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By

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Table of Contents:

Objectives

The objectives of this study are to:

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

2. examine the influence of tidal, lunar and hydrographic factors on young-of–the-year eel recruitment; and

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

Introduction

Measures of juvenile recruitment success have long been recognized as valuable tools in fisheries management. In Chesapeake Bay, these measures provide reliable indicators of year class strength for species such as blue crab (Lipcius and Van Engel, 1990), striped bass (Goodyear, 1985), and several other recreationally, commercially, and ecologically 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). The Mid-Atlantic states (i.e., New York, New Jersey, Delaware, Maryland, and Virginia) have accounted for the largest portion of the east coast landings (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 U.S. commercial harvest between 1987 and 1996 (ASMFC, 1999).

Harvests of American eel along the U.S. Atlantic Coast have declined in recent years, and similar patterns have been noted in the Canadian Maritime Provinces as well as in Europe with its congener, *A. anguilla* (Ciccotti et al., 1995). Fishery independent indices of abundance have also shown a decline in American eel populations in recent years (Richkus and Whalen, 1999; 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 glass eel recruitment success, these surveys have the potential to provide a more comprehensive understanding of physical and environmental factors affecting the American eel population.

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 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 transparent, leaf-shaped, ribbon-like larvae called leptocephali, which are transported by ocean currents (over 9-12 months) in a northwesterly direction. Within a year, metamorphosis into the glass eel stage occurs in the Western Atlantic near the east coast of North America. Coastal currents and active migration transport these glass eels into the rivers and estuaries of Virginia and Maryland from February to July. 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 fresh-to-brackish water habitats as a yellow eel. Upon maturity, eels migrate back to the Sargasso Sea to spawn and subsequently perish (Haro et al., 2000). It is during this migration, usually occurring from late summer through 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 migration occurs 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).

Methods

The FMP established the following minimum criteria for the sampling of 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.

Due to the importance of the eel fishery in Virginia and the Potomac River, efforts to quantify glass eel recruitment must ensure proper temporal and spatial sampling coverage. Numerous sites in both Virginia and Maryland were evaluated at the outset of the survey to provide the necessary spatial coverage and to assess suitable locations (Geer, 2001). Final site selection was based on known areas of glass eel recruitment, accessibility, and specific physical criteria suitable for recruitment to the sampling gear. The Maryland sampling of the Potomac River (northern shore site) was discontinued in 2001, due in part to the low catch rates (Geer, 2001). At the request of PRFC, the Virginia Institute of Marine Science (VIMS) has sampled two sites on the Potomac River's south shore (i.e., Gardy's Millpond and Clark's Millpond; Figure 1) from 2000 through 2007.

Eels were collected using Irish eel ramps (Figure 2) at both sites. Irish eel ramps are an approved gear as stated in the FMP (ASMFC, 1999). The configuration of these ramps (as described below) successfully attracts and captures glass eels and elvers in tidal waters of Chesapeake Bay. Ramp operation required continuous, gravity fed flow of water over the climbing substrate and through the collection device. Hoses were attached to the ramp and collection buckets with common poly vinyl chloride (PVC) pipe fittings, which allowed quick adjustment, removal and replacement during collection. Enkamat™ erosion control material was affixed to the floor of the ramp and allowed to extend into the water below the ramp to provide a textured climbing surface. The ramps were placed on an incline (15-45^o), often on land, with the ramp entrance and textured mat extending into the water. This 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 regularly adjusted to maintain minimal depth and proper velocity.

Traps were checked four days per week (generally Monday, Tuesday, Thursday and Friday), and only those eels captured in the ramp's collection bucket 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, wind speed, and precipitation were recorded during site visits. In addition, temperature data loggers (Stowaway Tidbits™) recorded hourly water temperature at each site. 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. Lengths, weights, and pigment stage (as described by Haro and Krueger, 1988) were collected from up to sixty eels each week. Glass eels were distinguished from elvers by length and/or pigmentation. Eels less than or equal to 85 mm total length (TL) were classified as glass eels, while those greater than 85 mm TL were classified as elvers. These two distinct length frequency modes likely represent different year classes (Geer, 2001).

Clark's Millpond (Coan River – Northumberland County) was sampled from 27 February to 5 July 2007. The spillway is approximately one meter above the creek. It was necessary to modify the ramp extension to allow eels total access to the spillway due to the steady and strong stream flow at this site (Figure 3). Gardy's Millpond (Yeocomico River – Northumberland County) was sampled over the same time span (Figure 4). The site contains a spillway that drains through four box culverts, across a riffle constructed of riprap and into a lotic area of the Yeocomico River.

Computation of CPUE was modified following a request by ASMFC. Glass eel and elver CPUEs at each site were standardized to a 24 hour soak time for the Irish eel ramp, and geometric means were calculated using the time period in which 95% of the cumulative total catch was sampled (i.e. dates in which 0%-2.5% and 97.5%-100% of the cumulative total catch was collected were excluded), in an effort to account for the interannual variability in the period of maximum recruitment. CPUEs for each of the previous sampling years were recalculated using the aforementioned method which explains any discrepancies in the CPUEs provided here and those given in previous reports.

Results and Discussion

A daily catch per unit effort (geometric mean CPUE) was calculated for each site as well as for both sites combined. Potomac River (Clark's and Gardy's Millponds combined) CPUEs for both glass eels and elvers have varied through time with glass eels exhibiting a slight decreasing trend while elvers have exhibited neither an increasing nor decreasing trend (Table 1 A - F; Figure 5). The overall glass eel CPUE in 2007 was four times greater than 2006, while the overall elver CPUE decreased threefold (Table 1 A - B; Figure 5).

Glass eel CPUE at Clark's Millpond has shown an increasing trend between 2000 and 2007, whereas elver CPUE has not exhibited an increasing or decreasing trend (Table 1 C-D; Figure 6, top). At Gardy's Millpond, glass eel CPUE has exhibited a significant decreasing trend (Table 1 E; Figure 6, bottom). Elver CPUE at this site has neither increased nor decreased since 2000 (Table 1 F; Figure 6, bottom).

