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Final Report

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Introduction

The Virginia Institute of Marine Science's American Eel Monitoring Survey (VIMS AEMS) continued its spring sampling to estimate relative abundance of young of year (YOY) American eels (*Anguilla rostrata*) in Virginia tributaries of Chesapeake Bay. Funding was provided by the Marine Recreational Fishing Advisory and Commercial Fishing Advisory Boards, which ensured compliance with the 1999 Atlantic States Marine Fisheries Commission (ASMFC) Interstate Fishery Management Plan for American Eels (FMP).

Fishery-independent studies of juvenile recruitment are a valuable fisheries management tool. In Chesapeake Bay, recruitment studies may provide reliable indicators of future year class strength for species such as blue crabs (Lipcius and Van Engel, 1990), striped bass (Goodyear, 1985), and other recreationally and commercially important species (Montane and Lowery, 2005).

The American eel, *A. rostrata,* is a valuable commercial species along the entire Atlantic coast from New Brunswick to Florida. In recent years, harvests along the U.S. Atlantic Coast have declined, with similar patterns occurring in the Canadian Maritime Provinces (Meister and Flagg, 1997). Since 1964, Chesapeake Bay commercial landings have significantly decreased. The Chesapeake Bay jurisdictions of Virginia, Maryland, and Potomac River typically represent 63% of the annual United States commercial harvest (ASMFC, 2000). Virginia commercial landings decreased from 140,878 lbs. in 2004 to 71,604 lbs. in 2005. The 2005 Virginia commercial landings are one-third of the average annual landings since mandatory reporting began in 1993 (VMRC, 2006).

Some fishery independent indices have shown a decline in American eel abundance in recent years (Richkus and Whalen, 1999), particularly in Virginia (Geer, 2003; Montane and Lowery, 2005). 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). Additionally, local factors such as unfavorable wind-driven currents may affect glass eel recruitment on continental shelves and may have a greater impact than fishing mortality or continental climate change (Knights, 2003).

Fisheries management techniques aren't 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 methods and management efforts. American eel are not usually considered a sport fish, though they may be caught by recreational fishermen (Collette and Klein-MacPhee, 2002). Young American eel are also used as baitfish in coastal areas (Jenkins and Burkhead, 1993). Absence of basic population dynamics data has hampered attempts at evaluation of regional exploitation rates (Social Research for Sustainable Fisheries, 2002). Additionally, relatively few published studies have addressed the recruitment of glass eels to Western North Atlantic estuaries from the Sargasso Sea spawning grounds.

The Atlantic States Marine Fisheries Commission (ASMFC) adopted the Interstate Fishery Management Plan (hereafter referred to as 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 (including Virginia) agreed to implement an annual survey for 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.

Life History

The American eel is a catadromous species which 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. The 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 rivers and estuaries from February to June (Able and Fahay, 1998). As growth continues, the glass eel becomes pigmented (elver stage) and within 12 –14 months acquires 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. 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 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 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). Eel YOY may use freshwater "signals" to enhance recruitment to local estuaries, thereby influencing year-class strength (Sullivan et al., *in review*).

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 parameters which may influence young of year eel recruitment.

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

Methods

Minimum criteria for YOY American eel sampling has been established in the ASMFC American Eel FMP, with the Technical Committee approving sampling gear. The timing and placement of gear must coincide with those periods of peak YOY onshore 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. A minimum of 60 glass eels (if present per system) must be examined for length, weight, and pigmentation stage weekly.

Numerous study sites in Virginia were evaluated in 2000 (Geer, 2001). Final site selection was based on known areas of glass eel recruitment, accessibility, and specific physical criteria (e.g. proper habitat), suitable for glass eel recruitment.

The two York River sites on the York River are Brackens Pond and Wormley Pond (Figures 1-3). Brackens Pond is located along the Colonial Parkway at the base of the Yorktown Naval Weapon Station Pier. Its proximity to the York River is less than 100 m with the tide often reaching 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 theYorktown 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 is located upstream of Route 790, just north of Kilmarnock, in Lancaster County. The reservoir is approximately 80 acres and drains into the Eastern Branch of the Corrotoman River, tributary to the Rappahannock River (Figures 1 and 4). Wareham's Pond is located adjacent to Kingsmill in James City County and drains directly into the James River which is only about 100 m away, though a high tide may reach the end of the spillway (Figures 1 and 5).

Irish eel ramps were used to collect eels at all sites (Figure 6). The ramp configuration successfully attracts and captures small eels in tidal waters of Chesapeake Bay. Ramp operation required the continuous flow of water over the climbing substrate and through the collection device. A passive supply of water to the trap is accomplished through gravity feed (Figure 6). 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. Submersion of the ramp entrance was undesirable, and as such was placed in shallow water (< 25 cm). These inclines, in combination with the 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.

Once eel recruitment had begun, traps were checked daily on the York River (Wormley and Brackens Ponds) and four days per week (Monday-Wednesday-Friday and alternating weekend days) on the Rappahannock River (Kamp's Millpond) and James River (Wareham's Pond). 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, pH, air temperature, wind direction and speed, 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 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). Lengths, weights, and pigmentation stages (see Haro and Krueger, 1988) were collected from 60 eels from each system weekly.

For analyses, a daily and annual catch per unit effort (CPUE) was established for each site. YOY and elver CPUE was also standardized per 24 hours of soak time and annual CPUE's were calculated as geometric means for data analyses. To examine whether a relationship existed between YOY or elver CPUE and lunar stage, we performed ANOVA with lunar stage as the factor and CPUE as the response. Lunar stage was divided into four quarters (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. Tukeys Pairwise comparisons (MINITAB, 1998) were run on the data, if appropriate. Relationships between YOY and elver CPUE were also investigated with respect to water temperature, barometric pressure (data from http://www.wunderground.com for Kamps Millpond was from Mosquito Point, White Stone, VA and Yorktown, VA for the other three sites) and lunar illumination fraction (data from http://imagiware.com/astro/moon.cgi) via multiple regression. CPUE was also examined as log-transformed (log x + 1) CPUE, but was only reported if a significant or nearly significant relationship existed. Similarly, in some cases, graphs of a particular environmental parameter were omitted, if a significant relationship did not exist with eel CPUE.

Sampling at the York River sites (Brackens and Wormley Ponds) was conducted from 21 February to 24 May 2005 (traps set on 18 February). Sampling at Wareham's Pond (James River) was conducted from 23 February to 20 May 2005 (trap set on 22 February) and sampling at Kamp's Millpond (Rappahannock River) from 16 March through 27 May 2005 (trap set on 10 March).

Results

In the York River (Brackens and Wormley Ponds combined) CPUE for both YOY and elvers were variable over the six years sampled, though YOY CPUE exhibited an increasing trend and elver CPUE a decreasing trend (Figure 7, top and bottom). Separately by site, YOY CPUE for Brackens Pond increased from 2004, but exhibited a decreasing trend (Figure 8, top). Wormley Pond YOY CPUE decreased from 2004 and showed a very slight increasing trend (Figure 8, top). Elver CPUE increased at Brackens Pond compared to 2004, but exhibited a decreasing trend (Figure 8, bottom). Elver CPUE decreased at Wormley Pond compared to 2004, and also showed a decreasing trend (Figure 8, bottom). Compared to 2004, YOY CPUE at Kamp's Millpond increased but YOY CPUE remained nearly the same at Wareham's Pond (Figure 9, top). Both sites showed decreasing trends in YOY CPUE (greater at Wareham's Pond; Figure 9, top). Both Kamp's Millpond and Wareham's Pond elver CPUE decreased compared to 2004, but both sites also exhibited increasing trends (Figure 9, bottom).

Daily YOY CPUE for Brackens Pond exhibited strong peaks from 20 March through 21 April 2005 (Figure 10, top). Daily YOY CPUE for Wormley Pond exhibited peaks from 7 March to 23 March 2005 and then again 19 April 2005 (Figure 11, top). Daily elver CPUE for the York River was highly variable at both sites (Figures 10 and 11, bottom). At Wormley Pond, significantly more ($P = 0.039$) glass eels were collected during the waxing moon compared to the full moon. Similarly, at Brackens Pond, when the data were log transformed, significantly more glass eels (P = 0.011) were collected during the waxing compared to the full moon.

Highest YOY CPUE at Kamp's Millpond occurred from 30 March to 3 April 2005 (Figure 12, top) and highest elver CPUE occurred from 23 March to 8 April 2005 (Figure 12, bottom). At Kamp's Millpond, significantly more glass eels (log-transformed) were collected during the waning moon compared to the waxing moon. Highest YOY CPUE at Wareham's Pond occurred from 21 March to 30 March 2005, while highest elver catch occurred from 30 March to 11 April 2005, and then again 11 May 2005 (Figure 13, top and bottom).

There was no relationship between CPUE and barometric pressure at any of the sites (see Figures 14-17). As water temperatures increased, catches of both YOY and elvers increased, early in the season and then tapered off later on in the study (Figures 18-21).

Results of the multiple regression examining water temperature, barometric pressure and lunar illumination fraction were variable. When all sites were combined, glass eel log-transformed CPUE decreased significantly with increasing water temperature ($P < 0.0005$, overall $P = 0.001$; $r^2 = 0.06$). At Wormley Pond, both glass eel and log-transformed glass eel CPUE were significantly inversely related to temperature ($P = 0.002$ and $P < 0.0005$, respectively; overall $P = 0.022$, $r^2 = 0.10$ and $P < 0.0005$, $r^2 = 0.46$). No significant relationships existed at Brackens Pond between CPUE and water temperature, barometric pressure or percent lunar illumination. Elver CPUE at Kamp's Millpond decreased significantly with increasing water temperature ($P = 0.007$; overall $P = 0.020$, $r^2 = 0.25$). Glass eel (log-transformed) CPUE also decreased significantly ($P = 0.033$; overall $P = 0.043$, $r^2 = 0.21$) with increasing percent lunar illumination. At Wareham's Pond, both elver and log-transformed elver catch significantly decreased with increasing percent lunar illumination ($P = 0.013$; overall $P = 0.034$, $r^2 = 0.18$ and $P = .044$; overall $P = 0.045$, $r^2 = 0.17$). Glass CPUE significantly increased with increasing percent lunar illumination ($P = 0.012$; overall $P = 0.042$, $r^2 = 0.17$).

Glass eels were also collected from each river with length, weight and pigment stage recorded. Glass eel length ranged from 48 to 72 mm total length (Figure 22). Glass eel weight significantly increased with increasing length ($r^2 = 0.59$, $P = < 0.0005$; Figure 23).

Overall in 2005, the James River was dominated by pigment stage 1 through 4, York River by stages 1 through 5 and Rappahannock River by stages 2 through 7 (Figure 24). Similar trends were apparent in 2004 (Figure 24). The further north the station was located, the later stage eels that were present. Eels that were staged in the Potomac River during 2005 (for the Potomac River Fisheries Commission Eel Study) exhibit a higher percentage of later stage eels (83% were stage 5 and later; see Montane et al., 2005). Glass eels from the York River (Wormley Pond) were stages 1 through 4 from 22 February to 21 March 2005, stages 1 through 6 from 28 March to 18 April 2005 and mostly stages 2 through 7 from 26 April to 2 May 2005 (Figure 25). Glass eels from the Rappahannock River (Kamp's Millpond) were mainly stages 2 through 6 from 30 March to 22 April 2005 and mainly stages 3 through 7 from 25 April to 15 May 2005 (Figure 26). Glass eels collected from the James River (Wareham's Pond) were stages 1 through 4 from 23 March to 4 April 2005 (Figure 27). Few glass eels were collected from the James River in 2005.

Glass eel length, weight and condition index (Fulton Condition Factor or K, see Anderson and Neumann, 1996) were analyzed for each tributary by year. Spring 2005 glass eel mean length and mean weight in the York River was higher than in 2004 (Figure 28), though values of K from 2003 to 2005 were similar and greater than 2002. Mean length and weight also increased in the Rappahannock River in 2005 compared to 2004, though K decreased in 2005 compared to 2004 (Figure 29). Glass eel mean length in the James River for 2005 was similar to 2004 and mean weight and K values for the James River were lowest during 2005, compared to 2003 and 2004 (Figure 30).

Discussion

Overall YOY and elver CPUE at the various sites was variable as in previous years (Montane et al., 2003, 2004). CPUE by lunar quarter was variable. In contrast, catch of yellow and silver eels in Canada was also lowest during the full moon (Cairns and Hooley, 2003). Effects of water temperature on CPUE were also highly variable, but usually an increase in water temperature early in the season coincided with an early eel (glass and elver) catch. Previous research has found that initial arrival of juvenile eels may be correlated to large increases in water temperature (Sorensen and Bianchini, 1986). Elvers may also delay upstream migration at freshwater interfaces until certain behavioral and physiological changes have occurred (Sorensen and Bianchini, 1986).

There did not appear to be any consistent relationship between CPUE and barometric pressure at any site. Variability in catches between sites may be due to the unique characteristics of each site. Distance of the sites to the larger adjacent river systems and distance upriver may play an important role in the variability of both YOY and elver catches.

Long term (20 + years) glass eel recruitment studies in both North Carolina and New Jersey have suggested glass eel lengths have been decreasing (Sullivan et al., *in review*). When examined over the four year period of length-weight data collected, decreasing trends in glass eel length were found as well. In general, glass eel size increases with increasing distance from the breeding grounds (Boetius, 1976). Mean lengths for the glass eels examined in this study was longest for those at the Rappahannock River (Kamp's Millpond), followed by York River (Wormley Pond) and then the James River (Wareham's Pond). Even within the Bay, sites further north exhibited longer glass eels. Along the North American Eastern Coast, glass eels from Nova Scotia were on average 6 mm longer than those from Florida (Vladykov, 1966 as reported by Boetius, 1976).

Conclusions and Recommendations

1. Irish eel ramps are an efficient passive gear for sampling YOY American eel in coastal Virginia.

2. Sampling should continue at the primary sites on the York, James and Rappahannock Rivers. Sampling should start at least as early as the previous year and continue later, if necessary. Given the great variability associated with spring temperatures in the Chesapeake Bay region, sampling must be over a wide water temperature range to ensure that sampling occurs at the start of the "run" of YOY eels.

