3-2018

Estimating Relative Abundance of Young-of-Year American Eel, Anguilla rostrata, in the Virginia Tributaries of Chesapeake Bay (Spring 2017)

Troy D. Tuckey
Virginia Institute of Marine Science

Mary C. Fabrizio
Virginia Institute of Marine Science

Recommended Citation
Tuckey, T. D., & Fabrizio, M. C. (2018) Estimating Relative Abundance of Young-of-Year American Eel, Anguilla rostrata, in the Virginia Tributaries of Chesapeake Bay (Spring 2017). Virginia Institute of Marine Science, William & Mary. https://doi.org/10.21220/V5BM93

Estimating Relative Abundance of Young-of-Year American Eel, *Anguilla rostrata,* in the Virginia Tributaries of Chesapeake Bay (Spring 2017)

Final Report for Project No. RF/CF 17-01

https://doi.org/10.21220/V5BM93

Troy D. Tuckey & Mary C. Fabrizio

Department of Fisheries Science
Virginia Institute of Marine Science, College of William & Mary
Gloucester Point, Virginia 23062

Submitted to Virginia Marine Resources Commission, Marine Recreational Fishing Advisory Board and Commercial Fishing Advisory Board.

March 2018

Acknowledgments

Thanks to the following individuals from VIMS who conducted the field collections**:** Wendy A. Lowery, Jillian Swinford, Jack Buchanan, Brian Gallagher, and to Cemil Saglam from Ege University, Izmir, Turkey. Thanks to the law enforcement officers of the Virginia Marine Resources Commission (VMRC) and to landowners and organizations that provided access to their properties, including the Acors family (Kilmarnock) for access to Kamp's Millpond, John Dunn and Charlotte Hollings (upstream of Kamp's Millpond), Dorothy Geyer of the National Park Service (Bracken's and Wormley Ponds), Kingsmill, and many others whose cooperation contributed to the success of this study. Cover photo by Jack Buchanan.

This project was supported by the VMRC Marine Recreational Fishing Advisory (MRFAB) and Commercial Fishing Advisory Boards (CFAB), Project No. RF/CF 16-01.

Table of Contents

Introduction

American Eel (*Anguilla rostrata*) is a valuable commercial species along the Atlantic coast of North America from New Brunswick to Florida. In the U.S., harvests have declined, with similar patterns occurring in the Canadian Maritime Provinces (Meister and Flagg 1997). An average of 62% of the annual landings of U.S. commercial harvest since 1993 have come from the Chesapeake Bay (personal communication from the National Marine Fisheries Service, Fisheries Statistics Division, 9 February 2015). In 2013, Virginia commercial landings were approximately 100,298 lbs; since mandatory reporting began in 1993, average annual landings in Virginia have been 193,200 lbs or 19% of the U.S. American Eel harvest (personal communication from the National Marine Fisheries Service, Fisheries Statistics Division, 9 February 2015).

A decline in abundance of American Eel has been observed in recent years with conflicting evidence regarding spatial synchrony throughout their range (Richkus and Whalen 1999; Sullivan et al. 2006). Hypotheses for the decline in abundance include shifts in location of the Gulf Stream, pollution, overfishing, parasites, altered oceanic conditions, and barriers to fish passage (Castonguay et al. 1994; Haro et al. 2000; Knights 2003). 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). However, limited knowledge about fundamental biological characteristics of glass eels 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 calls for efforts to collect American Eel data through both fishery-dependent and fishery-independent studies in coastal states. Consequently, member jurisdictions agreed to implement an annual survey for young-of-year (YOY or glass) American Eels. The survey is intended to "…characterize trends in annual recruitment of the YOY eels over time [to produce a] qualitative appraisal of the annual recruitment of American Eel to the U.S. Atlantic Coast" (ASMFC 2000). The development of these surveys began in 2000 with full implementation by 2001. Survey results provide necessary data on coastal recruitment success and further understanding of American Eel population dynamics. A recent American Eel benchmark stock assessment report found that the American Eel stock status is depleted and emphasized the importance of the coast-wide survey as an index of recruitment over the historical coastal range in the U.S. and an early warning of potential range contraction of the species (ASMFC 2012). In 2017, the Virginia Institute of Marine Science continued its spring sampling to estimate relative abundance of YOY American Eels in Virginia tributaries of Chesapeake Bay.

Life History

The American Eel is a catadromous species that 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. Eggs hatch into leaf-shaped transparent ribbon-like larvae called leptocephali, which are transported by ocean currents (over 9-12 months) in a generally northwesterly direction and can grow to 85 mm TL (Jenkins and Burkhead 1993). Within a year, metamorphosis into the next life stage (glass eel) occurs in the Western Atlantic near the east coast of North America. A reduction in length to about 50 mm TL occurs prior to reaching the continental shelf (Jenkins and Burkhead 1993). Coastal currents and active migration transport the glass eels (= YOY) into Maryland and Virginia estuaries from February to June (Able and Fahay 1998), though glass eels have been captured in the York River estuary as early as December (VIMS, unpublished data). As growth continues, the glass eel becomes pigmented (elver stage) and within 12 to 14 months acquires a dark color with an underlying yellow hue (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 takes place from late summer through autumn. Age at maturity varies greatly with location and latitude and in Chesapeake Bay may range from 2 to 18 years, but most eels reach maturity between age 2 and 6 (Owens and Geer 2003). American Eels 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).

It has been suggested that glass eel migration into estuarine habitats has a fortnightly periodicity related to tidal currents and stratification of the water column (Ciccotti et al. 1995). Additionally, alterations in freshwater flow (timing and magnitude) to bays and estuaries may affect the size, timing, and spatial patterns of upstream migration of glass eels and elvers (Facey and Van Den Avyle 1987). YOY eel may use freshwater "signals" to enhance recruitment to local estuaries, (Sullivan et al. 2006), or may respond to conspecific cues, such that the presence of glass eels in a particular water body attracts the recruitment of other glass eels to the same location (Schmucker et al. 2016).

Objectives

The objectives of this study were to:

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 factors, which may influence young-of-year eel recruitment.

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

Methods

Field Methods

Minimum criteria for YOY American Eel sampling were established in the ASMFC American Eel FMP, with the Technical Committee approving sampling gear and methods. The timing and placement of gear must coincide with periods of peak YOY shoreward migration. At a minimum, the gear must fish during flood tides during nighttime hours. The sampling season is designated as a minimum of four days per week for at least six weeks or for the duration of the run. At least one site must be sampled in each jurisdiction. The entire catch of YOY eels must be counted from each sampling event and a minimum of 60 glass eels (if present per jurisdiction) must be examined for length, weight, and pigmentation stage weekly.

Due to the importance of the eel fishery in Virginia, the methods used to monitor glass eel recruitment must ensure proper temporal and spatial sampling coverage, and provide reliable recruitment estimates. To provide the necessary spatial coverage and to assess suitable locations, numerous sites were evaluated previously (Geer 2001). Final site selection was based on known areas of glass eel concentrations, accessibility, and specific physical criteria (e.g., proper habitat) suitable for glass eel recruitment to the sampling gear. Four sites were selected: two on the York River estuary and one each on the Rappahannock and James river estuaries. The James River site (Wareham's Pond) is located in the Kingsmill area of James City County, VA. Wareham's Pond drains directly into the James River, which is about 100 m away, though high tides may affect water levels at the end of the spillway (Figure 1). The two sites on the York River are Bracken's Pond and Wormley Pond (Figure 1). Bracken's Pond is located along the Colonial Parkway at the base of the Yorktown Naval Weapons Station Pier and is less than 100 m from the York River; the tide often reaches the spillway. Wormley Pond, located on the Yorktown Battlefield, drains into Wormley Creek, which has a tidal range that routinely reaches 50 cm depth at the spillway. The final collection site is Kamp's Millpond, which drains into the eastern branch of the Corrotoman River, a tributary to the Rappahannock River (Figure 1). Kamp's Millpond covers approximately 80 acres and is located upstream of Route 790, north of Kilmarnock, VA.

Irish eel ramps were used to collect eels at all sites. The ramp configuration successfully attracts and captures small eels in tidal waters of Chesapeake Bay. Ramp operation requires a continuous flow of water over the climbing substrate and the collection device; continuous flow was accomplished through a gravity feed. Hoses were attached to the ramp and collection buckets to allow for quick removal of eels for sampling. Enkamat™ erosion control material on the ramp floor provided a textured climbing surface. 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 of the entire ramp. 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 most site visits. All eels were enumerated and placed above the impediment, with any subsample information recorded, if applicable. Specimens less than or equal to ~ 85 mm total length (TL) were classified as YOY, while those > 85 mm TL were considered elvers. These lengths correspond to the two distinct length-frequency modes observed in the 2000 survey, which likely reflects different year classes (Geer 2001; note: eels larger than 254 mm TL are not considered elvers, although this is not explicitly stated in Geer 2001). Length, weight, and pigmentation stage (see Haro and Krueger 1988) were recorded from 60 eels weekly. Indices of abundance for each site were calculated using the area-under-the-curve approach (Olney and Hoenig 2001).

