Existing Use Evaluation for Zones 3, 4, & 5 of the Delaware Estuary

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Summary

Severe pollution problems have affected the Delaware Estuary for over 100 years. A key component to the estuary's restoration was the establishment of water quality criteria by the Delaware River Basin Commission in 1967. Faced with technical and financial challenges, these 1967 standards included a compromise position for 38 miles of the 133 mile long estuary: a limited "use" for Zones 3, 4, and upper Zone 5 that did not include "propagation" and lower dissolved oxygen water quality criteria. Yet the 1967 goals were ambitious nonetheless, and the recovery in both dissolved oxygen and the living resources in these urban zones of the estuary have been tremendous. Recent data suggest that part of this recovery has been an exceedance of the 1967 goals for the "use" of the estuary, with substantial recovery in "propagation" even in Zones 3, 4, and 5. Because of Clean Water Act regulations requiring reconciliation of "existing uses" and "designated uses", these recent data warranted an evaluation to determine the extent to which a "propagation" use had been achieved for Zones 3, 4, and 5.

To evaluate the "propagation" use, DRBC reviewed existing fishery data collected since 2000 which quantified spawning and/or rearing of early life stages of estuarine fish. This evaluation attempted to both assess whether any evidence of successful reproduction existed for each species in each estuary zone, and the degree to which successful reproduction had been restored for that species. Detailed reviews were possible for 9 fish species: Atlantic Sturgeon, American Shad, Striped Bass, White Perch, Bay Anchovy, Atlantic Silverside, Alewife, Blueback Herring, and Atlantic Menhaden. For all species evaluated, successful reproduction was clearly demonstrated in one or more of the compromised estuary zones. In addition, moderate to strong reproduction was demonstrated for multiple species in each zone indicating substantial recovery in the "propagation" use for Zones 3, 4, and upper Zone 5. Weak and inconsistent spawning by Atlantic Sturgeon, and limited spatial recovery in spawning and rearing by American Shad and Striped Bass, suggested that full restoration of the "propagation" use is not supported by the current available data. Based on this evaluation, DRBC staff recommends that partial restoration of the "propagation" use be recognized for Zones 3, 4, and upper Zone 5 of the Delaware Estuary.

Introduction

Water quality problems have plagued the tidal Delaware River for decades, with early evidence of severe hypoxia extending at least to 1912 (Philadelphia 1914). The USGS began daily recordings of dissolved oxygen at the Ben Franklin Bridge and at Chester, PA, in the 1960s and these records provide the most comprehensive documentation on the timing and magnitude of the estuary's historic hypoxia. The dissolved oxygen conditions for 1967 (see Figure 1) are largely representative of this severe hypoxia, and show hypoxic conditions beginning in May and extending into November.

By the 1950s, the various water quality problems (including dissolved oxygen) and their effects on both human populations and the Delaware Estuary ecosystem warranted federal investment to circumscribe the problem and chart a course for recovery (FWPCA 1966). The U.S. Public Health Service initiated the Delaware Estuary Comprehensive Study (DECS) in 1961, focusing on a computer model for the effects of municipal and industrial wastewater inputs to the Delaware Estuary, and how reductions in those wastewater loadings could lead to recovery of the dissolved oxygen within the estuary.

Near the conclusion of this study, the 1965 revisions to the Federal Water Pollution Control Act authorized interstate water quality standards to protect both human uses and ecological uses (i.e., "propagation of fish and wildlife", PL 89-234) of such interstate waters. Combined with the recent formation of the Delaware River Basin Commission in 1961 to address both interstate water supply and interstate water quality problems, the 1965 revisions to the Federal Water Pollution Control Act established the requisite authorities and framework for DRBC to adopt water quality standards for the Delaware River in 1967.

Controversy surrounded the initial establishment of dissolved oxygen criteria for the Delaware Estuary because of the significant cost-benefit tradeoffs in terms of ecological restoration versus wastewater treatment costs (FWPCA 1966, Wright and Porges 1971). Dissolved oxygen goals as high as 4.5 mg/L and as low as 1.0 mg/L were evaluated in the policy making process of the 1960s, with a compromise being reached where a dissolved oxygen criterion of 3.5 mg/L would be selected for Zones 3, 4, and upper Zone 5 of the estuary. This 3.5 mg/L daily average dissolved oxygen criterion was then established through the 1967 adoption of DRBC's first Water Quality Regulations. It is important to note that this dissolved oxygen criterion has remained unchanged since 1967 (DRBC 2013).

In setting a dissolved oxygen criterion at the compromise value of 3.5 mg/L, and thus below the recognized requirements for fish and other aquatic life (e.g., FWPCA 1968), the DRBC, its member states, and the federal government set a goal for estuary restoration in these zones that protected only migratory fish passage and "low level maintenance of resident fish in the critical reaches of the estuary" (Wright and Porges 1971, pg. I-3/9). In terms of current water quality standards language, two levels of aquatic life use protection were established for the estuary in 1967. For Zone 2 upstream of the hypoxia, and in lower Zone 5 and throughout Zone 6 below

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the hypoxia, full aquatic life use protections were established with the designated use of "wildlife, maintenance and propagation of fish and other aquatic life, passage of anadromous fish" or similar language (DRBC 1967; see Appendix A). In the estuary's hypoxia regions of Zones 3, 4, and upper Zone 5, the "propagation" component to this use was removed and the aquatic life designated use (and thus the restoration goal) in these estuary zones was set to "wildlife, maintenance of resident fish and other aquatic life, fish passage".

Despite these compromises and the recognition in 1967 that full restoration of dissolved oxygen would be difficult, the recovery of both dissolved oxygen and most fish stocks in the Delaware Estuary have been remarkable. Striped Bass runs currently rival those of other major estuaries (e.g., Kahn et al. 1998), American Shad now freely migrate through, and spawn in, the Delaware Estuary (DRBFWMC 2011), and broader surveys of the fish assemblage show high catch rates and remarkable diversity (e.g., Pyle 2014). Sustained funding by DRBC and the USGS for the dissolved oxygen sensors at the Ben Franklin Bridge and Chester, PA, have documented the remarkably recovery in dissolved oxygen concentrations (see *waterdata.usgs.gov*). Figure 2 presents the full daily mean distribution of July dissolved oxygen at the Ben Franklin Bridge since the 1960s, showing the steady rise of summer dissolved oxygen beginning around 1980 and extending to ca. 2000, although dissolved oxygen has been quite variable since 2000.

As part of the recovery in dissolved oxygen and fish stocks, data began emerging that some degree of "propagation"[1] was occurring in Zones 3, 4, and upper Zone 5 where such fishery restoration was not anticipated in 1967. Because Clean Water Act regulations require any improvement in conditions to be captured and recognized, in part to prevent "backsliding" or loss of improvements gained through restoration efforts, data demonstrating successful reproduction in Zones 3, 4 and upper Zone 5 would serve as the initial basis for a re-evaluation of the designated uses for these estuary zones. Specifically, 40 CFR § 131.10(i) states "*Where existing water quality standards specify designated uses less than those which are presently being attained, the State shall revise its standards to reflect the uses actually being attained.*" In other words, if the "Existing Use" (i.e, the use presently being attained) is less than the "Designated Use" currently adopted in regulations, reconciliation is needed under federal rules.

The DRBC's Water Quality Advisory Committee began deliberations on this issue in 2009 as part of a broader evaluation of nutrient and dissolved oxygen conditions for the Delaware Estuary (see meeting minutes at *www.drbc.net*). A petition by three non-profit organizations in 2013 emphasized the need to proceed in reconciling the Existing Use with the Designated Use based on their evaluation of fishery data from the Delaware Estuary. Finally, the Water Quality

[1] The term "propagation" is not defined in DRBC's Water Quality Regulations. Often used in the context of artificial rearing (e.g., fish hatcheries), other regulatory agencies have defined propagation as "reproduction of fish, aquatic life and wildlife within their natural environment." (Delaware 2014). Based on the historical context of the aquatic life uses established in 1967, this report recognizes propagation somewhat more broadly as both the reproduction and the critical early life stage rearing necessary to recruit aquatic life into the population. For the fish species examined in detail in this report, this definition of propagation would include protection of spawning, eggs, larvae, and early stage juveniles.

Advisory Committee discussions culminated in a September 2013 resolution recommending the following:

> *"The WQAC recommends that within one year the DRBC staff will prepare for the Committee a description of the existing aquatic life uses of the Delaware Estuary with citation to source materials which will be used to craft a formal Finding of Existing Uses that will be presented by the Committee to the Commissioners."*

In this report, DRBC conducts an evaluation of existing fishery data to directly address the question as to whether, and to what degree, a broader "propagation" use has occurred in Zones 3, 4, and upper Zone 5 of the Delaware Estuary. The data sources and the methods for evaluating these data are first described. The results of the evaluation are then provided for each species in each of the three downgraded zones of the estuary. Finally, the individual evaluations are synthesized into a zone-specific assessment of the "propagation" use.

Data Sources

This report uses the results from three separate data collection efforts for resident and migratory fish species inhabiting the Delaware Estuary in order to evaluate the extent and consistency of "propagation" in Zones 3, 4, and 5. These data sets are described in detail below, but the decision to focus on these three data sets for the current evaluation is first discussed.

The evaluation of "propagation" in the broadest sense could include an evaluation of the reproductive success of many aquatic assemblages in the tidal Delaware Estuary, from planktonic invertebrates to freshwater mussels to anadromous fish. All are aerobic organisms utilizing the tidal Delaware River for reproductive output and subsequent nursery of juvenile organisms. Yet two factors recommend the use of the resident and migratory fish assemblages above other aquatic organisms. First, from a historical context, the restoration of dissolved oxygen in the Delaware Estuary centered on the restoration of fishery resources such as American Shad and Striped Bass. In order to assess the efficacy of the past 40+ years of dissolved oxygen restoration, its origins in fishery restoration argue for an evaluation of that fishery resource and the extent of successful "propagation" in this resource. Second, and more importantly, is the pragmatic reality that little or no data currently exist on the extent of successful reproduction for most organisms in the Delaware Estuary, and even less data exist on

the spatial and temporal patterns in that reproductive success. Only the intensive monitoring of fishery resources for both regulatory and management objectives produces quantitative data on the location and timing of successful spawning as well as the later rearing stages. Therefore, the current evaluation of "Existing Use" for Zones 3, 4, and 5 of the Delaware Estuary relies exclusively on previously collected fishery data for eggs, larvae, and juveniles of resident and migratory fishes utilizing these zones of the Delaware Estuary.

Fishery surveys in the Delaware Estuary have been (and continue to be) conducted to fulfill many objectives, from permit compliance to fishery management obligations to basic academic research. Much of this effort is directed at assessment of adult populations, and such surveys provide limited utility for the current assessment of "propagation" in the Existing Use context because of their focus on older life stages. Other surveys do capture and quantify early life stages for many fish species, but have limited spatial and/or temporal resolution and thus only provide presence/absence answers to questions that (as shown later) require evaluations of strength and consistency. Impingement & Entrainment reports at a single facility in an isolated year are examples of such valuable fishery data which have not been incorporated into this evaluation because they shed little additional light on the core questions beyond what is already established with more comprehensive data sources.

Three data collection efforts, however, directly target early life stages of one or more fish species and provide data that directly answer questions about the relative strength of spawning and rearing in the Delaware Estuary across a broader spatial and temporal extent. In particular, these three data sets share three common features that make them particularly well-suited for evaluating the "Existing Use" questions relative to the full "maintenance & propagation" use within DRBC's water quality regulations:

i. Quantitative data on the success of early life stages in Zones 3, 4, and/or 5 of the Delaware Estuary;
ii. Multiple years of data at known and consistent spatial locations;
iii. Data collection during the period from ca. 2000 to 2014 when dissolved oxygen conditions exhibited no long-term trends (see Figures 3 and 4).

The first of these three data sets was identified through discussions at the Delaware River Basin Fish & Wildlife Management Cooperative and comes from regulatory monitoring for the PSEG Salem Nuclear Generation Station, a large nuclear power plant located near the lower boundary of DRBC Zone 5 within the Delaware Estuary (~RM 51; see Figure 3). In advance of PSEG's submission of its renewal application in 2006, ichthyoplankton surveys were required throughout the tidal Delaware Estuary (river and bay) during 2002, 2003, and 2004. Detailed descriptions of the methodology can be found in the respective Biological Monitoring Program annual reports (PSEG 2002, PSEG 2003, PSEG 2004). In summary, the entire estuary from Trenton to the Atlantic Ocean was divided into 14 "zones" (see Figure 4; henceforth referred to as "reaches" to avoid confusion with DRBC water quality management zones), with multiple grids within each reach. Surveys were conducted twice monthly from April through July

resulting in 8 surveys each year. During any survey, station locations were randomly selected within each reach from among the grids, with multiple stations (ranging from 2 to 14) within each reach and somewhat even effort per unit area across the estuary. Sampling consisted of a 1 m diameter conical plankton net with 500 µm mesh netting and 500 µm mesh capture bucket. Depending on depth, single integrated tows proceeded at successively deeper vertical positions for a total trawl time of 4 to 6 minutes. Equal amounts of time were sampled at each depth, with no surveys at station locations with depths 10 ft or less, and increasing numbers of strata for increasing depths: for 10-20 ft depth, sampling at 5 ft and 15 ft strata; for 20-30 ft depths, sampling at 5 ft, 15 ft, and 25 ft strata; etc. Samples were preserved in the field with 10% formalin and stained with Rose Bengal. In the lab, a complex subsampling procedure was used, and identifications were made to species level, if possible, for each life stage. However, only "target species" were enumerated for all samples. These target species were Blueback Herring, Alewife, American Shad, Atlantic Menhaden, Bay Anchovy, Atlantic Silversides, White Perch, Striped Bass, Bluefish, Weakfish, Spot, and Atlantic Croaker along with two invertebrate groups (*Neomysis americana, Gammarus* spp.).

Data from the PSEG Ichthyoplankton surveys are provided as event summaries for each of PSEG's reaches, with results broken out by species for the following life stages: eggs, yolk sac larvae, post-yolk sac larvae, juveniles, adult, and undetermined larvae (see Appendix C). Thus, data from multiple survey stations are pooled to represent each of the PSEG reaches in the estuary for each survey date. The PSEG Ichthyoplankton results provide the most direct measure of spawning activity for key species such as American Shad and Striped Bass, although the high variability in catch rates for eggs and yolk sac larvae are important to keep in mind given their episodic occurrence and short life-stage duration. In addition, the PSEG Ichthyoplankton data provide some measure of the success by tracking each fish species through each of their early life stages, a key component in the overall assessment of successful "propagation" for the target species included in the PSEG surveys. As shown in Figure 4, however, the PSEG reaches cross the boundaries for DRBC zones, leading to some lack of specificity in the ichthyoplankton data.

The second data set identified for inclusion in this evaluation originated from a member of the Delaware River Basin Fish & Wildlife Management Cooperative. The NJ Division of Fish & Wildlife, Bureau of Marine Fisheries, conducts Delaware Estuary beach seine surveys from June through November each year, with initial sampling for these surveys beginning in 1980 and continuing every year through the present. These surveys constitute a key fishery independent monitoring project that is required under the Atlantic State Marine Fisheries Commission's "Fishery Management Plan for Striped Bass." Designed primarily for monitoring juvenile Striped Bass, the survey also currently records the abundance of all species captured. Full survey details are contained in annual reports posted on the Bureau of Marine Fisheries website (e.g., 2013 report at www.nj.gov/dep/fgw/artdelstudy14.htm), with key survey details summarized here. Seining occurs during daylight hours at beach locations within the tidal Delaware River with a 100 ft long, 6 ft deep bag-containing seine net with ¼ inch mesh. In addition to counts by species, lengths are measured for target species and the range of sizes is

recorded for non-target species. Sampling currently occurs at 32 fixed stations beginning upstream at RM 126 (Newbold Island) in DRBC Zone 2 and extending downstream to RM 53 (Augustine Beach) near the lower end of DRBC Zone 5 (Figure 3). Sampling stations and effort have remained highly consistent for the 2000-2013 period used in the current evaluation of Existing Use. Greater sampling effort occurs in Zones 2, 4, and 5 than in Zone 3 because fewer suitable "beach" seining locations are available in Zone 3. Fish species are typically identified in the field, with nearly 100 species identified through the duration of the survey.

It is important to distinguish the nature of data collected in the New Jersey Seine Survey from the data collected in the PSEG Ichthyoplankton survey, and to acknowledge the limitations with respect to the Existing Use question evaluated in this report. The New Jersey Seine Survey begins to capture fish of different species typically when they reach between 20 mm and 30 mm in length. Depending on the species, this could represent nearly mature fish (e.g., Bay Anchovy) or it could represent early young-of-year fish recently spawned and reared near an individual beach seine location (e.g., Striped Bass). In addition, because of varying fidelity to the estuary itself beyond the early nursery stage, some species can be more clearly identified as young-of-year juveniles spawned and/or reared within the estuary (e.g., American Shad) while other species use the estuary for all or a larger portion of their lifecycle, thus mixing young-of-year juveniles with older juvenile and adult fish (e.g., White Perch). As a result, the New Jersey Seine Survey provides a measure of the combined success of both spawning and rearing through the minimum size threshold for those species where young-of-year fish can be clearly identified (American Shad, Alewife, Blueback Herring, Striped Bass [note: although Striped Bass utilize the estuary for multiple years, the NJ Bureau of Marine Fisheries uses a suite criteria to accurately distinguish young-of-year from older fish]). For species where the distinction between young-of-year and older fish cannot be made (e.g., Atlantic Silversides, Bay Anchovy, Hogchoker, White Perch), these data provide more of a combined population estimate and an indicator of whether successful reproduction and rearing had occurred, but not a more narrow measures of "propagation" alone. In addition, and in contrast to the PSEG Ichthyoplankton surveys, the New Jersey Seine Survey samples and identifies all fish species collected in their survey. For the current Existing Use assessment, the New Jersey Seine Survey data are therefore more important for species whose young-of-year could be clearly distinguished.

The New Jersey Seine Survey thus provides important data for assessing propagation and, in particular, provides a historical context upon which to assess the current results. The survey's origins in the early 1980s cover the period when dissolved oxygen was only beginning to recover from decades of chronic hypoxia and when some migratory fishes were initiating their recovery within the Delaware Estuary. Such origins, combined with an unbroken time series, provide an insightful perspective on current spawning efforts. Those early years of the survey typically showed very low young-of-year abundance, especially in Zones 3 & 4, and these near-zero catches delineate the lower end of the "propagation" scale when fish spawning and recruitment was either low or failing. Although the lower end of the "propagation" scale is therefore clearly delineated, the upper end of the recruitment scale (e.g., pre-European numbers) that would

establish a benchmark for highly successful propagation within the estuary may not yet be attained and it is difficult to assess how complete the recovery of spawning and rearing has been without that historical upper range clearly delineated. Nevertheless, the temporal extent of the New Jersey Seine Survey at a minimum provides a clear measurement scale for both poor recruitment as well as moderate to strong recruitment for many estuarine species, yielding a scale that is well-positioned to answer questions about the success or failure of spawning and recruitment of estuarine fish species.

The third and final data set used for this report involves multiple targeted collections and tracking of early stage juvenile Atlantic Sturgeon (also known as river-resident juveniles; see species results below). Beginning in 2009, Delaware's Division of Fish & Wildlife shifted their sampling methods for juvenile Atlantic Sturgeon to better capture spring spawned young-of-year fish from the Delaware Estuary as well as both age-1 and age-2 fish which had overwintered in the Delaware Estuary. These targeted surveys for early stage, river-resident juvenile Atlantic Sturgeon were completed in 2009, 2010, 2011, 2012, and 2014. In addition, Brundage and O'Herron conducted separate surveys in order to tag and track juvenile Atlantic and Shortnose Sturgeon (Brundage and O'Herron 2010). For both research groups, surveys primarily involved small-mesh gill net deployment in targeted locations, with supplemental data collected through active and passive tracking of tagged individuals collected in the gill net surveys. Tracking also provided spatial data to improve the placement of gill net surveys. Gill net surveys focused on areas between Carney's Point, NJ (RM 71) and Marcus Hook, PA (RM 81) covering the upper portion of Zone 5 and the lower portion of Zone 4, although additional surveys further upstream and downstream were also included. Passive and active tracking extended throughout the Delaware Estuary from Zone 2 through Zone 6 (Delaware Bay). Detailed methods and results can be found in the various annual reports (Brundage & O'Herron 2010, Fisher 2010, Fisher 2011a, Fisher 2011b, Fisher 2012, Fisher 2013, Brundage & O'Herron 2014).

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Structure to Fishery Data Evaluation

The recovery of fish spawning and rearing in the Delaware Estuary involves a gradual process of increasing success as water quality, habitat, and overall stocks improve toward conditions existing prior to severe human alteration. Initially, some limited spawning and rearing may occur in the estuary, particularly for fish species tolerant of heavy human influences such as the hypoxia historically present in the Delaware Estuary. With continued recovery of impaired conditions, further increases in the spawning and rearing would be expected as more species of fish and more individuals of each species find increasingly suitable conditions for growth and development. With substantial restoration of conditions and with the resulting increases in population sizes, the utilization of the estuary may approach levels seen historically for many, if not most, fish species.

Recognizing the continuum in this recovery spectrum, the current report seeks to go beyond a simple yes/no (or binary) answer to the question about fish "propagation" in the estuary. To achieve a more continuous representation in the restoration of fish "propagation" for the Delaware Estuary, and to seek a relatively objective answer to these questions which undoubtedly contain many subjective elements, the evaluation of data for each fish species was broken into a series of yes/no questions (rather than a single yes/no question) that represents increasing levels of success in restoring each species' use of the Delaware Estuary. An example is shown in Table 1. These yes/no questions were evaluated separately for each fish species and for each of the three DRBC water quality zones where the "propagation" use is not currently designated in the DRBC Water Quality Regulations (Zones 3, 4, & 5; note that Zone 5 has different "uses" in the upper and lower portion; these two sections of Zone 5 were evaluated separately). And to acknowledge the lack of clear objective thresholds for decisions on each question, a middle category between "yes" and "no" was allowed and used in numerous settings when the data were considered equivocal.

