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By

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Acknowledgements

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Objectives

1. Determine number and size of eels recruiting to the Potomac River watershed.

2. Examine the diel, tidal, lunar, and water quality factors, which may influence young of year eel recruitment.

3. Collect basic biological information on recruiting eels including but not limited to: length, weight, and pigment stage.

Introduction

Measures of juvenile recruitment success have long been recognized as valuable fisheries management tools. In Chesapeake Bay, these measures provide reliable indicators for future year class strength for blue crabs (Lipcius and Van Engel, 1990), striped bass (Goodyear, 1985), and several other recreationally and commercially important species (Geer and Austin, 1999).

The American Eel, *Anguilla rostrata,* is a valuable commercial species along the entire Atlantic coast from New Brunswick to Florida. Landings along the U.S. Atlantic coast have varied from 290 MT in 1962 to a high of 1600 MT in 1975 (NMFS, 1999). In recent years, harvests along the U.S. Atlantic Coast seemingly declined, with similar patterns occurring in the Canadian Maritime Provinces, and in Europe with its congener *A. anguilla* (Ciccotti et al., 1995). The Mid-Atlantic states (New York, New Jersey, Delaware, Maryland, and Virginia) comprised the largest portion of the East Coast catch (88% of the reported landings) since 1988 (NMFS,1999). The Chesapeake Bay jurisdictions of Virginia, Maryland, and the Potomac River Fisheries Commission (PRFC) alone represent 30,15, and 18% respectively, of the annual United States commercial harvest for 1987-1996 (ASMFC, 2000). Fishery independent indices have shown a decline in American eel abundance in recent years as well (Richkus and Whalens, 1999; Geer, 2003). Hypotheses for this decline include locational shifts in the Gulf Stream, pollution, overfishing, parasites, and barriers to fish passage (Castonguay et al., 1994; Haro et al., 2000).

Fisheries management techniques are not often applied to American eels because basic biological information is not well known. Unknown biological parameters such as variation in growth rates and length at age have complicated stock assessment and management efforts. Though American eel are not usually considered a sport fish, their ubiquity and readiness to take a bait leads them to be caught by recreational fishermen (Collette and Klein-MacPhee, 2002). Absence of basic population dynamics data has hampered attempts at evaluation of regional exploitation rates (Social Research for Sustainable Fisheries, 2002). Additionally, relatively few studies have addressed the recruitment of glass eels to Atlantic coast estuaries from the Sargasso Sea spawning grounds.

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 the states' efforts to collect data on the resource and the fishery it supports through both fishery dependent and fishery independent studies. To this end, member jurisdictions (including the PRFC) agreed to implement an annual abundance survey for young of year (YOY) American eels. The survey is intended to "…characterize trends in annual recruitment of young of year 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 as pilot surveys in 2000 with full implementation by the 2001 season. Results from these surveys will provide critical data on eel coastal recruitment success and further understanding of American eel population dynamics.

Life History

The American eel is a catadromous species, present 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. The eggs hatch into leaf-shaped ribbon-like larvae called leptocephali, which are transported by the ocean currents (over 9-12 months) in a generally northwesterly direction. Within a year, metamorphosis into the next life stage (glass eel) occurs in the Western Atlantic near the East Coast of North America. Coastal currents and active migration transport the glass eels into rivers and estuaries from February to June in Virginia and Maryland. As growth continues, the eel becomes pigmented (elver stage) and within 12 –14 months acquires a dark color with underlying yellow (yellow eel stage; Facey and Van Den Avyle, 1987). 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. Age at maturity varies greatly with location and latitude, and in Chesapeake Bay may range from 8 to 24 years, with most being less than ten years old (Owens and Geer, 2003). *A. rostrata* 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). Metamorphosis into the silver eel stage occurs during the seaward migration that occurs from late summer through autumn.

It has been suggested that glass eel migration consists of waves of invasion (Boetius and Boetius, 1989 as reported by Ciccotti et al., 1995), and perhaps a fortnightly periodicity related to selective tidal stream transport (Ciccotti et al., 1995). Additionally alterations in freshwater inflow (patterns and magnitudes) to bays and estuaries may alter flow regimes and consequently affect the size, timing and spatial patterns of upstream migration of glass eels and elvers (Facey and Van Den Avyle, 1987).

Methods

The American Eel FMP created by the ASMFC established minimum criteria for YOY American eel sampling, with the ASMFC Technical Committee approving sampling gear. The timing and placement of gear must coincide with periods of peak YOY onshore migration. At a minimum, the gear must fish during flood tides occurring during the 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. On a weekly basis, a minimum of 60 specimens must be taken for length, weight, and pigment stage information.

Due to the importance of the eel fishery in Virginia and the Potomac River, additional methods have been implemented to insure proper temporal and spatial coverage, and to provide reliable estimates of recruitment success. 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. proper habitat), which are suitable for glass eel concentrations. The Maryland sampling of the Potomac River was discontinued in 2001, due in part to the low catch rates observed the previous year (Geer, 2001). At the request of PRFC, VIMS sampled ***two*** sites on the Potomac River (Gardy's Millpond and Clark's Millpond; see Figure 1) from 2000 – 2004, exceeding the FMP requirements.

Eels were collected with Irish eel ramps (Figure 2) at all locations. Irish eel ramps are an approved gear as stated in the FMP (ASMFC, 2000). The configuration of these ramps (as described below) proved successful for attracting and capturing small eels in tidal waters of Chesapeake Bay. Ramp operation required continuous flow of water over the climbing substrate and through the collection device. The water supply for the Irish ramp is through gravity feed, requiring at least one foot (30.5 cm) of head above the trap. Hoses were attached to the ramp and collection buckets with adapters, which allowed quick removal and replacement during collection. Enkamat™ erosion control material on the floor of the ramp and extending into the water below the ramp provided a textured climbing surface for eels. 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 above inclination, in combination with the 4^{o} elevation of the substrate inside the ramp, resulted in sufficient slope to create attractant flow. A hinged lid provided access for cleaning and flow adjustments. Flow over the textured climbing surface was adjusted to maintain minimal depths.

Traps were checked four days per week (Monday-Wednesday-Friday, and alternating weekend days). Only eels found in the ramp's collection bucket were recorded. Trap performance was rated on a scale of 1 to 4 (1= gear 100% efficient, 2 = gear > 50% efficient, 3 = gear < 50% efficient, 4= gear not functioning). Water temperature, pH, air temperature, wind direction, wind speed, and precipitation were recorded. In addition, starting in 2002, temperature data loggers (Stowaway Tidbits™) were deployed which recorded hourly water temperature. All eels were enumerated and returned to the water above the impediment, with any sub-sample information appropriately recorded. Young of year (YOY) eels were distinguished from elvers by their different pigmentation. This usually corresponds to a length differentiation of eels less than or equal to 85 mm total length (TL) classified as YOY, while those greater than 85 mm TL classified as elvers. These two distinct length frequency modes likely represent different year classes (Geer, 2001). Lengths, weights, and pigment stage (as described by Haro and Krueger, 1988) were collected from up to sixty eels weekly.

