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Evaluating Recruitment of American Eel, Anguilla rostrata, in the Potomac River (Spring 2024)

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Table of Contents:

Acknowledgments

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Introduction

American Eel (*Anguilla rostrata*) is a valuable commercial species along the Atlantic coast of North America from New Brunswick to Florida. Landings from Chesapeake Bay typically represent about 65% of the annual United States commercial harvest (ASMFC 2023). American Eel is also important to the recreational fishery as this species is often used as live bait for Striped Bass (*Morone saxatilis*) and Cobia (*Rachycentron canadum*). In 2021, Chesapeake Bay commercial landings of American Eel (284,297 lbs) represented 87% of the U.S. landings of yellow eel (personal communication from the National Marine Fisheries Service, Fisheries Statistics Division). Since the 1980s, harvest along the U.S. Atlantic Coast has declined, with similar patterns occurring in the Canadian Maritime Provinces (Meister and Flagg 1997). The American Eel Benchmark Stock Assessment report (ASMFC 2012) established that the American Eel is depleted in U.S. waters. The most recent American Eel Benchmark Stock Assessment confirmed the stock remains depleted and abundance is lower than what was reported in the 2017 stock assessment update (ASMFC 2017; ASMFC 2023).

Hypotheses for the decline in abundance of American Eel in recent years include locational shifts in the Gulf Stream, habitat loss pollution, overfishing, parasites, and barriers to fish passage (Castonguay et al. 1994; Haro et al. 2000; ASMFC 2023). The decline in abundance may or may not exhibit spatial synchrony (Richkus and Whalen 1999; Sullivan et al. 2006); additionally, factors such as unfavorable wind-driven currents may affect glass eel recruitment on the continental shelf and may have a greater impact than fishing mortality or continental climate change (Knights 2003). Limited knowledge about fundamental biological characteristics of juvenile American Eel throughout their range has complicated interpretation of juvenile abundance trends (Sullivan et al. 2006).

The Atlantic States Marine Fisheries Commission (ASMFC) adopted the Interstate Fishery Management Plan (FMP) for the American Eel in November 1999. The FMP focuses on increasing coastal states' efforts to collect American Eel data through both fishery-dependent and fishery-independent studies. Consequently, member jurisdictions 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 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 in 2001. Survey results provide necessary data on coastal recruitment success and contribute to the understanding of American Eel population dynamics. The American Eel Benchmark Stock Assessment report (ASMFC 2012) emphasized the importance of the coast-wide survey for providing data useful in calculating an index of recruitment over the historical coastal range and for serving as an early warning of potential range contraction of the species. The most recent American Eel Benchmark Assessment (2023) recommends the continuation of glass eel sampling, but eliminates the requirement to measure length, weight, and pigment stage for glass eels because no discernable trends in these metrics were observed during 20 years of sampling. Funding for the Virginia Institute of Marine Science's spring survey in the Potomac River was provided by the Potomac River Fisheries Commission, thereby ensuring compliance with the 1999 ASMFC Interstate Fishery Management Plan for American Eels.

Life History

The American Eel is a facultative catadromous species that occurs along the Atlantic and Gulf coasts of North America, the Atlantic coast of South America extending northward from Brazil, and inland in the St. Lawrence Seaway and Great Lakes (Murdy et al. 1997; Benchetrit and McCleave 2016). 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. Eggs hatch into leaf-shaped, transparent, ribbon-like larvae called leptocephali, which are transported by ocean currents (for 9-12 months) in a generally northwesterly direction and can grow to 85 mm total length (TL; Jenkins and Burkhead 1993). Within one 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 (= young of the year, or YOY) into Maryland and Virginia estuaries between February and June (Able and Fahay 1998). Ciccotti et al. (1995) suggested that glass eel migration occurs as waves of invasions with perhaps a fortnightly periodicity related to tidal currents and stratification of the water column. Alterations in the timing and magnitude of freshwater flow to bays and estuaries may affect the

magnitude, timing, and spatial patterns of upstream migration of glass eels (Facey and Van Den Avyle 1987). Young-of-year eels may use freshwater "signals" to enhance recruitment to local estuaries, thereby influencing year-class strength in a particular estuary (Sullivan et al. 2006).

As glass eels grow, they become pigmented (elver stage), and within 12 to 14 months eels acquire a dark color with an underlying yellow tone (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. Metamorphosis into the silver eel stage occurs during the seaward migration that occurs from late summer through autumn. Age at maturity varies greatly with location and latitude, and in Chesapeake Bay, mature eels 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 to the Sargasso Sea to spawn and die (Haro et al. 2000).

Objectives

The objectives of our study in the Potomac River were to:

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

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

Methods

Minimum criteria for YOY American Eel sampling were established in the ASMFC American Eel FMP. Specifically, the timing and placement of gear must coincide with periods of peak YOY onshore migration. At a minimum, the gear must be deployed during nighttime flood tides. 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 and at least 60 glass eels (if present per system) must be examined for length, weight, and pigmentation stage weekly. However, the requirements stemming from the 2023 stock assessment have changed and

collection of length, weight, and pigment stage information is now optional (ASMFC 2023). Because the field portion of this study was completed under a grant prepared in 2023 before the reporting requirement was changed, we followed the previous requirement and report length, weight, and pigment stage for American eels captured in spring 2024.

Due to the importance of the eel fishery in Virginia and the Potomac River, the methods used must ensure proper temporal and spatial sampling and yield reliable recruitment estimates. To provide the necessary spatial coverage and to assess suitable locations, numerous sites in both Virginia and Maryland were evaluated previously (Geer 2001). Final site selection was based on known areas of glass eel concentrations, accessibility, and specific physical criteria (e.g., appropriate habitat) suitable for glass eel 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 in 2000 (Geer 2001). At the request of PRFC, the Virginia Institute of Marine Science (VIMS) began sampling two sites on the southern shore of the Potomac River (Gardy's Millpond and Clark's Millpond; Figure 1) in 2000.

