Estimating Relative Abundance of Young-of-the-Year American Eel *Anguilla rostrata* in the Virginia Tributaries of Chesapeake Bay (Spring 2006)

Final Report

Submitted by

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Submitted to

Virginia Marine Resources Commission
Marine Recreational Fishing Advisory Board &
Commercial Fishing Advisory Board

Project No. RF/CF 06-01

August 2007

Acknowledgments

Several landowners and organizations provided access to sampling sites during the study. Thanks to the Acors family, John Dunn, and Charlotte Hollings for access above and below the spillway at Kamp's Millpond. Thanks to Charles Rafkind of the National Park Service for access to Bracken's Pond spillway and Wormley Pond spillway. Thanks to Timothy O'Connor and Kingsmill Resort for access to Wareham's Pond. Virginia Marine Resources Commission (VMRC) law enforcement officers deserve thanks for their assistance in ensuring the security of the survey gear (i.e., preventing vandalism and theft of the eel traps).

Julia Ellis, Courtney Ford, and Mandy Hewitt deserve special thanks for their participation in the field work.

The results included in this report were presented at the ASMFC American Eel Young-of-the-Year Workshop in Charleston, SC (12-13 December 2006).

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Introduction

The Marine Recreational Fishing Advisory Board and the Commercial Fishing Advisory Board of the Virginia Marine Resources Commission funded the spring sampling activities of the Virginia Institute of Marine Science's American Eel Monitoring Survey (VIMS AEMS) in 2006. The goal of this study is to provide estimates of the relative abundance of young-of–the-year (YOY) American eel (*Anguilla rostrata*) in the Virginia tributaries of Chesapeake Bay. This work ensured compliance with the reporting requirements set forth by the 1999 Atlantic States Marine Fisheries Commission (ASMFC) Interstate Fishery Management Plan (FMP) for American Eel (ASMFC 2000; ASMFC 2006).

The American eel is a valuable commercial species and is harvested along the entire Atlantic Coast from New Brunswick to Florida. Landings along the U.S. Atlantic Coast, including those in Chesapeake Bay, have declined in recent years. Similar declines have occurred in the Canadian Maritime Provinces (Meister and Flagg, 1997). While American eel are usually not considered a sport fish, recreational anglers often use this species as a baitfish (Jenkins and Burkhead, 1993).

Fishery-independent studies of juvenile recruitment are a valuable fisheries management tool. In Chesapeake Bay, recruitment studies may provide reliable indicators of year class strength for species such as blue crab (Lipcius and Van Engel, 1990), striped bass (Goodyear, 1985), and other species of recreational, commercial, and ecological importance (Montane and Fabrizio, 2006). Several 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 Fabrizio, 2006). Possible explanations for this decline include Gulf Stream shifts, pollution, overfishing, parasites, and barriers to fish passage (Castonguay et al., 1994; Haro et al., 2000). In addition, local factors such as unfavorable wind-driven currents may affect glass eel survival on continental shelves and may have a greater impact than fishing mortality or continental climate change (Knights, 2003).

Efforts to assess and manage American eel have been hampered by a lack of basic biological information, such growth rate and length at age. The ASFMC American Eel Fishery Management Plan (hereafter referred to as FMP) was adopted in 1999 and attempted to address these data gaps by encouraging coastal states to augment their American eel data collection efforts through both fishery-dependent and fishery-independent studies. Several states, including Virginia, each implemented an annual survey intended to quantify the recruitment of YOY American eel to estuarine and freshwater habitats. The development of these various state surveys began in 2000, and most were fully implemented by 2001. Besides quantifying YOY recruitment success, these surveys have the potential to provide a more comprehensive understanding of physical and environmental factors affecting the American eel population.

American Eel Life History

The American eel is a catadromous species occurring 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 is supported throughout its range by a single spawning population (Meister and Flagg, 1997; Haro et al., 2000). Spawning takes place during winter and 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 northwesterly direction and can grow to 85 mm TL (Jenkins and Burkhead, 1993). Within a year, metamorphosis into the glass eel stage occurs in the Western Atlantic near the east coast of North America. During migration to the continental shelf, glass eel total length decreases from about 85 mm TL to about 50 mm TL (Jenkins and Burkhead, 1993). Coastal currents and active migration transport the glass eels into Maryland and Virginia estuaries between February and 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 into freshwater rivers, streams, lakes, and ponds, while others remain in estuaries. Most of the eel's life is spent in these fresh-to-brackish water habitats as a yellow eel. Upon maturity, eels migrate back to the Sargasso Sea to spawn and die (Haro et al., 2000). It is during this spawning migration, usually beginning in late summer or autumn, that metamorphosis into the silver eel stage occurs. American eel age at maturity varies by location, and eels from Chesapeake Bay have been found to mature and migrate at an earlier age (i.e., approximately 10 years) than those inhabiting more northern areas (Hedgepeth, 1983; Owens and Geer, 2003).

It has been suggested that glass eel migrations occur in waves (Boetius and Boetius, 1989 as reported by Ciccotti et al., 1995), perhaps with a two-week periodicity related to selective tidal stream transport (Ciccotti et al., 1995). Further, changes in patterns and magnitudes freshwater inflow to bays and estuaries may affect the size, timing, and spatial patterns of the upstream migration of glass eels and elvers (Facey and Van Den Avyle, 1987). Evidence suggests that glass eels are highly sensitive and attracted to geosmin, an earthy odor which is produced by actinomycetes in freshwater, and migrations into estuaries and streams may be influenced by the strength of this signal (Tosi and Sola, 1993). These factors, taken together, likely shape the year class strength of American eel.

Project Objectives

The objectives of this study are to:

1. monitor the glass eel migration into the Virginia tributaries of Chesapeake Bay in an effort to determine the spatial and temporal components of recruitment;

2. examine environmental parameters which may influence young-of-the-year eel recruitment; and

3. collect basic biological information including length, weight, and pigment stage of eels.

Sampling Methods

The FMP established the following minimum criteria for the sampling of YOY American eel (i.e., glass eels) with gear approved by the ASMFC Technical Committee:

1) timing and placement of gear must coincide with periods of peak onshore migration;
2) at a minimum, the gear must fish during nighttime flood tides;
3) sampling must occur a minimum of four days per week for at least six weeks or for the duration of the run;
4) at least one site must be sampled in each jurisdiction;
5) the entire catch of glass eels must be counted from each sampling event; and
6) 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 suitable for recruitment (Figure 1).

Two sites were selected on the York River, Brackens Pond (Figure 2) and Wormley Pond (Figure 3). Brackens Pond is located along the Colonial Parkway at the base of the Yorktown Naval Weapons Station Pier. The sampling site is less than 100m from the York River, and the high tide often reaches the spillway. Wormley Pond is located on the Yorktown Battlefield and drains into Wormley Creek, which has a tidal range that routinely reaches a depth of 50 cm at the spillway. This site could not be sampled in the spring of 2000 because the road over the spillway was destroyed by Hurricane *Floyd* and repairs were not completed until autumn 2000.

Kamp's Millpond is located upstream of Route 790, just north of Kilmarnock, VA, in Lancaster County (Figure 4). The reservoir is approximately 80 acres and drains into the eastern branch of the Corrotoman River, a tributary to the Rappahannock River.

Wareham's Pond is located at Kingsmill Resort in James City County, VA, and drains directly into the James River, approximately 100m away. High tide often inundates the spillway (Figure 5).

Irish eel ramps were used to collect eels at all sites (Figure 6). The ramp configuration successfully attracts and captures glass eels and elvers near tidal waters. The ramp design allows 24-hour collection of glass eels from the time it is set, thereby surpassing the minimum sampling criterion for fishing of gear. Ramp operation requires the continuous flow of water over the climbing substrate and through the collection device. At each site, the eel ramp was placed below the dam and a siphon was used to deliver water from the pond to the ramp through gravity feed. The flow of water must be regulated so that the ramp area is attractive to the young eels (i.e., water flow must be less than the surrounding spillway area). Flow was regulated using a valve located between the intake siphon hose and the trap. Inside the trap, the floor has a 4^o slope with textured matting (Enkamat™), which provides a climbing surface for the eels. At each site, the trap was placed on an incline ($15\text{-}45^o$), and the ramp entrance was positioned so that the bottom edge was flush with the culvert floor and the textured matting extended into the water. A hose attached to the side of the ramp routes the eels into a collection bucket. During high tides, the ramp entrance may be submerged, however, the ramp continues to be effective as long as the outlet hose to the collection bucket is not submerged. A hinged lid on the trap provides access for checking flow adjustments.

Sampling at the York River sites (Brackens Pond and Wormley Pond) was conducted from 17 February to 19 May 2006. Sampling was conducted over the same time period at Wareham's Pond (James River), while Kamp's Millpond (Rappahannock River) was sampled between 28 February and 25 May 2006.

During the glass eel run, traps were checked at least four days per week. Only eels in the collection bucket were counted and 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) for later evaluation. Water temperature, pH, air temperature, wind direction and speed, and precipitation were recorded during site visits. All eels were enumerated and returned to the water above the trap to prevent them from being re-collected by the trap. Subsampling, if applicable, was done volumetrically. Specimens less than or equal to 85 mm total length (TL) and without full pigmentation were classified as glass eels (i.e., YOY eels), while those fully pigmented and 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 reflected differing year classes (Geer, 2001). Lengths, weights, and pigmentation stages (Haro and Krueger, 1988) were collected from 60 glass eels (if present) from the York River (Wormley Creek site) each week.

A daily catch per unit effort (CPUE) for the Irish eel ramp was calculated for each site for glass eels and elvers. CPUEs were standardized per 24 hours of soak time in order to calculate a total geometric mean for each site for the year. In an effort to examine whether a relationship exists between YOY or elver CPUE and lunar stage, we performed an 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 or first quarter, (3) the week of the full moon starting on the day of the full moon and (4) the week of the waning moon or last quarter. If YOY or elver CPUE varied with lunar stage, Tukey's pairwise comparisons (MINITAB, 1998) were used to compare CPUEs among lunar phases. Trends in YOY and elver CPUE were also investigated with respect to water temperature, barometric pressure (barometric pressure measured at Mosquito Point, White Stone, VA was used for Kamp's Millpond, while the barometric pressure measured at Yorktown, VA was used for the other three sites, from http://www.wunderground.com) 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 relationship existed. This report focuses on examining relationships between CPUE, lunar quarter, percent lunar illumination and water temperature.

