State of Narragansett Bay and Its Watershed
2017 Technical Report

Watershed Ecosystem Condition Indicators

CHAPTER 19:
STREAM INVERTEBRATES


Photo: Flat River, Exeter, RI (Ayla Fox)
BACKGROUND

- Insects, worms, snails, mussels, and crayfish—known collectively as stream benthic macroinvertebrates—are excellent indicators of water quality conditions. They rely on intact habitat and clean water, and state agencies monitor these invertebrates in wadeable streams throughout the Narragansett Bay Watershed. The assemblage of stream invertebrates that live at a particular site reflects the effects of both short-term and cumulative stressors such as stormwater discharges, increased water temperatures, excess nutrients, sedimentation, and other physical alterations of stream habitat, all driven by changes in climate and land use.

KEY FINDINGS

- **Status**

  **Streams with Good Macroinvertebrate Health and Good Habitat Quality:** Of the 78 sites assessed for stream invertebrates between 2002 and 2014, 62 sites (79 percent) were classified as having both good macroinvertebrate health and good habitat quality. The Pawtuxet River Basin appeared to have the healthiest stream conditions with nineteen of its 21 sites (90 percent) in this classification. However, the other three River Basins also had 67 to 80 percent of their sites in this classification.
Introduction

Stream benthic macroinvertebrates are a large group of animals (insects, worms, snails, mussels, and crayfish) that dwell in fresh water. In a comprehensive review, Wallace and Webster (1996) reported that stream invertebrates serve as prey for fish, amphibians, mammals, birds, waterfowl, and other wildlife; influence nutrient cycles, primary productivity, and decomposition of organic matter (e.g., fallen leaves); and serve as important indicators of stream condition. Some freshwater invertebrates such as crayfish, mussels, worms, and snails spend their entire life in the water, while insects such as dragonflies, damselflies, mayflies, and beetles spend only their early life stages in streams before emerging from the water to fly. Invertebrates depend on healthy stream habitats, sufficient amounts of water, and adequate water quality. When stream habitat, water quality, or water quantity begin to degrade, the macroinvertebrate community is affected. Accordingly, invertebrates in freshwater streams are monitored to indicate ecological condition (Plafkin et al. 1989, Barbour et al. 1999).

Stream macroinvertebrates are impacted by stormwater runoff, water pollution, changes in water temperature and flow, erosion, sedimentation, and habitat degradation (Thorp and Covich 1991). Landscape stressors that influence the status of stream invertebrates include increased impervious cover (Morse et al. 2003), land use such as urbanization (Moore and Palmer 2005), and nutrient loading (Yuan 2010). Urbanization adversely affects stream ecosystems, and evidence is mounting that even low levels of urbanization can cause significant changes in stream biology, physical habitat, and chemistry (Morse et al. 2003, Yuan 2010, Coles et al. 2014). Large increases in impervious cover, together with increases in storm drains and channelization, can result in increases in the velocity and amount of water flowing in streams. An analysis of the relationship between stream insects and impervious cover in Maine streams found that increasing impervious cover (greater than six percent) was related to a decline in the taxonomic richness of the stream insect community (Morse et al. 2003). Of the 52 subwatersheds (HUC12) in the Narragansett Bay Watershed, 44 subwatersheds had over six percent impervious cover (see "Impervious Cover" chapter).

Land use changes, contributing increased pollutants such as sediment, nutrients from fertilizers, and other contaminants, have been linked to numerous types of changes in streams, such as (1) hydrology, including the amount, movement, and distribution of water, (2) physical habitat, the actual structure of the stream that is home for organisms (biota), such as invertebrates and fish, and (3) chemistry. While the mechanisms for these effects are understood, the response of streams to the multiple stressors associated with urbanization are complex. To support management, further investigation and analysis are needed to better characterize the effects of various stressors on stream conditions and to better understand the range of response in wadeable streams to urbanization in the Narragansett Bay Watershed (USGS 2004, Coles et al. 2014). Climate change also affects stream invertebrates through changes in precipitation patterns and rising temperatures (Poff et al. 2010, Fengqing 2013 et al.).