One site (Gardy's Millpond, Northumberland County) continues to be sampled on the Potomac River. Gardy's Millpond contains a spillway that drains through four box culverts, across a riffle constructed of riprap and into a lotic area of the Yeocomico River. Clark's Millpond was sampled in previous years, however, conditions at the site have changed and there have been few glass eels and elvers in recent years (Tables 1 and 2). Furthermore, the conditions at the spillway at Clark's Millpond have deteriorated and are no longer safe for sampling. Thus, American eel sampling was terminated at Clark's Millpond in 2016.

An Irish eel ramp was used to collect eels. The ramp configuration successfully attracts and captures small eels in tidal waters of Chesapeake Bay. Ramp operation requires continuous flow of water over the climbing substrate and the collection device and was accomplished through gravity feed. A hose was attached to the ramp and to the collection bucket with adapters to allow for quick removal for sampling. Enkamat^{TM} erosion control material on the ramp floor provided a textured climbing surface and extended into the water below the trap. The ramp was placed on an incline (15-45^{o}), with the ramp entrance and textured mat extending into the water. The ramp entrance was placed in shallow water (< 25 cm) to prevent

submersion. The inclined ramp and an additional 4° incline of the substrate inside the ramp provided sufficient slope to create attractant flow. A hinged lid provided access for cleaning and flow adjustments.

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, air temperature, and precipitation were recorded during site visits. All eels were counted and placed above the impediment, with any subsample information recorded, if applicable. Specimens less than or equal to ~ 85 mm 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 two year classes (Geer 2001). Individual length, weight, and pigmentation stage information (see Haro and Krueger 1988) were recorded weekly. Daily catch (raw number of eels captured per day) and annual area-under-the-curve (AUC; Olney and Hoenig 2001) indices are presented. Annual AUC indices were standardized to a 24-hour sampling time.

Results and Discussion

Glass eels were sampled at Gardy's Millpond between 15 February and 7 June 2024; the study period encompassed 113 days. Glass eel recruitment at Gardy's Millpond resulted in the collection of 792 glass eels in 2024 (Table 1). Glass eels were first captured in early March (Figure 2). Relative abundance of glass eels was the second highest ever observed at Gardy's Millpond in 2024, marking the last three years as the highest in the time-series. The 2024 index was more than three times the time-series average ($index_{2024}$ = 844.28; mean long-term index = 269.63; Figure 4).

Elvers were first captured on 29 February 2024 at Gardy's Millpond and continued throughout the sampling period with multiple peaks throughout the survey (Figure 3). We observed below-average catch of elvers in 2024 (index = 337.63; Table 2; Figure 5) compared with the time-series average of 792.47. Initial arrival and migration of elvers may be correlated with increases in water temperature, however, elver migration may be delayed at freshwater interfaces until certain behavioral and physiological changes have occurred (Sorensen and Bianchini 1986).

Pigmentation stages of Potomac River glass eels included fish classified in stages 1 through 7 (Figure 6). Glass eels captured in the Potomac River typically exhibit late-stage pigmentation patterns beginning with stage 3 and darker individuals (Figure 7). Pigmentation stages in 2024 were slightly skewed with most eels at stage 3. Lengths of glass eels captured in 2024 ranged from 49.5 to 67.4 mm TL (average length = 56.9 mm TL, SE = 0.19) and weights ranged from 0.06 to 0.28 g (mean = 0.14 g, SE = 0.02; Figure 8). Lengths of glass eels captured in 2024 were similar to previous years (Figure 9).

Glass eels from the Potomac River are more developed (later stages) and are likely older than those at sites closer to the mouth of Chesapeake Bay. Total catch of glass eels in the Potomac River is typically below that observed in other VA tributaries, which may be due to natural mortality or a dilution effect as glass eels migrate into a variety of habitats available in lower Chesapeake Bay. Although glass eel recruitment in the Potomac River has been relatively high in recent years, variation in recruitment remains lower than that found at other sites in the lower Chesapeake Bay (Tuckey and Fabrizio 2021). Reduced variation in recruitment indices in the Potomac River may allow for the earlier detection of change because there is less noise in the signal compared with widely varying recruitment pulses observed in other lower Chesapeake Bay systems. Additionally, the relatively stable abundance of elvers observed in the Potomac River is consistent with the abundance of elvers found at other sites in VA and suggest that the carrying capacity of small, impounded water bodies appears relatively stable across years. This hypothesis relies on the similar abundance of elvers found in the James, York, and Rappahannock rivers despite orders of magnitude greater abundances of glass eels at these sites (Tuckey and Fabrizio 2021).

Conclusions

1. Recruitment of glass eels in 2024 was the second highest ever observed at Gardy's Mill and marks the last three years as the highest in the time-series.
2. The length of glass eels captured at Gardy's Millpond remains relatively consistent since 2000.
3. We found more early-pigment stage eels in 2024 compared with previous years.
4. The index for elvers was below average in 2024.

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Table 1. Summary of glass eel collections in the Potomac River at Clark's Millpond (2000 – 2016) and Gardy's Millpond (2000 – 2024). Sampling at Clark's Millpond was discontinued after 2016 due to a change at that site that no longer attracted glass eels. Catch per unit effort is calculated as the Area Under the Curve (AUC).