Lengths and weights were incorporated into a Fulton condition factor (K) using the formula $K = (W/L^3)/100{,}000$ (Anderson and Neumann, 1996), in an effort to contribute to the understanding of the biology of this species.

Results and Discussion

In the York River (Brackens Pond and Wormley Pond combined), the CPUEs for both glass eels and elvers have been variable since 2000, though glass eels exhibited an increasing trend and elvers a decreasing trend over the period (Figure 7). When separated by site, 2006 glass eel CPUE increased relative to 2005 for both Brackens Pond and Wormley Pond but exhibited no trend over the time series (Figure 8, top). Elver CPUE has declined at both sites over this period (Figure 8, bottom).

In the Rappahannock River, the Kamp's Millpond 2006 glass eel CPUE was less than the 2005 value and showed a slight decreasing trend over the time series (Figure 9, top). Elver CPUE at Kamp's did not change substantially from the 2005 value (Figure 9, bottom).

In the James River, glass eel CPUE increased at Wareham's Pond in 2006 compared with the previous year (Figure 9, top) but there was no evident trend from 2003 to 2006. The 2006 elver CPUE at Wareham's increased compared with 2005, and the time series exhibited a slight increasing trend (Figure 9, bottom).

Non-standardized catch (daily CPUE) was plotted against moon phase for each site

(Figure 10-13). The effect of lunar quarter on standardized 24-hour CPUE was investigated using ANOVA, and regressions were used to elucidate the relationship between percent illumination and CPUE. At Wormley Pond, significantly more glass eels were caught during the week of the waxing moon compared to the full and waning moons ($F = 4.61$, $df = 3, 84$, $p = 0.005$). CPUE increased significantly with increasing percent illumination for Brackens Pond glass eel CPUE ($r^2 = 0.08$, $p = 0.007$), Wormley Pond glass eel CPUE ($r^2 = 0.05$, $p = 0.046$) and Kamp's Millpond elver CPUE, though r^2 values were low indicating that lunar illumination explained only a small portion of the total variance in the CPUEs.

Water temperature was collected both downstream and upstream of the Irish eel ramp at each of the sites. Since the downstream and upstream temperatures followed the same trends (Figures 14-17), analyses were conducted with respect to glass eel or elver CPUE on the downstream temperatures only. Simple linear regressions were performed on non-standardized CPUE, log-transformed non-standardized CPUE, 24-hour standardized CPUE and log-transformed 24-hour CPUE vs. downstream water temperature. Log-transformed glass eel CPUE decreased significantly at three sites (Brackens Pond, Wormley Pond and Wareham's Pond) as downstream temperature increased ($r^2 = 0.06$, $p = 0.028$; $r^2 = 0.12$, $p = 0.0009$; $r^2 = 0.12$, $p = 0.013$, respectively, Figures 14, 15, and 17), however, this is probably a spurious relationship since the glass eel "run" occurs in spring when air and water temperatures are continuing to warm at the sites. Non-standardized elver catch increased significantly with increasing downstream water temperature only at Wareham's Pond ($r^2 = 0.09$, $p = 0.034$; Figure 17). R-squared values were very low in each of these cases, again indicating that the explanatory variable (i.e., water temperature) accounted for only a small portion of the total variance in the CPUE. In general, increasing water temperature early in the survey may act as a trigger to start or enhance recruitment to the eel traps. Similarly a cold spell occurring after initial recruitment has been shown to decrease the rate of recruitment to the trap.

Lengths, weights and pigment stages were collected from glass eels sampled from Wormley Pond. Glass eels at stages 1 through 4 occurred from 20 February through 13 March 2006, stages 1 through 5 from 20 March through 3 April 2006, stages 1 through 6 on 10 April and stage 2 through 6 on 17 April (Figure 18). No stage 7 (i.e., the most advanced pigment stage) glass eels were collected in 2006 at Wormley Pond, which is not unusual as few stage 7 glass eels have been recorded previously at this site (Montane et al., 2006a). Glass eel collections at locations closer to the mouth of Chesapeake Bay were comprised mainly of early stage pigmented eels whereas glass eel sampled from areas further up the Bay contained more later stage eels (Figure 19). Glass eels of pigment stage 7 are more often collected in the Rappahannock River (Montane et al., 2006a) and Potomac River (Montane et al., 2006b).

Glass eel length during 2006 ranged from 47 to 68 mm total length (Figure 20). Glass eel weight increased significantly with increasing length ($r^2 = 0.14$, $p < 0.0005$; Figure 21). Mean length, weight and condition index were also examined for the past five years. From 2002 to 2006, mean annual glass eel length exhibited a decreasing trend (Figure 22, top). Mean length in 2002 was significantly different from that in 2004, 2005 and 2006 ($F = 23.23$, $df = 4, 2587$, $p < 0.0005$). Mean annual weight exhibited an increasing trend between 2002 and 2006 (Figure 22, middle). Mean glass eel condition index (K), which is a function of both length and weight, exhibited a significant positive slope over time ($t = 3.48$, $df = 1$, $p = 0.04$; Figure 22, bottom).

Future Considerations

Due to the unique nature of each sampling site and the resulting variability in the performance of the survey gear, the generation of a Chesapeake Bay-wide annual estimate of recruitment for glass eels and elvers is problematic. Thus, it may be necessary to continue reporting separate recruitment indices for each site. Pond drainage area, distance from the ocean, discharge, and other physical parameters should continue to be evaluated, however, so that perhaps a relative value can be generated for each sampling site. These values may then be used to weight catch rates at each site and, in turn, allow these catch rates to be combined into an overall estimate of juvenile eel recruitment for Chesapeake Bay.

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. 2006 American Eel Sampling Sites.

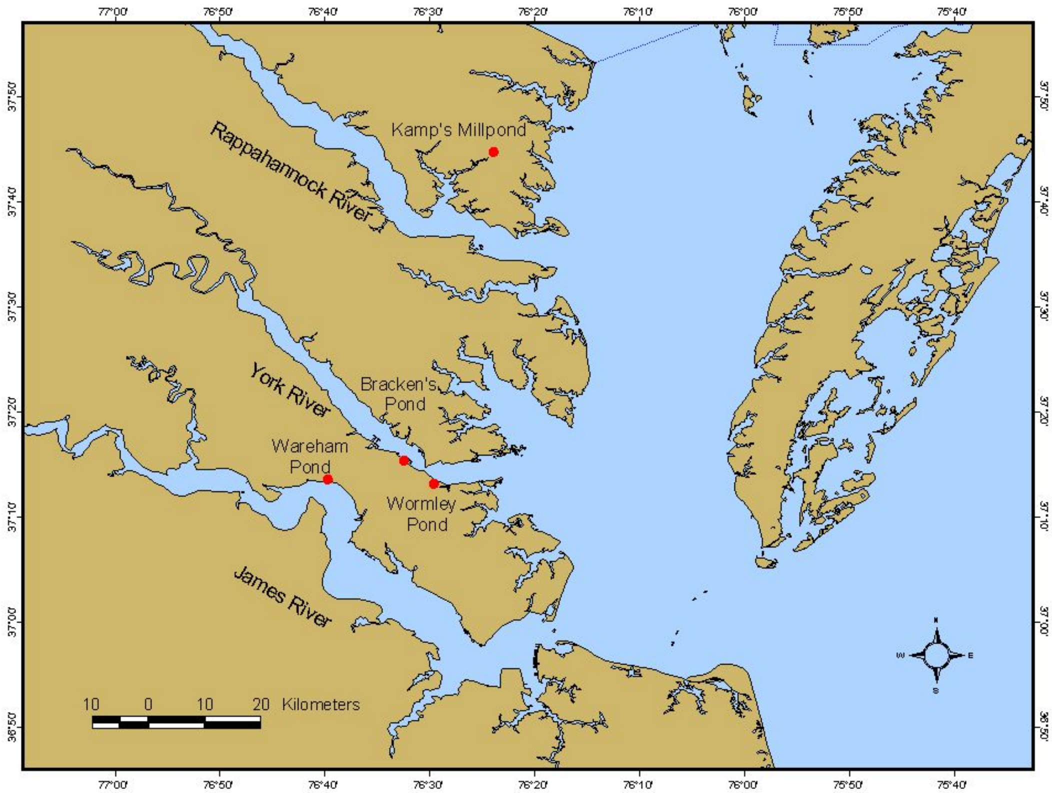


Figure 2. Bracken's Pond spillway and tailrace. Irish ramp was set against the right wall on the upstream end of culvert.

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

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

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

Figure 6. An Irish eel ramp with lid open. The arrows indicate the flow of water as well as eel movement through the trap.

Figure 7. Glass eel (top) and elver (bottom) CPUE (Geometric Means) for York River pooled sites (Brackens Pond and Wormley Pond combined, 2000-2006).

