FINAL 2018-2020 DELISTING DOCUMENT
WATERBODY IMPAIRMENTS REMOVED FROM THE IMPAIRED WATERS LISTS

January 2021

Rhode Island Department of Environmental Management
Office of Water Resources
235 Promenade Street
Providence, RI 02908

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BLACKSTONE RIVER (RI0001003R-01A AND RI0001003R-01B)

- RI0001003R-01A Blackstone River from the MA-RI border to the CSO outfall located at River and Samoset Streets in Central Falls. Woonsocket, North Smithfield, Cumberland, Lincoln and Central Falls

- RI0001003R-01B Blackstone River from the CSO outfall located at River and Samoset Streets in Central Falls to the Slater Mill Dam. Central Falls, Pawtucket.

DISSOLVED OXYGEN AND PHOSPHORUS (TOTAL)

RIDEM listed the Blackstone River as impaired for dissolved oxygen in 1996 with a nutrient listing added in 1998. In 2008, the nutrient listing was changed to total phosphorus due to the links between total phosphorus and elevated chlorophyll *a* that caused some low dissolved oxygen swings in impoundments. When RIDEM split the Blackstone River into two segments in 2002, the impairments were carried over to each segment. A TMDL has not been completed on the dissolved oxygen or total phosphorus causes. Both Blackstone segments will remain impaired for Aquatic Life use (dissolved cadmium, dissolved lead, and total iron), Primary and Secondary Contact use (enterococcus, fecal coliform), and Fish Consumption use (mercury in fish tissue and PCBs in fish tissue). The upstream Blackstone River (RI0001003R-01A) segment will also remain impaired for Aquatic Life use (non-native aquatic plants).

Based upon extensive chemical monitoring in late 1990s and application of a dissolved oxygen water quality model (QUAL2E) to the Blackstone River, a waste load allocation was completed which concluded that (seasonal) advanced treatment at the three municipal WWTFs in Massachusetts (Upper Blackstone Water Pollution Abatement District (UBWPAD), Grafton, and Uxbridge) and one in municipal WWTF in Rhode Island (Woonsocket) would be required to enable the Blackstone River to attain the instantaneous dissolved oxygen standard of 5.0 mg/l (at 7Q10 flow). The model showed that the DO sag in Massachusetts was primarily driven by SOD and BOD and NH_3 decay. In Rhode Island, the DO sag was primarily driven by phosphorus, SOD and NH_3 decay. The final WLA alternative set BOD at all WWTFs at 10 mg/L and NH_3 at 2 mg/L. Total Phosphorus was set at various limits for the WWTFs. Draft permits were issued in 1999. Rhode Island delisted the Blackstone River for ammonia impairments in 2008[1].

The following figure shows the Blackstone River from Worcester, Massachusetts to Pawcatuck, Rhode Island with WWTFs labelled along with the Rhode Island segments.

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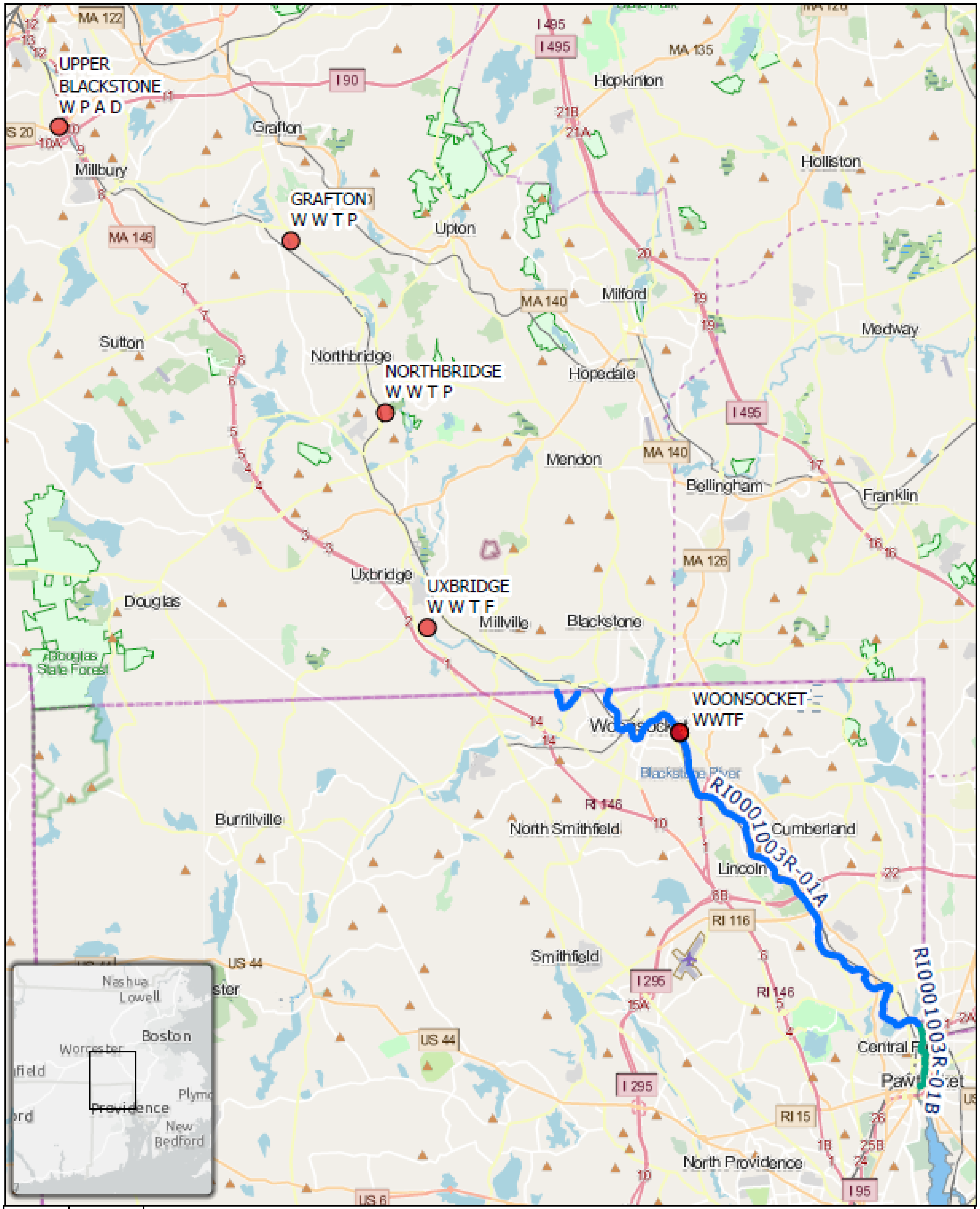
[1] RIDEM. 2008. State of Rhode Island and Providence Plantations 2008 Integrated Water Quality Monitoring and Assessment Report. Rhode Island Department of Environmental Management.



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Scale:	1:190,000	
Date:	5/27/2020	
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Blackstone River with WWTFs and Rhode Island Waterbody Segments Labelled

The calibrated and validated QUAL2E model used to establish a total phosphorus limit necessary to restore water quality in the River assumed the following conservative conditions: 7Q10 flow of the receiving water, discharge facilities running at design flow and permit limits, and pollutant loading from tributaries and nonpoint sources. Since the Northbridge WWTF discharges to a wetland on the Blackstone Canal with no observed phosphorus signal in the Blackstone River, the model analysis only included its flow and not a pollutant load[2].

Though the model and water quality data supporting model development are dated, there is no new information to suggest that the model is not accurate, nor that there are significant new sources of pollutants that would impact dissolved oxygen, and thus the waste load allocation is still considered valid.

In 2008, RIDEM reissued the RIPDES permit for the Woonsocket WWTF (RIPDES Permit No. RI0100111) and EPA reissued the NPDES permit for UBWPAD (NPDES Permit No. MA0102369), which required advanced treatment to reduce phosphorus (limit of 0.1 mg/L[3]). In 2013, EPA reissued NPDES permits for Grafton (NPDES Permit No. MA0101311), Northbridge (NPDES Permit No. MA0100722), and Uxbridge (NPDES Permit No. MA0102440). These smaller facilities were given phosphorus permit limits of 0.2 mg/L along with a quantity limit of 4 lbs/per day for Grafton, 4.2 lbs/day for Uxbridge, and 3.3 lbs/day for Northbridge. The permit for Uxbridge did not require the plant meet a phosphorus limit of 0.2 mg/L until the plant exceeded a flow of 1.25 MGD, at which time its quantity limit would remain 4.2 lbs/day. Woonsocket met their lower phosphorus permit limit beginning with the 2017 summer season, with UBWPAD significantly reducing their phosphorus load beginning with the 2015 summer season. The following table contains the last five years of phosphorus concentration and load data collected at the WWTFs between May and October.

Blackstone River WWTF Seasonal (May-October) Total Phosphorus Concentrations and Loads*

	2014		2015		2016		2017		2018		2019	
	mg/L	**lb/day**	**mg/L**	**lb/day**	**mg/L**	**lb/day**	**mg/L**	**lb/day**	**mg/L**	**lb/day**	**mg/L**	**lb/day**
Grafton	0.97	11.75	0.93	11.29	0.90	10.18	0.87	11.49	0.18	2.51	0.18	2.3
UBWPAD	0.43	92.40	0.18	42.09	0.21	38.30	0.18	38.19	0.21	50.83	0.19	42.6
Uxbridge	0.37	2.45	0.25	1.63	0.26	1.64	0.18	1.43	0.27	1.52	0.21	1.1
Northbridge	0.13	0.89	0.12	0.76	0.10	0.77	0.13	0.96	0.15	1.12	0.16	1.3
Woonsocket	0.35	12.35	1.67	61.98	0.48	17.00	0.07	3.72	0.09	4.42	0.1	5.1
SUM	**NA**	**119.8**	**NA**	**117.8**	**NA**	**67.9**	**NA**	**55.8**	**NA**	**57.9**	**NA**	**52.4**

*The concentration numbers shown are not calculated the same as calculations for permit compliance.

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[2] Wright, Dr. Raymond. 1997. Blackstone River Watershed Dissolved Oxygen Wasteload Allocation for Massachusetts and Rhode Island: Coordinated Effort of the USEPA, MADEP, and RIDEM. University of Rhode Island.

[3] The 0.1 mg/l total phosphorus seasonal limit is a 60-day rolling average for UBWPAD.

The RIDEM water quality regulations contain a narrative nutrient criterion[4] that specifies nutrient levels should not impair any use. There are many tools that can be used to assess compliance with a narrative nutrient criterion. In the case of the Blackstone River, RIDEM opted to primarily use compliance with the oxygen criteria because, as mentioned above, past modeling demonstrated that elevated phosphorus was causing dissolved oxygen impairments. RIDEM will discuss oxygen criteria compliance in the next section.

USGS collects monthly nutrient samples from one location in the Rhode Island section Blackstone River. Station 1113895 is located at Roosevelt Street in Pawtucket. Total phosphorus concentrations are shown in the table below with 2007 used as a baseline year prior to latest phosphorus permit reductions. The data in the table below show that total phosphorus concentrations have dropped significantly since 2007. While RIDEM does not have a numeric phosphorus criterion, the 1986 EPA Quality Criteria for Water recommends that a "desired goal for the prevention of plant nuisances in streams or other flowing waters not discharging directly to lakes or impoundments is 100 ug/L total P (Mackenthun, 1973). All annual averages since 2016 have been below this threshold. The station location is shown in the following figure.

USGS Blackstone River at Roosevelt Average Total Phosphorus Concentrations (µg/L) [*]

	2007	2014	2015	2016	2017	2018	2019
Annual	251.2	64.9	91.2	76.4	65.6	57.3	53.0
May-Oct	187.2	68.3	103.5	73.2	78.7	72.3	58.0
Jan-Apr and Nov-Dec	315.2	61.5	78.8	79.7	52.5	42.2	48.0

[*] The period of record for water quality data begins 2-13-2007 No 2006 data is available for this station.

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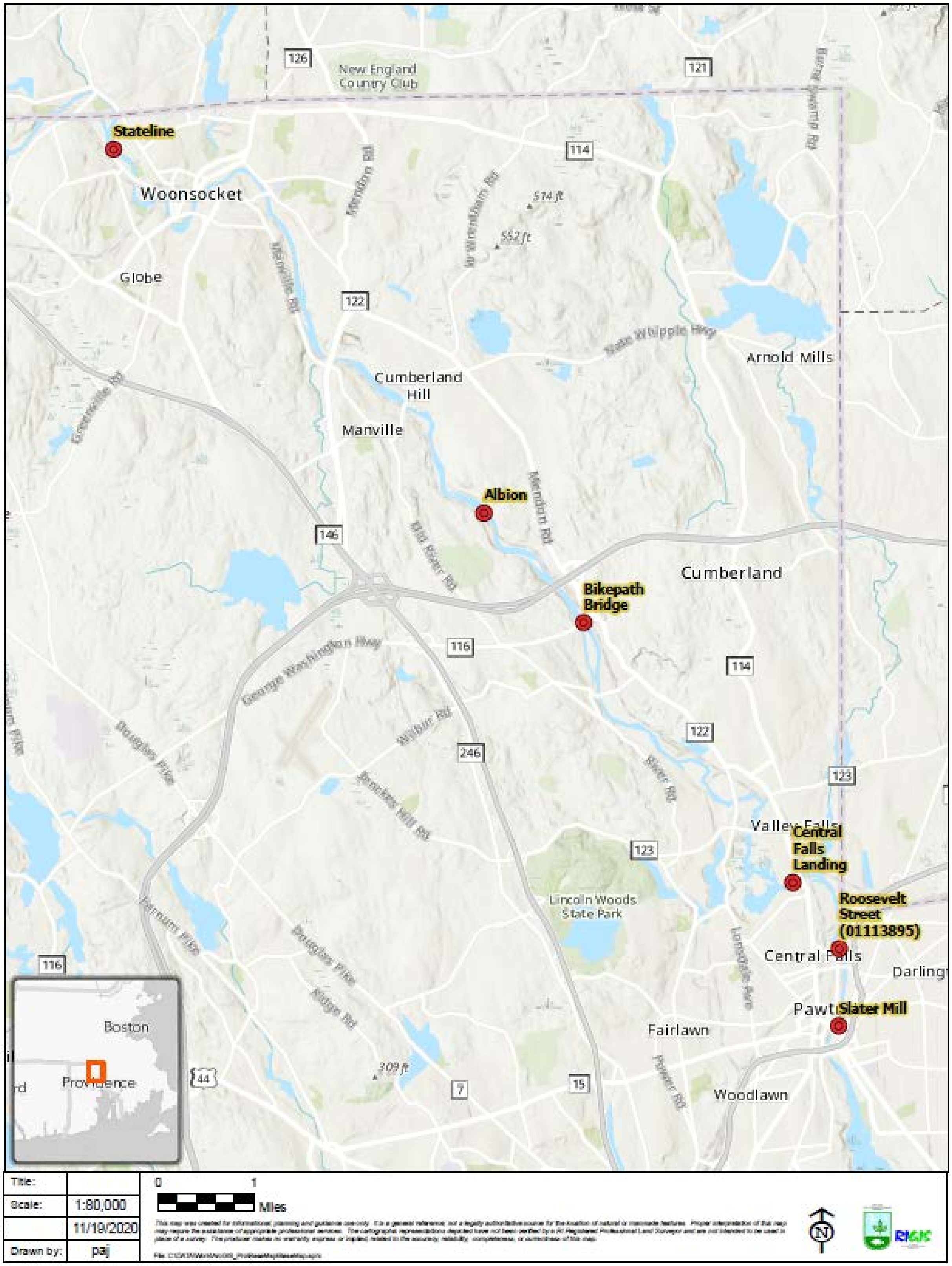
[4] None in such concentration that would impair any usages specifically assigned to said Class, or cause undesirable or nuisance aquatic species associated with cultural eutrophication, nor cause exceedance of the criterion above in a downstream lake, pond, or reservoir. New discharges of wastes containing phosphates will not be permitted into or immediately upstream of lakes or ponds. Phosphates shall be removed from existing discharges to the extent that such removal is or may become technically and reasonably feasible.



Blackstone River Monitoring Stations

Since the mid-2000s, the Narragansett Bay Commission (NBC) has sampled the Blackstone River at multiple locations throughout the year. NBC analyzes samples for ortho-phosphorus[5], not total phosphorus. RIDEM is presenting this data to show that the trend of decreasing phosphorus in the Blackstone River extends throughout the Rhode Island reach of the Blackstone River. The following tables compares seasonal average (May through October) ortho-phosphorus average concentrations in 2006 to the last five years. 2006 is shown as a baseline year prior to the latest phosphorus permit reductions. The data for 2007 is also shown, due to the period of record at the USGS Roosevelt Street station beginning in 2007 presented below. The station locations are shown in the previous figure.