Clark's Millpond (Coan River – Northumberland County) was sampled from March 8th to May 30th 2004. The spillway was approximately one meter above the creek with a strong and steady stream flow, requiring a modified ramp extension (G. Wippelhauser, pers. comm.) to allow the eels to traverse the spillway (Figure 3). Gardy's Millpond (Yeocomico River – Northumberland County) was sampled from March 8th to May 24th 2004 (Figure 4). The site contains a spillway that drains through four box culverts, across riprap into a coarse sand area of the Yeocomico River.   The Virginia Department of Game and Inland Fisheries maintains the site.

A daily catch per unit effort (CPUE) was calculated for each site. CPUE for the Irish eel ramp was calculated as catch per 24 hours of soak time. Annual CPUE (geometric means) were calculated for Clarks and Gardy's Millponds combined. To examine whether a relationship existed between YOY or elver CPUE and lunar stage, an Analysis of Variance (ANOVA) was performed with lunar quarter as the factor and CPUE as the response. Lunar quarter was divided into four stages (according to van Montfrans et al., 1995): (1) the week of the new moon beginning on the day of the new moon, (2) the week of the waxing moon, (3) the week of the full moon starting on the day of the full moon and (4) the week of the waning moon.

Results

The overall (both sites combined) geometric mean YOY CPUE in 2004 was just slightly lower than 2000 (3.17 compared to 3.26, respectively; Table 1; Figure 5). Elver CPUE increased from 2003 and was the second highest since the start of the survey. For the five years sampled thus far, YOY CPUE's have exhibited alternating low and high indices (i.e. no trend), while those for elvers have increased (Figure 5). In 2004, YOY CPUE at Clark's was nearly double that of Gardy's (2.64 and 1.35, respectively; Figure 6A) with slightly more elvers collected at Gardy's than Clarks Millponds (4.61 and 2.68, respectively; Figure 6B).

YOY CPUE at Clark's Millpond during 2004 was double that in 2003 (Figure 6A). Elver CPUE was slightly less than that of 2003 (Figure 6A). YOY were captured from April 15th through May 30th (Figure 7) with most collected on April 20-21st and May 14th and 17th. Elvers were captured throughout the survey beginning March 27th and continuing through May 28th (Figure 7), with two elver peaks occurring nearly at the same time as the YOY peaks. There was a significant positive relationship between CPUE of YOY and elvers at Clark's Millpond (r^2 = 0.06, P = 0.029),

The YOY CPUE at Gardy's Millpond decreased significantly from 2000 to 2004 (r^2 = 0.82, P = 0.033; Figure 6B). The CPUE for elvers was slightly greater than last year (Figure 6B). YOY were captured from April 1st through May 19th (Figure 8) with no major peaks. Elvers were captured throughout the survey beginning March 10th and continuing through May 17th (Figure 8) with a major peak in CPUE April 19th, and minor peaks April 20th through April 23rd. YOY and elver recruitment comparisons for Gardy's and Clark's Millponds show that the sampling regime used captured recruitment peaks in all years sampled (Figures 7 and 8).

Every glass eel pigmentation stage except for stage 2 was collected (Figures 9 and 10). Toward the end of the survey, only stages 5 through 7 were collected (Figure 9). Most (96.3%) of the eels staged were stages 4 through 7 (Figure 10). Pigmentation stages for the Potomac sites were more advanced than those collected from the James and York Rivers (VIMS American Eel Survey, unpublished data) possibly a result of the longer migration period necessary to reach the middle Chesapeake Bay. Glass eel weight significantly increased (r^2 = 0.60, P = 0.0005) with glass eel length (Figure 11).

Presently it is unknown whether a particular environmental parameter was a driving force or hindrance to the recruitment migration of eels to fresh water. Water temperature at Gardy's and Clark's Millponds were nearly identical (difference of 0.4^{o}C mean temperature) and varied between 9.0^{o}C and 27.4^{o}C (Figures 12 and 13) but only Clarks showed a significant positive relationship with YOY and elver CPUE. Increased temperature resulted in increased CPUE of both YOY and elvers (r^2 = 0.23, P = 0.0005; r^2 = 0.14, P = 0.001, respectively*).* When Gardy's catch was lagged ten days, the YOY CPUE increased significantly with increased temperature (r^2 = 0.15, P = 0.001). Similarly when Clark's CPUE was lagged ten days, both YOY and elver CPUE were significantly related (r^2 = 0.14 and 0.16, respectively, P = 0.001 for both).

YOY CPUE for Clark's was significantly higher during the period of the waxing moon than the other lunar quarters (F= 3.34, P = 0.024, df = 3,72; Tukeys Pairwise Comparisons Test, MINITAB, 1998) suggesting a recruitment lag period of a week after the full moon. YOY CPUE for Gardy's was significantly higher during the week of new moon, followed by the week of the waxing moon. Elver CPUE at both sites was highest during the weeks of the waxing moon and the full moon.

Discussion

Some Atlantic Coast states had low recruitment this year (G. Wippelhauser, Maine DNR, pers. comm.), possibly a result of not setting their traps out long enough. The YOY recruitment period at Clarks Millpond appeared to last longer this year than in the past (Figure 7), though our traps were out longer in 2004 than previous years. In general, combined CPUE for YOY eels and elvers at the Potomac sites increased slightly compared to 2003. Initial migration may be mediated by temperature and precipitation (proxy for salinity), and then be associated with a lunar periodicity. Overall, we found highest recruitment during the week of the waxing moon (during the week after the new moon). In 2003, highest recruitment occurred during the week of the waning moon (Montane et al, 2003). If the run is highly variable from year to year (as is suspected, and exhibited by the total YOY CPUE in 2004), a very productive site one year may be unproductive the next. Conversely, poor sites in one year may be very productive in others, hence the need for long term continual time series data.

Questions remain as to the exact timing of the run and the influence physical parameters of a site may have on recruitment. Initial arrival of juvenile eels may be correlated to large increases in water temperature (Sorensen and Bianchini, 1986). Drastic increases in water temperature resulted in increased recruitment in mid-April for Clark's YOY and elvers and Gardy's elvers. Increased temperature resulted in significant increases in CPUE of both YOY and elvers at Clark's Millpond. Elvers may also delay upstream migration at freshwater interfaces until certain behavioral and physiological changes have occurred (Sorensen and Bianchini, 1986).