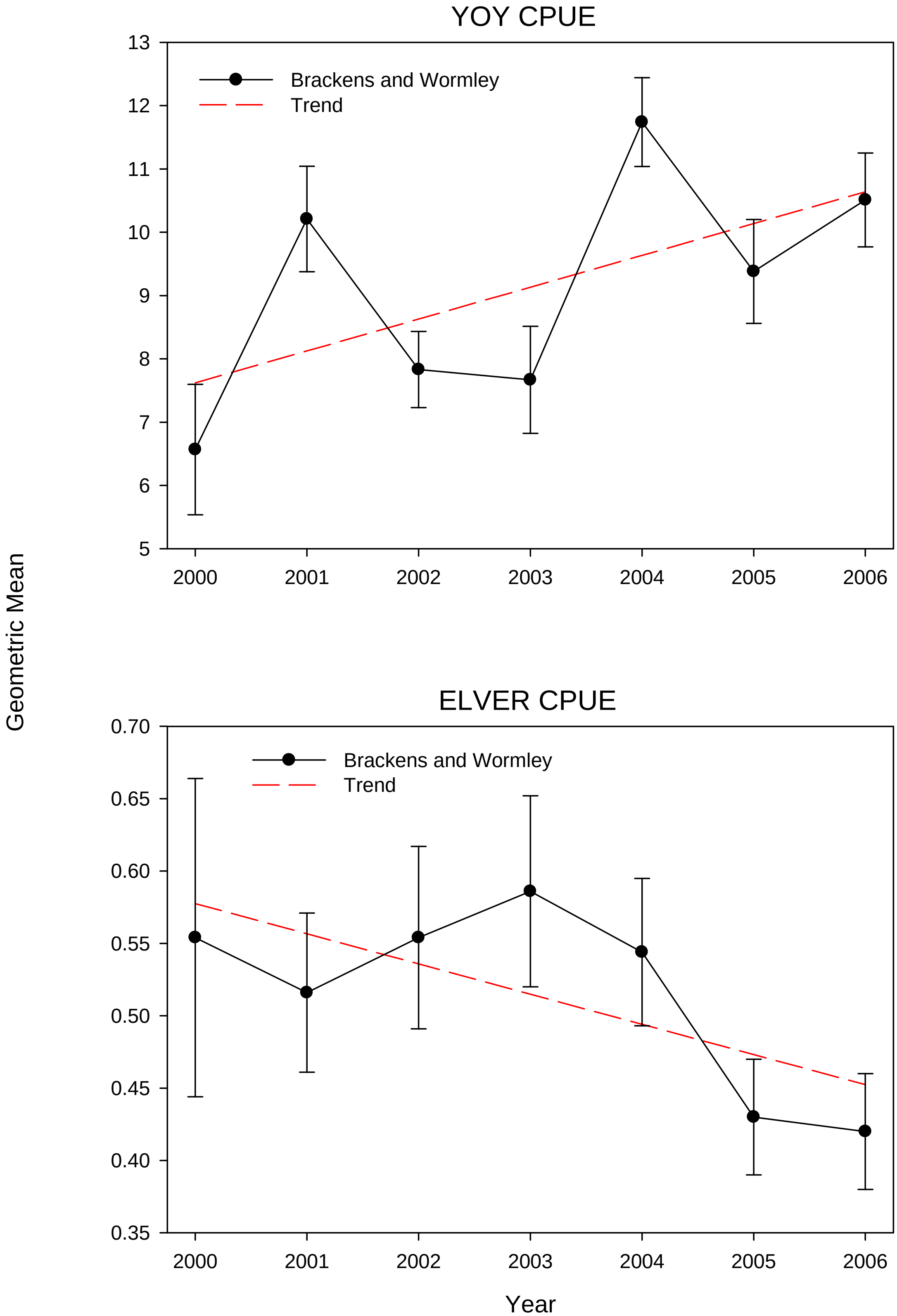


Figure 8. Glass eel (top) and elver (bottom) CPUE (Geometric Means) separated by site for Brackens Pond and Wormley Pond (2000-2006).

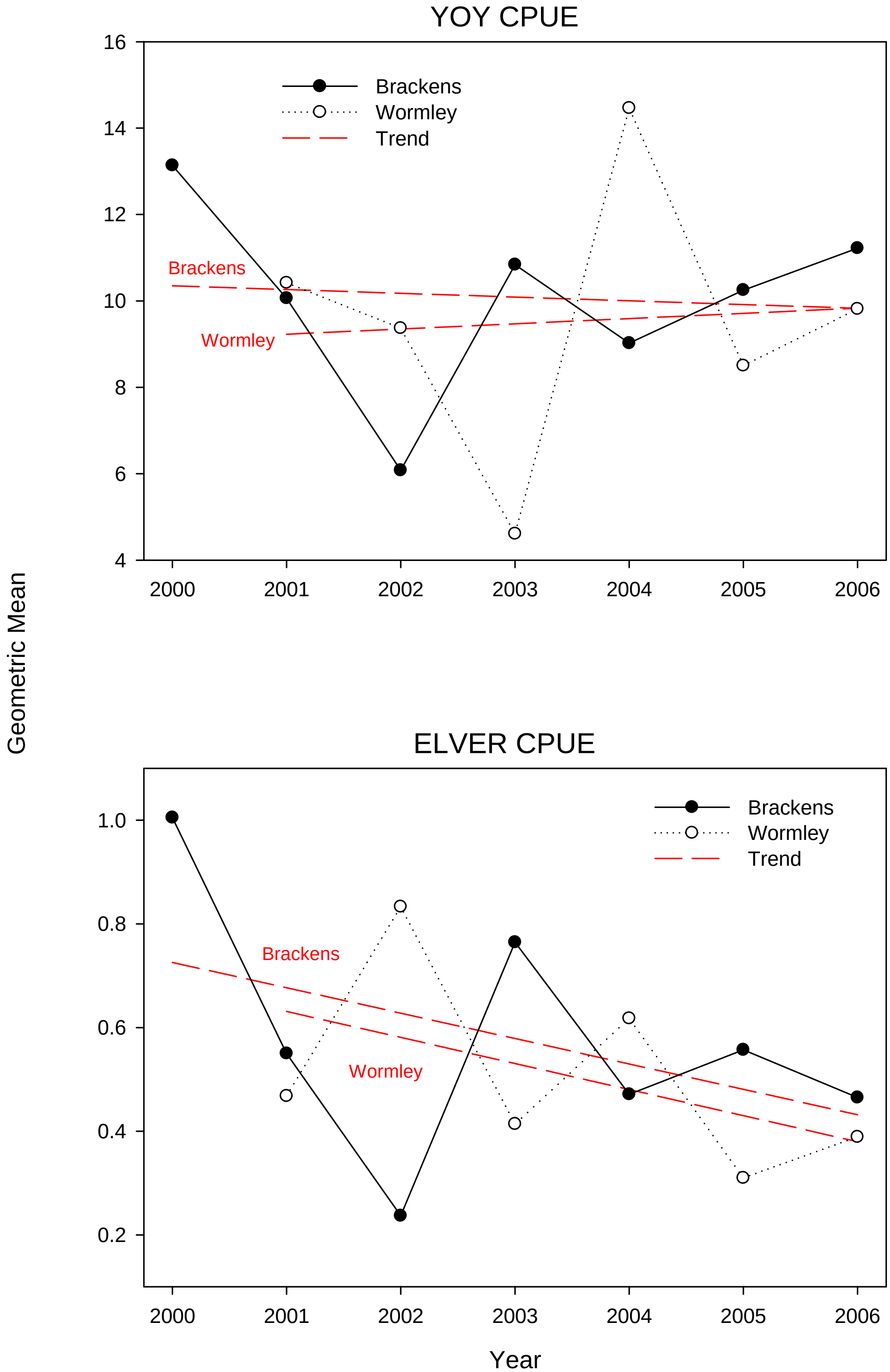


Figure 9. Glass eel (top) and elver (bottom) CPUE (Geometric Means) for Kamp's Millpond (2000-2006) and Wareham's Pond (2003-2006).

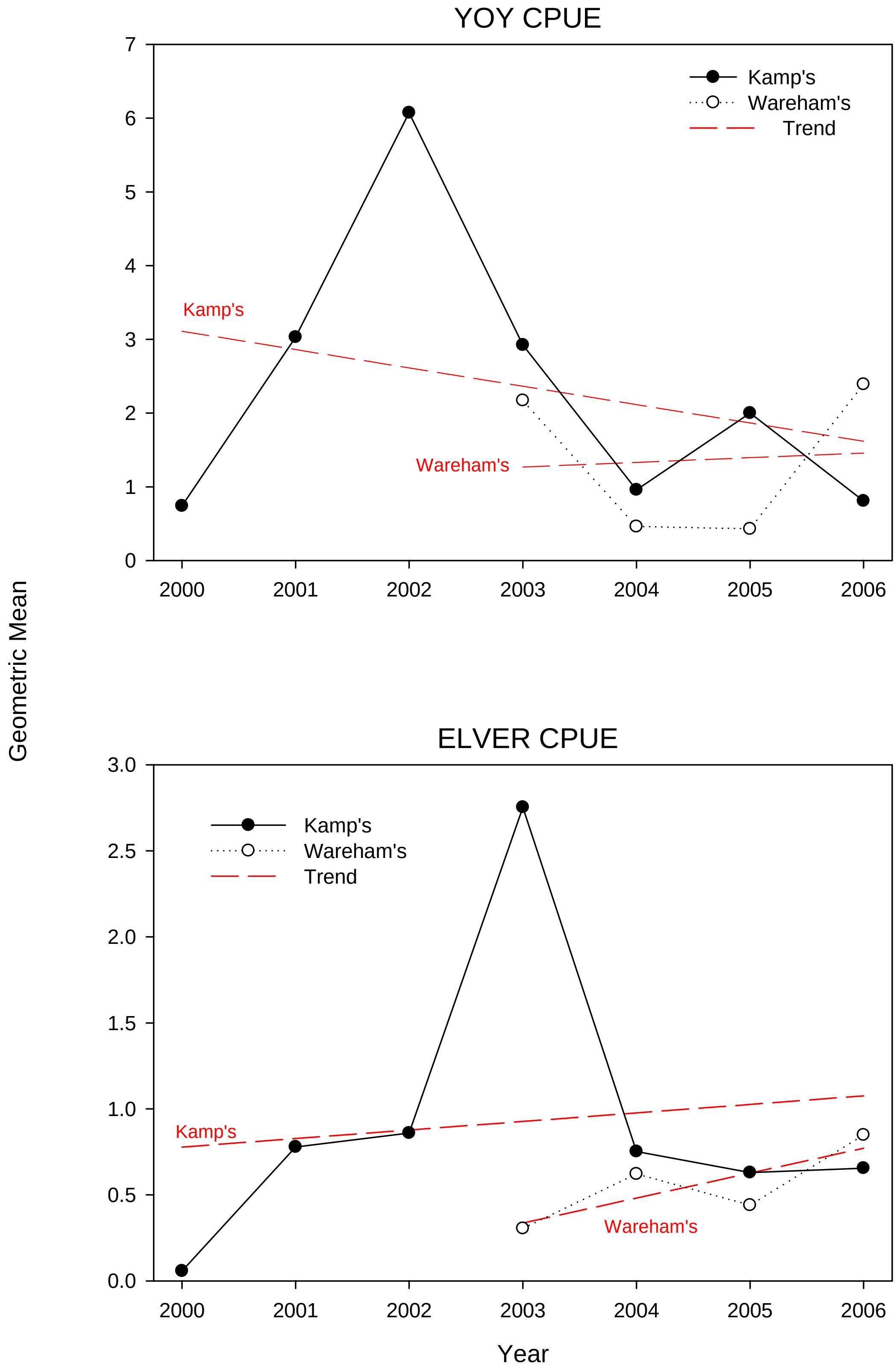


Figure 10. Daily glass eel and elver CPUE vs. lunar quarter for Brackens Pond (York River) for 2006 (daily catch, non-standardized).

