Estimating Relative Abundance of Young of Year American Eel, *Anguilla rostrata*, in the Virginia Tributaries of Chesapeake Bay.

Final Report

Submitted by

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Introduction

Measures of juvenile recruitment success have long been recognized as a valuable fisheries management tool. In the Chesapeake Bay, these measures provide reliable indicators for future year class strength for blue crabs (Lipcius and Van Engel, 1990), striped bass (Goodyear, 1985), as well as 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 (Meister and Flagg, 1997). Since 1964, Chesapeake Bay landings have significantly decreased. 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). Some fishery independent indices have shown a decline in American eel abundance in recent years (Richkus and Whalens, 1999), particularly in Virginia (Geer, 2003; Montane et al., 2004). 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). 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).

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 methodologies and management efforts. 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 the estuaries from the spawning grounds of the Sargasso Sea.

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 data on the resource and the fishery it supports through both fishery dependent and independent studies. To this end, member jurisdictions (including Virginia) 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 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 2001. Survey results will provide necessary data on coastal recruitment success and further the understanding of American eel population dynamics.

The Virginia Institute of Marine Science's American Eel Monitoring Survey (VIMS AEMS) continued its spring sampling to estimate relative abundance of YOY American eels in Virginia tributaries of Chesapeake Bay. Funding was provided by the VMRC MRFAB and CFAB, which ensured compliance with the 1999 ASMFC Interstate American Eel FMP.

<u>Life History</u>

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 (or young of year, YOY) into Maryland and Virginia rivers and estuaries from February to June, though they are most common in February and March (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). *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). 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 Eel FMP, with the Technical Committee approving sampling gear. The timing and placement of gear must coincide with those periods of peak 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. A minimum of 60 glass eels (if present per system) must be examined for length, weight, and pigment stage weekly.

Due to the importance of the eel fishery in Virginia and the Chesapeake Bay, 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 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*. suitable habitat), which promote glass eel recruitment.

Two sites on the York River were 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 a depth of 50 cm at the spillway. This site could not be sampled in 2000 because the road crossing over the spillway was destroyed by Hurricane *Floyd* and repairs were not completed until Fall 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). Once presence of eels was determined at a site, sampling began. 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. The passive supply of water to the traps through gravity feed required that the water level be considerably higher above the trap than below it, or that water traveling at high velocity be available nearby (Figure 6). Hoses were attached to the ramp and collection buckets with adapters that allowed for quick removal for collecting. Enkamat^{TM} 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 considered 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. Flow over the textured climbing surface was adjusted to maintain a depth of 5-10 mm.

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 Mill Pond) and James River (Wareham's Pond). Only eels found 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 working; 2 = gear working, but not efficiently; 3 = gear not working). 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 'young-of-year' or 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 pigment stage (see Haro and Krueger, 1988) were collected from 60 eels from each system weekly.

Sampling was conducted from 18 February to 18 May 2004 at Wormley and Brackens Ponds, 23 February 2004 to 18 May 2004 at Wareham's Pond and 8 March 2004 to 24 May 2004 at Kamp's Millpond.

For analyses, a daily and annual catch per unit effort (CPUE) was established for each site. CPUE for the Irish eel ramp was catch standardized per 24 hours of soak time and were calculated as geometric means. 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 and discharge (Brackens Pond only). CPUE was also examined as log-transformed (log x + 1) CPUE, but is 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.

Results

CPUE for YOY varied over the five years sampled, when both Brackens and Wormley were combined, though the elver mean was fairly consistent (Table 1; Figure 7). Since 2000, YOY CPUE exhibited an increasing trend while the elver time series did not exhibit a trend (Figure 7 top and bottom).

In 2004, eel YOY CPUE in the York River increased at Wormley Pond, and decreased at Brackens Pond (Figure 8A, top) compared to 2003. Since 2000, Wormley YOY CPUE showed an increasing trend and Brackens a decreasing one. Elver CPUE decreased at Brackens Pond from 2003 to 2004, and showed a decreasing trend since 2000 (Figure 8, bottom). Wormley Pond elver CPUE increased in 2004 compared to 2003 and no trend existed for the time series (Figure 8, bottom). Both Kamp's and Wareham's YOY CPUE decreased in 2004 compared to 2003 (Figure 9, top). In 2004, elver CPUE decreased at Kamp's Millpond and increased at Wareham's Pond (compared to 2003) with both sites exhibiting an overall increasing trend with respect to elver CPUE for the time series (Figure 9, bottom).

Eel YOY at Wormley Pond were first collected 20 February 2004 (Figure 10, top) and most peaks in YOY CPUE were variable from 2 March to 20 March 2004. YOY were first collected at Brackens Pond on 21 February, with peaks in early to mid-April (Figure 10, top). Elvers at Wormley and Brackens Ponds were first collected on 21 February (Figure 10, bottom). Brackens elver CPUE were highly variable over time while five peaks in elver CPUE occurred at Wormley throughout the 2004 season (Figure 10, bottom).

Eel YOY were first collected at Kamp's Millpond (Rappahannock River) 2 April with peaks in CPUE in mid April (Figure 11, top). Elver CPUE was highest late March, mid-April and mid-May (Figure 11, bottom). Eel YOY were first collected at Wareham's Pond (James River) 8 March, with CPUE exhibiting four peak periods throughout the survey (Figure 12, top).

Elvers were also first collected 8 March at Wareham's Pond and exhibited major peaks mid-April (Figure 12, bottom).

Statistically, CPUE by lunar quarter was variable but usually highest during the week of the full moon (stage 3) for most of the sites (see Figures 10-12). At Brackens Pond, YOY CPUE was double that of the other quarters during the week of the full moon. At Wormley Creek, YOY CPUE was highest during the week of the full moon, while elver CPUE was highest during during the week of the waxing moon (Figure 10, top). CPUE at Kamp's Millpond was highest during the week of the new moon for both elvers (significant at $P = 0.029$) and glass eels. At Wareham's Pond, significantly more glass eels were collected during the week of the full moon ($P = 0.006$), than the other lunar quarters. Nearly significantly more elvers were collected during the week of the waning moon ($P = 0.057$), than the other lunar quarters.

Effects of water temperature on CPUE were highly variable. Brackens Pond elver CPUE increased significantly with increasing temperature ($r^2 = 0.07$, $P = 0.023$). Brackens Pond YOY CPUE (log transformed) also increased significantly with increasing temperature ($r^2 = 0.12$, $P = 0.003$). Wormley Pond YOY CPUE decreased significantly with increasing temperature ($r^2 = 0.18$, $P = 0.0005$). There was no relationship between water temperature and CPUE of YOY or elvers at Wareham's Pond. At Kamp's Millpond, YOY CPUE increased significantly with increasing temperature ($r^2 = 0.12$, $P = 0.032$).

There was no relationship between Brackens Pond elver or glass eel CPUE or log-transformed CPUE and discharge. Similarly, there was no relationship between elver or glass eel CPUE (or log-transformed CPUE) and precipitation at any of the sites. Only Wormley Creek elvers exhibited any relationship with barometric pressure, YOY CPUE was highly variable compared to barometric pressure (Figure 13). As barometric pressure increased, elver CPUE increased significantly ($r^2 = 0.13$, $P = 0.001$).