With only five years of data, most of the variability associated with eel recruitment in Chesapeake Bay remains an unknown, though with a few more years of data and comprehensive analysis of the Potomac and other Virginia tributaries sampled (sites sampled by VIMS for VMRC), some of the trends may become more apparent.

Conclusions and Recommendations

1. In general, CPUE for YOY eels and elvers increased slightly in the Potomac during 2004 compared to 2003. Initial migration may be mediated by temperature and precipitation (proxy for salinity), and then be associated with a lunar periodicity.

2. Irish eel ramps are an effective gear for sampling YOY eels in coastal Virginia.

3. Sampling should start on or around March 1, and continue through June 1, if necessary, to capture peak recruitment. Given the great variability associated with spring temperatures in the Chesapeake region, sampling must be over a wide range of temperatures ensuring sampling occurs during optimal temperature regimes.

4. The ultimate goal of this survey is to provide estimates of recruitment for YOY eels and elvers. 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. Parameters such as drainage area, distance from the ocean, discharge, and other physical parameters should be evaluated in an attempt to provide a relative value for each site. This value can then be used to weight the catch rates at each site, to provide a more reliable abundance estimate.

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Table 1. Potomac River catch statistics by site and year (2000-2004).

Site	Start Date	End Date	YOY		Elver		Sample Days
			Total	CPUE	Total	CPUE	
Clark's	30-Mar-00	16-May-00	15	1.24	5	1.09	47
Gardy's	12-Apr-00	16-May-00	291	3.95	15	1.32	34
Potomac River 2000 Totals			306	3.26	20	1.31	81

Site	Start Date	End Date	YOY		Elver		Sample Days
			Total	CPUE	Total	CPUE	
Clark's	16-Mar-01	12-May-01	24	1.05	225	3.79	57
Gardy's	12-Mar-01	12-May-01	71	2.29	300	7.18	61
Potomac River 2001 Totals			95	2.30	525	10.85	118

Site	Start Date	End Date	YOY		Elver		Sample Days
			Total	CPUE	Total	CPUE	
Clark's	9-Mar-02	2-May-02	115	2.15	90	2.28	55
Gardy's	9-Mar-02	2-May-02	129	2.00	273	3.84	55
Potomac River 2002 Totals			224	3.15	363	5.28	110

Site	Start Date	End Date	YOY		Elver		Sample Days
			Total	CPUE	Total	CPUE	
Clark's	11-Mar-03	16-May-03	24	1.24	225	2.80	66
Gardy's	11-Mar-03	16-May-03	71	1.66	300	4.09	66
Potomac River 2003 Totals			95	1.87	525	6.13	132

Site	Start Date	End Date	YOY		Elver		Sample Days
			Total	CPUE	Total	CPUE	
Clark's	8-Mar-04	30-May-04	447	2.64	314	2.68	83
Gardy's	8-Mar-04	24-May-04	39	1.35	483	4.61	77
Potomac River 2004 Totals			486	3.17	803	6.63	160

Figure List

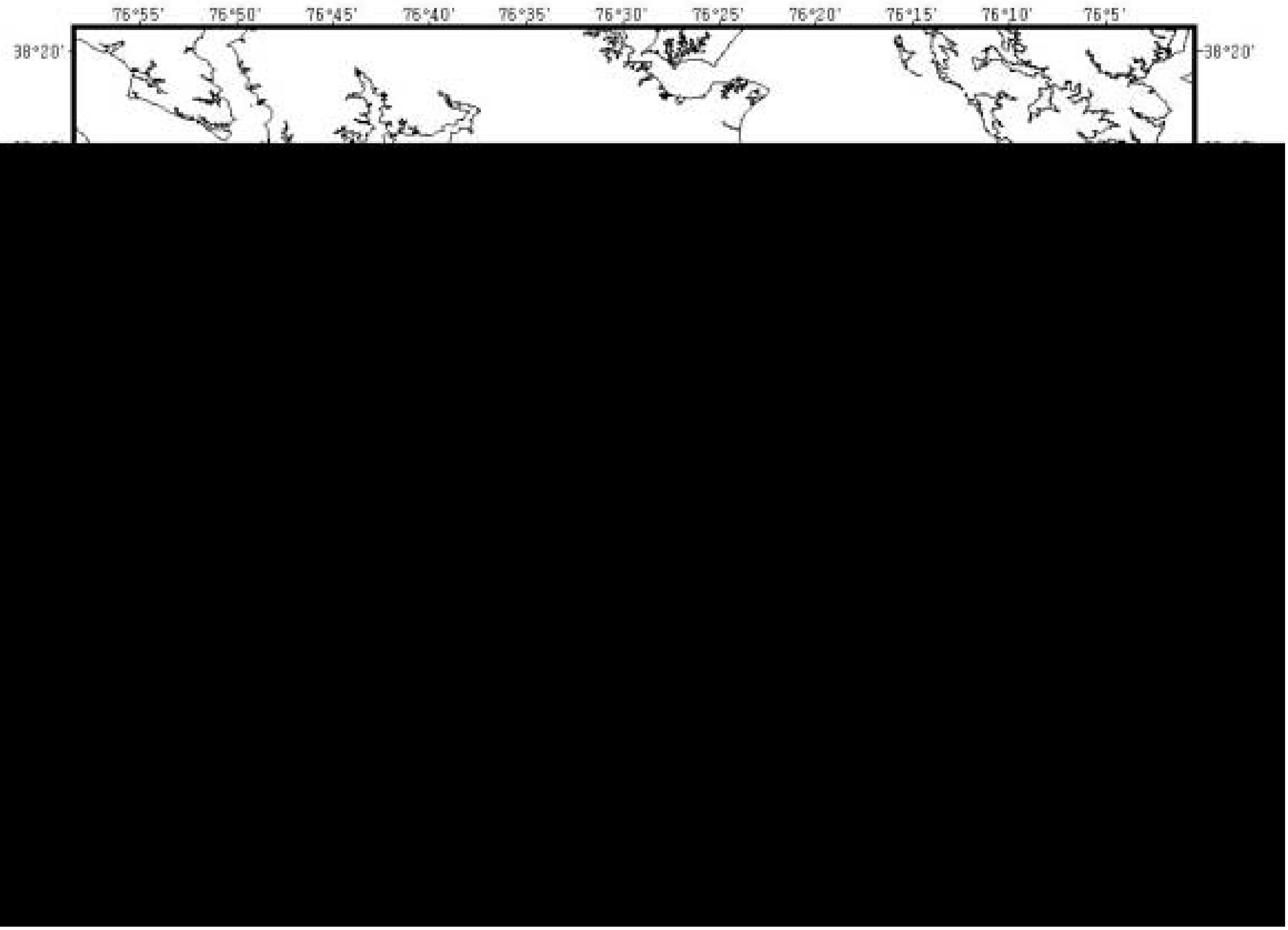

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Figure 1. Potomac River Sampling Site in 2004.

