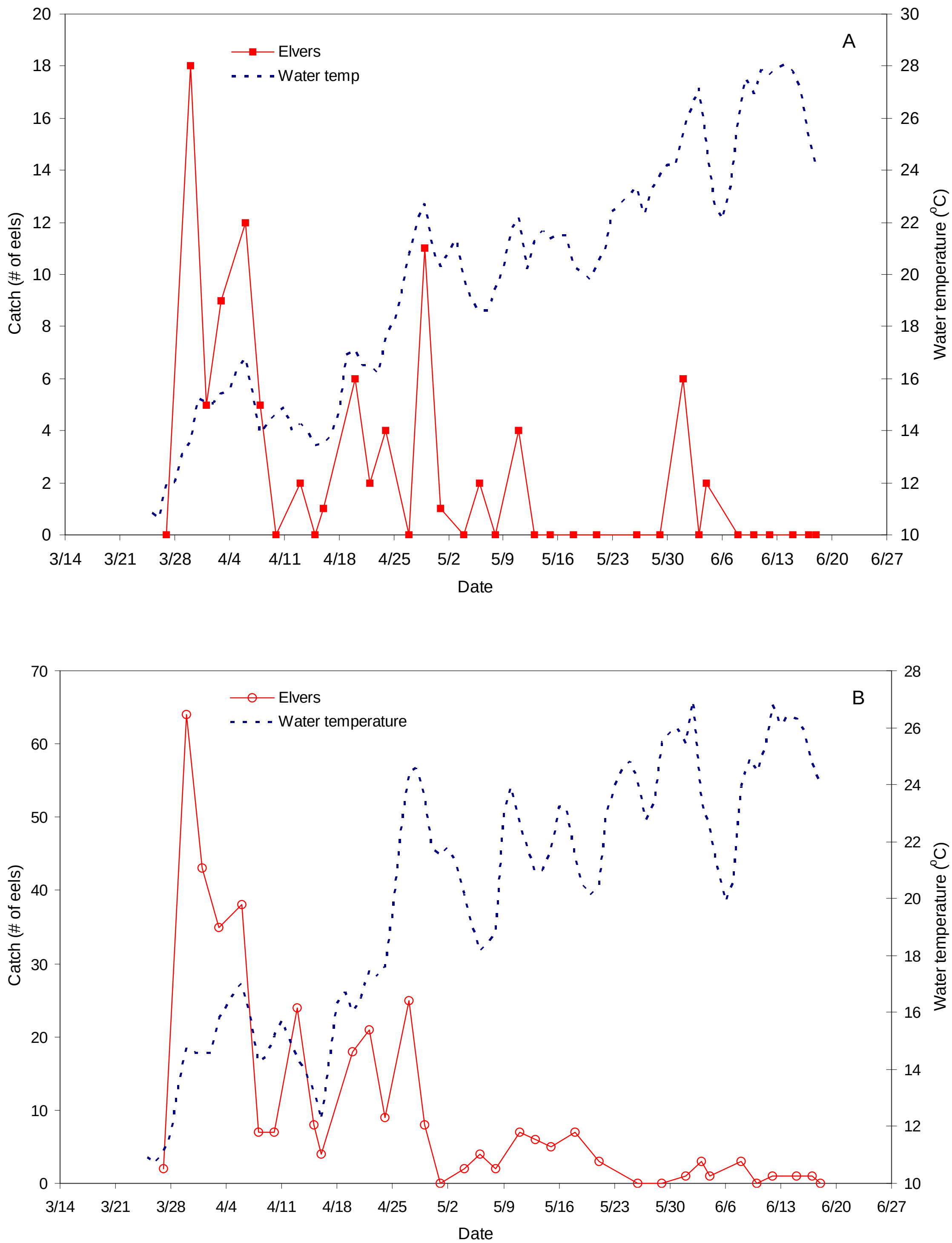

Figure 3. The total number of elver eels captured during each sampling event and water temperature at A) Clark's Millpond and B) Gardy's Millpond, 2009.