Initial stages in "propagation" success can be demonstrated with some evidence of eggs, larvae, and/or early juvenile stages in a specific estuary zones. Even if such data are not consistent year after year, the presence of measureable numbers of early life stage individuals allows for an affirmative answer to the question, "Is there any evidence of successful reproduction?" This is the first question addressed along the continuum.

Further restoration would then be demonstrated with increased numbers of early life stage individuals and/or increased consistency among years in catch data for these early life stages. Such moderate levels of consistency would permit an affirmative answer to the question, "Is there regular evidence of successful reproduction for this species?" This is the second and middle category for evaluating the degree of successful reproduction.

More complete restoration is then demonstrated with a high level of consistency and substantial numbers of these early life stage individuals in most years. Of course, estimates of population sizes and spawning success are notoriously uncertain or variable for many fish

species, so a high degree of consistency does not necessarily require equal numbers year after year without any breaks in the string of successful year classes. Instead, this high variability is acknowledged and helps establish expectations for the third question, "Are there strong numbers and high consistency of successful reproduction?"

Table 1. Example of the Evaluation Matrix. (Overall structure is explained in text. The first three color-coded columns in the table indicate priorities in different studies. The first shows whether the 1979 Task Force (Nadeau et al. 1979) identified the species as a key "migratory or marine/estuarine" (m), "resident (freshwater/brackish water)" (f). The second shows a red box for those species included as part of PSEG Salem's targeted species list. The third column shows in blue species averaging more than 10,000 fish caught per year and in green species averaging more than 10 fish caught per year in the NJ Seine Survey.

Species X

1979 Task Force	PSEG target (12 spp)	NJ: 10 K/yr and 10/yr groups	Common name	Scientific name		Any evidence of successful reproduction?	Regular evidence of successful reproduction?	Strong numbers & high consistency of successful reproduction?
m			Species X	*Genus species*				
					Zone 3	Y	Y	?
					Zone 4	Y	?	N
					Zone 5 (upper) *RM 70-78.8*	Y	N	N
					Zone 5 (lower) *RM 48.2-70*	N	N	N

This third and highest level of "propagation" restoration used in this report proved to be the most problematic and ambiguous of the three categories for evaluating the fishery data. Two issues arose. First, it was not always clear how consistent and how high catch data needed to be to qualify for a "yes" in this category, with discussions of a more rigorous threshold. Although a number of candidate thresholds were considered, a clear choice for a threshold was not apparent and none was employed in the current evaluation. The second limitation with this highest category involves the degree to which it represents full successful restoration of "propagation" for any particular species. Although some managed stocks (e.g., Striped Bass) have officially been designated as "restored" by management agencies, quantitative historical data are typically

sparse and involve comparisons across different sampling methods. Thus, even for populations who have seen substantial recovery, it is difficult or impossible to infer whether population sizes have recovered to levels seen prior to major alteration of the estuarine ecosystem (water quality, habitat, etc.). In the absence of such comparative data, this study contends that an affirmative answer to this highest category of "propagation" still leads to ambiguity on the question of whether the "propagation" use has been fully restored or whether continued improvement toward full restoration remains possible; both levels of restoration may be implied by a "yes" to this question.

Because subjectivity persisted even with these attempts to minimize its influence, initial evaluations for key species were presented to fishery biologists both at a Delaware River Basin Fish & Wildlife Cooperative technical committee meeting, and in smaller group settings with fishery biologists from the states of Delaware, New Jersey, and Pennsylvania. Data from multiple sources were reviewed for the key species, and the decisions for each question were evaluated. Typically, a consensus could be reached on the appropriate answer to each question, but complete agreement was not always possible.

Two additional and important clarifications are needed to understand the current data evaluation, with the two issues being related. The first relates to different evaluation standards for different species. The second relates to different expectations for fish species in different zones of the estuary.

This report did not typically apply different standards in the data evaluation matrix for different species. As described above, the data that would qualify for an affirmative or negative evaluation to the "any" vs "regular" vs "strong" questions were largely the same for all species. One important distinction was made to account for the salinity regime in which spawning occurs for each species. For obligate freshwater spawning fish, affirmative answers to the questions in freshwater zones (i.e., Zones 3 and 4) required increasing demonstration of eggs and larval presence and abundance. However, a number of marine and brackish water fish species use different salinity regimes for different stages in their spawning and larval rearing phases (e.g., Bay Anchovy, Atlantic Menhaden). For these more marine or brackish water species, the demonstration of low to moderate levels of "use" for an estuary zone could be demonstrated without substantial data on eggs, in particular. Thus, the use of upper Zone 5 for Bay Anchovy was assessed as affirmative for the "regular" level because substantial and moderately consistent numbers of larval and juvenile fish were observed even though eggs were not similarly strong. In contrast, the lack of consistent egg numbers in Zone 4 for American Shad, despite substantial evidence of larval and juvenile use in this zone, led to an ambiguous evaluation for whether American Shad use qualified as "regular evidence of successful reproduction". This approach constituted the only incorporation of life history and habitat use into the evaluation matrices, and the only change in the standards by which different species were evaluated.

More broadly, each fish species evaluated in this report does not have the same expected use in all zones of the estuary. As mentioned above and in the species descriptions below, different salinity requirements and preferences among species leads to substantially different expectations

for which fish should be "propagating" in the brackish lower Zone 5 than in the purely freshwater Zone 3. In addition to salinity, each species has different habitat preferences that make even similar salinity zones (e.g., Zones 2, 3, and 4) more or less suitable for each species. These differences in the basic ecology for each fish leads to different expectations for what "successful propagation" looks across multiple species for each zone of the estuary. A group of primarily fisheries biologists attempted to define these different expectations for many of the key species (although Atlantic Sturgeon were omitted) in 1979 when evaluating the fishery and D.O. requirements in the estuary (Nadeau et al. 1979; see Appendix B for Table 1 of their evaluation). Given the history of gross pollution in the estuary and the sparse availability of reliable historic data, any such attempt at setting the precise expectations for fish recovery in the estuary is subject to debate, and the evaluation in Nadeau et al. would benefit from an updated review of these expectation in light of the observed recovery seen since 1979. Unfortunately, a thorough review of the expectations for each species based on both historical data and current biological requirements was beyond the scope of the current study. Nevertheless, the Table 1 expectations in Appendix B begin to distinguish the varying expectations for "successful propagation" among the estuary's zones. In particular, the 1979 evaluation shows, for instance, that Bay Anchovy were not expected to use Zone 4 in appreciable numbers for spawning or nursery, while American Shad were not expected to use Zone 5 in appreciable numbers for spawning and nursery activities. These broader expectations for each zone are therefore used in the final evaluation for each zone of the estuary (see Conclusions section), while acknowledging some uncertainly for the exact expectation in each zone.

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Results – Species Level Evaluations for Successful "Propagation"

Each species' evaluation is presented separately below beginning with fish whose data most directly addresses the questions of "propagation" for the estuary

ATLANTIC STURGEON

Atlantic Sturgeon (*Acipenser oxyrhynchus*) are large (to 14 ft / 4 m), long-lived (60 years), and late-maturing (5 to 22 years) anadromous fish that use tidal estuaries for spawning (ASSRT 2007 and references therein). Spawning occurs in a zone beginning at the salt front and extending upstream to the fall line, although exact locations are not know for each estuary. In the Delaware Estuary, this zone extends from upper Zone 5 through Zone 2. Spawning occurs in spring and early summer, perhaps as late as mid to late June in the Delaware River (Simpson and Fox 2007). Individuals are not believed to spawn every year but instead may return every 1 to 5 years to their spawning grounds. Juvenile sturgeon become tolerant to brackish water and reside in both freshwater and brackish water areas within their natal estuary for one or more years (river-resident juveniles). Sub-adults then join the larger coastal migrations of Atlantic Sturgeon. It is important to note that laboratory work has shown that young juvenile fish sustain high mortality under depressed dissolved oxygen conditions (e.g., Secor and Gunderson 1998).

Recent surveys have confirmed successful reproduction and recruitment of Atlantic Sturgeon in the Delaware Estuary. Although isolated young-of-year catches have been noted for decades, the first documentation of at least a small to moderate year class occurred with the capture of over 60 young-of-year sturgeon beginning in the fall of 2009 (Fisher 2010, Brundage & O'Herron 2010). However, subsequent surveys have shown only sporadic success for Atlantic Sturgeon spawning and rearing. The following year in 2010, no young-of-year Atlantic Sturgeon were captured when fishing in a manner consistent with the 2009 efforts. In 2011, another successful year class was documented when nearly 50 young-of-year were captured (Fisher 2012). In 2012, only two young-of-year Atlantic Sturgeon were captured during targeted surveys (Fisher 2013). Limited surveys were conducted in 2013, so no comparable data exist. Then in 2014, another successful year class was documented with over 100 river-resident juveniles captured during the targeted surveys, although size ranges prevented clear indications

for the number of young-of-year fish (I. Park *personal communication*, H. Brundage *personal communication*).

Gill net captures of young-of-year Atlantic Sturgeon were all made in lower Zone 4 and upper Zone 5 (above RM 70) within the Delaware Estuary. Tagging of select individuals subsequently showed extensive use of all zones in the Delaware Estuary for juvenile rearing (Brundage & O'Herron 2010, Fisher 2011b, Brundage & O'Herron 2014). Although the location of Atlantic Sturgeon spawning grounds within the Delaware River remains unknown and somewhat controversial (Simpson 2008, Breece et al. 2013), the initial collection of young-of-year fish in both upper Zone 5 and lower Zone 4 leads to an affirmative answer within these two zones for the question, "Is there any evidence of successful reproduction?" For Zone 3 and lower Zone 5, the movement of tagged age-0 fish into and through these zones, combined with the possibility of suitable spawning habitat in both Zone 2 and Zone 3, leads to the uncertain and inconclusive answer of "?" for the question, "Is there any evidence of successful reproduction?" for Zone 3 and for lower Zone 5. Furthermore, the initial positive results in 2009 combined with the failure or near failure to capture young-of-year fish in both 2010 and 2012 leads to a "no" decision for all zones with respect to both of the two higher classifications: "Is there regular evidence of successful reproduction for this species?" and "Are there strong numbers and high consistency of successful reproduction?"

Table 2. Evaluation Matrix for Atlantic Sturgeon in Zones 3, 4, and 5 of the Delaware Estuary

Atlantic Sturgeon

1979 Task Force	PSEG target (12 spp)	NJ: 10 K/yr and 10/yr groups	Common name	Scientific name		Any evidence of successful reproduction?	Regular evidence of successful reproduction?	Strong numbers & high consistency of successful reproduction?
			Atlantic Sturgeon	*Acipenser oxyrhynchus*				
					Zone 3	?	N	N
					Zone 4	Y	N	N
					Zone 5 (upper) *RM 70-78.8*	Y	N	N
					Zone 5 (lower) *RM 48.2-70*	?	N	N

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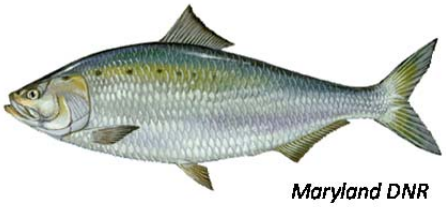
AMERICAN SHAD



American Shad (*Alosa sapidissima*) are an anadromous fish of the western Atlantic Ocean, with spawning runs extending from the Saint Johns River, Florida, to the Saint Lawrence River, Canada. Spawning occurs in both tidal and non-tidal freshwater regions of coastal rivers and streams during spring and early summer. Juvenile shad spend their first summer within their natal river and migrate to the Atlantic Ocean in late summer and fall of that same year. American Shad have been the focus of fisheries and water quality management programs for over 100 years in the Delaware River (e.g., Gay 1892, Hardy 2009) and were a key component to the dissolved oxygen recovery programs of the 1960s and 1970s (FWPCA 1966, Wright and Porges 1971). American Shad have been shown to be sensitive to low dissolved oxygen levels (Stier and Crance 1985).

Summary results from PSEG Ichthyoplankton data are presented in Figure 5. American Shad eggs were primarily caught in lower Zone 2 and upper Zone 3, with broader distributions for both yolk sac larvae and post-yolk sac larvae. The broader distribution of post-yolk sac larva likely represents passive movement via river currents as well as increased catchability for this life stage due to its longer persistence time in the estuary. Overall, these data show successful "propagation" for American Shad in Zones 2, 3, and 4 of the estuary, with some utilization of upper Zone 5, as well. The strength and consistency, however, varies by zone. In Zone 3, relatively high and consistent larval fish numbers were collected in the three survey years, but egg numbers varied markedly within the zone in all three years, with higher egg densities collected in the lower areas of Zone 2 and the upper areas of Zone 3 compared to the lower areas of Zone 3. In Zone 4, moderately strong densities of larvae were collected in all three years, but American Shad eggs were rarely collected.

Figure 6 presents the young-of-year catches for American Shad in Zone 3, 4, and 5 for the New Jersey Seine Survey. The main pattern in these results is the restoration of the nursery in the Delaware Estuary beginning in the late 1980s. In addition, even with fewer stations and thus lower sampling effort in Zone 3, these results show high and relatively consistent use of Zone 3 when compared to Zones 4 and 5 downstream. Zone 4 results are similar to the Zone 3 results, although greater frequency of low catches is seen in Zone 4 than in Zone 3 for any given year. Finally, young-of-year American Shad show substantially less use of Zone 5 than of the upstream zones

Based on the combined results from the two surveys, American Shad propagation has been documented in Zones 3 and 4 since 2000, with some sparse evidence for larval fish use and stronger evidence for juvenile fish use in upper Zone 5. An affirmative answer is indicated in all

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three zones for this first question, "Is there any evidence of successful reproduction?" while a negative response is indicated for lower Zone 5. For Zone 3, the high egg catches in the upper areas of the zone and the strong larval fish numbers in all years further indicate an affirmative answer to the second question, "Is there regular evidence of successful reproduction for this species?" However, the inconsistent egg densities in all three years within Zone 3 indicate some decrease in the utilization of lower sections of Zone 3, and an ambiguous "?" is thus provided for the highest level of use and the question, "Are there strong numbers and high consistency of successful reproduction?"

In Zone 4, the sparse egg catches and the tapering numbers of larval fish provide ambiguity to the question, "Is there regular evidence of successful reproduction for this species?" Certainly some regular use of Zone 4 is indicated, but for later stages of immature and juvenile American Shad, and an ambiguous "?" answer is provided for Zone 4 at this second level. Furthermore, these same patterns and the lower catches of young-of-year American Shad in Zone 4 together indicate a "no" answer to the highest utilization question, "Are there strong numbers and high consistency of successful reproduction?"

Finally in Zone 5, only sparse numbers of larval American Shad have been collected in the upper section above RM 70, although increased use by young-of-year fish is noted. This indicates substantial use by later stages of juvenile American Shad more consistent with a nursery function. Thus, a negative response is indicated for both of the higher use questions: "Is there regular evidence of successful reproduction for this species?" and "Are there strong numbers and high consistency of successful reproduction?" For lower Zone 5, the absence of any eggs or larvae leads to negative responses for all questions.

Table 3. Evaluation Matrix for American Shad in Zones 3, 4, and 5 of the Delaware Estuary

American Shad

1979 Task Force	PSEG target (12 spp)	NJ: 10 K/yr and 10/yr groups	Common name	Scientific name		Any evidence of successful reproduction?	Regular evidence of successful reproduction?	Strong numbers & high consistency of successful reproduction?
m			American Shad	*Alosa sapidissima*				
					Zone 3	Y	Y	?
					Zone 4	Y	?	N
					Zone 5 (upper) *RM 70-78.8*	Y	N	N
					Zone 5 (lower) *RM 48.2-70*	N	N	N

STRIPED BASS

Striped Bass (*Morone saxatilis*) are an anadromous species native to the western Atlantic Ocean from Florida to Canada. They are long-lived (up to 30 years) with males maturing relatively early (3 years) while females mature later at a much larger size (6+ years, 25+ inches). The Delaware Estuary is one of the four primary spawning grounds for Striped Bass including the Hudson River and the Chesapeake Bay and its tributaries (Able and Fahay 1998). Spawning occurs in tidal freshwater to oligohaline zones (less than 3 ppt salinity; Wang and Kernehan 1979). For the Delaware Estuary, spawning begins in early April and can extend into June and July, although peak activity occurs in late April or early May (Wang and Kernehan 1979). Juvenile fish spend 2 or more years in coastal estuaries (and may move upstream into non-tidal areas) before joining coastal migratory populations. Striped Bass population management and recovery has been a model for other species' management, with Striped Bass populations largely recovering from historic lows by the 1990s (e.g., ASMFC 1995),

Summary results from the PSEG Ichthyoplankton surveys are presented in Figure 7. Consistent patterns are seen across the three years of surveys, with egg and larval catches extending from Zone 2 through Zone 5 each year and peak abundances in Zone 4 and, particularly, Zone 5. Reduced numbers are apparent in Zone 3. Overall, these ichthyoplankton data largely match adult Striped Bass spawning survey patterns, with consistent documentation of Striped Bass spawning beginning in Zone 2 and peaking in Zones 4 and 5 (M. Kaufman *personal communication*, G. Murphy *personal communication*).

Results from the New Jersey Seine Survey are presented in Figure 8. It is worth emphasizing that the New Jersey Seine Survey is primarily designed and implemented to accurately represent Striped Bass young-of-year recruitment. Among the many strengths in these data, New Jersey fisheries biologists use highly developed length criteria that vary through the season to separate young-of-year fish from age-1 and older fish. The most striking pattern in these data, like with the American Shad, is the overall recovery of Striped Bass spawning in the Delaware Estuary since the 1980s that is related to both the restoration of dissolved oxygen within the Delaware Estuary and the broader restoration of the Striped Bass stock along the Atlantic coast. Within the more recent past, Figure 8 largely corroborates the patterns seen in the PSEG Ichthyoplankton results, with Zone 4 and Zone 5 demonstrating highly similar data distributions for young-of-year fish. In the seine data, however, there is even greater similarity in the Zone 4 and Zone 5 results indicating both the upstream shift in Striped Bass towards Zone 4 as summer progresses (and the salt line within the Delaware Estuary moves increasingly upstream), as well as an

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increased use of Zone 4 for young-of-year nursery grounds. Like the ichthyoplankton results, decreased catches in Zone 3 further highlight the more limited use of Zone 3 by Striped Bass early life stages compared to both Zone 4 and Zone 5 downstream.

The combined and largely consistent patterns from the ichthyoplankton surveys and the seine surveys clearly demonstrate successful reproduction by Striped Bass in all zones of the Delaware Estuary. Within the evaluation matrix, an affirmative answer to the question, "Is there any evidence of successful reproduction?" is thus indicated for Zones 3, 4, and 5. In addition, the regularity in even the modest ichthyoplankton and young-of-year catches for Zone 3, combined with the stronger catches in Zones 4 and 5, indicate an affirmative answer for all three zones to the questions, "Is there regular evidence of successful reproduction for this species?" Finally, the consistently high catches of eggs and larvae in Zone 5 provides a clear indication for "strong numbers and high consistency of successful reproduction" while the somewhat reduced egg and larval catches in Zone 4 create an ambiguous response to this question. In Zone 3, where numbers are clearly reduced for all early life stages, a negative response in indicated for this third question within the evaluation matrix.

Table 4. Evaluation Matrix for Striped Bass in Zones 3, 4, and 5 of the Delaware Estuary

Striped Bass

1979 Task Force	PSEG target (12 spp)	NJ: 10 K/yr and 10/yr groups	Common name	Scientific name		Any evidence of successful reproduction?	Regular evidence of successful reproduction?	Strong numbers & high consistency of successful reproduction?
m			Striped Bass	*Morone saxatilis*				
					Zone 3	Y	Y	N
					Zone 4	Y	Y	?
					Zone 5 (upper) *RM 70-78.8*	Y	Y	Y
					Zone 5 (lower) *RM 48.2-70*	Y	Y	Y

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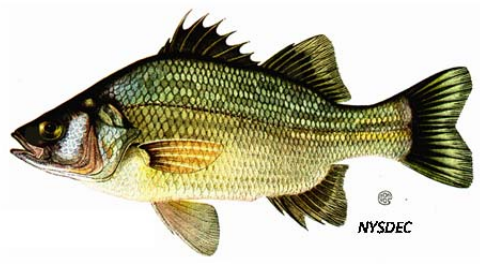
WHITE PERCH



White Perch (*Morone americana*) is the second of two species in the genus *Morone* native to the Delaware Estuary, and is one of the most abundant fish species in the Delaware Estuary. In contrast to Striped Bass, White Perch are semi-anadromous and typically remain resident within a river system while conducting seasonal migrations from brackish waters to tidal freshwaters as well as migrating above the head-of-tide into non-tidal rivers and streams. Spawning occurs in oligohaline tidal areas (less than 3 ppt salinity) as well as both tidal and non-tidal freshwater zones (Wang and Kernehan 1979). For the Delaware Estuary, spawning begins in late March and can extend into June (Wang and Kernehan 1979).

White Perch results from the PSEG Ichthyoplankton surveys are presented in Figure 9. These results demonstrate a broad utilization across most of the Delaware Estuary by White Perch, with high egg catches beginning in the upper reaches of Zone 2 and extending into Zone 5. Likewise, larval fish densities persisted in all three years at high levels through Zones 2, 3, 4, and much of Zone 5. Although Zone 5 shows some tapering in the distribution, it is noteworthy that one or more reaches in Zone 5 meet or exceed the catches for larval White Perch demonstrated in the upstream estuary zones.

White Perch catches in the New Jersey Seine Survey are presented in Figure 10. It is important to recognize that the results in Figure 10, unlike the seine results from previously reviewed species, do not represent young-of-year fish alone. Instead, because of the resident behavior of White Perch and because of overlapping size distributions among age classes, the results in Figure 10 indicate the combined abundance of both young-of-year fish and mostly younger age classes of resident White Perch. This blending of age classes limits the ability to infer the degree of successful "propagation" for White Perch based on these data. These results (and additional length distribution data provided by NJ Bureau of Marine Fisheries) primarily assist in demonstrating broad utilization by young-of-year and older age classes throughout the estuary, and confirm that young-of-year fish are indeed using Zones 3, 4, and 5 as early life stage rearing habitat.