Blackstone River Seasonal Average (May-October) Ortho-Phosphorus Concentrations (µg/L) [1]

	2006	2007	2014	2015	2016	2017	2018	2019
Stateline	68.7	207.2	19.7	25.6	26.0	20.0	19.9	14.4
Bike Path (Route 116)	72.0	295.9	25.1	53.6	33.3	19.6	13.2	13.5
Roosevelt Street	NA	105	27.3	42.8	33.8	27.5	21.1	19
Slater Mill	57.4	116.3	20.7	33.6	26.9	17.5	13.2	12.4

[1] Data collected at the Stateline, Bike Path (Route 116), and Slater Mill were collected by the Narragansett Bay commission. Data collected at Roosevelt Street were collected by the United States Geological Survey.
NA – Data was not available for download.

USGS also measures instantaneous dissolved oxygen during its monthly sampling. The minimum dissolved readings are shown in the tables below. While the instantaneous criteria is the most appropriate comparison, all readings are above the Rhode Island instantaneous, daily average, and 7-day mean warm water criteria[6]. Values above the water quality criteria are required for aquatic life. As expected, lower dissolved oxygen readings (mg/L) are seen in the warmer months.

USGS Blackstone River at Roosevelt Street Minimum Dissolved Oxygen (mg/L)

	2007	2014	2015	2016	2017	2018	2019
Annual	7.2	8.2	7	7.9	7.9	8	7.4
May-Oct	7.2	8.2	7	7.9	7.9	8	7.4
Jan-Apr and Nov-Dec	10.2	10.5	10.5	10.6	9.7	10.7	9.2

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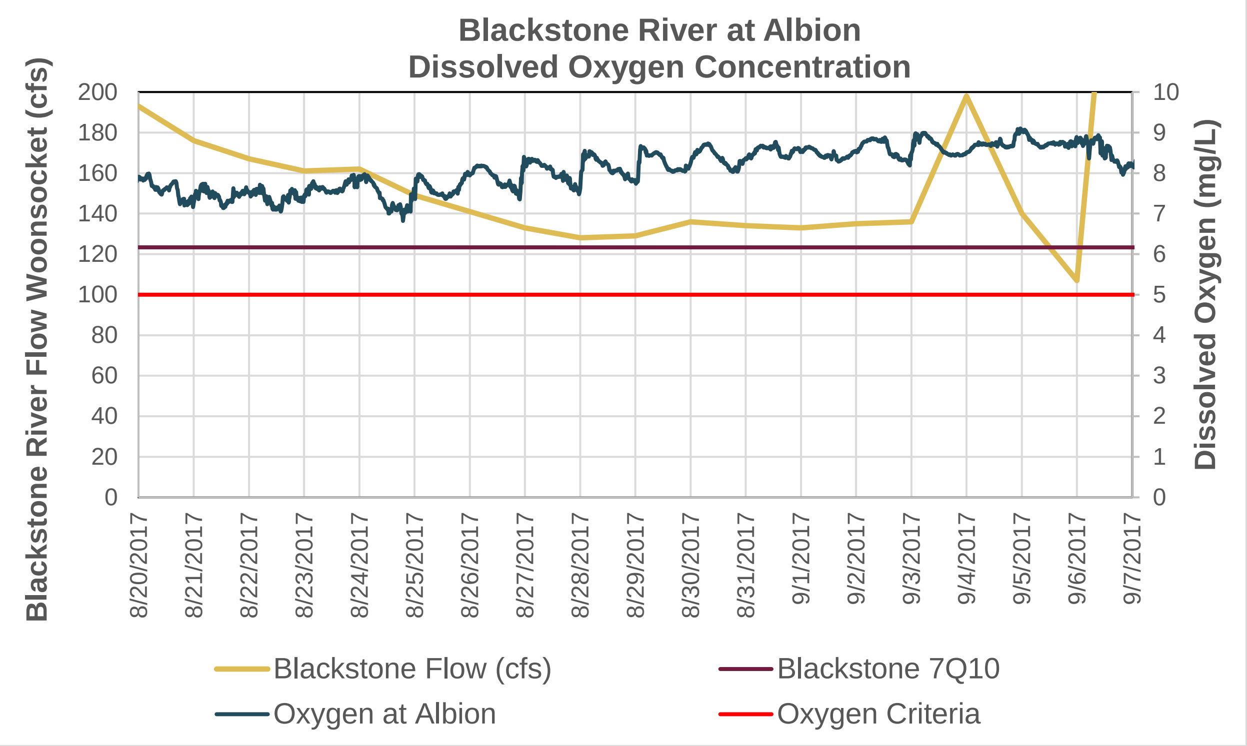
[5] http://snapshot.narrabay.com/app/WaterQualityInitiatives/NutrientMonitoring

[6] Warm Water Fish Habitat - Dissolved oxygen content of not less than 60% saturation, based on a daily average, and an instantaneous minimum dissolved oxygen concentration of at least 5.0 mg/l, except as naturally occurs. The 7-day mean water column dissolved oxygen concentration shall not be less than 6 mg/l.

USGS Blackstone River at Roosevelt Street Minimum Dissolved Oxygen (% Saturation)

	2007	2014	2015	2016	2017	2018	2019
Annual	80	88	86	90	91	95	92
May-Oct	84	88	86	90	91	95	93
Jan-Apr and Nov-Dec	80	96	97	93	92	96	92

In 2017, continuous dissolved oxygen measurements were taken just upstream of the dams at Albion and Central Falls Landing in the Blackstone River. Each location was at a model-predicted “sag point” in the river. The sondes were deployed between 06/29/17 and 09/07/17. Beginning in late August, average daily flow stayed within 10 cfs of 7Q10 flow for one week before dropping below 7Q10 flow for one day on 09/06/17. As shown in the graphs[7] below, the Blackstone River is achieving compliance with the dissolved oxygen criteria. Given that the river has demonstrated compliance at these predicted lowest dissolved oxygen locations during low flow conditions, based upon the QUAL2E modeling results, it is expected that the entire Blackstone River (RI0001003R-01A and RI0001003R-01B) in Rhode Island complies with its phosphorus and dissolved oxygen criteria.



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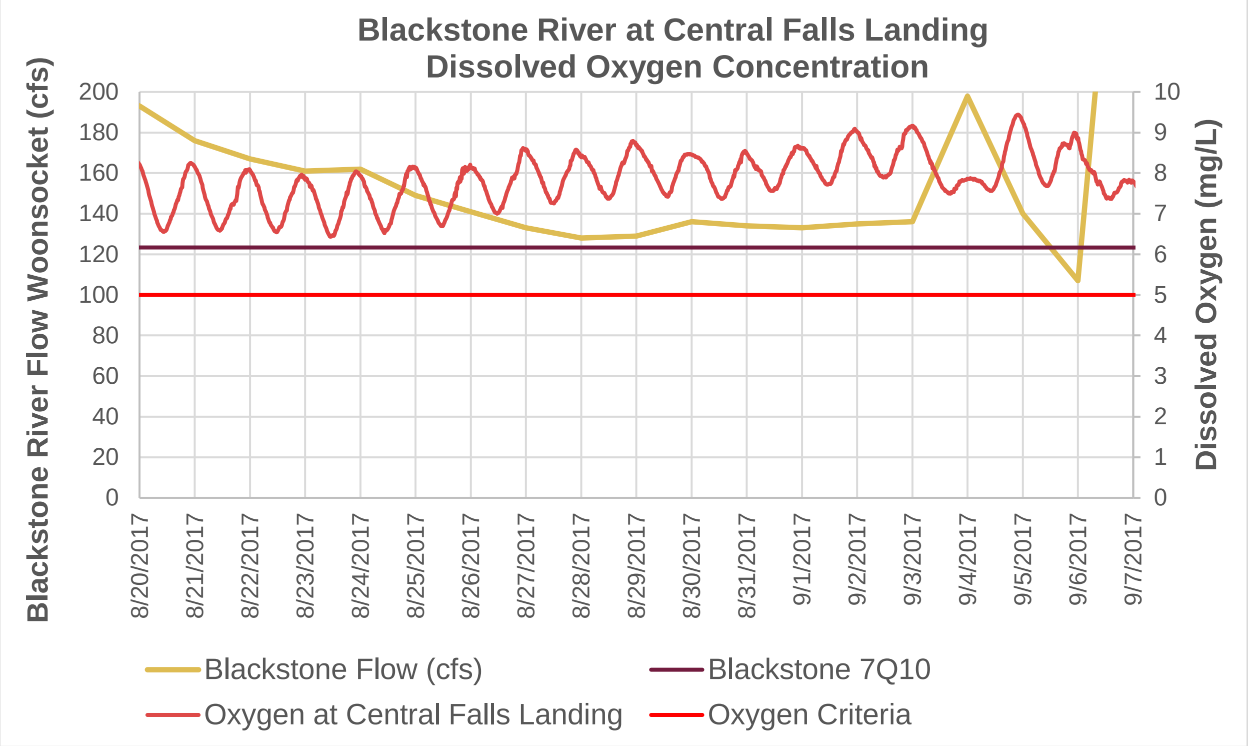
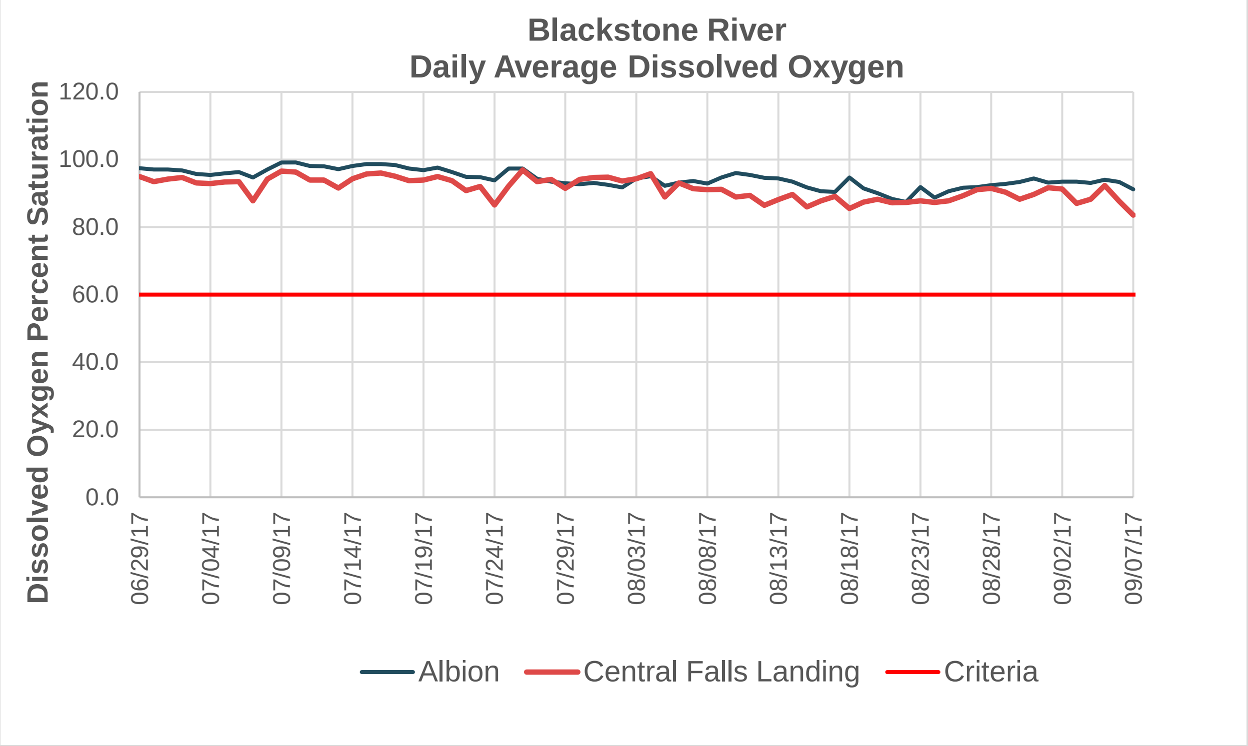
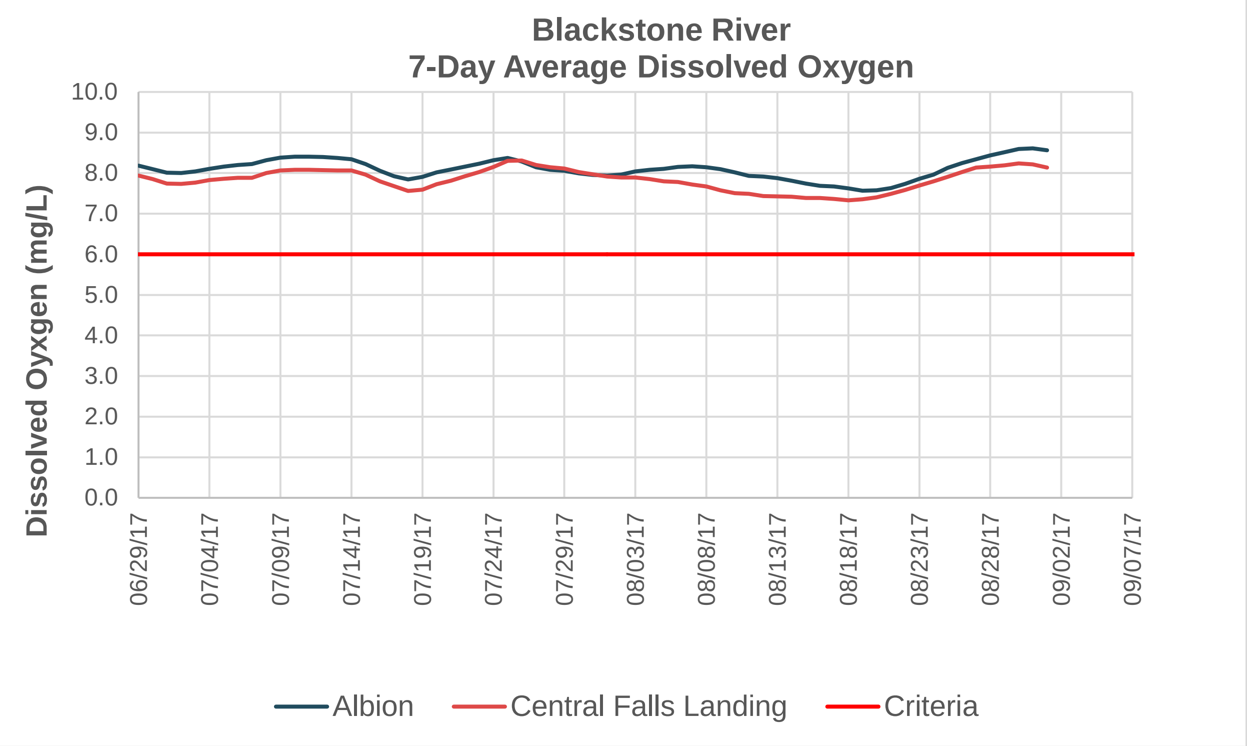
[7] “Raw” data, including the complete deployment record are available upon request.


Blackstone River at Central Falls Landing
Dissolved Oxygen Concentration
Blackstone River Flow Woonsocket (cfs)
Dissolved Oxygen (mg/L)
200
180
160
140
120
100
80
60
40
20
0
10
9
8
7
6
5
4
3
2
1
0
8/20/2017
8/21/2017
8/22/2017
8/23/2017
8/24/2017
8/25/2017
8/26/2017
8/27/2017
8/28/2017
8/29/2017
8/30/2017
8/31/2017
9/1/2017
9/2/2017
9/3/2017
9/4/2017
9/5/2017
9/6/2017
9/7/2017
Blackstone Flow (cfs)
Blackstone 7Q10
Oxygen at Central Falls Landing
Oxygen Criteria


Blackstone River
Daily Average Dissolved Oxygen
Dissolved Oyxgen Percent Saturation
120.0
100.0
80.0
60.0
40.0
20.0
0.0
06/29/17
07/04/17
07/09/17
07/14/17
07/19/17
07/24/17
07/29/17
08/03/17
08/08/17
08/13/17
08/18/17
08/23/17
08/28/17
09/02/17
09/07/17
Albion
Central Falls Landing
Criteria


Blackstone River
7-Day Average Dissolved Oxygen
Dissolved Oyxgen (mg/L)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
06/29/17
07/04/17
07/09/17
07/14/17
07/19/17
07/24/17
07/29/17
08/03/17
08/08/17
08/13/17
08/18/17
08/23/17
08/28/17
09/02/17
09/07/17
Albion
Central Falls Landing
Criteria

UPPER NARRAGANSETT BAY (RI0007024E-01) *

- *New Segment RI0007024E-01B Upper Narragansett Bay from a line from Rocky Point jetty in Warwick to the southwest (landward) corner of Colt State Park pier south to a line from Warwick Point through Providence Point on Prudence Island, to Popasquash Point in Bristol. Warwick, Bristol, Portsmouth

- RI0007024E-01 Upper Narragansett Bay from Conimicut Point-Nayatt Point boundary south, including waters south of a line from Adams Point, Barrington to Jacobs Point, Warren, to a line from Warwick Point in Warwick through Providence Point on Prudence Island, to Poppasquash Point in Bristol. Warwick, Barrington, Bristol, Portsmouth, Warren

FECAL COLIFORM

This segment of the Upper Narragansett Bay is listed on RI's 2016 303(d) List of Impaired Waters as not supporting shellfishing designated use due to fecal coliform. This impairment was first listed in RI's 1992 303(d) List. This delisting will only delist the southern portion of the Upper Narragansett Bay (RI0007024E-01) waterbody, resulting in two new segments. The new description for the southern portion of Upper Narragansett Bay (RI0007024E-01B) represents the area to be removed from RI's 2018-2020 303(d) List of Impaired Waters. The new A segment Upper Narragansett Bay (RI0007024E-01A) will remain impaired for Shellfish Consumption on the 2018-2020 303(d) List of Impaired Waters with fecal coliform as the cause.