Lengths of YOY eels measured ranged from 48 – 67 mm TL (Figure 14). Most of the YOY eels examined were collected from the York River and exhibited the widest size range (Figure 14). There was a significant positive relationship between YOY length and weight for all eels examined (all systems combined; $r^2 = 0.73$, $P < 0.0005$). Linear regressions of weight vs. length by system were very similar (see Figure 15). Pigmentation stages of York River glass eels began as mainly stages 1, 2 and 3 (Figure 16). By mid-March, stages 4 though 6 were also collected (Figure 16). A few stage 7 eels were collected in late April and their numbers increased through mid-May (Figure 16).

At Wareham's Pond, stage 2 through 6 glass eels were collected (Figure 17). Later stage glass eels were collected at Kamp's Millpond (Figure 18). Stages 4-7 predominated later in the survey at Wareham's Pond (Figure 18).

Discussion

Overall CPUE was variable as in previous years (Montane et al., 2003, 2004). CPUE by lunar quarter was variable but usually highest during the week of the full moon (stage 3) for most of the sites. In contrast, catch of the yellow and silver eels in Canada was lowest during the full moon (Cairns and Hooley, 2003). Effects of water temperature on CPUE were also highly variable. In some cases, elver catch was significantly related (Brackens Pond elver and log-transformed glass CPUE), while in others, glass eel CPUE was significantly related to temperature either positively (Brackens Pond log transformed and Kamp's Millpond) or negatively (Wormley Pond). There was no relationship between Brackens Pond elver or glass eel CPUE or log-transformed CPUE and discharge. Similarly, there was no relationship between elver or glass eel CPUE (or log-transformed CPUE) and precipitation at any of the sites. Only Wormley Pond elvers exhibited any relationship with barometric pressure. As barometric pressure increased, elver CPUE increased significantly. Variability in catches between sites may be due to the unique characteristics of each site. The most influential factor possibly being the distance of the sites to the larger adjacent river systems.

Conclusions and Recommendations

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

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Table 1. Catch statistics for 2000-2004 sampling seasons. CPUE is shown as standardized catch per 24 hours of soak time.

Year	Brackens and Wormley YOY	Brackens and Wormley Elver	Brackens YOY	Brackens Elver	Wormley YOY	Wormley Elver	Kamp's YOY	Kamp's Elver	Wareham's YOY	Wareham's Elver
2000	6.57	0.55	13.14	1.01	*	*	0.74	0.06	*	*
2001	10.21	0.52	10.06	0.55	10.42	0.47	3.03	0.78	*	*
2002	7.83	0.55	6.08	0.24	9.37	0.83	6.07	0.86	*	*
2003	7.67	0.59	10.84	0.76	4.61	0.41	2.92	2.75	2.17	0.31
2004	11.74	0.55	9.02	0.47	14.46	0.62	0.96	0.75	0.46	0.62

Figure 1. 2004 American Eel Sampling Sites.

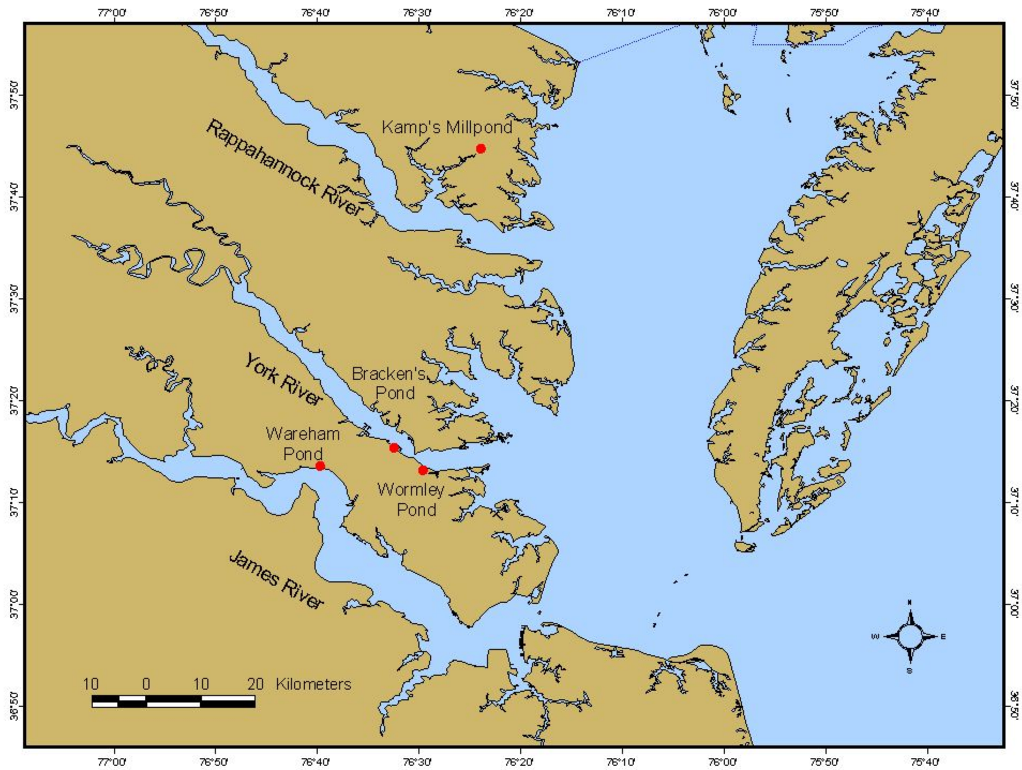


Figure 2. Brackens Pond spillway and tailrace. Irish ramp was set against the right wall on upstream end of culvert.

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. An Irish eel ramp showing its configuration. The arrows indicate the flow of water as well as eel movement.

Figure 7. Eel YOY (top) and Elver (bottom) CPUE for Brackens and Wormley Pond (York River) combined, 2000-2004.