Initial arrival and migration of glass eels may be correlated to large increases in water temperature, while elver migration may be delayed at freshwater interfaces until certain behavioral and physiological changes have occurred (Sorensen and Bianchini, 1986). As water temperature increased, the number of glass eels captured at Clark's Millpond increased, though a large spike in catch did not occur until the water temperature reached 25^{o} C (Figure 7, top). Elver catches at this site occurred regularly throughout the survey without obvious relationship to water temperature (Figure 7, bottom). At Gardy's Millpond there did not appear to be any relationship between glass eel catch and water temperature (Figure 8, top), as only a single large collection occurred during sampling. Elvers were captured throughout the sampling period without an obvious relationship to water temperature (Figure 8, bottom).

At Clark's Millpond, a large influx of glass eels occurred during the last month of the survey, although specimens were collected in smaller numbers beginning early April (Figure 9, top). There was no apparent relationship between glass eel catch and lunar phase (Figure 9, top) at this site. Elvers collections at Clark's Mill also appeared to be independent of lunar phase (Figure 9, bottom). Visual inspection of the data again revealed no relationship between lunar phase and catch of either glass eels or elvers at Gardy's Millpond (Figure 10).

Glass eels exhibiting pigmentation stages 3 through 7 were collected (Figures 11 and 12). Only three stage 3 eels were collected, and all were sampled from Gardy's Millpond. The more developed stages (5 through 7) were collected at both Clark's and Gardy's Millponds later in the survey (Figure 12). The pigmentation stages of eels sampled from the Potomac River sites were, in general, more advanced than those collected from James and York River sites (VIMS American Eel Survey, unpublished data) possibly due to the greater distance and, in turn, longer migration period necessary to reach the middle Chesapeake Bay. As found in previous years, glass eel weight increased with length (Figure 13). Long term (20+ years) glass eel recruitment studies in both North Carolina and New Jersey have suggested glass eel lengths have been decreasing (M. Sullivan, pers. comm.). This does not seem to be the case in the Potomac River, however (Figure 14). Glass eel condition, analyzed using the Fulton Condition Index (K) described in Anderson and Neumann (1996), reveals a trend toward more robust individuals (i.e., increasing weight at a given length).

The timing of glass eel recruitment is highly variable from year to year, as is CPUE. Thus, a very productive site one year may be unproductive the next and vice versa, reinforcing the need for a long term continual time series of data. Much of the variability associated with eel recruitment in Chesapeake Bay remains an unknown due to the short (i.e., seven years) time series of data available. It is possible, however, that with the addition of several more years of data, from the Potomac and other Virginia tributaries, a comprehensive analysis may reveal trends in American eel recruitment.

Some of the data presented in this report were recently incorporated into the American Eel Stock Assessment. Data collected for this study prior to 2007 were presented at the 2006 American Eel Sampling Workshop in Charleston, SC.

Conclusions and Recommendations

1. Catch per unit effort for glass eels increased at Clark's Millpond and Gardy's Millpond during 2007 compared to 2006. Elver CPUE decreased at both sites. Visual inspection of the data did not reveal an obvious relationship between CPUE and lunar phase.

2. Irish eel ramps remain an effective gear for sampling glass eels in coastal Virginia.

3. Sampling should begin in March and continue until peak recruitment has occurred. Peak recruitment in 2007 this did not occur until June.

4. The ultimate goal of this survey is to provide estimates of recruitment for glass eel and elver stage American eels. 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 abundance index for each sampling site. 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 could then be used to weight the catch rates at each site and provide a more reliable abundance estimate.

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Table 1. Potomac River catch statistics by year (2000-2007). Dates and CPUE (geometric mean) for 95% catch.

A. Sites Combined - Glass Eels

SITE	YEAR	Start Date	End Date	Total Catch	Number Used	Trap Days	CPUE Geo Mean	Standard Error
Combined	2000	16-Apr	12-May	306	295	27	4.510	0.280
	2001	8-Apr	24-Apr	733	711	17	11.223	0.467
	2002	29-Mar	27-Apr	244	233	30	5.649	0.138
	2003	9-Apr	13-May	95	87	35	1.886	0.114
	2004	13-Apr	27-May	486	461	45	5.712	0.164
	2005	30-Mar	26-May	317	305	58	4.000	0.095
	2006	20-Mar	21-May	126	119	63	1.373	0.083
	2007	23-Mar	1-Jul	683	619	70	5.877	0.123

B. Sites Combined - Elvers

SITE	YEAR	Start Date	End Date	Total Catch	Number Used	Trap Days	CPUE Geo Mean	Standard Error
Combined	2000	5-Apr	15-May	20	17	41	0.245	0.052
	2001	16-Mar	8-May	829	801	54	9.842	0.112
	2002	15-Mar	27-Apr	363	346	44	5.614	0.127
	2003	17-Mar	8-May	525	503	53	6.868	0.114
	2004	10-Mar	20-May	797	740	72	6.558	0.107
	2005	23-Mar	19-May	375	365	58	5.266	0.073
	2006	10-Mar	21-May	845	821	73	6.367	0.118
	2007	15-Mar	27-Jun	288	275	105	2.030	0.059

C. Clark's Millpond - Glass Eels

SITE	YEAR	Start Date	End Date	Total Catch	Number Used	Trap Days	CPUE Geo Mean	Standard Error
CLARKS	2000	28-Apr	15-May	15	12	18	0.650	0.088
	2001	9-Apr	22-Apr	4	3	14	0.186	0.069
	2002	1-Apr	27-Apr	115	109	27	3.387	0.115
	2003	25-Apr	15-May	24	22	21	0.902	0.090
	2004	21-Apr	27-May	447	430	37	6.006	0.179
	2005	13-Apr	26-May	223	213	44	3.311	0.128
	2006	6-Apr	22-May	80	77	47	1.311	0.079
	2007	26-Apr	1-Jul	435	379	67	3.934	0.122

D. Clark's Millpond - Elvers

SITE	YEAR	Start Date	End Date	Total Catch	Number Used	Trap Days	CPUE Geo Mean	Standard Error
CLARKS	2000	5-Apr	15-May	5	3	41	0.078	0.022
	2001	19-Mar	10-May	205	196	53	2.711	0.099
	2002	13-Mar	21-Apr	90	83	40	1.810	0.071
	2003	17-Mar	8-May	225	213	53	2.165	0.140
	2004	2-Apr	23-May	314	299	52	3.029	0.153
	2005	28-Mar	24-May	62	59	58	0.773	0.068
	2006	15-Mar	24-May	153	146	71	1.351	0.081
	2007	15-Mar	27-Jun	90	85	105	0.646	0.045