As mentioned, the assessment of reproductive success and the extent of "propagation" for White Perch can mainly be inferred through the PSEG Ichthyoplankton surveys. The New Jersey Seine Surveys clearly demonstrate that young-of-year juveniles currently use Zones 2, 3, 4, and 5, helping to support an affirmative answer to the question, "Is there any evidence of successful reproduction?" The PSEG Ichthyoplankton provide even greater insight into the strength of this utilization by White Perch, demonstrating strong and relatively consistent egg

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and larval catches in Zones 2, 3, 4, and upper Zone 5. Combined, these data reveal a broad and highly successful utilization of the Delaware Estuary and demonstrate an affirmative assessment to the two additional matrix questions of "Is there regular evidence of successful reproduction for this species?" and "Are there strong numbers and high consistency of successful reproduction?" for all zones except lower Zone 5. Indeed, the success of White Perch across such a broad extent of the Delaware Estuary provides a scale upon which to evaluate the other estuarine fish species. Only in lower Zone 5 did the data show decreasing use by White Perch, with low egg catches and inconsistent larval densities within the zone and among years. These results provide some ambiguity to the second question, "Is there regular evidence of successful reproduction for this species?" within lower Zone 5, and a negative response to the question, "Are there strong numbers and high consistency of successful reproduction?"

Table 5. Evaluation Matrix for White Perch in Zones 3, 4, and 5 of the Delaware Estuary

White Perch

1979 Task Force	PSEG target (12 spp)	NJ: 10 K/yr and 10/yr groups	Common name	Scientific name		Any evidence of successful reproduction?	Regular evidence of successful reproduction?	Strong numbers & high consistency of successful reproduction?
f			White Perch	*Morone americana*				
					Zone 3	Y	Y	Y
					Zone 4	Y	Y	Y
					Zone 5 (upper) *RM 70-78.8*	Y	Y	Y
					Zone 5 (lower) *RM 48.2-70*	Y	?	N

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BAY ANCHOVY

Diana Rome Peebles

Bay Anchovy (*Anchoa mitchilli*) is perhaps the most abundant fish of the Delaware Estuary (Wang and Kernehan 1979). They inhabit a broad range of estuarine and coastal marine habitats, and their distribution spans all salinity regimes of the Delaware Estuary. They are short-lived (typically 3 years or less) and repetitively spawn throughout late spring and summer in moderate to high salinity waters (typically 5 ppt or higher). Larval fish appear to have some ability to migrate up-estuary, with both viable larvae and juvenile fish collected at higher densities in more freshwater areas than eggs (Wang and Kernehan 1979, Able and Fahay 1998).

Bay Anchovy results from the PSEG Ichthyoplankton surveys are presented in Figure 11. It is important to note that even higher densities of eggs and larvae (peaks annually exceeding 100,000 and thus natural log scale of 12 on Figure 11) were collected further downstream in Delaware Bay; these higher Delaware Bay catches are not shown in the figure. Given the Bay Anchovy's natural history, the pattern in Figure 11 primarily demonstrates a preference for higher salinities in spawning. However, substantial and somewhat consistent catches of eggs are seen lower Zone 5, with sizable catches of larvae in upper Zone 5 and even into Zone 4. Only in 2004 were catches of Bay Anchovy larvae still appreciable upstream in Zone 3.

The results from New Jersey Seine Surveys are presented in Figure 12 for Bay Anchovy. Two important notes are warranted about this figure. First, because catches in Zone 3 were typically very low with many zero catches, data are presented for Zone 4, upper Zone 5 (RM 70 to 78.8), and lower Zone 5 (RM 48.2 to 70). Second, seine surveys for Bay Anchovy will necessarily capture relatively late stages of juveniles given their size range, and all catches will represent a mixture of juveniles and mature adults, some of whom are also young-of-year. Thus, the results presented in Figure 12 do not narrowly represent "propagation" success by focusing on early life stages. Supplemental length distribution data provided by NJ Bureau of Marine Fisheries help to demonstrate that juvenile fish were included in the Bay Anchovy catch, and that some nursery use exists for these early life stages.

The combined results from the Bay Anchovy ichthyoplankton and seine surveys primarily confirms the more intense and complete use of higher salinity areas of the Delaware Estuary for spawning and rearing activities. Nevertheless, the capture of eggs in lower Zone 5 and the capture of larvae relatively consistently in both Zone 4 and Zone 5 suggests a broader utilization of the Delaware Estuary for early life stages of the Bay Anchovy than simply the higher salinity waters of Delaware Bay (Zone 6). For Zone 3 of the estuary, the presence of larval fish in 2004 provides some ambiguity for the question, "Is there any evidence of successful reproduction?" while it is clear that a negative answer is warranted in Zone 3 for the two higher demonstrations

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of early life stages. For Zone 4, the increased regularity of both larval fish catches and capture in the seine surveys leads to an affirmative response to the question, "Is there any evidence of successful reproduction?" Yet there remains uncertainty about how regular this use is, and it does not include the earlier spawning and egg stages of reproduction, leading to an ambiguous answer for the question, "Is there regular evidence of successful reproduction for this species?" and a negative response to the question, "Are there strong numbers and high consistency of successful reproduction?" In upper Zone 5, more regular larval catches indicate an affirmative answer to the questions, "Is there any evidence of successful reproduction?" and "Is there regular evidence of successful reproduction for this species?", while the lack of eggs and the much higher catches downstream indicate a negative response to the question, "Are there strong numbers and high consistency of successful reproduction?" Finally in lower Zone 5, the regular presence of eggs and larvae combined with juvenile catches in the seine surveys demonstrates an affirmative answer to both of the first two "use" questions. However, comparisons to data from Delaware Bay also demonstrate that much stronger and more complete utilization occurs further down in the estuary and thus a negative response is warranted for the final question, "Are there strong numbers and high consistency of successful reproduction?"

Table 6. Evaluation Matrix for Bay Anchovy in Zones 3, 4, and 5 of the Delaware Estuary

Bay Anchovy

1979 Task Force	PSEG target (12 spp)	NJ: 10 K/yr and 10/yr groups	Common name	Scientific name		Any evidence of successful reproduction?	Regular evidence of successful reproduction?	Strong numbers & high consistency of successful reproduction?
m			Bay Anchovy	*Anchoa mitchilli*				
					Zone 3	?	N	N
					Zone 4	Y	?	N
					Zone 5 (upper) *RM 70-78.8*	Y	Y	N
					Zone 5 (lower) *RM 48.2-70*	Y	Y	N

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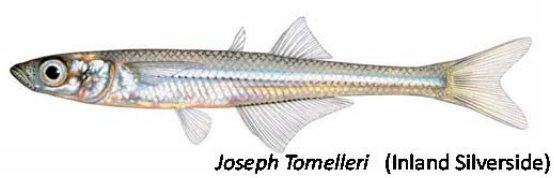
ATLANTIC SILVERSIDE



Atlantic Silverside (*Menidia menidia*) is also among the most abundant species in the Delaware Estuary (Wang and Kerhehan 1979). Atlantic Silverside are short-lived fish, with typical lifespans of 2 yrs or less (Fay et al. 1983). Although found from freshwater to saltwater zones, they are most common in the higher salinity waters of Delaware Bay and its associated tidal wetlands. Spawning occurs in intertidal areas in spring and summer, typically at salinities greater than 15 ppt, with repeat spawning occurring through the spawning season. For the current data evaluation, it is worth emphasizing that the intertidal spawning and adhesive eggs likely lead to poor representation of the eggs stage with open-water ichthyoplankton surveys such as the PSEG surveys of 2002, 2003, and 2004. Despite this limitation for eggs, larval Atlantic Silverside can be a dominant catch in ichthyoplankton samples (Able and Fahay 1998).

Atlantic Silverside results from the PSEG Ichthyoplankton surveys are presented in Figure 13 showing larvae in these three years largely confined to the lower portions of Zone 5 (RM 48.2 to RM 70), and eggs poorly represented in these open-water samples. Not shown in Figure 13 are the results further downstream in Delaware Bay, where larval abundances were typically as high or higher than those seen in lower Zone 5. As mentioned above, the lack of eggs in the ichthyoplankton collections is expected given spawning behaviors and egg characteristics. Overall, these results demonstrate nearly exclusive use of lower Zone 5 and seaward for reproduction and early life stages, with little or no use of Zones 3 or 4 by these life stages.

New Jersey Seine Survey results are presented in Figure 14. Like with Bay Anchovy, catches of Atlantic Silverside were typically very low in Zone 3 and thus Figure 14 focuses on the patterns in Zone 4, upper Zone 5, and lower Zone 5. Also like Bay Anchovy, seine catches represent multiple overlapping year classes and stages of maturity, and cannot narrowly quantify the numbers of immature young-of-year fish in each sample. As a result, the results in Figure 14 do not capture patterns in "propagation" alone but more broadly assess habitat use by multiple life stages. Additional length distribution data from the NJ Bureau of Marine Fisheries, however, establishes that some young-of-year fish are using all zones of the Delaware Estuary, including upstream in Zone 2. Yet the seine data for Atlantic Silverside primarily indicate use of zones in the estuary with moderate to high salinities and sparse use of the freshwater and oligohaline areas.

The patterns from the ichthyoplankton and seine surveys indicate that the "propagation" use for Atlantic Silverside resides mainly in the high salinity zones of the estuary. For Zone 3 and Zone 4, no eggs or appreciable larval numbers indicate a negative response to all three matrix questions. For upper Zone 5, the sporadic larval fish catches leave ambiguous the response to even the basic question, "Is there any evidence of successful reproduction?" Thus, in upper Zone 5, the higher two matrix questions are negative with no "regular" nor "consistent" or

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"strong" indications of early life stage use. Instead, these zones primarily are utilized as nursery areas by some small fraction of the juveniles as well as small numbers of adult fish. Only in lower Zone 5 do the data indicate an affirmative answer to the propagation questions, with both of the first use questions, "Is there any evidence of successful reproduction?" and "Is there regular evidence of successful reproduction for this species?" being supported with an affirmative answer from the regular larval fish catches. However, these catches in lower Zone 5 were at times less consistent and weaker than Delaware Bay catches, leading to an ambiguous assessment for the final question, "Are there strong numbers and high consistency of successful reproduction?"

Table 7. Evaluation Matrix for Atlantic Silverside in Zones 3, 4, and 5 of the Delaware Estuary

Atlantic Silverside

1979 Task Force	PSEG target (12 spp)	NJ: 10 K/yr and 10/yr groups	Common name	Scientific name		Any evidence of successful reproduction?	Regular evidence of successful reproduction?	Strong numbers & high consistency of successful reproduction?
m			Atlantic Silverside	*Menidia menidia*				
					Zone 3	N	N	N
					Zone 4	N	N	N
					Zone 5 (upper) *RM 70-78.8*	?	N	N
					Zone 5 (lower) *RM 48.2-70*	Y	Y	?

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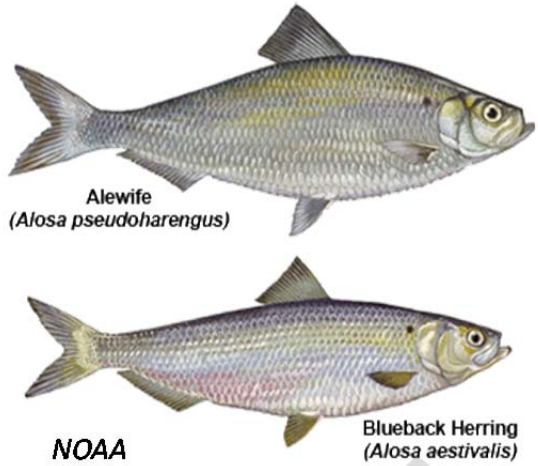
ALEWIFE & BLUEBACK HERRING



Alewife and Blueback Herring (*Alosa pseudoharengus* and *Alosa aestivalis*, respectively) are regularly considered and managed together as a pair of species referred to as River Herring. These two species can be somewhat difficult to distinguish in the field, and their behaviors and life histories broadly overlap. Like American Shad, the River Herring are anadromous fish which return to freshwater habitats from the ocean to spawn, although the exact preferences and localities for spawning of the two species continue to be researched and evaluated across their distributional range. For the current data review and assessment, these two species are likewise considered together because of the mixed and confounding patterns within the data sets that suggest possible confusion of the species or poor delineation of the timing and location of reproductive behaviors.

Results from the PSEG Ichthyoplankton surveys are presented in three figures (Figures 15, 16, and 17). These data show Alewife to be the dominant species spawning and rearing across many estuary zones, with Blueback Herring rarely detected in sampling, and the undetermined eggs/larvae of "*Alosa* spp." mirroring the Alewife patterns. Results from the New Jersey Seine Survey are presented in Figures 18 and 19 for Alewife and Blueback Herring, respectively. These data represent primarily young-of-year production in the two species (some limited numbers of adults and age-1 fish are also caught), and are thus expected to provide some correspondence to the earlier life stages monitored via the ichthyoplankton surveys. Yet the patterns from the seine surveys reveal opposite dominance patterns, with Blueback Herring catches orders of magnitude higher than the Alewife catches. Moreover, field observations in the Delaware Estuary more closely match the results from the seine survey, with Blueback Herring frequently encountered while Alewife remain rare (M. Kaufman *personal communication*).

Multiple explanations could individually or collectively reconcile the apparent conflicting patterns from the two data sets. First, incorrect identifications could have reversed the species identity in either the ichthyoplankton or the seine surveys. Second, each sampling technique could be biased toward sampling one species preferentially over the other species. For instance, the daytime, near-shore seine sampling is well-suited for collecting young-of-year Striped Bass but likely under-samples schooling pelagic fish such as Alewife. Third, the spatial and temporal extents of each survey may lend themselves to increased efficiency in sampling one species over the other. These and other explanations highlight the challenge in distinguishing successful reproduction and rearing for each of these species, and underscore the decision by many agencies

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and organizations to simply pool the two species as the broader River Herring complex despite important distinctions in their life histories.

Regardless of the reasons, the conflicting patterns in the ichthyoplankton and seine surveys severely limit the current assessment of "propagation" for each species. At the very least, eggs, larvae, and juveniles of both species have been identified in Zones 3 and 4 as well as the upper portion of Zone 5, leading to an affirmative response to the question, "Is there any evidence of successful reproduction?" The ichthyoplankton data further indicate moderate to strong spawning success in multiple years across Zones 2, 3, 4, and upper 5. However, it is not clear which of the two species (or perhaps both) are broadly utilizing the estuary for spawning and rearing. The assessment of the two higher "use" questions results is the ambiguous "?" for both species in Zones 3 and 4 because of these unresolved discrepancies between the two data sets, For upper Zone 5, weaker results regardless of species ID leads to an ambiguous answer to the question, "Is there regular evidence of successful reproduction for this species?" and a negative answer to the highest question, "Are there strong numbers and high consistency of successful reproduction?" For lower Zone 5, this initial question of "Is there any evidence of successful reproduction?" is answered in the affirmative because of moderate larval catches in multiple years, while the remaining categories are not supported given the lack of eggs and inconsistencies in larval catches for either species.

Table 8. Evaluation Matrix for Alewife & Blueback Herring in Zones 3, 4, and 5 of the Delaware Estuary

Alewife & Blueback Herring

1979 Task Force	PSEG target (12 spp)	NJ: 10 K/yr and 10/yr groups	Common name	Scientific name		Any evidence of successful reproduction?	Regular evidence of successful reproduction?	Strong numbers & high consistency of successful reproduction?
m			Alewife	*Alosa pseudoharengus*				
					Zone 3	Y	?	?
					Zone 4	Y	?	?
					Zone 5 (upper) *RM 70-78.8*	Y	?	N
					Zone 5 (lower) *RM 48.2-70*	Y	N	N
m			Blueback Herring	*Alosa aestivalis*				
					Zone 3	Y	?	?
					Zone 4	Y	?	?
					Zone 5 (upper) *RM 70-78.8*	Y	?	N
					Zone 5 (lower) *RM 70-78.8*	Y	N	N

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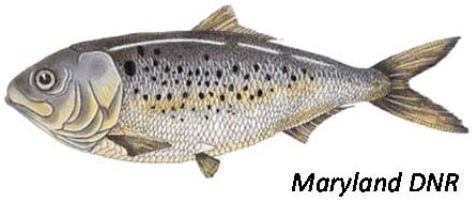
ATLANTIC MENHADEN



Atlantic Menhaden (*Brevoortia tyrannus*) is another member of the Clupeidae family along with American Shad, Alewife, and Blueback Herring. Atlantic Menhaden adults are migratory coastal fish, with estuaries utilized as both nursery and seasonal adult habitats. Spawning primarily occurs in near-shore oceanic settings and can occur during both northward and southward migrations along the coast. Larval and juvenile Atlantic Menhaden then utilize estuaries as nursery grounds, with "ingress" into the Delaware Estuary peaking from December through May (Wang and Kernehan 1979). Juvenile fish continue to move further up-estuary into oligohaline and the lower freshwater portions of estuaries. Thus, both larval and juvenile Atlantic Menhaden (but not eggs/spawning) may use multiple zones within the Delaware Estuary.

For the current data evaluation, a limitation needs to be acknowledged for Atlantic Menhaden since the timing of both PSEG Ichthyoplankton and NJ Seine surveys only partially overlap with the period of larval and juvenile use of the Delaware Estuary. The current data sets can, therefore, only partly describe to use of the Delaware Estuary for "propagation" by Atlantic Menhaden.

Results from the PSEG Ichthyoplankton surveys are presented in Figure 20 for Atlantic Menhaden. Strong differences were seen among the three years surveyed, with 2002 showing a broad distribution of post-yolk sac larvae in many estuarine zones, while 2003 showed very low catches everywhere (low catches of larvae were also seen in Delaware Bay in 2003). In 2004, lower catches were observed than in 2002 but some utilization of Zone 5 was seen in addition to moderate catches in Delaware Bay (Zone 6).

Results from the New Jersey Seine Survey are shown in Figure 21. Overall catches were very low in Zone 3, so results from Zone 4 are presented along with separate analyses for upper and lower Zone 5. Juvenile Atlantic Menhaden were captured in all estuary zones, but only sporadically in Zones 2 and 3. In Zone 4, Atlantic Menhaden were not captured on a typical survey (i.e., median is zero for most years) but moderate to high catches are nevertheless somewhat common. In both upper and lower Zone 5, Atlantic Menhaden are more frequently encountered, although occasional very large catches (e.g., more than 1000 juvenile fish in a single seine haul) are seen at a frequency similar to Zone 4.

The combined results from the two surveys suggest some utilization of Zones 4 and 5 by larval and juvenile Atlantic Menhaden. Ichthyoplankton results were more variable, suggesting strong among-year difference in use (perhaps reflecting broader stock status). For Zone 3, low and inconsistent catches of larvae and juveniles provides only an ambiguous "?" answer to the first question, "Is there any evidence of successful reproduction?" and clear "no" answers for higher use questions. For Zone 4, increased consistency and use across both larval and juveniles

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indicates "yes" for the initial question, "Is there any evidence of successful reproduction?" However, although juvenile catches were seen occasionally each year, moderate larval catches in Zone 4 only occurred in 2002, leading to an ambiguous answer to the question, "Is there regular evidence of successful reproduction for this species?" and a negative answer to the question "Are there strong numbers and high consistency of successful reproduction?" Finally, little or no distinction can be made between the results from upper Zone 5 and lower Zone 5, both in the ichthyoplankton surveys and the seine surveys. In addition, the larval catches in Zone 5 were among the highest seen throughout the estuary (including Zone 6) for both 2002 and 2004, even if large differences were seen among years. These results indicate that both upper and lower Zone 5 show regular Atlantic Menhaden use, and thus a "yes" to the questions, "Is there any evidence of successful reproduction?" and "Is there regular evidence of successful reproduction for this species?" However, both the inconsistency among years and the complex use of the estuary year-round without sufficient data during all seasons provides an ambiguous answer for the final question, "Are there strong numbers and high consistency of successful reproduction?"

Table 9. Evaluation Matrix for Atlantic Menhaden in Zones 3, 4, and 5 of the Delaware Estuary

Atlantic Menhaden

1979 Task Force	PSEG target (12 spp)	NJ: 10 K/yr and 10/yr groups	Common name	Scientific name		Any evidence of successful reproduction?	Regular evidence of successful reproduction?	Strong numbers & high consistency of successful reproduction?
m			Atlantic Menhaden	*Brevoortia tyrannus*				
					Zone 3	?	N	N
					Zone 4	Y	?	N
					Zone 5 (upper) *RM 70-78.8*	Y	Y	N
					Zone 5 (lower) *RM 48.2-70*	Y	Y	N

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ADDITIONAL SPECIES EVALUATED

A number of additional fish species use Zones 3, 4, and 5 as important parts of their spawning and/or nursery habitat. Data were evaluated for these additional species, but either the data were too sparse to provide any specific insight or the results were ambiguous and did not establish whether a given zone was being used for successful reproductive effort. For four species (Spot, Atlantic Croaker, Weakfish, Bluefish), the primary use centered on Delaware Bay (Zone 6) and catches in the upper zones of the estuary were so sparse that no clear indication of successful reproduction could be established. For Hogchoker, larval and juvenile use is expected throughout the estuary based on life history information, and Hogchokers were captured across all zones of the estuary. However data were not collected on larval fish, and juveniles could not be reliably identified in the seine surveys. As a result, the extent of use by Hogchokers in each zone could not be established. For Inland Silverside, a species similar to Atlantic Silverside but with a lower salinity preference, substantial use of Zones 3, 4, and 5 may be possible for spawning and rearing but no larval fish data were available and seine data could not separate mature from juvenile fish. Finally, Gizzard Shad were not directly assessed in the PSEG Ichthyoplankton surveys but may have been recorded in some of the broader taxonomic categories like "Clupeidae" undetermined. As a resident fish, the NJ Seine Survey data also provided little specificity on the location and extent of juvenile use of the different estuary zones.