3. The ultimate goal of this survey is to provide annual estimates of recruitment for YOY eels and elvers. Considering the unique nature of each site, and the performance variability of the sampling gear at these sites, it may be necessary to develop an "index" for each site. Parameters such as pond drainage area, distance from the ocean, discharge, and other physical parameters should continue to be evaluated in an attempt to provide a relative value for each site. This value may then be used to weigh the catch rates at each site to provide an overall estimate of juvenile eel recruitment.

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.

Further information on past VIMS American Eel Recruitment research can be found at http://www.vims.edu/fish/eels/eel_publications.html.

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Figure 1. 2005 American Eel Sampling Sites.

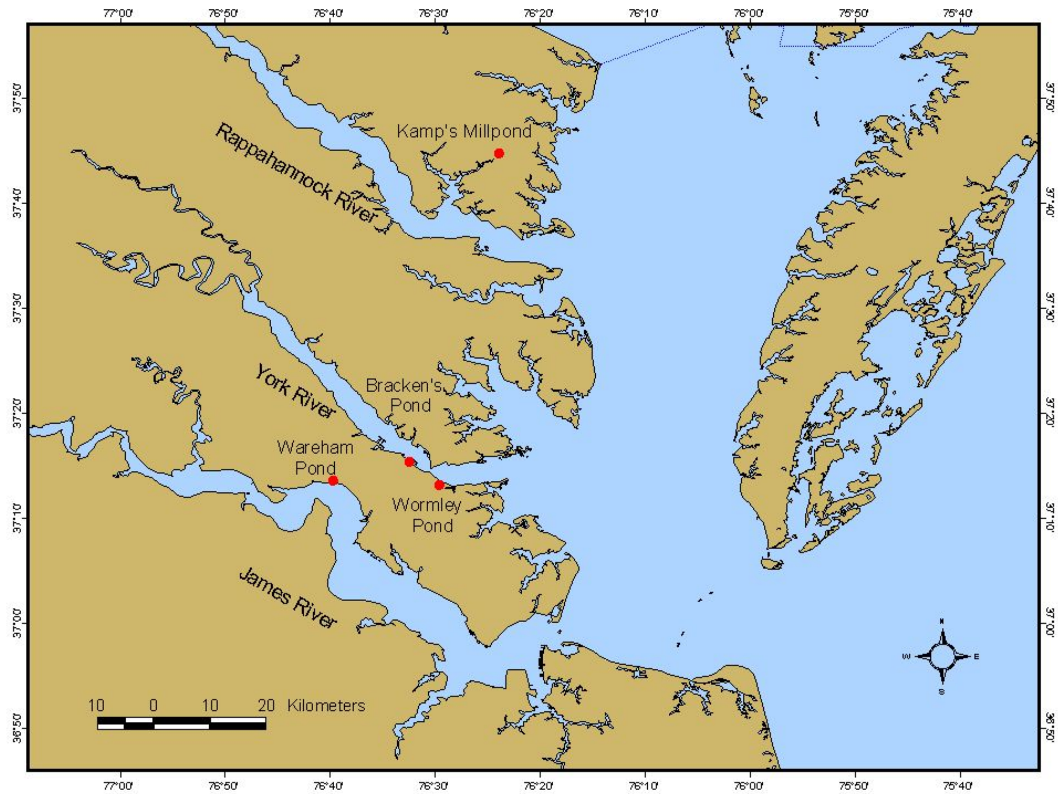


Figure 2. Brackens Pond spillway and tailrace. Irish ramp was set against the right wall on upstream end of culvert.

Figure 3. Bridge over Wormley Creek with Wormley Pond in background. Irish ramp was set under upstream edge of bridge at the base of the dam.

Figure 4. Kamp's Millpond spillway and tailrace. Irish ramp is on far side of creek.

Figure 5. Wareham's Pond spillway.
Irish ramp is in the foreground.

Figure 6. Example of an Irish eel ramp used in this study. The arrows indicate the flow of water as well as eel movement.

Figure 7. YOY (top) and Elver (bottom) CPUE (Geometric Means) for the York River (Brackens and Wormley Ponds combined, 2000-2005).

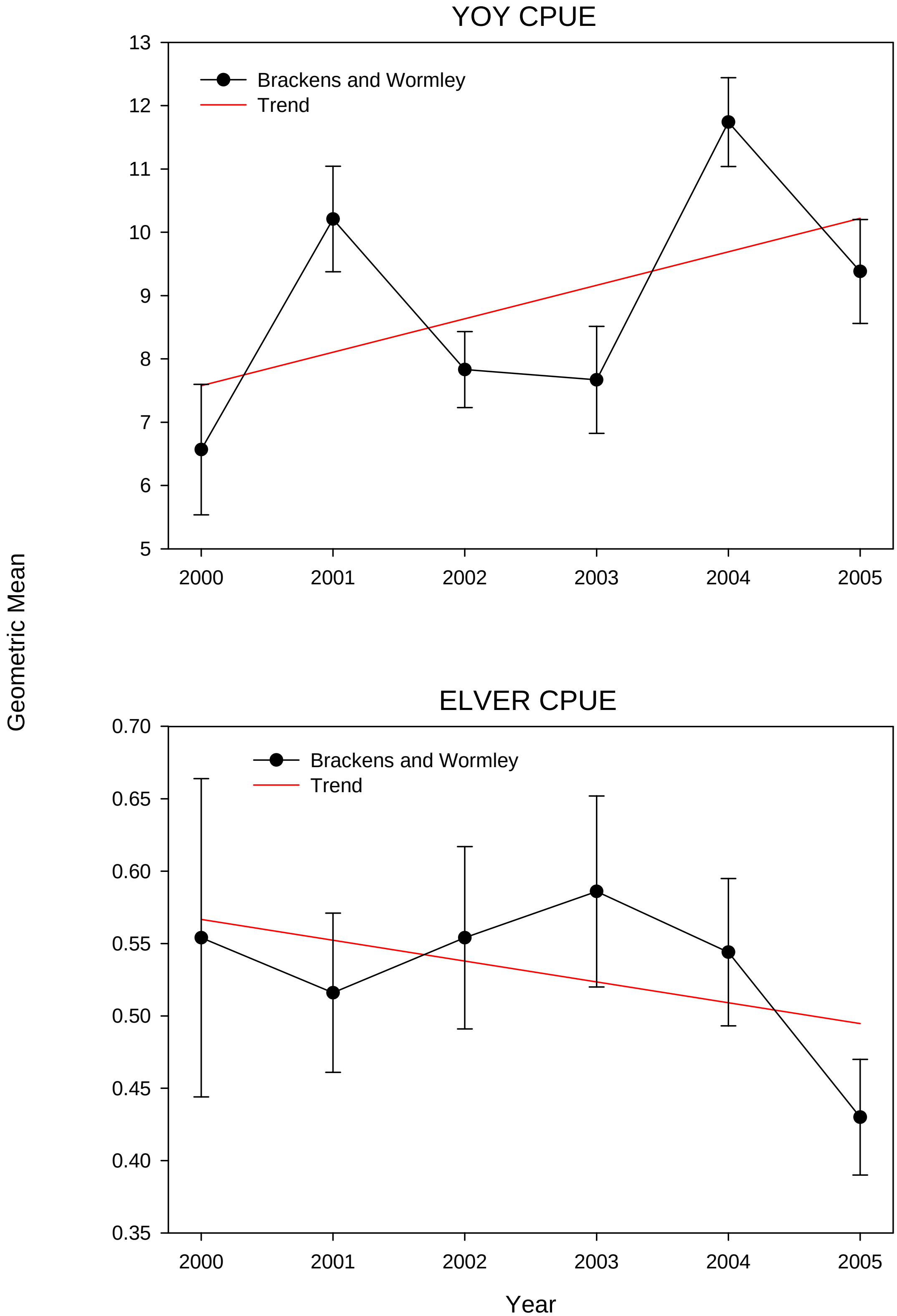


Figure 8. YOY (top) and Elver (bottom) CPUE (Geometric Means) for Brackens and Wormley Ponds (2000-2005).

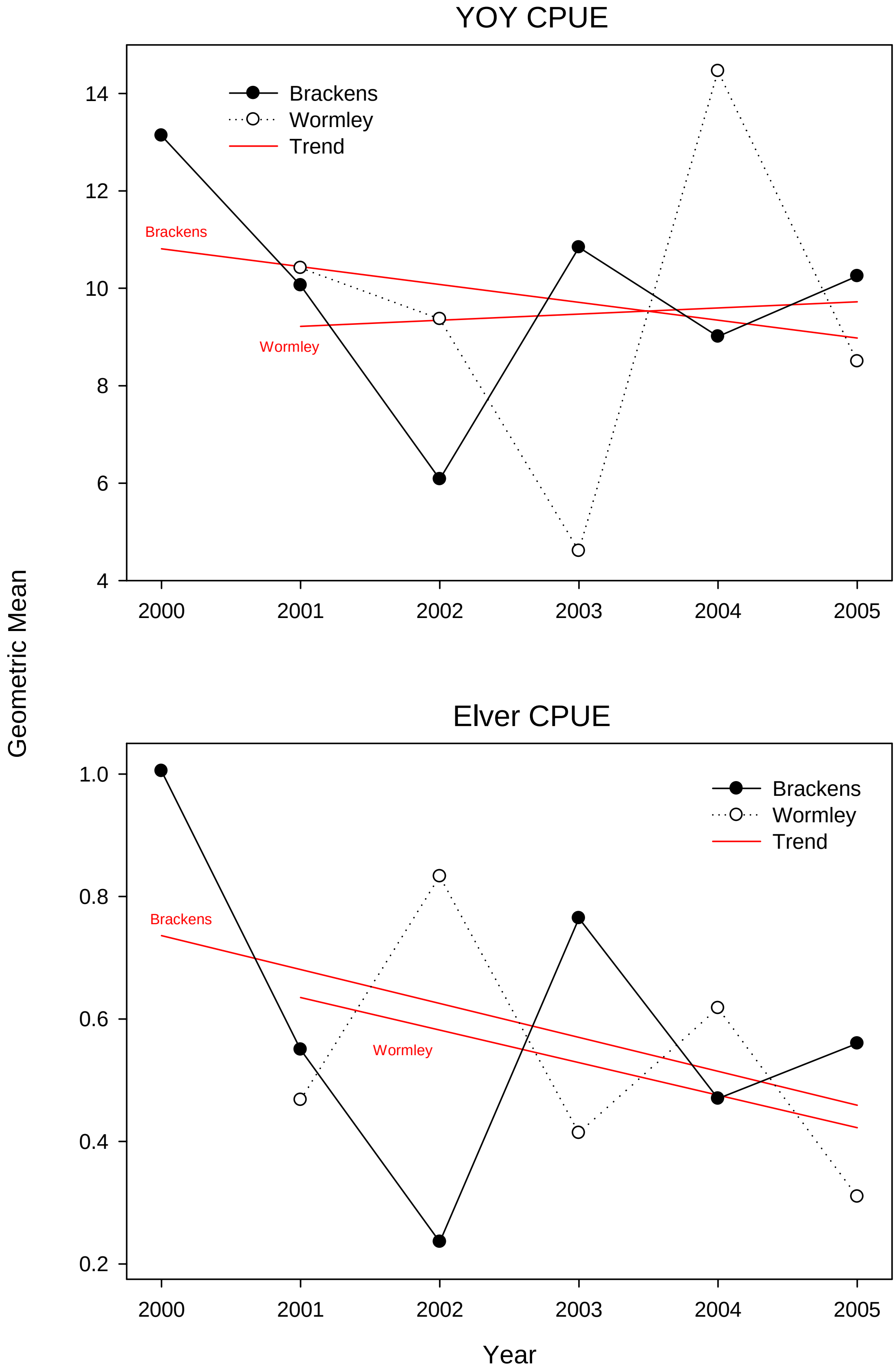


Figure 9. YOY (top) and Elver (bottom) CPUE (Geometric Means) for Kamp's (2000-2005) and Wareham's Ponds (2003-2005).