Results

Collections of young-of-year American Eel began on 20 February 2017 at Wormley Pond, 10 April 2017 at Bracken's Pond in the York River estuary, on 1 March 2017 at Wareham's Pond in the James River estuary, and on 24 March 2017 at Kamp's Millpond in the Rappahannock River estuary. Traps were removed on 23 May 2017 from Wormley Pond (95 days of continuous sampling), Bracken's Pond (46 days of continuous sampling) and Wareham's Pond (85 days of continuous sampling). The trap on the Rappahannock River (Kamp's Millpond) was removed on 28 June 2017 after 99 days of sampling. The short duration of the trap deployment at Bracken's Pond was due to unfavorable conditions for recruitment at that site earlier in the year. The outflow of Bracken's Pond, which empties into the York River, was partially blocked and raised the water level to a point that would not allow the trap to fish properly. After the water level dropped, we were able to set the trap, but for a shorter period of time. In all, we collected 1,129 glass eels at Bracken's Pond, 25,176 glass eels at Wormley Pond (York River system), 3,352 glass eels at Wareham's Pond (James River system), and 1,088 glass eels at Kamp's Millpond (Rappahannock River system; Table 1). Glass eel catch rates in 2017 were below-average at all sites, except Wareham's Pond where it was average (Figures 2 and 3).

Glass eels were captured at all sites as soon as traps were deployed (Figure 4). The majority of glass eels recruiting to Wormley Pond occurred in March and a similar recruitment pulse occurred at Wareham's Pond from mid-March to mid-April. Glass eels arrived at Kamp's Millpond nearly a month later (April) compared to Wormley Pond. There was one large recruitment event at Bracken's Pond in mid-April, but this unusual timing was likely due to the blockage of the outflow of Bracken's Pond noted above. Peak counts of glass eels typically occur first in the York River estuary, followed by the James, Rappahannock, and Potomac river estuaries (Figure 5).

Elver indices were average at Wormley Pond and Kamp's Millpond and above-average at Wareham's Pond in 2017 (Table 2; Figure 6). Elver collections were below-average at Bracken's Pond in 2017. Catches of elver eels occurred throughout the monitoring period at all sites (Figure 7). In the York River estuary, there was a large pulse of elvers that occurred during early March. We continued to capture elvers at Wormley and Bracken's ponds between the peak catches, but at reduced numbers. In the James River estuary there were two large pulses of elver eels in late Match/early April and May (Figure 7C). The capture of elvers in the Rappahannock River estuary was continuous throughout the sampling period with a peak in early-May (Figure 7D).

We examined 491 glass eels from Wormley Pond for weight, length, and pigment stage determination in 2017. Total length (TL) of these glass eels ranged from 43.1 to 66.7 mm, with a mean length of 56.1 mm (3.56 standard deviation, SD). Weights of individual glass eels ranged from 0.058 to 0.272 g and averaged 0.131 g (0.034 SD; Figure 8). Mean TL of glass eels recruiting to Wormley Pond on the York River has remained consistent since 2002 (Figure 9). Glass eel pigment stages in the York River were primarily stages 2 and 3, consistent with previous years (Figure 10).

Conclusions

Glass eel recruitment was below-average at all sites, except Wareham's Pond, where we observed average recruitment in 2017. The timing of glass eel recruitment was consistent with other years, with peak recruitment occurring earlier at sites in the York and James rivers and a delay of one month in the Rappahannock River, which is furthest from the mouth of Chesapeake Bay.

The timing of recruitment of glass eels to monitoring sites in Virginia supports the hypothesis of several pulses of glass eels entering and dispersing throughout Chesapeake Bay. Earliest arrival of glass eels is typically observed at Wormley Pond in the York River estuary (55.7 km from the mouth of the Bay), followed by Bracken's Pond in the York system (59.4 km), Wareham's Pond in the James River estuary (77.8 km), and finally Kamp's Millpond in the Rappahannock River estuary (101 km). Additionally, glass eels arrive at two sites located on the Virginia side of the Potomac River estuary (> 101 km from the mouth of the Bay) much later than at locations near the mouth of Chesapeake Bay. It is interesting to note that relative abundance indices at sites closer to the mouth of Chesapeake Bay tend to show greater variation than those further from the mouth of the Bay (Potomac River sites; Tuckey and Fabrizio 2016).

The area below the spillway at Wareham's Pond was redesigned in 2013 and catches of elvers continue to be above the historic average, whereas relative abundance levels of elvers at other sites have not shown similar increases. This result suggests that changes to the site at Wareham's has positively influenced the catch of elvers at this location. However, no notable change in recruitment of glass eels has occurred.

We continue to collect American eel juveniles from the VIMS Juvenile Fish Trawl Survey in an effort to determine how recruitment of glass eels translates into yellow-phase eel production. This unfunded project is underway and we have collected and processed more than 800 eels from various sources for age, length, weight, and disease status.

Literature Cited

Able, K. W. and M. P. Fahay. 1998. The First Year in the Life of Estuarine Fishes in the Middle Atlantic Bight. Rutgers University Press, New Jersey. 342 pp.

ASMFC. 2000. Fishery Management Plan for American Eel, *Anguilla rostrata*.

ASMFC. 2012. American Eel Benchmark Stock Assessment. Stock Assessment Report No. 12-01 of the Atlantic States Marine Fisheries Commission.

Castonguay, M., P.V. Hodson, C. M. Couillard, M. J. Eckersley, J. D. Dutil and G. Verreault. 1994. Why is recruitment of American Eel, *Anguilla rostrata*, declining in the St. Lawrence River and Gulf? Can. J. Fish. Aquat. Sci. 51:479-488.

Ciccotti, E. T. Ricci, M. Scardi, E. Fresi and S. Cataudella. 1995. Intraseasonal characterization of glass eel migration in the River Tiber: space and time dynamics. J. Fish Biol. 47:248-255.

Facey, D. E. and M. J. Van Den Avyle. 1987. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic) - American Eel. U. S. Fish Wildl. Serv. Biol. Rep. 82(11.74). U. S. Army Corps of Engineers, TR EL-82-4. 28 pp.

Geer, P.J. 2001. Evaluating recruitment of American Eel, *Anguilla rostrata*, to the Potomac River---Spring 2001. Report prepared for Potomac River Fisheries Commission. Virginia Institute of Marine Science Gloucester Point, Virginia 23062. 21 pp.

Haro, A. J. and W. H. Krueger. 1988. Pigmentation, size and migration of elvers, *Anguilla rostrata* (Lesueur), in a coastal Rhode Island stream. Can. J. Zool. 66:2528-2533.

Haro, A., W. Richkus, K. Whalen, W.-Dieter Busch, S. Lary, T. Brush and D. Dixon. 2000. Population decline of the American Eel: Implications for research and management. Fisheries 25(9): 7-16.

Hedgepeth, M. Y. 1983. Age, growth and reproduction of American Eels, *Anguilla rostrata* (Lesueur), from the Chesapeake Bay area. Master's Thesis. College of William and Mary. 61 pp.

Jenkins, R. E. and N. M. Burkhead. 1993. Freshwater fishes of Virginia. American Fisheries Society. Bethesda, MD. 1079 pp.

Knights, B. 2003. A review of the possible impacts of long-term oceanic and climate changes and fishing mortality on recruitment of anguillid Eels of the Northern Hemisphere. The

Science of the Total Environment 310(1-3): 237-244.

Meister, A. L. and L. N. Flagg. 1997. Recent developments in the American Eel fisheries of eastern North America. Focus 22(1): 25-26.

Murdy, E.O., R.S. Birdsong and J.A. Musick. 1997. Fishes of Chesapeake Bay. Smithsonian Institution Press. 324 pp.

Olney, J. E. and J. M. Hoenig. 2001. Managing a fishery under moratorium: Assessment opportunities for Virginia's stocks of American Shad. Fisheries 26: 6-11.

Owens, S. J. and P. J. Geer. 2003. Size and age structure of American Eels in tributaries of the Virginia portion of the Chesapeake Bay. Pages 117-124 in D. A. Dixon (Editor). Biology, Management and Protection of Catadromous Eels. American Fisheries Society, Symposium 33, Bethesda, MD, USA.

Richkus, W. and K. Whalen. 1999. American Eel, *Anguilla rostrata*, scoping study. A literature review and data review of the life history, stock status, population dynamics, and hydroelectric impacts. Final Report, March 1999 by Versar, Inc., Prepared for EPRI.