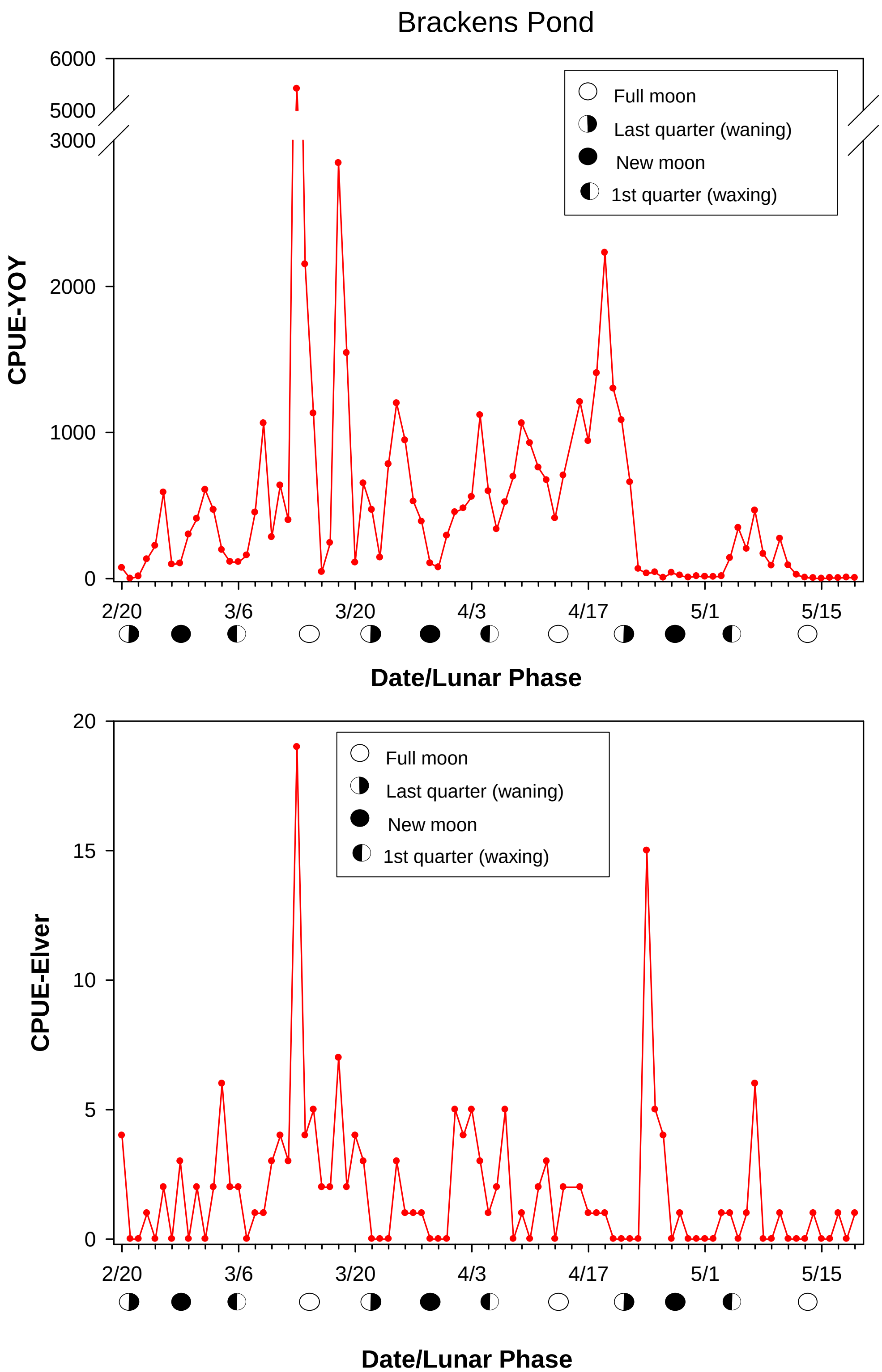
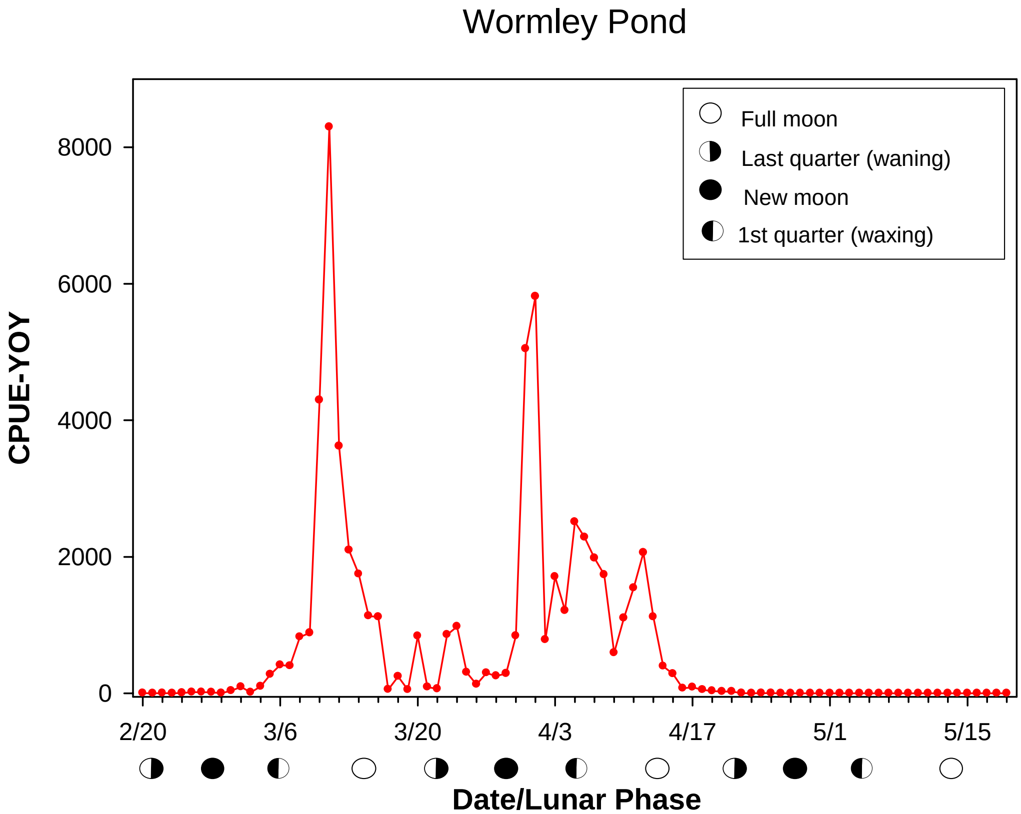


Figure 11. Daily glass eel and elver CPUE vs. lunar quarter for Wormley Pond (York River) for 2006 (daily catch, non-standardized).



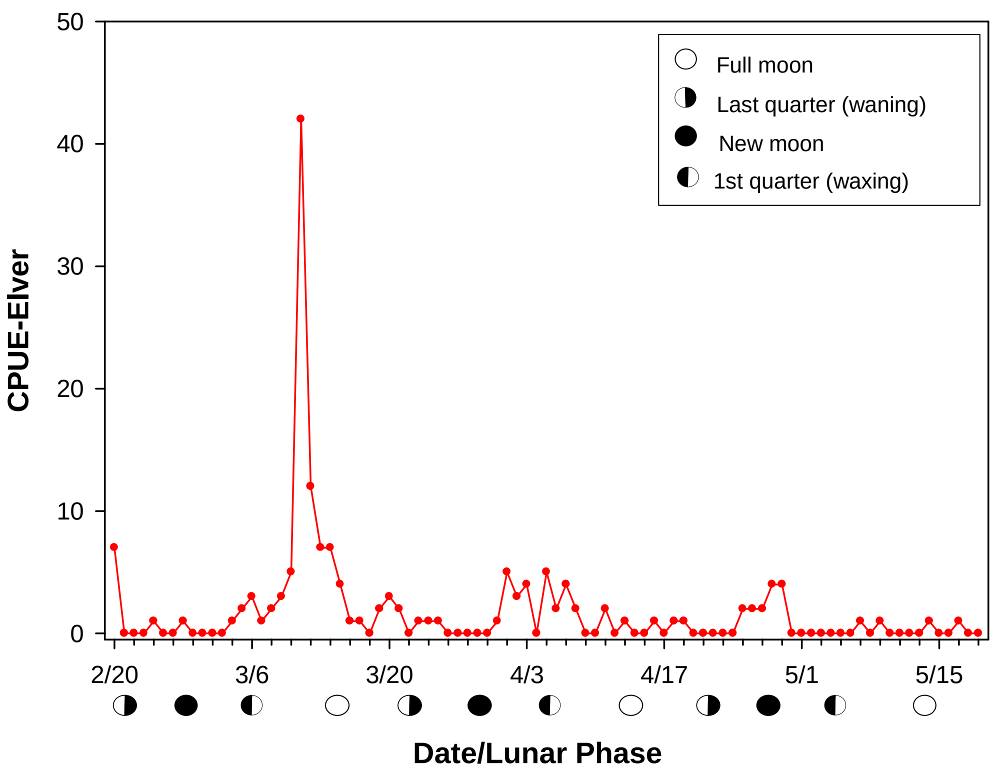
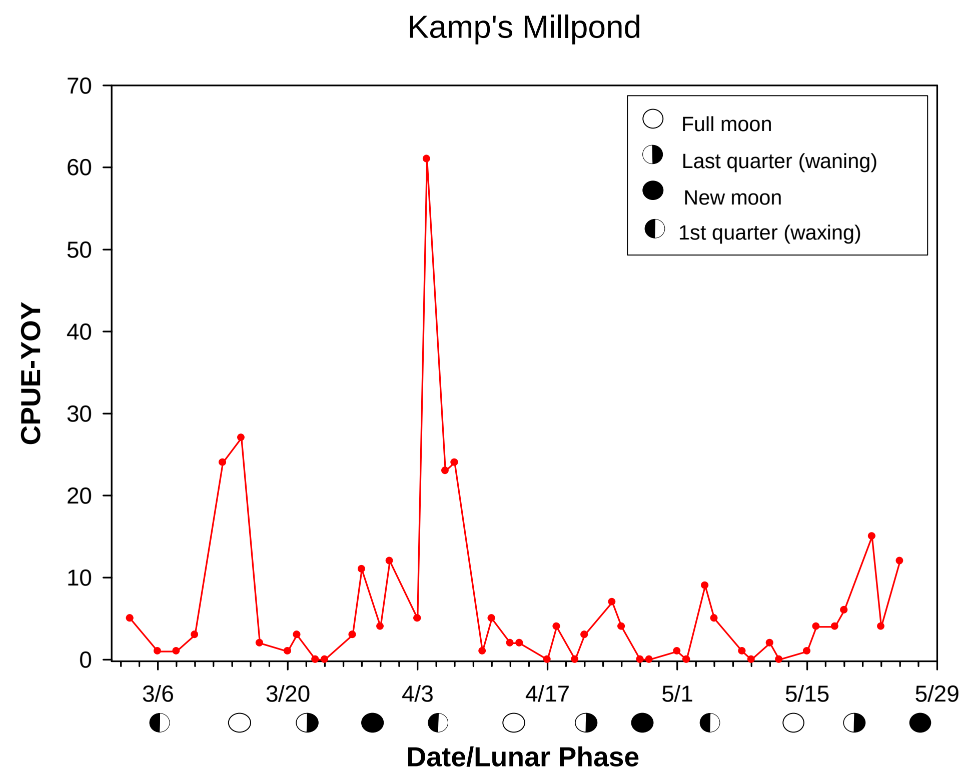