Many more species of fish were captured and recorded as part of the New Jersey Seine Surveys. In addition, distribution and abundance data exist for species such as freshwater mussels and benthic invertebrates, but these data sets typically provide little specific information on the question of "successful reproduction". As a result, although some data were available for many additional fish and non-fish species, these additional data sources were not used in the current evaluation of the Existing Use with respect to questions of "propagation".

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Conclusions

Successful "propagation" in Zones 3, 4, and upper Zone 5 is clearly supported by the three primary data sources evaluated in this report. Thus, the goals for fishery restoration established in 1967 through DRBC's designated uses have been exceeded, at least in part by the successful restoration of dissolved oxygen to 3.5 mg/L as a daily average concentration. The current designated use in Zone 3, 4, and the upper 8.8 miles of Zone 5 includes only "maintenance" of fish and other aquatic life; the "Existing Use" based on data collected since 2000 indicates that at least some degree of "propagation" (i.e., spawning and/or rearing of early stage larvae and juveniles) has been achieved in these 38 miles of the 133 mile long Delaware Estuary.

The current data evaluation also seeks to determine the strength of that "propagation" use across the suite of species for which specific relevant data were available. Because of different expectations for each species in the three estuary zones, each of these zones will be summarized separately.

In Zone 3 (Table 10), the evaluations for Atlantic Sturgeon, American Shad, and Striped Bass all fall short of the highest possible expectations for their recovery (e.g., see Appendix B). In particular, Atlantic Sturgeon catch rates and tracking data show sparse use of Zone 3. Both American Shad and Striped Bass exhibit moderate numbers and some consistency in eggs, larvae, and juveniles, but numbers are not as strong or as consistent as in other freshwater zones of the estuary. White Perch, on the other hand, shows strong numbers and high consistency in eggs, larvae, and juvenile use of Zone 3. Unfortunately, although some sizeable numbers exist for either Alewife or Blueback Herring, the ambiguity in these data sets precludes a more specific evaluation on the strength of these two species' recovery in Zone 3. Finally, the three marine or brackish water species (Atlantic Menhaden, Bay Anchovy, Atlantic Silverside) are not expected to show extensive use of this freshwater zone of the estuary, and their weaker evaluation for Zone 3 does not reflect a failure in the "propagation" use. Overall, then, some moderate to strong recovery in "propagation" has been seen in Zone 3, but full "propagation" is not established.

The evaluation of Zone 4 (Table 11) is similar to Zone 3. Atlantic Sturgeon young-of-year have been caught in recent years in this zone, but overall numbers are small and year-on-year catches are highly sporadic. American Shad numbers also show substantial weakness in Zone 4, with a near absence of eggs in the 2002, 2003, and 2004 PSEG Ichthyoplankton surveys despite sizeable larval catches and similar habitats as upstream in Zone 3. Striped Bass numbers are moderately strong across eggs, larvae, and juveniles, but somewhat higher and more consistent data are seen further downstream in Zone 5 for eggs and larvae, indicating somewhat less use of Zone 4 than Zone 5 by Striped Bass for spawning and rearing. White Perch continue to show strong numbers in Zone 4 indicating a high degree of use of this zone, while both Alewife and Blueback Herring continue to be uncertain for Zone 4 because of ambiguity in the data sets. For the marine or brackish species, both Atlantic Menhaden and Bay Anchovy begin to show

appreciable use of Zone 4, which is not surprising given the beginning of the salinity transition in lower Zone 4 depending on the time of year and freshwater inflows. Together, these data (like in Zone 3) demonstrate moderate to strong recovery in "propagation" for Zone 4, but again full "propagation" has not been established.

In upper Zone 5 (RM70 to RM78.8; Table 12), some level of Atlantic Sturgeon spawning has been demonstrated, but the numbers and consistency again are weak and fall far short of attaining the full expectations for a successful population. By contrast, both White Perch and Striped Bass demonstrate strong numbers and high consistency across all early life stages examined. For both species, nearly complete or complete attainment of "propagation" is seen. For the three freshwater Clupeidae (American Shad, Alewife, and Blueback Herring), numbers begin to or strongly taper off in this zone where the transition to brackish water is more evident than upstream. These reductions in use for the three species may be a natural attenuation and therefore may not be a failure to attain an expected use in these 8.8 miles of the estuary, although appreciable ambiguity exists, particularly for Alewife and Blueback Herring (see Appendix B). Finally, the increased use by larval and juvenile Atlantic Menhaden and Bay Anchovy matches the life history expectations for these species. Across all species, then, the data for upper Zone 5 largely reflect moderate to strong attainment of expectations, with Atlantic Sturgeon numbers representing the weakest recovery and poorest demonstration of successful reproduction by species expected to use upper Zone 5.

Finally, in lower Zone 5 (RM48.2 to RM70), both strength and weakness are seen in Table 13. However, here in lower Zone 5, the designated use for these 22 miles of the estuary currently includes both "maintenance" and "propagation" and the data evaluation reflects the more complete attainment of expected "propagation" for this estuary zone. Specifically, this reach of estuary represents the more distinct salinity transition, with only Striped Bass clearly expected to use lower Zone 5 as a core part of its spawning during early spring when freshwater inflows are typically higher and the salt line is shifted down-estuary. As Table 13 shows, Striped Bass demonstrate strong and consistent evidence of successful reproduction here in lower Zone 5. Other species show less extensive use of lower Zone 5, but all of these shifts are expected based on their life history. The marine and brackish species primarily spawn either further down in Delaware Bay or the Atlantic Ocean, so the "regular" use of lower Zone 5 demonstrates a high degree of expected use. For the freshwater species, the tapering down of spawning and rearing in this salinity transition zone likewise matches the life history expectations of these species. Together, these data demonstrate a more complete use of lower Zone 5 for spawning and rearing in a manner consistent with each species' life history.

A cautionary note is needed at this point. The evaluation of "propagation" in each estuary zone, and particularly the current attempt to identify the strength of any demonstrated spawning and rearing for these fish species, must not be confused with an evaluation of the causes for any failure to completely attain the expected patterns of spawning and rearing of these fish species. This report does not demonstrate, for instance, that water quality (e.g., dissolved oxygen) is the reason for the weaker-than-expected spawning and rearing numbers of any species. Many

factors, both natural and anthropogenic, continue to impact the populations of all fish species evaluated in this report (e.g., Iannuzzi et al. 2009). Most notable are the current population sizes for some species (e.g., Atlantic Sturgeon) that likely are too low to saturate the spawning and rearing grounds in any given year. But additional factors, such as habitat conditions and climate, likely play an important role in the strength of spawning and rearing for all species. The failure to demonstrate full attainment of the "propagation" use in Zones 3, 4, and upper Zone 5 may, therefore, reflect both limitations in water quality conditions as well as limitations in many other facets of each species' biology. It is beyond the scope of this report to attempt to attribute the limitations in "propagation" to any one or any suite of causative agents.

The combined data sets evaluated for this report nevertheless indicate that the "Existing Use" attained within the Delaware Estuary in the period between 2000 and 2014 includes "propagation" for Zones 3, 4, and the upper 8.8 miles of Zone 5. In each of these zones, the evidence is moderate or even strong for one or more species, indicating substantial progress in attaining the full Clean Water Act aquatic life goal of "maintenance and propagation" for the species evaluated. The "Existing Use" for Zones 3, 4, and upper Zone 5 therefore substantially exceeds the "designated use" of only "maintenance". But the data evaluated in this report also indicates that weakness in successful reproduction exists for one or more species for all three zones. Thus, full attainment of a "maintenance and propagation" use has not been demonstrated at this time based on the data available and examined for this existing use evaluation.

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Table 10. Final Evaluation Matrix for Zone 3 across all species with sufficient data

Zone 3 (RM 95 to RM 108.4)							
1979 Task Force	PSEG target (12 spp)	NJ: 10 K/yr and 10/yr groups		Common name	Scientific name	Any evidence of successful reproduction?	Regular evidence of successful reproduction?	Strong numbers & high consistency of successful reproduction?
				Atlantic Sturgeon	*Acipenser oxyrhynchus*	?	N	N
m				Striped Bass	*Morone saxatilis*	Y	Y	N
f				White Perch	*Morone americana*	Y	Y	Y
m				Alewife	*Alosa pseudoharengus*	Y	?	?
m				Blueback Herring	*Alosa aestivalis*	Y	?	?
m				American Shad	*Alosa sapidissima*	Y	Y	?
m				Atlantic Menhaden	*Brevoortia tyrannus*	?	N	N
m				Bay Anchovy	*Anchoa mitchilli*	?	N	N
m				Atlantic Silverside	*Menidia menidia*	N	N	N

Table 11. Final Evaluation Matrix for Zone 4 across all species with sufficient data

Zone 4 (RM 78.8 to RM 95)							
1979 Task Force	PSEG target (12 spp)	NJ: 10 K/yr and 10/yr groups		Common name	Scientific name	Any evidence of successful reproduction?	Regular evidence of successful reproduction?	Strong numbers & high consistency of successful reproduction?
				Atlantic Sturgeon	*Acipenser oxyrhynchus*	Y	N	N
m				Striped Bass	*Morone saxatilis*	Y	Y	?
f				White Perch	*Morone americana*	Y	Y	Y
m				Alewife	*Alosa pseudoharengus*	Y	?	?
m				Blueback Herring	*Alosa aestivalis*	Y	?	?
m				American Shad	*Alosa sapidissima*	Y	?	N
m				Atlantic Menhaden	*Brevoortia tyrannus*	Y	?	N
m				Bay Anchovy	*Anchoa mitchilli*	Y	?	N
m				Atlantic Silverside	*Menidia menidia*	N	N	N

Table 12. Final Evaluation Matrix for upper Zone 5 across all species with sufficient data

Zone 5 upper (RM 70 to RM 78.8)							
1979 Task Force	PSEG target (12 spp)	NJ: 10 K/yr and 10/yr groups		Common name	Scientific name	Any evidence of successful reproduction?	Regular evidence of successful reproduction?	Strong numbers & high consistency of successful reproduction?
				Atlantic Sturgeon	*Acipenser oxyrhynchus*	Y	N	N
m				Striped Bass	*Morone saxatilis*	Y	Y	Y
f				White Perch	*Morone americana*	Y	Y	Y
m				Alewife	*Alosa pseudoharengus*	Y	?	N
m				Blueback Herring	*Alosa aestivalis*	Y	?	N
m				American Shad	*Alosa sapidissima*	Y	N	N
m				Atlantic Menhaden	*Brevoortia tyrannus*	Y	Y	N
m				Bay Anchovy	*Anchoa mitchilli*	Y	Y	N
m				Atlantic Silverside	*Menidia menidia*	?	N	N

Table 13. Final Evaluation Matrix for lower Zone 5 across all species with sufficient data

Zone 5 lower (RM 48.2 to RM70)							
1979 Task Force	PSEG target (12 spp)	NJ: 10 K/yr and 10/yr groups		Common name	Scientific name	Any evidence of successful reproduction?	Regular evidence of successful reproduction?	Strong numbers & high consistency of successful reproduction?
				Atlantic Sturgeon	*Acipenser oxyrhynchus*	?	N	N
m				Striped Bass	*Morone saxatilis*	Y	Y	Y
f				White Perch	*Morone americana*	Y	?	N
m				Alewife	*Alosa pseudoharengus*	Y	N	N
m				Blueback Herring	*Alosa aestivalis*	Y	N	N
m				American Shad	*Alosa sapidissima*	N	N	N
m				Atlantic Menhaden	*Brevoortia tyrannus*	Y	Y	N
m				Bay Anchovy	*Anchoa mitchilli*	Y	Y	N
m				Atlantic Silverside	*Menidia menidia*	Y	Y	?

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Figure 1. USGS Dissolved Oxygen Data for the sensor at the Ben Franklin Bridge (station 01467200) showing daily average, daily minimum, and daily maximum values from April 1, 1967, thru November 1, 1967 (data available at *waterdata.usgs.gov)*

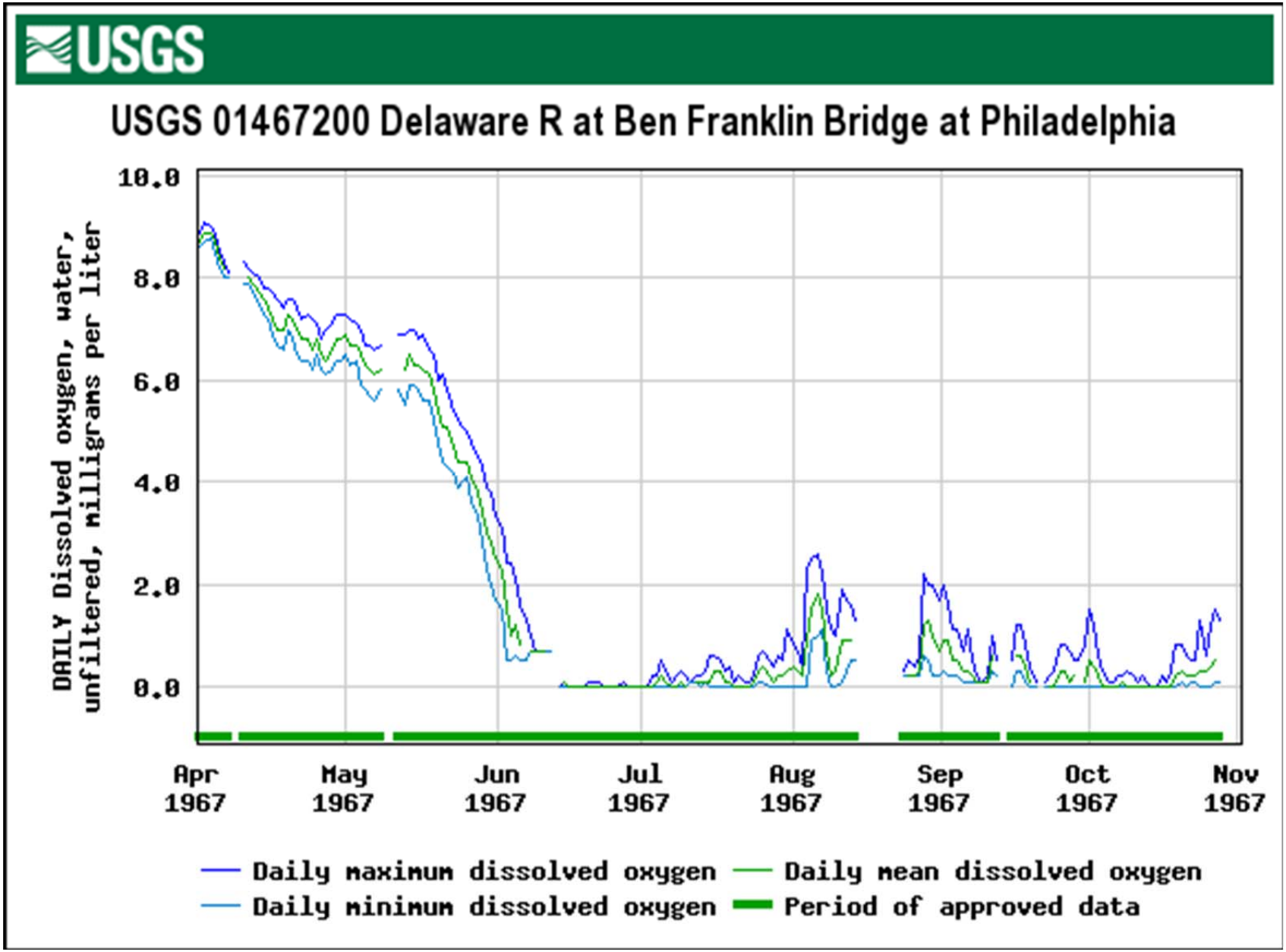


Figure 2. USGS Dissolved Oxygen Data for the sensor at the Ben Franklin Bridge (station 01467200) the distribution of 24-hour daily average values during the month of July from 1965 thru 2014 (data available at *waterdata.usgs.gov).*

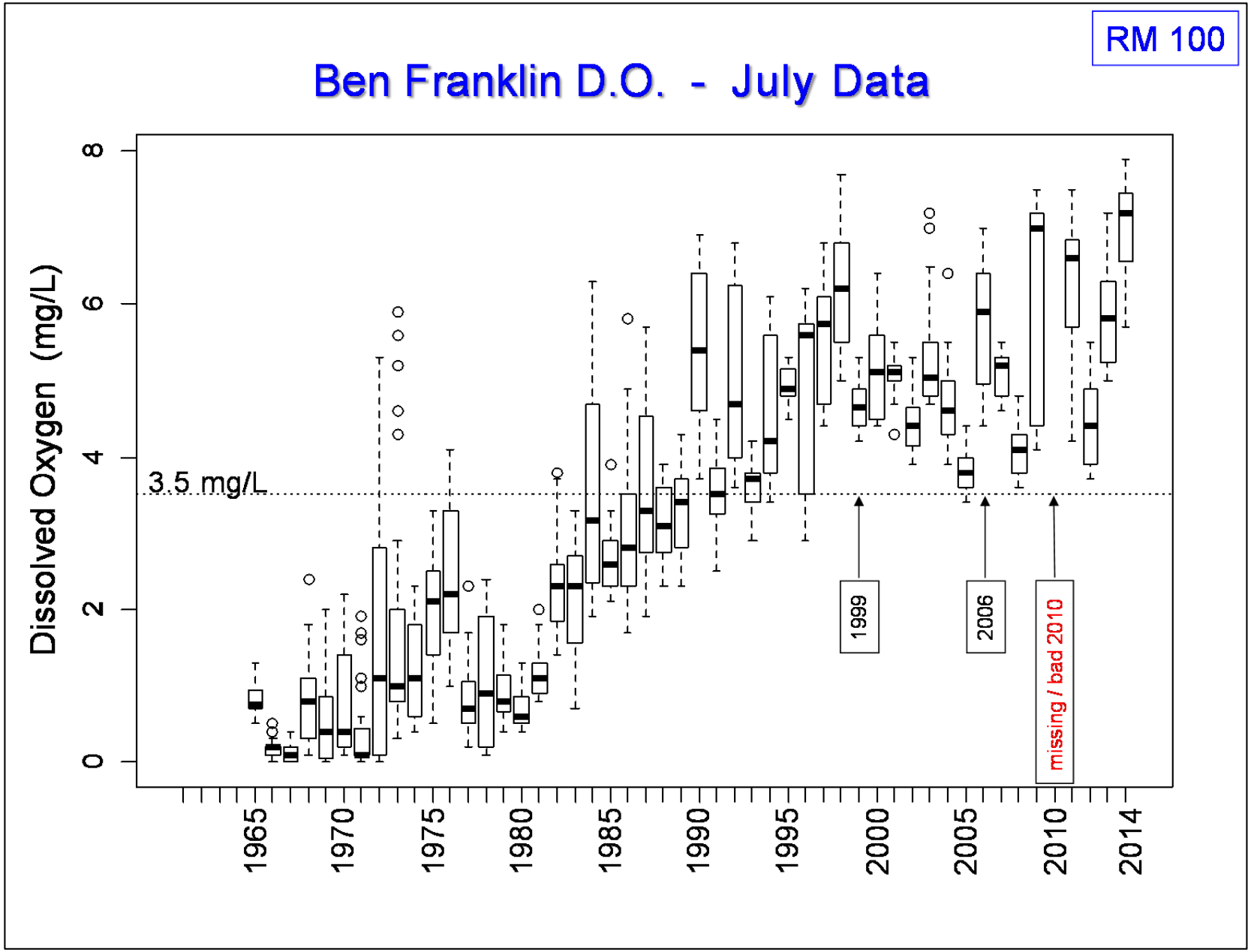


Figure 3. Map of the Delaware Estuary and DRBC Water Quality Zones

Figure 4. Map of the Delaware Estuary with DRBC Water Quality Zones and PSEG survey "zones" or reaches for 2002-2004 Ichthyoplankton surveys

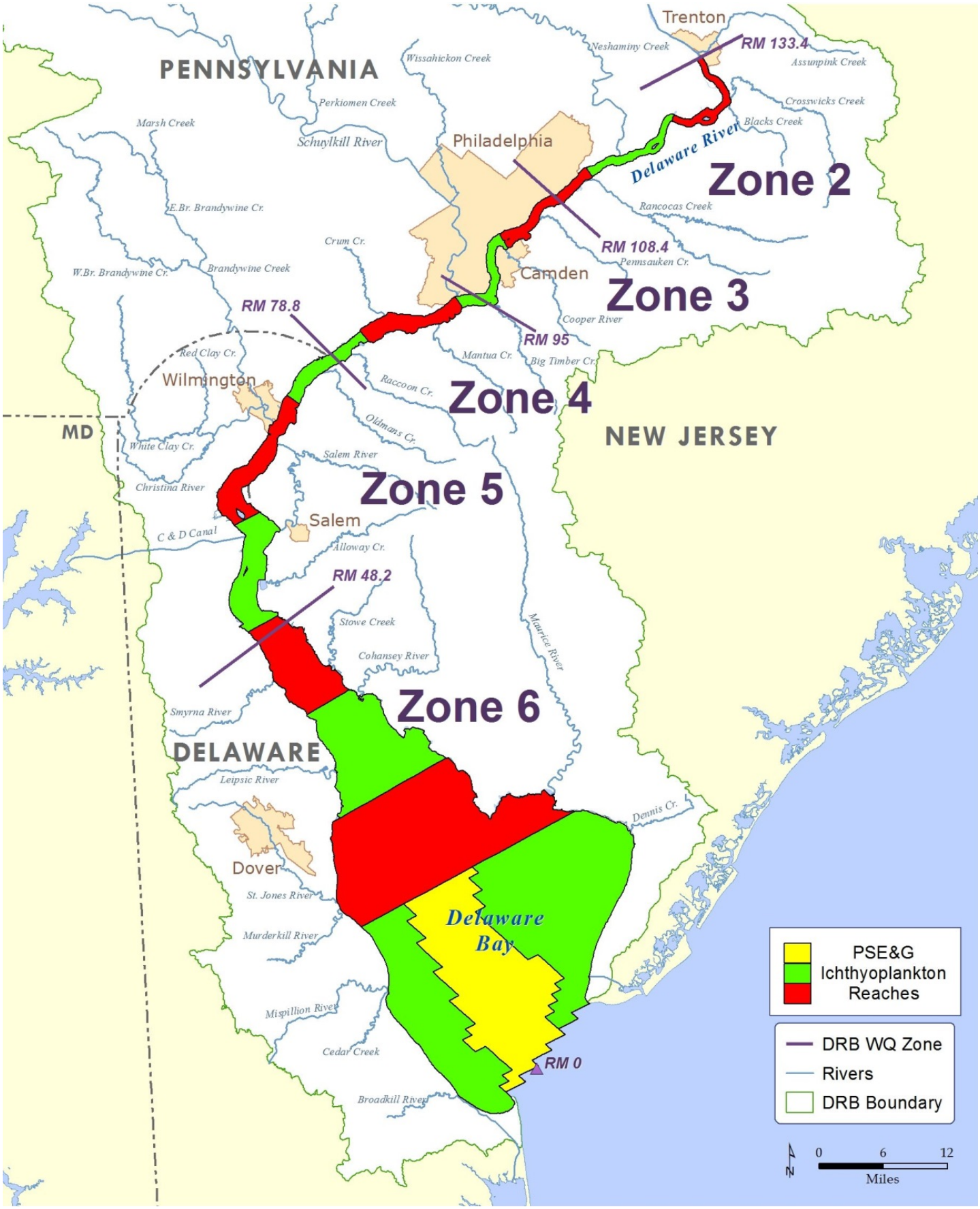


Figure 5. American Shad data summary from PSEG Ichthyoplankton surveys of 2002-2004 showing data distribution for all 8 surveys in each zone for each year as box-and-whisker plots (DRBC water quality zones are separated by dashed lines; PSEG survey reaches are indicated by blue bars at the top of each graph)