Schmucker, A. K., N. S. Johnson, H. S. Galbraith, and W. Li. 2016. Glass-eel stage American eels respond to conspecific odor as a function of concentration. Transactions of the American Fisheries Society 145:712-722.

Sullivan, M. C., K. W. Able, J. A. Hare and H. J. Walsh. 2006. *Anguilla rostrata* glass eel ingress into two, U. S. east coast estuaries: patterns, processes and implications for adult abundance. J. Fish. Bio. 69:1081-1101.

Tuckey, T. D. and M. C. Fabrizio. 2017. Evaluating recruitment of American Eel, *Anguilla rostrata*, to the Potomac River, Spring 2017. Report prepared for Potomac River Fisheries Commission. Virginia Institute of Marine Science Gloucester Point, Virginia 23062. 19 pp.

Table 1. Total number of glass American Eels captured and the index of abundance using Area Under the Curve method (AUC). 'NA' indicates that data are not available due to construction at this site in 2013.

Site	Year	Total Caught	AUC index	Site	Year	Total Caught	AUC index
Wormley Pond	2001	82,267	83,492.5				
	2002	31,518	32,638.7				
	2003	14,385	13,725.6	Wareham's Pond	2003	2,230	2,350.6
	2004	78,258	79,293.5		2004	158	165.3
	2005	56,259	55,660.7		2005	225	224.1
	2006	61,211	59,855.0		2006	3,280	3,266.3
	2007	90,988	90,705.0		2007	953	959.3
	2008	9,012	9,220.6		2008	2,456	2,417.2
	2009	8,367	8,404.2		2009	5,322	5,192.3
	2010	139,391	149,154.2		2010	672	648.5
	2011	66,953	62,410.3		2011	12,871	14,318.0
	2012	65,312	65,271.7		2012	3,933	4,042.1
	2013	42,415	42,362.2		2013	NA	NA
	2014	36,894	38,447.9		2014	1,979	1,969.8
	2015	40,071	46,619.6		2015	5,218	5,737.6
	2016	40,154	44,829.6		2016	915	936.2
	2017	25,176	25,141.2		2017	3,352	3,384.7
Bracken's Pond	2000	61,228	62,884.7	Kamp's Millpond	2000	139	129.9
	2001	52,838	54,113.1		2001	3,956	4,030.2
	2002	7,413	7,590.8		2002	11,217	11,064.5
	2003	77,592	75,405.4		2003	2,387	2,377.5
	2004	29,914	30,281.7		2004	524	516.2
	2005	65,983	65,885.3		2005	2,084	2,145.0
	2006	45,738	47,093.6		2006	302	298.6
	2007	46,758	46,266.8		2007	313	311.5
	2008	1,165	1,150.3		2008	481	479.0
	2009	69	67.5		2009	179	179.0
	2010	23,044	30,087.8		2010	4,734	4,462.0
	2011	69,660	62,697.5		2011	1,860	1,980.4
	2012	62,738	85,747.3		2012	67,045	43,654.3
	2013	29,272	28,486.3		2013	2,426	2,457.2
	2014	3,376	3,863.9		2014	4,167	3,693.9
	2015	35,328	38,294.8		2015	508	485.1
	2016	358	399.5		2016	947	950.8
	2017	1,129	1,025.4		2017	1,088	1,145.90

Table 2. Total number of elver American Eels captured and the index of abundance using Area Under the Curve method (AUC). 'NA' indicates that data are not available due to construction at this site in 2013.

Site	Year	Total Caught	AUC index	Site	Year	Total Caught	AUC index
Wormley Pond	2001	171	171.4				
	2002	315	314.6				
	2003	138	140.5	Wareham's Pond	2003	84	84.7
	2004	257	264.7		2004	260	256.4
	2005	105	108.6		2005	148	148.6
	2006	160	158.4		2006	469	471.2
	2007	619	612.8		2007	682	676.7
	2008	139	140.0		2008	511	512.8
	2009	31	32.0		2009	275	275.7
	2010	80	71.9		2010	306	323.4
	2011	79	104.9		2011	463	523.0
	2012	79	69.9		2012	496	516.0
	2013	99	112.1		2013	NA	NA
	2014	64	74.7		2014	1,368	1,399.9
	2015	107	103.1		2015	946	1,173.4
	2016	248	340.4		2016	2,061	1,976.5
	2017	100	133.5		2017	850	857.8
Bracken's Pond	2000	528	535.4	Kamp's Millpond	2000	5	4.9
	2001	334	341.1		2001	222	225.4
	2002	52	52.2		2002	224	222.9
	2003	411	416.7		2003	1,968	1,972.6
	2004	171	180.0		2004	250	246.1
	2005	231	229.9		2005	196	198.6
	2006	166	172.7		2006	312	310.0
	2007	723	717.8		2007	32	31.7
	2008	262	260.9		2008	37	45.1
	2009	3	3.0		2009	33	34.5
	2010	190	219.9		2010	132	125.9
	2011	525	644.2		2011	104	213.7
	2012	462	542.8		2012	891	730.7
	2013	354	398.4		2013	218	222.5
	2014	163	174.5		2014	259	246.5
	2015	358	548.0		2015	119	239.1
	2016	685	800.3		2016	364	452.8
	2017	116	125.1		2017	269	277.6

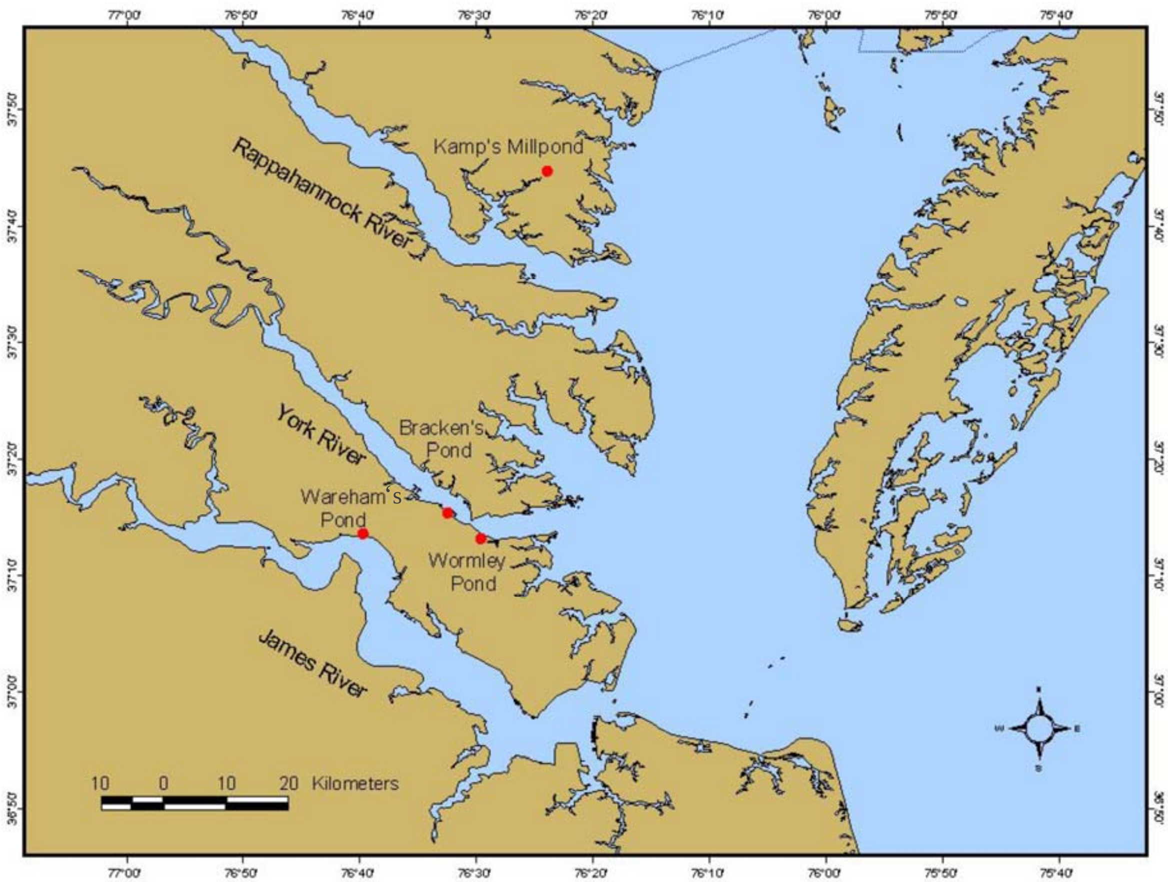

Figure 1. American Eel sampling sites in sub-estuaries of the Chesapeake Bay: the Rappahannock (Kamp's Millpond), York (Wormley Pond and Bracken's Pond), and James (Wareham's Pond) estuaries, Virginia, 2017.