Figure 12. Daily glass eel and elver CPUE vs. lunar quarter for Kamp's Millpond (Rappahannock River) for 2006 (daily catch, non-standardized).



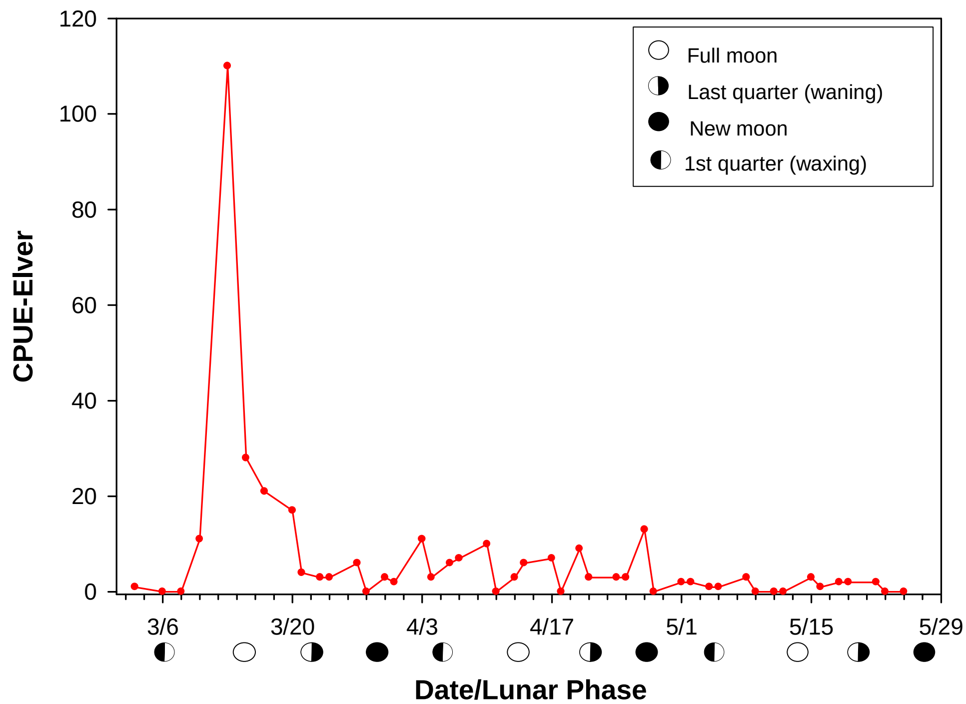
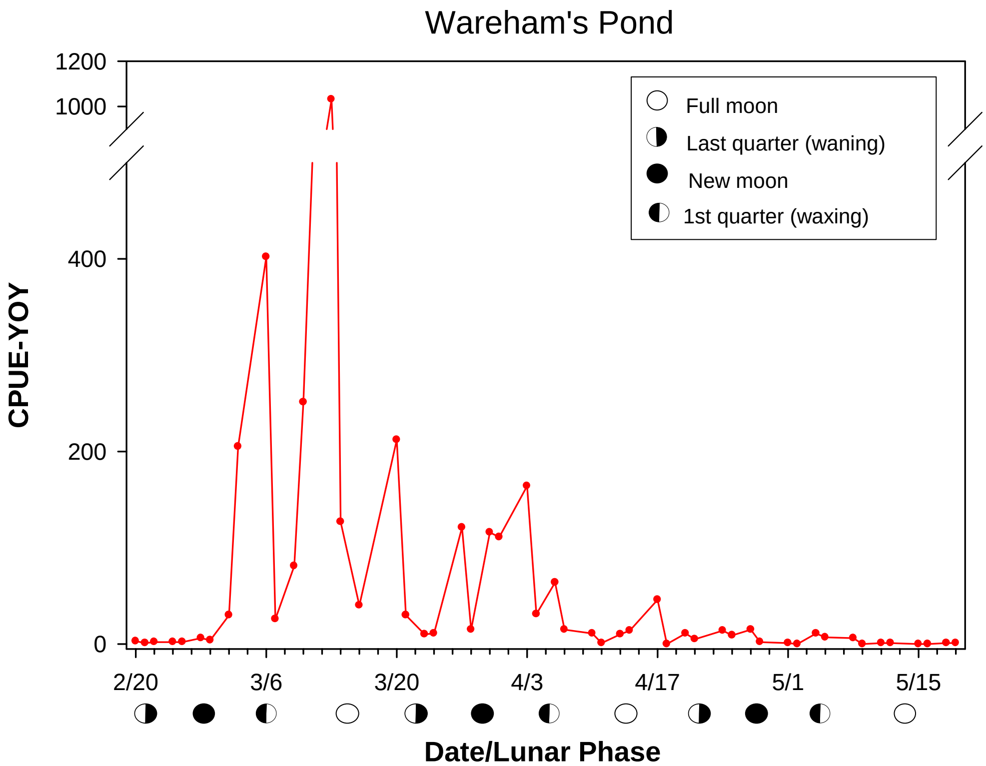


Figure 13. Daily glass eel and elver CPUE vs. lunar quarter for Wareham's Pond (James River) for 2006 (daily catch, non-standardized).



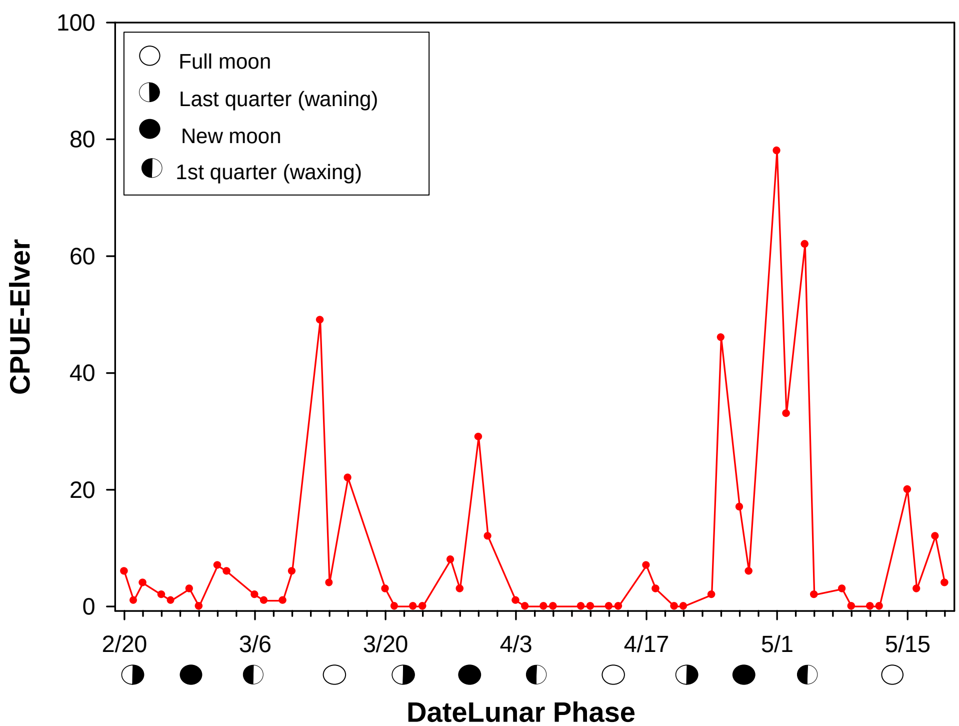


Figure 14. Daily glass eel and elver CPUE vs. water temperature (downstream and upstream of trap) for Brackens Pond (York River) for 2006 (daily catch, non-standardized).