E. Gardy's Millpond - Glass Eels

SITE	YEAR	Start Date	End Date	Total Catch	Number Used	Trap Days	CPUE Geo Mean	Standard Error
GARDYS	2000	16-Apr	27-Apr	291	262	12	18.266	0.183
	2001	8-Apr	24-Apr	729	707	17	10.956	0.471
	2002	29-Mar	25-Apr	129	122	28	2.281	0.190
	2003	7-Apr	13-May	71	68	37	1.407	0.103
	2004	2-Apr	18-May	39	38	47	0.612	0.071
	2005	28-Mar	5-May	94	89	39	1.462	0.126
	2006	17-Mar	11-May	46	39	56	0.419	0.066
	2007	23-Apr	27-Jun	248	237	66	1.590	0.120

F. Gardy's Millpond - Elvers

SITE	YEAR	Start Date	End Date	Total Catch	Number Used	Trap Days	CPUE Geo Mean	Standard Error
GARDYS	2000	16-Apr	15-May	15	14	30	0.232	0.065
	2001	16-Mar	1-May	624	605	47	7.887	0.135
	2002	15-Mar	27-Apr	273	261	44	3.682	0.154
	2003	19-Mar	6-May	300	280	49	4.248	0.109
	2004	10-Mar	11-May	483	470	63	4.663	0.109
	2005	23-Mar	17-May	313	304	56	4.540	0.072
	2006	10-Mar	14-May	692	672	66	5.300	0.129
	2007	15-Mar	27-Jun	198	190	105	1.320	0.059

Figure List

Figure 1. Potomac River sampling sites.

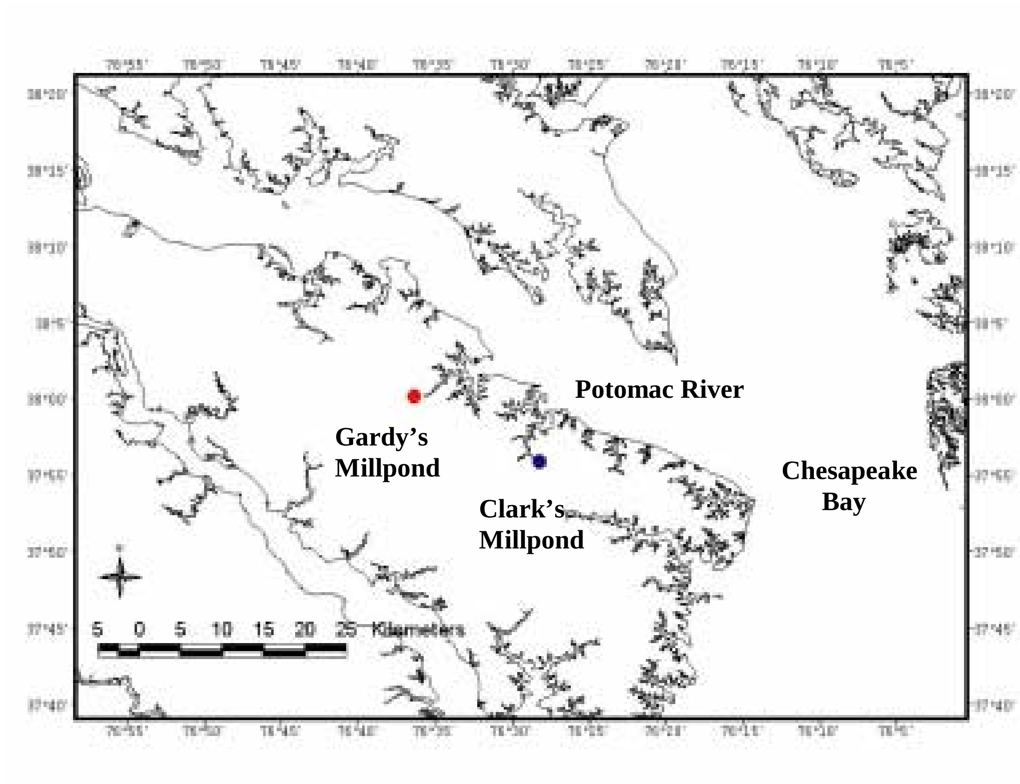


Figure 2. The Irish Ramp at Gardy's Millpond showing its configuration. The arrows indicate the flow of water and eels.

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. This was replaced in 2004 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 geometric mean CPUE for glass eels and elvers (Gardy's Millpond and Clark's Millpond, combined), 2000 - 2007.