Source	Year	Start Date	End Date	Total Catch	AUC
Clark's	2000	1-Apr	16-May	15	23.74
	2001	16-Mar	12-May	4	4.05
	2002	8-Mar	2-May	115	115.79
	2003	11-Mar	16-May	24	40.21
	2004	8-Mar	30-May	447	468.93
	2005	10-Mar	27-May	223	295.78
	2006	28-Feb	25-May	80	90.53
	2007	27-Feb	5-Jul	435	470.33
	2008	19-Mar	20-Jun	22	31.98
	2009	25-Mar	18-Jun	42	42.68
	2010	19-Mar	21-Jul	421	389.06
	2011	16-Mar	28-Jun	46	104.51
	2012	23-Feb	16-Jul	419	495.38
	2013	21-Feb	7-Jun	196	208.07
	2014	10-Mar	13-Jun	1	1.00
	2015	25-Mar	30-Jun	1	1.00
	2016	28-Mar	29-Jun	3	3.00
Gardy's	2000	12-Apr	16-May	291	286.85
	2001	12-Mar	12-May	729	730.25
	2002	8-Mar	2-May	129	129.50
	2003	11-Mar	16-May	71	70.01
	2004	8-Mar	24-May	39	38.86
	2005	10-Mar	27-May	94	102.68
	2006	28-Feb	25-May	46	45.39
	2007	27-Feb	5-Jul	248	260.09
	2008	19-Mar	20-Jun	187	178.94
	2009	25-Mar	18-Jun	231	229.92
	2010	19-Mar	21-Jul	90	80.25
	2011	16-Mar	28-Jun	35	36.78
	2012	23-Feb	16-Jul	261	259.83
	2013	21-Feb	13-Jun	333	383.86
	2014	10-Mar	13-Jun	243	253.10
	2015	25-Mar	30-Jun	113	118.42
	2016	25-Mar	29-Jun	42	42.12
	2017	21-Mar	28-Jul	402	544.16
	2018	27-Feb	1-Jun	101	98.79
	2019	19-Mar	18-Jul	130	173.30
	2020	6-Mar	29-Jun	185	227.66
	2021	17-Mar	14-Jun	369	388.85
	2022	28-Feb	10-Jun	712	826.79
	2023	22-Feb	23-Jun	898	964.76
	2024	15-Feb	7-Jun	792	844.28

Table 2. Summary of elver collections in the Potomac River at Clark's Millpond (2000 – 2016) and Gardy's Millpond (2000 – 2024). Sampling at Clark's Millpond was discontinued after 2016 due to a change at that site that no longer attracted eels. Catch per unit effort is calculated as the Area Under the Curve (AUC).

Source	Year	Start Date	End Date	Total Catch	AUC
Clark's	2000	1-Apr	16-May	5	10.69
	2001	16-Mar	12-May	205	253.67
	2002	8-Mar	2-May	90	90.95
	2003	11-Mar	16-May	225	237.72
	2004	8-Mar	30-May	314	316.36
	2005	10-Mar	27-May	62	62.33
	2006	28-Feb	25-May	153	195.68
	2007	27-Feb	5-Jul	90	90.31
	2008	19-Mar	20-Jun	276	289.16
	2009	25-Mar	18-Jun	90	90.46
	2010	19-Mar	21-Jul	208	209.59
	2011	16-Mar	28-Jun	84	114.09
	2012	23-Feb	16-Jul	268	256.69
	2013	21-Feb	7-Jun	148	158.23
	2014	10-Mar	13-Jun	13	14.63
	2015	25-Mar	30-Jun	11	11.09
	2016	28-Mar	29-Jun	18	18.08
Gardy's	2000	12-Apr	16-May	15	16.46
	2001	12-Mar	12-May	624	660.76
	2002	8-Mar	2-May	273	277.15
	2003	11-Mar	16-May	300	300.78
	2004	8-Mar	24-May	483	476.76
	2005	10-Mar	27-May	313	330.15
	2006	28-Feb	25-May	692	827.71
	2007	27-Feb	5-Jul	198	198.23
	2008	19-Mar	20-Jun	393	385.88
	2009	25-Mar	18-Jun	360	358.27
	2010	19-Mar	21-Jul	375	317.53
	2011	16-Mar	28-Jun	507	527.09
	2012	23-Feb	16-Jul	411	406.59
	2013	21-Feb	13-Jun	664	1564.73
	2014	10-Mar	13-Jun	967	982.11
	2015	25-Mar	30-Jun	591	656.03
	2016	25-Mar	29-Jun	124	208.23
	2017	21-Mar	28-Jul	546	655.35
	2018	27-Feb	1-Jun	396	450.10
	2019	19-Mar	18-Jul	1684	3554.12
	2020	6-Mar	29-Jun	1044	2428.21
	2021	17-Mar	14-Jun	489	480.54
	2022	28-Feb	10-Jun	913	1019.97
	2023	22-Feb	23-Jun	1531	1936.42
	2024	15-Feb	7-Jun	256	337.63

Figure 1. Sampling sites in the Potomac River. Sampling at Clark's Millpond was discontinued after 2016.