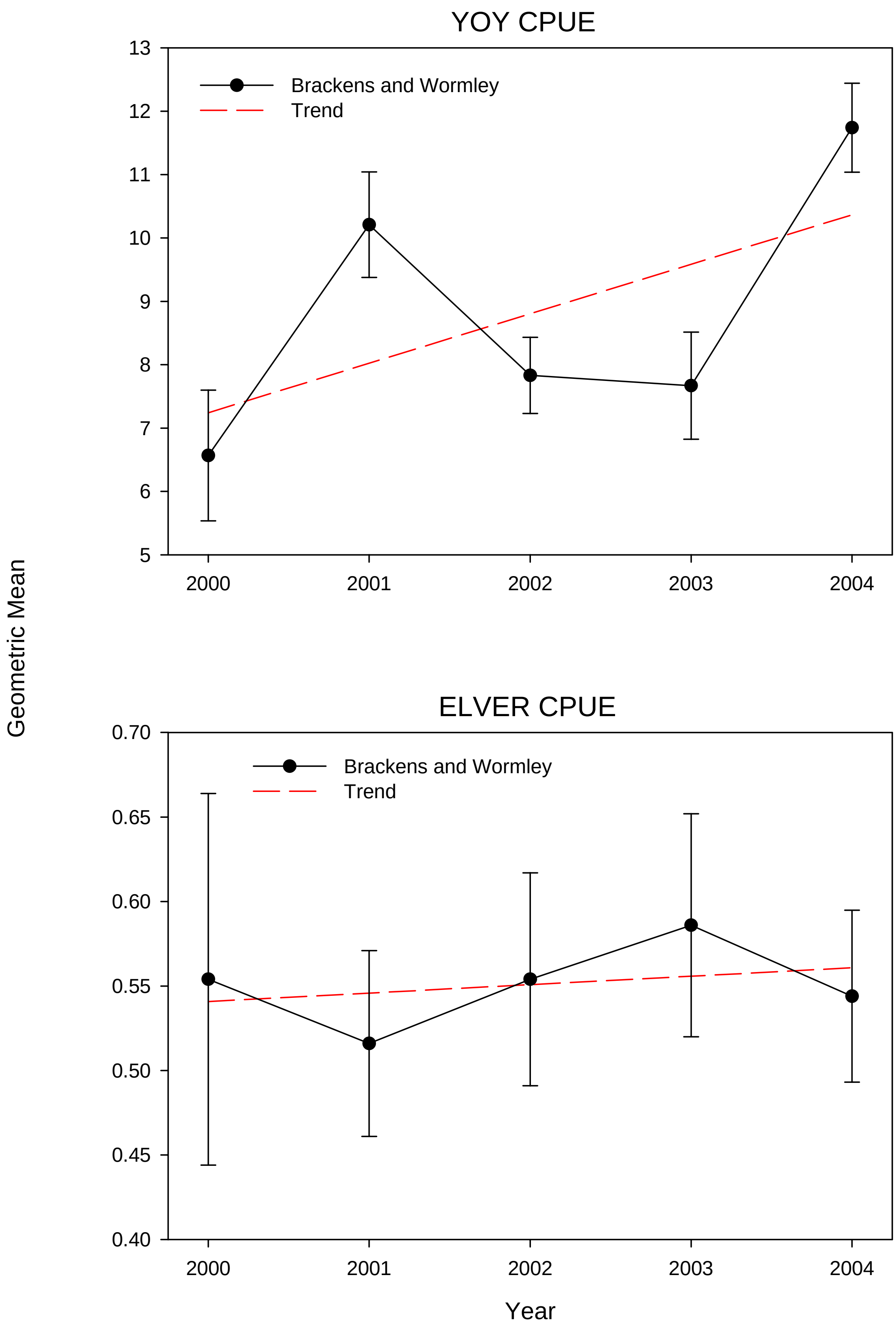


Figure 8. Eel YOY (top) and Elver (bottom) CPUE for Brackens Pond and Wormley Pond (York River) separately, 2000-2004.

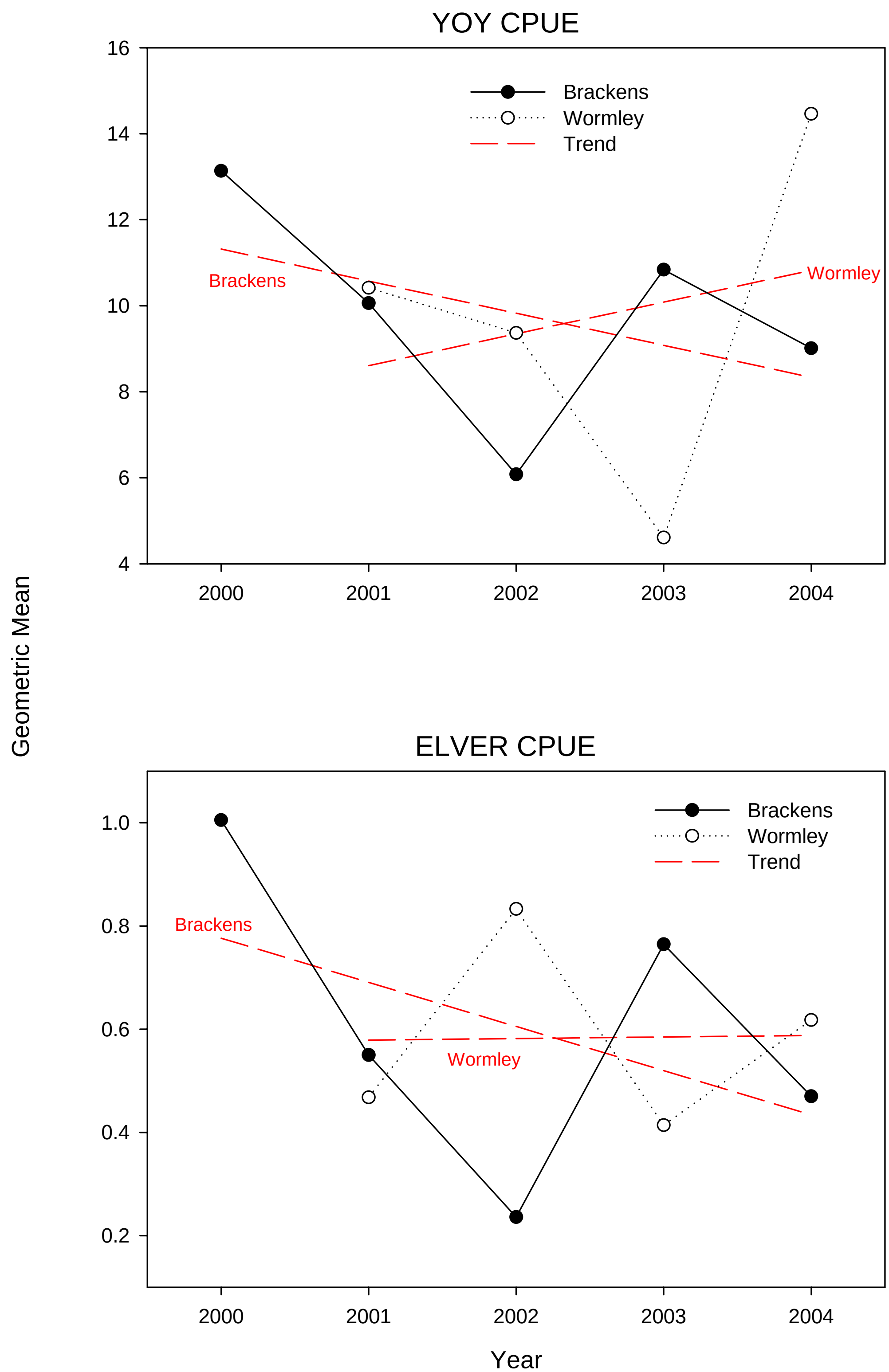


Figure 9. Eel YOY (top) and Elver (bottom) CPUE for Kamp’s Millpond (Rappahannock River) and Wareham’s Pond (James River) separately, 2000-2004.