This delisting is a result of the completion of Phase II of the Narragansett Bay Commission's (NBC) combined sewer overflow (CSO) project. The second component of the improvements to the Fields Point wastewater treatment system, referred to here as Phase II, is the capturing of combined sewage and stormwater that previously overflowed into tributaries of the Providence River being captured and directed to the tunnel constructed in Phase I and then subsequently pumped to the Fields Point facility for processing. This has eliminated a significant volume of combined sewage and stormwater that previously discharged to the upstream rivers and entered the Upper Bay via the Providence River. Due to the completion of this portion of the CSO project, an improvement in water quality throughout the lower Providence River and Upper Bay has allowed for reclassification of these shellfishing waters. The area previously identified as Conditional Area B by the RIDEM Shellfishing Program changed to approved status in May 2017[8]. This former Conditional Area B is the area to be delisted in the newly created B segment (RI0007024E-01B) described above and shown below.

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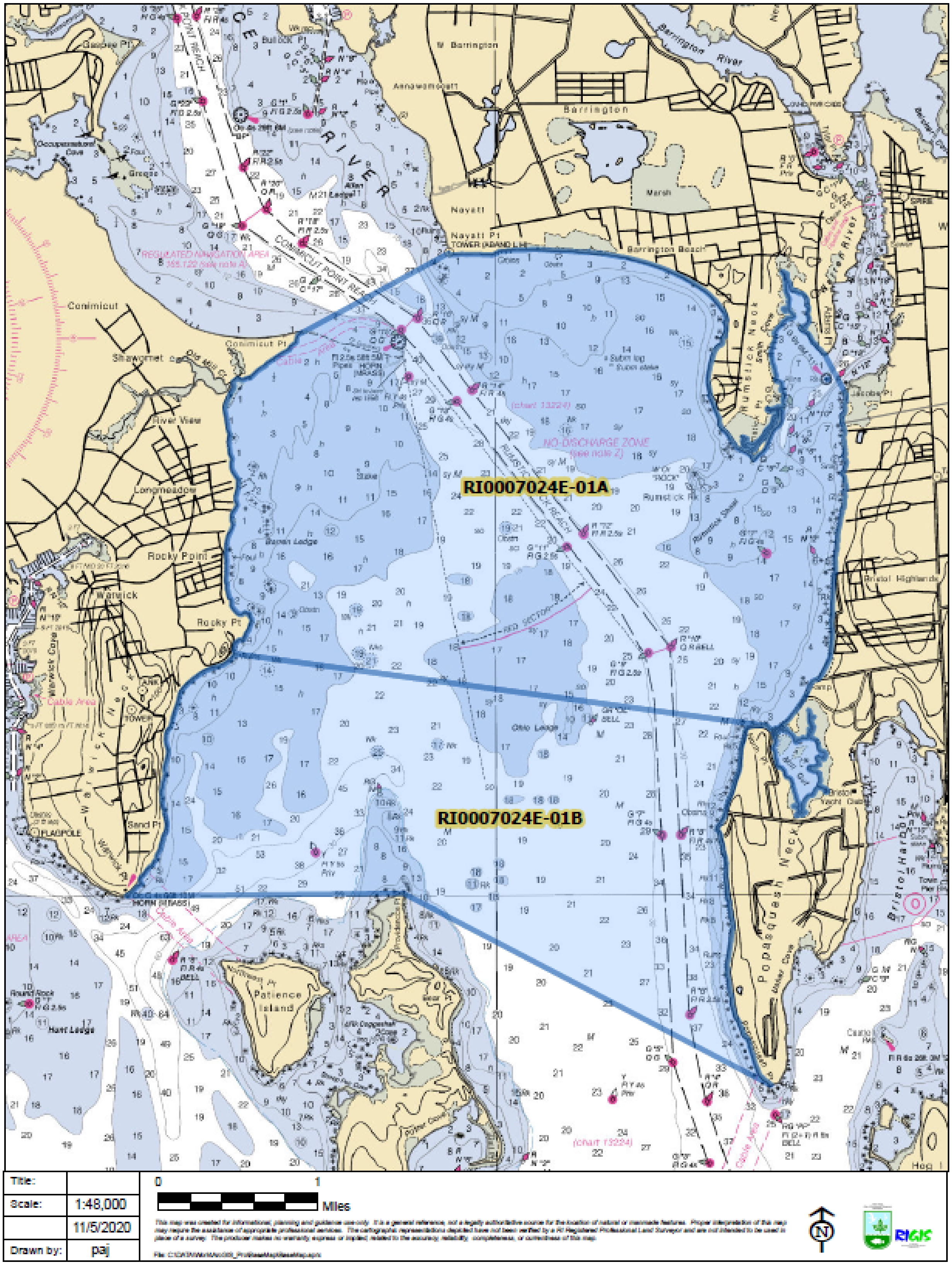
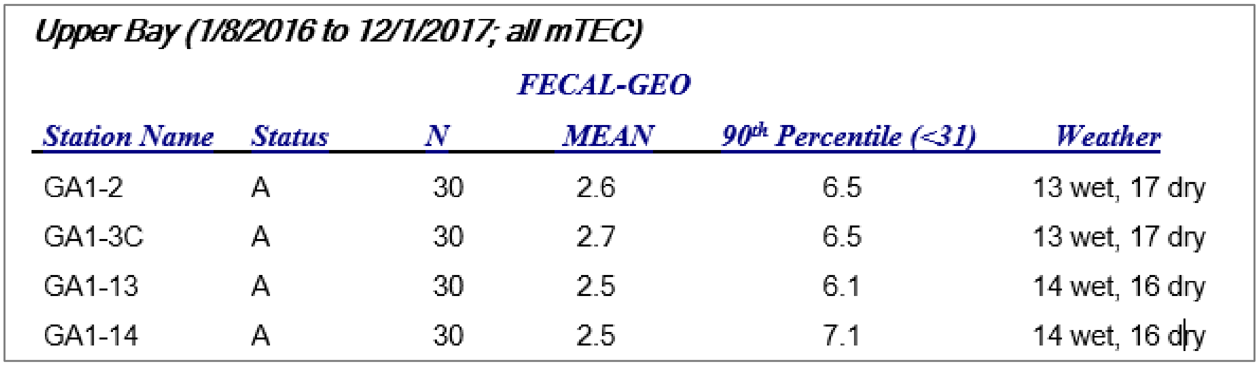
[8] RIDEM. 2016. *2016 Shellfish Program Classification Report*. Rhode Island Department of Environmental Management.



Upper Narragansett Bay with New Waterbody Segments Labeled.

As described in the Consolidated Assessment and Listing Methodology (CALM), Shellfish Consumption Use assessments are determined by the Shellfish Growing Area Classification (Approved, Seasonal Closure, Conditional Closure, Prohibited) and are assigned in accordance with the State's Shellfish Growing Area Monitoring Program approved by the federal Food and Drug Administration's (FDA) National Shellfish Sanitation Program (NSSP) and supporting data. This waterbody segment is operated in Approved Status, meaning there is no impairment to the shellfish harvesting use. A waterbody fully supports shellfishing use when there is no water quality related shellfishing restrictions in effect (i.e. Approved Status)[9]. This shellfish growing water continues to be monitored for fecal coliform levels to ensure that they meet the approved criteria and are protective of public health. The new segment RI0007024E-01B has met its Approved Status since its reclassification in 2017.

2017 Fecal Coliform Statistics from RIDEM Shellfish Growing Area 1[10]



Upper Bay (1/8/2016 to 12/1/2017; all mTEC)

			FECAL-GEO		
Station Name	**Status**	**N**	**MEAN**	**90th Percentile (<31)**	**Weather**
GA1-2	A	30	2.6	6.5	13 wet, 17 dry
GA1-3C	A	30	2.7	6.5	13 wet, 17 dry
GA1-13	A	30	2.5	6.1	14 wet, 16 dry
GA1-14	A	30	2.5	7.1	14 wet, 16 dry

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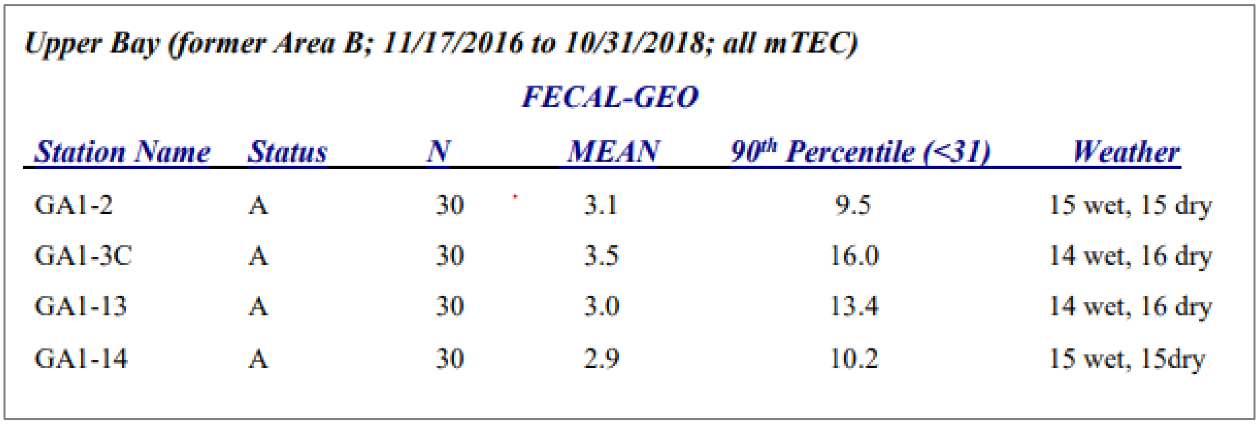
[9] In SA and SA{b} areas, if the actual water quality data attains the applicable fecal coliform criteria (geometric mean value of 14 colony forming units (cfu) per 100 mL and not more than either 10% or not more than the estimated 90th percentile of the samples shall exceed an MPN value of 31 cfu per100 mL for mTEC, the shellfishing use is considered Fully Supporting for assessment purposes.

[10] RIDEM. 2018. *2017 Shellfish Program Classification Report*. Rhode Island Department of Environmental Management.

2018 Fecal Coliform Statistics from RIDEM Shellfish Growing Area 1[11]

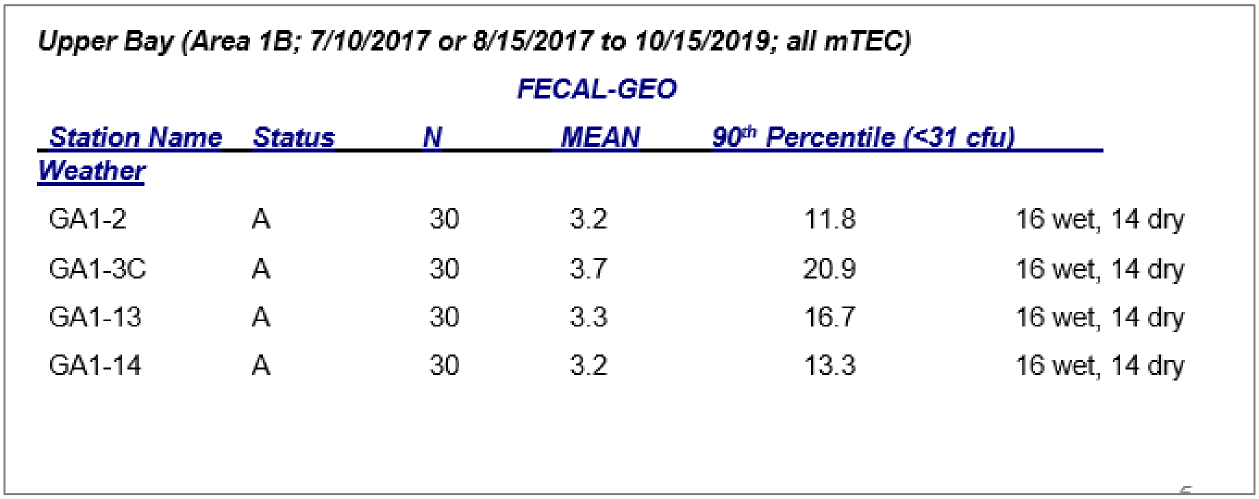


Upper Bay (former Area B; 11/17/2016 to 10/31/2018; all mTEC)

FECAL-GEO

Station Name	Status	N	MEAN	90th Percentile (<31)	Weather
GA1-2	A	30	3.1	9.5	15 wet, 15 dry
GA1-3C	A	30	3.5	16.0	14 wet, 16 dry
GA1-13	A	30	3.0	13.4	14 wet, 16 dry
GA1-14	A	30	2.9	10.2	15 wet, 15dry

2019 Fecal Coliform Statistics from RIDEM Shellfish Growing Area 1[12]



Upper Bay (Area 1B; 7/10/2017 or 8/15/2017 to 10/15/2019; all mTEC)

FECAL-GEO

Station Name	Status	N	MEAN	90th Percentile (<31 cfu)	Weather
GA1-2	A	30	3.2	11.8	16 wet, 14 dry
GA1-3C	A	30	3.7	20.9	16 wet, 14 dry
GA1-13	A	30	3.3	16.7	16 wet, 14 dry
GA1-14	A	30	3.2	13.3	16 wet, 14 dry

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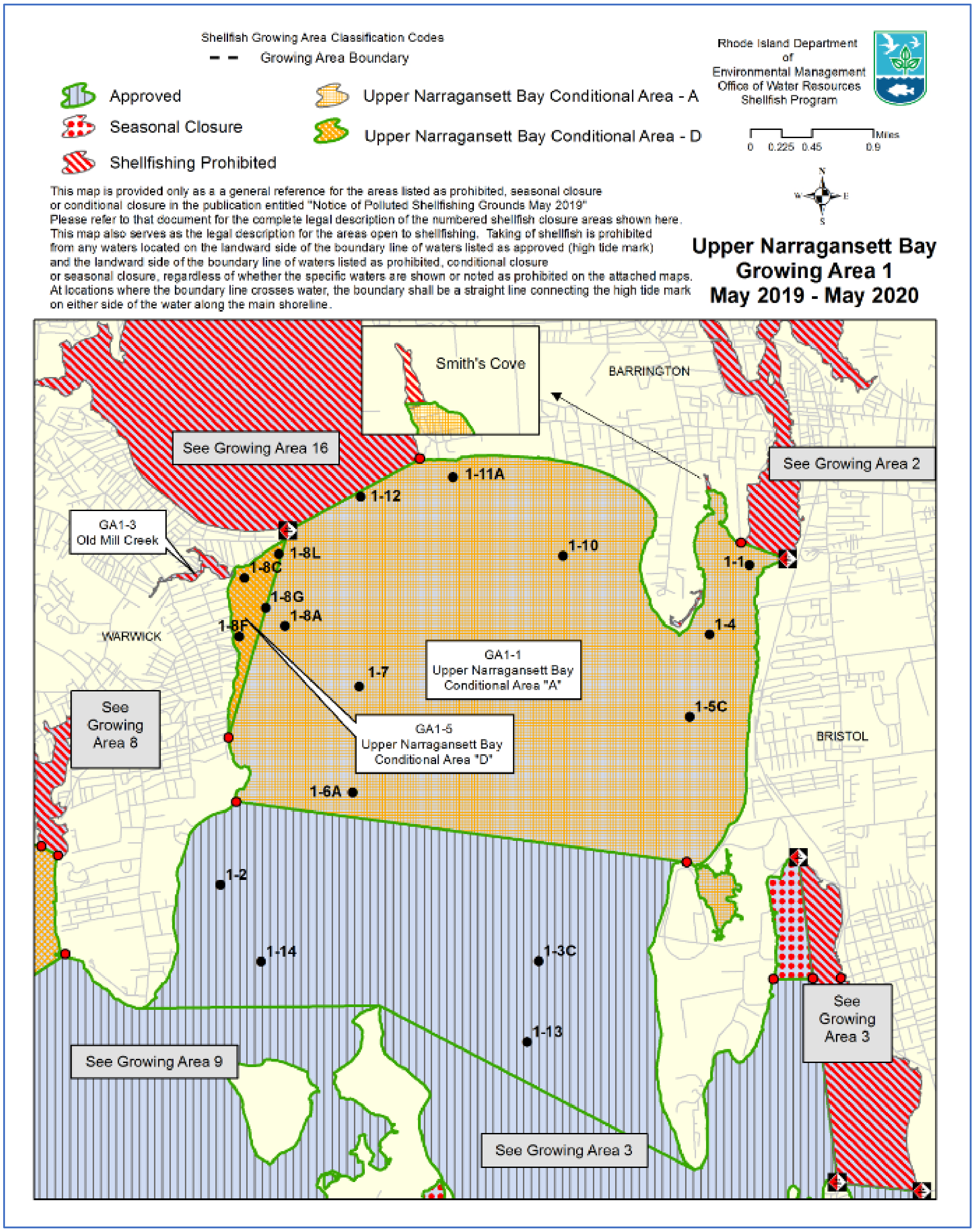
[11] RIDEM. 2019. *2018 Shellfish Program Classification Report*. Rhode Island Department of Environmental Management.