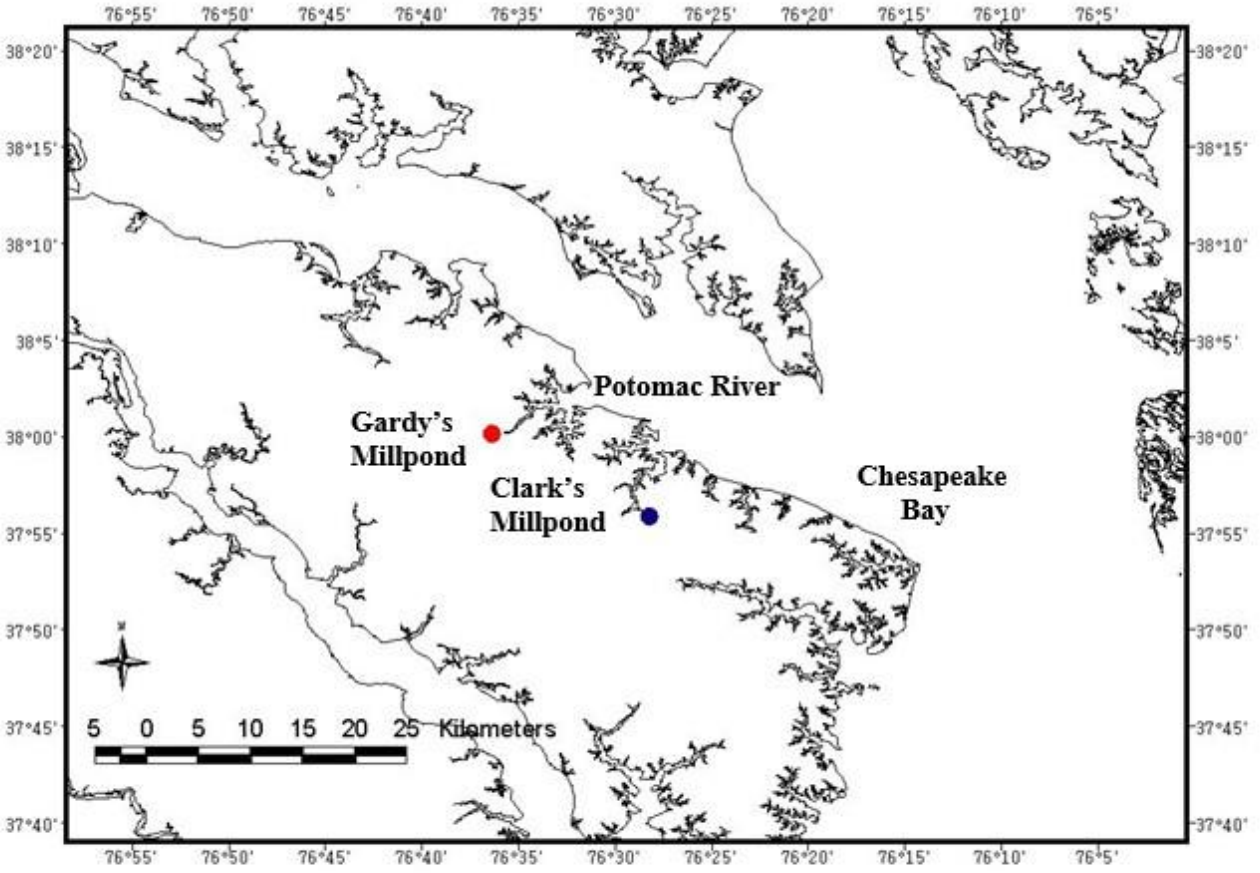

Figure 2. Number of glass eels captured during each sampling event and water temperature (^{0}C) at Gardy's Millpond, 2024.

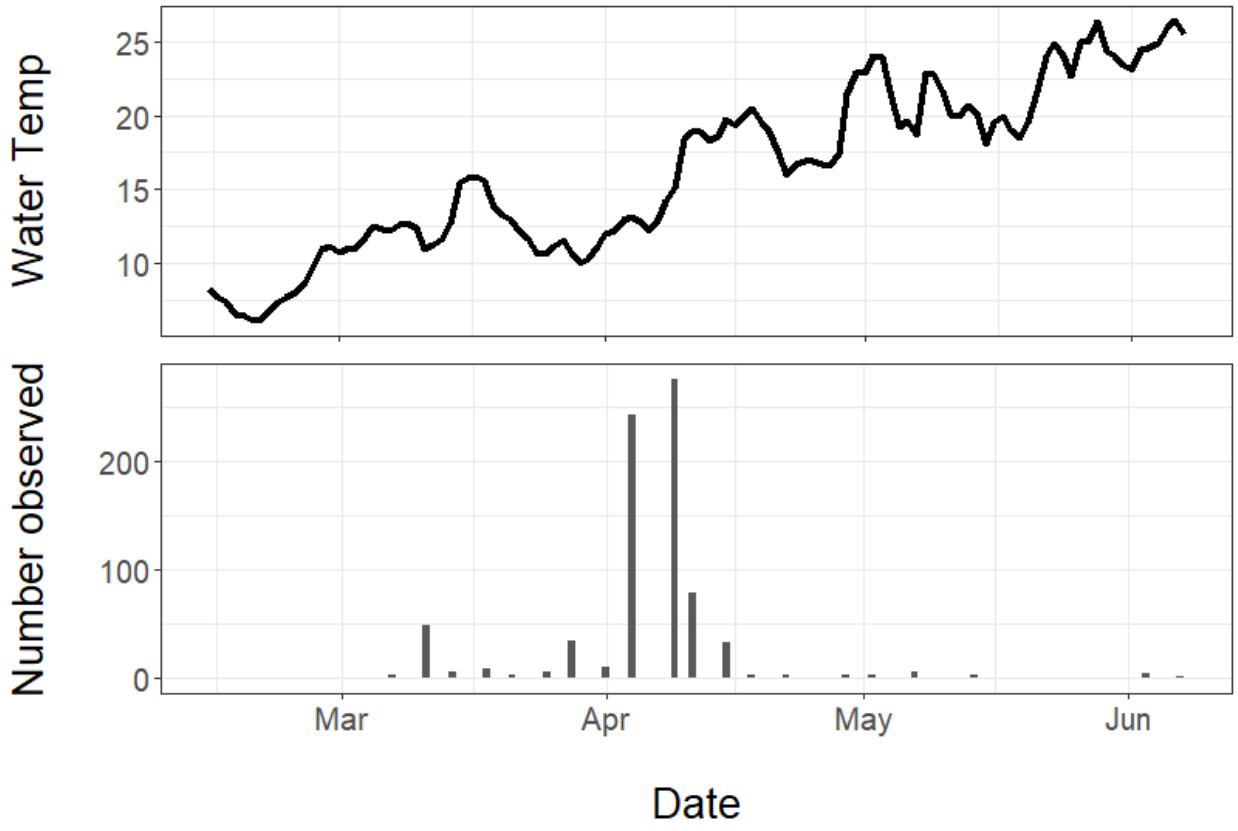

Figure 3. Number of elvers captured during each sampling event and water temperature (^{0}C) at Gardy's Millpond, 2024.