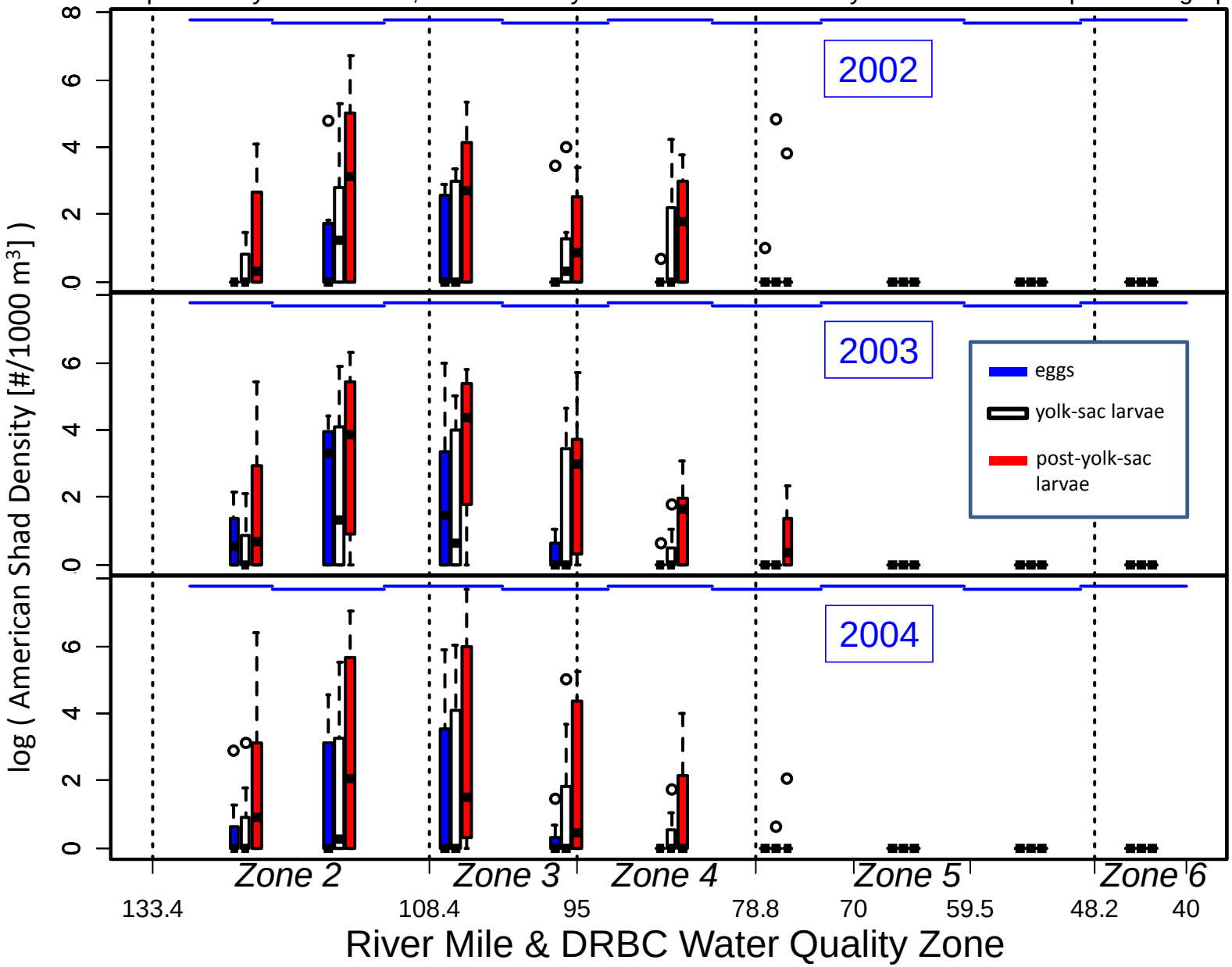


Figure 6. American Shad Young-of-Year data summary from New Jersey Seine Surveys for DRBC Water Quality Zones 3, 4, and 5. Full data distributions across all surveys within a Zone for a given year are presented as box-and-whisker plots.

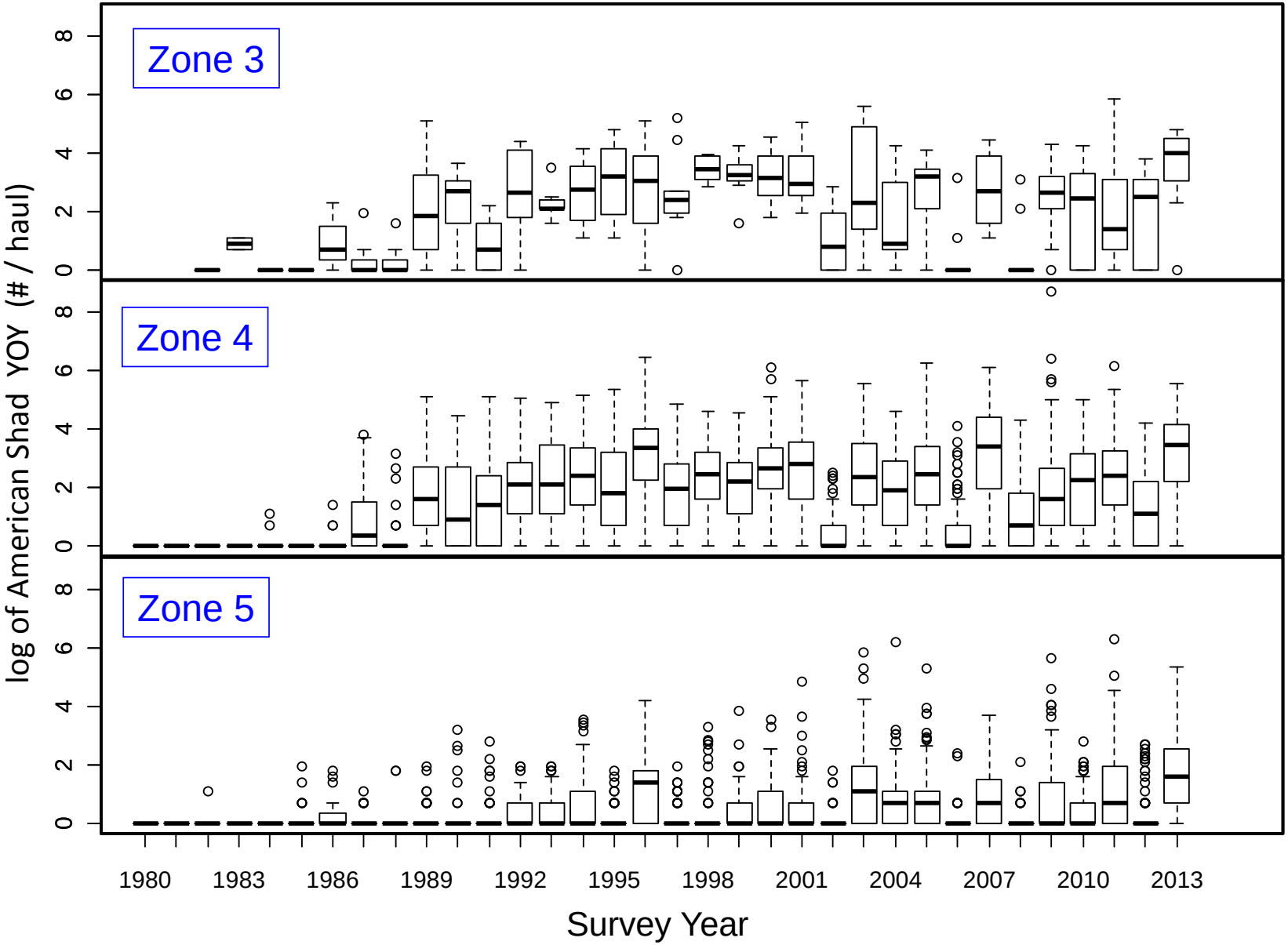


Figure 7. Striped Bass data summary from PSEG Ichthyoplankton surveys of 2002-2004 showing data distribution for all 8 surveys in each zone for each year as box-and-whisker plots (DRBC water quality zones are separated by dashed lines; PSEG survey reaches are indicated by blue bars at the top of each graph)

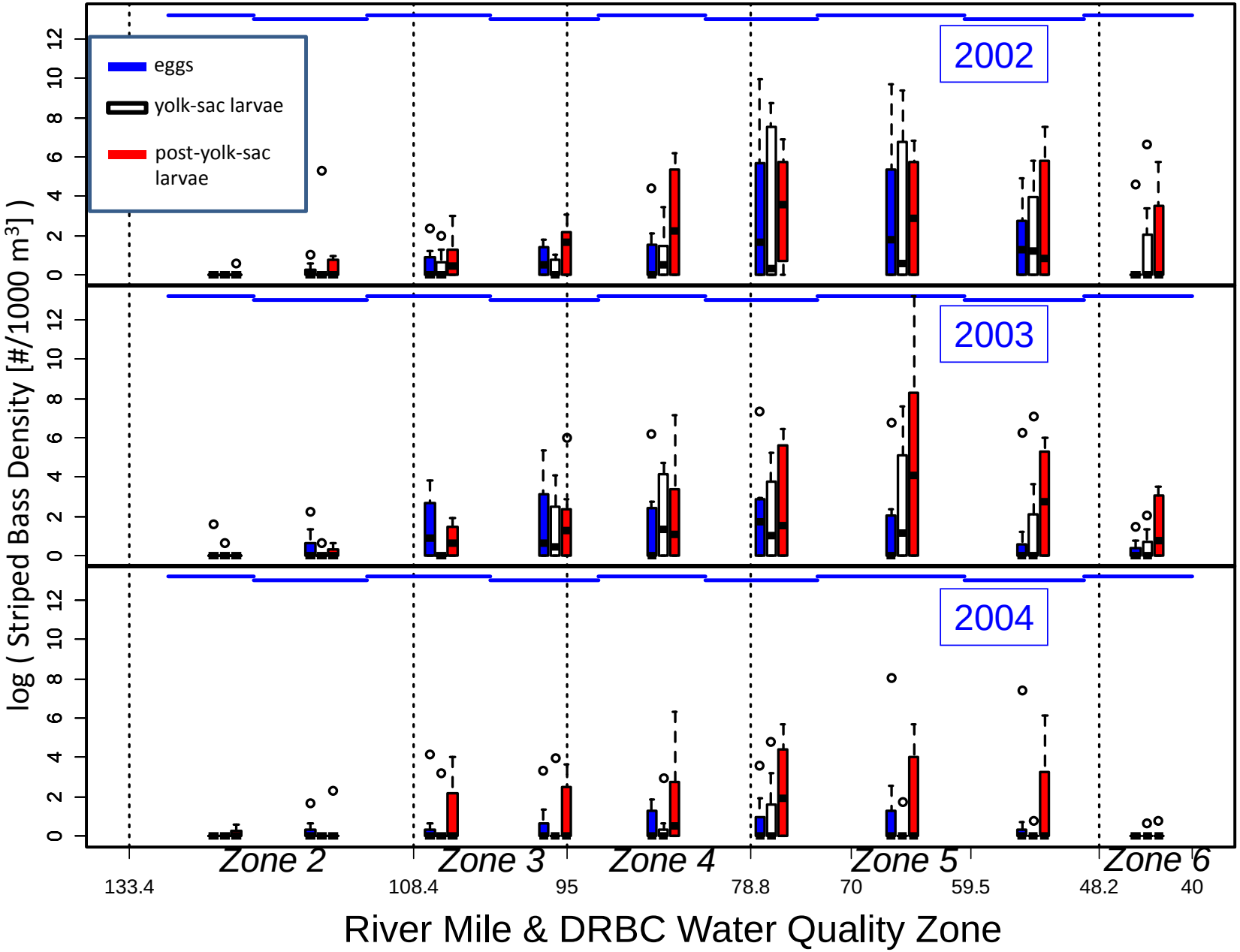


Figure 8. Striped Bass Young-of-Year data summary from New Jersey Seine Surveys for DRBC Water Quality Zones 3, 4, and 5. Full data distributions across all surveys within a Zone for a given year are presented as box-and-whisker plots.

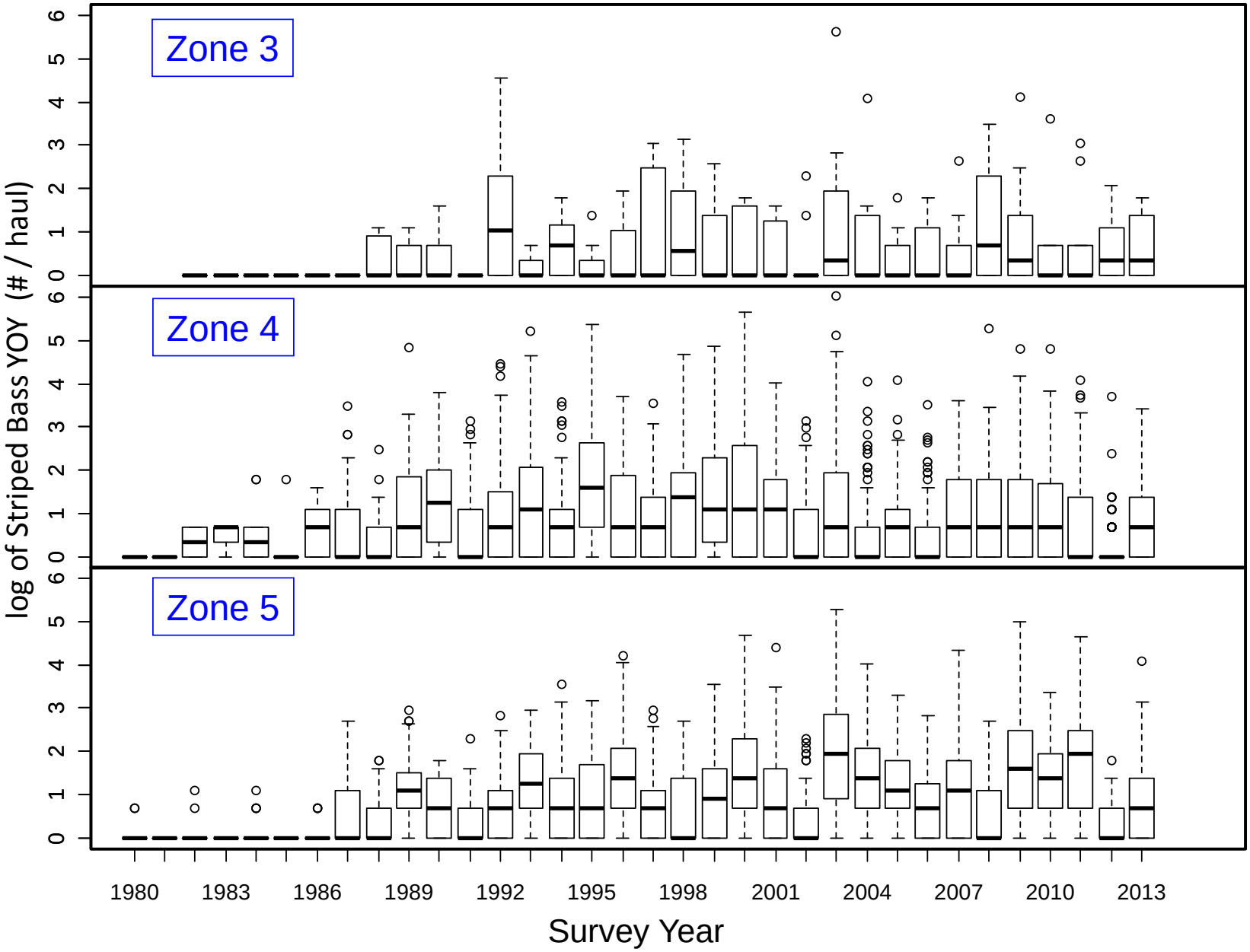


Figure 9. White Perch data summary from PSEG Ichthyoplankton surveys of 2002-2004 showing data distribution for all 8 surveys in each zone for each year as box-and-whisker plots (DRBC water quality zones are separated by dashed lines; PSEG survey reaches are indicated by blue bars at the top of each graph)

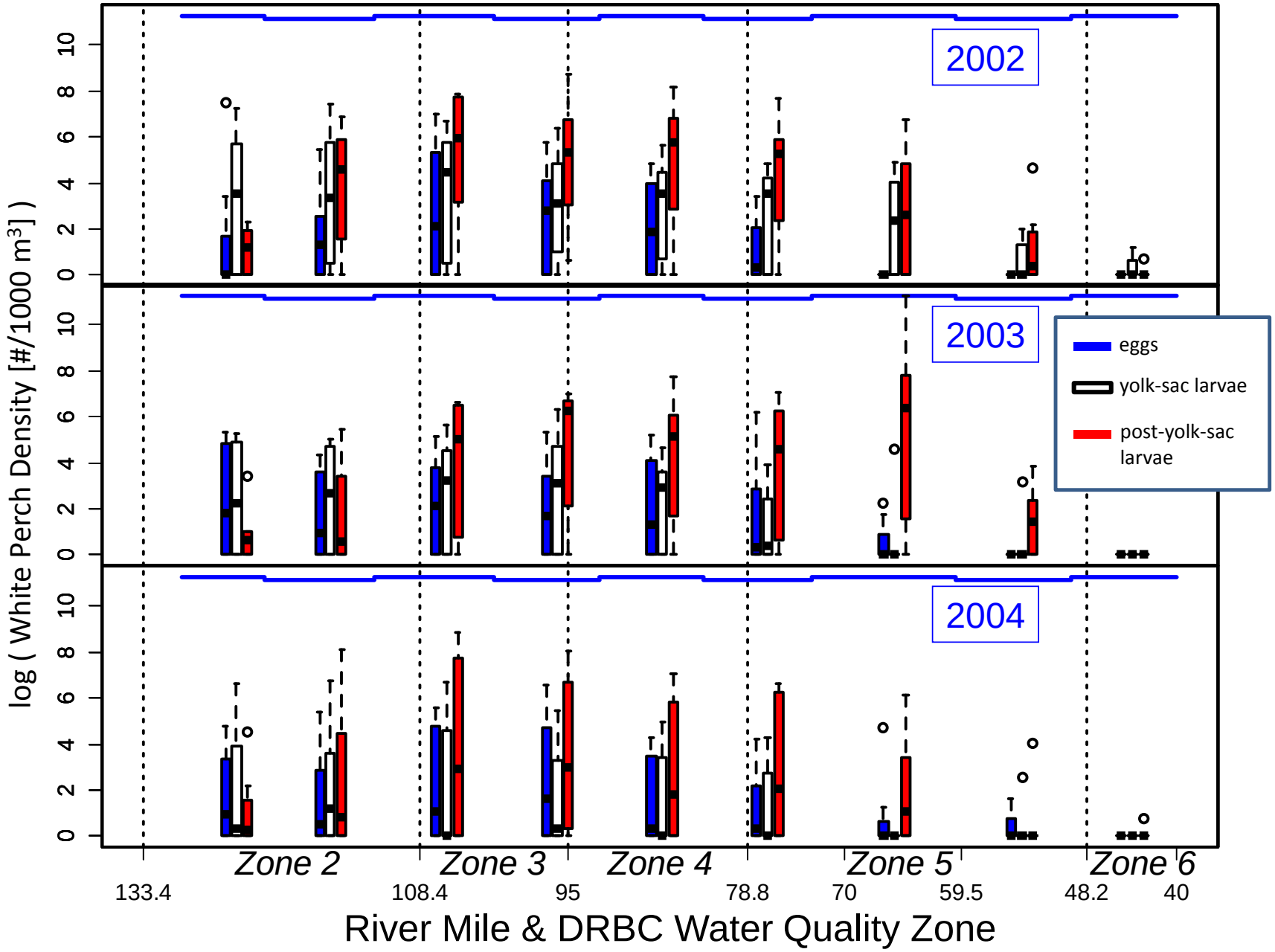


Figure 10. White Perch data summary from New Jersey Seine Surveys for DRBC Water Quality Zones 3, 4, and 5. Full data distributions across all surveys within a Zone for a given year are presented as box-and-whisker plots. *(note: catches are for multiple year classes; these data do not solely represent young-of-year fish)*