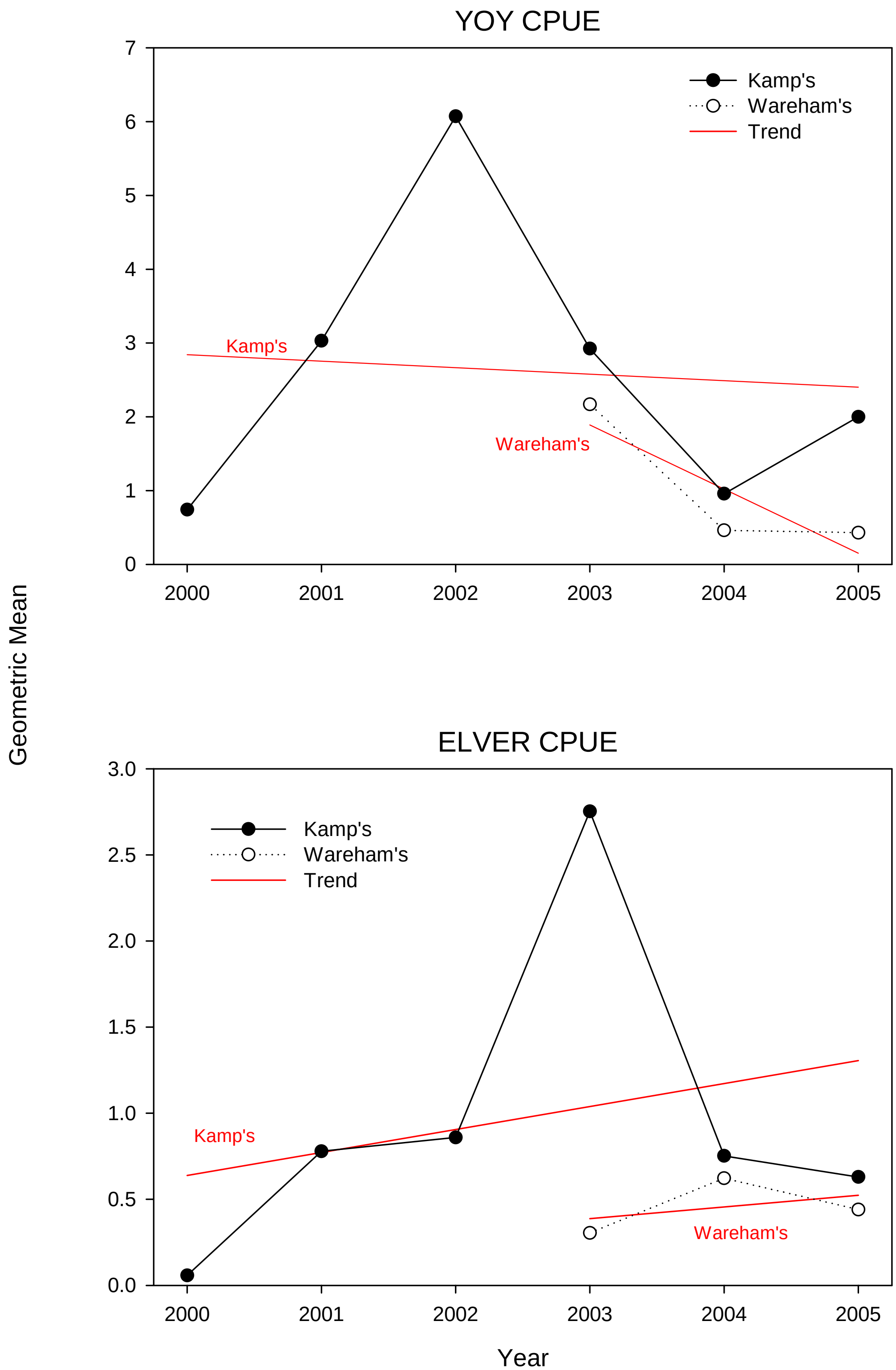


Figure 10. Daily YOY and Elver CPUE vs. lunar quarter for Brackens Pond (York River) for 2005 (daily catch, non-standardized).

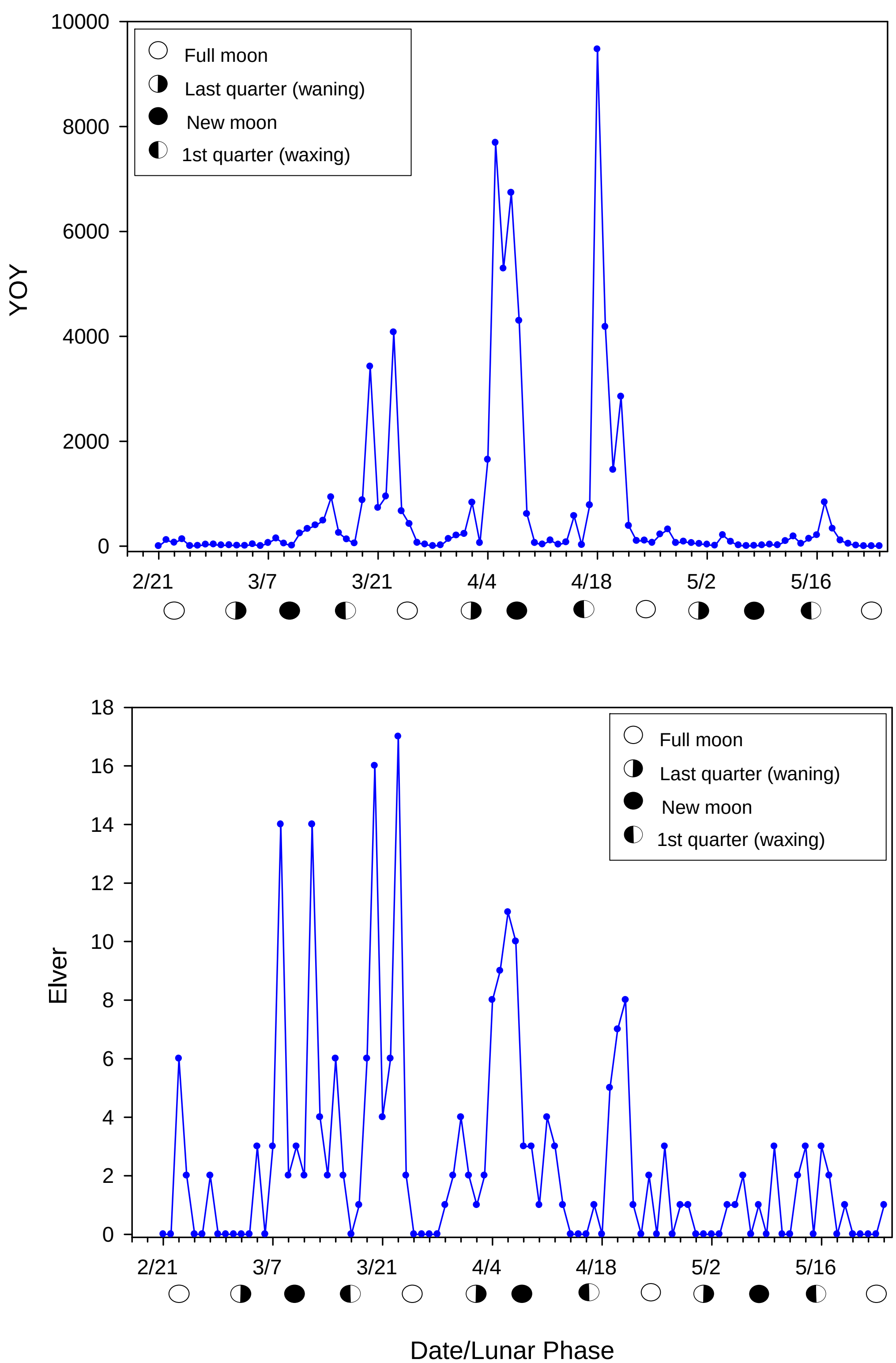
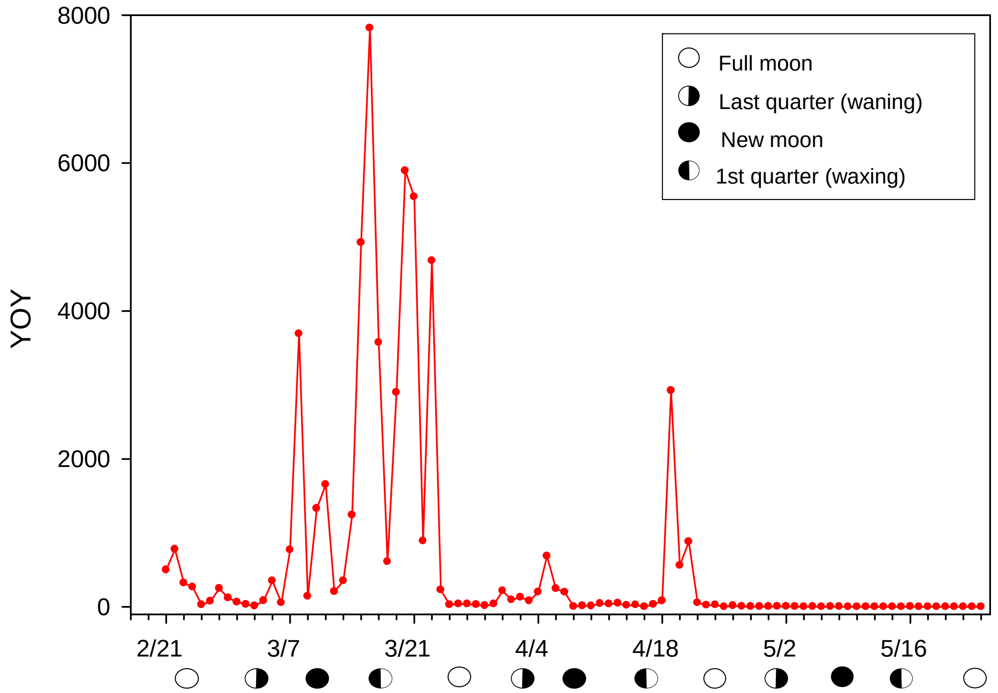


Figure 11. Daily YOY and elver CPUE vs. lunar quarter for Wormley Pond (York River) for 2005 (daily catch, non-standardized).



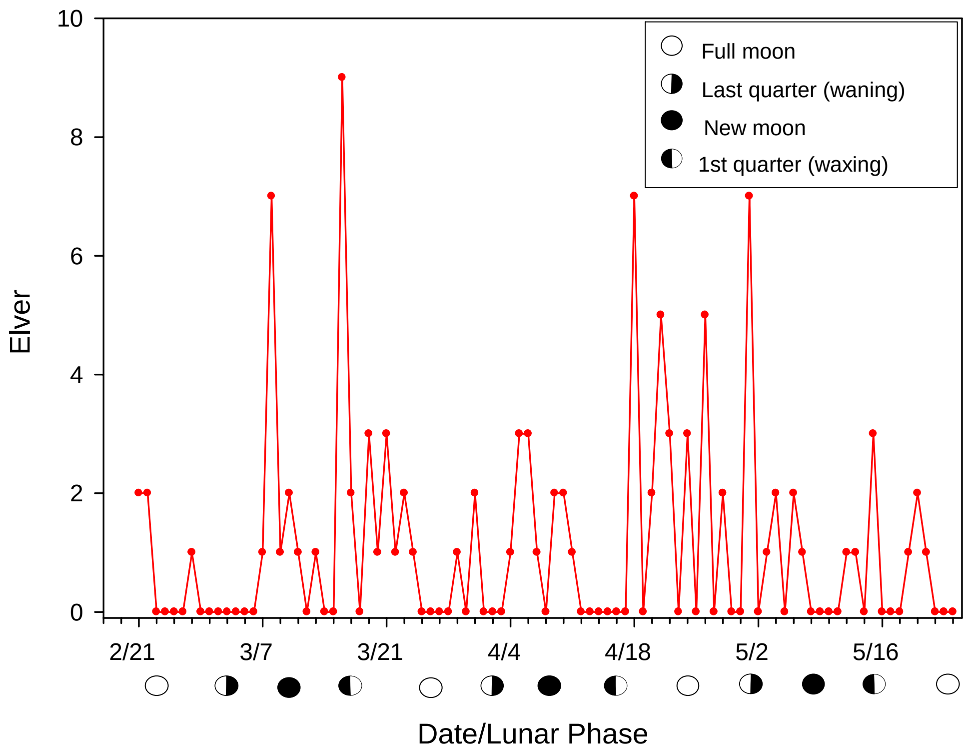
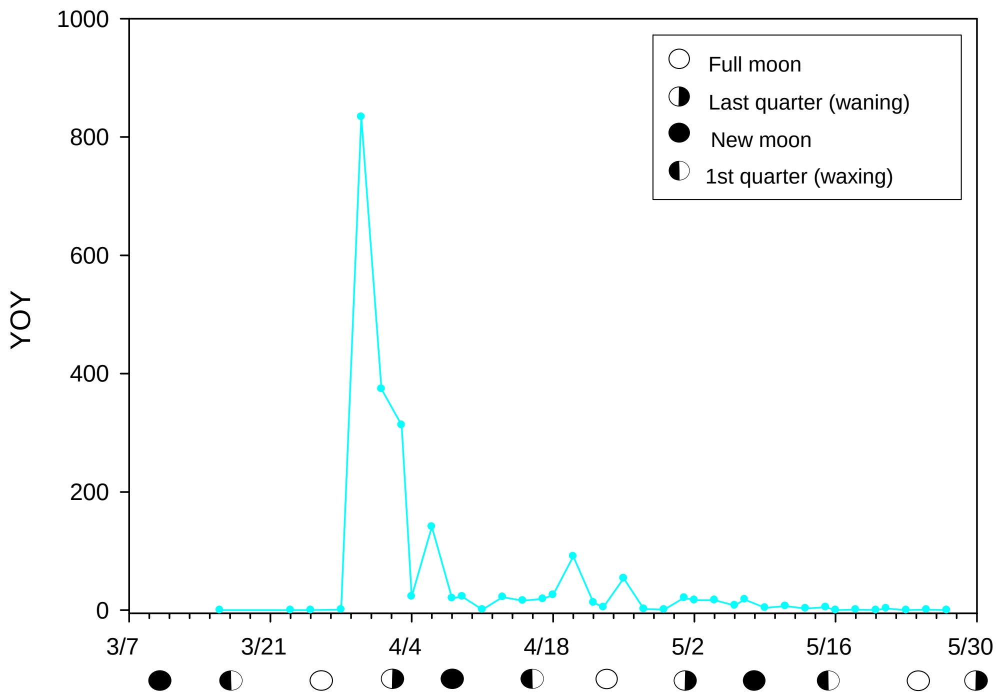


Figure 12. YOY and elver CPUE vs. lunar quarter for Kamp's Millpond (Rappahannock River) for 2005 (catch non-standardized).