Figure 2. The Irish ramp at Gardy's Millpond showing its configuration.
The arrows indicate the flow of water as well as eels.

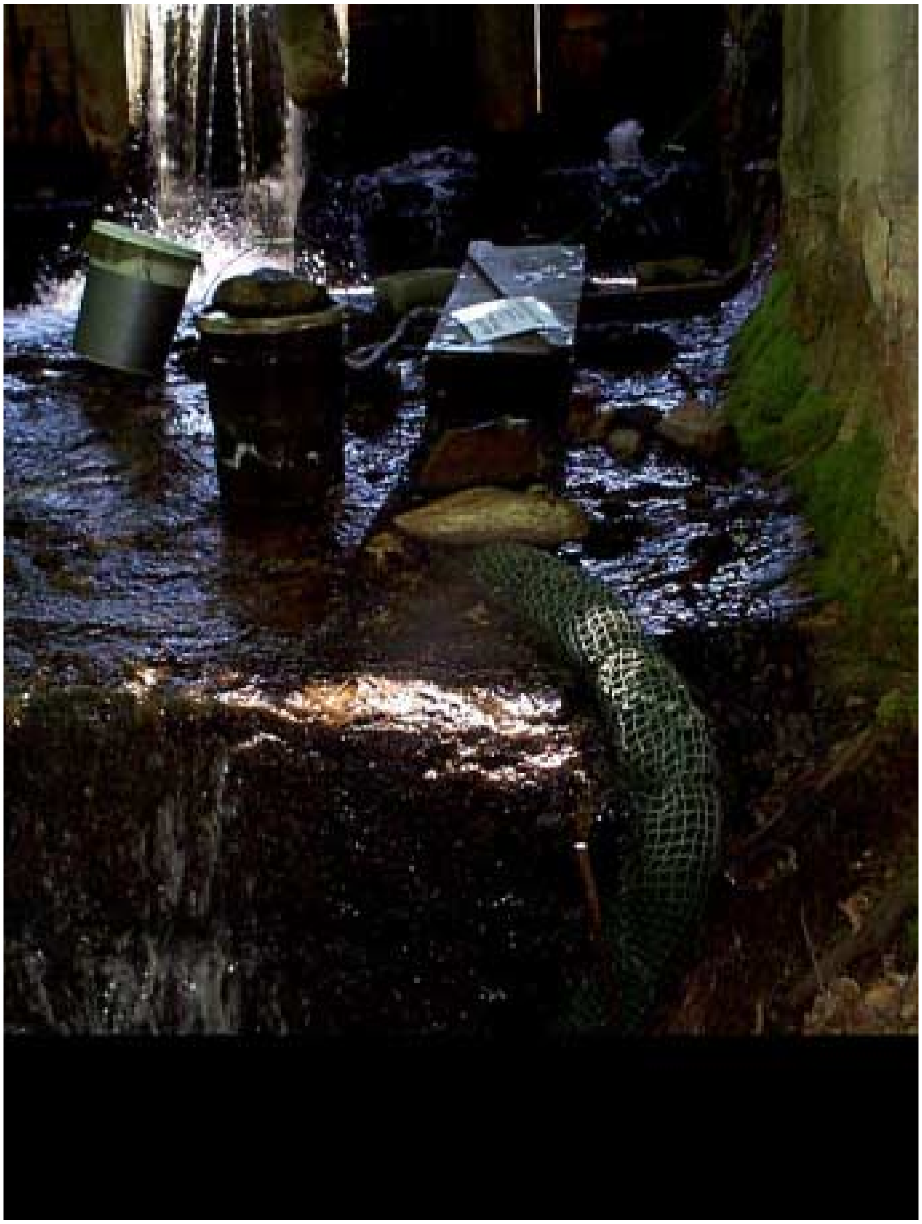


Figure 3. The Irish ramp at Clark's Millpond (Coan River). The green tube in the foreground was initially used as the modified ramp extension. In 2004, the "tube" was replaced with ¼" Delta knotless nylon placed in layers in the same location.

Figure 4. The spillway at Gardy's Millpond (Yeocomico River). The Irish ramp was located in the culvert on the left.

Figure 5. Potomac River CPUE for YOY and Elvers
(Clark's and Gardy's Millponds combined)
2000-2004