Aquatic organisms that dwell in riverine systems respond to environmental and biological interactions,
influencing the species assemblage of fish (see “Freshwater Fish Communities” chapter) and invertebrates (Annear et al. 2004). Since macroinvertebrates live months and even years in a stream, they encounter a wide range of stressors throughout the seasons. The macroinvertebrate communities assimilate the effects of different pollution sources over time, providing an aggregate or cumulative measure of stressors (Plafkin et al. 1989). If a stream macroinvertebrate community lacks pollution-sensitive species or is dominated by pollution-tolerant species, it is generally indicative of poor water quality conditions and stream habitat disturbance. Macroinvertebrate communities sampled from degraded waters usually have low species richness and abundance. Therefore, sampling the resident communities provides a stable representation of constantly fluctuating environmental conditions (Rosenberg and Resh 1996). Quantifying macroinvertebrate diversity and abundance can serve as an indicator to characterize the general conditions of a watershed. An example of different macroinvertebrate communities indicating various stream conditions is shown in Figure 1.

Because benthic macroinvertebrate communities reflect water quality and aquatic habitat disturbance over time and are relatively easy to collect and identify, biomonitoring is a cost-effective screening tool to monitor for general stressors (Barbour et al. 1999). In fact, stream macroinvertebrates are the most widely used biological assemblage in monitoring conducted by state water resource agencies (USEPA, undated). In New England, state agencies have used various methods of biomonitoring to evaluate rivers and streams (Shelton and Blocksom 2004). The Massachusetts Department of Environmental Protection (MassDEP) began collecting macroinvertebrate, habitat, and physical-chemical data from wadeable streams (streams shallow enough for the analyst to safely walk into with chest waders) beginning in 1983, while the Rhode Island Department of Environmental Management (RIDE) began a wadeable treatment.

![Figure 1. Example of stream macroinvertebrate communities as indicators of water quality conditions and stream habitat disturbance. Credit: Tom Danielson, Maine DEP.](image-url)
stream macroinvertebrate sampling program in 1991 in cooperation with Roger Williams University (RIDEM 2005).

Sampling protocols have evolved over the years, but wadeable stream methodologies are generally based on the EPA’s Rapid Bioassessment Protocols (Barbour et al. 1999) to measure local habitat features (e.g., physical structure, flow regime), water quality parameters, and macroinvertebrate communities (Nuzzo 2003, ESS Group, Inc. 2014). The quality of in-stream habitat and surrounding buffer habitats are major factors influencing the health and diversity of stream invertebrates (Plafkin et al. 1989). Each state agency’s quality assurance and quality control documents describe their specific methods, as does the Consolidated Assessment and Listing Methodology for the Preparation of the Integrated Water Quality Monitoring and Assessment report (MassDEP 2016, RIDEM 2014).

In this chapter, the Narragansett Bay Estuary Program reports on the number of sites in the Narragansett Bay Watershed that were characterized as either “good” or “poor” based on macroinvertebrate health and habitat quality by the state agencies, MassDEP and RIDEM. The Estuary Program and partners simplified the state classification-categories for benthic macroinvertebrate health and habitat quality and then combined macroinvertebrate health and habitat quality into a general indicator of stream condition in the Narraganset Bay Watershed. Because the Estuary Program relied on data from state agencies in Massachusetts and Rhode Island, the categorization scheme used in this chapter was developed through a bi-state effort involving MassDEP and RIDEM. Massachusetts and Rhode Island use different metrics in their respective indices of biological integrity (IBIs) (Nuzzo 2003, ESS Group, Inc. 2014), but the resulting classification categories are similar. For example, the numeric thresholds used by RIDEM correspond to the same qualitative descriptors used by MassDEP. It is important to highlight that the individual and collective metrics used by each state for their IBIs were not the focus of this indicator.