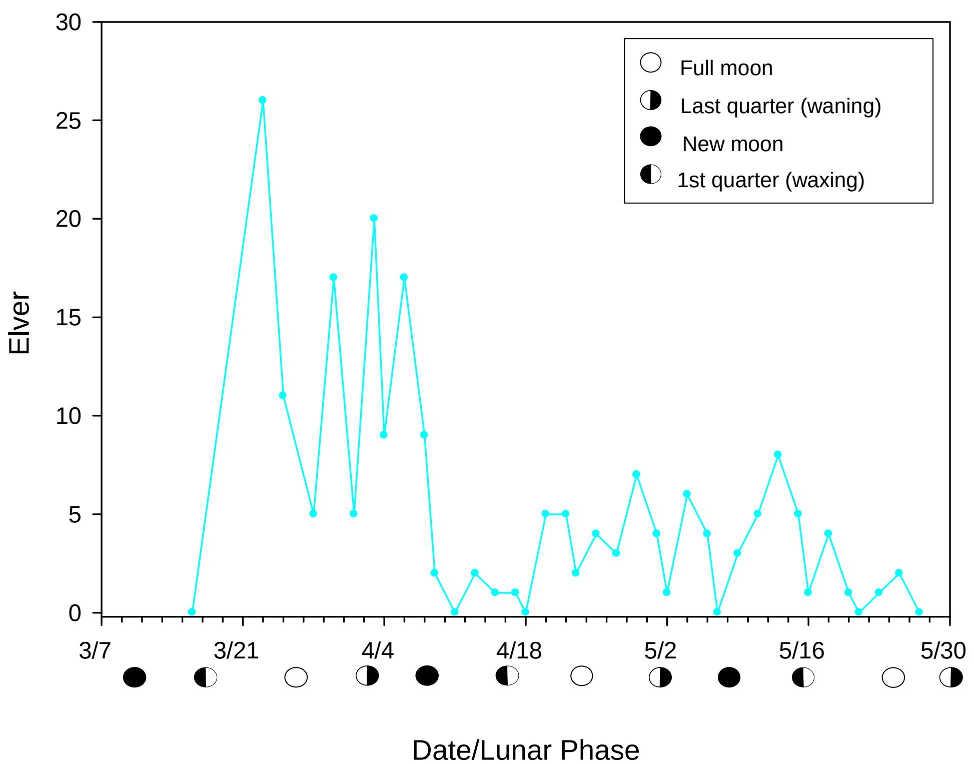


Figure 13. YOY and elver CPUE vs. lunar quarter for Wareham's Pond (James River) for 2005 (catch non-standardized).

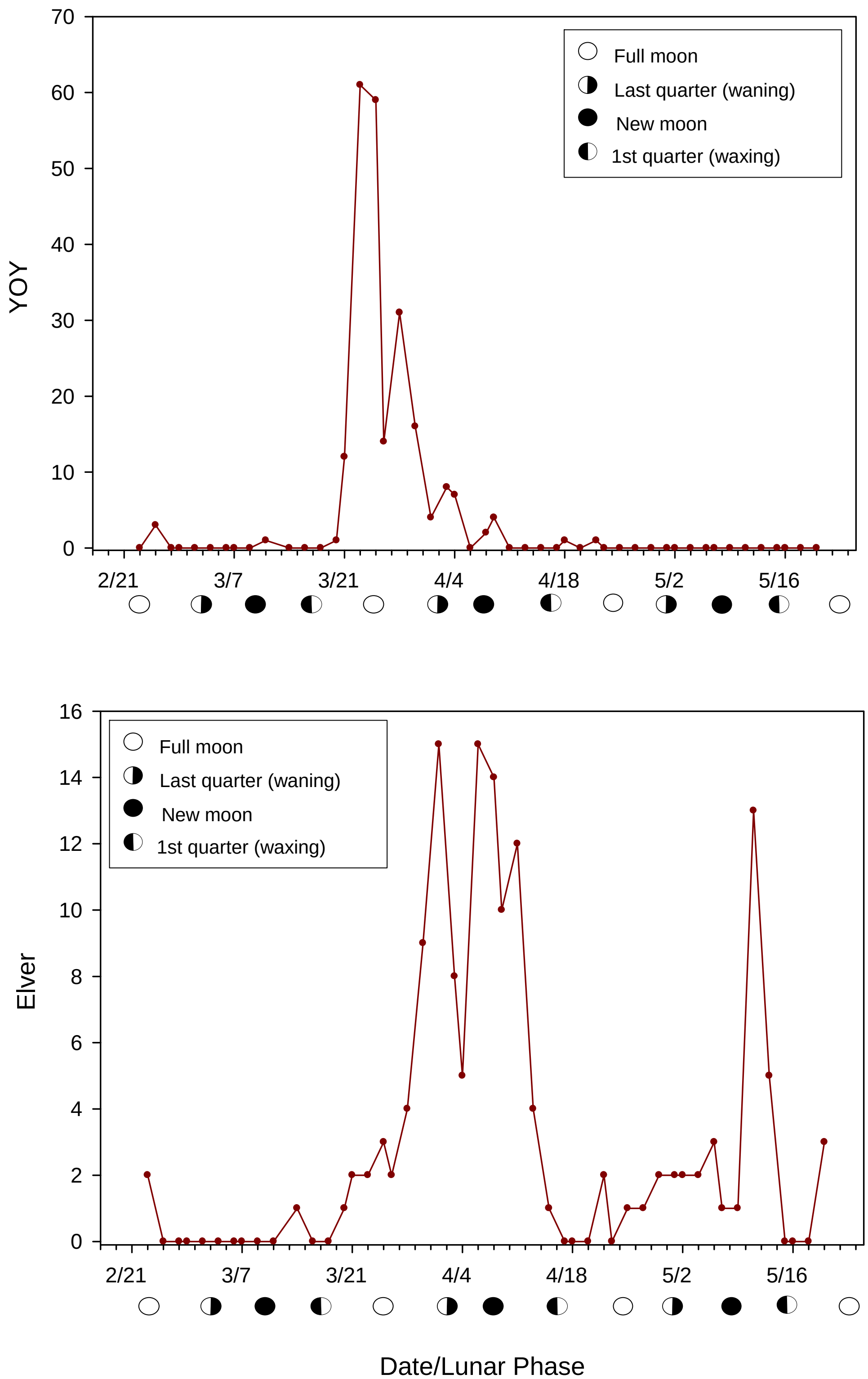
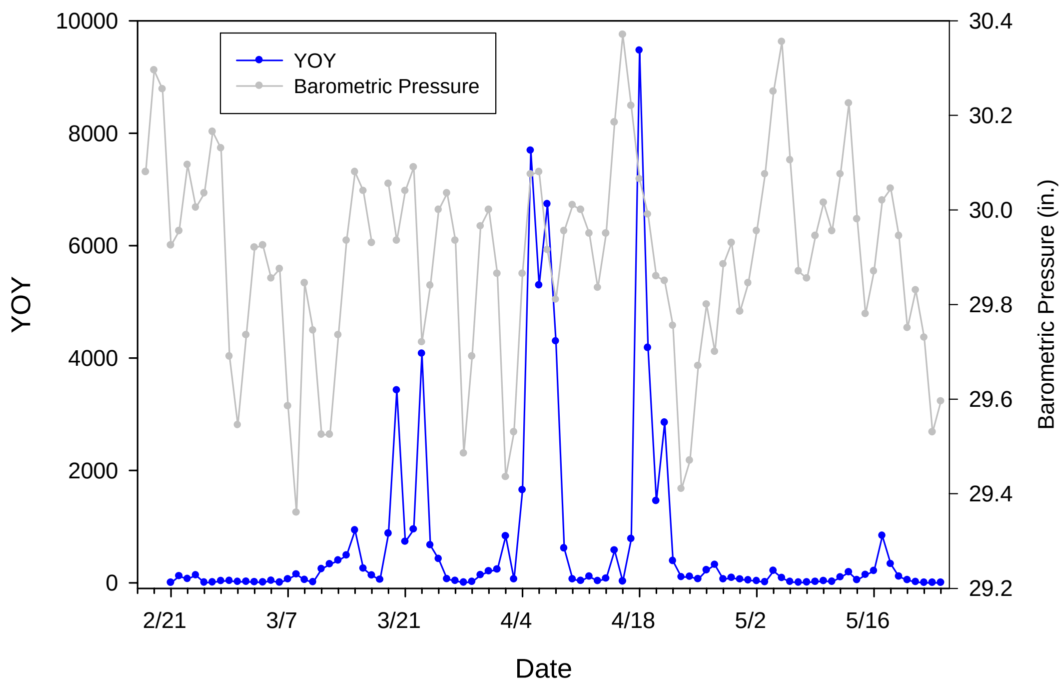


Figure 14. Daily YOY and Elver CPUE vs. barometric pressure for Brackens Pond (York River) for 2005 (daily catch, non-standardized).



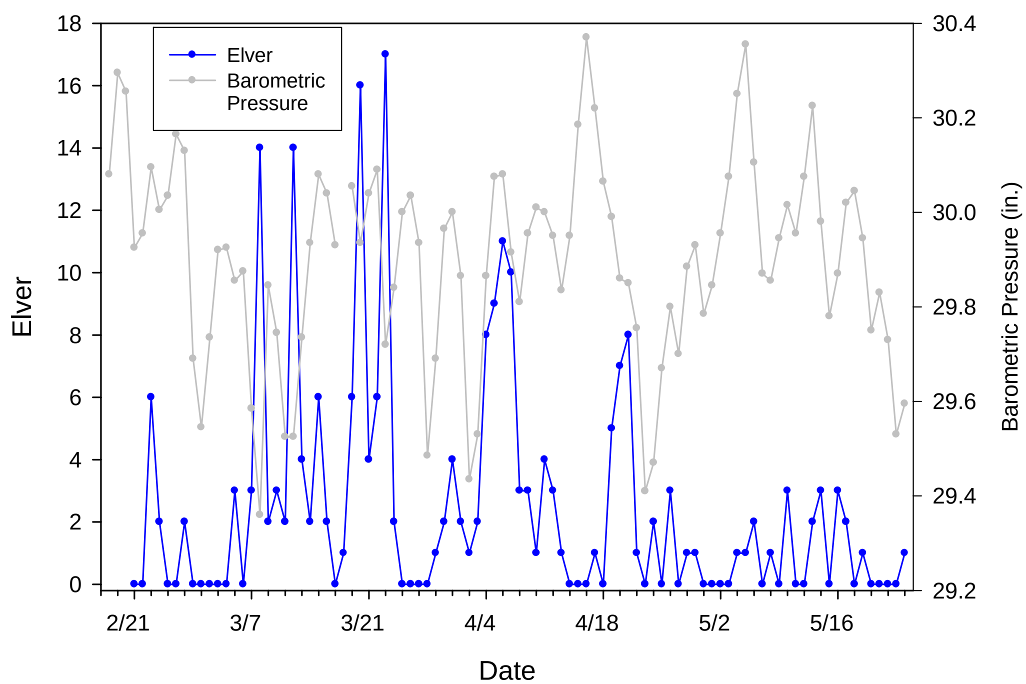
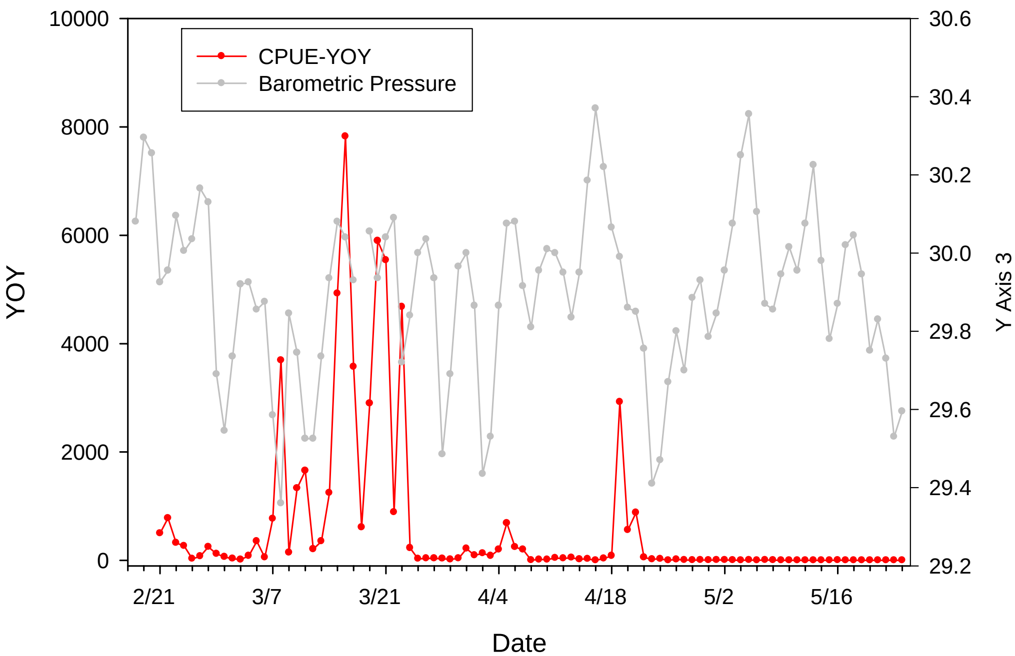


Figure 15. Daily YOY and elver CPUE vs. barometric pressure for Wormley Pond (York River) for 2005 (daily catch, non-standardized).