[12] RIDEM. 2020. *2019 Shellfish Program Classification Report*. Rhode Island Department of Environmental Management.



This map is provided only as a a general reference for the areas listed as prohibited, seasonal closure or conditional closure in the publication entitled "Notice of Polluted Shellfishing Grounds May 2019" Please refer to that document for the complete legal description of the numbered shellfish closure areas shown here. This map also serves as the legal description for the areas open to shellfishing. Taking of shellfish is prohibited from any waters located on the landward side of the boundary line of waters listed as approved (high tide mark) and the landward side of the boundary line of waters listed as prohibited, conditional closure or seasonal closure, regardless of whether the specific waters are shown or noted as prohibited on the attached maps. At locations where the boundary line crosses water, the boundary shall be a straight line connecting the high tide mark on either side of the water along the main shoreline.

Shellfish Growing Area Map Showing Former Conditional Area B as an Approved Shellfish Harvesting Water with Monitoring Station Labeled.

MT. HOPE BAY (RI0007032E-01A, RI0007032E-01B, RI0007032E-01C, RI0007032E-01D)

- RI0007032E-01A Mt. Hope Bay south and west of the MA/RI border, and east of a line from Touisset Point to the channel marker buoy R “4” and south and east of a line from buoy R “4” to the southernmost landward end of Bristol Point and south of a line from Bristol Point to the Hog Island shoal light, to the southwestern extremity of Arnold Point in Portsmouth where a RIDEM range marker has been established; and west of a line from the end of Gardiner’s Neck Road, Swansea to buoy N”2”, through buoy R4 to Common Fence Point, Portsmouth excluding the waters defined in RI0007032E-01E. Warren, Portsmouth*
** Note: See:* https://rules.sos.ri.gov/regulations/part/250-150-05-1 *for RI0007032E-01E description.*

- RI0007032E-01B Mt. Hope Bay waters north and west of a line from the southernmost landward end of Bristol Point to buoy R “4” and west of a line from buoy R “4” to the DEM range marker on Touisset Point, and south of the Bristol Narrows. Bristol, Warren

- RI0007032E-01C Mt. Hope Bay waters south of a line from Borden’s Wharf, Tiverton, to buoy R “4” and west of a line from buoy R “4” to Brayton Point, Somerset, MA., and east of a line from the end of Gardiner’s Neck Road in Swansea to buoy N “2”, through buoy R4 to Common Fence Point, Portsmouth, and north of a line from Portsmouth to Tiverton at the railroad bridge at “The Hummocks” on the northeast point of Portsmouth. Portsmouth

- RI0007032E-01D Mt. Hope Bay waters south and west of the MA-RI border and north of a line from Borden’s Wharf, Tiverton to buoy R “4” and east of a line from buoy R “4” to Brayton Point in Somerset, MA. Bristol, Portsmouth and Tiverton.

FISH BIOASSESSMENTS

Introduction

The four assessment units in the Rhode Island portion of Mt. Hope Bay (RI0007032E-01A, RI0007032E01B, RI0007032E-01C, RI0007032E-01D) were originally listed as impaired for aquatic life use with fish bioassessments as a cause in 1996. The source of this impairment was found to be Brayton Point Station’s thermal discharge. Brayton Point Station, at one point was the largest fossil fuel burning power plant in New England, was located on the shores of Mt. Hope Bay in Somerset, Massachusetts. In 2007, EPA and owner Dominion Energy agreed to end all litigation and fully implement EPA’s Brayton Point NPDES Permit (No. MA 0003654) requiring both the reduction of the annual heat discharge to the bay by 96% and water withdrawal from the bay by approximately 94%. Therefore, the cause of fish bioassessment was reclassified from Category 5 (303d list) to Category 4B (other pollution control requirements are expected to result in attainment of the water quality standard associated with the impairment) in 2008. These segments were also listed for water temperature impairment cause in 2000 due to the Brayton Point Power Station’s thermal inputs, and water temperature was reclassified as Category 4B in 2008 for the same permit. Water temperature was delisted as an aquatic life

impairment cause in the 2016 Integrated Reporting cycle:
http://dem.ri.gov/programs/benviron/water/quality/surfwq/pdfs/iwlr16.pdf

Prior analyses had indicated that Mt. Hope Bay water surface temperature was elevated by approximately 0.8 °C due to the Brayton Point plant thermal discharge; although this fluctuates seasonally with the greatest temperature elevation during late summer and autumn (Sen, 1996; Carney, 1997; Mustard et al., 1999). The installation of closed cycle cooling in 2012 was expected to reduce the water temperature impairment in Mt. Hope Bay. Now with Brayton Point Station permanently shut down as of June 2017, thermal discharges to Mt. Hope Bay have stopped. The fisheries data analysis conducted by the Rhode Island Department of Environmental Management's Division of Marine Fisheries (RIDEM/DMF) summarized below and presented in full in Addendum A examines available Mt. Hope Bay finfish community data to evaluate abundance and species composition prior to and after construction of the cooling towers and species composition comparison to Narragansett Bay finfish community data.
The data and analysis presented document that the Rhode Island waters of Mt. Hope Bay comply with RI's Water Quality Standards (250-RICR-150-05-1.10(B)(1)) after the removal of the anthropogenic stressor causing the artificial increased water temperature leading to reductions in finfish. However, these segments will continue to be listed as impaired for aquatic life use with causes of total nitrogen and dissolved oxygen and impaired for shellfishing use (Segments A and B) and primary and secondary contact use (Segments C and D) with fecal coliform as the cause.

Statistical Analysis Summary
The results presented in the 2020 RIDEM/DMF report confirm the analysis completed by Gibson in 1995, which was the basis of the original fish bioassessment impairment on the 1996 303(d) List, showing that the finfish community was impaired by the thermal output of the Brayton Point Power Station. In Gibson (1995), finfish in Mt. Hope Bay declined significantly with increase in cooling water flow and deviated from regional trends locally in Narragansett Bay and throughout southern New England. The 2020 RIDEM/DMF report shows fish abundance in Mt. Hope Bay as highly influenced by the thermal output of Brayton Point Power Station during both times of high and low inputs, and since removal of the cooling water through cooling towers and complete shutdown of the Brayton Point, finfish abundance has increased to the highest levels in the time period analyzed and species composition is aligning with the current Narragansett Bay finfish community.

The 2020 RIDEM/DMF report notes that previous work on Narragansett Bay has documented a late 20th century shift from demersal to warm-water species (Collie et al. 2008). The evaluation of the Mt. Hope Bay fish community should take the shift in the greater Narragansett Bay fish community into consideration for analysis of recovery in Mt. Hope Bay. While the timing of these shifts in the finfish community were disconnected between the two systems, as evidenced by the rapid decrease of colder water species (winter flounder and cunner) in Mt. Hope Bay related to Brayton Point Power Station thermal inputs and the delayed increase in abundance of warm-water species (scup and black sea bass) in Mt. Hope Bay during its recovery following decreases and cessation of Brayton Point Power Station thermal inputs, the overall shifts in finfish communities show that Mt. Hope Bay is returning to a state consistent with current finfish community in the greater Narragansett Bay.

WOOD RIVER & TRIBS (RI0008040R-16D)

- RI0008040R-16D Wood River and tributaries from the Alton Pond dam to the confluence with the Pawcatuck River. Richmond, Hopkinton, Charlestown

DISSOLVED COPPER

This segment of the Wood River is listed on RI's 2016 303(d) List of Impaired Waters as not supporting aquatic life designated use due to dissolved copper. This impairment was first listed in RI's 2010 303(d) List based on dry weather data collected 2004-2006. Freshwater aquatic life criteria for certain metals are expressed as a function of hardness, because hardness can affect the toxicity of these metals. Increasing hardness has the effect of decreasing the toxicity of metals. Ambient hardness values reported in mg/l as CaCO3 are used to determine applicable acute and chronic metals criteria following US EPA recommended equations provided in § 1.26 of RIDEM's Water Quality Regulations (RIDEM 2018).

One exceedance of acute criteria and two exceedances of chronic criteria (two stations on the same date) were identified using criteria derived from average hardness concentrations. Rhode Island now uses hardness at the time of sample to calculate acute and chronic criteria for each sampling event. Based on the recalculation of the criteria one of the chronic exceedance should not have been identified as violations of criteria. RIDEM revisited the segment in 2011 and 2018 as part of the dry weather ambient river monitoring program. No exceedances of acute or chronic criteria were documented. All samples met acute and chronic criteria using the hardness-based criteria. The dry weather data, presented below, indicate that the water quality of this segment is meeting the State of Rhode Island's water quality criteria for dissolved copper and will not be included on the 2018-2020 303(d) list as impaired for dissolved copper. No causes will be added, and water chemistry collected in 2011, 2015, and 2018 by the ARM program shows this segment to be fully supporting aquatic life use. These results show dissolved oxygen, pH, temperature, turbidity, and chloride are all meeting water quality criteria supportive of the aquatic life use designation. This segment will be considered Fully Supporting aquatic life use.

Wood River & Tribs (RI0008040R-16D) Dissolved Copper

Sample Date	Detection Limit (µg/L)	Quantitation Limit (µg/L)	Concentration (µg/L)	Hardness[1] (mg/L)	Copper Criteria (µg/L)	
					Acute	Chronic
5/12/2011	0.13	0.13	0.515	11.23	1.7	1.4
9/12/2011	0.13	0.13	0.73	10.6	1.6	1.3
10/3/2011	0.13	0.13	0.661	11.4	1.7	1.4
6/26/2018	0.13	1.0	0.287	16.1	2.4	1.9
7/10/2018	0.13	1.0	0.347	16.0	2.4	1.9
7/30/2018	0.13	1.0	0.227	12.4	1.9	1.5
8/29/2018	0.13	1.0	0.409	15.1	2.3	1.8
9/20/2018	0.13	1.0	0.523	14.5	2.2	1.7

ATTACHMENT: EXAMINING THE EFFECTS OF THE BRAYTON POINT POWER STATION ON MT. HOPE BAY'S FINFISH COMMUNITY

Examining the effects of the Brayton Point Power Station on Mt. Hope Bay's finfish community

Rhode Island Department of Environmental Management Division of Marine Fisheries

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Summary

Open-cycle cooling at the Brayton Point Power Station was implicated in the rapid decline of the Mt. Hope Bay finfish community in the mid-1980s. As a result, the Brayton Point NPDES Permit required a 94% decrease in water withdrawal at the plant, which was achieved via the construction of cooling towers in 2011 and 2012. The Mt. Hope Bay finfish community's response to Brayton Point Power Station's various phases of water uptake was examined, with focus on finfish abundance and species composition since the cooling towers were commissioned.

Cooling water was that which was drawn in from nearby water bodies, used to cool the generating units at Brayton Point, and was then discharged—at a temperature about 7 to 10 °C above ambient—back into Mt. Hope Bay. Thus, high levels of cooling water flow were associated with high levels of heat output from the plant into the bay. Finfish abundance in Mt. Hope Bay was negatively correlated with Brayton Point Power Plant cooling water flow throughout the period of 1979 to 2014, suggesting that there were direct effects of heated water effluent on the finfish community. Additionally, the species composition of Mt. Hope Bay experienced abrupt changes around years when the level of cooling water flow at Brayton Point changed significantly.

Since the cooling towers went online in 2011, aggregate fish abundance has experienced time series high levels in Mt. Hope Bay, suggesting that the implementation of closed-cycle cooling enabled an increase in finfish presence close to the plant. Recent high-abundance years can be attributed in part to warm-water species which were rare in Mt. Hope Bay before the high coolant flow years began. This change in dominant species appears to be reflective of larger Narragansett Bay-wide environmentally driven species composition shifts and may indicate that the Mt. Hope Bay finfish community is becoming more closely aligned with that of the larger Narragansett Bay system.

Data Sources:

1. Mt. Hope Bay trawl surveys

Normandeau Associates, Inc.[1] - previously known as Marine Research, Inc. (MRI) - ran two trawl surveys adjacent to Brayton Point Power Station in Mt. Hope Bay to assess finfish

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[1] Normandeau and MRI are used interchangeably in this document.

population responses to the plant. The standard trawl survey data set served as the primary data source for the analyses presented herein. Given the Wilcox trawl survey only spanned approximately 20 years, this data set served as a ground-truthing data source for qualitative comparisons with the standard trawl.

The **standard trawl survey** ran from 1972 to 2014. Eight fixed stations in upper Mt. Hope Bay (Figure 1) were sampled through 1985, when two stations were discontinued; the remaining six stations were sampled monthly throughout the time series. In 1997, four additional stratified-random (by depth) stations were added to the sampling program (Figure 2). The standard trawl survey employed an otter trawl with 1.5-inch stretched mesh in the cod end, conducting 15 minute tows at a speed of about 2 to 3 knots.

Normandeau's **Wilcox trawl survey** ran from 1996 to 2016, sampling 10 randomly selected depth-stratified stations throughout Mt. Hope Bay (Figure 2). This trawl program was implemented to allow for better sampling of smaller and more fusiform fishes that were not well retained by the standard otter trawl. The Wilcox trawl survey's net was constructed with a 0.25-inch mesh liner in the cod end. Tows were conducted for 15 minutes at a speed between 2 to 3 knots. More detailed methods for both surveys may be found in Brayton Point Station's 2014 Report.

2. Rhode Island Department of Environmental Management trawl surveys

The Rhode Island Department of Environmental Management (RI DEM) conducted two finfish abundance surveys during the time period of Brayton Point operations. The **DEM seasonal trawl survey** has operated since 1979, sampling 11 fixed stations and 14 randomly chosen stations throughout Narragansett Bay biannually, in the spring and fall (Figure 3). The **DEM monthly trawl survey** began in 1990, and sampled 11 fixed stations in Narragansett Bay (excluding Mt. Hope Bay) monthly (Figure 3). The seasonal trawl survey data set, with spring and fall data combined, served as the primary data source for the analyses presented in this report. The monthly trawl survey, because it is limited in length, served as a supplementary data set for qualitative comparisons with the seasonal trawl survey.

Both the seasonal and monthly trawl surveys employed an otter trawl equipped with 0.25-inch mesh liner to conduct 20-minute tows at a speed of about 2.5 knots. For detailed methods, refer to RI DEM's F-61 Annual Performance Report:
http://www.dem.ri.gov/programs/bnatres/marine/pdf/F61_2017Report.pdf .

Figure 1. Mt. Hope Bay fixed stations sampled in Normandeau's standard trawl program. Figure is from Brayton Point Station's 2014 Annual Report. Black lines demarcate trawl transects for each of the stations. These stations were sampled for the entirety of the time series (1972-2014) except for Crossleg and Mid-Bay, which were discontinued after 1985. The Intake station was excluded from analysis because tow duration was inconsistent with that of all other stations. In 1997, four random stations were added to the standard trawl sampling program; these were selected from the stations presented in Figure 2.