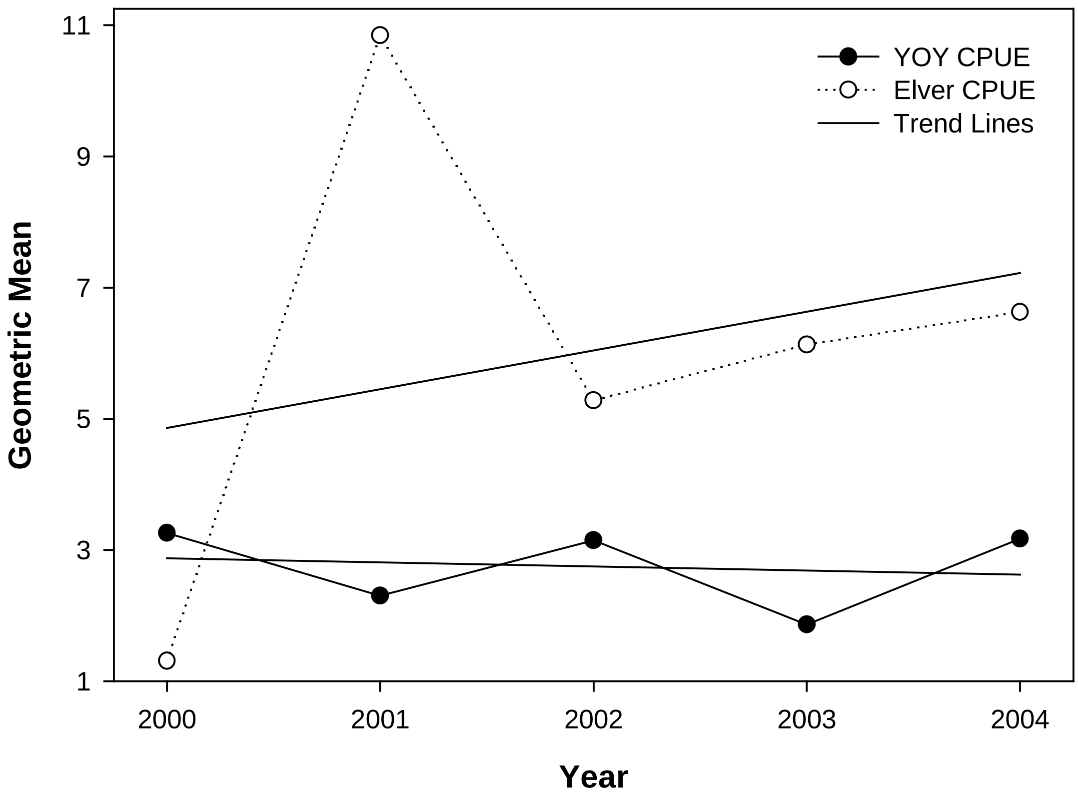
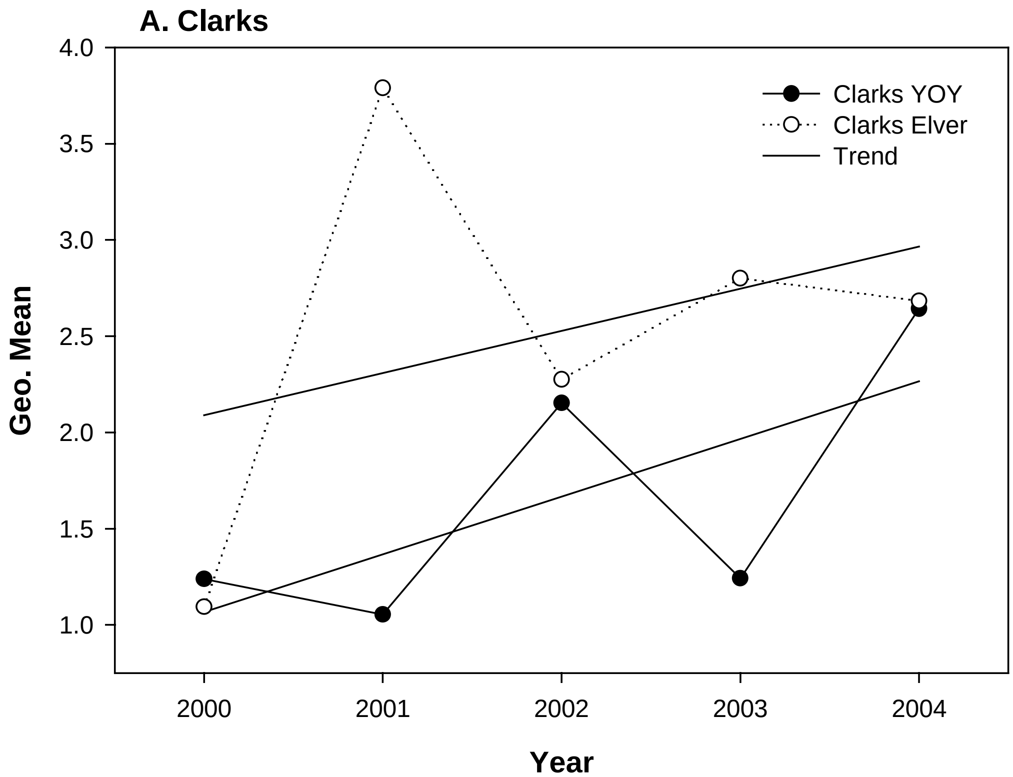


Figure 6. CPUE for YOY and Elvers at Clark's and Gardy's Millponds. 2000-2004



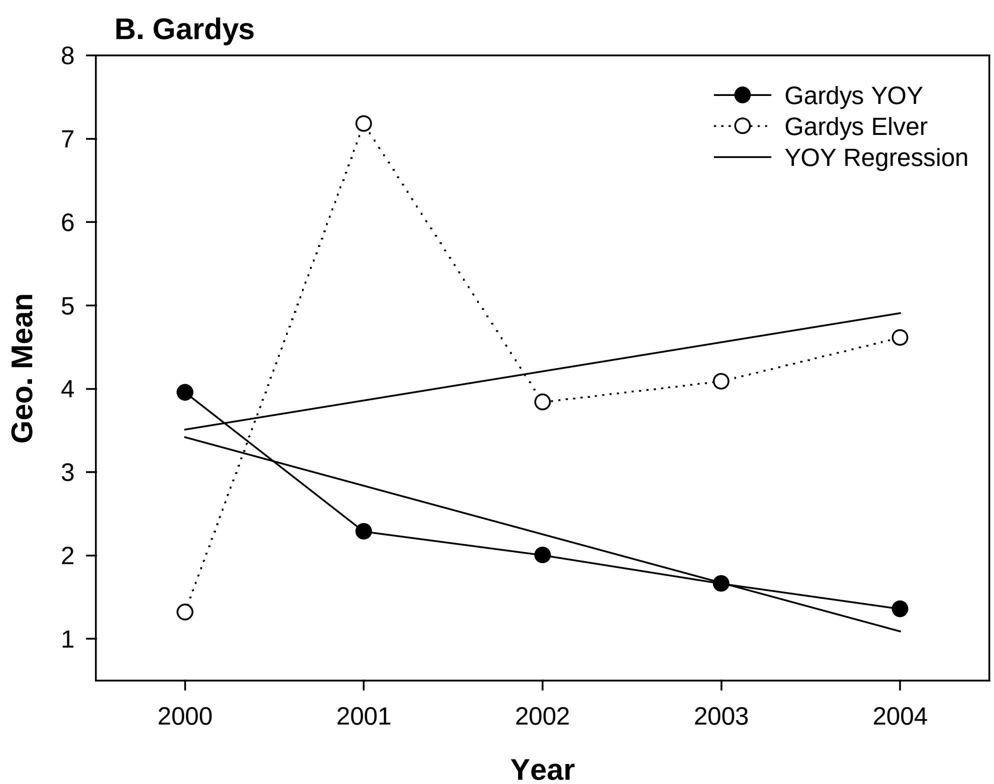


Figure 7.