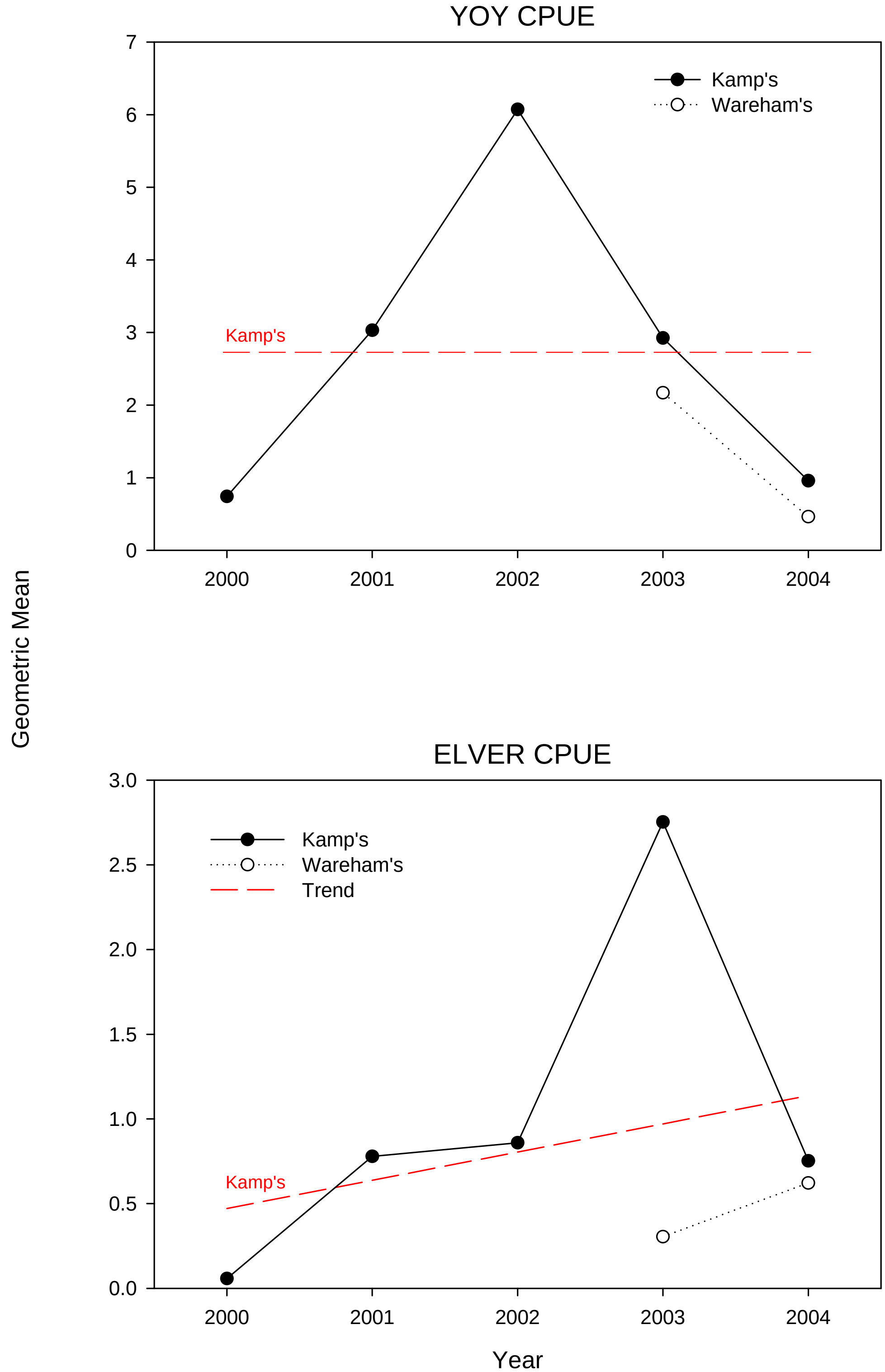
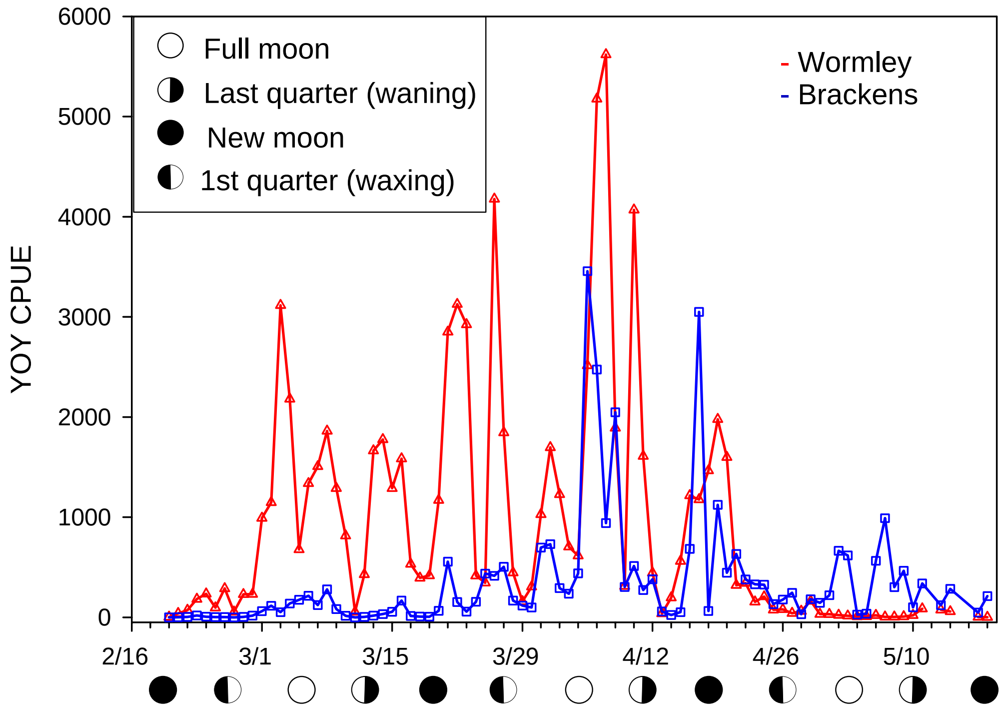


Figure 10. York River (Brackens and Wormley Ponds) Eel YOY (top) and elver (bottom) CPUE, for duration of study, by site (Spring 2004).



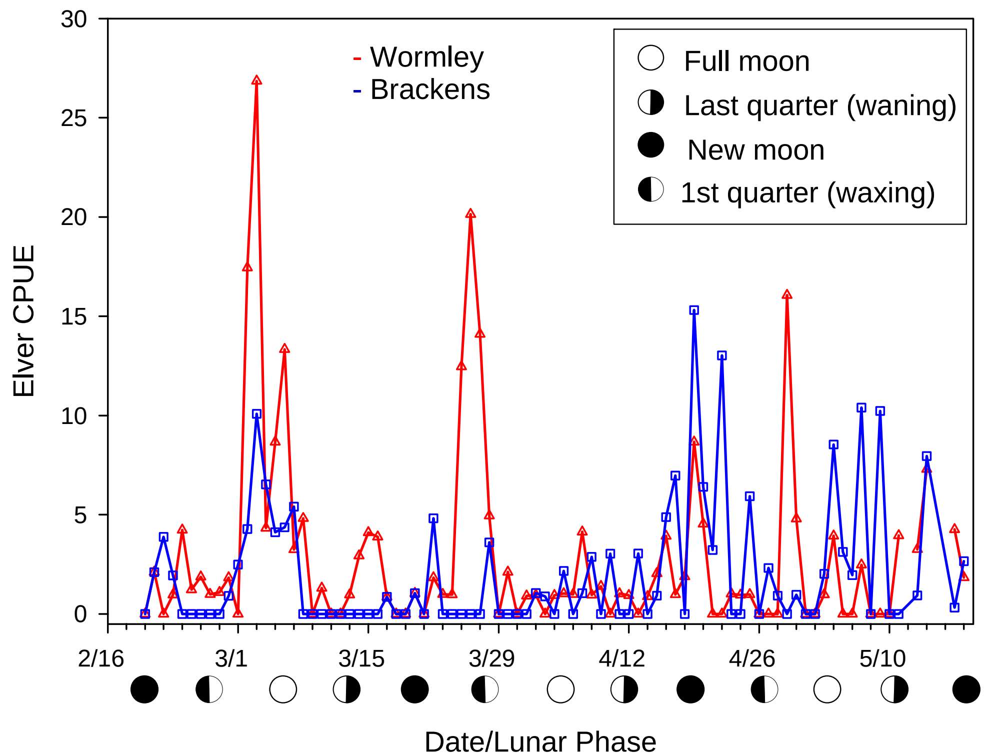


Figure 11. Rappahannock River (Kamp's Millpond) Eel YOY (top) and Elver CPUE (bottom) for duration of study (Spring 2004).