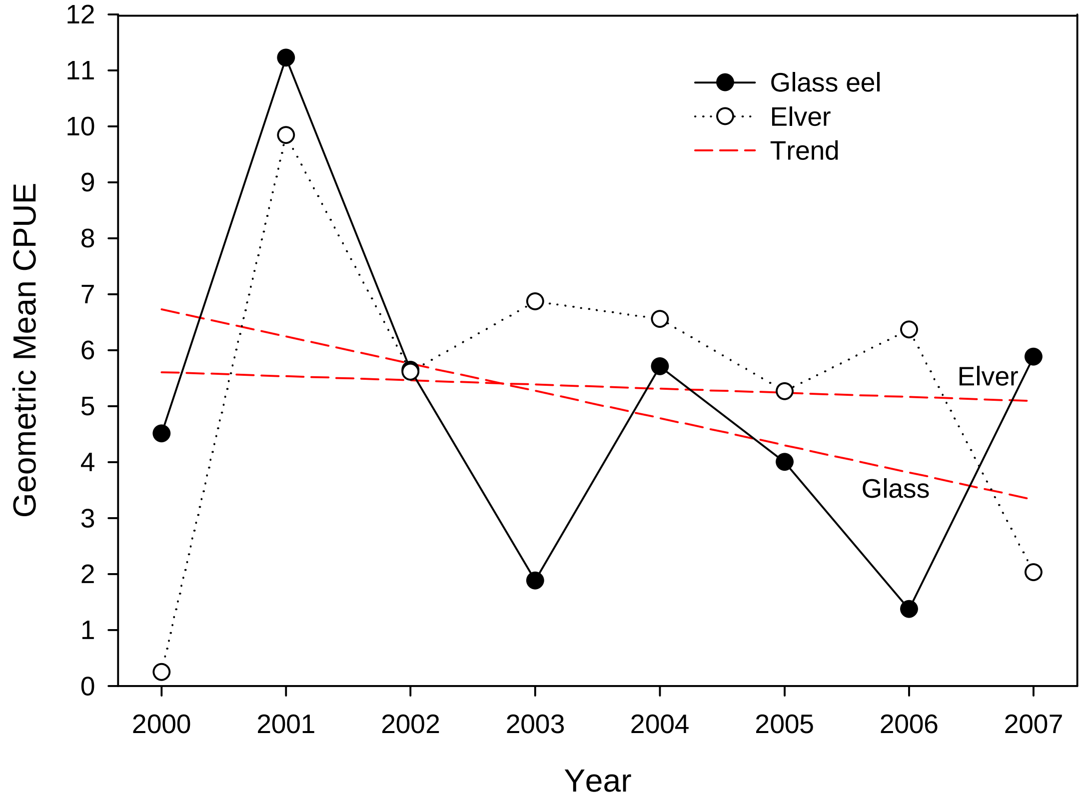
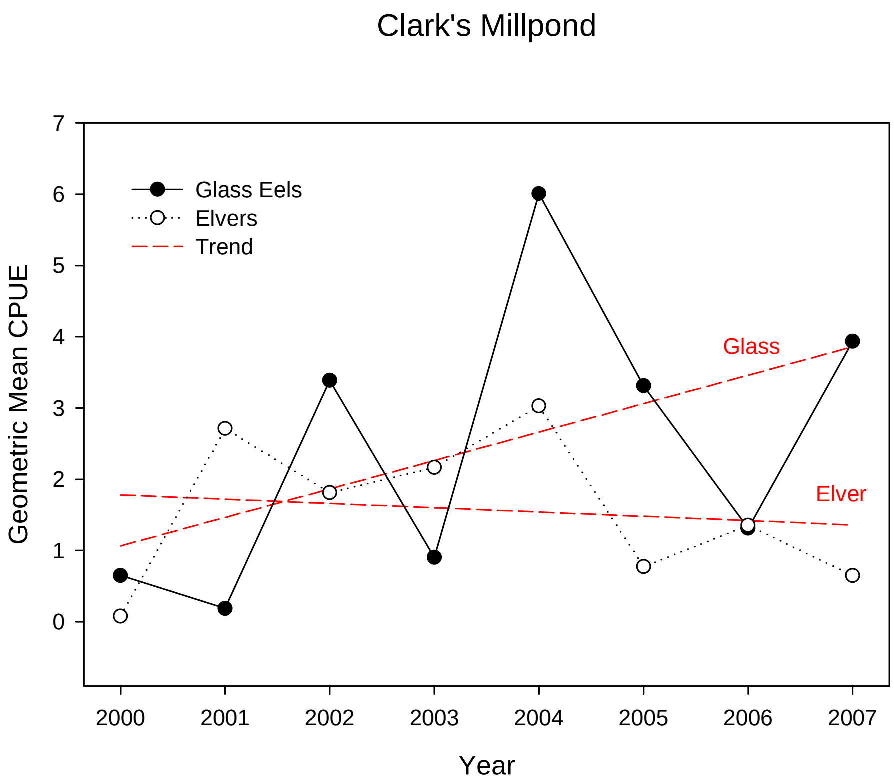


Figure 6. Glass eel and elver CPUE at Clark's Millpond and Gardy's Millponds for 2000-2007.



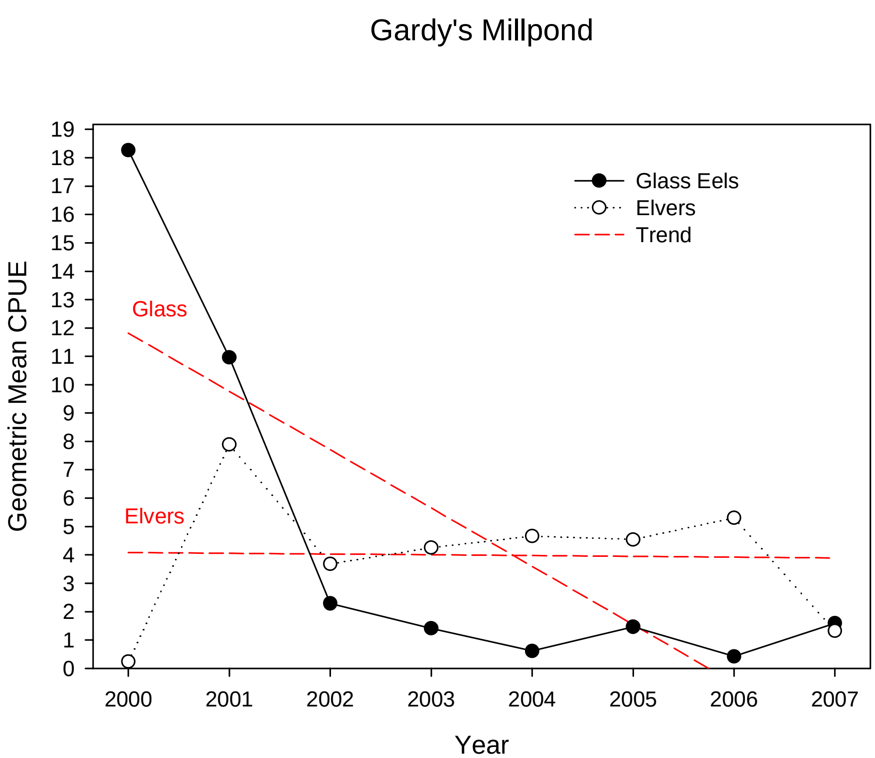
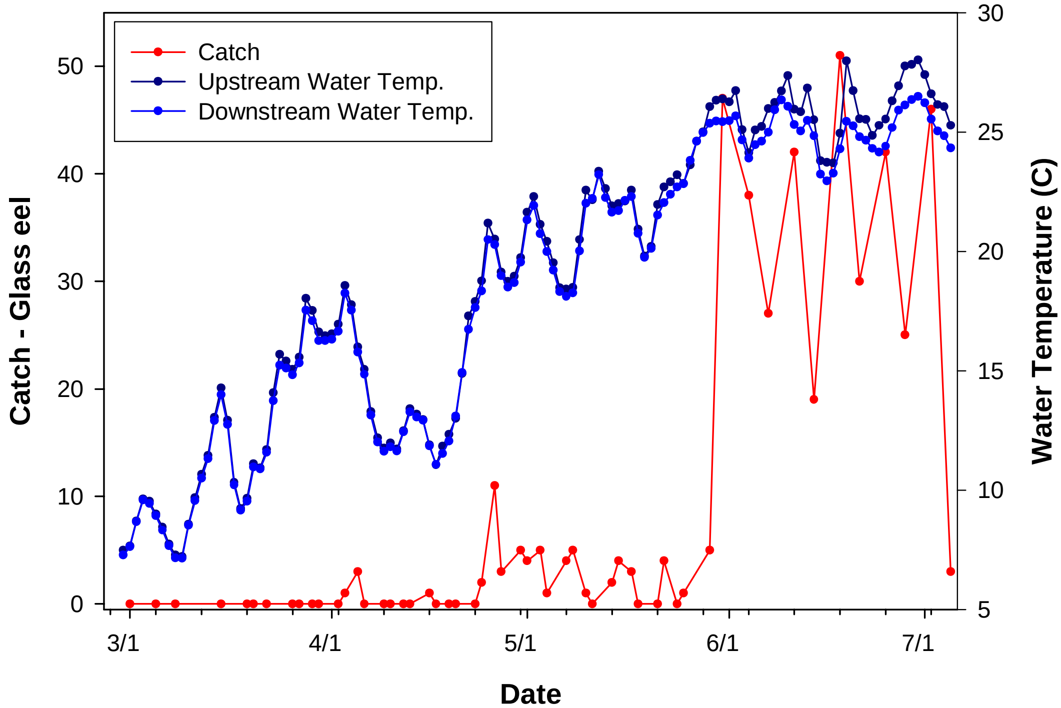