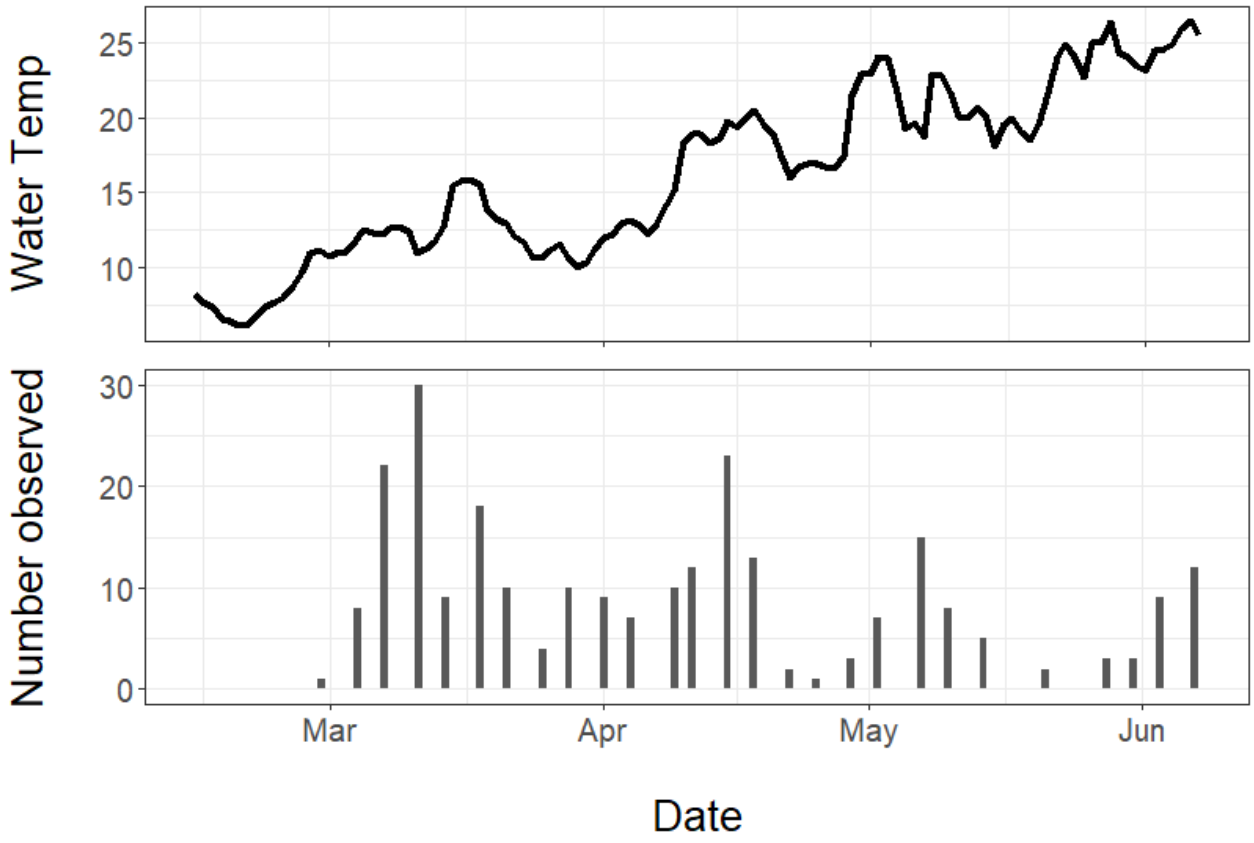

Figure 4. Glass eel index (area-under-the-curve method) from 2000 to 2024. Collections in 2000 followed different protocols and are not directly comparable to collections in later years. Time-series average for 2024 consists of data from 2001 to 2023. Sampling at Clark's Millpond was discontinued after 2016.