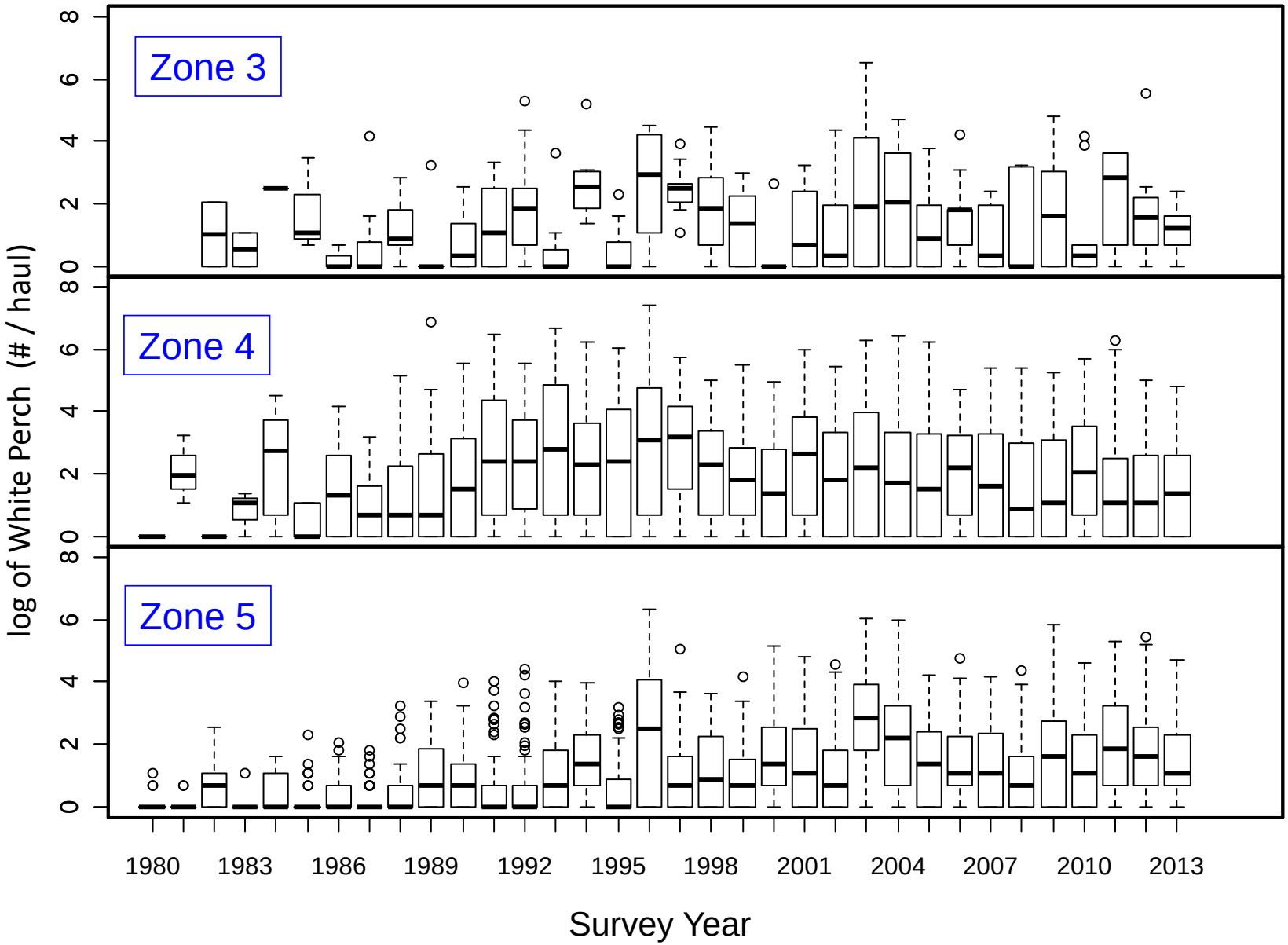


Figure 11. Bay Anchovy data summary from PSEG Ichthyoplankton surveys of 2002-2004 showing data distribution for all 8 surveys in each zone for each year as box-and-whisker plots (DRBC water quality zones are separated by dashed lines; PSEG survey reaches are indicated by blue bars at the top of each graph; higher salinity reaches of PSEG surveys with peak abundance for Bay Anchovy are not shown)

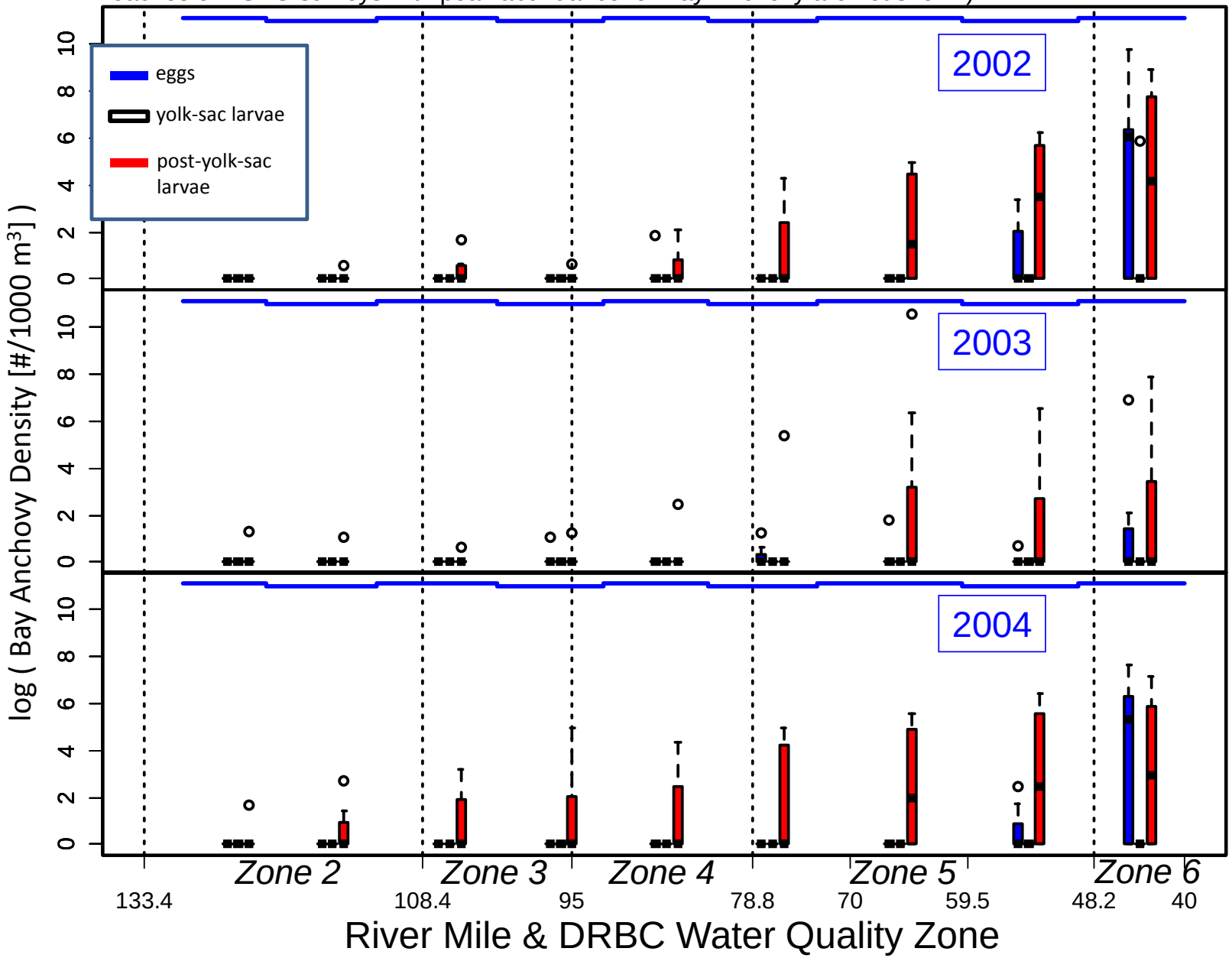


Figure 12. Bay Anchovy data summary from New Jersey Seine Surveys for DRBC Water Quality Zones 4 and 5, with data from the two sub-zones of Zone 5 presented separately. Full data distributions across all surveys within a Zone for a given year are presented as box-and-whisker plots. *(note: catches are for both juvenile and mature fish across multiple year classes; these data do not solely represent immature fish)*

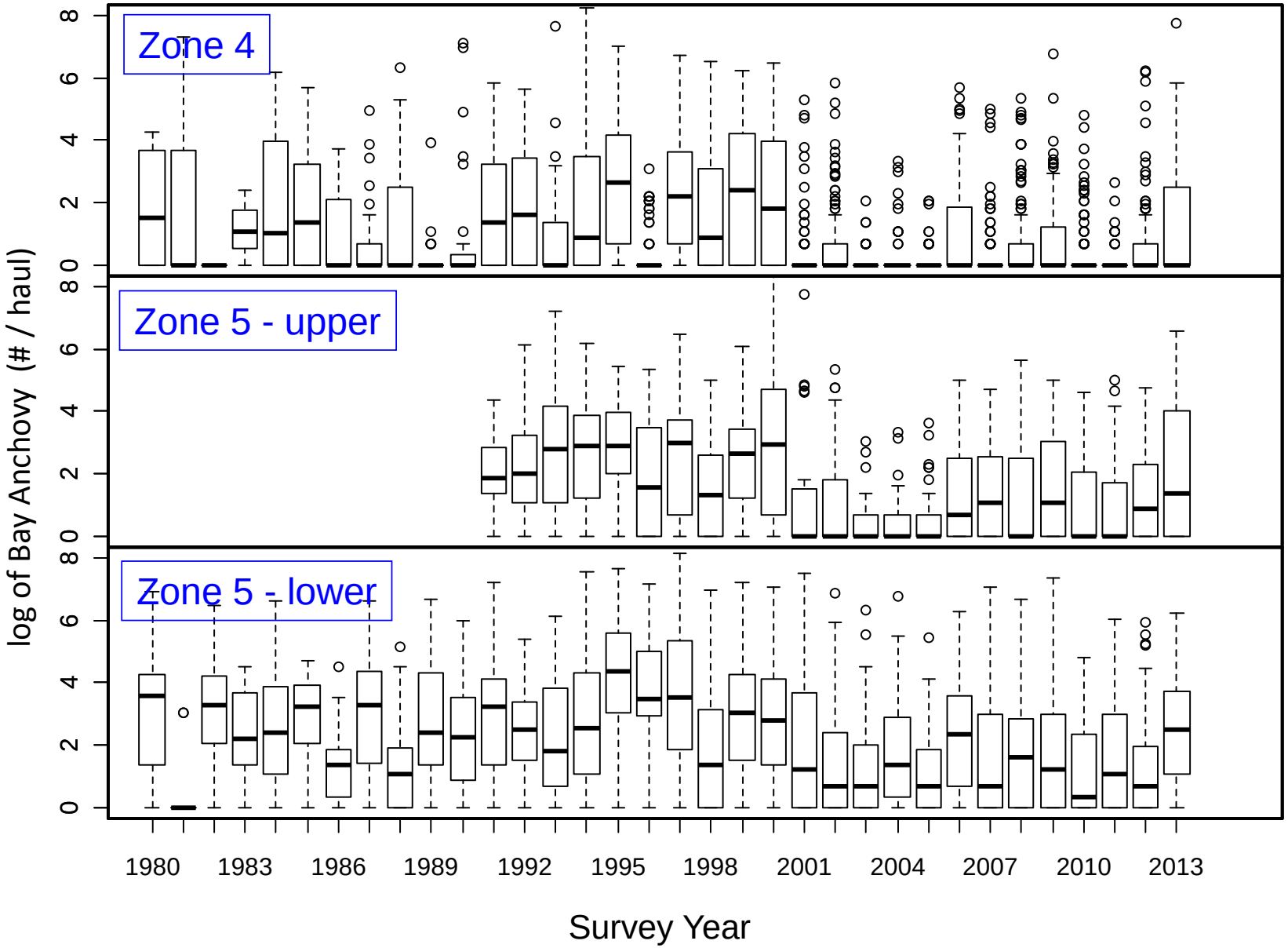


Figure 13. Atlantic Silverside data summary from PSEG Ichthyoplankton surveys of 2002-2004 showing data distribution for all 8 surveys in each zone for each year as box-and-whisker plots (DRBC water quality zones are separated by dashed lines; PSEG survey reaches are indicated by blue bars at the top of each graph; higher salinity reaches of PSEG surveys with peak abundance for Bay Anchovy are not shown)

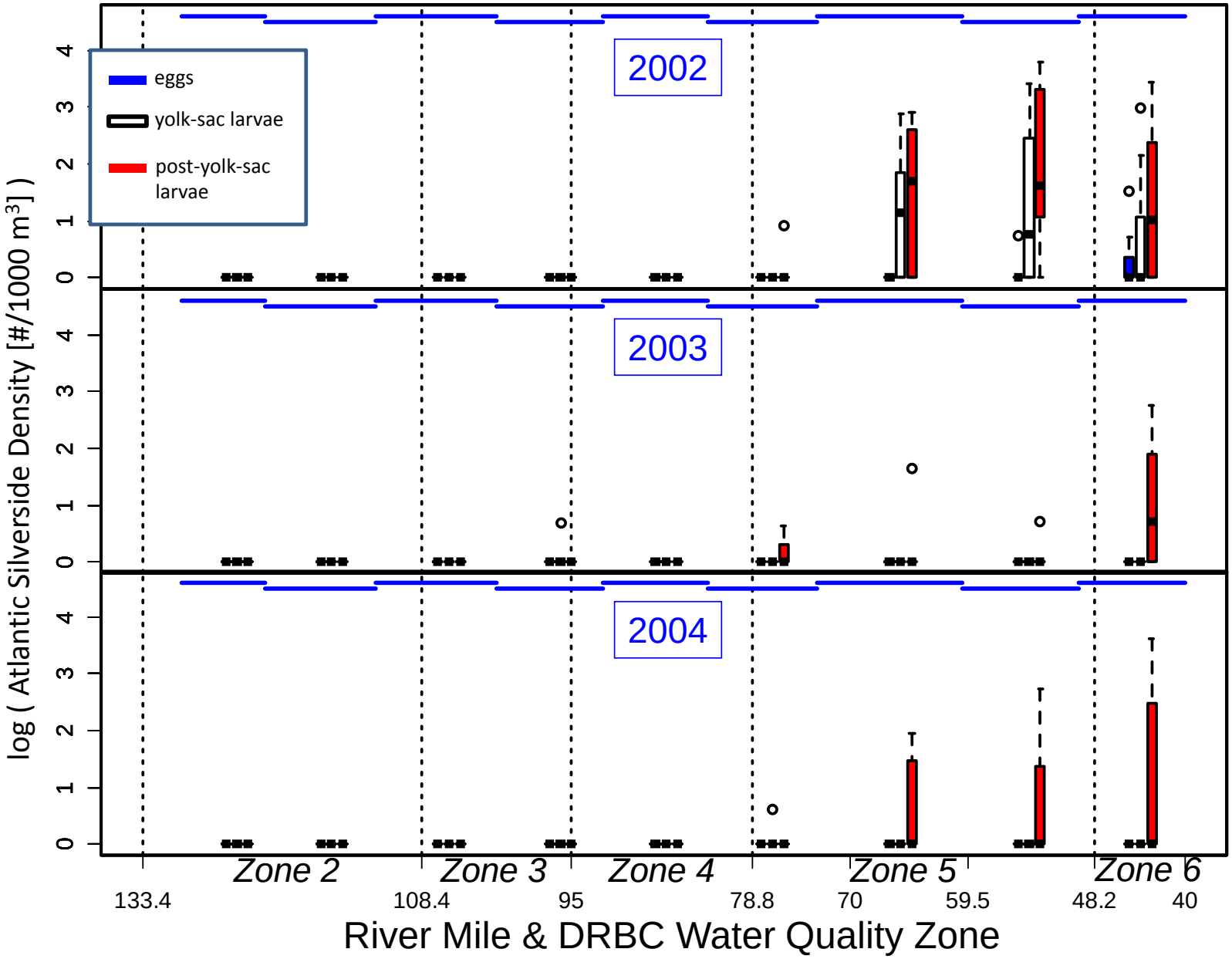


Figure 14. Atlantic Silverside data summary from New Jersey Seine Surveys for DRBC Water Quality Zones 4 and 5, with data from the two sub-zones of Zone 5 presented separately. Full data distributions across all surveys within a Zone for a given year are presented as box-and-whisker plots. *(note: catches are for both juvenile and mature fish across multiple year classes; these data do not solely represent immature fish)*

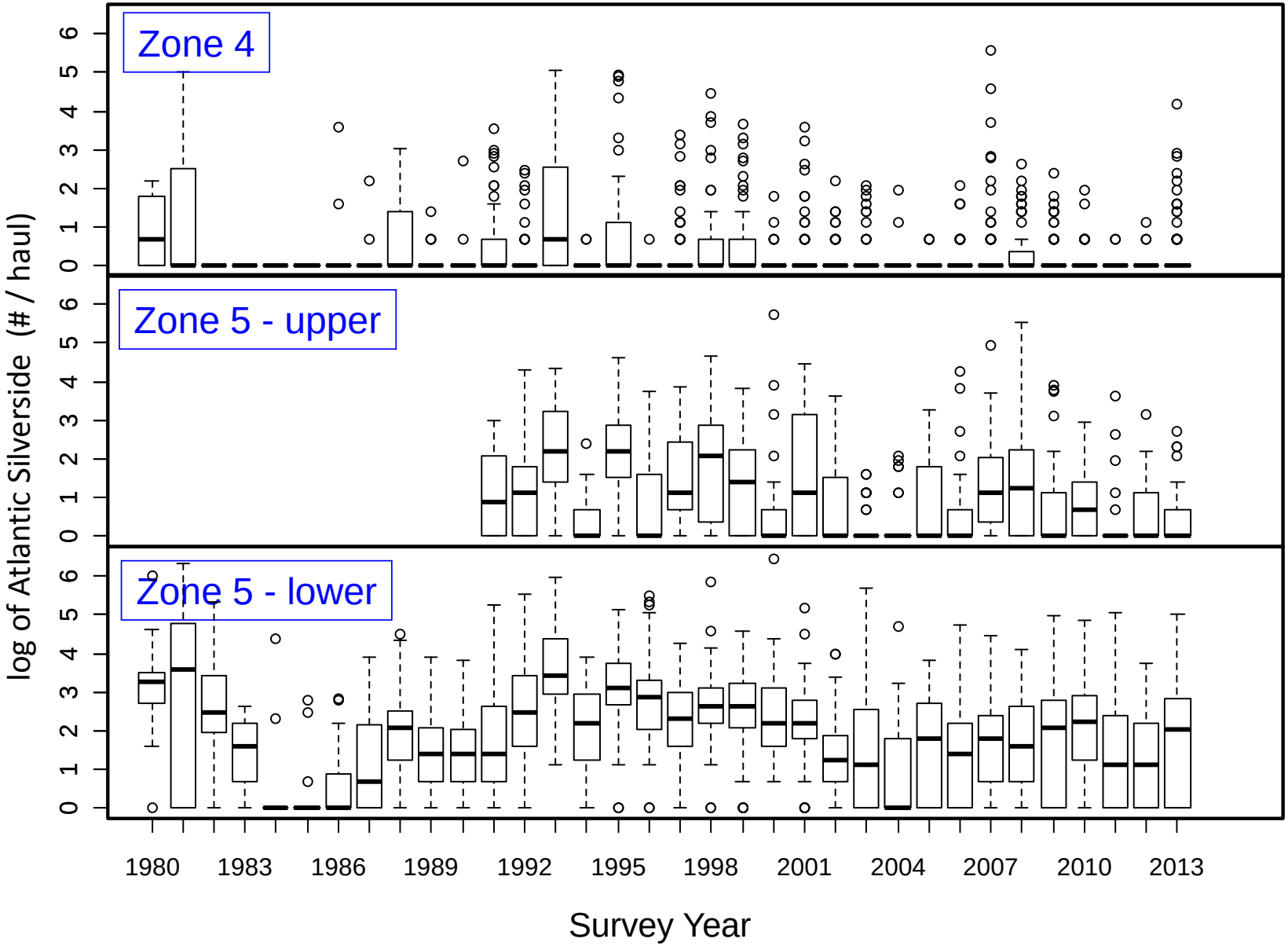


Figure 15. Alewife data summary from PSEG Ichthyoplankton surveys of 2002-2004 showing data distribution for all 8 surveys in each zone for each year as box-and-whisker plots (DRBC water quality zones are separated by dashed lines; PSEG survey reaches are indicated by blue bars at the top of each graph)