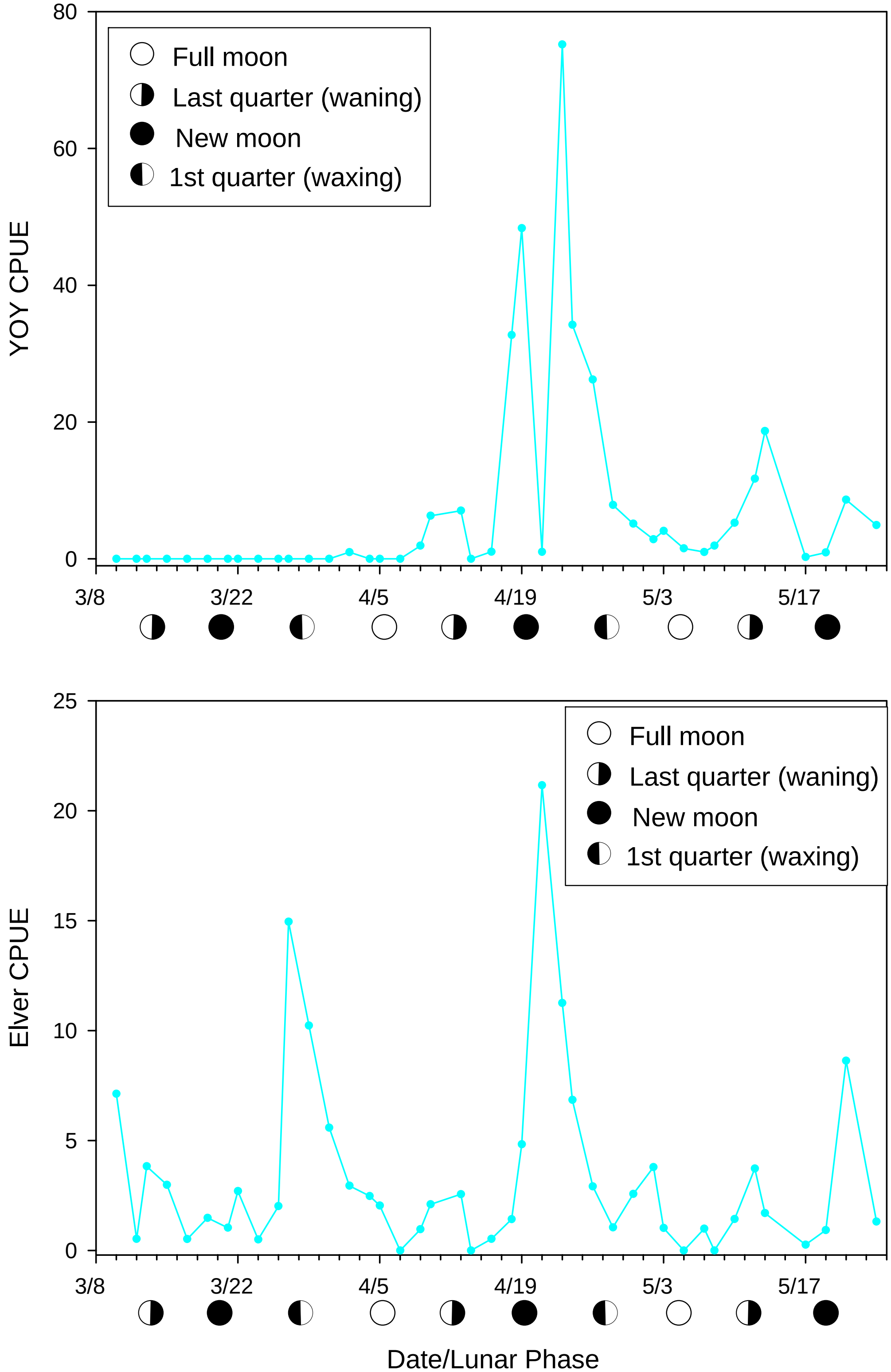


Figure 12. James River (Wareham's Pond) Eel YOY (top) and Elver CPUE (bottom) for duration of study (Spring 2004).