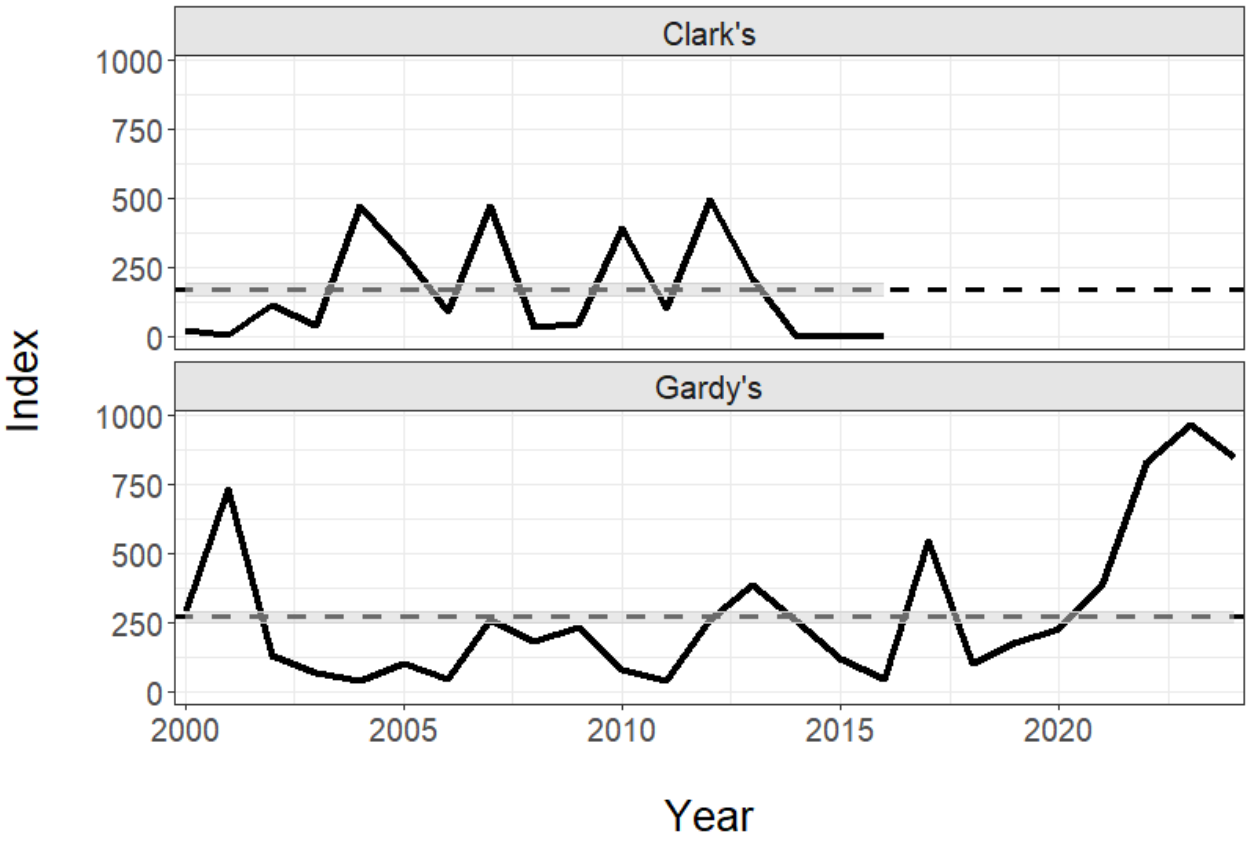

Figure 5. Elver eel index (area-under-the-curve method) from 2000 to 2024. Collections in 2000 followed different protocols and are not directly comparable to collections in later years. Time-series average for 2023 consists of data from 2001 to 2023. Sampling at Clark's Millpond was discontinued after 2016.

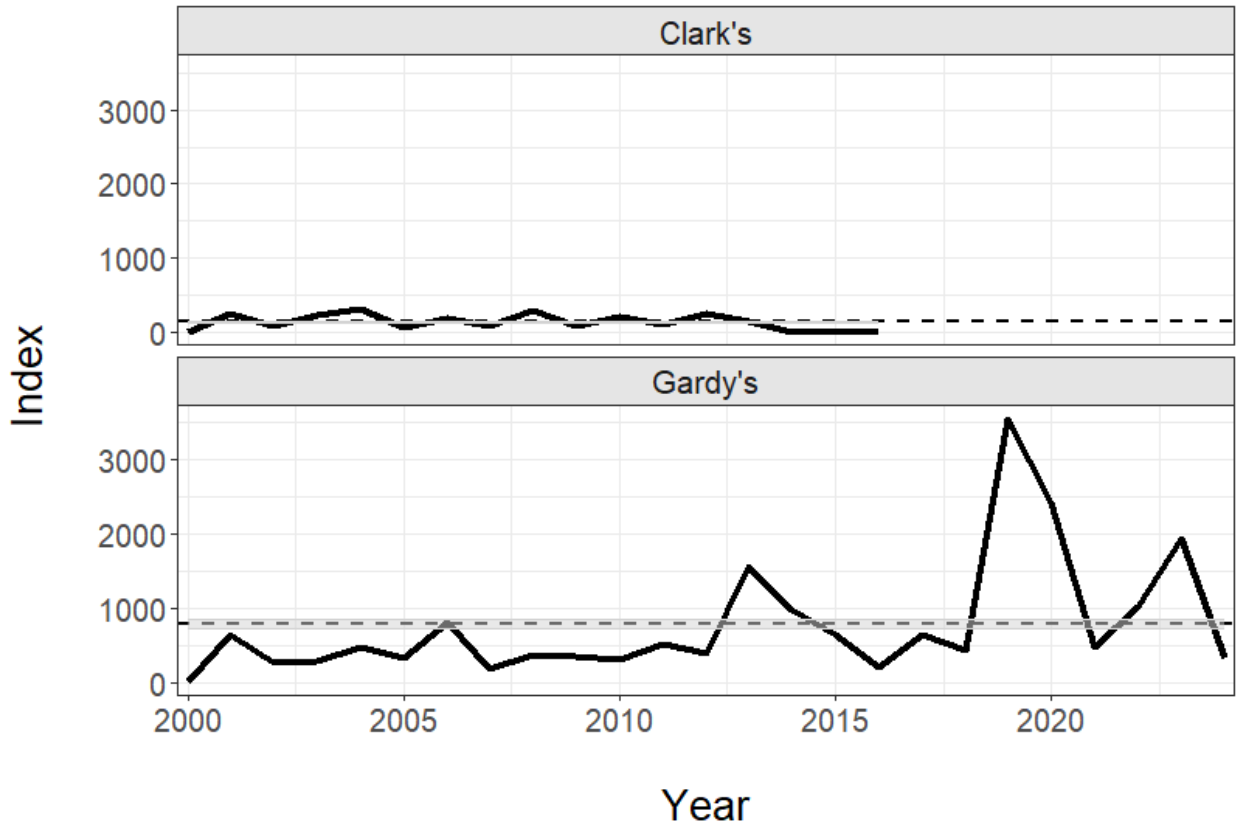

Figure 6. Glass eel pigment stage frequency distribution for the Potomac River, 2024 (N = 300).