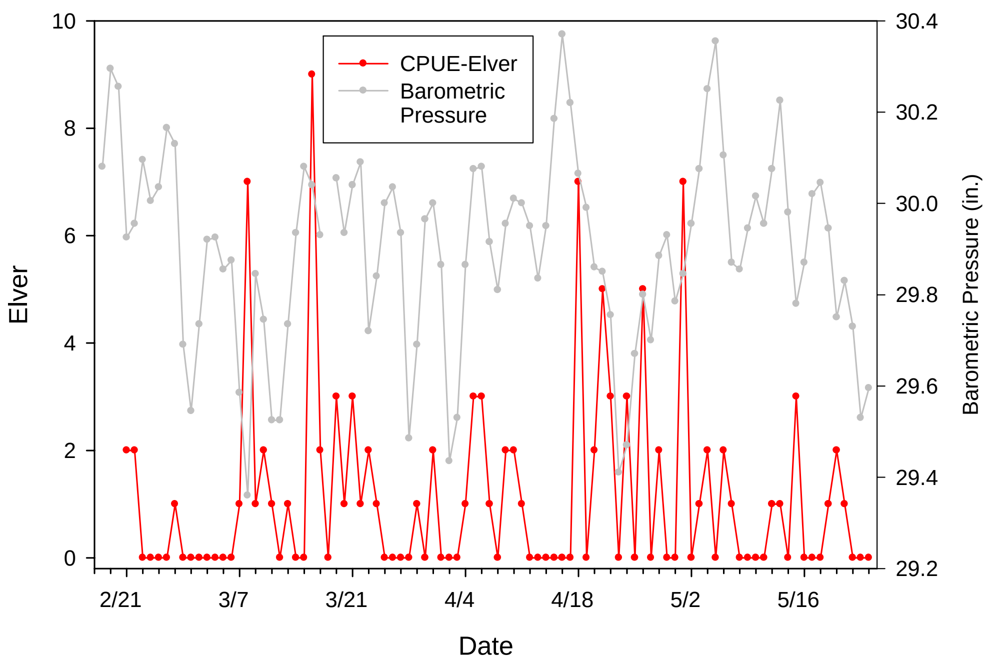
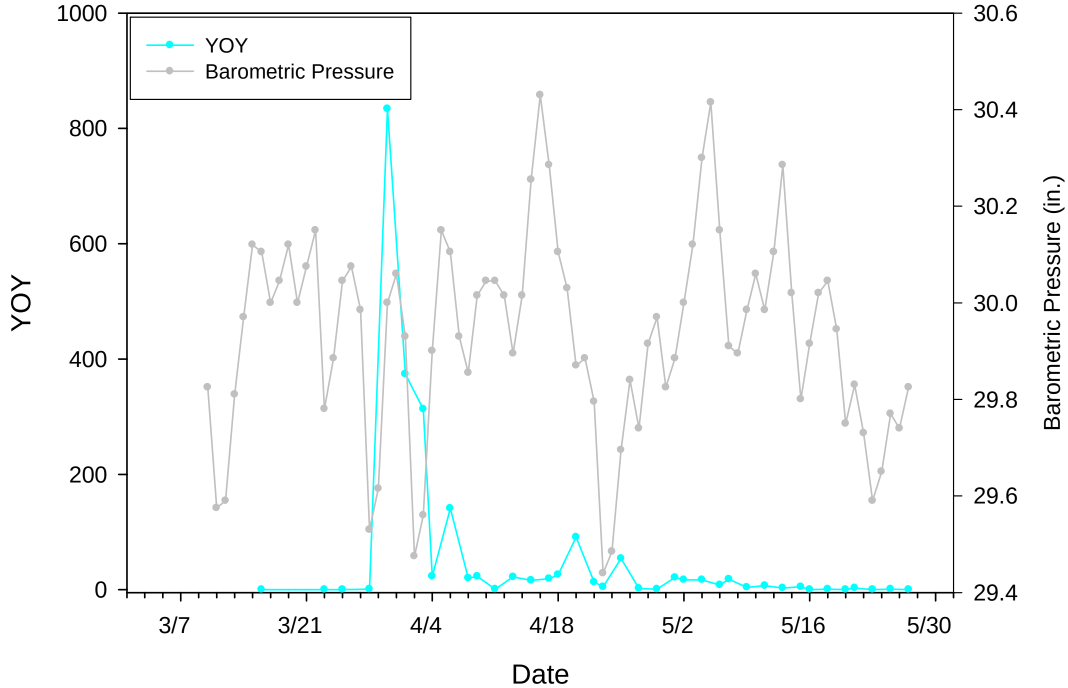


Figure 16. YOY and elver CPUE vs. barometric pressure for Kamp's Millpond (Rappahannock River) for 2005 (catch non-standardized).



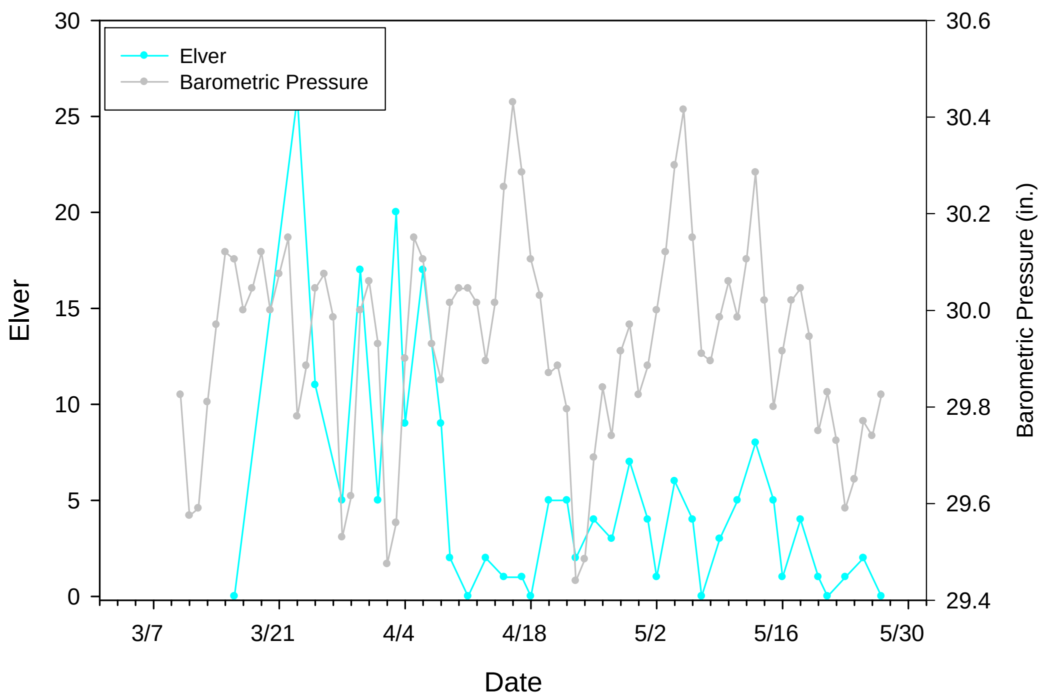
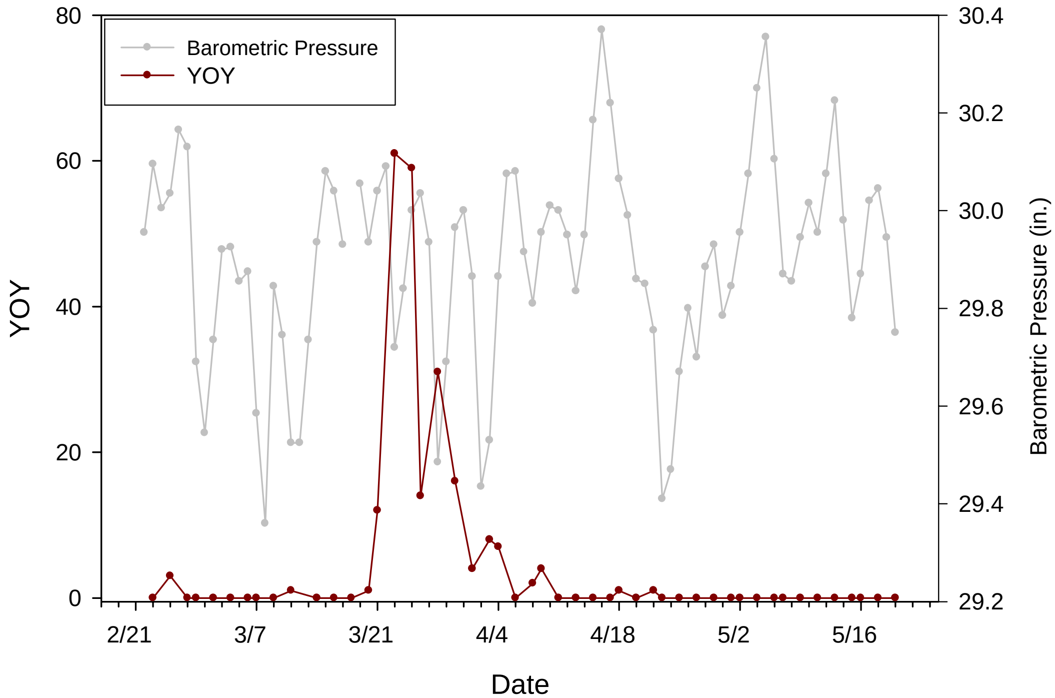


Figure 17. YOY and elver CPUE vs. barometric pressure for Wareham's Pond (James River) for 2005 (catch non-standardized).



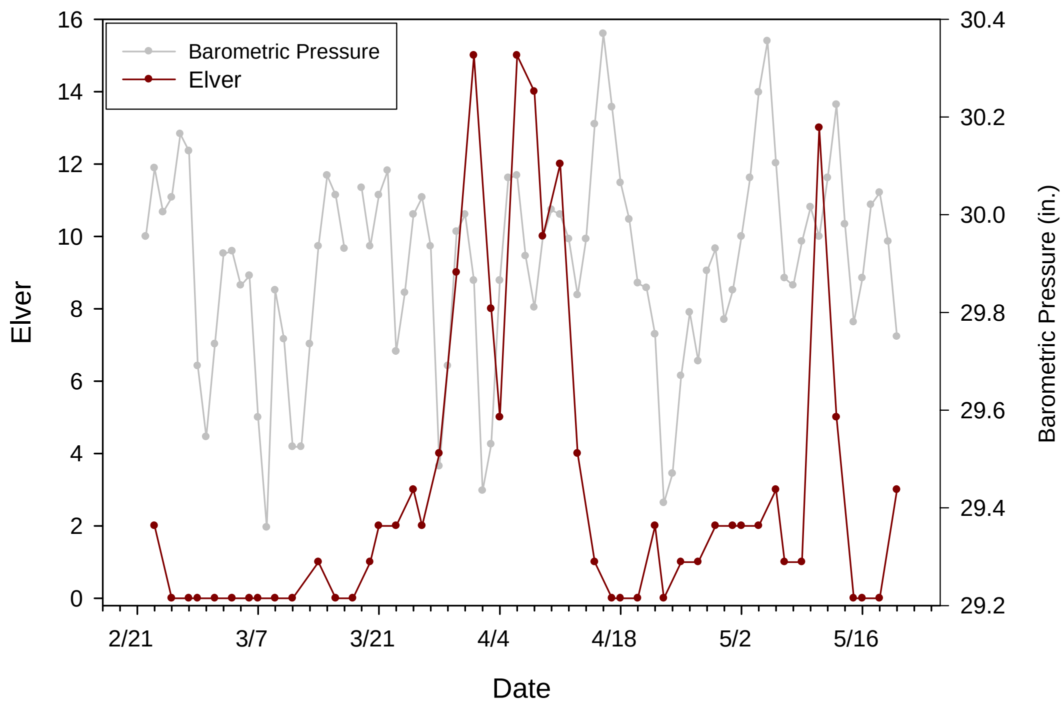
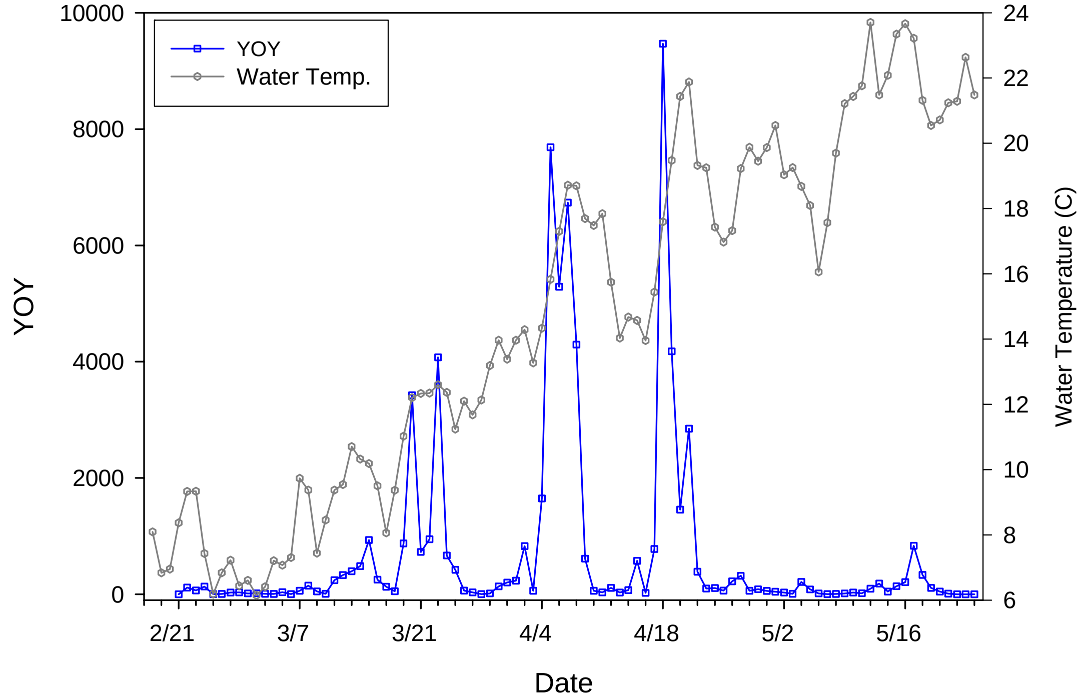


Figure 18. Daily YOY and Elver CPUE vs. water temperature for Brackens Pond (York River) for 2005 (daily catch, non-standardized).