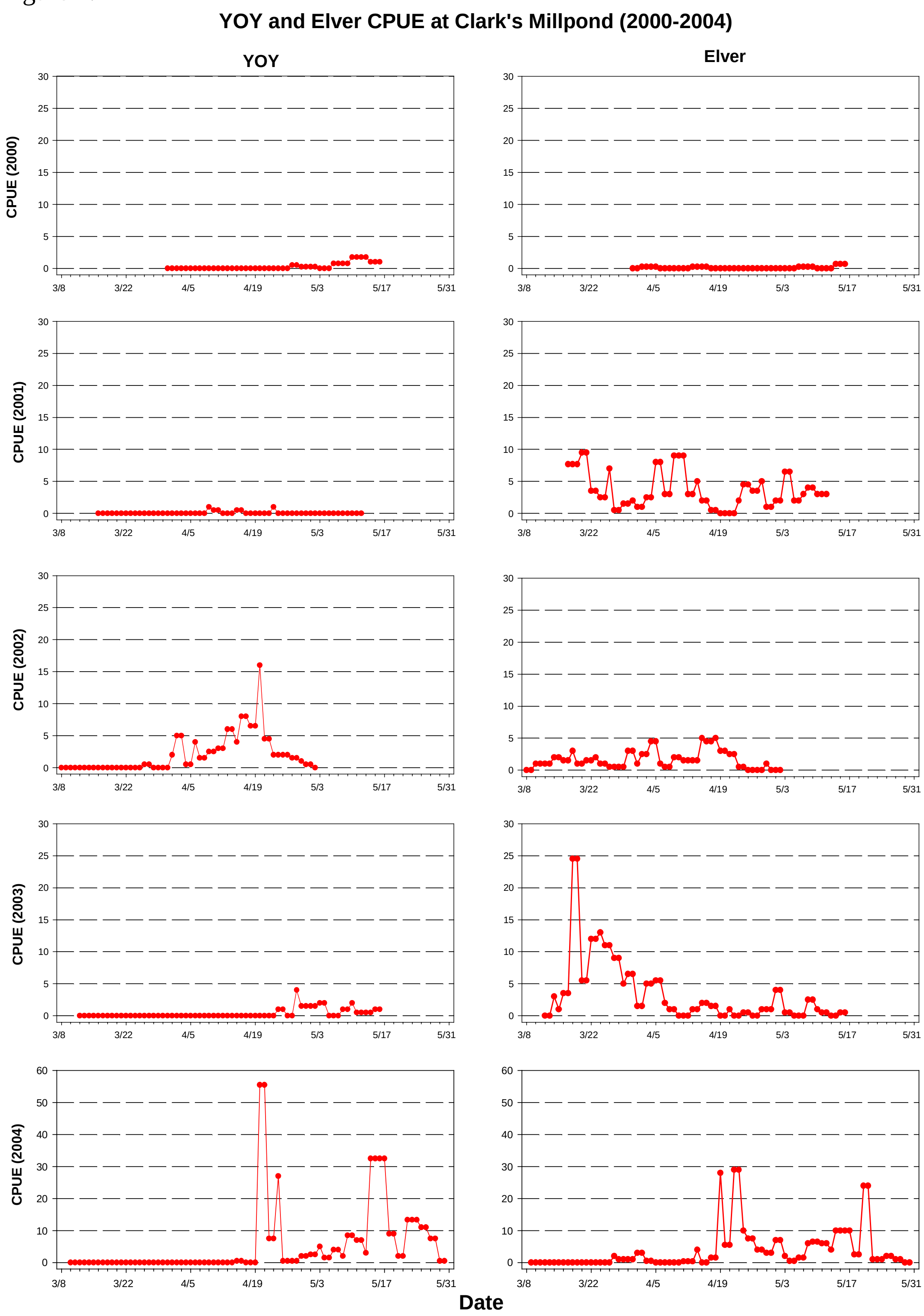
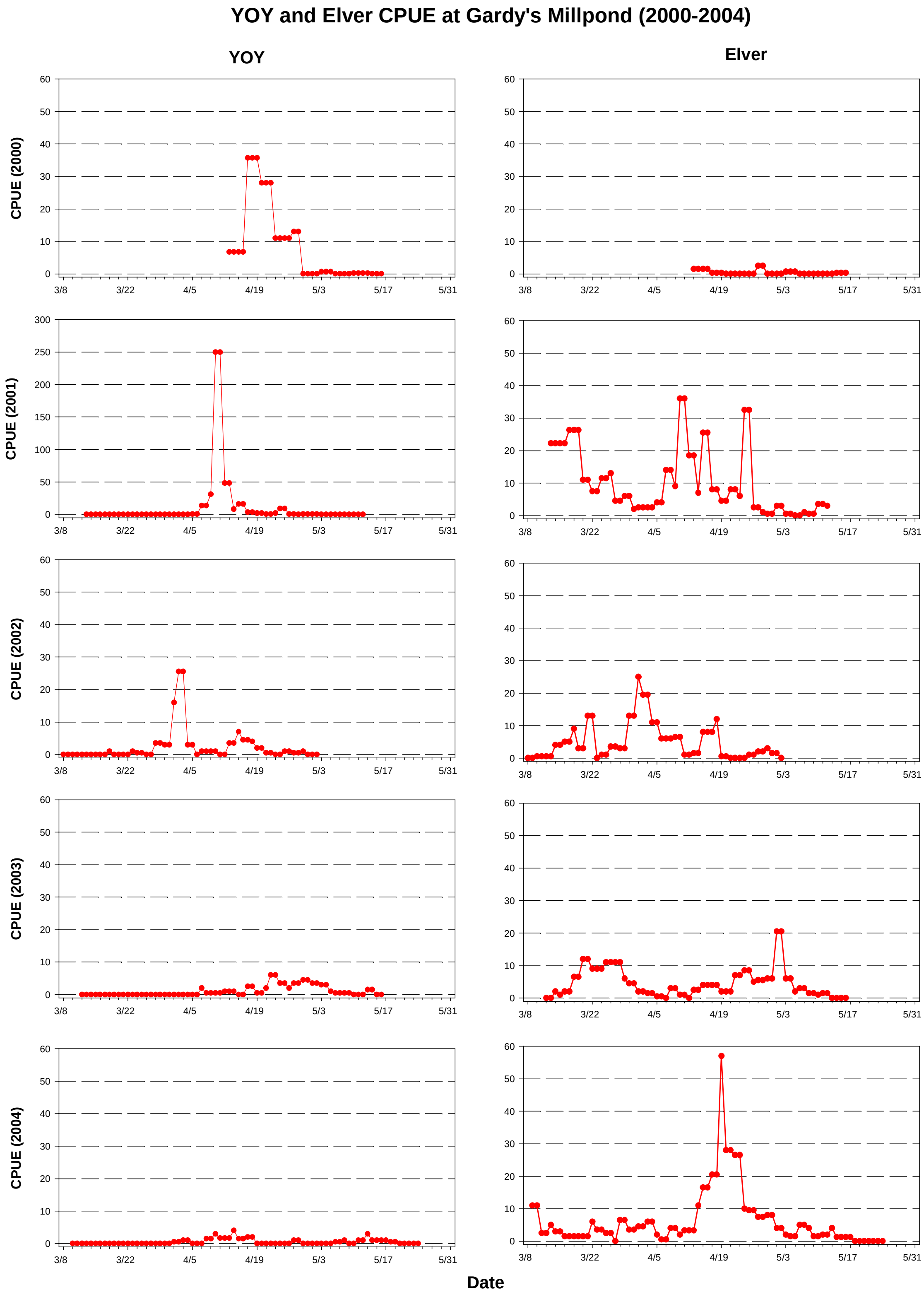

YOY and Elver CPUE at Clark's Millpond (2000-2004)
YOY
Elver
CPUE (2000)
CPUE (2001)
CPUE (2002)
CPUE (2003)
CPUE (2004)
Date
3/8
3/22
4/5
4/19
5/3
5/17
5/31

Figure 8.