**Methods**

Habitat and invertebrate data are collected from streams and used by both Massachusetts and Rhode Island to assess stream conditions relative to state water quality criteria. Using a net, invertebrate samples are collected from stream sites and then brought to the lab for taxonomic identification and enumeration. Habitat quality is evaluated visually following the Rapid Bioassessment Protocol, scoring ten parameters that describe in-stream habitats, stream channel morphology (shape), and structure of the stream banks and buffers (Barbour et al. 1999). This information is supplemented with data on additional physical characteristics of the site observed during monitoring: surrounding land use; presence or absence of dams; local stream erosion; potential non-point source pollution; stream width, depth and flow; inorganic and organic substrate types; and presence of odors, oils and deposits (Plafkin et al. 1989), as observed in the field and relying on best professional judgment.

The states calculate stream macroinvertebrate health according to each state’s Index of Biotic Integrity (IBI) data and habitat quality based on state scores, and this information is used as part of each state’s Integrated Water Quality Monitoring and Assessment Report (MassDEP 2012 and 2016, RIDEM 2014). The Narragansett Bay Estuary Program summarized the data from state agencies to categorize stream macro-invertebrate health and habitat quality.

Habitat measurements used in the methods in this chapter are not the results reported under the official state “Fish & Wildlife Habitat” in the 303(d) state assessment reports. Each state uses several types of data (habitat, invertebrates, and multiple water quality parameters) to assess if a waterbody is meeting its “Fish & Wildlife Habitat” use. However, the metrics used by each state vary. Therefore, the category used by the Estuary Program to determine habitat quality condition should not be compared against the determinations made by the states for aquatic life use.

It is also important to keep in mind that site selection for monitoring followed the states’ protocols for sampling stream macroinvertebrates. In general, the streams are characterized by riffles, and in Rhode Island, these sites are within the Southern New England Coastal Plains and Hills ecoregion (Griffith et al. 2009, Figure 2). Riffles are characterized by shallow depths and streambeds composed of cobbles and other coarser materials over which the water flows, whereas pools are deeper areas of streams characterized by finer materials such as silt. Riffles are considered to contribute to healthy aquatic environments because the turbulent flow leads to high concentrations of dissolved oxygen.

This indicator quantifies the number of sites by stream condition level for sites in the Massachusetts and Rhode Island portions of the Narragansett Bay Watershed.
STREAM MACROINVERTEBRATE HEALTH

Data collected through sampling the macroinvertebrate assemblage allows for the calculation of total taxa, percent of dominant taxa, and other metrics that can be used to help distinguish overall stream condition. Based on earlier work, both MassDEP and RIDEM have selected certain metrics that are combined to form an Index of Biotic Integrity (IBI). The IBIs allow an invertebrate sample to be scored using a scale in which higher scores represent better stream conditions. Although Rhode Island and Massachusetts use differing metrics and equations, both states have threshold values that they use to categorize the invertebrate sample results. Rhode Island refers to the categorization as a Biological Condition Category, while Massachusetts uses a Rapid Bioassessment Protocol Status (Table 1).

For this indicator’s metric of good or poor macroinvertebrate health, the Estuary Program combined the state data using thresholds for stream macroinvertebrate health because 1) it was determined by both state agencies that the descriptors used by MassDEP to classify the IBI results are comparable with the thresholds used by RIDEM, 2) it was not within the scope of this chapter to reconcile metrics from different IBIs, and 3) a classification-category can provide a useful picture of the stream conditions characterized by macroinvertebrate health and habitat quality, as discussed below. For results of metrics and IBIs as developed by each state, the reader should contact MassDEP and/or RIDEM.

Stream macroinvertebrate data available for this indicator were collected from 2002 to 2014 in Rhode Island and from 2006 to 2009 in Massachusetts. Both state agencies have monitored different basins each year and over time sampled throughout the Watershed, with a somewhat higher density of sampling sites located in Rhode Island. The implications of the temporal differences in the data are discussed further below.