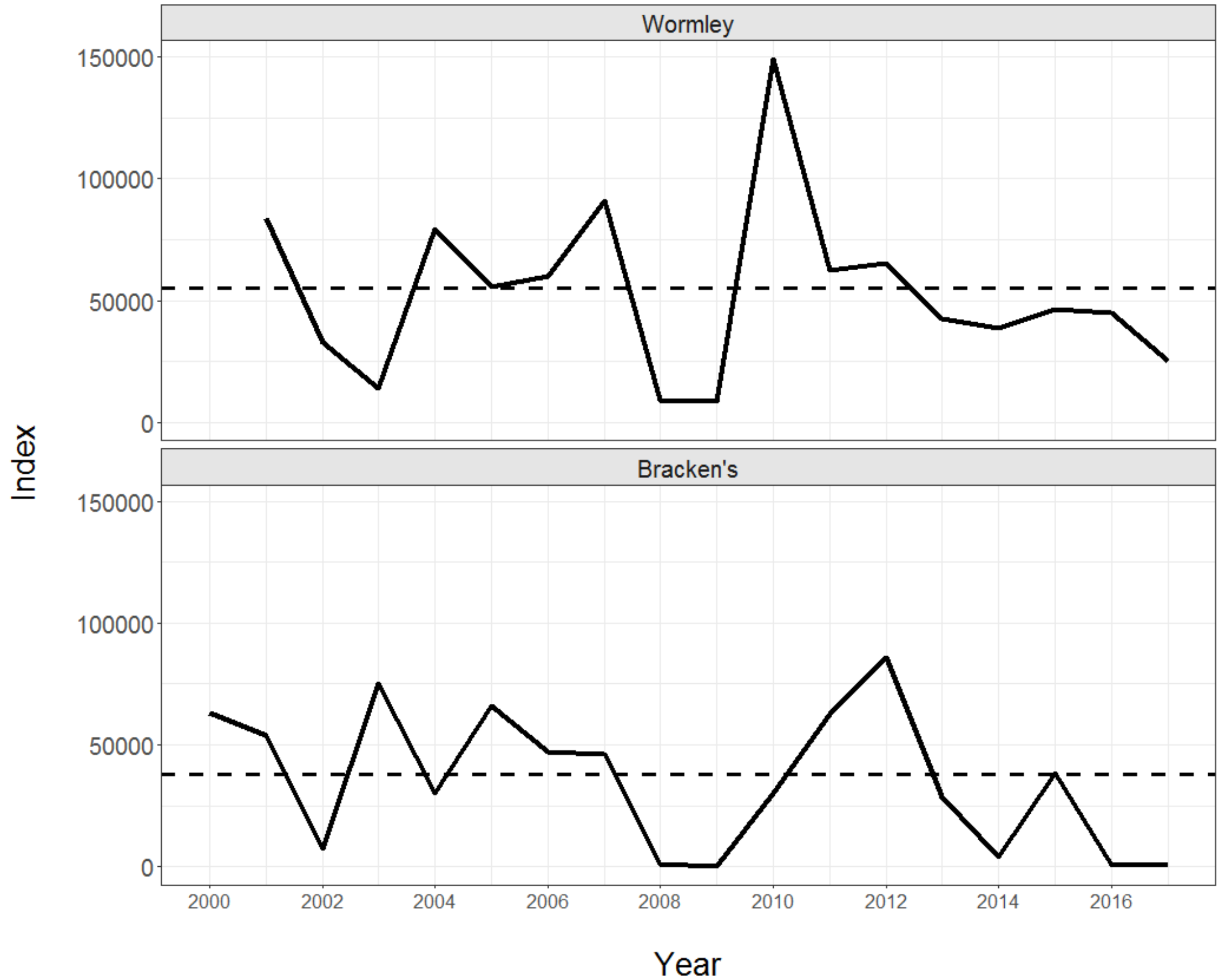

Figure 2. Abundance indices and time series average calculated by the area-under-the-curve method for glass American Eels from Wormley Pond and Bracken's Pond (York River estuary). Time series averages are shown as dotted lines.

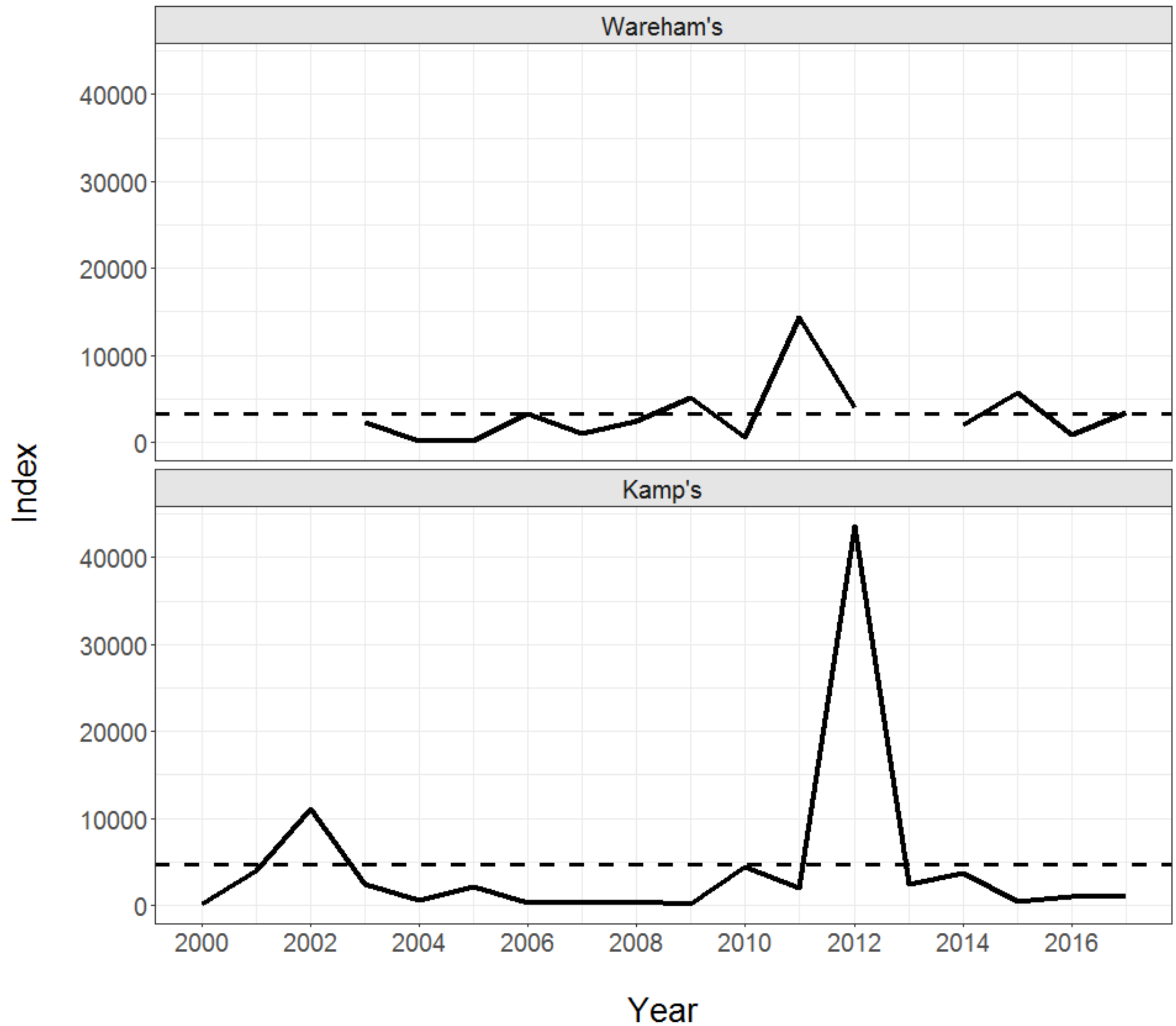

Figure 3. Abundance indices and time series average calculated by the area-under-the-curve method for glass American Eels from Wareham's Pond (James River estuary) and Kamp's Millpond (Rappahannock River estuary). Time series averages are shown as dotted lines. Wareham's Pond was not sampled in 2013 due to dam construction at our sampling site.