YOY and Elver CPUE at Gardy's Millpond (2000-2004)
YOY
Elver
CPUE (2000)
CPUE (2001)
CPUE (2002)
CPUE (2003)
CPUE (2004)
3/8
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5/31
Date

Figure 9. Potomac River Pigmentation Stages 2004 (Gardy's and Clark's combined)

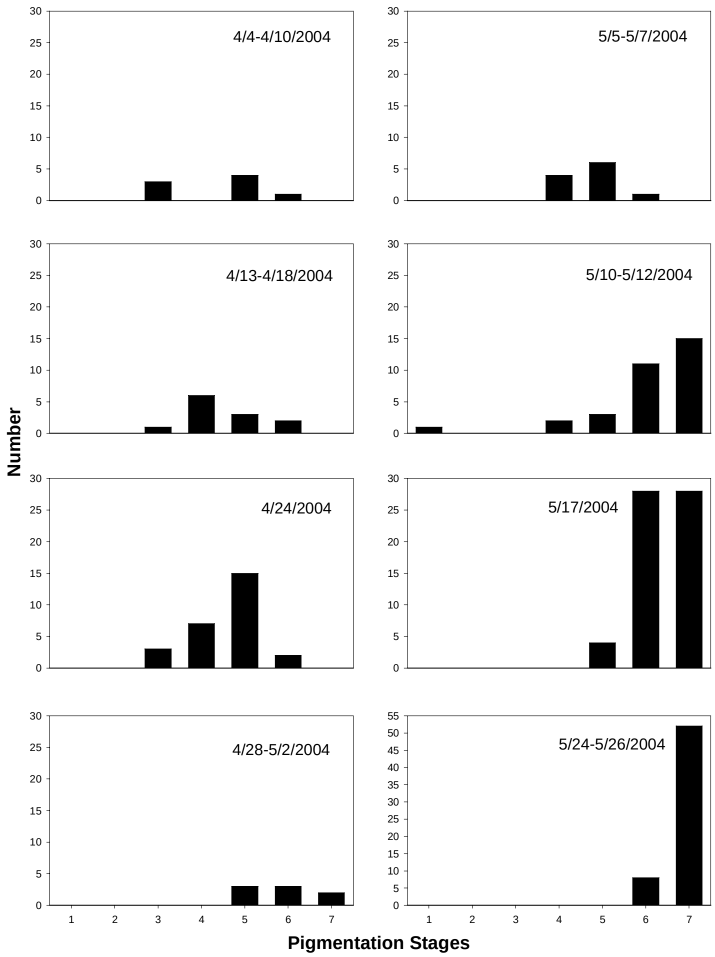


Figure 10. Frequency distribution of glass eel pigmentation stages