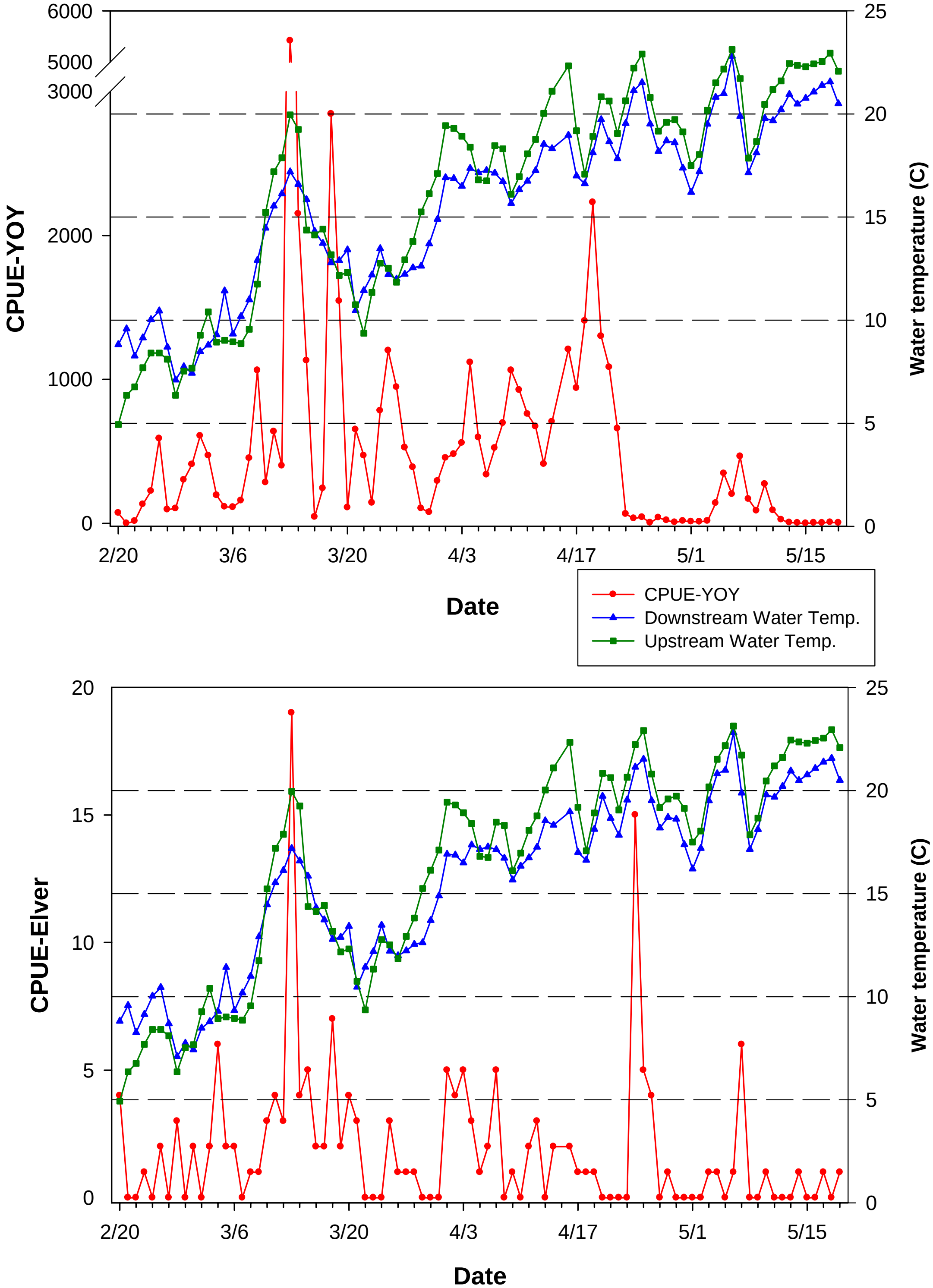


Figure 15. Daily glass eel and elver CPUE vs. water temperature (downstream and upstream of trap) for Wormley Pond (York River) for 2006 (daily catch, non-standardized).

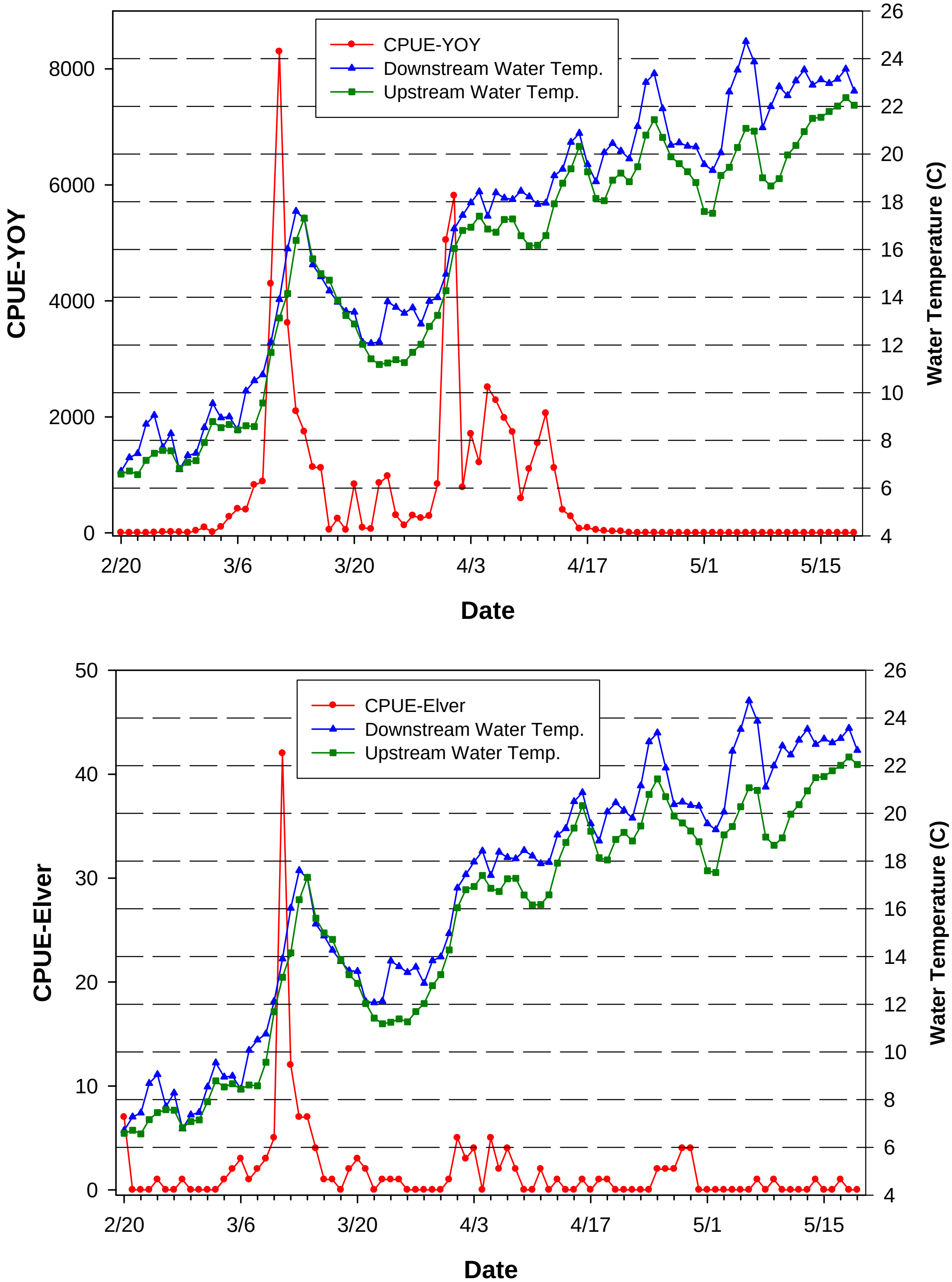
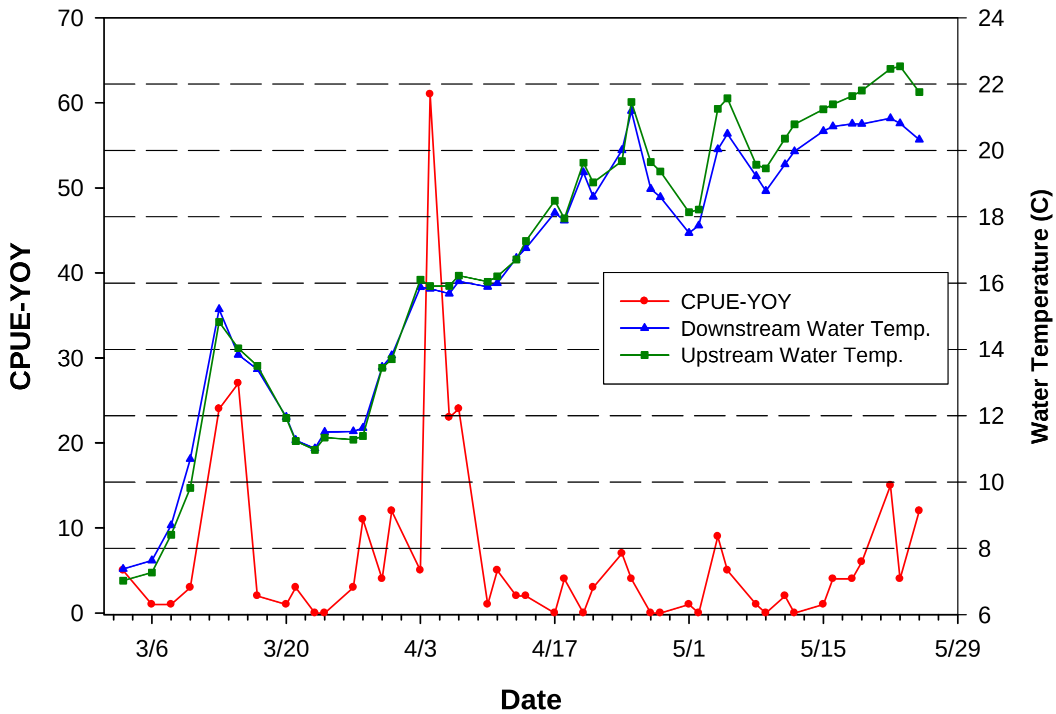


Figure 16. Daily glass eel and elver CPUE vs. water temperature (downstream and upstream of trap) for Kamp's Millpond (Rappahannock River) for 2006 (daily catch, non-standardized).