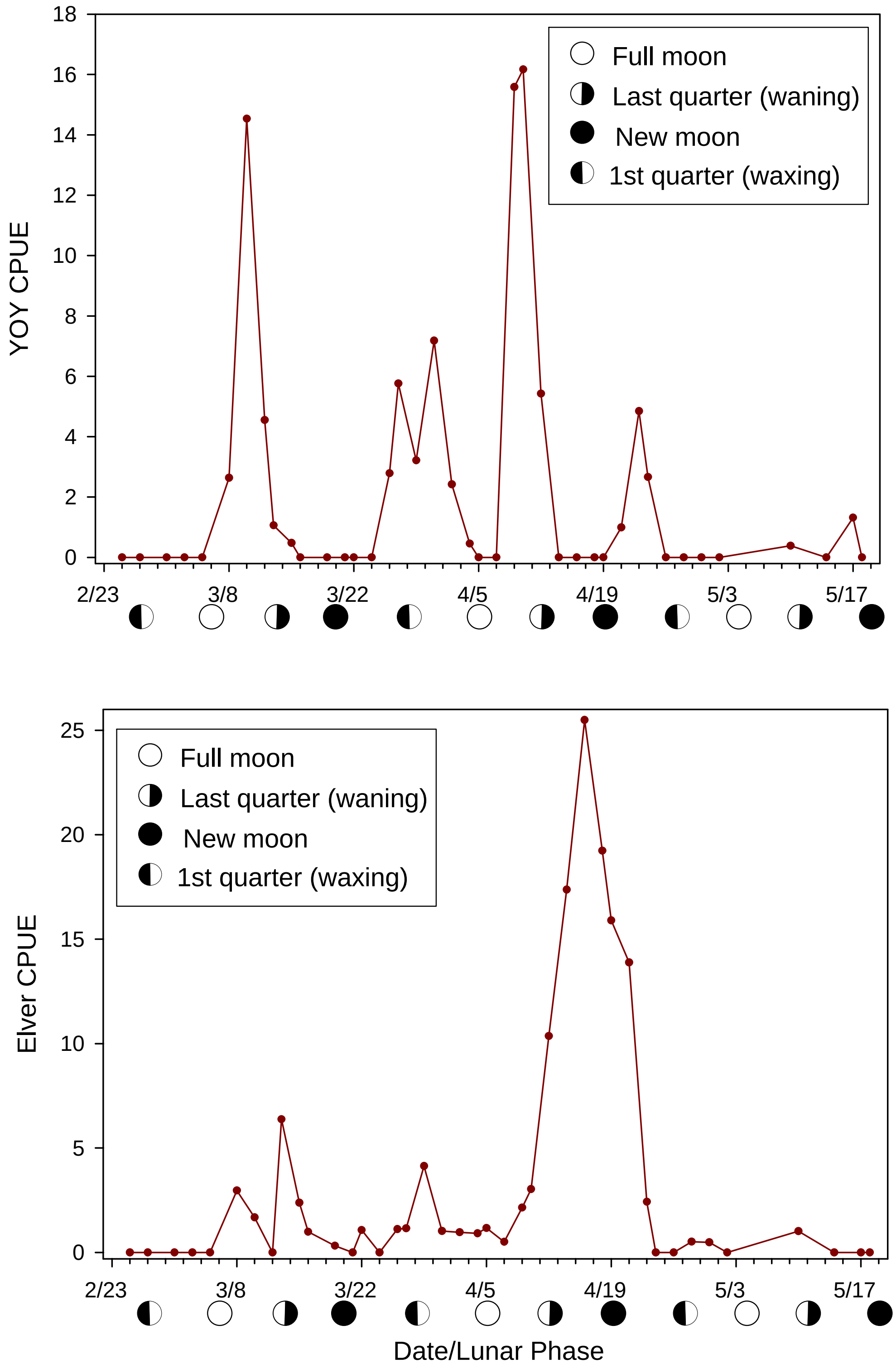
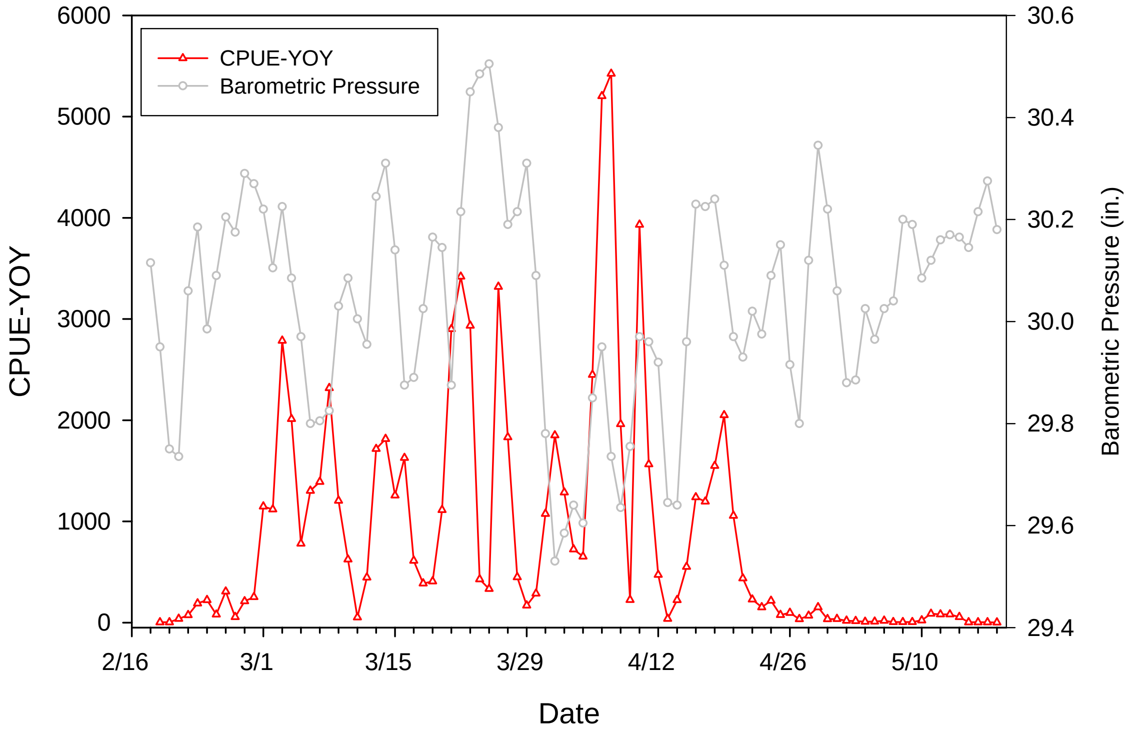


Figure 13. YOY and Elver CPUE vs. Barometric Pressure at Wormley Pond.



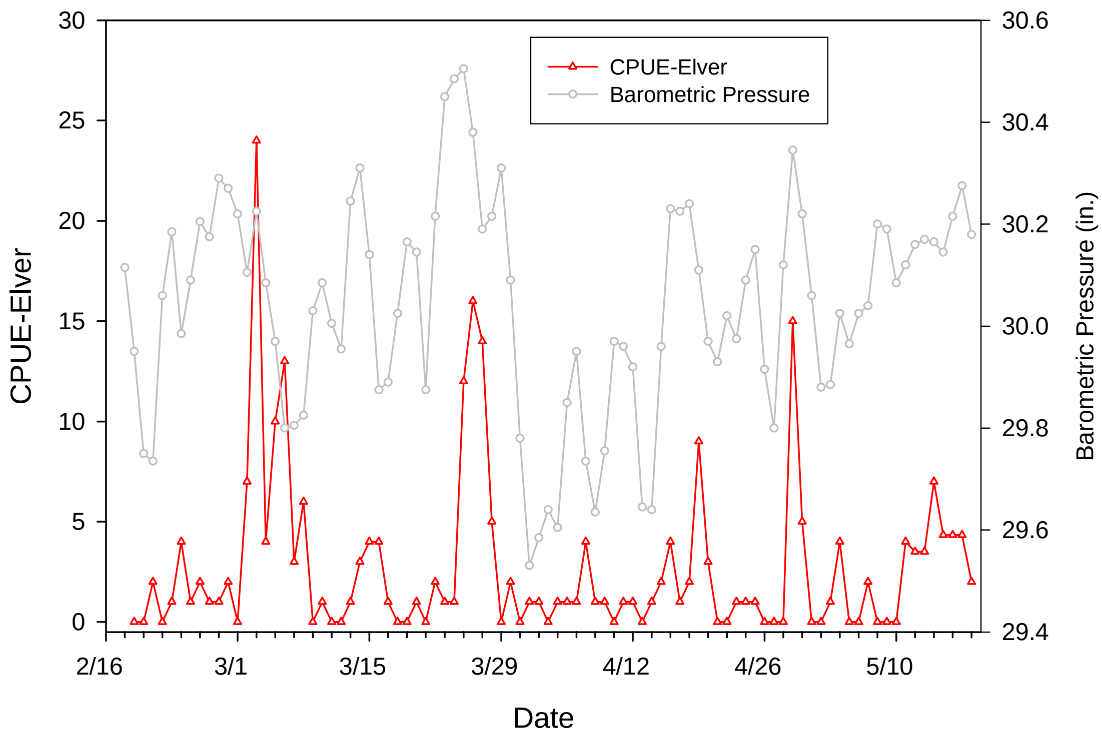


Figure 14. Glass eel length frequency (all rivers combined) for 2004 survey.