Figure 7. Glass eel and elver catch vs. water temperature at Clark's Millpond during 2007.



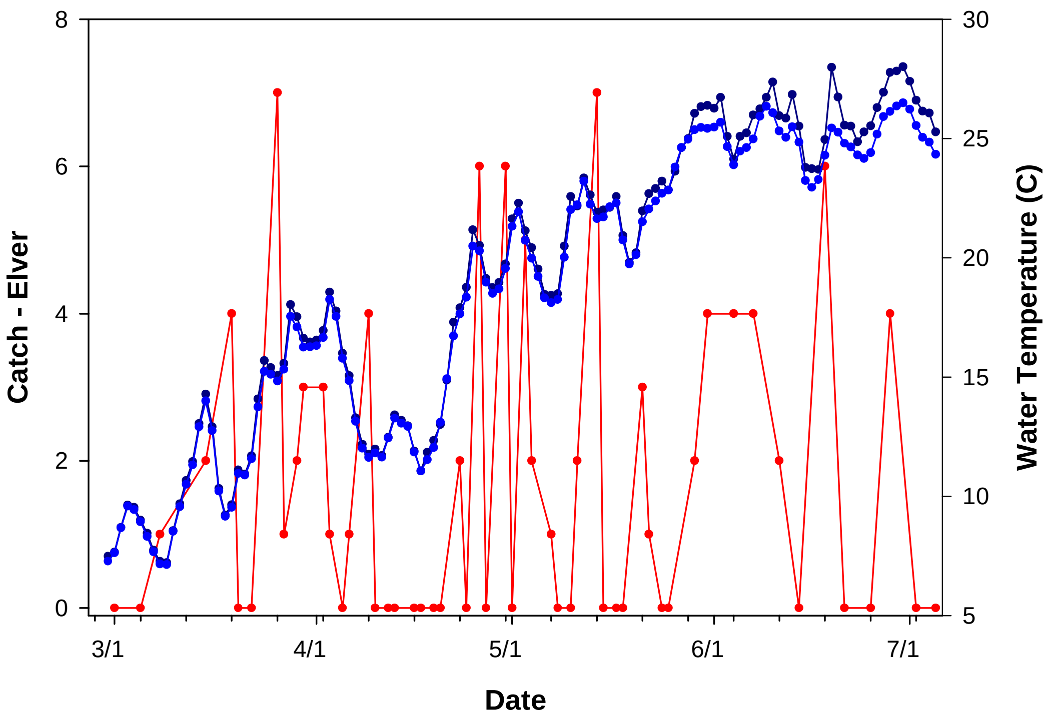
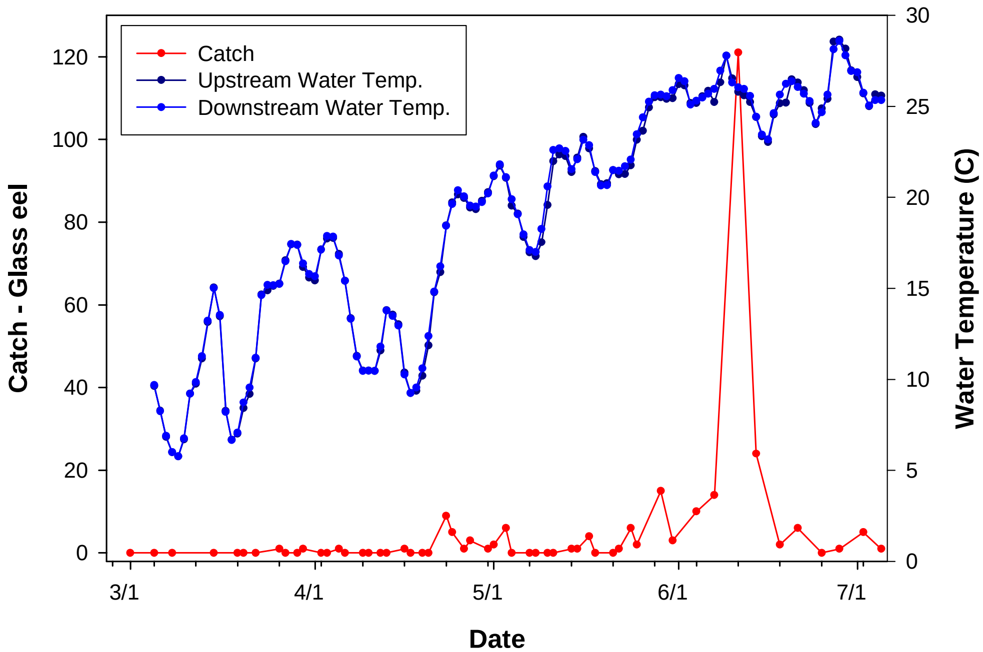


Figure 8. Glass eel and elver catch vs. water temperature at Gardy's Millpond during 2007.