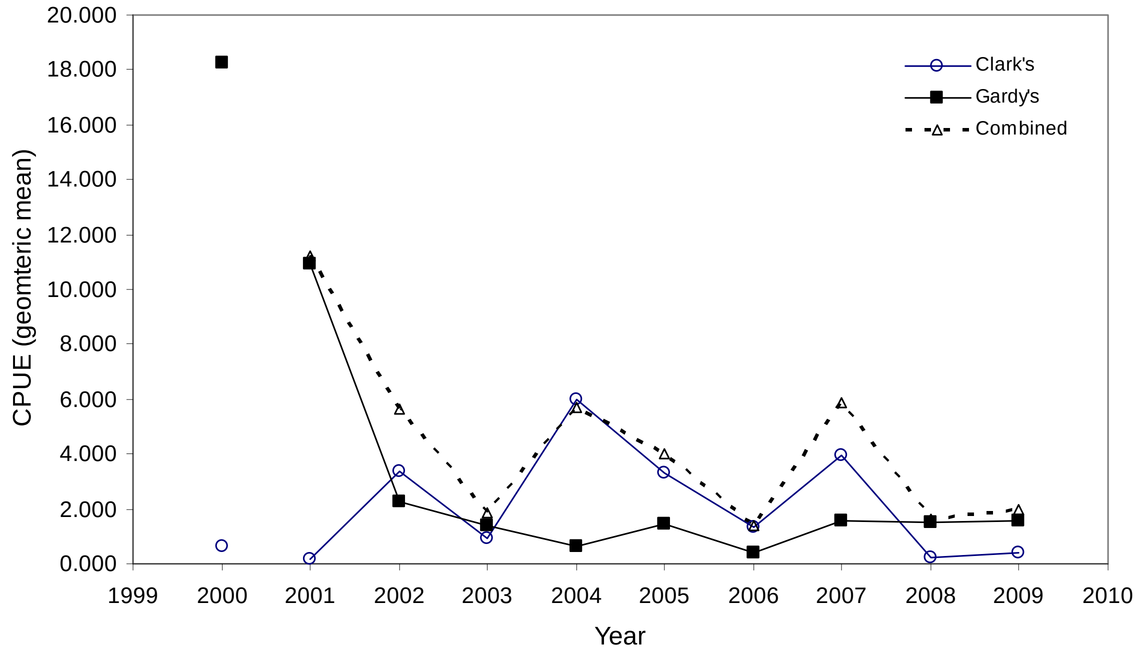

Figure 4. Glass eel CPUE (95% geometric mean) from 2000 to 2009. Collections in 2000 followed different protocols and are not directly comparable to collections in later years.