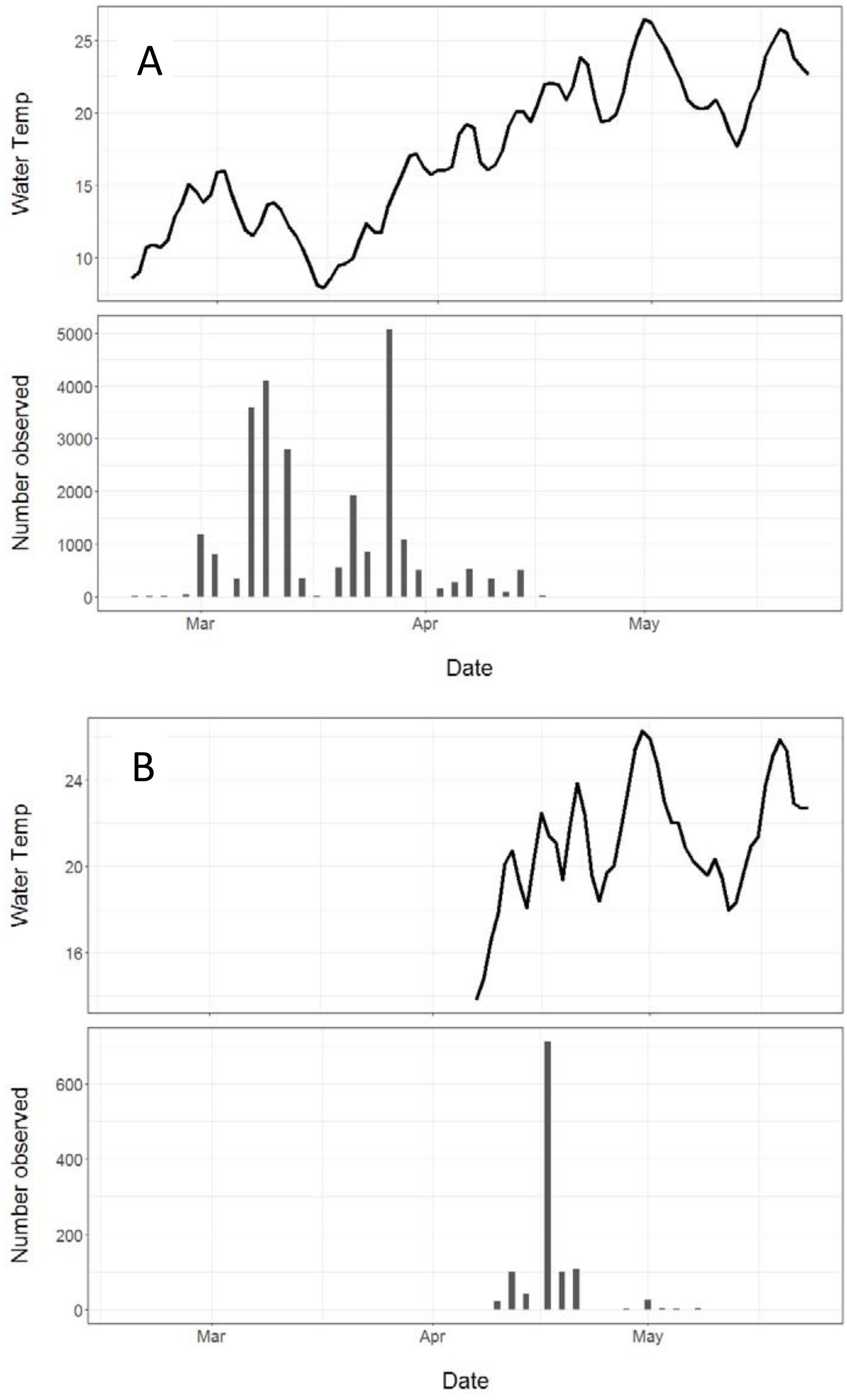

Figure 4. Water temperature (top panel) and glass American Eel catches (bottom panel) from (A) Wormley Pond, and (B) Bracken's Pond in 2017. Note axis scales are not uniform.

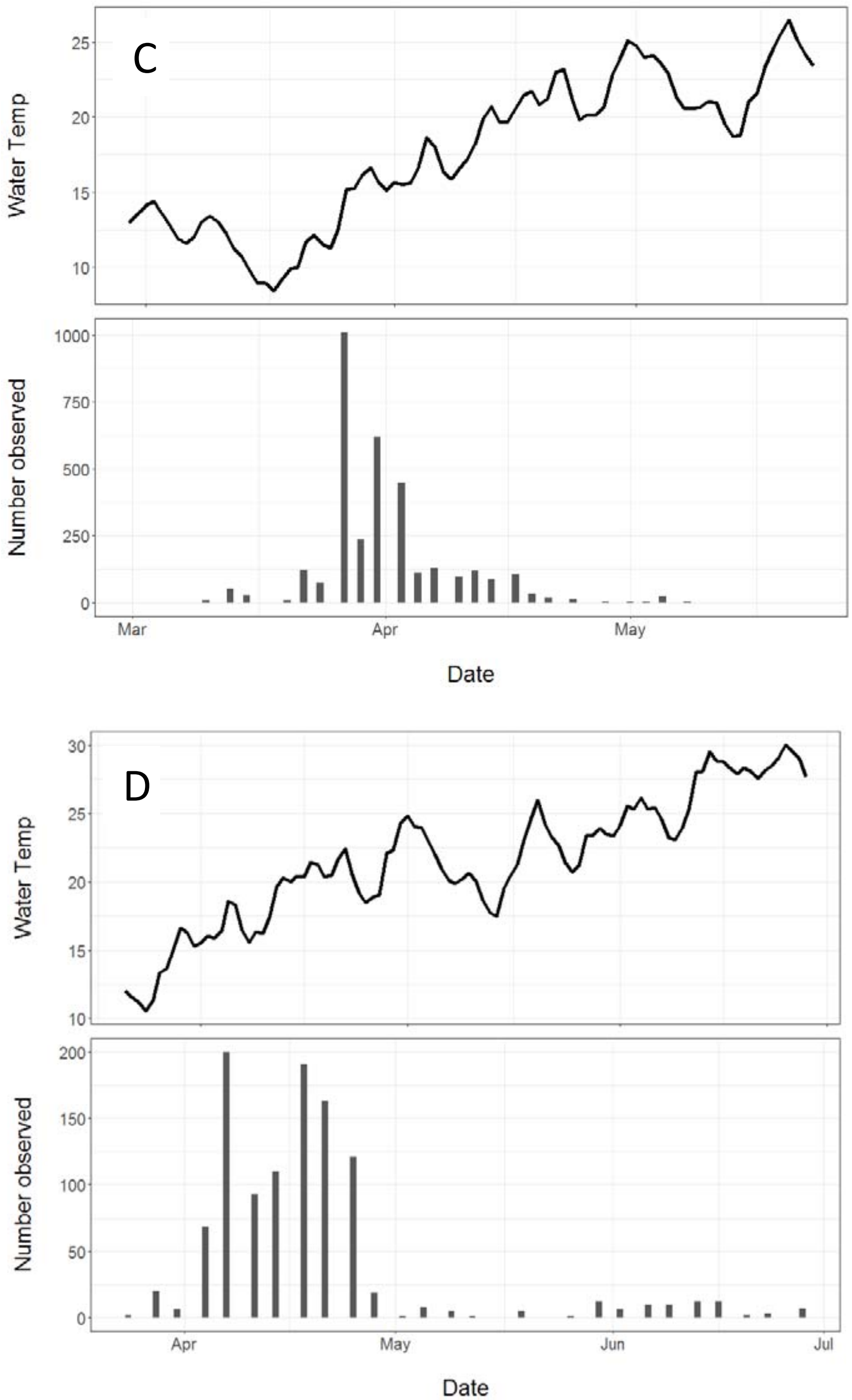

Figure 4 continued. Water temperature (top panel) and glass American Eel catches (bottom panel) from (C) Wareham's Pond, and (D) Kamp's Millpond in 2017. Note axis scales are not uniform.