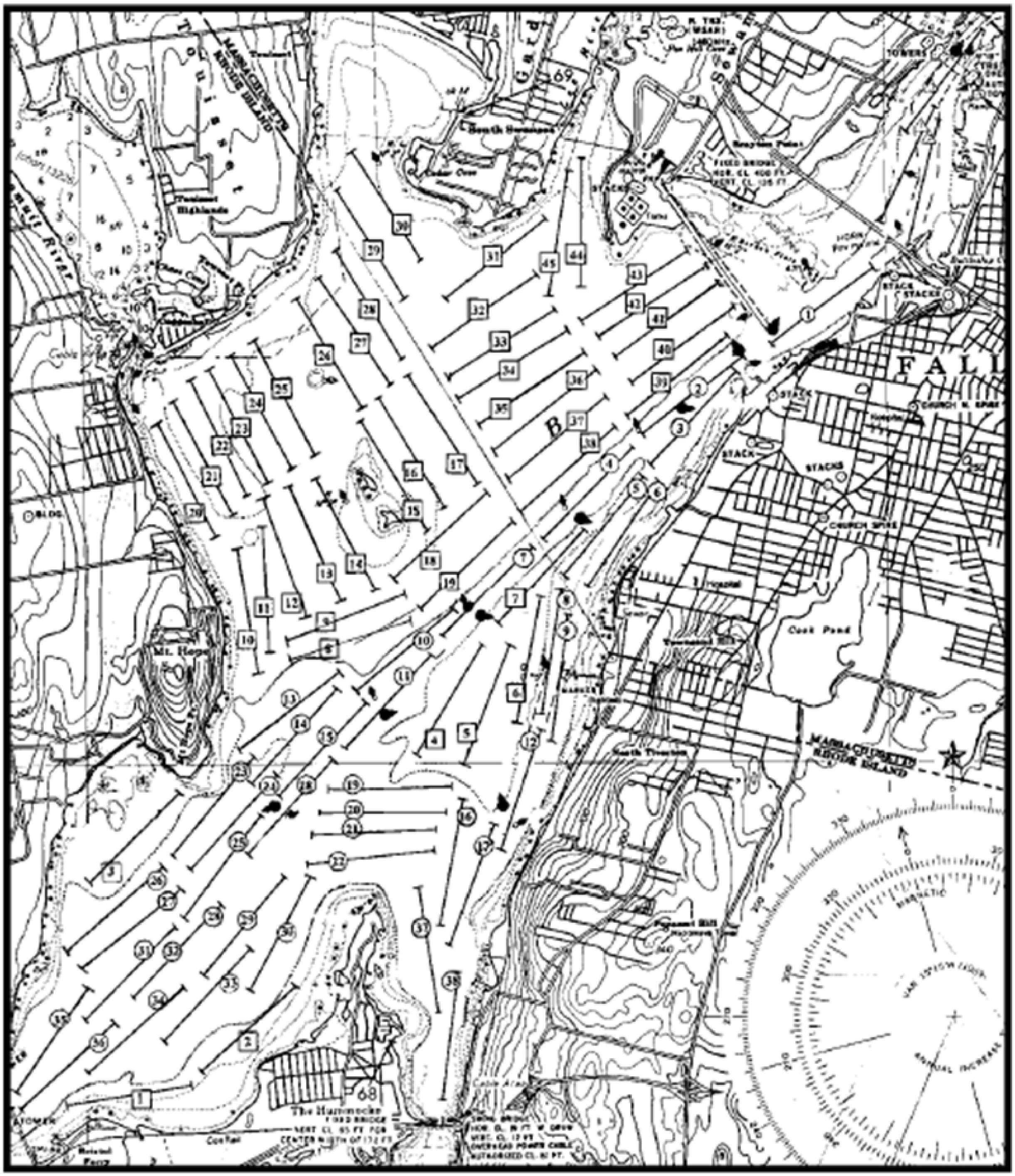

Figure 2. Mount Hope Bay transects established for random sampling with Normandeau's standard and Wilcox trawls. Black lines demarcate trawl transects for each of the stations. Shallow and deep water stations are marked with squares and circles, respectively. Figure is from Brayton Point Station's 2016 Annual Report.

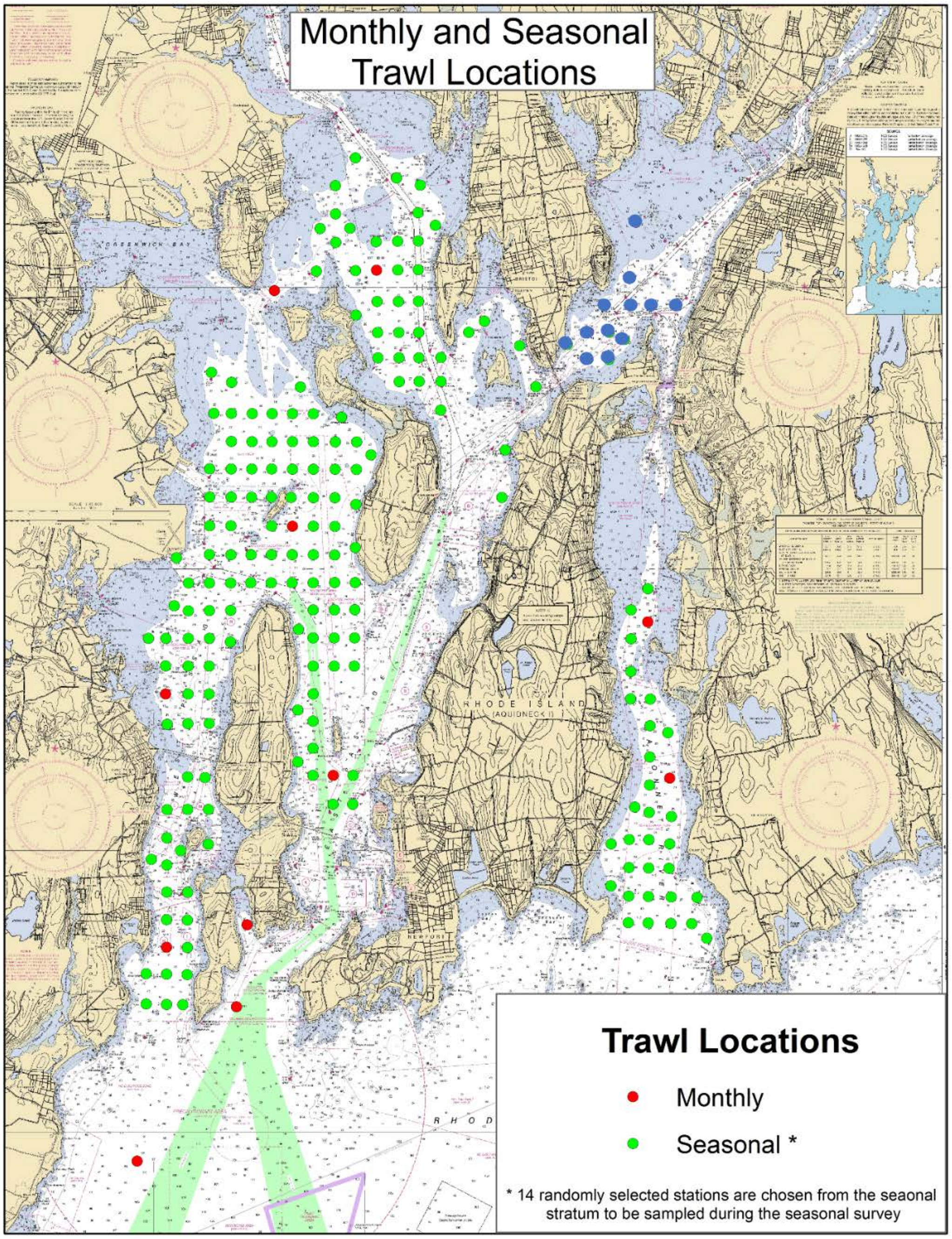

Figure 3. Station map for Rhode Island Department of Environmental Management's Narragansett Bay trawl surveys. Monthly trawl stations, in red, were sampled as part of both the monthly survey and the seasonal survey. Green circles represent stations from which seasonal survey sites were randomly sampled. Mount Hope Bay stations, in blue, were excluded from the analyses to isolate Narragansett Bay trends for comparison to Normandeau's Mt. Hope Bay.

3. Brayton Point Power Station cooling water flow

Cooling water, which was water discharged by Brayton Point after being used to cool its generating units, was measured continuously until the plant was decommissioned. This water typically entered the bay at a temperature about 7 to 10 °C above ambient (Mustard et al. 1999). Thus, high levels of cooling water flow are associated with high levels of heat released into Mt. Hope Bay. Circulating water flow data was obtained from Normandeau's Brayton Point Station 2017 Annual Report (Figure 4). Annual average flow data are the average circulating water flow, in billions of gallons per day, calculated as the mean across the averages for each calendar month.

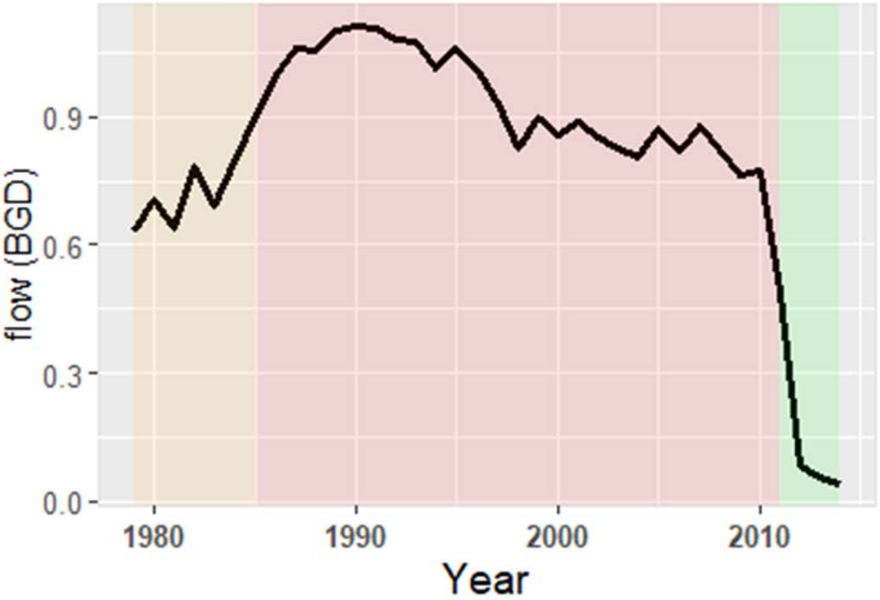

Figure 4. Annual average circulating cooling water flow at Brayton Point Power Station, 1979-2014, measured in billions of gallons per day. Orange, red, and green background panels indicate medium (1979-1984), high (1985-2010) and low (2011-2014) Brayton Point cooling water flow phases, respectively

Analytical Methods:

Previously, biomass dynamic models and time series analysis published as part of a Rhode Island Department of Environmental Management (RI DEM) report (Gibson 1995), showed a rapid and dramatic response of finfish communities in Mt. Hope Bay to the commission of a fourth operating unit at the Brayton Point Power Station. The sharp decline in aggregate fish abundance coincided with a 45% increase in cooling water flow at the power station. This Mt. Hope Bay finfish decline was shown to diverge from regional trends in Narragansett Bay and throughout southern New England. Thus, it was determined that Brayton Point Power Station was responsible for reducing aggregate finfish abundance by more than 80% in Mt. Hope Bay.

The analyses presented here examine the effects of Brayton Point Power Station on Mt. Hope Bay finfish communities since the Gibson report was published and since open-cycle cooling was discontinued at Brayton Point. Time series analyses methods were used to characterize the relationship between cooling water flow at Brayton Point and finfish abundance in Mt. Hope Bay. Species composition changes were described using multivariate ordination methods and hierarchical clustering techniques. Finally, some species-specific trends were described to contextualize some of the results of time series analysis and ordination methods.

Following the Gibson 1995 report, Narragansett Bay sampling outside of Mt. Hope Bay was used as a control system to contextualize trends observed in Mt. Hope Bay. If any observed changes in Mt. Hope Bay were driven by a region-wide phenomenon (i.e. environmental change) rather than by drivers specific to Mt. Hope Bay (i.e. the power plant), these changes would be expected to occur throughout the Narragansett Bay system. Divergence in trends between Mt. Hope Bay and the rest of Narragansett Bay would thus indicate that there are drivers of abundance or species composition unique to Mt. Hope Bay.

It is important to note that due to the differences in gear type, sampling methods, and sampling locations between the trawl surveys examined, absolute abundance values should not be directly compared between these surveys. However, each trawl surveys remained consistent in their respective sampling methodology throughout the study period, so temporal patterns in abundance and species composition may be analyzed *within* each survey and compared *across* the surveys. Analysis of trends and temporal patterns within surveys is of focus here and is the basis for comparison between Mt. Hope Bay and the rest of Narragansett Bay (see Gibson 1995).

Data Processing

For comparison to the Gibson report, trawl data were subset to those species which were selected for the 1995 report based on either numerical dominance in the Normandeau survey or commercial, recreational or ecological significance. These species are: alewife *Alosa pseudoharengus*, Atlantic cod *Gadus morhua*, Atlantic herring *Clupea harengus*, Atlantic menhaden *Brevoortia tyrannus*, Atlantic silverside *Menidia menidia*, bay anchovy *Anchoa mitchilli*, blueback herring *Alosa aestivalis*, bluefish *Pomatomus saltatrix*, butterfish *Peprilus triacanthus*, cunner *Tautogolabrus adspersus*, haddock *Melanogrammus aeglefinus*, hogchoker *Trinectes maculatus*, northern searobin *Prionotus carolinus*, oyster toadfish *Opsanus tau*, pollock *Pollachius virens*, rainbow smelt *Osmerus mordax*, scup *Stenotomus chrysops*, skates *Leucoraja spp., Raja spp.*, striped bass *Morone saxatilis*, striped searobin *Prionotus evolans*, summer flounder *Paralichthys dentatus*, tautog *Tautoga onitis*, weakfish *Cynoscion regalis*, windowpane flounder *Scophthalmus aquosus*, and winter flounder *Pseudopleuronectes americanus*.

Average annual abundance for each species was calculated as the arithmetic mean number per tow over the year, with the exception of long-term numerically dominant species sampled in the Normandeau trawl surveys. For the Normandeau standard trawl, indices for winter flounder, windowpane flounder, tautog, hogchoker, scup, butterfish, and skates were calculated using a delta distribution method (Smith 1988). This method is an efficient abundance estimator for samples containing many zero values. In this study, estimates produced via the delta mean method are not expected to produce results substantially different from results that would be produced from analysis using arithmetic means (Brayton Point 2014 Annual Report). For the Normandeau Wilcox survey, depth-stratified abundance was calculated for the same long-term numerically dominant species listed above. The average annual abundances of the species listed above were aggregated for time series analysis of finfish abundance.

To characterize changes in the species composition of Mt. Hope Bay, all species identified in the Normandeau standard trawl survey were included in the analysis. Annual average catch per tow of the six numerically dominant species were calculated as described above for time series analysis. All other species were calculated as the arithmetic mean number per tow over the year. As the control time series, the DEM seasonal trawl survey was subset to those species which were encountered in the Normandeau standard trawl survey.

Time Series Analysis

The general structure of an ARMA(1,1) model (applied to a raw time series, or an integrated time series when appropriate), is:

$$Y_t = \varphi_1 Y_{t-1} - \theta_1 e_{t-1} + \alpha_t$$

Where φ_1 represents an autoregressive coefficient at lag 1, θ_1 represents a moving average coefficient at lag 1, and α_t is the residual error term.

Autoregressive Integrated Moving Average models, ARIMAs, are a class of statistical models used to analyze time series data (Cryer and Chan, 2008). These models provide a means of characterizing the autocorrelative structure of a time series (i.e. accounting for how a variable at a given time point relates to previous values of that variable). An ARIMA(p,d,q) model can consist of three components:

> **-AR(p)** Autoregressive term, accounting for dependence of an observation at a given time with observations at previous time points (at a given lag)
>
> **-I(d)** Integration, indicating the use of differencing raw observations to make a time series stationary (removing a time trend so that the series can be modeled without influence from a trend bias). This is achieved by subtracting a given observation from the previous time step observation.
>
> **-MA(q)** Moving average term, accounting for the dependence of an observation on the residuals from a moving average model applied to lagged observations.

Mt. Hope Bay finfish abundance trends were examined by fitting a suite of models to the area’s log-transformed time series of aggregate finfish abundance. To account for Narragansett Bay system-wide trends that could explain trends in Mt. Hope Bay, the Narragansett Bay abundance time series was included as an explanatory covariate in candidate time series models. Removing system-wide trends in this way allowed for other covariates to be fitted to patterns specific to Mt. Hope Bay abundance that could not be explained by larger system-wide drivers. Models were also fit to Mt. Hope Bay finfish abundance with and without cooling water flow as an explanatory covariate. Alternative models were compared using the Bayesian information criterion (BIC), along with tests for normality, autocorrelation, and stationarity in the residuals.

Following the Gibson 1995 report, intervention terms were incorporated into time series models. These intervention terms corresponded to years of significant change in mean cooling water flow at Brayton Point, determined via ordinary least squares regression of the cooling water flow time series. Cooling water flow intervention years were identified as 1984, 1996, and 2010 (Appendix a). By including these years as intervention terms in time series models, it could be tested whether these significant changes in plant operation corresponded with an abrupt change in finfish abundance.

Finfish community species composition

Species composition analysis was conducted using non-metric multidimensional scaling (nMDS), an ordination method wherein the dissimilarity between samples (in this case, years) is determined based on the values of many variables (in this case, abundances of sampled species) (Ramette, 2007). Non-metric multidimensional scaling provides a representation of each year's species community in a reduced number of dimensions and calculates the distance between all years in the sample. Years of similar community composition are indicated via closer ordination, whereas those that are dissimilar have greater distances between them.

A nMDS was performed on Normandeau's standard trawl survey species composition data and the DEM Narragansett Bay trawl survey data. Hierarchical clustering was conducted with the output coordinates of each of these procedures to see how species composition compared between years of the time series. Clusters of species community composition were compared between Mt. Hope Bay and Narragansett Bay.

Results and Interpretation

Time series analysis

An intervention-only model was selected as the most appropriate among the aggregate finfish abundance time series models tested. This model did not incorporate any autoregressive parameters; rather, it accounted only for a change in mean abundance corresponding to breakpoints in cooling water flow (years 1984, 1996, and 2010). While incorporation of the intervention term in 1996 marginally improved the model fit over the model incorporating interventions in years 1984 and 2010 alone, the model including all three intervention terms achieved stationary residuals (augmented Dickey-Fuller test), and was thus selected as the best model (for alternative model diagnostics and residual plots of the selected model, see Appendix b).