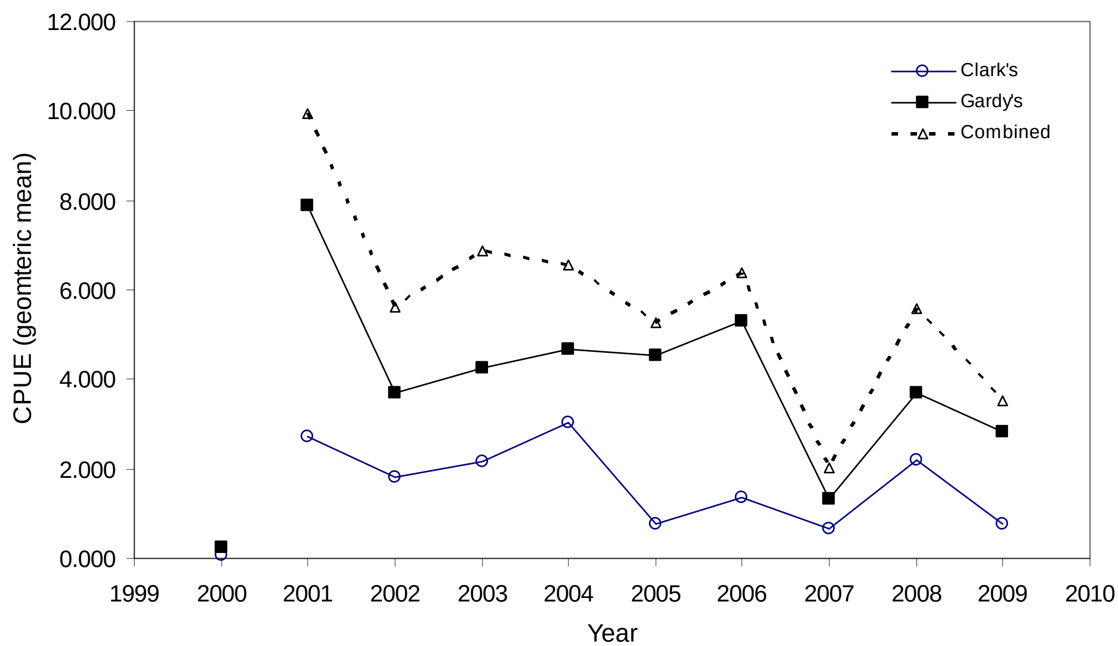

Figure 5. Elver eel CPUE (95% geometric mean) from 2000 to 2009. Collections in 2000 followed different protocols and are not directly comparable to collections in later years.

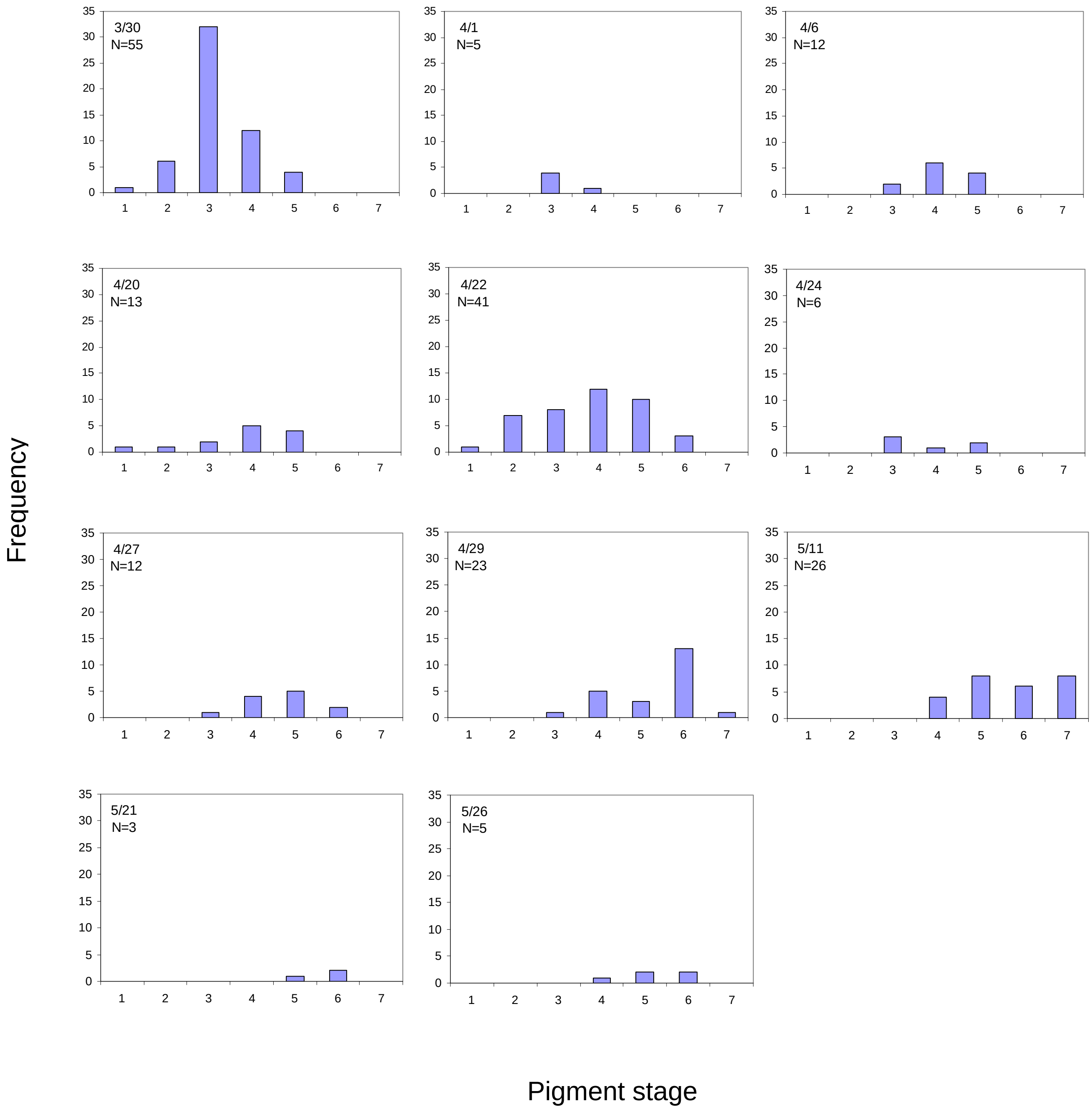

Figure 6. Glass eel pigment stage by date of capture for the Potomac River in 2009.