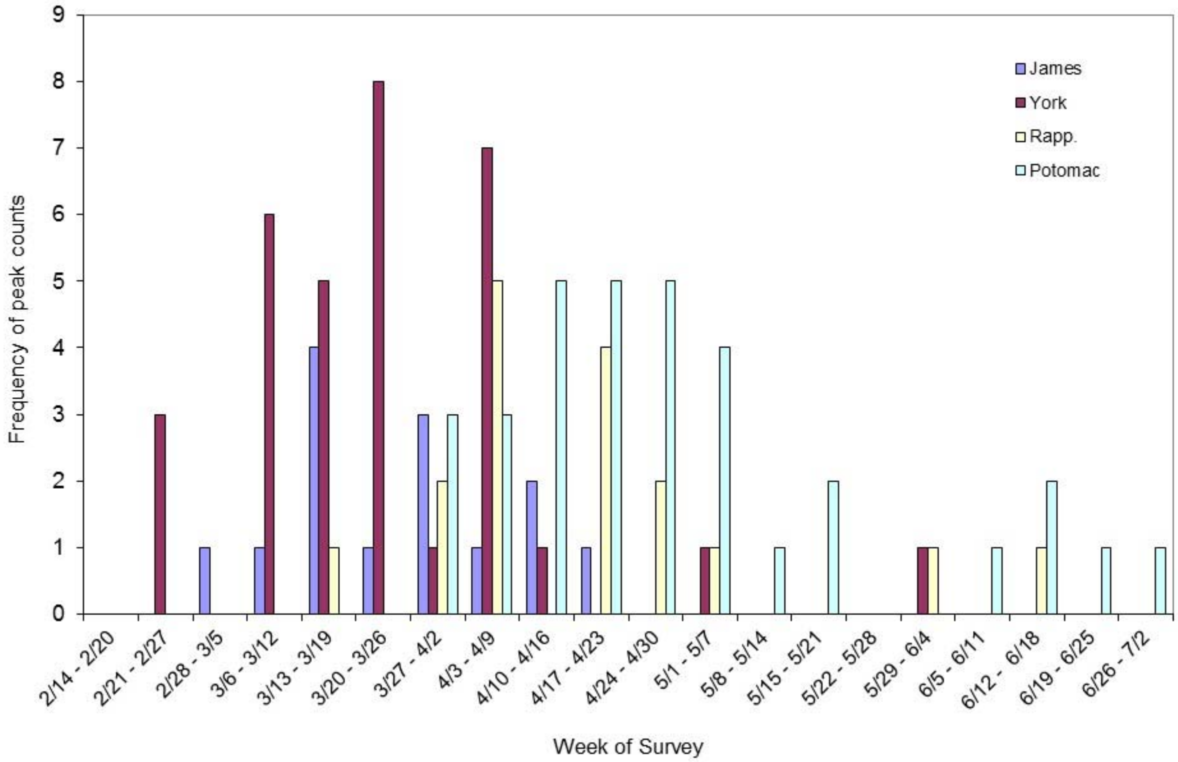

Figure 5. Survey week during which peak counts of glass eels were observed at each site from 2001 to 2017. Two sites are monitored in the York and Potomac estuaries each year (n = 33 observations per river; only one site was monitored in each river in 2017). In the James River estuary, one site was monitored continuously since 2003, though this site was not accessible in 2013 (n = 14 observations). In the Rappahannock River estuary, one site was monitored each year (n = 17 observations). Potomac River data are from Tuckey and Fabrizio (2017).

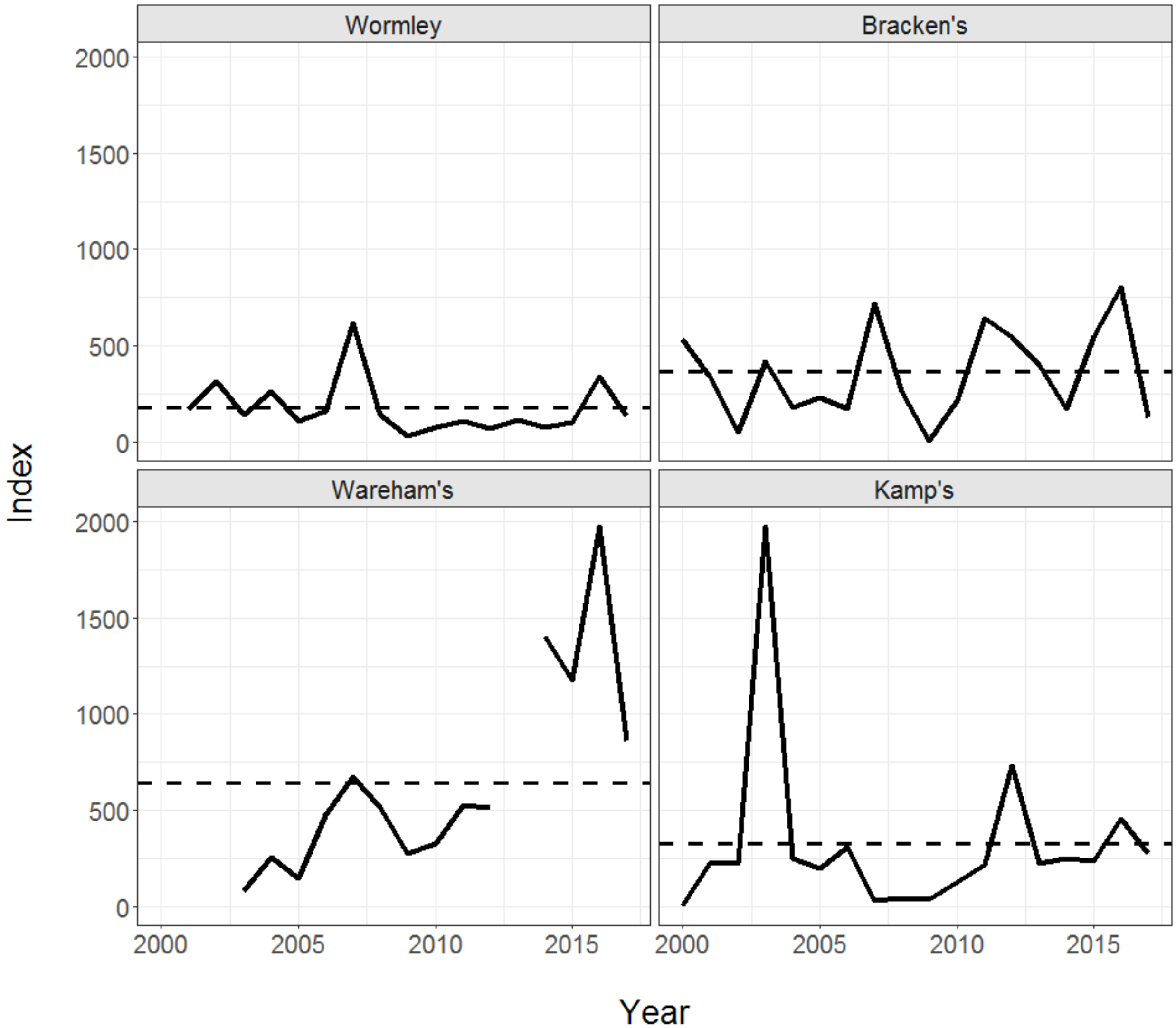

Figure 6. Abundance indices and time series average calculated by the area-under-the-curve method for elver American Eels from Wormley Pond, Bracken's Pond (York River estuary), Wareham's Pond (James River estuary) and Kamp's Millpond (Rappahannock River estuary). Time series averages are shown as dotted lines.