The selected model performed better than models incorporating cooling water flow as a continuous external regressor. Rather than a consistent relationship between cooling water flow and abundance, there appear to be stationary phases of cooling water flow that correspond to phases of abundance. Periods of highest cooling water flow at Brayton Point were associated with the lowest aggregate finfish abundances in the Normandeau trawl survey (Figure 5, Figure 6). The same relationship was not seen in the DEM seasonal trawl survey time series; no significant correlation could be shown between the Narragansett Bay-wide survey and Brayton Point cooling water flow.

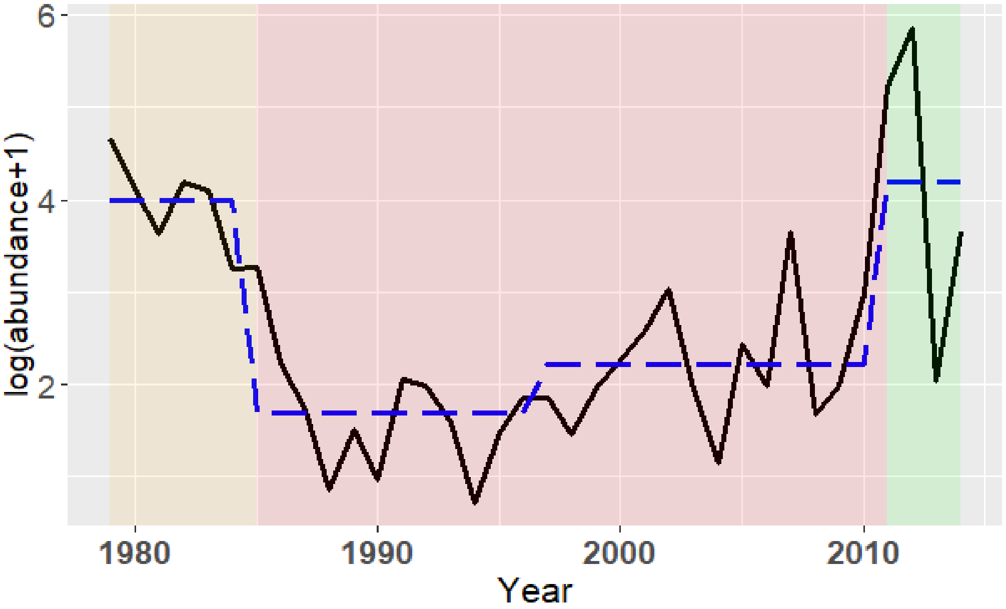

Figure 5. Time series of log-transformed aggregate finfish abundance in Mt. Hope Bay 1979-2014 (black), with selected intervention-only time series model (dashed blue line). Orange, red, and green background panels indicate medium, high and low Brayton Point cooling water flow phases, respectively. The selected model demonstrates the negative correlation between the plant's water output and finfish abundance; the years of lowest average abundance occurred when cooling water flow was at time series high levels (see Figure 4).

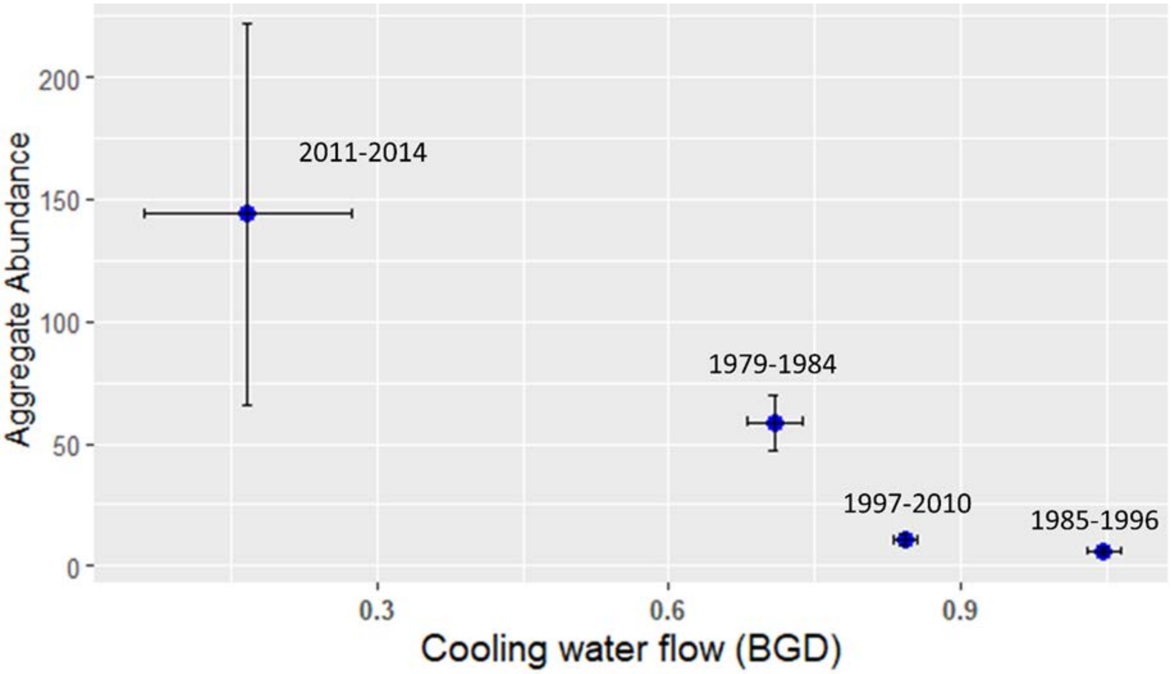

Figure 6. Biplot of average aggregate finfish abundance vs. average cooling water flow in Mt. Hope Bay during high (1985-1996), medium-high (1997-2010), medium (1979-1984), and low (2011-2014) levels of cooling water flow. Bars display standard error of each estimate. Highest aggregate abundances are associated with the lowest levels of flow. Years since the cooling towers were commissioned have higher abundance levels than years during open-cycle cooling was employed by Brayton Point.

The difference in abundance trends between Mt. Hope Bay and the rest of the Narragansett Bay provides evidence that there may be disparate drivers of finfish community dynamics between the two systems. The high level of correspondence between finfish abundance regimes and Brayton Point cooling water flow regimes indicates that the power plant was likely a significant driver of finfish abundance in Mt. Hope Bay from 1979 to 2014. While the Normandeau trawl survey displayed lowest abundances during Brayton Point’s high-flow years, the DEM trawl surveys exhibited a slowly increasing trend over the same time period (Figure 7).

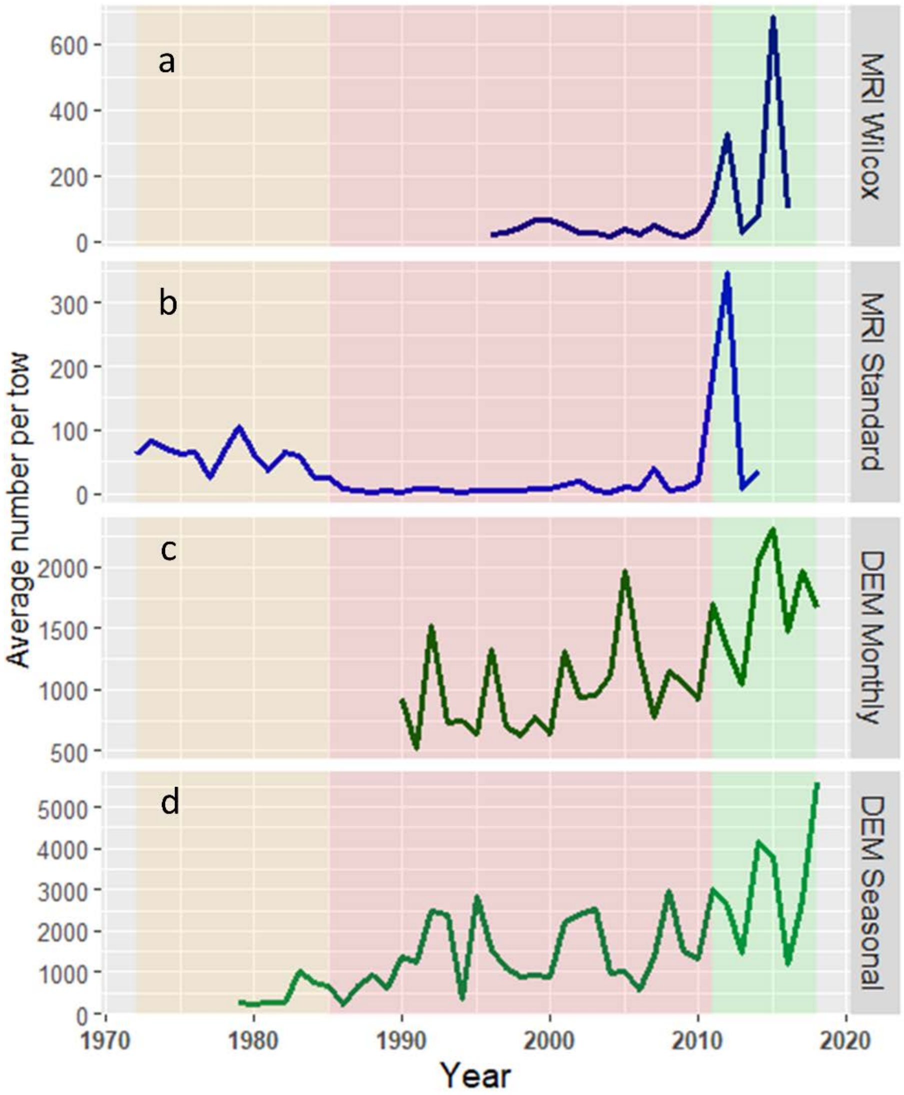

Figure 7. Time series of non-transformed aggregate finfish abundance in a) Normandeau's Wilcox trawl survey, b) Normandeau's standard trawl survey, c) RI DEM's monthly trawl survey, and d) RI DEM's seasonal trawl survey. Panels (a) and (b) represent Mt. Hope Bay finfish abundance; panels (c) and (d) represent Narragansett Bay finfish abundance. Orange, red, and green background panels indicate medium, high, and low levels of cooling water flow, respectively. Because of differences in sampling gear, methods, and location, absolute abundance should not be compared between trawl surveys.

Although aggregate finfish abundance has been highly variable since 2011, when the cooling towers were commissioned, the most recent years of the Normandeau trawl survey have represented some of the highest abundance years seen in the entire time series (Figure 6, Figure 7). This may be evidence of a recovery of the finfish community since open-cycle cooling was terminated at Brayton Point.

Community species composition analysis

Hierarchical clustering of nMDS coordinates in 3 dimensions revealed species composition clusters in the Mt. Hope Bay community aligning with phases of power plant operations (Figure 8). Three broad clusters of similarity in community composition were indicated for the following year groups: 1972-1986; 1987-1997; and 1998-2014. The number of hierarchical clusters may be selected arbitrarily but was chosen here based on the results of bivariate segmentation procedures which revealed three composition clusters (Appendix d). The breakpoints between the indicated clusters closely align with cooling flow breakpoint years; the first cluster coincides with the medium-flow regime, and the second cluster aligns with the highest flow regime. Regardless of the choice of clustering level (i.e. the value to which the green line in Figure 8 is set), direct comparison of clusters between Mt. Hope Bay and Narragansett Bay—via both segmentation and hierarchical clustering-reveals that there are abrupt shifts in the Mt. Hope Bay community which are not evident in the rest of Narragansett Bay.

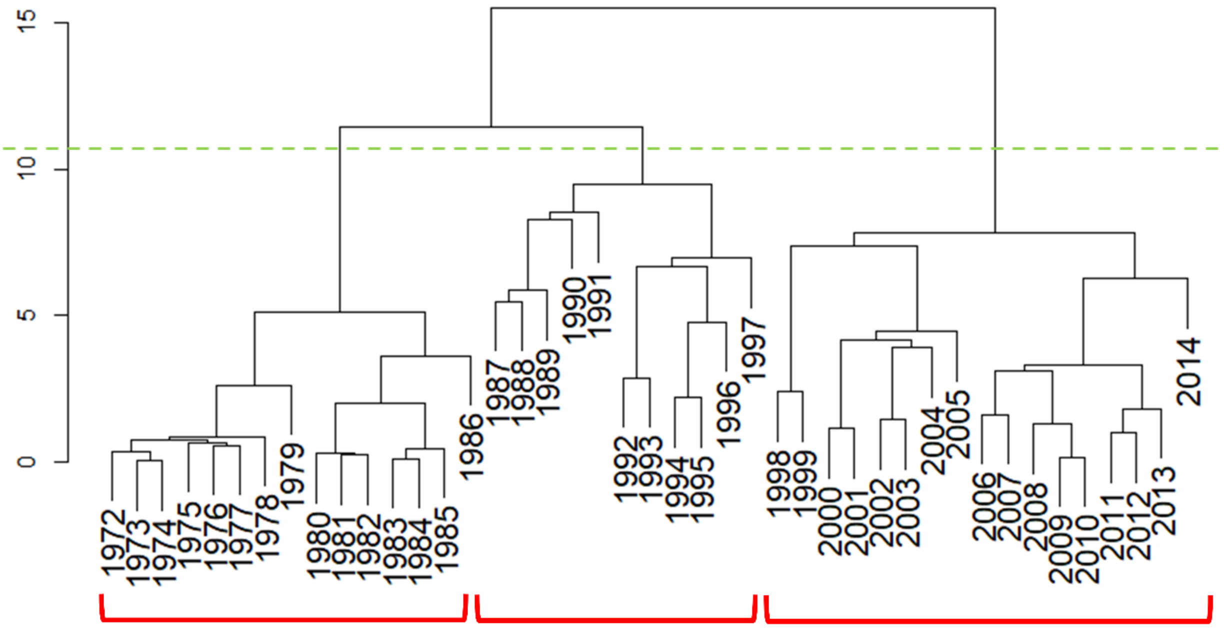

Figure 8. Hierarchical clustering of nMDS output coordinates for Mt. Hope Bay species composition. Branching at higher numbers on the vertical axis indicates higher levels of dissimilarity between clusters/years. The clustering of species composition by years reveals three broad community groups: 1972-1986; 1987-1997; and 1998-2014.

Clustering of Narragansett Bay species composition did not reveal as much dissimilarity between year groups as was found in Mt. Hope Bay. Further, cluster breakpoints did not align with power plant operations. Shifts in community species composition appear to have been more gradual through time in the Narragansett Bay system than in the Mt. Hope Bay system. Bivariate segmentation of the Narragansett Bay nMDS coordinates reveals that there were no distinct phases in community species composition (Figure 9). Rather, the community looks to have gradually shifted over the time series; this gradual shift is evidenced by the upward trend in nMDS dimension 1 (Figure 10).

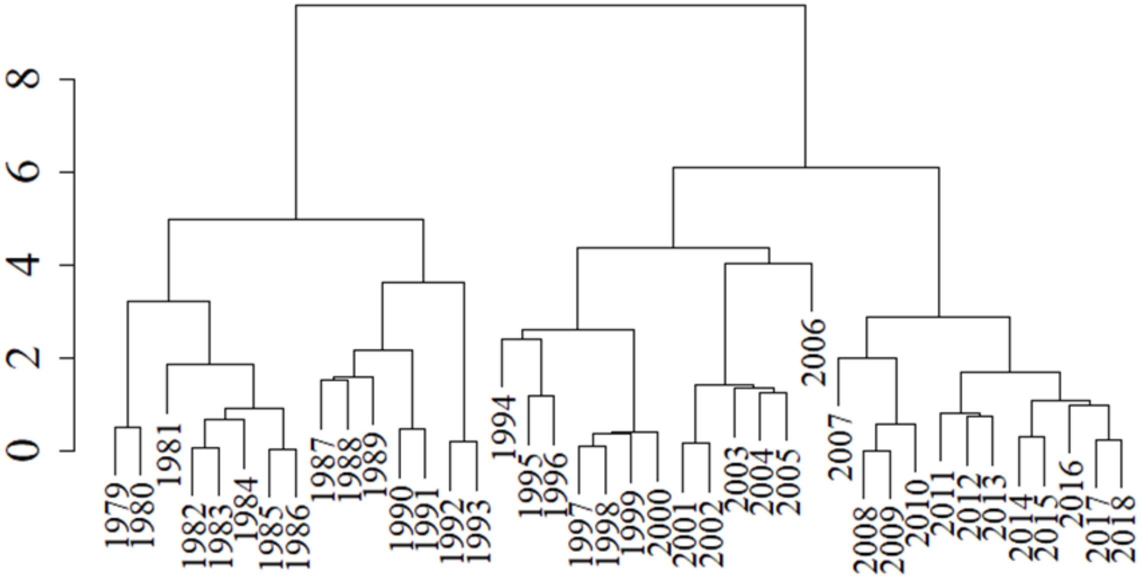

Figure 9. Hierarchical clustering of nMDS output coordinates for Narragansett Bay species composition. Branching at higher numbers on the vertical axis indicates higher levels of dissimilarity between clusters/years. Narragansett Bay species composition appears to be more similar among years than Mt. Hope Bay species composition, and without major breakpoints that coincide with changes in cooling water flow at Brayton Point.