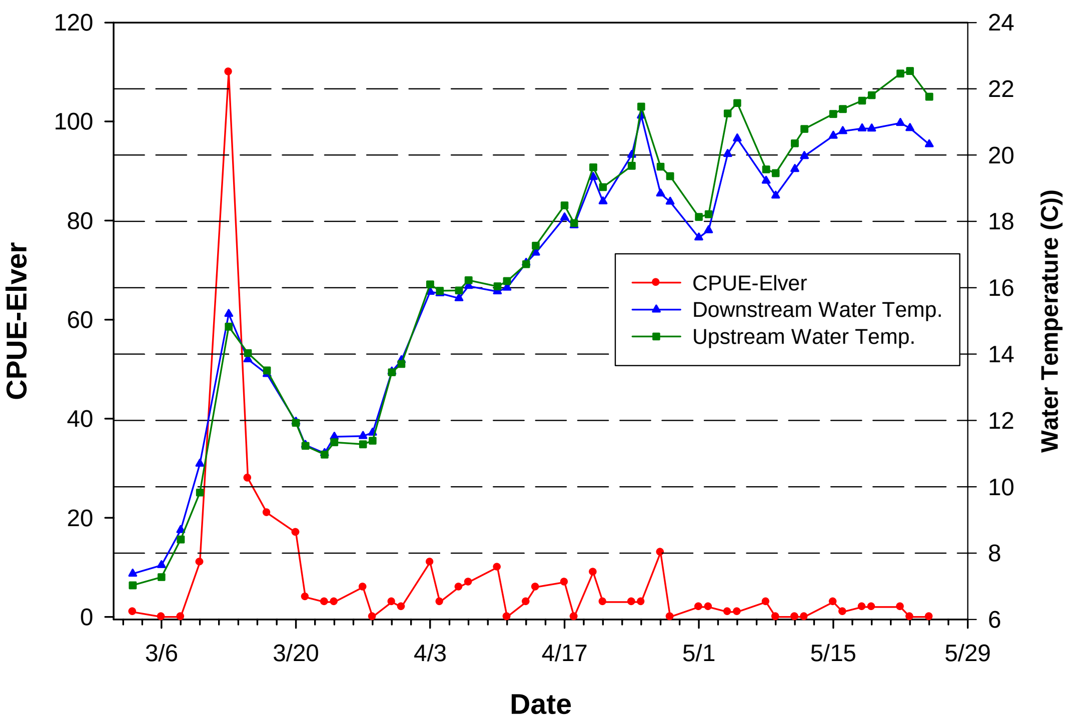
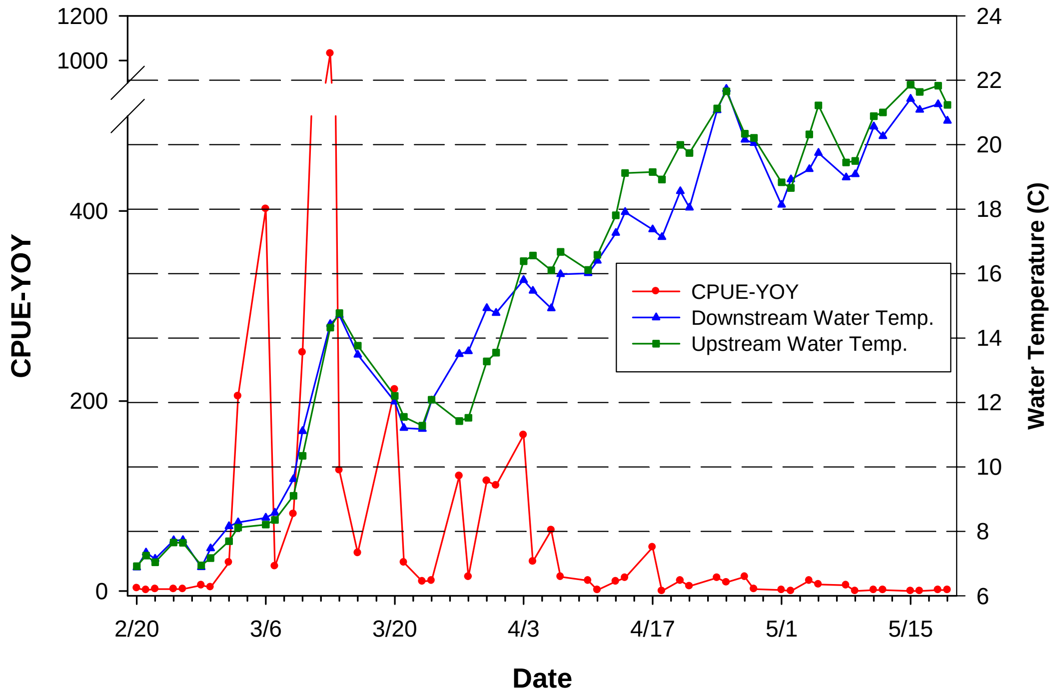


Figure 17. Daily glass eel and elver CPUE vs. water temperature (downstream and upstream of trap) for Wareham's Pond (James River) for 2006 (daily catch, non-standardized).



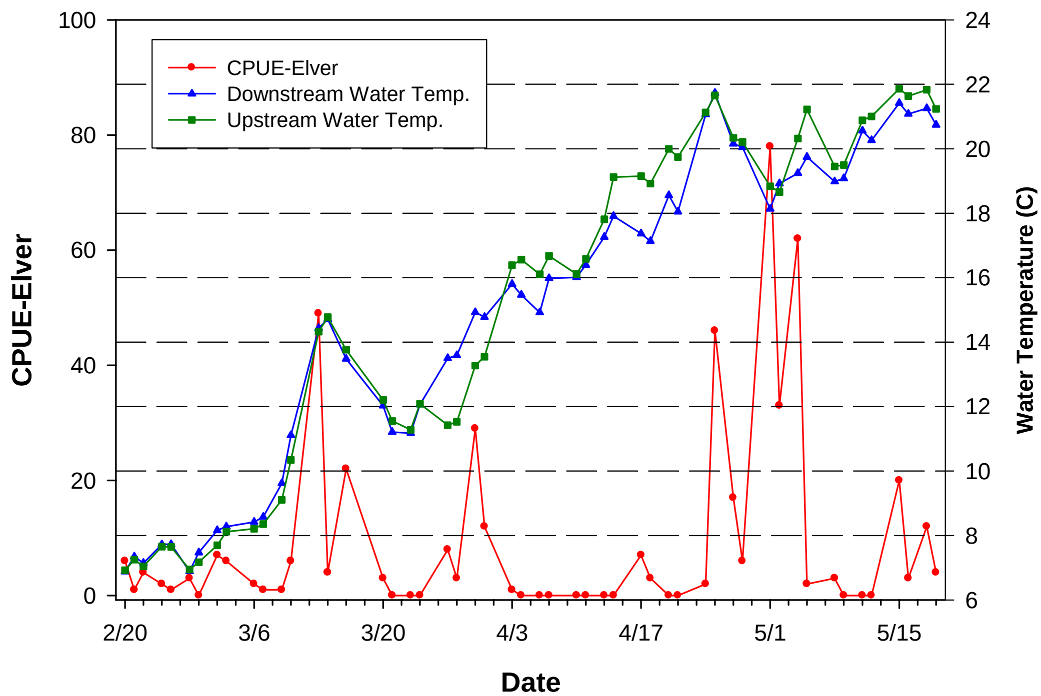


Figure 18. Wormley Pond (York River) glass eel pigmentation stages during the 2006 survey, by week.

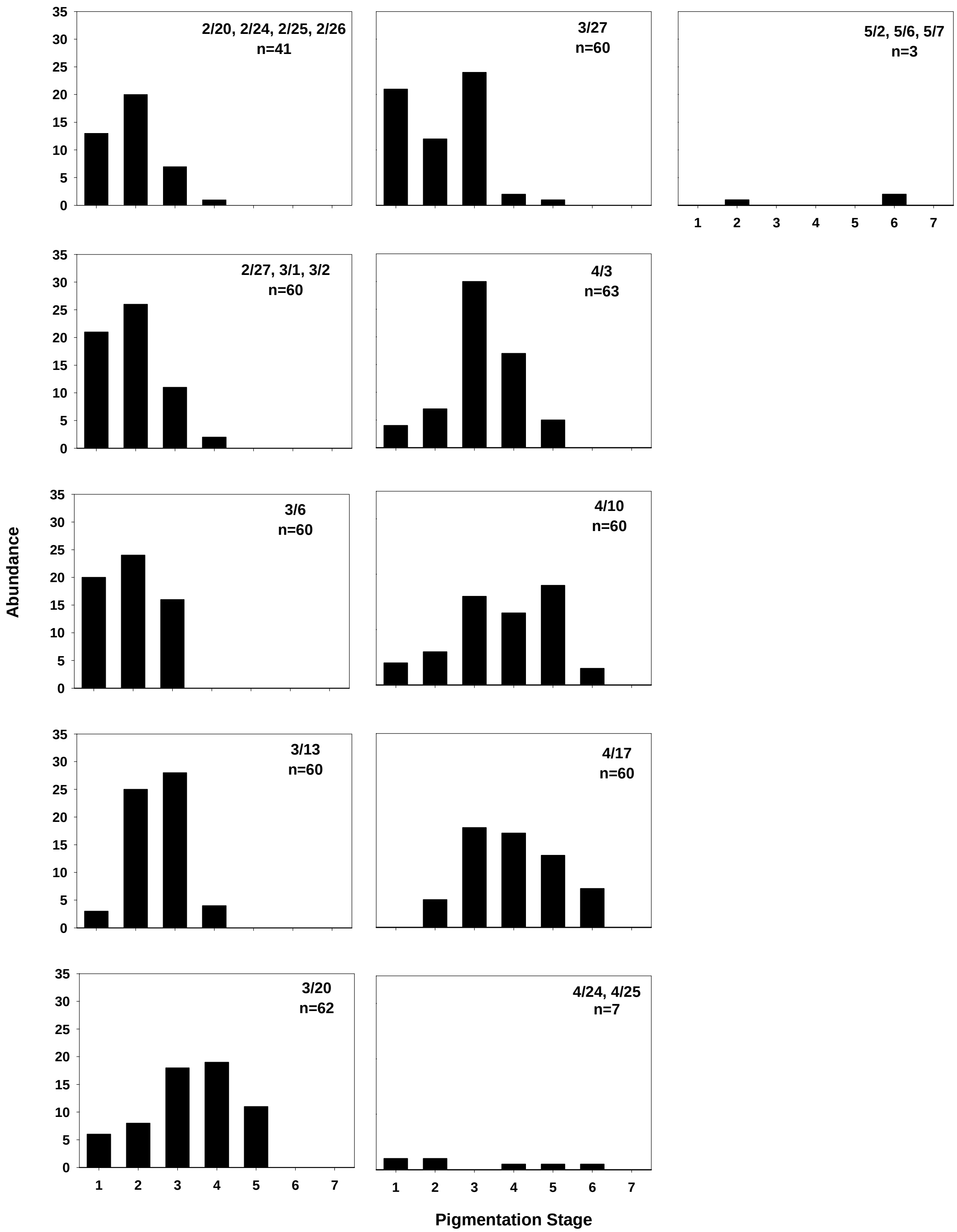


Figure 19. Comparison of pigment stages between the York and Potomac rivers, 2004 -2006.