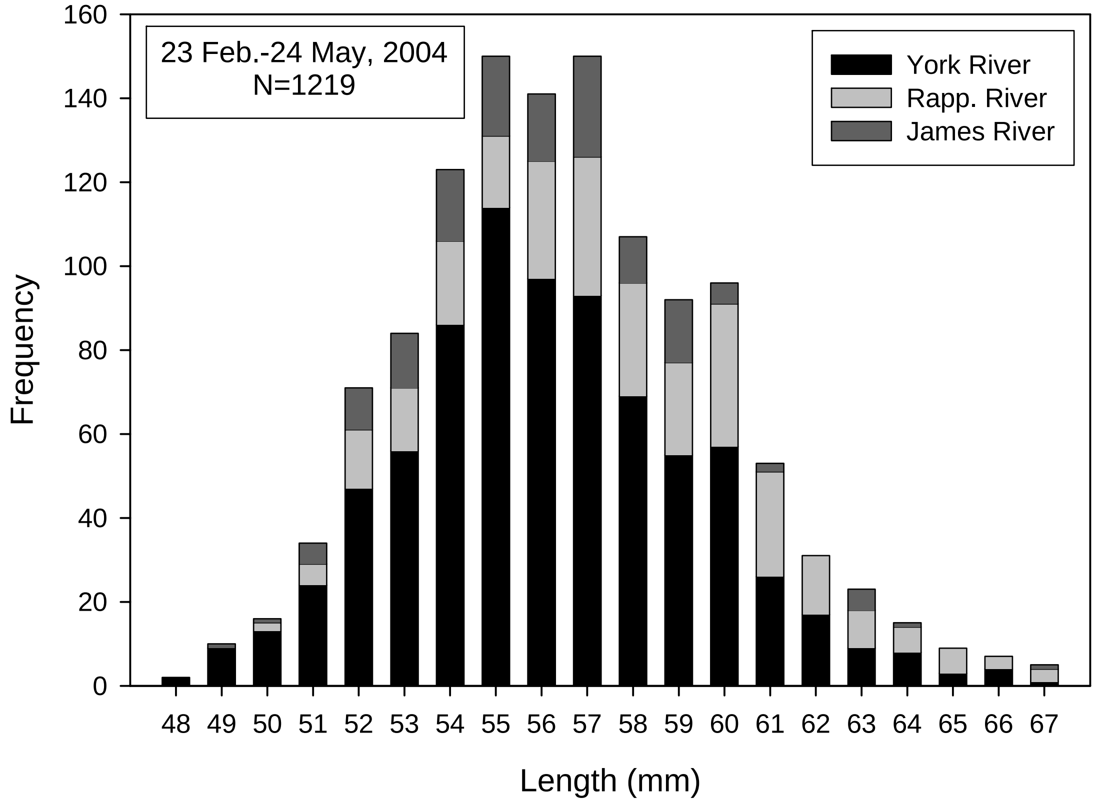


Figure 15. Linear regression of weight vs. length for glass eels, by river.

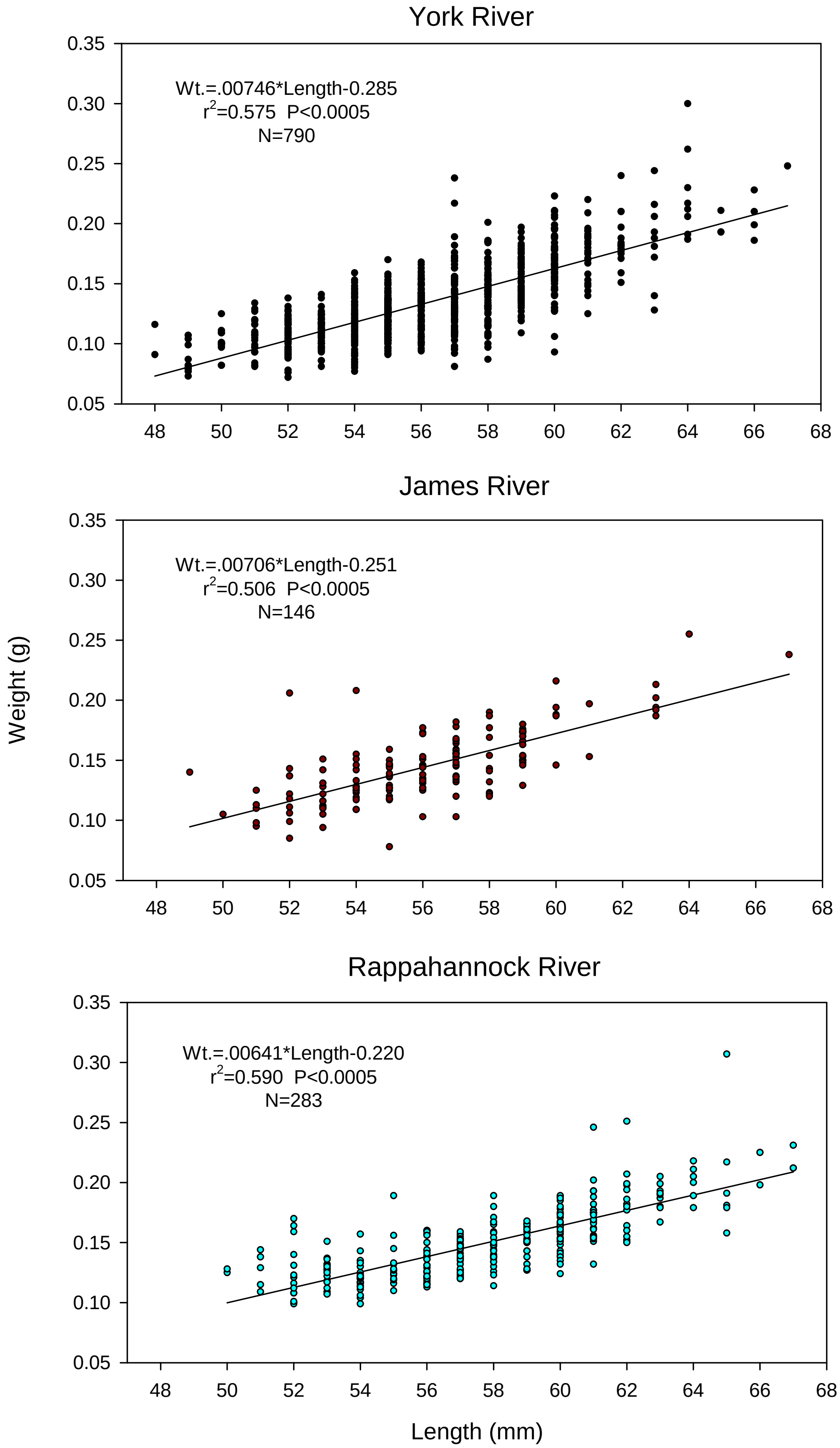


Figure 16. York River (Wormley Pond) glass eel pigmentation stages during the 2004 survey.