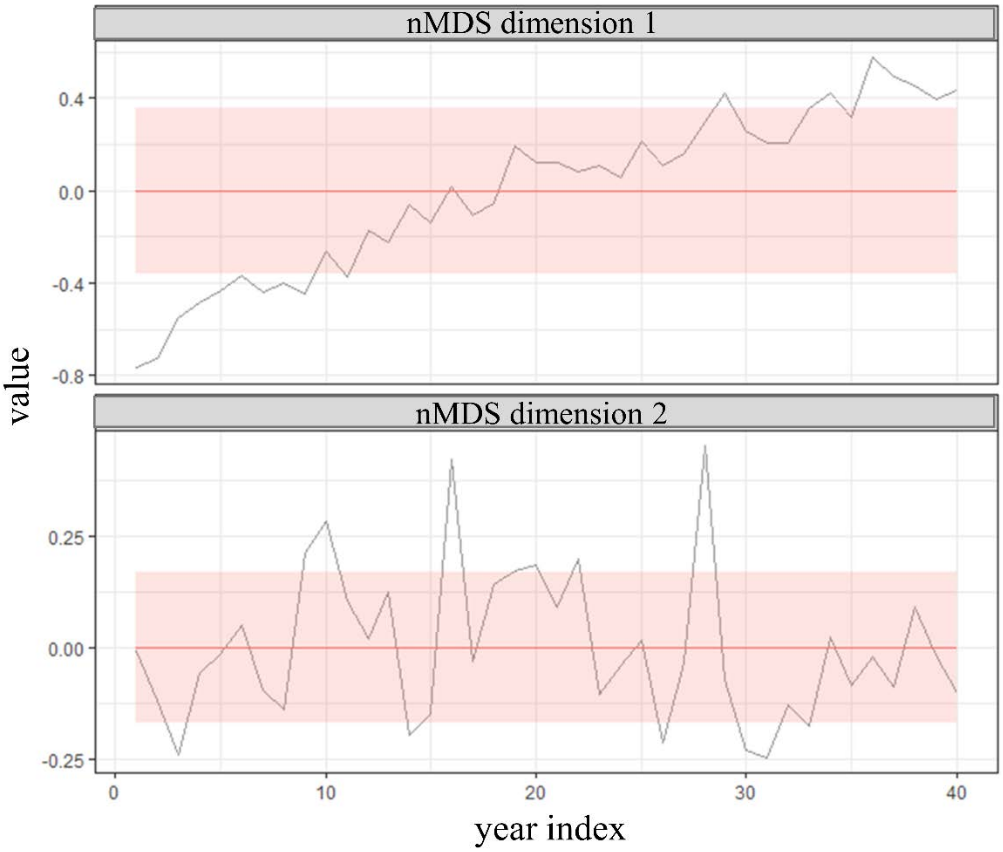

Figure 10. Bivariate segmentation plot of nMDS dimensions 1 and 2 from analysis of species composition in Narragansett Bay. No breakpoints were detected in the bivariate time series, suggesting that species composition did not undergo abrupt changes during the study period. This contrasts with Mt. Hope Bay, where three distinct segments were detected.

Both Narragansett Bay and Mt. Hope Bay have undergone shifts in species composition since the 1970s, but these changes seem to have come about at different rates within each of the two systems. While there has been a gradual shift in the species composition of the greater Narragansett Bay, Mt. Hope Bay's finfish community appears to have abruptly shifted at two changepoints, resulting in three phases of community species composition over the examined time series. Because these phases align with Brayton Point Power Station cooling water flow regimes, the power plant may be implicated as a driver of finfish community species composition in Mt. Hope Bay.

Narraganset Bay has undergone a shift in species composition from demersal fish species to warm-water species over the latter half of the 20th century (Collie et al. 2008). It should be noted that any recovery assessment of Mt. Hope Bay fish communities must account for the fact that the greater Narragansett Bay system has undergone significant change in species composition over the course of Brayton Point's operations. Accordingly, the Mt. Hope Bay finfish community is not assumed to return to a state resembling its pre-power plant baseline.

A few species-specific trends were compared between Mt. Hope Bay and the greater Narragansett Bay system. For the highlighted species, long-term trends were similar between the Mt. Hope Bay and Narragansett Bay control time series, but the timing of abundance shifts was misaligned between the two systems. For example, winter flounder underwent a decline in Mt. Hope Bay which occurred rapidly in the mid-1980s. The decline of winter flounder in the greater Narragansett Bay system appears to have been less rapid and occurred later, slowly decreasing from the mid-1980s to the 1990s (Figure 11). Cunner followed a similar pattern, wherein the decline in Mt. Hope Bay—which appears to have occurred around 1985—preceded a more gradual system-wide decline (Figure 12). Conversely, scup and black sea bass have been increasing in abundance throughout southern New England for more than a decade (Collie et al. 2008) but have only been seen in substantial numbers in Mt. Hope Bay during the most recent low-effluent regime (Figure 13 and Figure 14).

The trajectories of these species in Mt. Hope Bay were directionally aligned with Narragansett Bay-wide trends—in other words, whether these species experienced long-term decline or population increase was consistent between the two systems. However, Brayton Point inputs appear to have influenced the timelines for these species in Mt. Hope Bay. The high-flow period from 1985 to 2010 is associated with low abundance in Mt. Hope Bay, regardless of the dynamics of the larger Narragansett Bay system, while Mt. Hope Bay abundance before and after the high-flow period appears to more consistently reflect abundance trends in the Narragansett Bay system. Those species which experienced a long-term decline in the greater Narragansett Bay system have not exhibited a Mt. Hope Bay recovery since the cooling towers were commissioned, while species that have increased in abundance in Narragansett Bay appear to have shown a Mt. Hope Bay recovery in the recent low-flow phase. The limited species-specific analyses presented here indicate that the recent increase in Mt. Hope Bay finfish abundance can be at least partially attributed to species that were not previously abundant in this water body, but that have been thriving in the rest of Narragansett Bay.

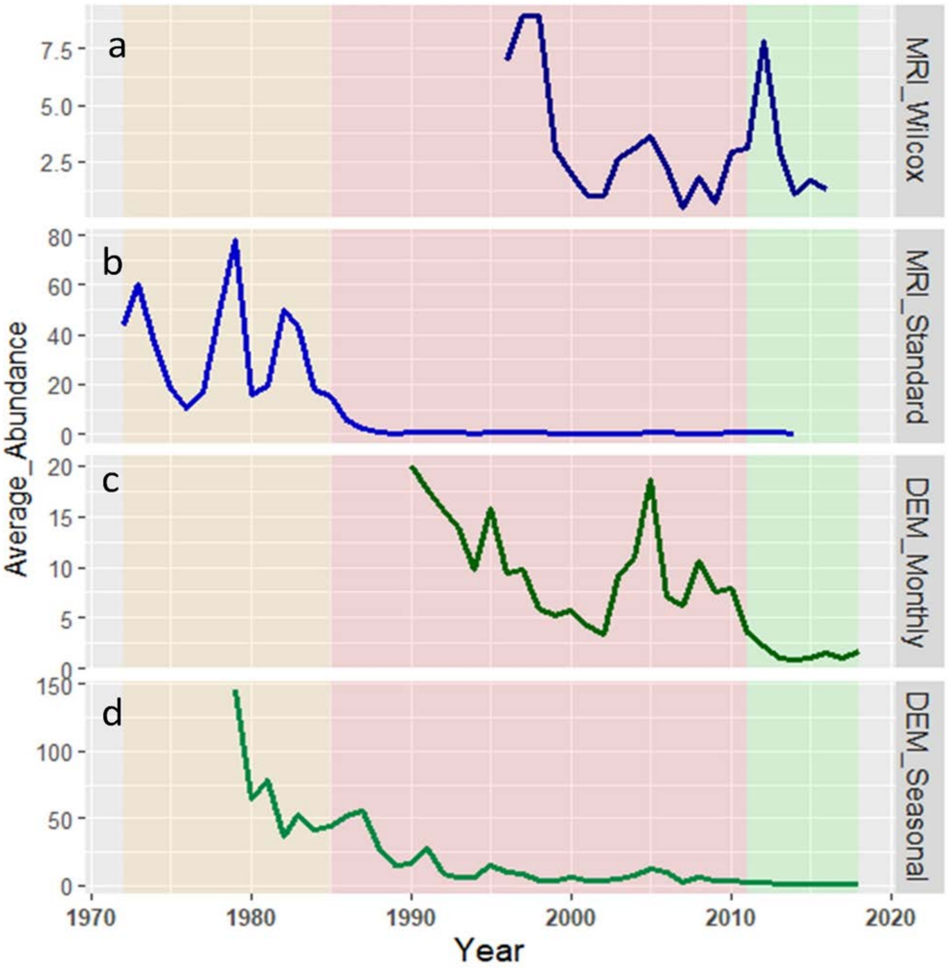

Figure 11. Time series of winter flounder abundance in a) Normandeau's Wilcox trawl survey, b) Normandeau's standard trawl survey, c) RI DEM's monthly trawl survey, and d) RI DEM's seasonal trawl survey. Panels a and b represent Mt. Hope Bay; panels c and d represent Narragansett Bay. Orange, red, and green background panels indicate medium, high, and low levels of cooling water flow, respectively. Because of differences in sampling gear, methods, and location, absolute abundance should not be compared between trawl surveys. This figure highlights the difference between temporal patterns in Mt. Hope Bay and the rest of Narragansett Bay—winter flounder in Mt. Hope Bay experienced a sharp decline in the mid-1980s, while winter flounder in Narragansett Bay decreased more steadily throughout the 1980s.

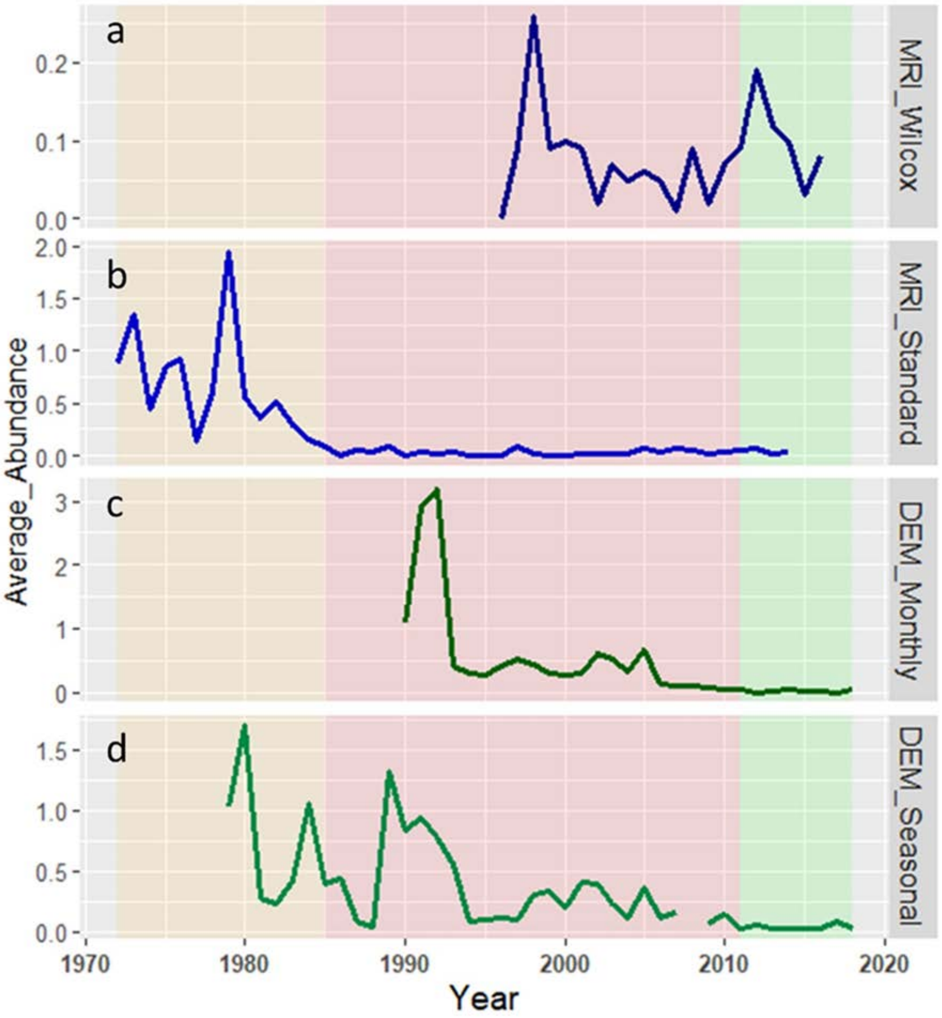

Figure 12. Time series of cunner abundance in a) Normandeau's Wilcox trawl survey, b) Normandeau's standard trawl survey, c) RI DEM's monthly trawl survey, and d) RI DEM's seasonal trawl survey. Panels a and b represent Mt. Hope Bay; panels c and d represent Narragansett Bay. Orange, red, and green background panels indicate medium, high, and low levels of cooling water flow, respectively. Because of differences in sampling gear, methods, and location, absolute abundance should not be compared between trawl surveys. This figure highlights the difference between temporal patterns Mt. Hope Bay and the rest of Narragansett Bay—cunner in Mt. Hope Bay experienced a sharp decline in the mid-1980s, while cunner in Narragansett Bay decreased later, over a longer period.

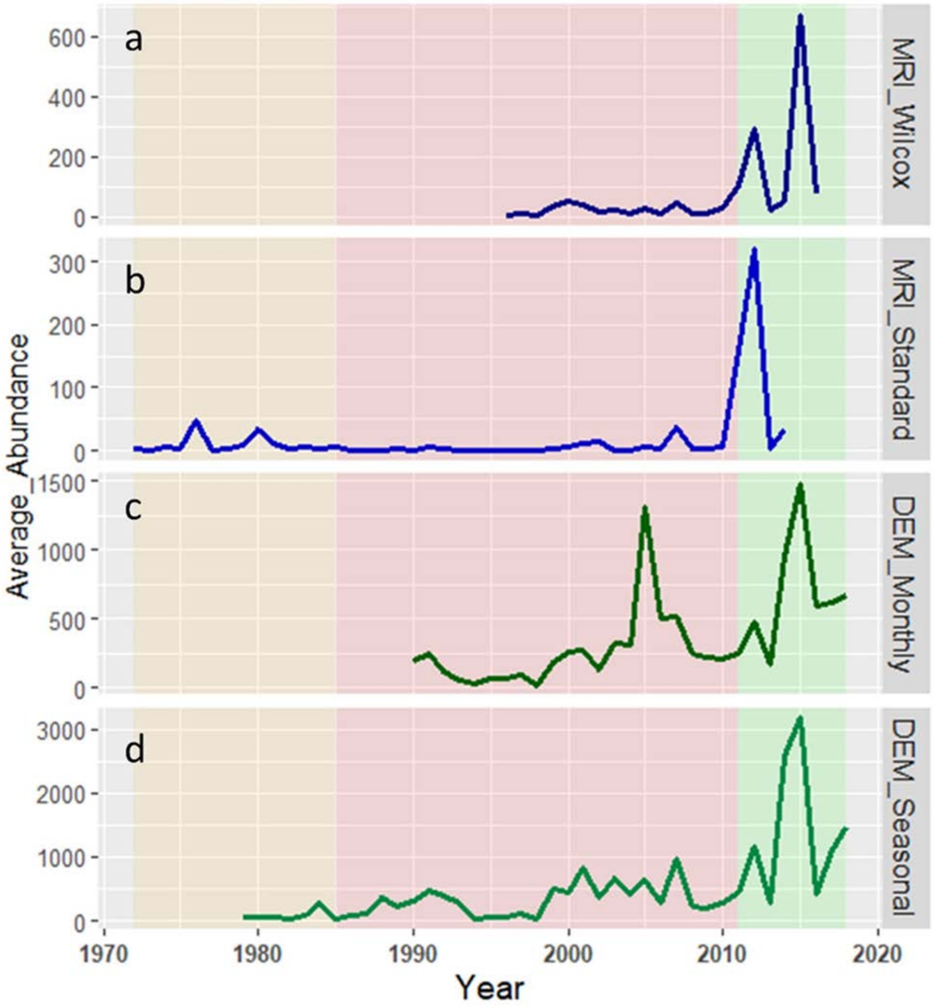

Figure 13. Time series of scup abundance in a) Normandeau's Wilcox trawl survey, b) Normandeau's standard trawl survey, c) RI DEM's monthly trawl survey, and d) RI DEM's seasonal trawl survey. Panels a and b represent Mt. Hope Bay; panels c and d represent Narragansett Bay. Orange, red, and green background panels indicate medium, high, and low levels of cooling water flow, respectively. Because of differences in sampling gear, methods, and location, absolute abundance should not be compared between trawl surveys. This figure highlights the difference between temporal patterns in Mt. Hope Bay and the rest of Narragansett Bay—scup have been increasing in abundance in Narragansett Bay over the past two decades but have only been observed in large numbers in Mt. Hope Bay in years since the cooling towers were commissioned.