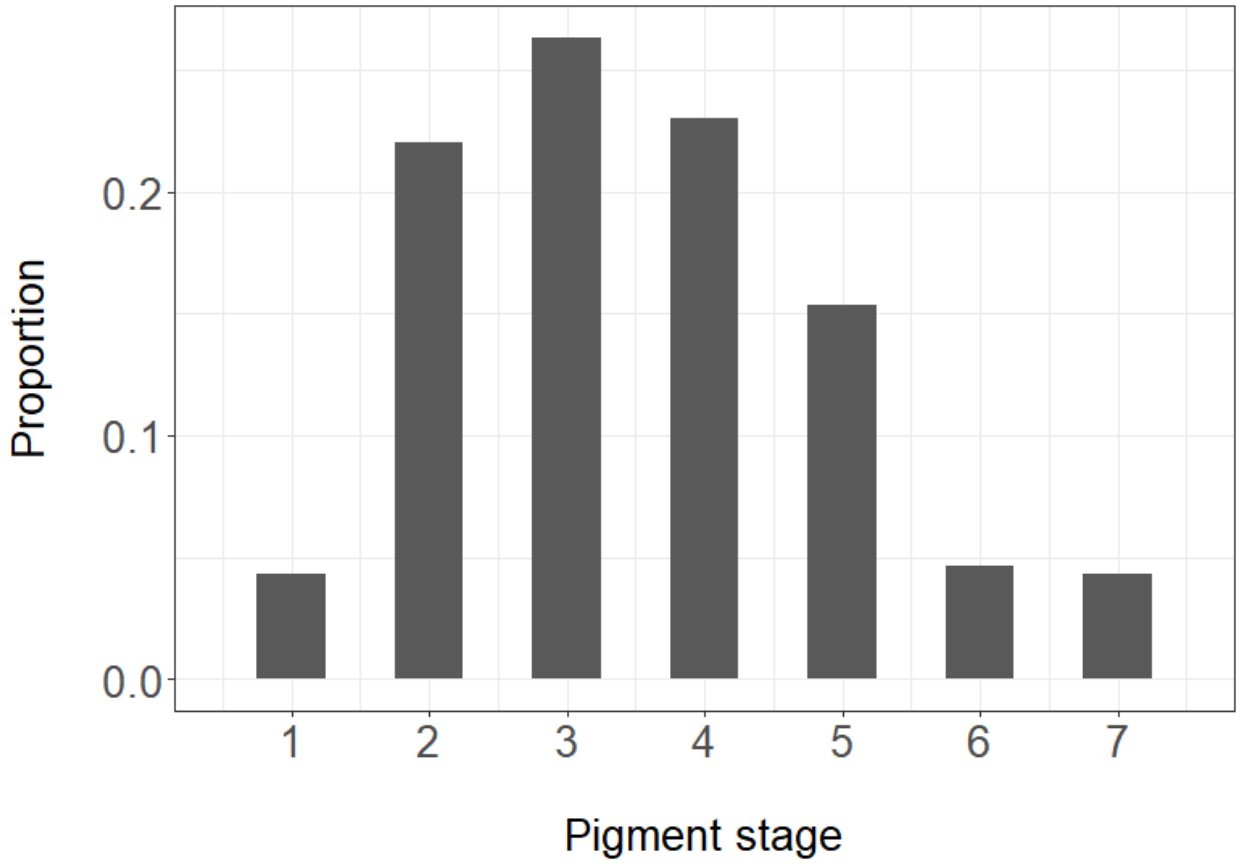

Figure 7. Glass eel pigment stage frequency distribution for the Potomac River, 2002 – 2024 (except 2003, which was not assessed that year).