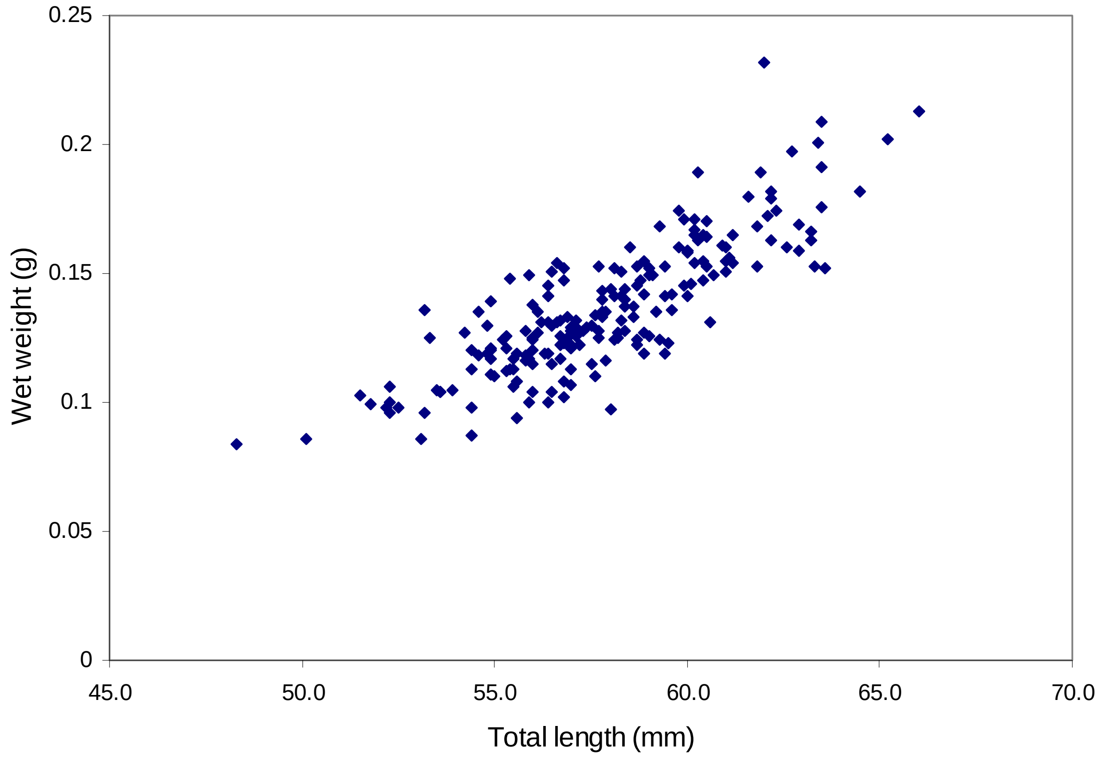

Figure 7. Total length and wet weight of glass American eels captured at Clark's and Gardy's Millponds, 2009. (avg. TL = 57.9 mm, avg. wt. = 0.14 g)