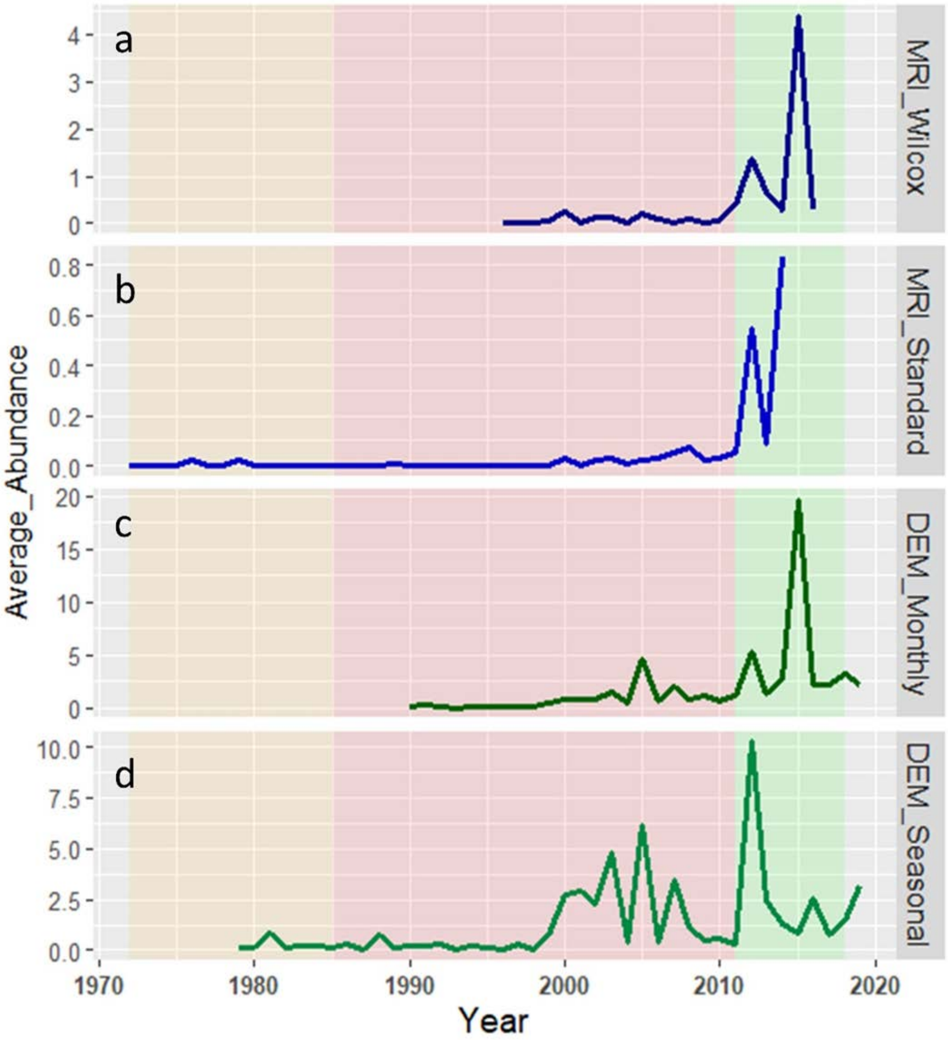

Figure 14. Time series of black sea bass abundance in a) Normandeau's Wilcox trawl survey, b) Normandeau's standard trawl survey, c) RI DEM's monthly trawl survey, and d) RI DEM's seasonal trawl survey. Panels a and b represent Mt. Hope Bay; panels c and d represent Narragansett Bay. Orange, red, and green background panels indicate medium, high, and low levels of cooling water flow, respectively. Because of differences in sampling gear, methods, and location, absolute abundance should not be compared between trawl surveys. This figure highlights the difference between temporal patterns in Mt. Hope Bay and the rest of Narragansett Bay—black sea bass have been increasing in abundance in Narragansett Bay over the past two decades but have only been observed in large numbers in Mt. Hope Bay in years since the cooling towers were commissioned.

Summary of Results

The results presented here indicate:

1. *Finfish abundance in Mt. Hope Bay was negatively correlated with Brayton Point Power Plant cooling water flow* from 1979-2014, suggesting that there were direct effects of heated water effluent on the finfish community.
2. The species composition of Mt. Hope Bay experienced abrupt changes around years when the level of cooling water flow at Brayton Point changed. In contrast, the greater Narragansett Bay system experienced a more gradual shift in species composition over the study period. These *abrupt species composition shifts suggest that changes in power plant operations influenced finfish community species composition in Mt. Hope Bay*.
3. *In years since the cooling towers went online in 2011, aggregate fish abundance has experienced time series high levels in Mt. Hope Bay*. This suggests that the construction of cooling towers, which decreased the cooling water flow into the Bay, enabled a recovery of finfish presence close to the plant. Recent high-abundance years can be attributed in part to the increase in warm-water species which were rare in Mt. Hope Bay before the high-flow years began. This change in dominant species appears to be reflective of larger Narragansett Bay-wide environmentally driven species composition shifts.

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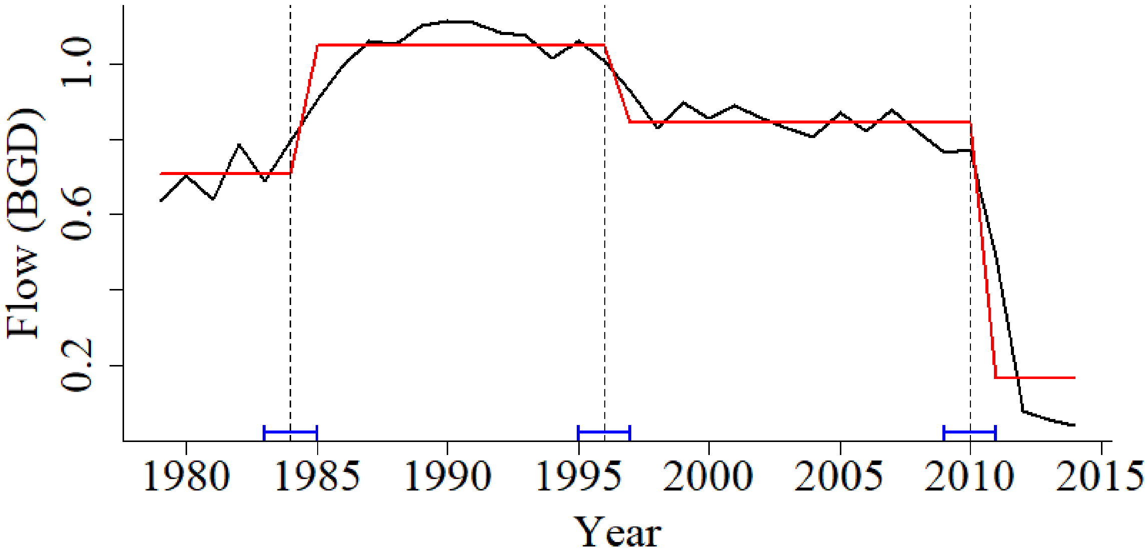
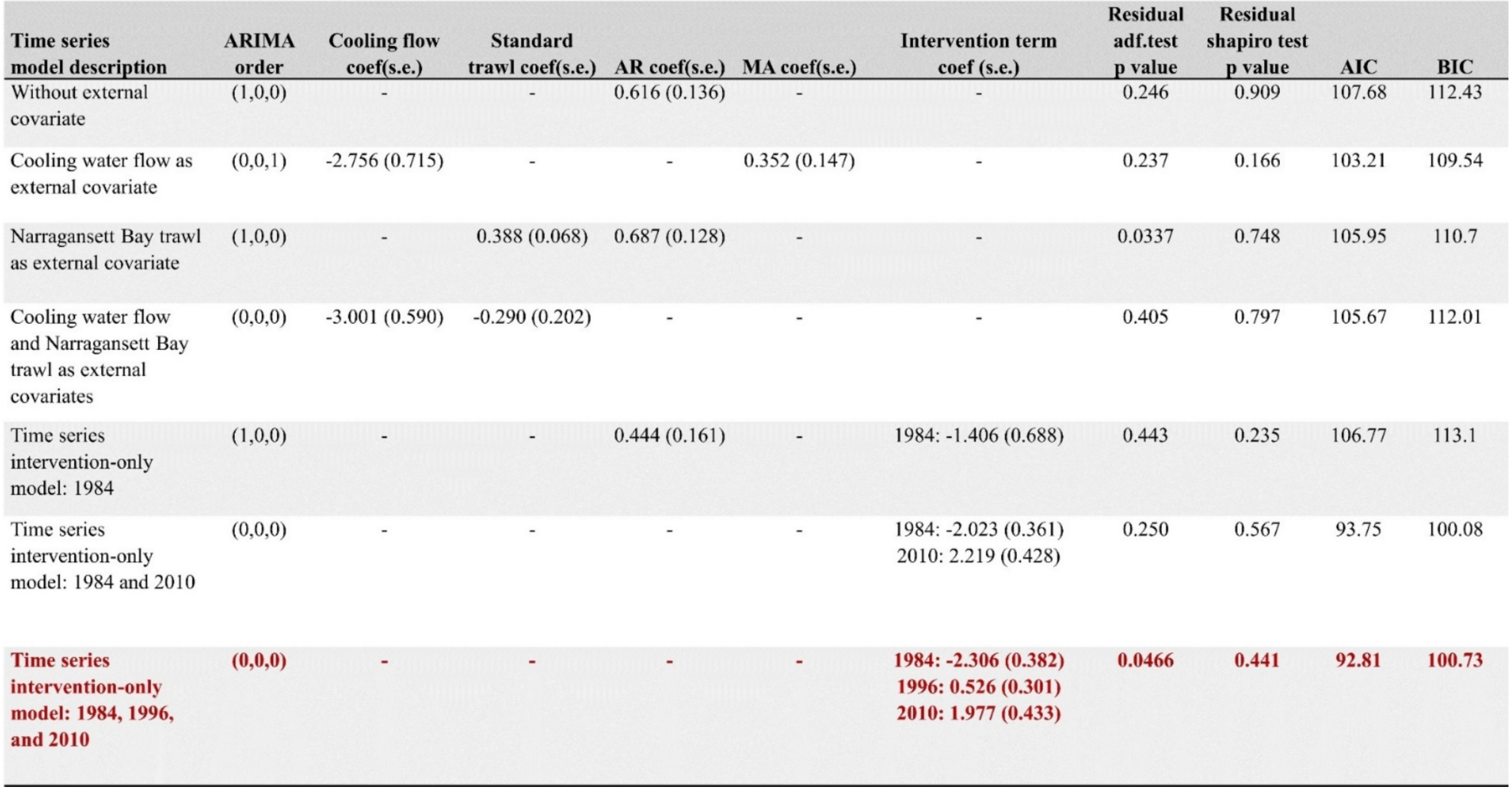
Appendices.

Appendix a. Time series of Brayton Point cooling water flow, in black, with intervention years chosen via breakpoint analysis (ordinary least squares regression to find significant changes in the mean). Breakpoint years are indicated with dotted vertical lines, and 95% confidence intervals are indicated in blue. Mean level of cooling water flow is indicated by the red line.

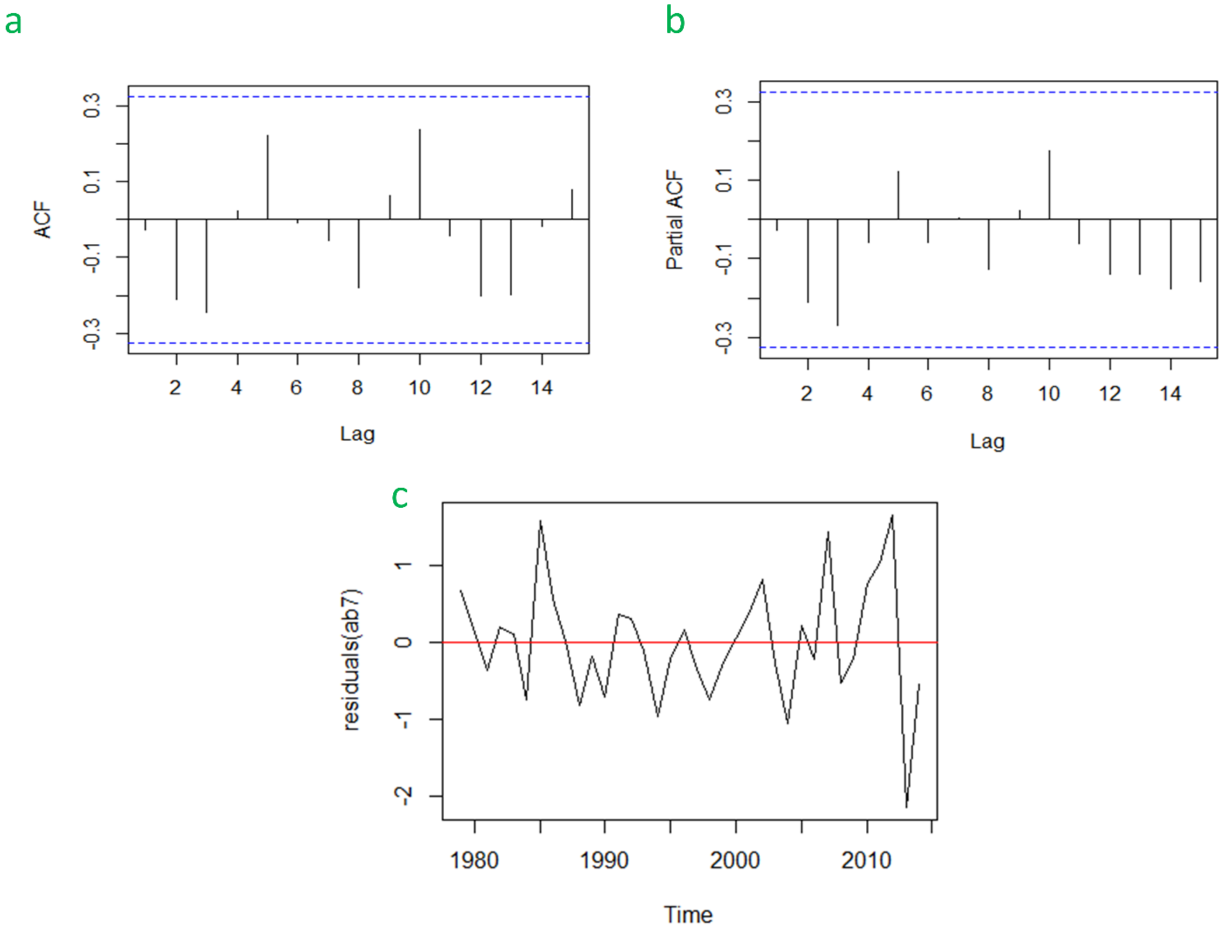


Appendix b. Summary table of candidate time series models for Mt. Hope Bay aggregate abundance. The order of ARIMA models was determined by using the auto.arima function in R. The chosen model is indicated in red. Residuals of the candidate models were tested for stationarity (lack of trend) using the augmented Dickey-Fuller test (p<0.05 indicates stationarity), and were tested for normality using the Shapiro-Wilk test (p>0.05 indicates normality).



Time series model description	ARIMA order	Cooling flow coef(s.e.)	Standard trawl coef(s.e.)	AR coef(s.e.)	MA coef(s.e.)	Intervention term coef (s.e.)	Residual adf.test p value	Residual shapiro test p value	AIC	BIC
Without external covariate	(1,0,0)	-	-	0.616 (0.136)	-	-	0.246	0.909	107.68	112.43
Cooling water flow as external covariate	(0,0,1)	-2.756 (0.715)	-	-	0.352 (0.147)	-	0.237	0.166	103.21	109.54
Narragansett Bay trawl as external covariate	(1,0,0)	-	0.388 (0.068)	0.687 (0.128)	-	-	0.0337	0.748	105.95	110.7
Cooling water flow and Narragansett Bay trawl as external covariates	(0,0,0)	-3.001 (0.590)	-0.290 (0.202)	-	-	-	0.405	0.797	105.67	112.01
Time series intervention-only model: 1984	(1,0,0)	-	-	0.444 (0.161)	-	1984: -1.406 (0.688)	0.443	0.235	106.77	113.1
Time series intervention-only model: 1984 and 2010	(0,0,0)	-	-	-	-	1984: -2.023 (0.361) 2010: 2.219 (0.428)	0.250	0.567	93.75	100.08
Time series intervention-only model: 1984, 1996, and 2010	**(0,0,0)**	**-**	**-**	**-**	**-**	**1984: -2.306 (0.382)** **1996: 0.526 (0.301)** **2010: 1.977 (0.433)**	**0.0466**	**0.441**	**92.81**	**100.73**

Appendix c. Selected time series model diagnostics. Subplots a and b show the ACF and PACF, respectively, of the residuals of the model. Plot c is the time series plot of the model’s residuals.



Appendix d. Bivariate segmentation plot of nMDS dimensions 1 and 2 from analysis of species composition in Mt. Hope Bay. Three breakpoints were detected in the bivariate time series, suggesting that species composition underwent two abrupt changes during the study period. The three segments correspond to the following year groups: 1972-1983; 1984-1997; and 1998-2014. These years align closely with years during which Brayton Point cooling water flow changed substantially.