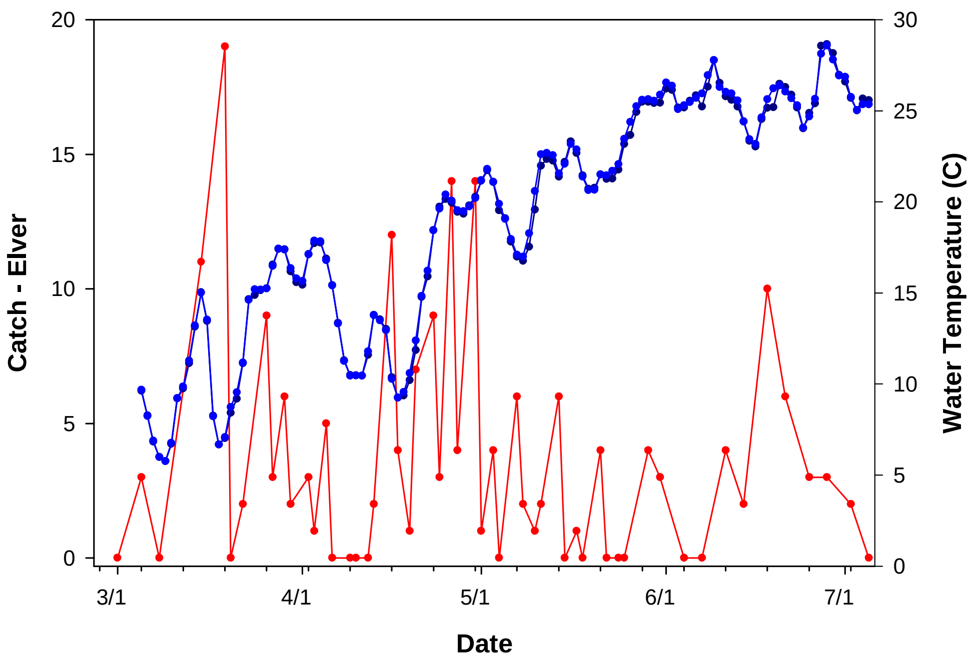
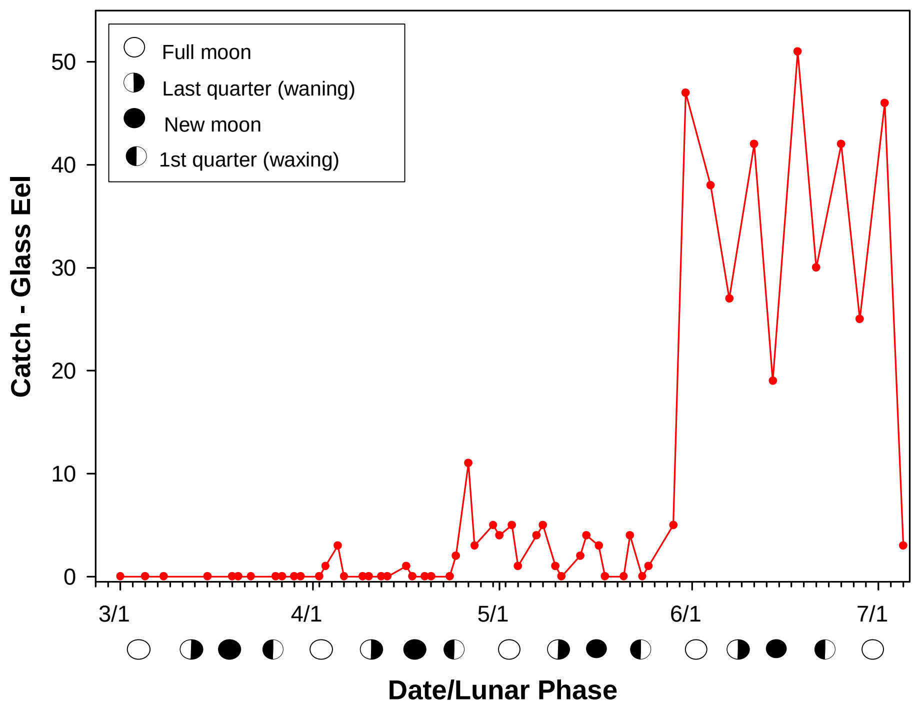


Figure 9. Catch versus lunar phase for glass eels and elvers at Clarks Millpond during 2007.



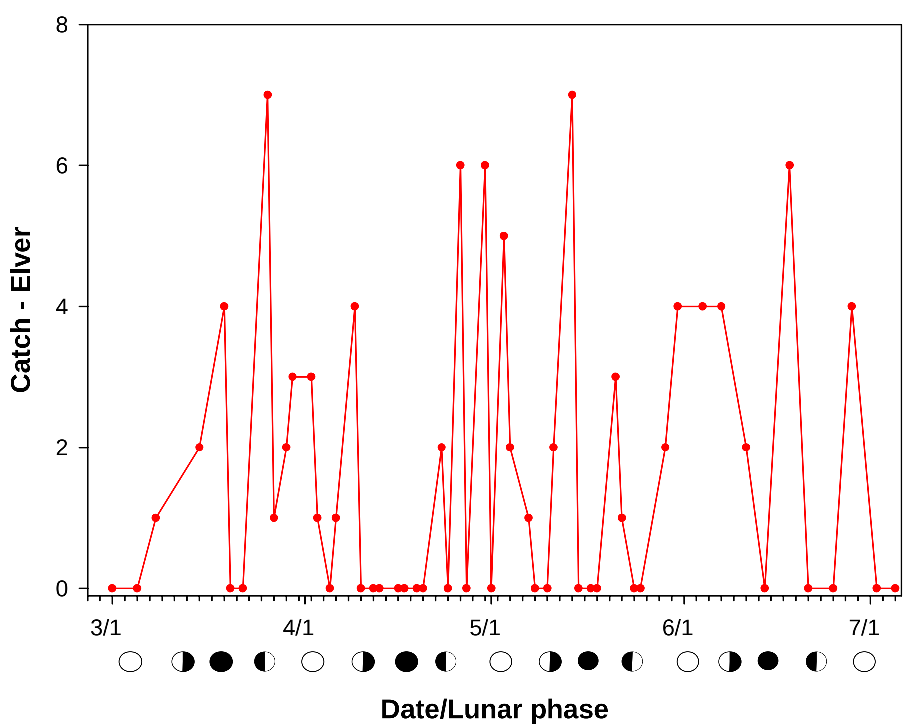


Figure 10. Catch versus lunar phase for glass eels and elvers at Gardy's Millpond during 2007.