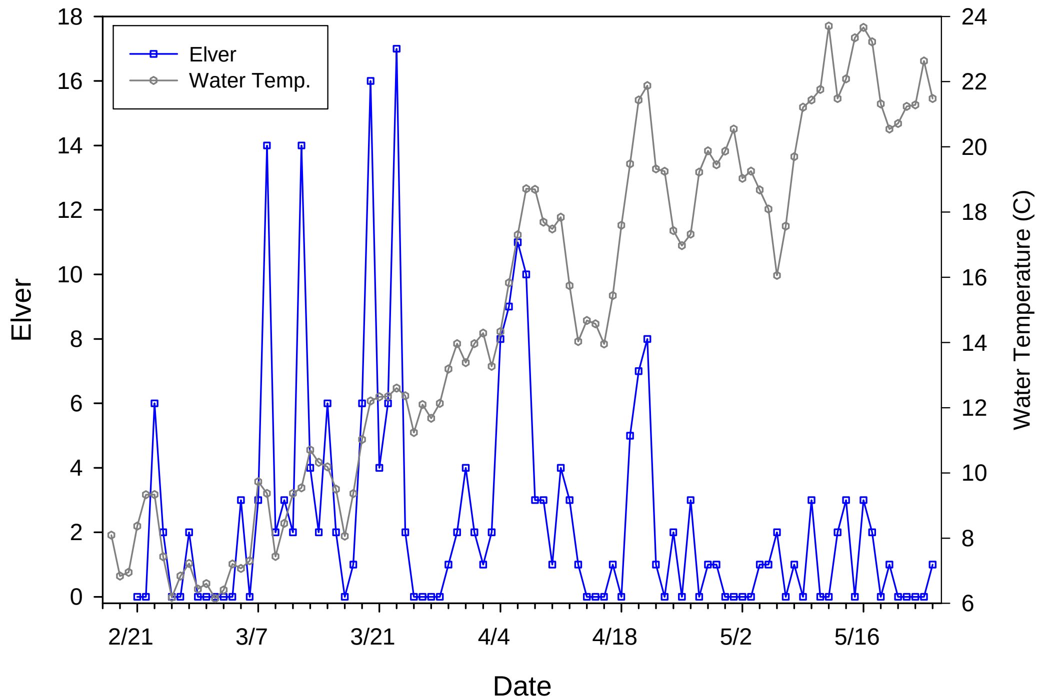
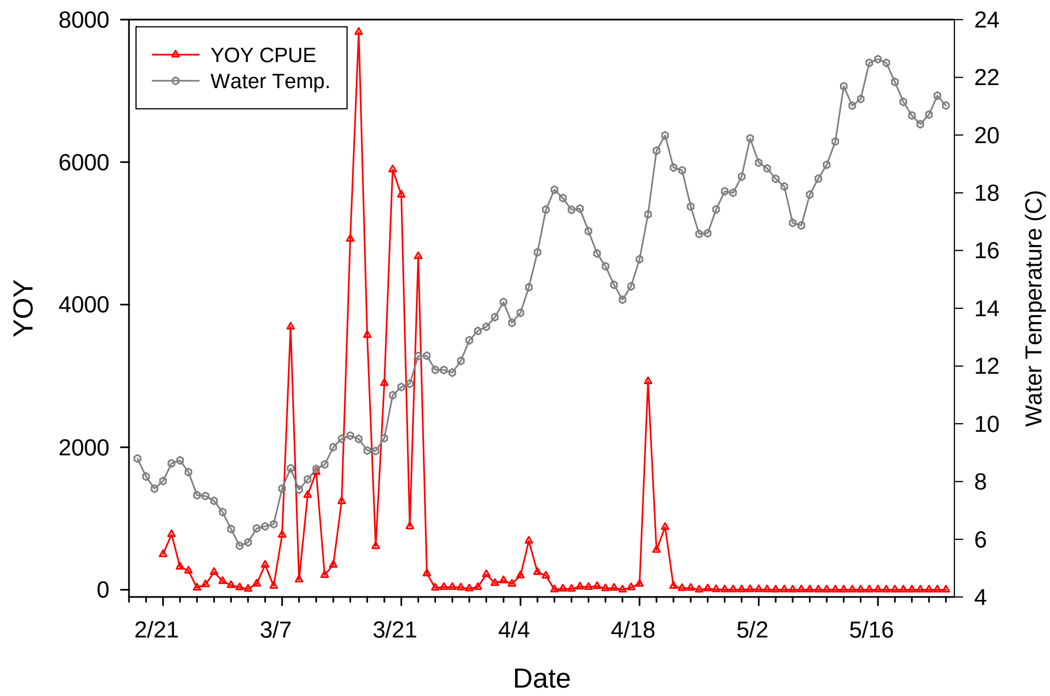


Figure 19. Daily YOY and elver CPUE vs. water temperature for Wormley Pond (York River) for 2005 (daily catch, non-standardized).



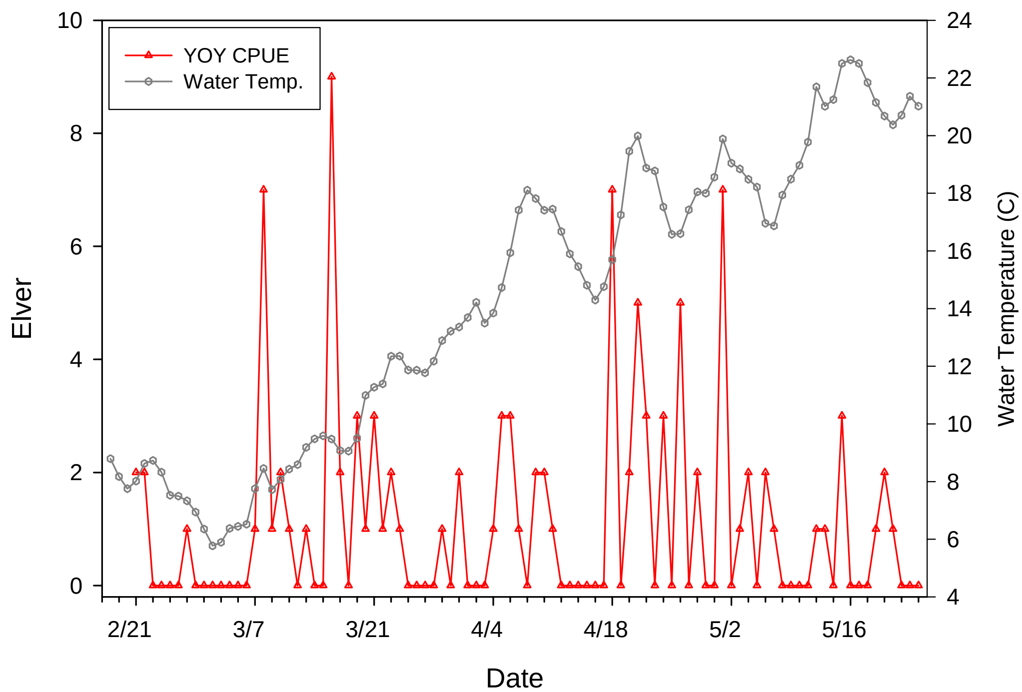
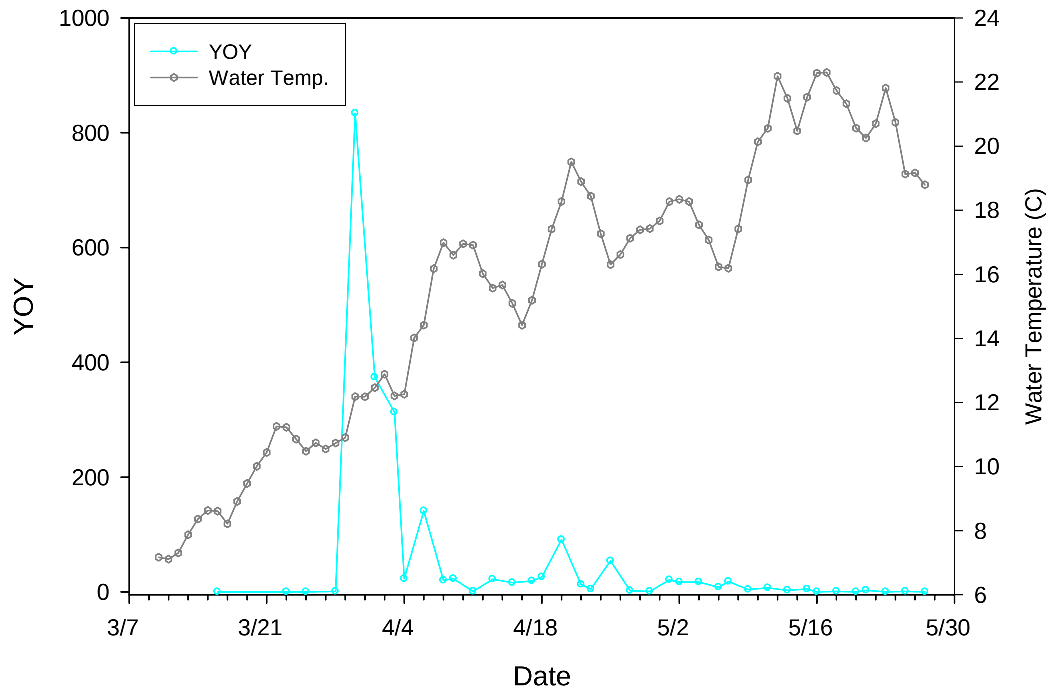


Figure 20. YOY and elver CPUE vs. water temperature for Kamp's Millpond (Rappahannock River) for 2005 (catch non-standardized).



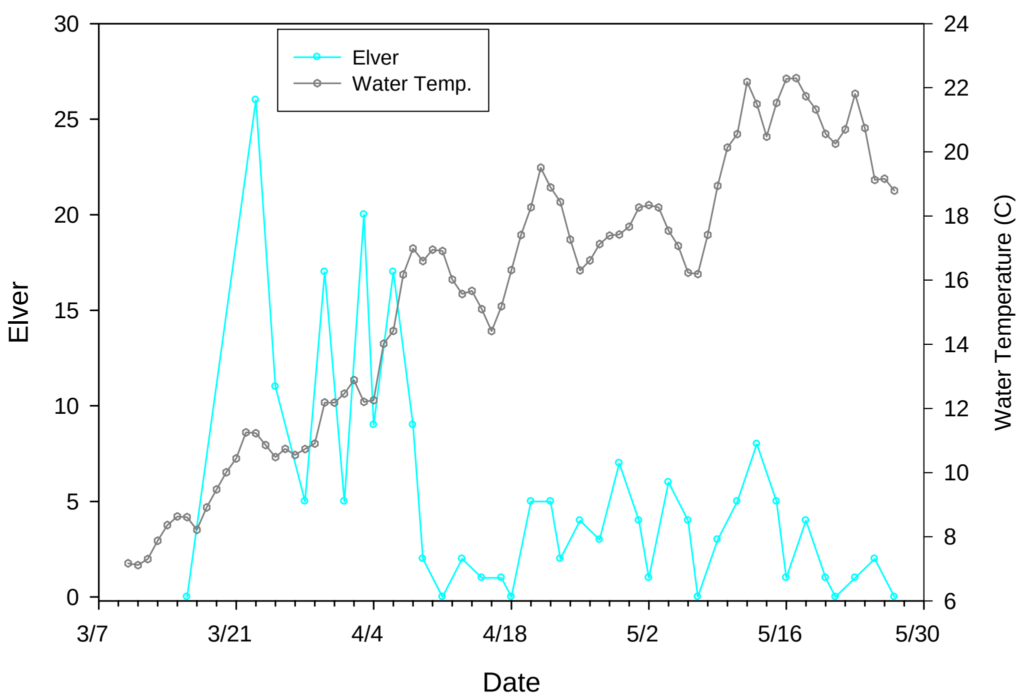
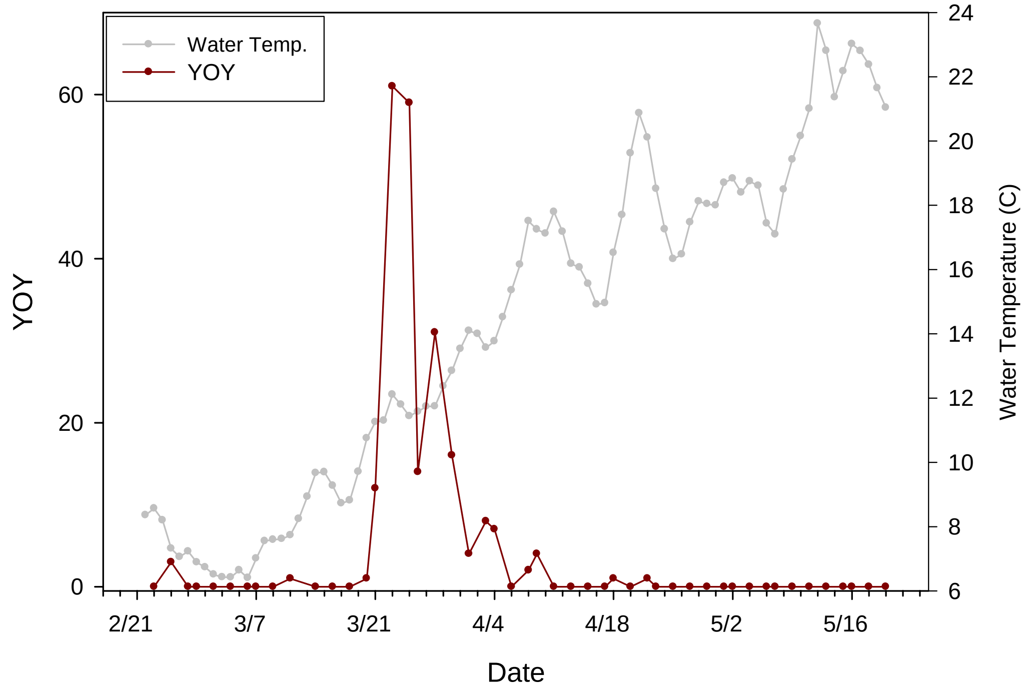


Figure 21. YOY and elver CPUE vs. water temperature for Wareham's Pond (James River) for 2005 (catch non-standardized).