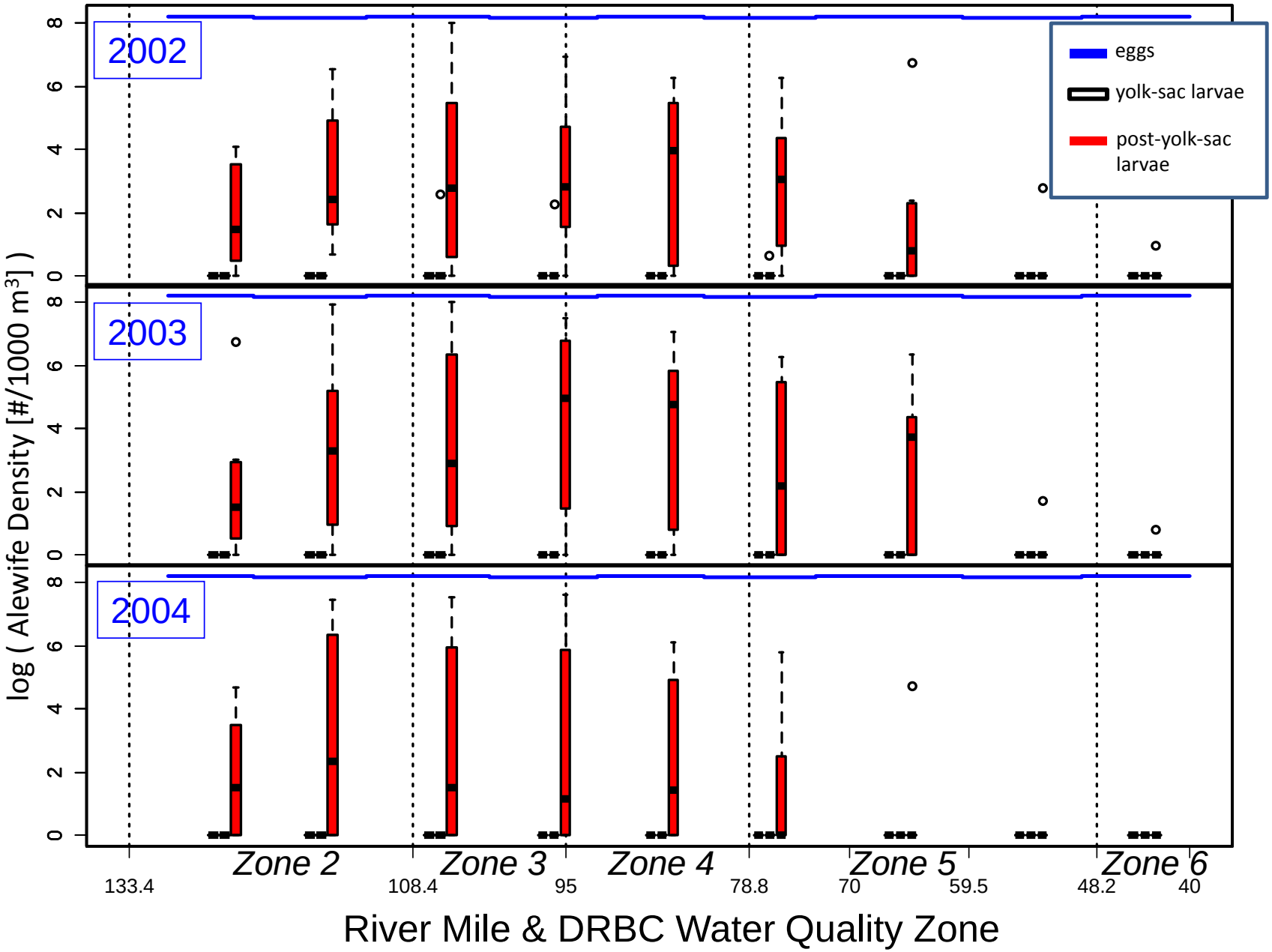


Figure 16. Blueback Herring data summary from PSEG Ichthyoplankton surveys of 2002-2004 showing data distribution for all 8 surveys in each zone for each year as box-and-whisker plots (DRBC water quality zones are separated by dashed lines; PSEG survey reaches are indicated by blue bars at the top of each graph)

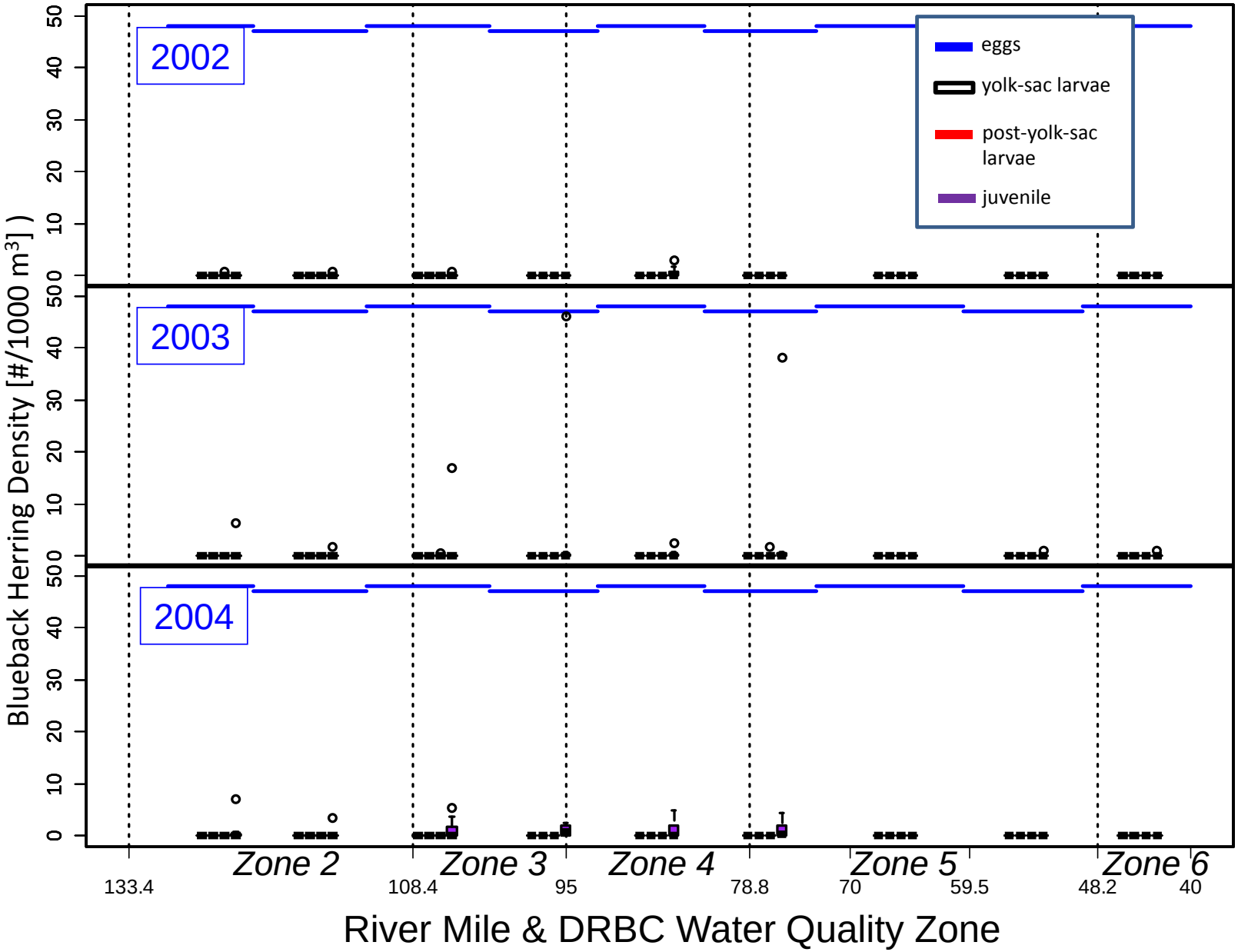


Figure 17. "*Alosa* spp." (indistinguishable Alewife & Blueback Herring eggs & larvae) data summary from PSEG Ichthyoplankton surveys of 2002-2004 showing data distribution for all 8 surveys in each zone for each year as box-and-whisker plots (DRBC water quality zones are separated by dashed lines; PSEG survey reaches are indicated by blue bars at the top of each graph)

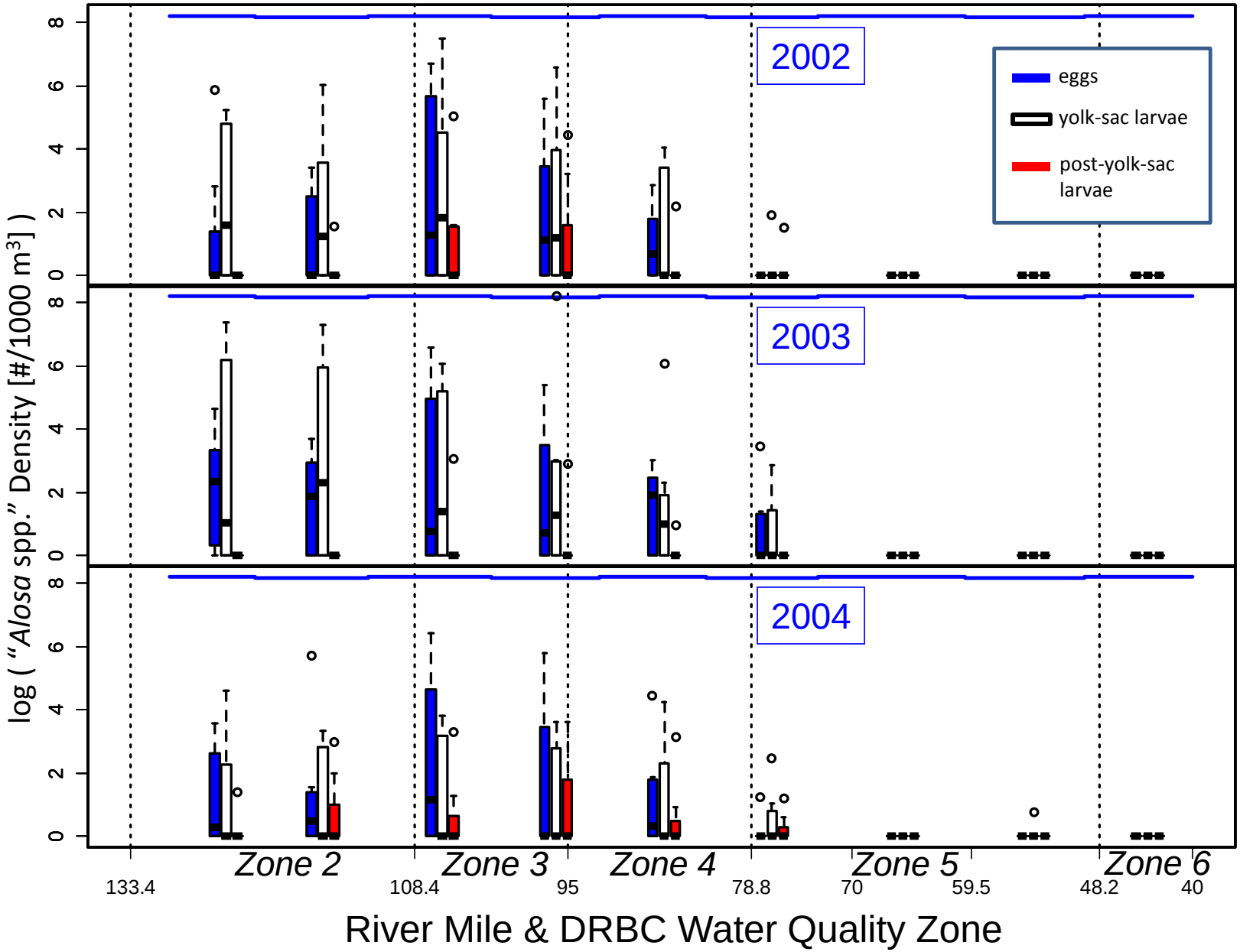


Figure 18. Alewife data summary from New Jersey Seine Surveys for DRBC Water Quality Zones 3, 4, and 5. Full data distributions across all surveys within a Zone for a given year are presented as box-and-whisker plots. *(note: primarily young-of-year fish, with some age-1 and adult fish at times collected)*

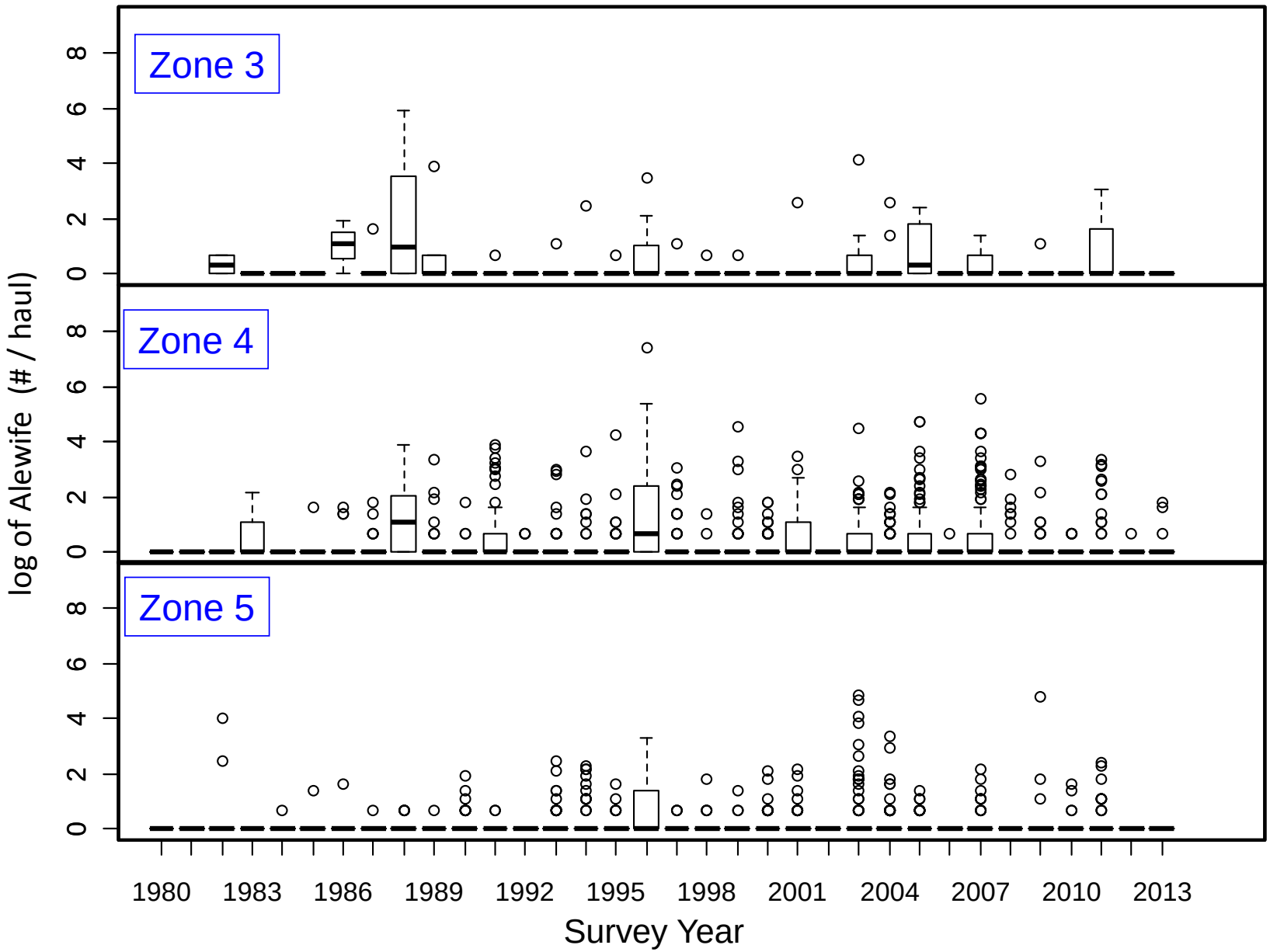


Figure 19. Blueback Herring data summary from New Jersey Seine Surveys for DRBC Water Quality Zones 3, 4, and 5. Full data distributions across all surveys within a Zone for a given year are presented as box-and-whisker plots. *(note: primarily young-of-year fish, with some age-1 and adult fish at times collected)*

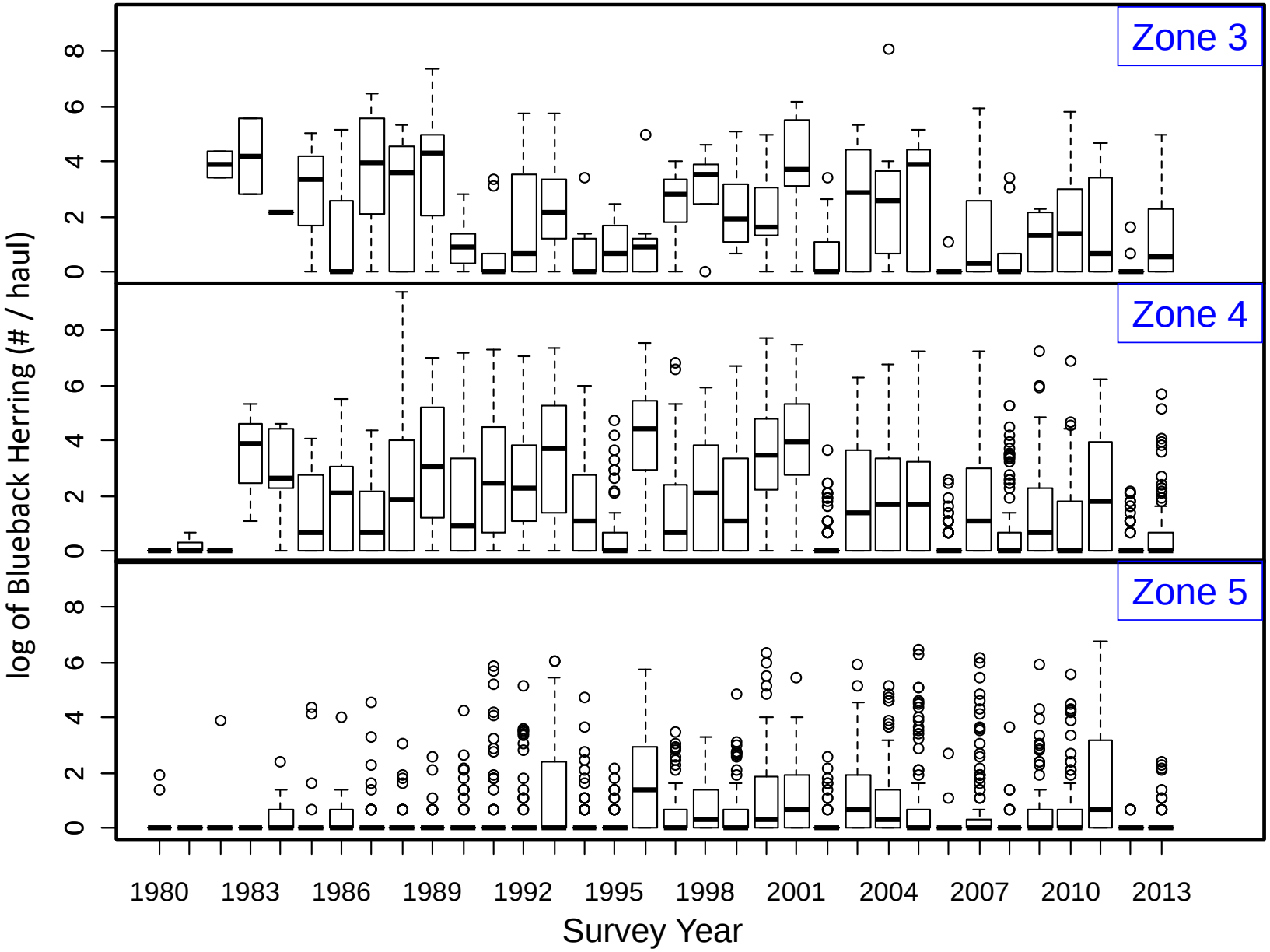


Figure 20. Atlantic Menhaden data summary from PSEG Ichthyoplankton surveys of 2002-2004 showing data distribution for all 8 surveys in each zone for each year as box-and-whisker plots (DRBC water quality zones are separated by dashed lines; PSEG survey reaches are indicated by blue bars at the top of each graph)