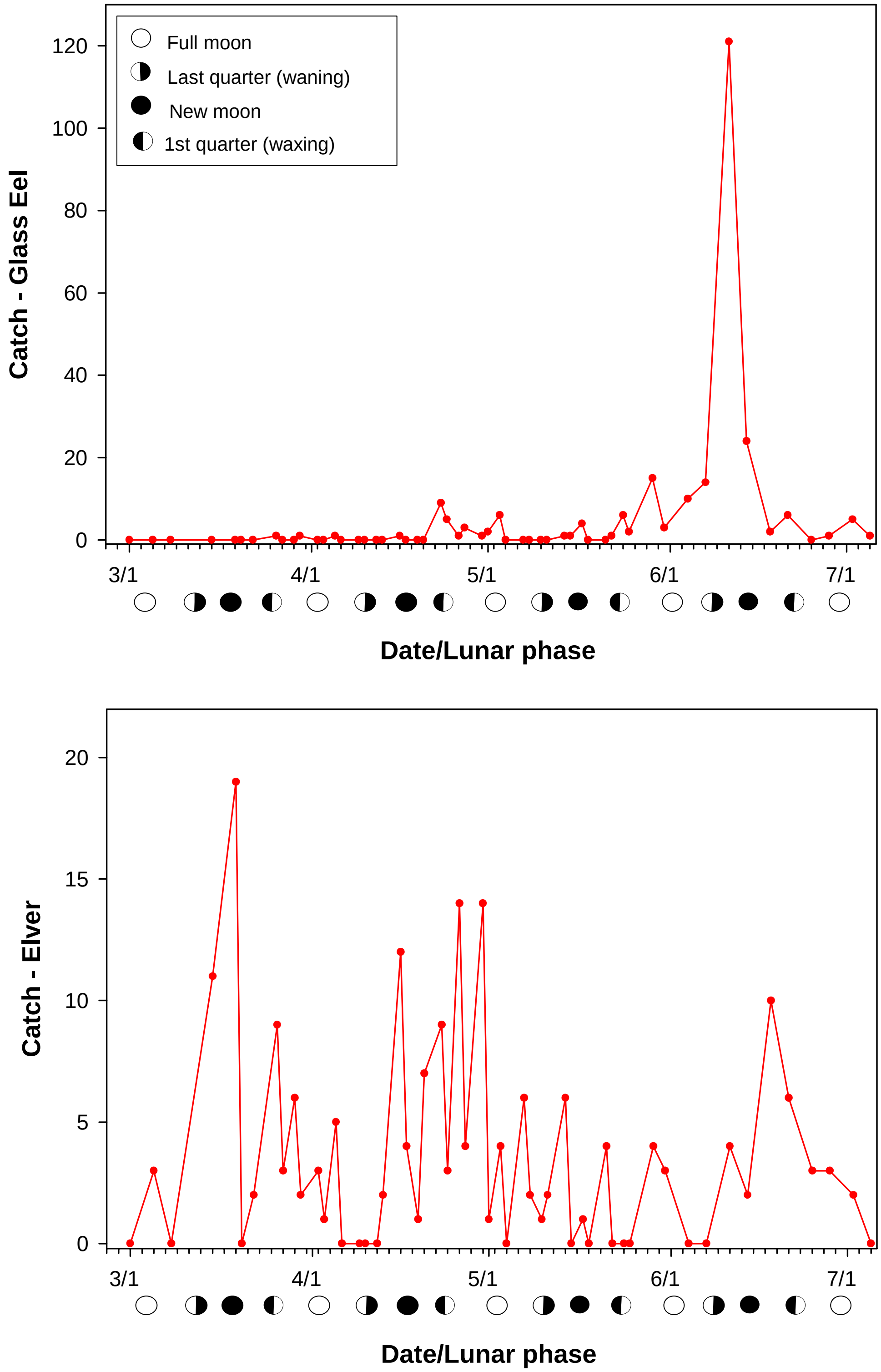


Figure 11. Pigmentation stages of glass eels collected (Gardy's Millpond and Clark's Millpond, combined) during 2007.