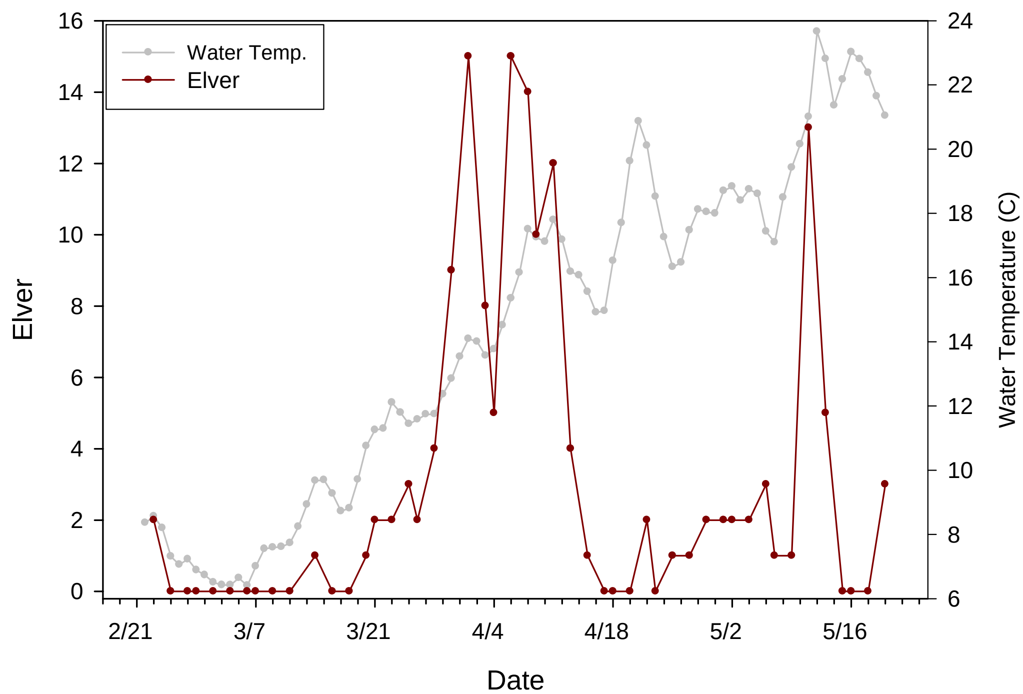


Figure 22. Glass eel length frequencies for 2005, by river.

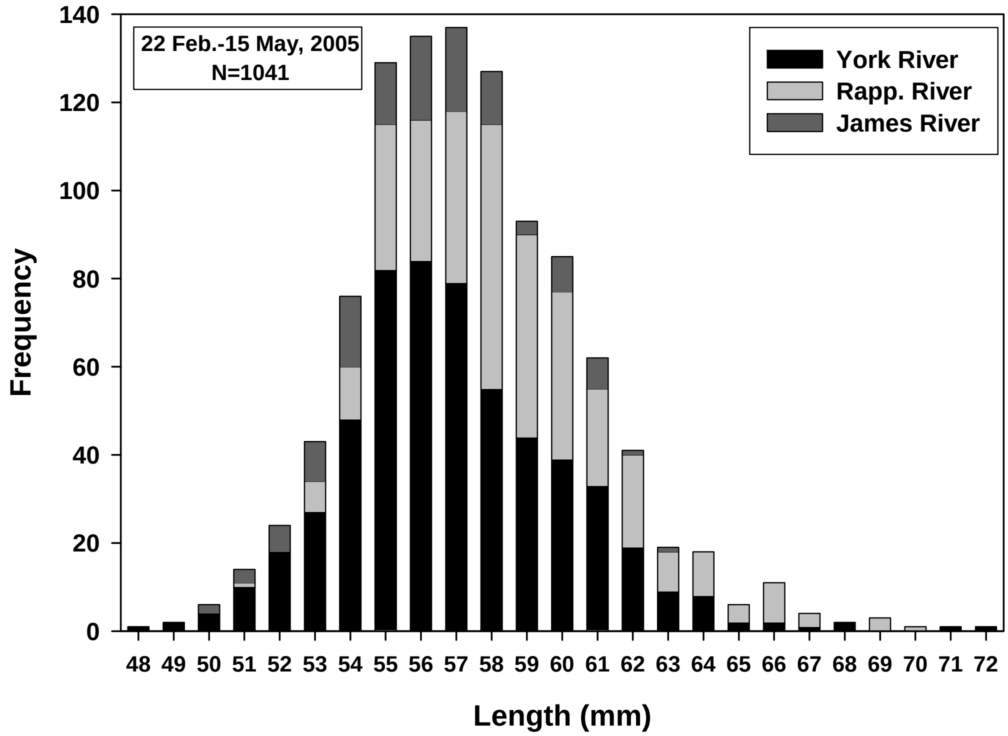


Figure 23. Linear regression of glass eel weight vs. length (York, James and Rappahannock Rivers combined).

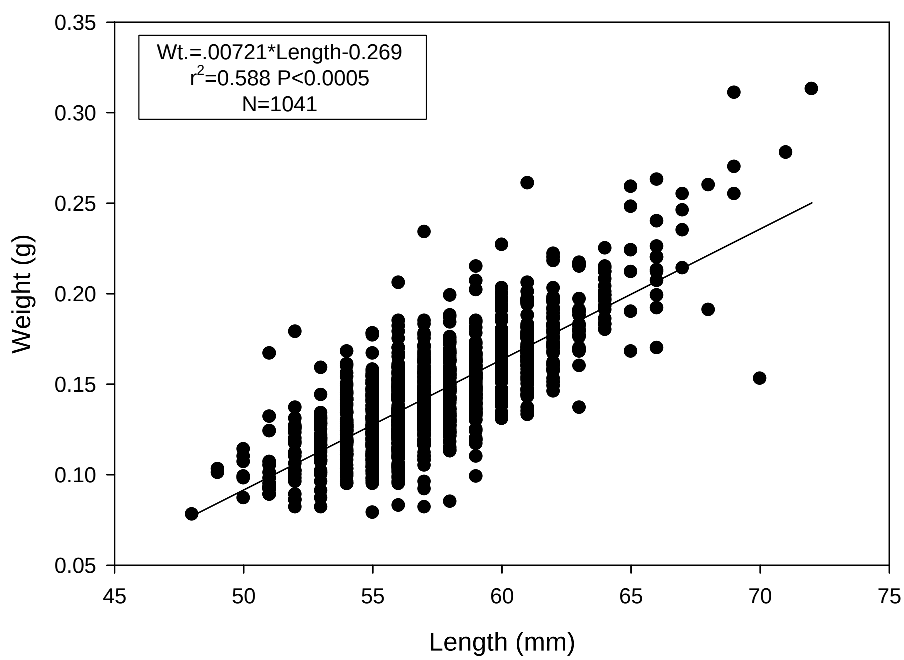


Figure 24. 2004 and 2005 glass eel pigmentation stages by river. Potomac data from Montane et al., (2005).

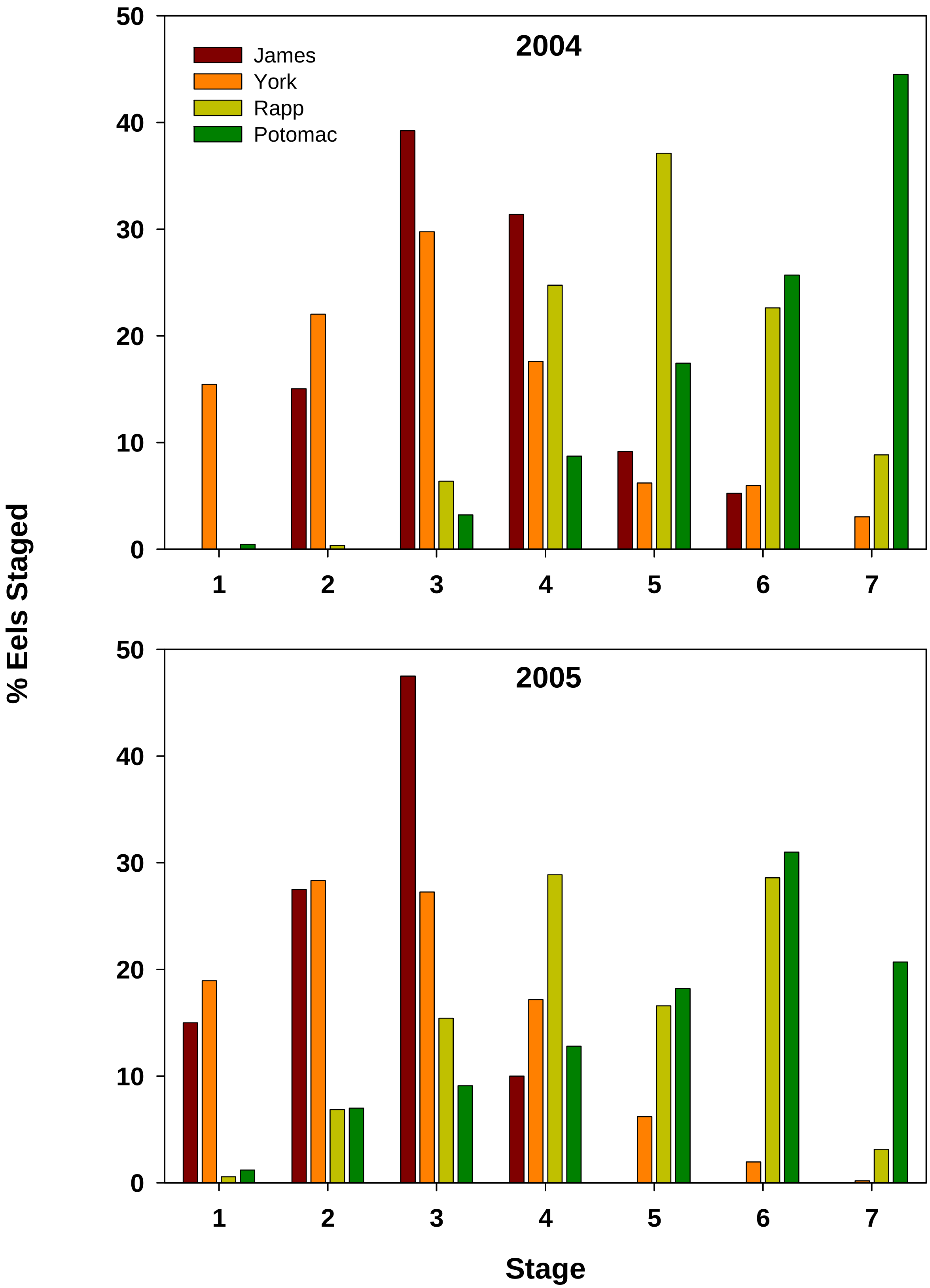


Figure 25. Wormley Pond (York River) glass eel pigmentation stages during the 2005 survey, by week.

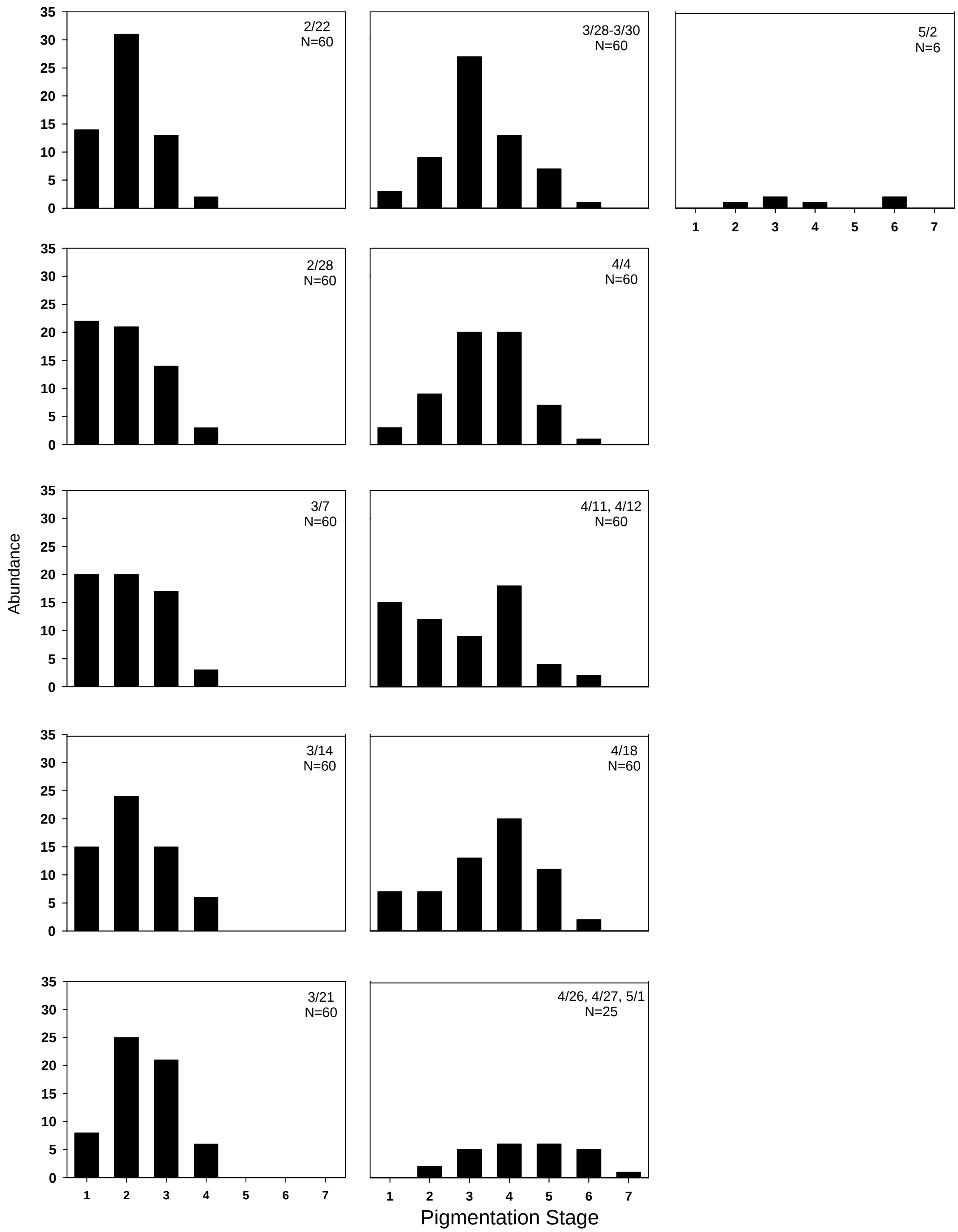


Figure 26. Kamp's Millpond (Rappahannock River) glass eel pigmentation stages during the 2005 survey, by week.