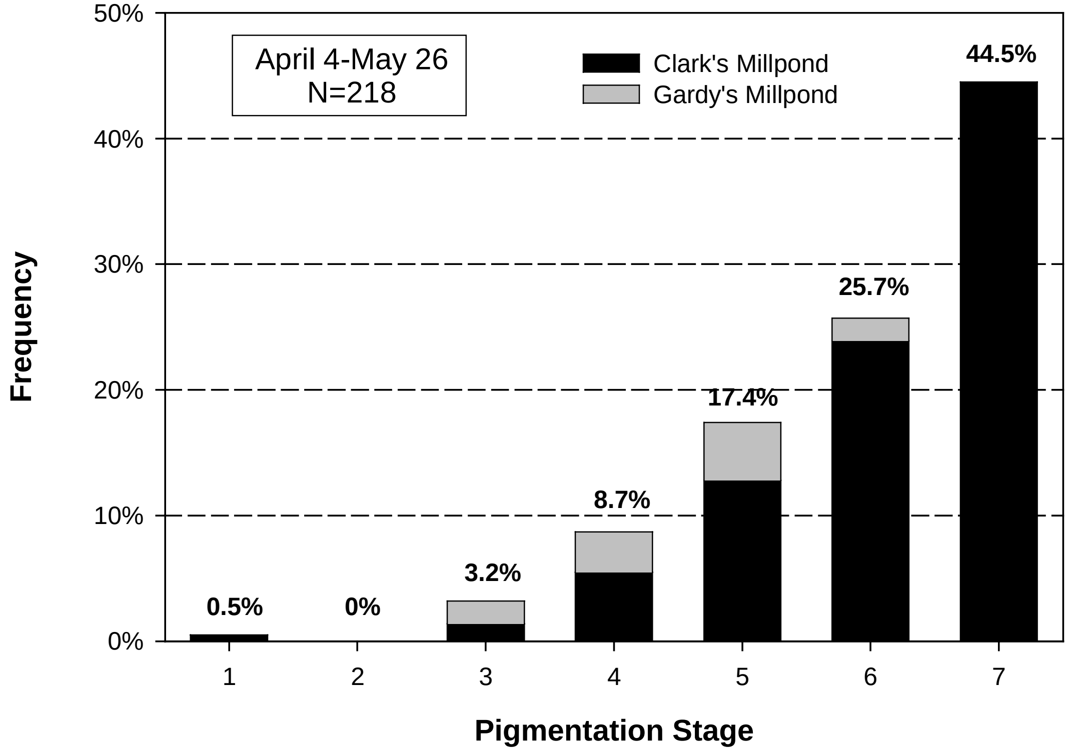


Figure 11. Glass eel length-weight regression

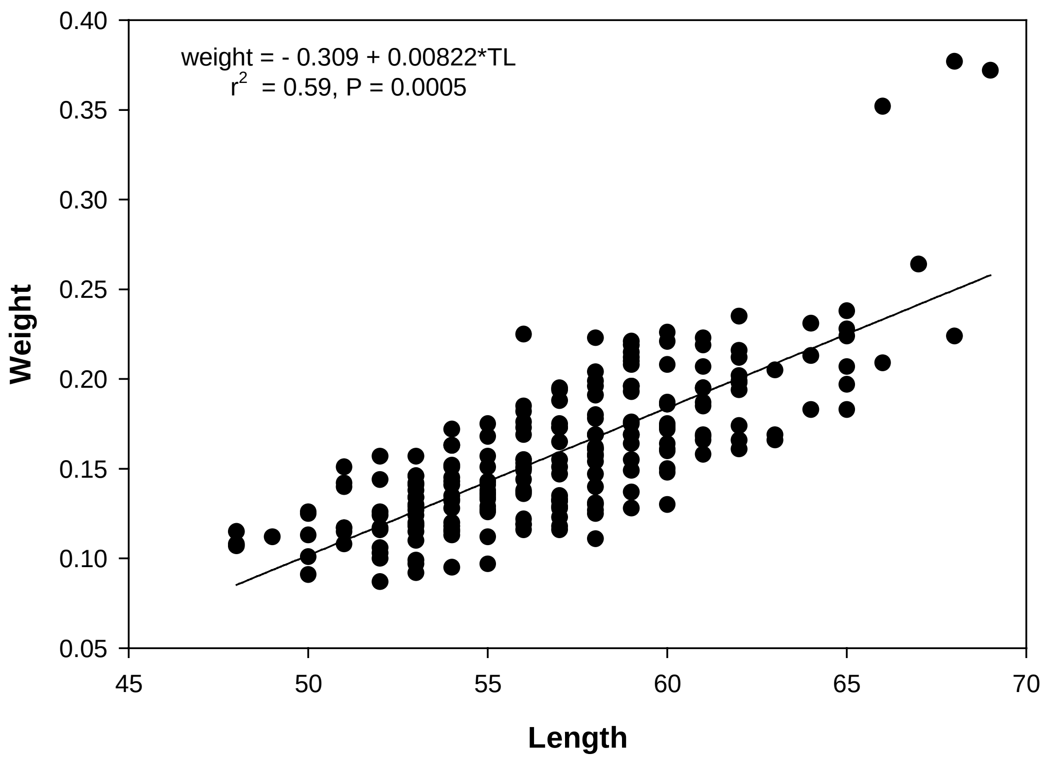
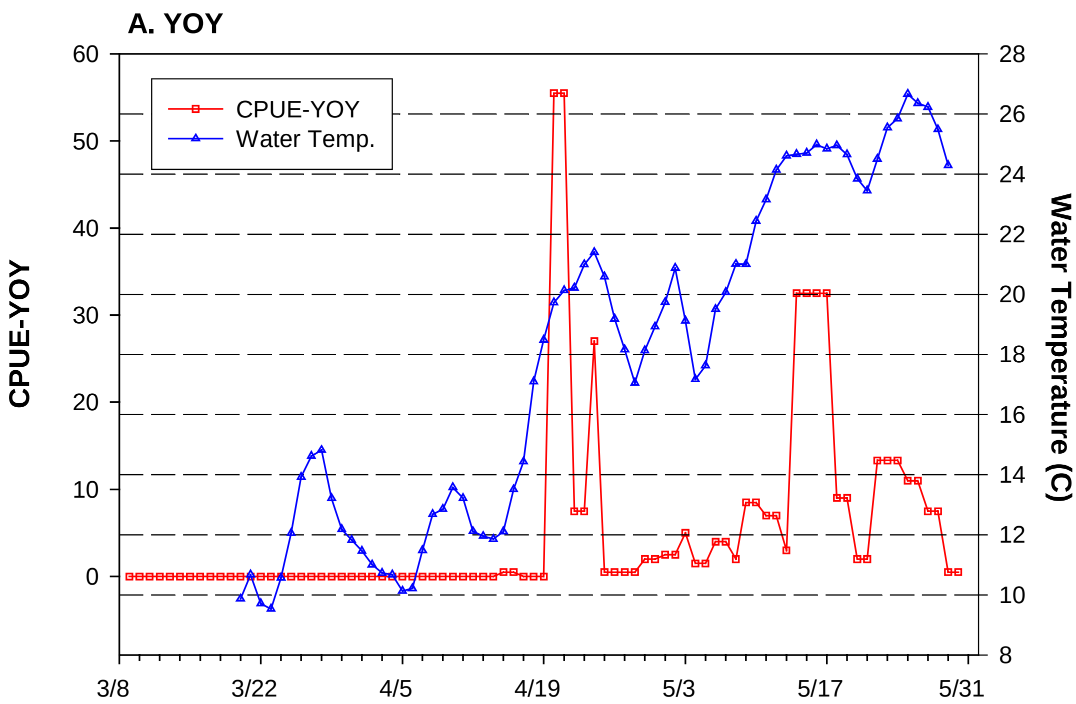


Figure 12. YOY and Elver CPUE vs. Water Temperature at Clark's Millpond



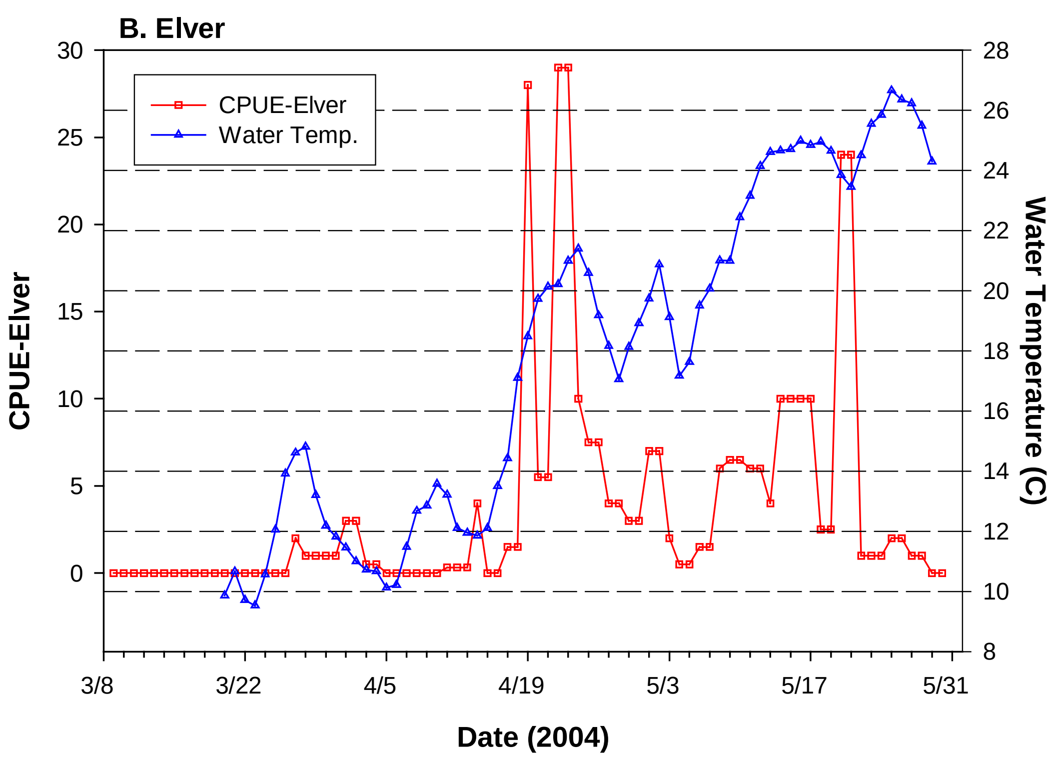


Figure 13. YOY and Elver CPUE vs. Water Temperature at Gardy's Millpond