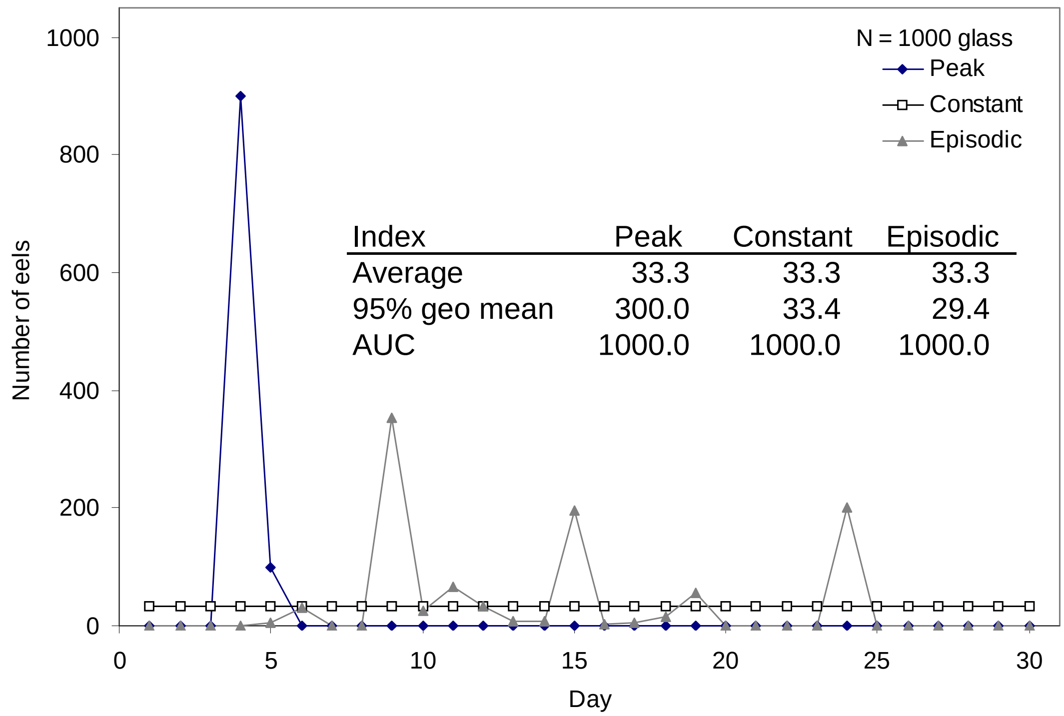

Figure 8. The potential influence of three glass eel recruitment patterns -- a single peak event (Peak), constant recruitment throughout the survey period (Constant), and periodic peaks in abundance (Episodic) -- on the value of three methods for calculating the index of abundance: arithmetic average, 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 = 1000 glass eels) for all three recruitment pattern scenarios were constant.