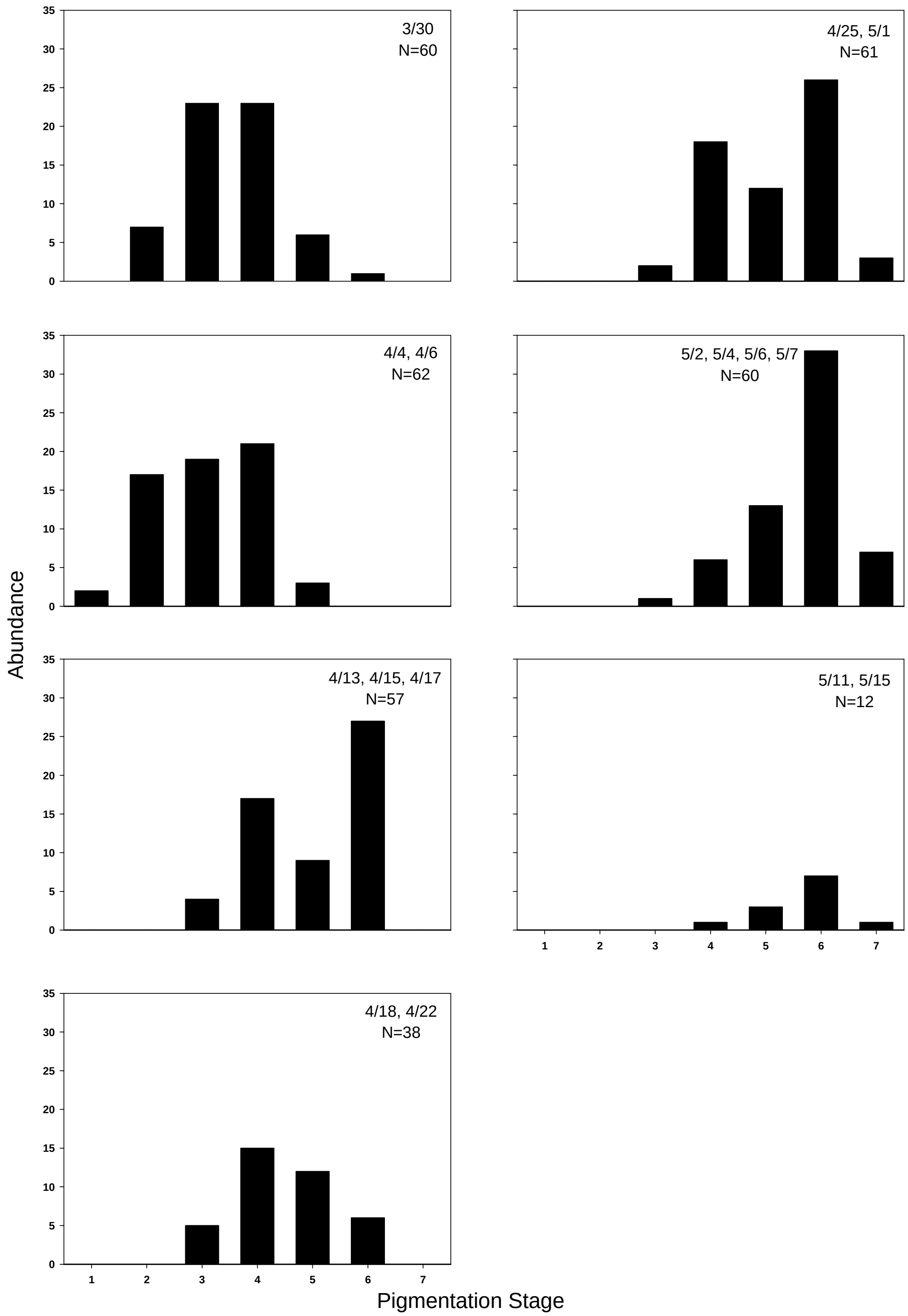


Figure 27. Wareham's Pond (James River) glass eel pigmentation stages during the 2005 survey.

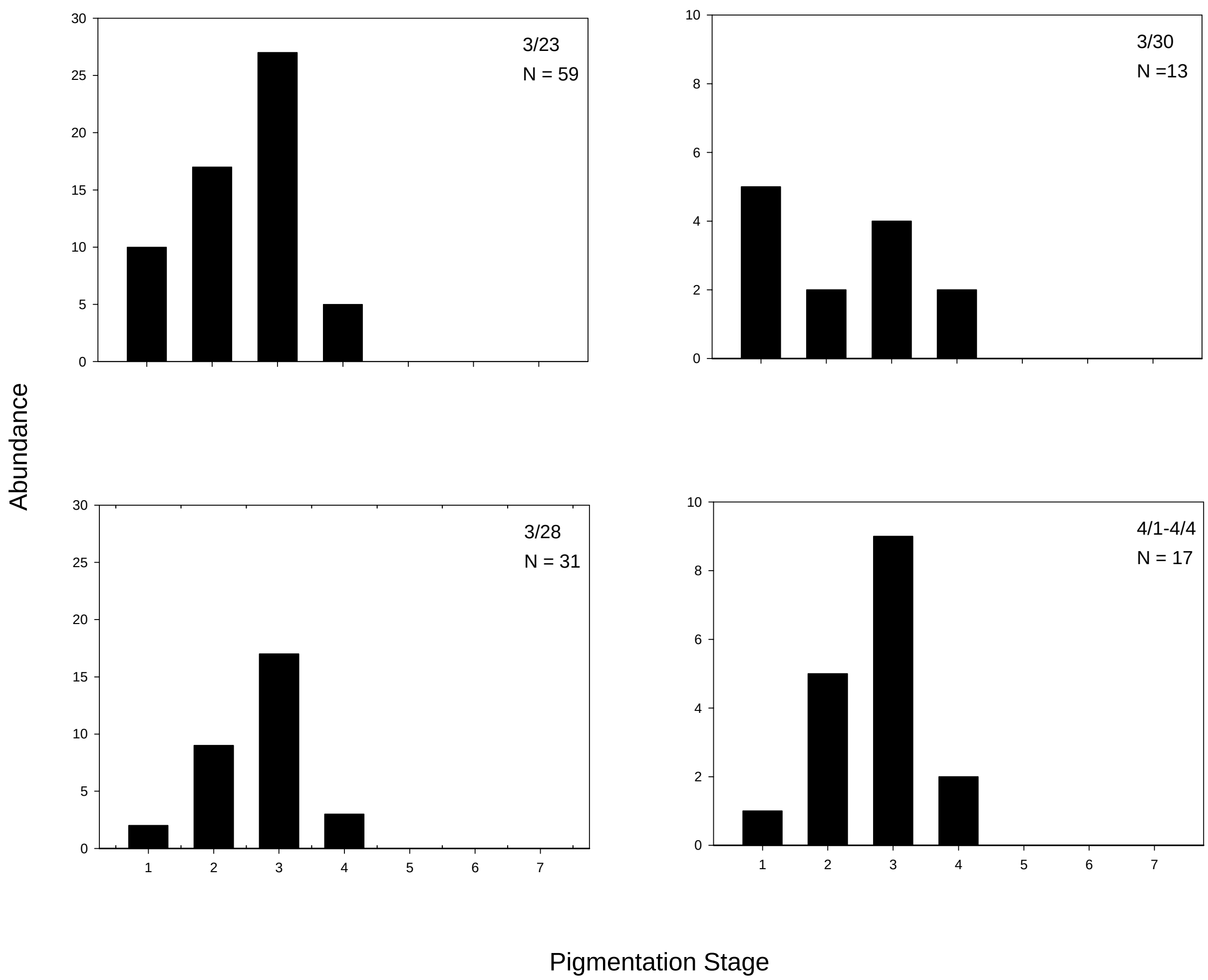


Figure 28. Mean length, weight and condition index for York River glass eels, 2002-2005.

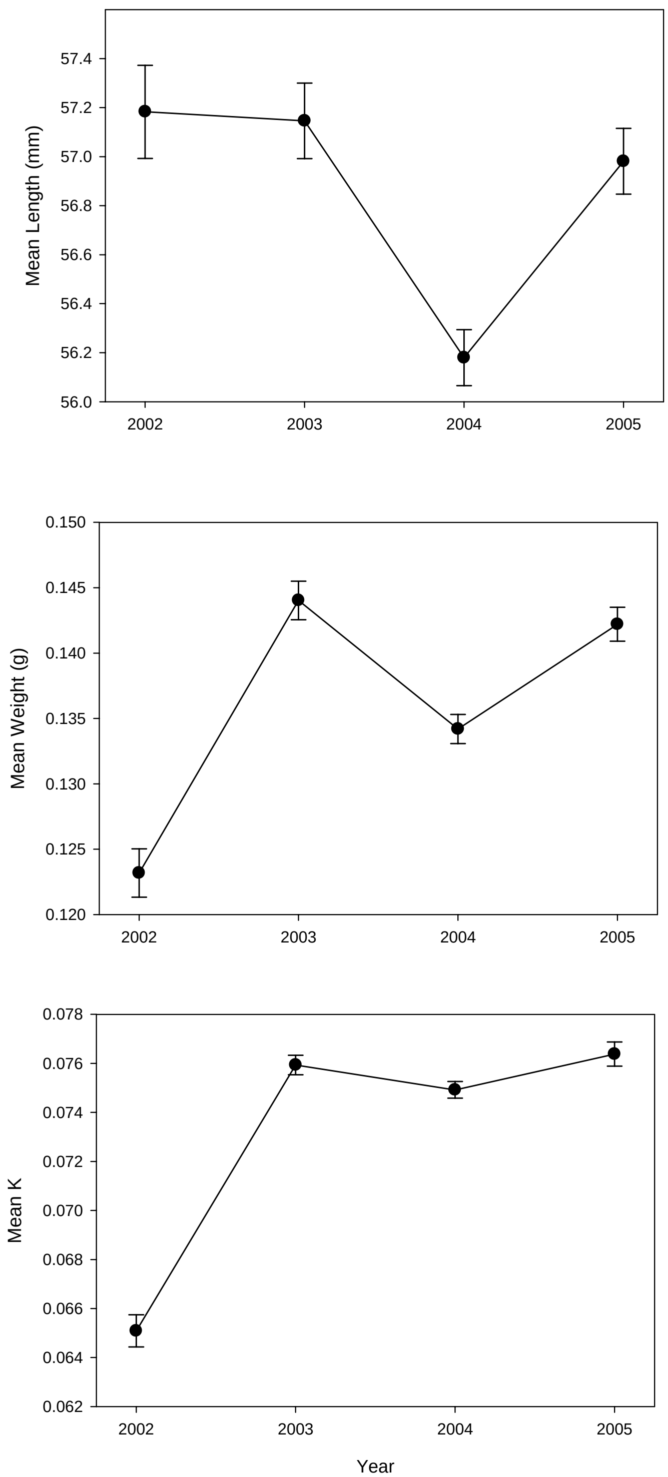


Figure 29. Length, weight and condition index for Rappahannock River glass eels, 2002-2005.

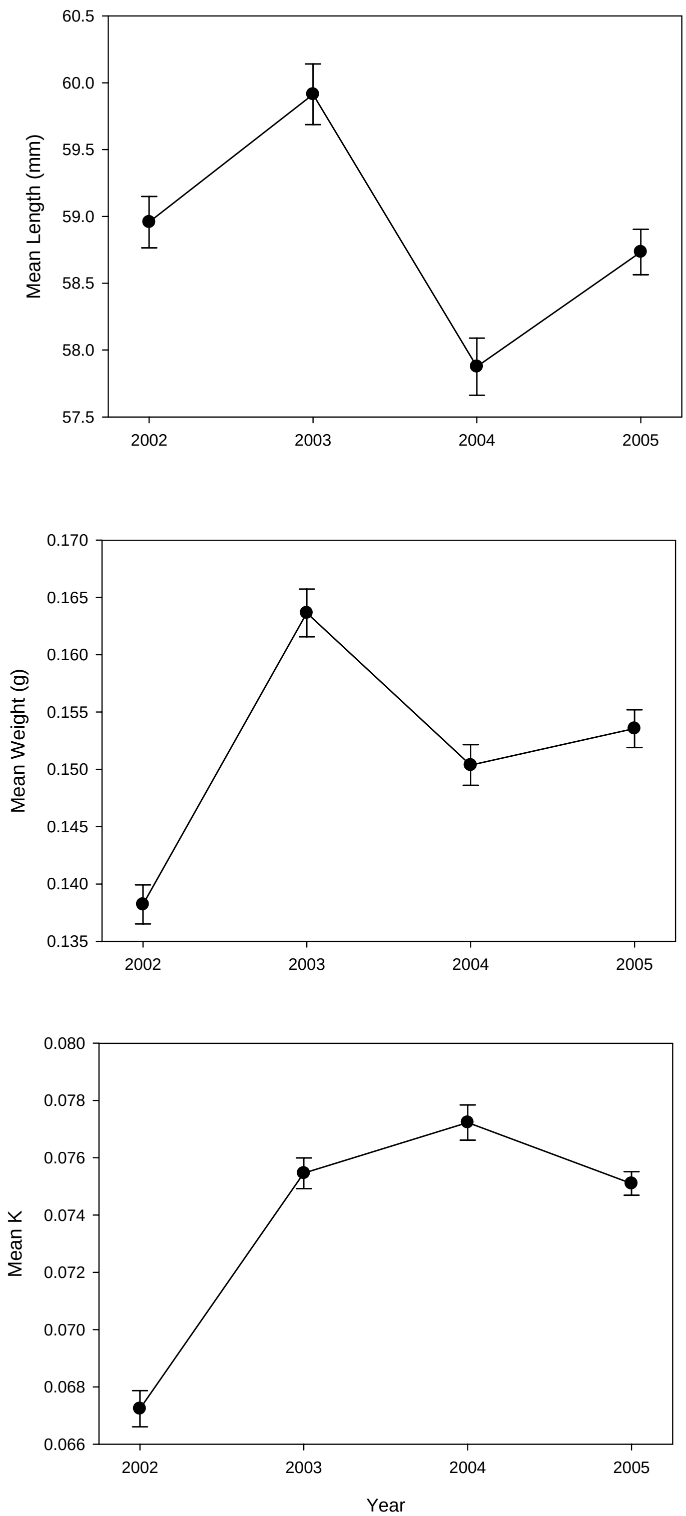


Figure 30. Length, weight and condition index for James River glass eels, 2003-2005.