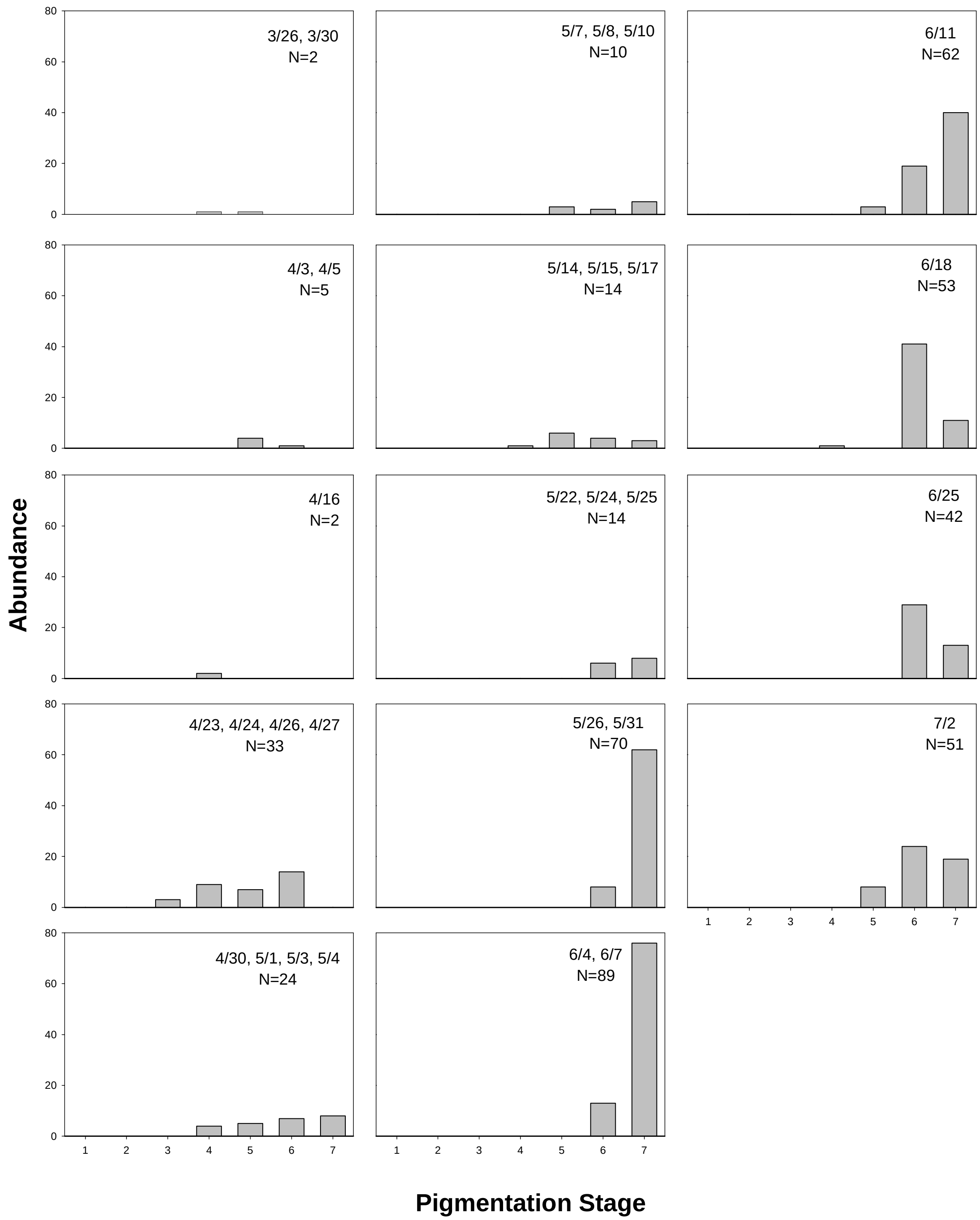


Figure 12. Frequency distribution of glass eel pigmentation during 2007 at Clark's Millpond and Gardy's Millpond.

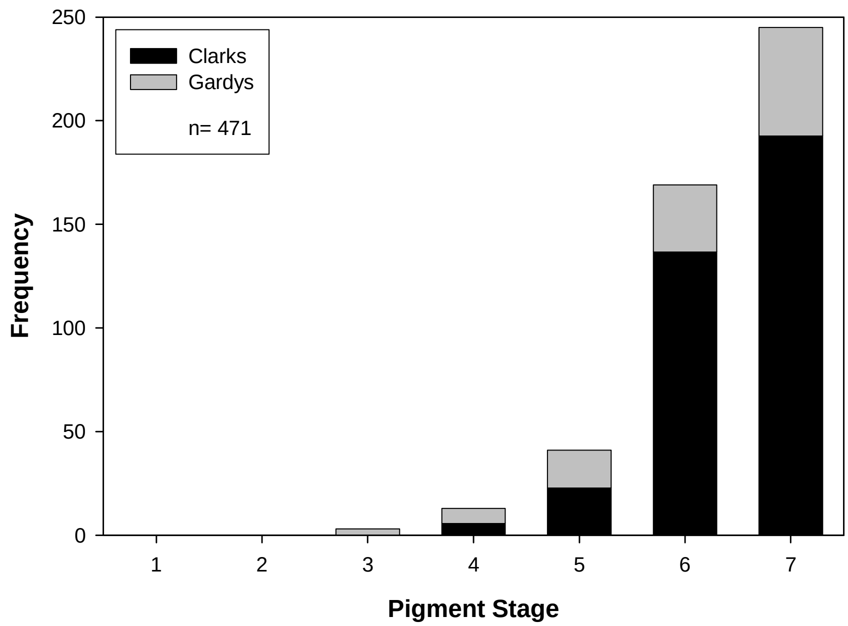


Figure 13. Glass eel length-weight regression (Clark's Millpond and Gardy's Millpond, combined). (Note: Solid line denotes regression line)

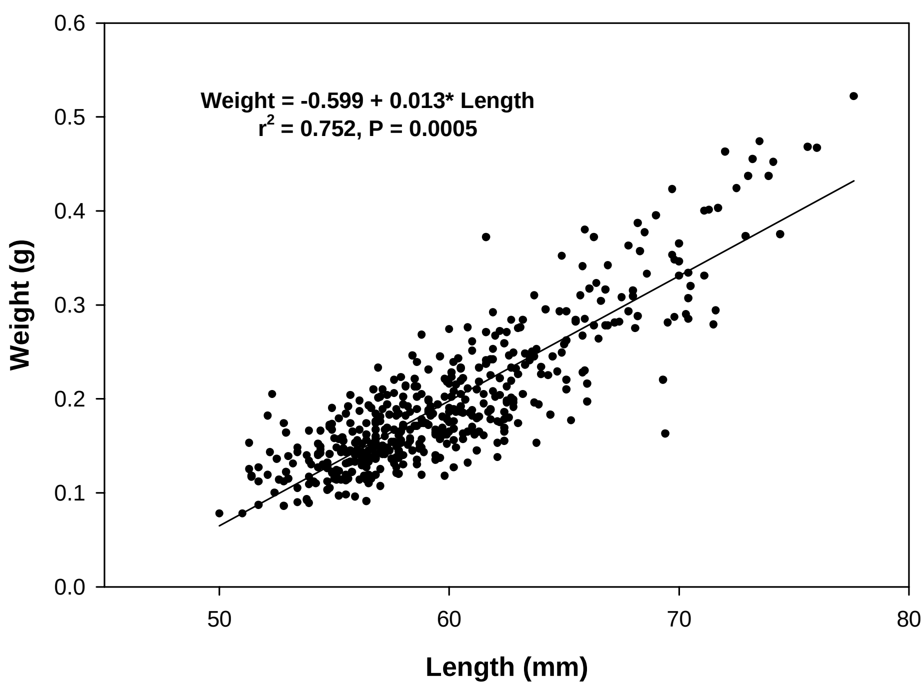


Figure 14. Length, weight and condition index (K) for glass eels examined from Potomac River sites (combined), 2002-2007. Note: Due to low numbers of eels collected in 2003, no biological data were available.