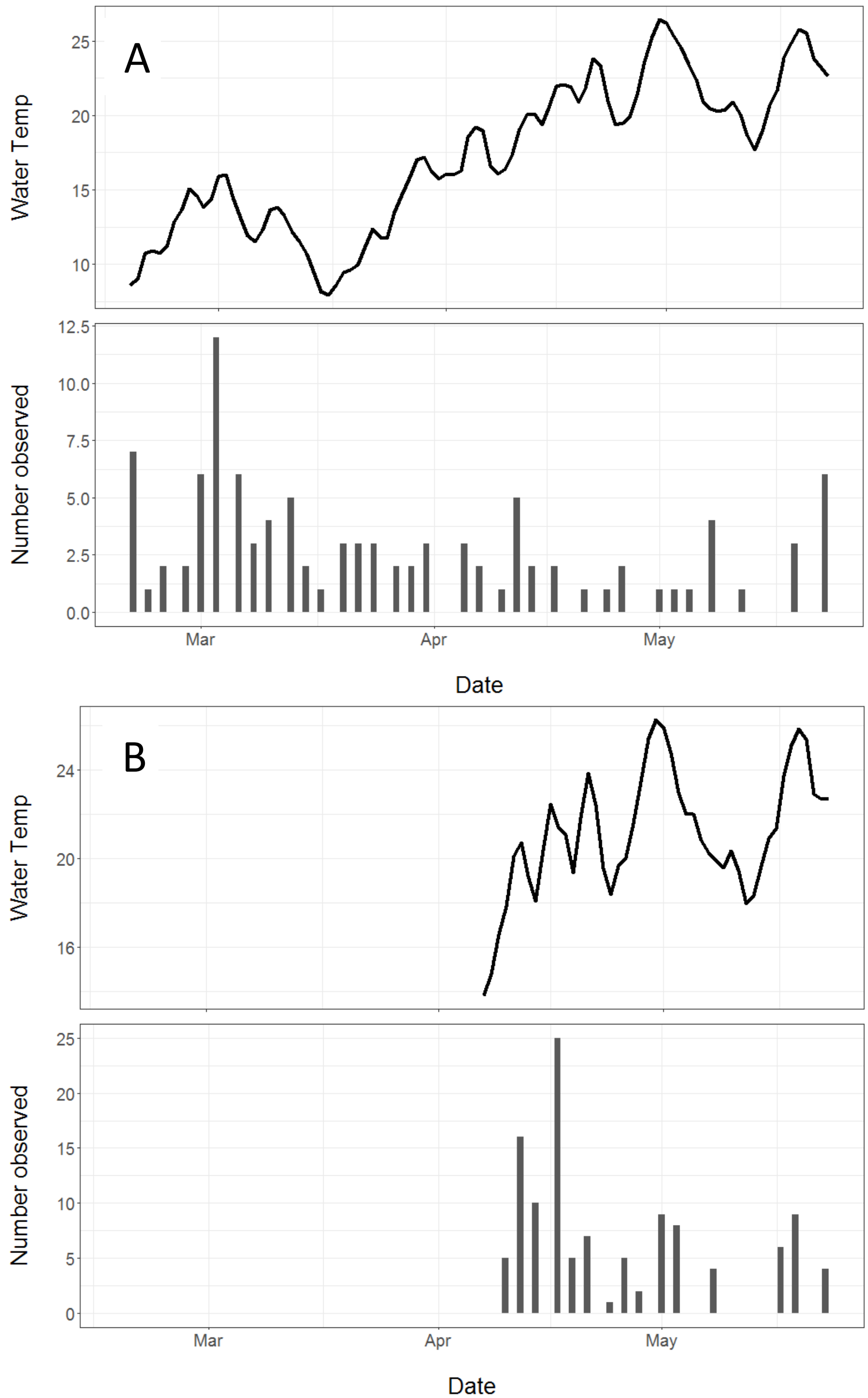

Figure 7. Water temperature (top panel) and elver American Eel catches (bottom panel) from (A) Wormley Pond, and (B) Bracken's Pond in 2017. Note axis scales are not uniform.

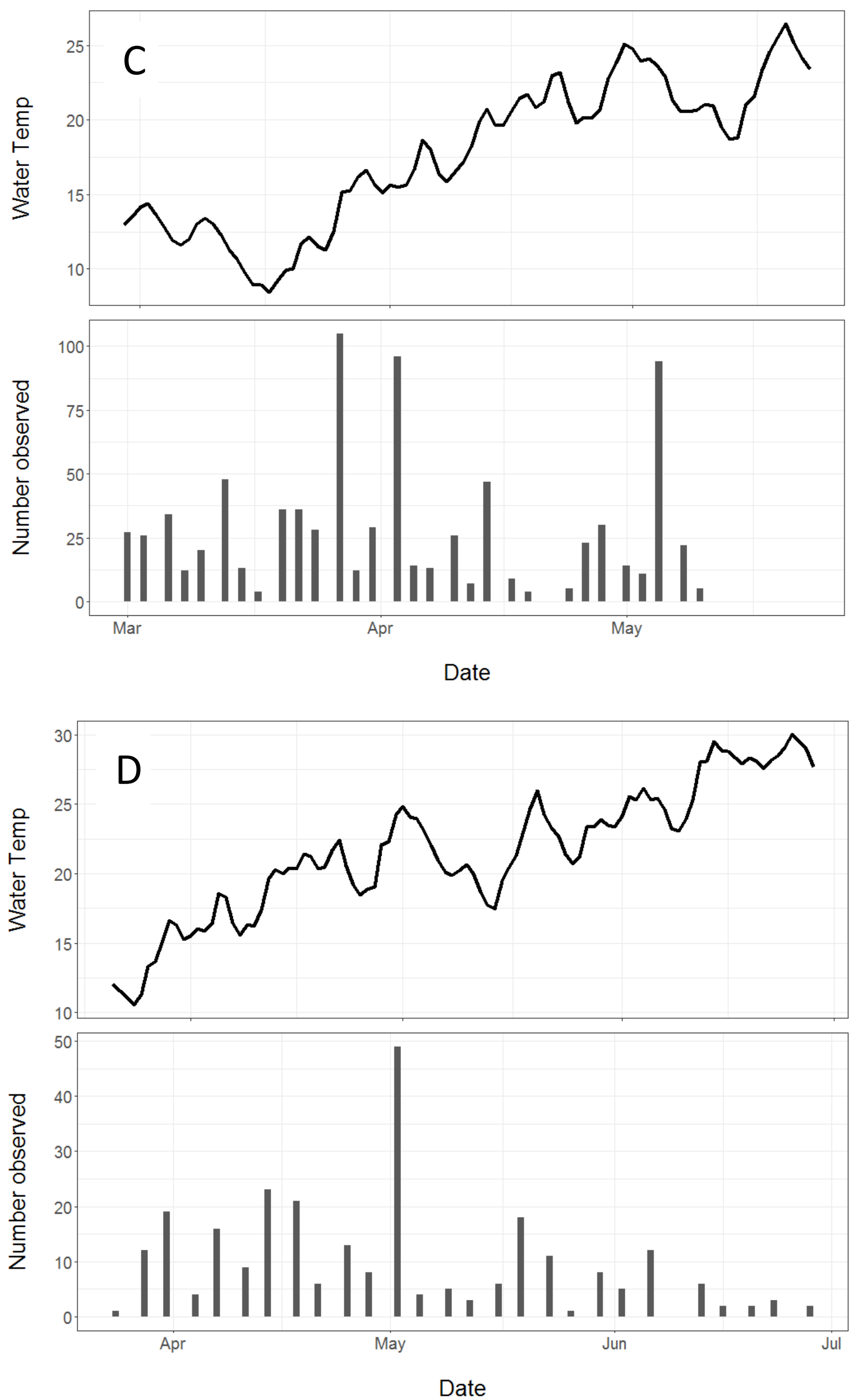

Figure 7 continued. Water temperature (top panel) and elver American Eel catches (bottom panel) from (C) Wareham’s Pond, and (D) Kamp’s Millpond in 2017. Note axis scales are not uniform.

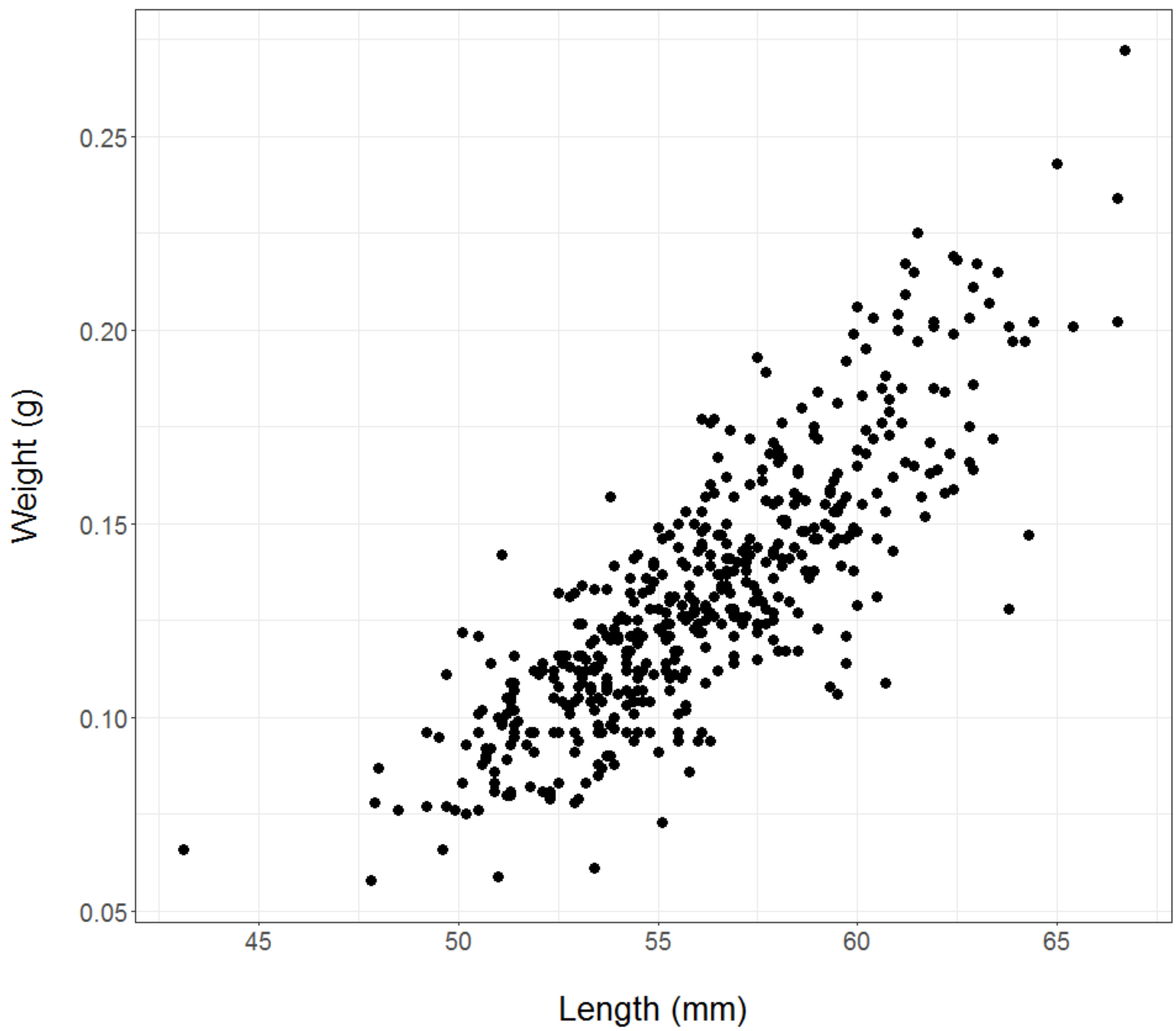

Figure 8. Length-weight relationship for glass American Eels from the York River estuary, 2017. Average TL = 56.1 mm, average weight = 0.131 g, N = 491 eels.