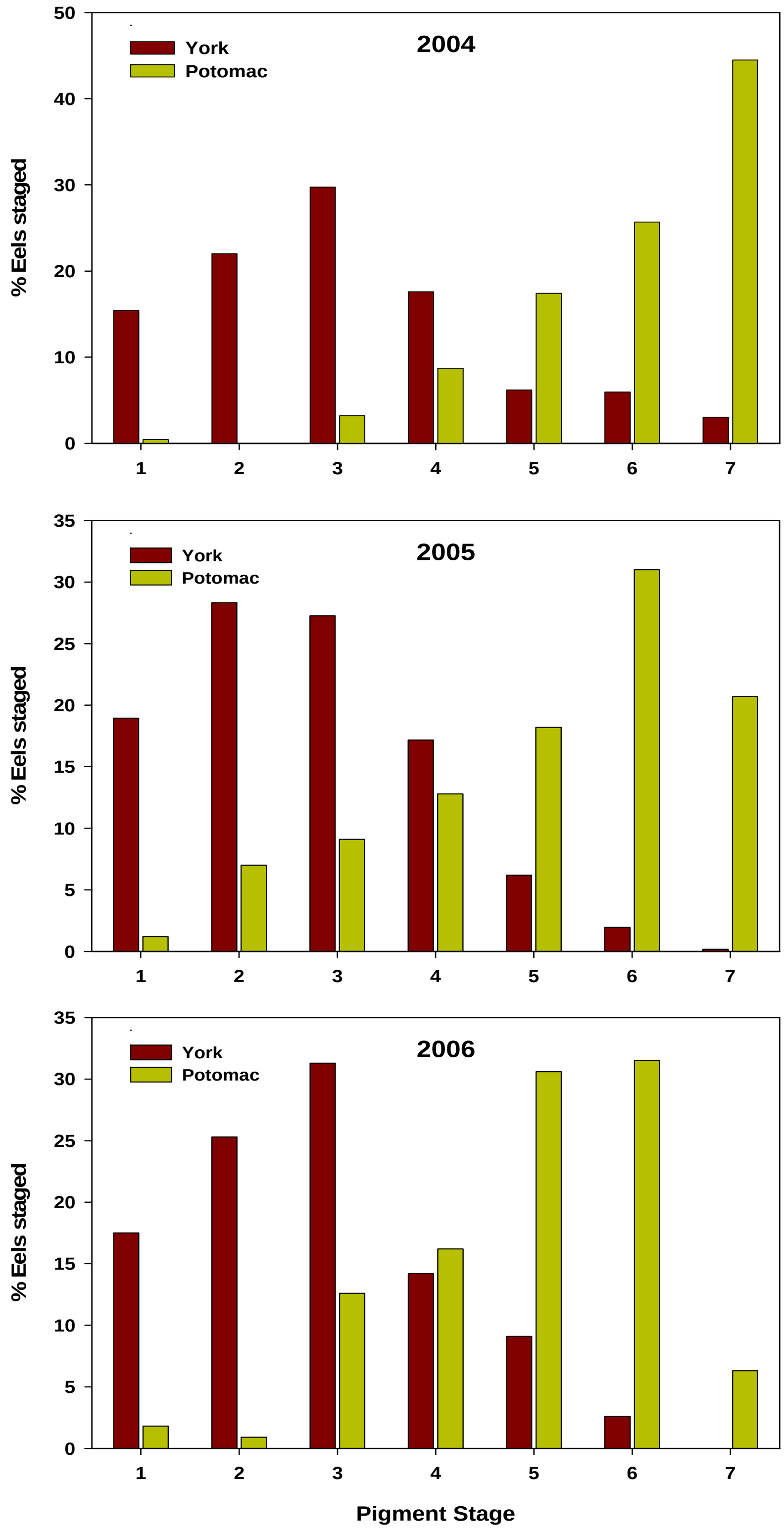


Figure 20. York River glass eel length frequency (2006).

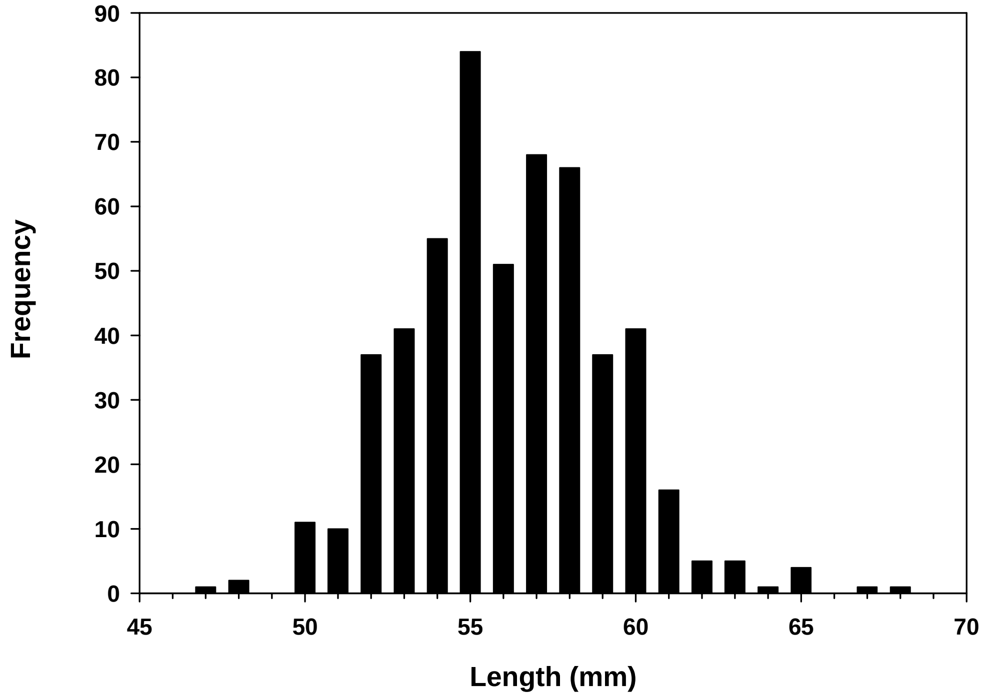


Figure 21. Linear regression of weight vs. length for York River (2006) glass eels.

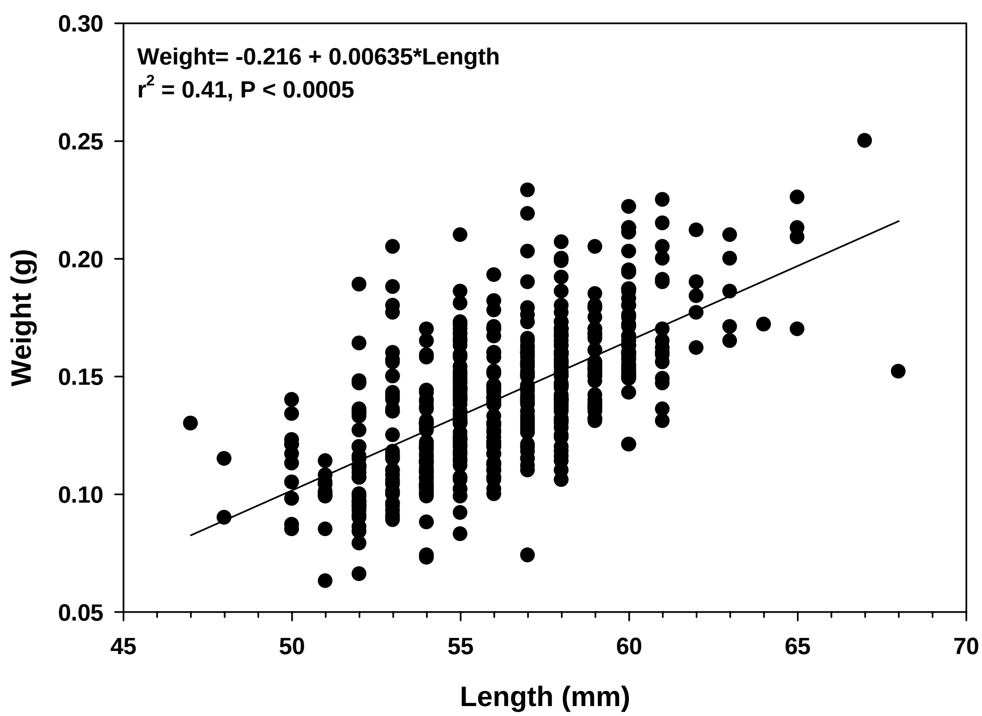


Figure 22. Mean length, weight and condition index (K) for York River glass eels, 2002-2006. Error bars denote standard error, dashed line denotes trend or regression lines.