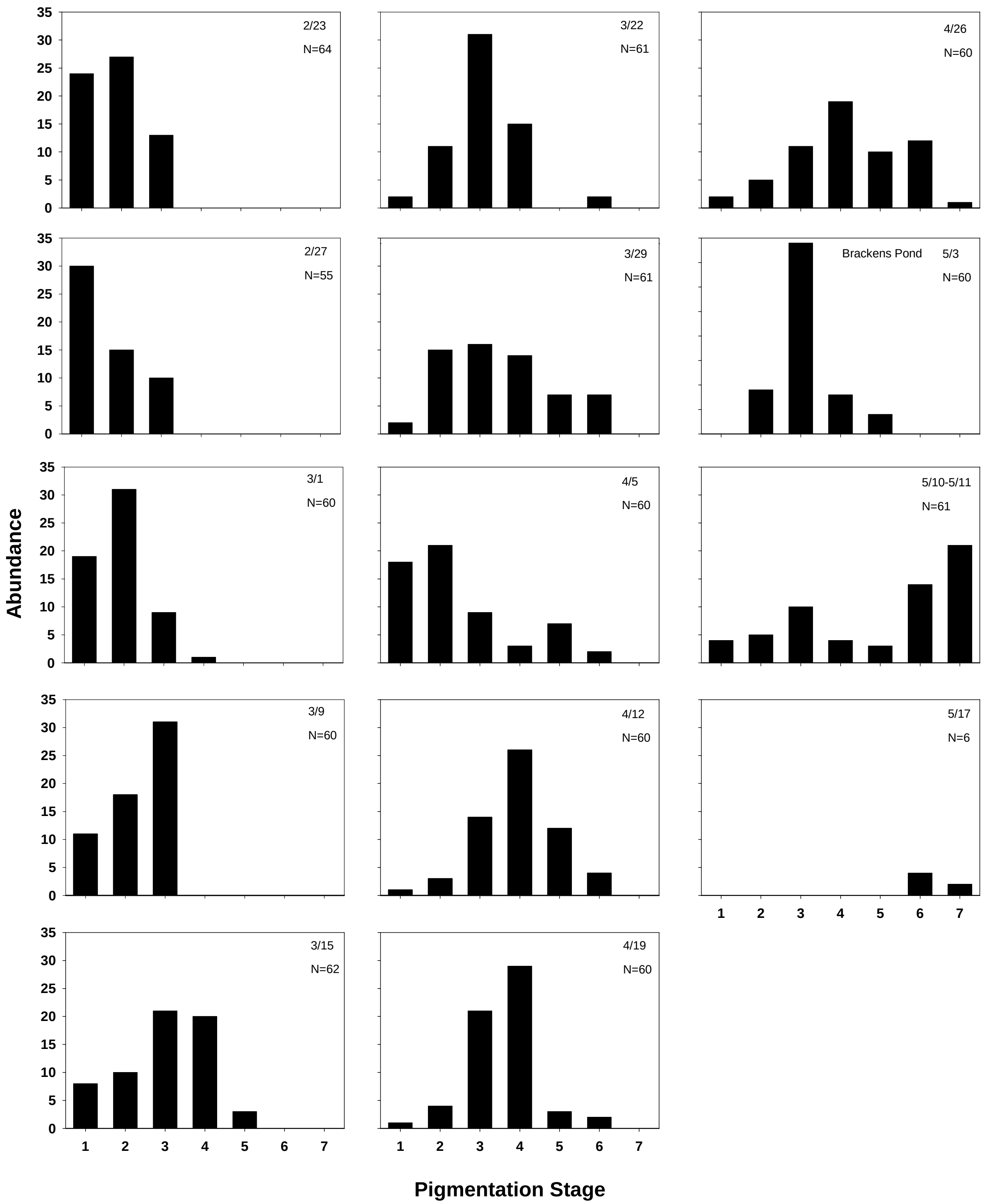


Figure 17. Pigmentation stages of James River glass eels during the 2004 survey.

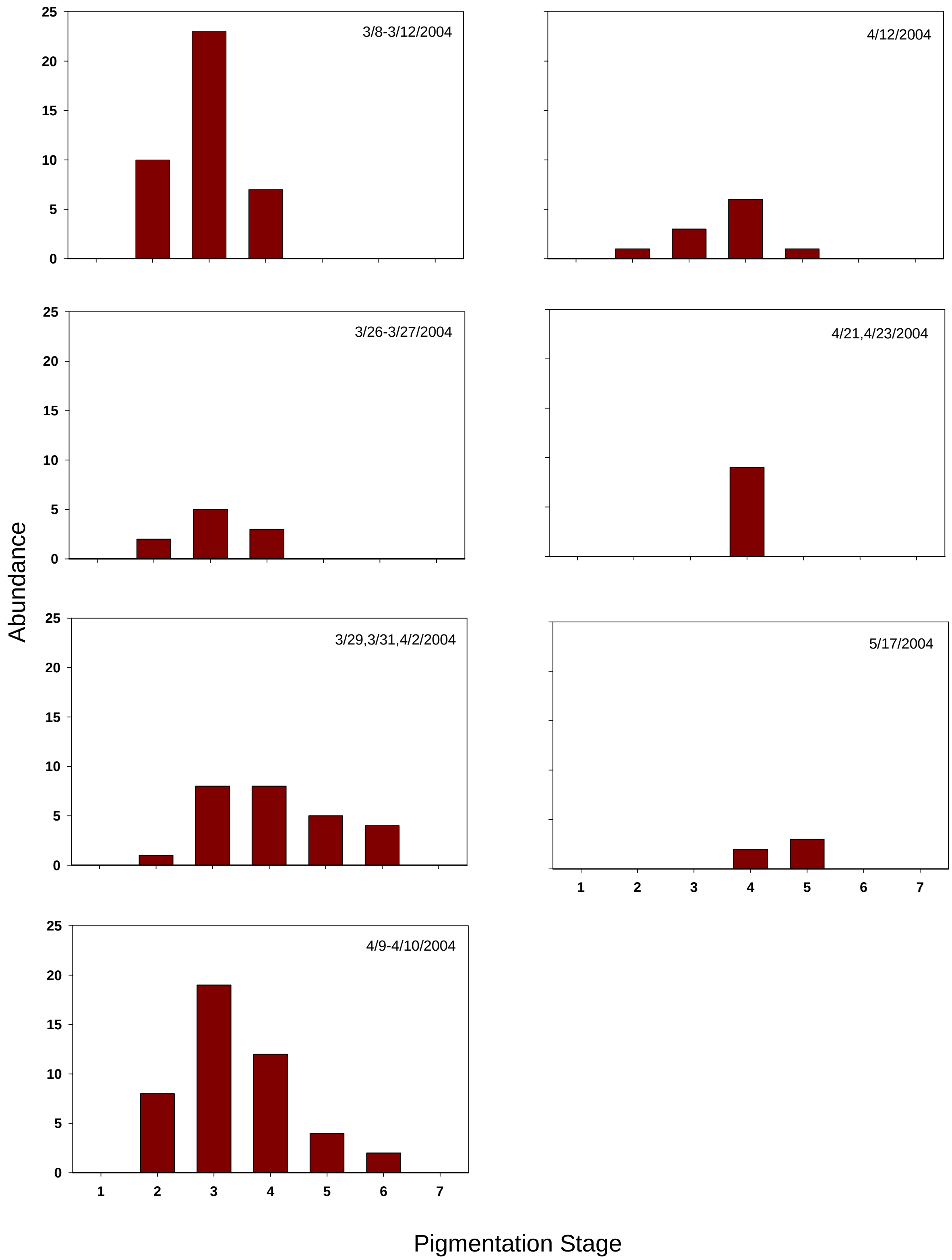


Figure 18. Pigmentation stages of Rappahannock River glass eels during the 2004 survey.