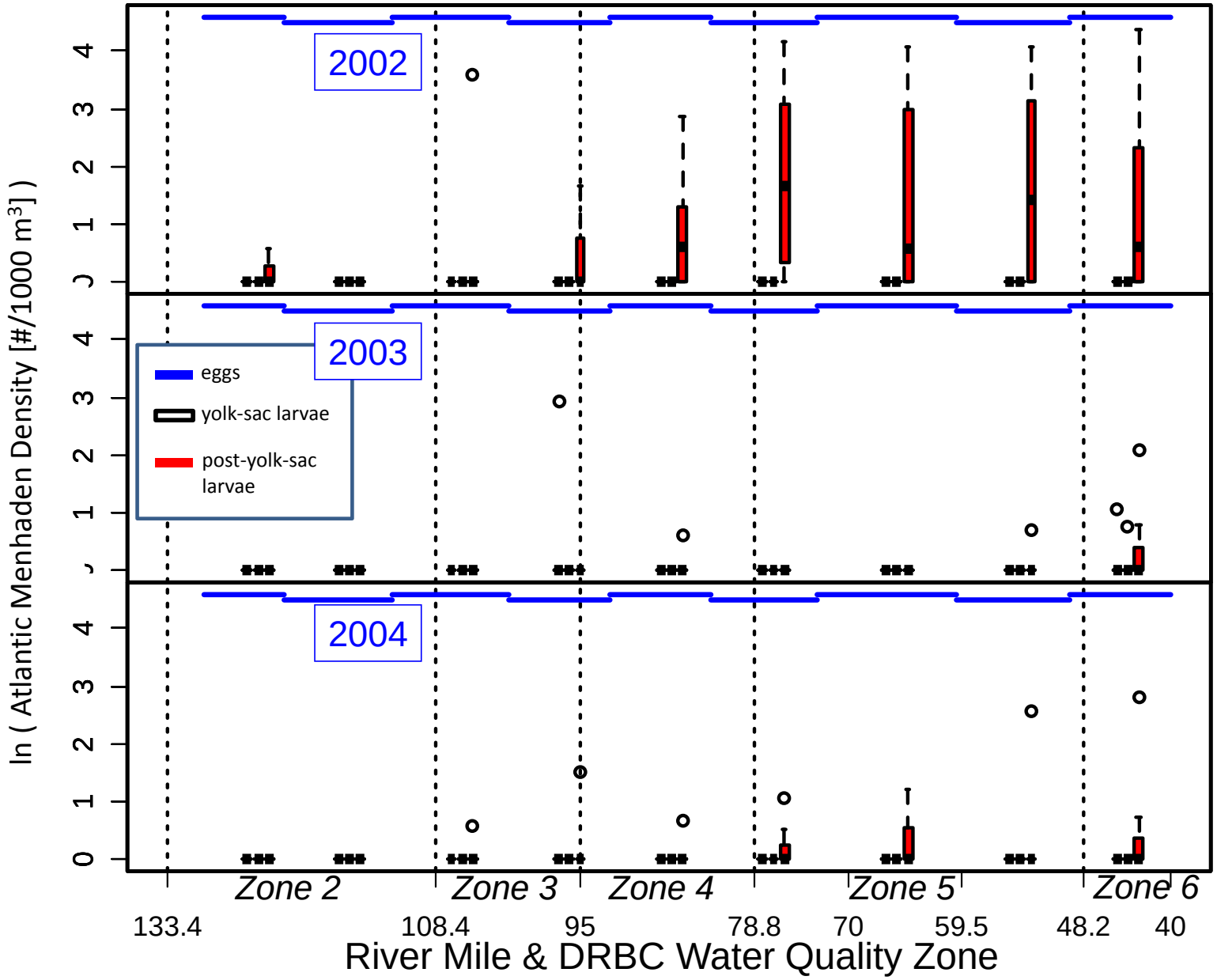
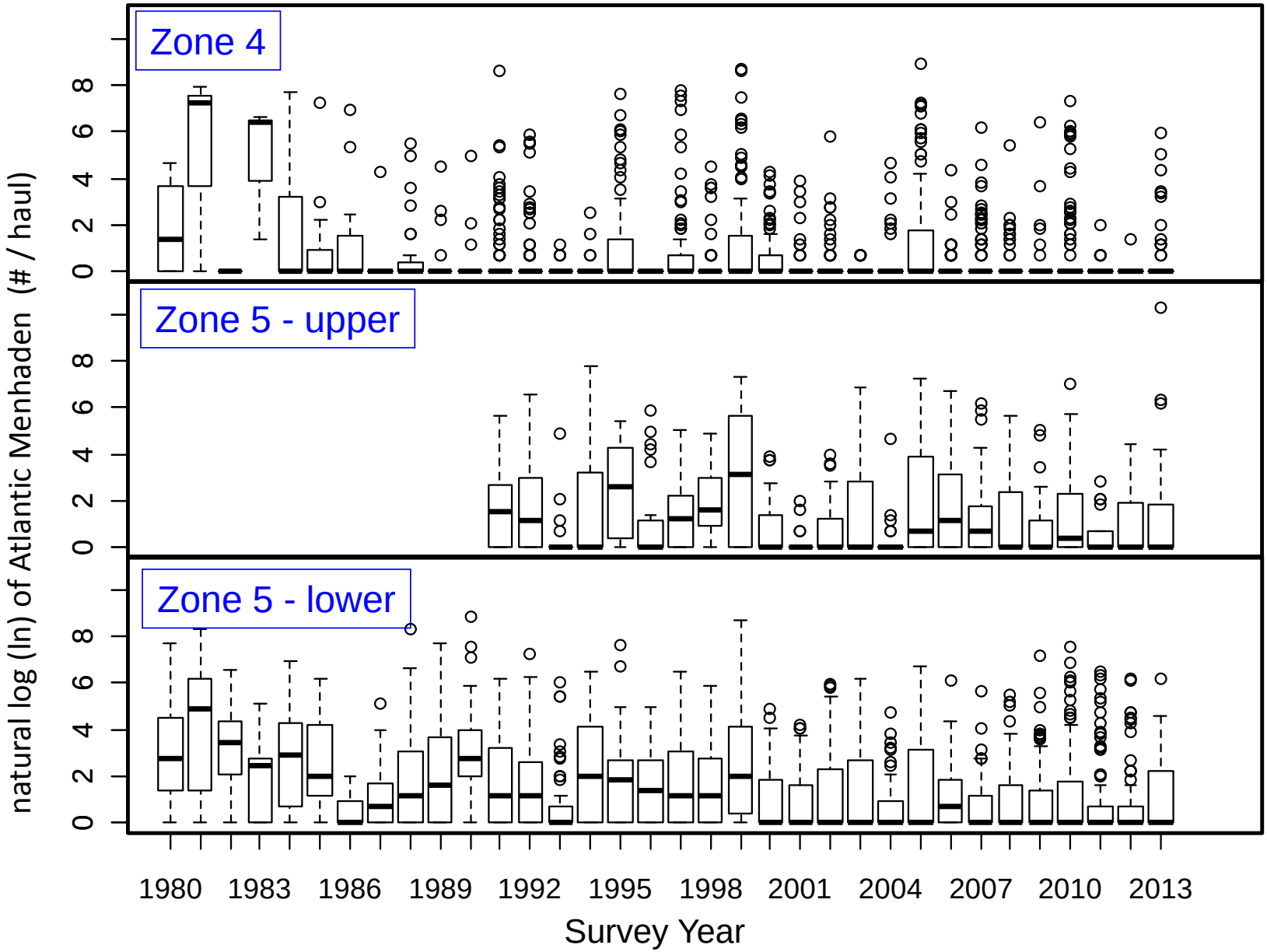


Figure 21 Atlantic Menhaden data summary from New Jersey Seine Surveys for DRBC Water Quality Zones 4 and 5, with data from the two sub-zones of Zone 5 presented separately. Full data distributions across all surveys within a Zone for a given year are presented as box-and-whisker plots. *(note: primarily young-of-year fish, with some age-1 and adult fish at times collected)*



Appendix A. 1967 Water Quality Regulations & DRBC Resolution Approval

NO. 67-2

A RESOLUTION to amend the Comprehensive Plan with respect to water quality standards for the Delaware River Estuary and Bay.

WHEREAS, the Commission undertook a basinwide water pollution abatement and control program as authorized by its resolution of May 6, 1966 (No. 66-7), and as a first step in the formulation of that program, the Commission conducted a major conference on water pollution problems of the basin in Philadelphia on July 27, 1966; and

WHEREAS, the Commission has received and considered the preliminary report of the Delaware River Estuary Comprehensive Study conducted and prepared by the Federal Water Pollution Control Administration of the United States Department of the Interior, and the various findings and conclusions thereof; and

WHEREAS, a public hearing was duly held by the Commission on the 26th day of January, 1967, at Trenton, New Jersey, upon proposed water quality standards, as authorized or required by the Federal Water Pollution Control Act, as amended, and Articles 5 and 13 of the Delaware River Basin Compact, following the publication of notice pursuant to law; and

WHEREAS, the Commission has duly considered the results of its staff investigations, the facts and arguments presented at the public hearings, and all of the data and communications received by the Commission, and has consulted with interested parties in accordance with the Compact, and in consideration thereof the Commission has made certain determinations with respect to water quality standards for the Delaware River Estuary and Bay, and the tributaries thereof; and

WHEREAS, upon such investigations, public hearings and otherwise, the Commission finds and determines that the effectuation of national policy as set forth in the Water Pollution Control Act (Public Law 84-660) as last amended by the Clean Water Restoration Act of 1966 (P.L. 89-753), and of the purposes and provisions of the Delaware River Basin Compact and the Comprehensive Plan adopted pursuant thereto, requires that the Commission assume jurisdiction to control future pollution and abate existing pollution in the waters of the Delaware River Basin, by amendment of the Comprehensive Plan and by the adoption and promulgation of rules, regulations and standards pursuant to Article 5 of the Delaware River Basin Compact; now therefore

BE IT RESOLVED by the Delaware River Basin Commission:

1. The Comprehensive Plan is hereby amended by renumbering the existing Section X to Section XII and by the addition thereto of a new section, to be designated Section X Water Quality Standards, to read as follows:

Section X

Water Quality Standards

(The text of the standards is attached)

2. This resolution shall take effect immediately. All resolutions and parts of resolutions, and all parts of the Comprehensive Plan, heretofore adopted which are inconsistent with any provision of this resolution are, to the extent of such inconsistency, hereby repealed. This resolution will not apply to existing effluents pending the adoption by the Commission of rules and regulations to implement the Comprehensive Plan as amended, pursuant to Article 5 of the Compact.

Raymond P. Shafer
Chairman

W. Binton Whitall
Secretary

ADOPTED: March 2, 1967

Amended by 67-7

QUALITY STANDARDS FOR THE INTERSTATE WATERS OF THE DELAWARE RIVER BASIN

ARTICLE I

ESTUARY GENERALLY

Water uses

Uses paramount. Water uses shall be paramount in determining stream quality objectives which, in turn, shall be the basis for determining effluent quality requirements.

Uses to be protected. The quality of waters shall be maintained in a safe and satisfactory condition for the following uses: (a) agricultural, industrial, and public water supplies after reasonable treatment, except where natural salinity precludes such uses; (b) wildlife, fish and other aquatic life; (c) recreation; (d) navigation; (e) controlled and regulated waste assimilation in reasonable compatibility with other uses; and (f) such other uses as may be provided by the Comprehensive Plan.

Stream quality objectives

Limits. The waters shall not contain substances attributable to municipal, industrial, or other discharges in concentrations or amounts sufficient to preclude the specified water uses to be protected. Within this requirement, the waters shall be substantially free from unsightly or malodorous nuisances due to floating solids, sludge deposits, debris, oil, scum, substances, in concentrations or combinations which are toxic or harmful to human, animal, plant, or aquatic life, or that produce color, taste, or odor.

Effluent quality requirements

Disinfection. Wastes (exclusive of stormwater bypass) containing human excreta shall be effectively disinfected before being discharged into surface bodies of water.

Public safety. Effluents shall not create a menace to public health or safety at the point of discharge.

Limits. Discharges shall not contain more than negligible amounts of debris, oil, scum or other floating materials, suspended matter which will settle to form sludge, toxic substances or substances that produce color, taste and odors.

Other considerations

Combined sewers. Any new facility or project combining sanitary or industrial waste with stormwater drainage, which would have a substantial effect on the quality of waters of the basin, shall not be permitted, whether or not any such project or facility discharges into an existing combined system.

Access and reports. The Commission, or its duly authorized representatives, shall have access, at reasonable hours, to observe and inspect waste treatment facilities and to collect samples for analyses. Upon written request, operation reports shall be submitted to the Commission.

Zones. The Delaware River and Bay may be divided into zones which will facilitate the management of surface and underground water quality. The required percentage reduction of biochemical oxygen demand of all wastes will be uniform within zones.

Definitions

Biochemical oxygen demand. Biochemical oxygen demand as determined under standard laboratory procedures for 5-days at 20° C.

Carbonaceous oxygen demand. That part of the ultimate oxygen demand associated with biochemical oxidation of carbonaceous, as distinct from nitrogenous, material.

Effective disinfection. The destruction of pathogenic organisms in such manner and under such controls as shall be prescribed by Commission regulations.

River mile. The distance, in statute miles, of a location or item measured from "mile zero" essentially along the centerline of the navigation channel. Mile zero is located [illegible]

intersection of a line between the Cape May Light and the tip of Cape Henlopen.

Application

This Article shall apply to the Delaware River Estuary and Bay, including the tidal portions of the tributaries thereof.

ARTICLE II

ZONE 2

Description

Zone 2 is that part of the Delaware River extending from the head of tidewater at Trenton, New Jersey, R.M. (River Mile) 133.4 (Trenton-Morrisville Toll Bridge) to R.M. 108.4 below the mouth of Pennypack Creek, including the tidal portions of the tributaries thereof.

Water uses

Uses to be protected. The quality of Zone 2 waters shall be maintained in a safe and satisfactory condition for the following uses: (a) agricultural, industrial, and public water supplies after reasonable treatment; (b) wildlife, maintenance and propagation of resident fish and other aquatic life, passage of anadromous fish; (c) recreation; and (d) navigation.

Stream quality objectives

Dissolved oxygen, daily average concentration shall not be less than 5.0 mg/l (milligrams per liter) except during the periods from April 1 to June 15 and September 16 to December 31 when the dissolved oxygen shall not average less than 6.5 mg/l; chlorides, maximum 15-day mean 50 mg/l; pH; between 6.5 and 8.5; total alkalinity, between 20 and 100 mg/l; hardness, maximum monthly mean 95 mg/l; temperature, shall not exceed 5° F above the average daily temperature gradient displayed during the 1961 - 1966 period, or a maximum of 86° F, whichever is less; phenols, maximum 0.005 mg/l; threshold odor number not to exceed 24 @ 60° C; syndets (synthetic detergents) measured as M.B.A.S. (methylene blue active substances), maximum monthly mean 0.5 mg/l; turbidity, maximum monthly mean 40 units, maximum 150 units; radioactivity, alpha emitters, maximum 3 pc/l (picocuries per liter), beta emitters, maximum 1,000 pc/l.

Effluent quality requirements

All discharges shall meet the effluent quality requirements of Article 1. The biochemical oxygen demand shall be reduced at all times by at least 85 percent. The carbonaceous oxygen demand from all outfalls in the Zone (exclusive of stormwater bypass) shall not exceed that assigned by Commission regulations.

ZONE 3

Description

Zone 3 is that part of the Delaware River extending from R. M. 108.4 to R. M. 95.0, below the mouth of Big Timber Creek, including the tidal portions of the tributaries thereof.

Water uses

Uses to be protected. The quality of Zone 3 waters shall be maintained in a safe and satisfactory condition for the following uses: (a) agricultural, industrial, and public water supplies after reasonable treatment; (b) wildlife, maintenance of resident fish and other aquatic life, passage of anadromous fish; (c) recreation; and (d) navigation.

Stream quality objectives

Dissolved oxygen, daily average concentration shall not be less than 3.5 mg/l, except during the periods from April 1 to June 15 and September 16 to December 31 when the dissolved oxygen shall not average less than 6.5 mg/l; chlorides, maximum 200 mg/l; pH, between 6.5 and 8.5; total alkalinity, between 20 and 120 mg/l; hardness, maximum monthly mean 150 mg/l; temperature, shall not exceed 5° F above the average daily temperature gradient displayed during the 1961 - 1966 period, or a maximum of 86° F, whichever is less; phenols, maximum 0.005 mg/l; threshold odor number not to exceed 24 @ 60° C; syndets (M.B.A.S.), maximum monthly mean 1.0 mg/l; turbidity, maximum monthly mean 40 units; maximum 150 units; radioactivity, alpha emitters, maximum 3 pc/l, beta emitters, maximum 1,000 pc/l.

Effluent quality requirements

All discharges shall meet the effluent quality requirements of Article I. The biochemical oxygen demand shall be reduced at all times by at least 85 percent. The carbonaceous oxygen demand from all outfalls in the Zone (exclusive of stormwater bypass) shall not exceed that assigned by Commission regulations.

ZONE 4

Description

Zone 4 is that part of the Delaware River extending from R. M. 95.0 to R. M. 78.8, the Pennsylvania-Delaware boundary line, including the tidal portions of the tributaries thereof.

Water uses

Uses to be protected. The quality of Zone 4 waters shall be maintained in a safe and satisfactory condition for the following uses: (a) industrial water supply after reasonable treatment; (b) wildlife, maintenance of resident fish and other aquatic life, passage of anadromous fish; (c) recreation; and (d) navigation.

Stream quality objectives

Dissolved oxygen, daily average concentration shall not be less than 3.5 mg/l, except during the periods from April 1 to June 15 and September 16 to December 31 when the dissolved oxygen shall not average less than 6.5 mg/l; chlorides, maximum 250 mg/l at R. M. 92.47; pH, between 6.5 and 8.5; total alkalinity, between 20 and 120 mg/l; temperature, shall not exceed 5° F above the average daily temperature gradient displayed during the 1961 - 1966 period, or a maximum of 86° F, whichever is less; phenols, maximum 0.02 mg/l; threshold odor number not to exceed 24 @ 60° C; syndets (M.B.A.S.), maximum monthly mean 1.0 mg/l; turbidity, maximum monthly mean 40 units, maximum 150 units; radioactivity, alpha emitters, maximum 3 pc/l, beta emitters, maximum 1,000 pc/l.

Effluent quality requirements

All discharges shall meet the effluent quality requirements of Article 1. The biochemical oxygen demand shall be reduced at all times by at least 85 percent. The carbonaceous oxygen demand from all outfalls in the Zone (exclusive of stormwater bypass) shall not exceed that assigned by Commission regulations.

ZONE 5

Description

Zone 5 is that part of the Delaware River extending from R. M. 78.8 to R. M. 48.2, Liston Point, including the tidal portions of the tributaries thereof.

Water uses

Uses to be protected. The quality of Zone 5 waters shall be maintained in a safe and satisfactory condition for the following uses: (a) industrial water supply after reasonable treatment; (b) wildlife, maintenance of resident fish and other aquatic life, propagation of resident fish from R. M. 70.0 to R. M. 48.2, passage of anadromous fish; (c) recreation; and (d) navigation.

Stream quality objectives

Dissolved oxygen, daily average concentration shall not be less than 3.5 mg/l at R. M. 78.8, 4.5 mg/l at R. M. 70.0 and 6.0 mg/l at R. M. 59.5, except during periods from April 1 to June 15 and September 16 to December 31 when the dissolved oxygen shall not average less than 6.5 mg/l in the entire zone; pH, betwen 6.5 and 8.5; total alkalinity, between 20 and 120 mg/l; temperature shall not exceed 5° F above the average daily temperature gradient displayed during the 1961 - 1966 period, or a maximum of 86° F, whichever is less; phenols, maximum 0.02 mg/l; threshold odor number not to exceed 24 @ 60° C; syndets (M.B.A.S.), maximum monthly mean 1.0 mg/l; turbidity, maximum monthly mean 40 units, maximum 150 units; radioactivity, alpha emitters, maximum 3 pc/l, beta emitters, maximum 1,000 pc/l.

Effluent quality requirements

All discharges shall meet the effluent quality requirements of Article 1. The biochemical oxygen demand shall be reduced at all times by at least 85 percent. The carbonaceous oxygen demand from all outfalls in the Zone (exclusive of stormwater bypass) shall not exceed that assigned by Commission regulations.

ZONE 6

Description

Zone 6 is that part of Delaware Bay extending from R. M. 48.2 to R. M. 0.00, the Atlantic Ocean, including the tidal portions of the tributaries thereof.

Water uses

Uses to be protected. The quality of Zone 6 waters shall be maintained in a safe and satisfactory condition for the following uses: (a) industrial water supply after reasonable treatment; (b) wildlife, maintenance and propagation of resident fish, shellfish, and other aquatic life, and passage of anadromous fish; (c) recreation and (d) navigation.

Stream quality objectives

Dissolved oxygen, daily average concentration shall not be less than 6.0 mg/l; pH, between 6.5 and 8.5; total alkalinity, between 20 and 120 mg/l; temperature, shall not exceed 5° F above the average daily temperature gradient displayed during the 1961 - 1966 period, or a maximum of 86° F, whichever is less; phenols, maximum 0.02 mg/l; threshold odor number not to exceed 24 @ 60° C; syndets (M.B.A.S.), maximum monthly mean 1.0 mg/l; turbidity, maximum monthly mean 40 units, maximum 150 units; radioactivity, alpha emitters, maximum 3 pc/l, beta emitters, maximum 1,000 pc/l; coliform, MPN (most probable number) not to exceed U. S. Public Health Service's shellfish standards in designated shellfish areas.

Effluent quality requirements

All discharges shall meet the effluent quality requirements of Article 1. The biochemical oxygen demand shall be reduced at all times by at least 85 percent.

Appendix B. Table 1 and Selected Text from Nadeau et al. 1979

Nadeau, R., R. Hemmett, J. Miller, R.W. Miller, D.M. Clark, D. Jacangelo, L. Skinner, R.W. Marshall, T.A. Strekal, C. Emery, S.D. Selzer, D.P. Pollison, R.C. Albert, R.C. Kausch, and A.A. Anderson. 1979. Dissolved Oxygen Requirements of a "Fishable" Delaware River Estuary. Report to the Delaware River Basin Commission by the Ad Hoc Task Force to Evaluate Dissolved Oxygen Requirements of Indigenous Estuary Fish. *{available online at http://www.state.nj.us/drbc/library/documents/del-estuary_DOrequirements_1979report.pdf}*

Nadeau et al. 1979 introduce Table 1 on pages 1 & 2 of their report:

> *"Based on the knowledge of individual Task Force members and data concerning past and present Delaware Estuary Fisheries, the Task Force developed a list of thirteen migratory fish, thirteen resident fish, and one endangered fish species (Table 1). This tabulation represents a target Estuary Fish population in terms of sensitive game, forage, commercial and desired fish species rather than a total anticipated population. Total estuary fish populations are assumed to increase proportionately to the target species.*
>
> *"For each target fish, Table 1 presents existing and potential activities (spawning, nursery, passage) by Estuary zone. The Task Force feels that current limitations on existing activities and population sizes, particularly in Zone 4, do not meet the intent of the National "fishable" goal. Restoration of fish populations to include the listed potential activities, however, will result in a minimal level of fisheries required to satisfy the national goal."*

TABLE I

Selected Fish of Interest by Zone and Activity

Aquatic Species	DELAWARE RIVER ZONE*											
	2			3			4			5		
Migratory or Marine/Estuarine:	S	N	P	S	N	P	S	N	P	S	N	P
Striped bass	o	o	x	o	o	x	o	o	x	x	x	x
Alewife	x	x	x		x	x		o	x		x	x
Blueback herring	x	x	x		x	x		o	x		x	x
American shad	o	x	x	o	o	x	o	o	x			x
Mummichog			x**			x	x	x	x	x	x	x
Bay anchovy											x	x
Menhaden								x	x		x	x
Bluefish											x	x
Weakfish											x	x
Spot											x	x
Atlantic croaker											x	x
Atlantic silversides											x	x
Blue crab			x**			x**			x**		x	x
Resident (freshwater/brackish water):												
Pumpkinseed/bluegill	x	x	x	x	x	x	o	o	x	x	x	x
Largemouth bass	x	x	x	o	o	x	o	o	o	o	o	o
Walleye	x+	x	x									
Channel catfish	x	x	x	x	x	x	o	o	x	x	x	x
Black crappie	x	x	x	o	o	o	o	o	o			x
Golden shiner	x	x	x	x	x	x	o	o	o			x
White perch	x	x	x	x	x	x	o	o	x	x	x	x
Silvery minnow	x	x	x	x	x	x	o	o	x	x	x	x
Carp	x	x	x	x	x	x	x	x	x	x	x	x
Goldfish	x	x	x	x	x	x	x	x	x	x	x	x
Brown bullhead	x	x	x	x	x	x	x	x	x	x	x	x
Yellow perch												x
Endangered Species												
Short nose sturgeon	x	x	x		o	x		o	x		x	x

*Key

S = Spawning
N = Nursery
P = Passage
o = potential
x = existing

**Limited or occasional presence (limited for reasons other than water quality)
+ Limited spawning in area (limited for reasons other than water quality)

Appendix C. PSEG Ichthyoplankton Data from 2002, 2003, and 2004 Biological Monitoring Program Annual Reports