In 2002, RIDEM expanded its biological monitoring program to begin collecting data using EPA’s Rapid Bioassessment Protocol identifying macroinvertebrates at a higher taxonomic resolution (ESS 2014). In 2004, the monitoring station selection process was expanded to incorporate a rotating basin approach. More recently, RIDEM began moving toward development of a new assessment method using a biotic index to compare stations against a reference condition model, known as the Multi-Metric Biological Condition Index (abbreviated as MBCI in tables). The MBCI is a tool to classify stream health relative to the reference condition (Tetra Tech 2011) for stations located in the Southern New England Coastal Plains and Hills ecoregion (Griffith et al. 2009; Figure 2).

In Massachusetts, MassDEP shifted in 2010 from targeted sampling in each watershed (each with its own reference, or “least disturbed,” site). The Massachusetts Probabilistic Monitoring and Assessment Program (MAP2) uses data from randomly selected sites to generate an unbiased assessment of water quality conditions throughout the state (MAP2 2017). In conjunction with this approach, the agency in 2011 developed a Reference Site Network using statewide probabilistic sampling of basins on a rotating basis (Nuzzo, personal correspondence). From these data, the agency intends to develop metrics to distinguish between healthy and unhealthy aquatic ecosystems, rather than selecting a reference site for each watershed each time sampling is conducted. However, the most recent data from the five-year cycle of probabilistic analysis between 2010 and 2015 were not available at the time this chapter was written.

<table>
<thead>
<tr>
<th>Macroinvertebrate Health Level</th>
<th>MassDEP Rapid Bioassessment Protocol Status</th>
<th>RIDEM IBI Thresholds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good Macroinvertebrate Health</td>
<td>Not Impacted</td>
<td>&gt;85</td>
</tr>
<tr>
<td></td>
<td>Slightly Impacted</td>
<td>56–85</td>
</tr>
<tr>
<td>Poor Macroinvertebrate Health</td>
<td>Moderately Impacted</td>
<td>36–55</td>
</tr>
<tr>
<td></td>
<td>Severely Impacted</td>
<td>&lt;35</td>
</tr>
</tbody>
</table>
HABITAT QUALITY

Both MassDEP and RIDEM use the same habitat assessment protocol to observe and quantify each of the ten habitat parameters at each site, as listed below, to report a total habitat score, on a scale of 0 to 20 or 0 to 10, depending on the parameter (Nuzzo 2003, ESS 2014):

1. Instream Cover (Fish)
2. Epifaunal Substrate
3. Embeddedness
4. Channel Alteration
5. Sediment Deposition
6. Frequency of Riffles/Velocity-Depth
7. Channel Flow Status
8. Bank Vegetative Protection
9. Bank Stability
10. Riparian Vegetative Zone Width

These scores can be grouped into four categories (from optimal to poor habitat condition) to describe the general habitat conditions at a sampling station (Table 2). Using those scores, the Estuary Program categorized habitat quality as Good or Poor (Table 2).

STREAM CONDITION LEVEL COMBINING MACROINVERTEBRATE HEALTH AND HABITAT QUALITY

The Estuary Program and partners simplified the state classification-categories for benthic macroinvertebrate health and habitat quality (Tables 1 and 2) and then combined macroinvertebrate health and habitat quality into a general indicator of stream condition in the Narraganset Bay Watershed. As shown in Table 3, the Estuary Program’s indicator has three categories:

- Good Macroinvertebrate Health and Good Habitat Quality
- Poor Macroinvertebrate Health and Good Habitat Quality
- Poor Macroinvertebrate Health and Poor Habitat Quality