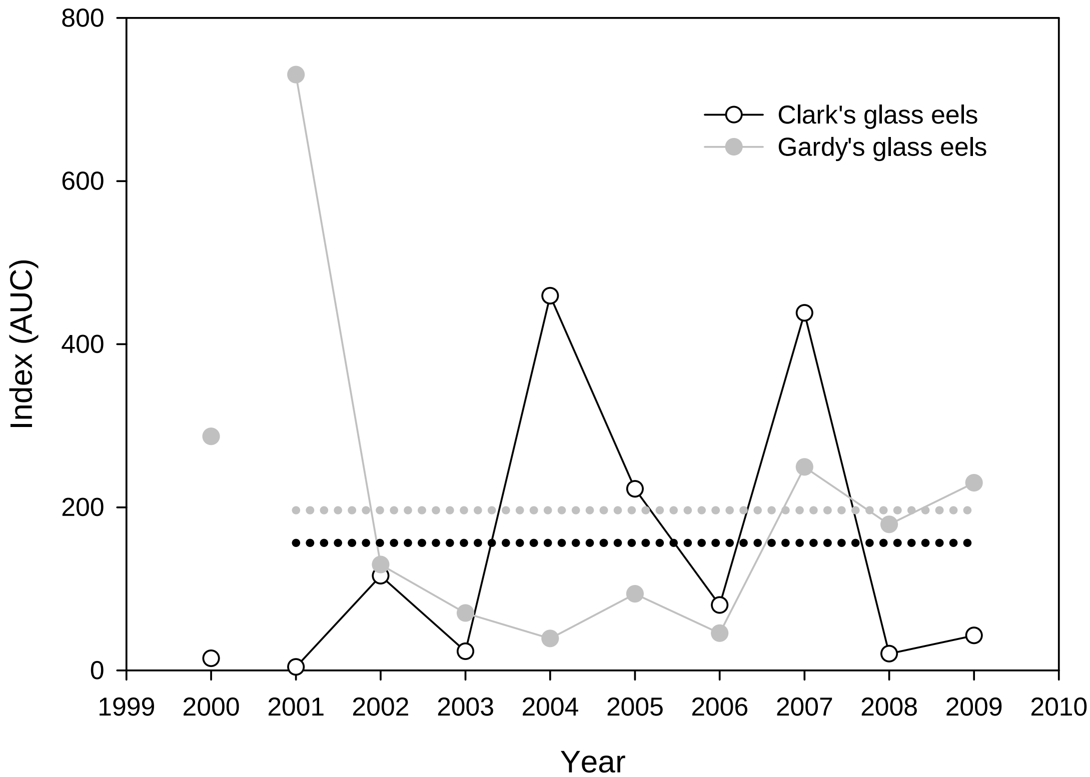

Figure 9. Glass eel recruitment indices (area-under-the-curve method) for Clark’s (open circles) and Gardy’s Millponds (filled circles) from 2001 to 2009. The index value from 2000 is not included in the time series because effort was directed differently during this exploratory year to establish the appropriate sampling window. Time series averages for each site are shown as a dotted line in black (Clark’s Millpond = 156.18) or gray (Gardy’s Millpond = 196.19).

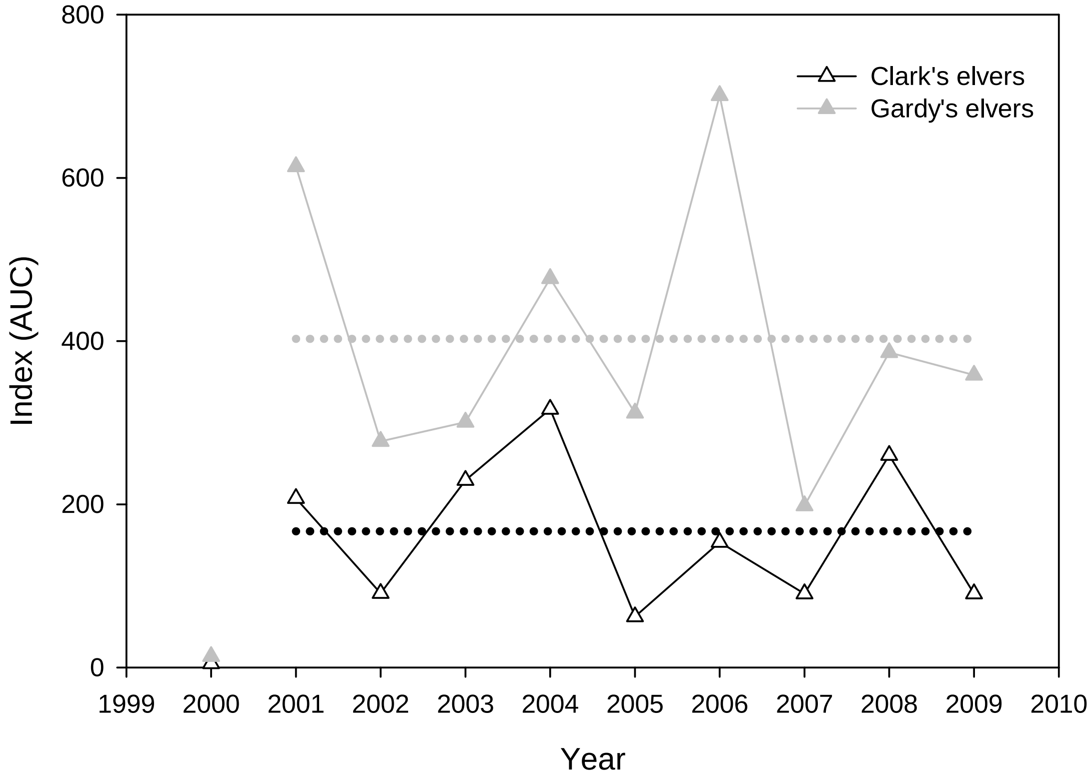

Figure 10. Elver recruitment indices (area-under-the-curve method) for Clark's (open triangles) and Gardy's Millponds (filled triangles) from 2001 to 2009. The index value from 2000 is not included in the time series because effort was directed differently during this exploratory year to establish the appropriate sampling window. Time series averages for each site are shown as a dotted line in black (Clark's Millpond = 166.70) or gray (Gardy's Millpond = 402.64).