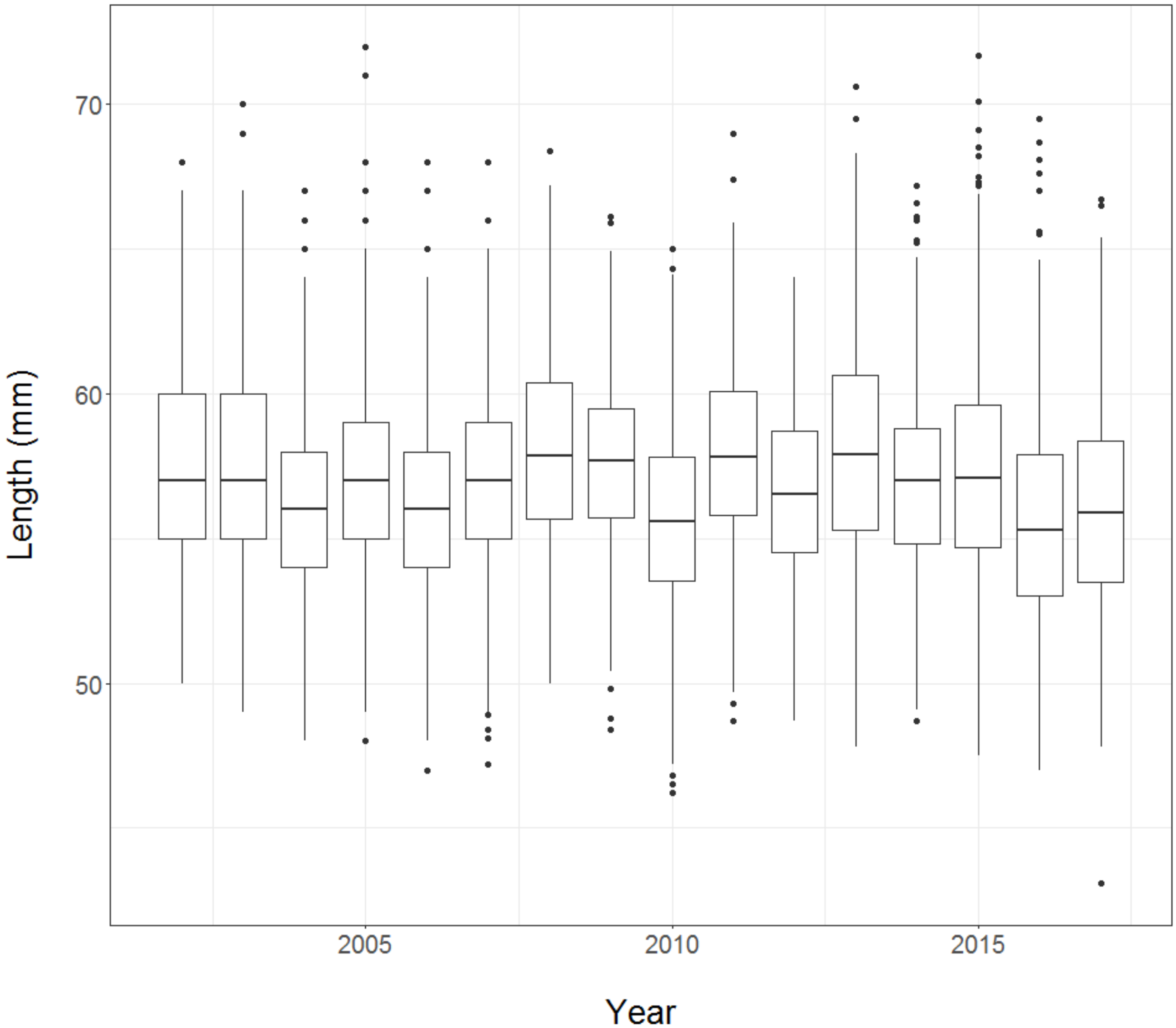

Figure 9. Total length (mm) of glass American Eels collected with Irish Eel ramps from 2002 to 2017 from Wormley Pond in the York River estuary, Virginia. Long-term mean 56.9 mm (n = 17 years). The line indicates the median, the boxes indicate the 25th and 75th percentiles, the lines indicate the 5th and 95th percentiles and the dots indicate outliers.

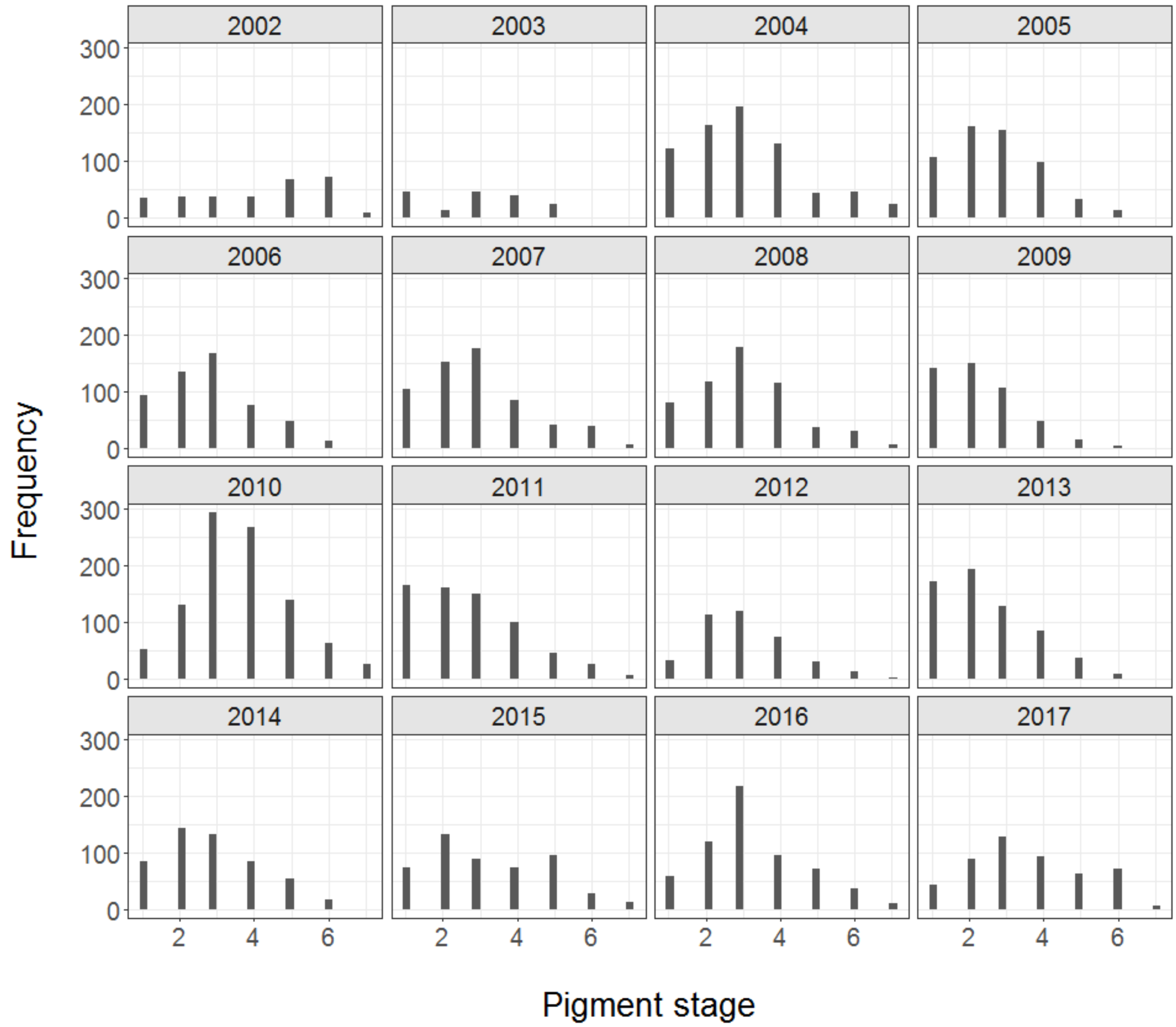

Figure 10. Frequency of pigment stages for glass eels by year for the York River estuary.