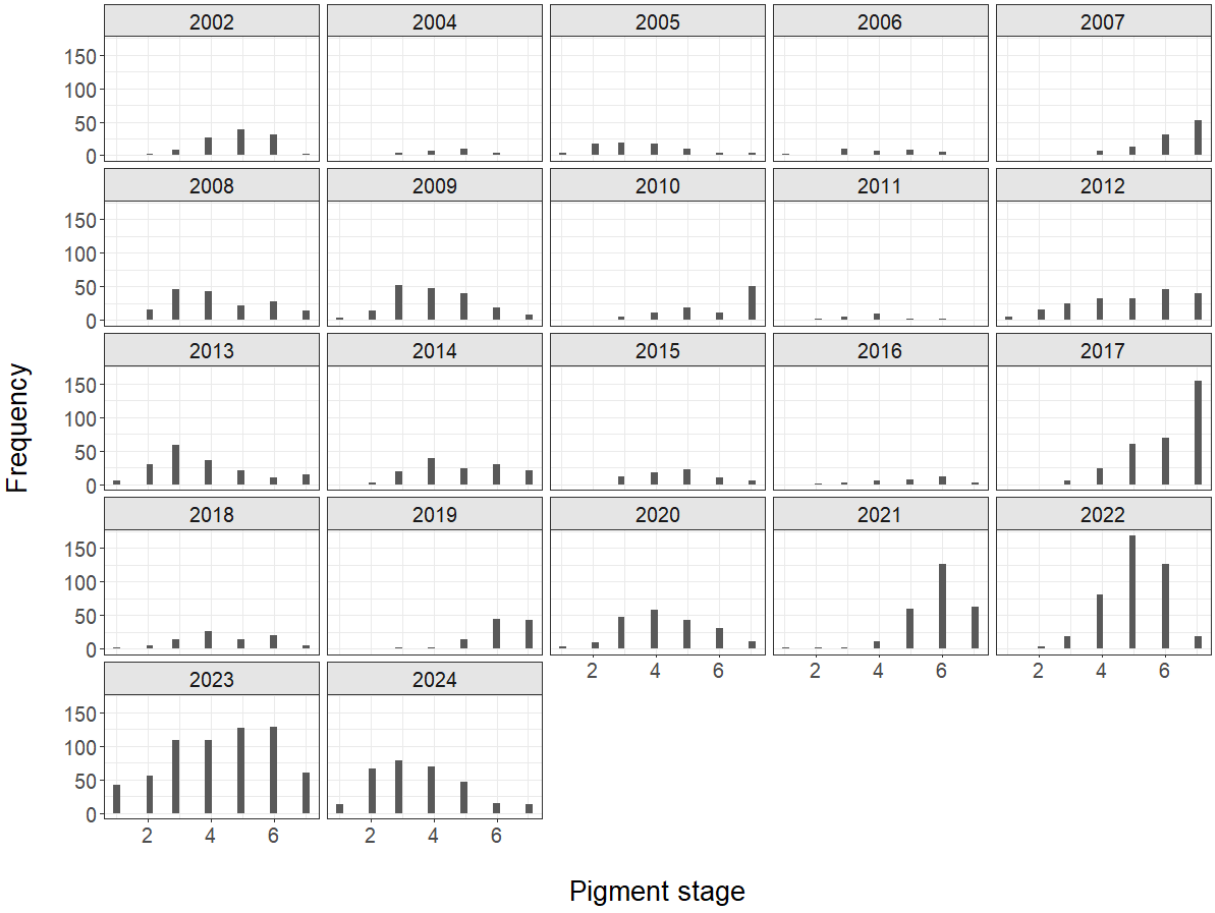

Figure 8. Total length and wet weight of glass eels captured at Gardy's Millpond, 2024. Average TL = 56.9 mm (SE = 0.19), average weight = 0.14 g (SE = 0.02), N = 300 eels.

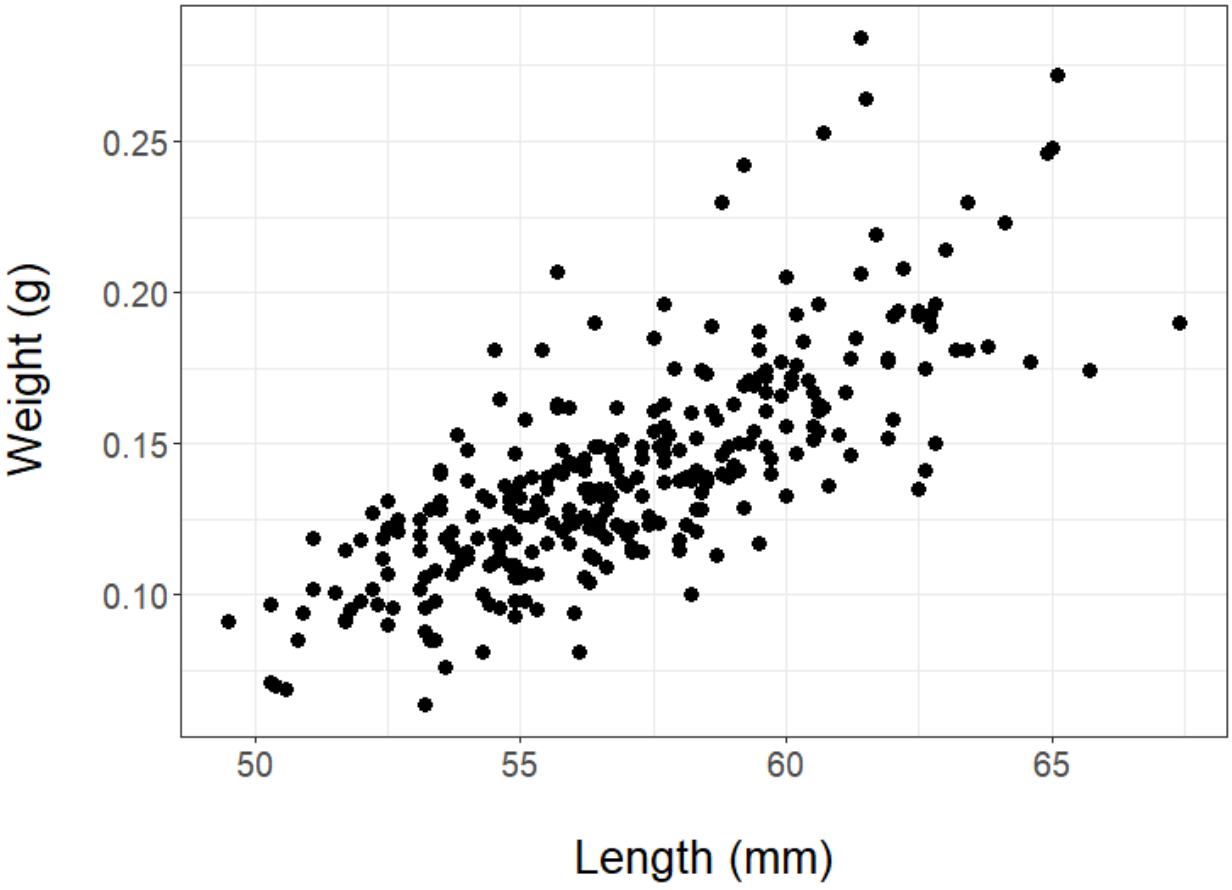

Figure 9. Annual length distribution of glass eels captured at Gardy's Millpond from 2002 to 2024 (excluding 2003).