Macroinvertebrate data for Rhode Island were from 2002 to 2014, and those for Massachusetts were from 2006 to 2009. To identify sites from the state-wide macroinvertebrate monitoring programs that are located within Narragansett Bay Watershed, the latitude and longitude for each sampling site were mapped, and associated with River Basins, HUC10 watersheds, and HUC12 subwatersheds, by means of geospatial analysis (Esri 2016; see the Appendix for definitions, lists and maps of River Basins, HUC10 watersheds, and HUC12 subwatersheds). Because macroinvertebrate monitoring follows the timeline of each state’s strategy for water quality assessment, using a basin-based rotation approach, the majority of the sampling sites were not monitored more than once within the data collection period. Thus, a trend analysis was not possible due to lack of temporal data for all sites. Because the data were collected over a period of twelve years and many streams were

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Table 2. The Narragansett Bay Estuary Program’s categories of Good and Poor Habitat Quality, derived from the Rapid Bioassessment Protocol (USEPA) utilized by Massachusetts and Rhode Island.

<table>
<thead>
<tr>
<th>Habitat Quality Levels</th>
<th>State Habitat Condition Categories</th>
<th>State Habitat Total Score Thresholds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good Habitat Quality</td>
<td>Optimal Habitat&lt;sup&gt;(1)&lt;/sup&gt;</td>
<td>&gt;150</td>
</tr>
<tr>
<td></td>
<td>Suboptimal Habitat&lt;sup&gt;(2)&lt;/sup&gt;</td>
<td>101–150</td>
</tr>
<tr>
<td>Poor Habitat Quality</td>
<td>Marginal Habitat&lt;sup&gt;(3)&lt;/sup&gt;</td>
<td>51–100</td>
</tr>
<tr>
<td></td>
<td>Poor Habitat&lt;sup&gt;(4)&lt;/sup&gt;</td>
<td>&lt;51</td>
</tr>
</tbody>
</table>

<sup>(1)</sup> Optimal Habitat scores range between 16 to 20, or 9 to 10, depending on the scale that corresponds to each parameter.

<sup>(2)</sup> Suboptimal Habitat scores range between 11 to 15, or 6 to 8, depending on the scale that corresponds to each parameter.

<sup>(3)</sup> Marginal Habitat scores range between 6 to 10 or 3 to 5, depending on the scale that corresponds to each parameter.

<sup>(4)</sup> Poor Habitat scores range between 0 to 5, or 0 to 2, depending on the scale that corresponds to each parameter.
Table 3. The Estuary Program’s three stream condition levels used to categorize monitoring sites: Good Macroinvertebrate Health and Good Habitat Quality (blue); Poor Macroinvertebrate Health and Good Habitat Quality (green); Poor Macroinvertebrate Health and Poor Habitat Quality (orange). The colors correspond to sites in each category on the map in Figure 2.

<table>
<thead>
<tr>
<th>Habitat Quality</th>
<th>Macroinvertebrate Health</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>GOOD</td>
<td>Good Macroinvertebrate Health and Good Habitat Quality</td>
<td></td>
</tr>
<tr>
<td>POOR</td>
<td>Poor Macroinvertebrate Health and Poor Habitat Quality</td>
<td></td>
</tr>
</tbody>
</table>

* The combination of poor habitat and good invertebrate health is generally not encountered and therefore was not included in the Estuary Program’s categorization scheme.

Table 4. Number and density of stream macroinvertebrate sample sites and total stream miles in the River Basins of the Narragansett Bay Watershed.

<table>
<thead>
<tr>
<th>River Basins</th>
<th>Number of Sites (Percent of All Sites in the Watershed)</th>
<th>Total Stream (1) Miles in the River Basin</th>
<th>River Basin Area (square miles)</th>
<th>Density of Sites in Basin (sites per stream mile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blackstone River</td>
<td>30 (38%)</td>
<td>1,137.0</td>
<td>474.6</td>
<td>0.03</td>
</tr>
<tr>
<td>Coastal Narragansett Bay</td>
<td>15 (19%)</td>
<td>827.4</td>
<td>468.9</td>
<td>0.02</td>
</tr>
<tr>
<td>Pawtuxet River</td>
<td>21 (27%)</td>
<td>443.6</td>
<td>231.9</td>
<td>0.05</td>
</tr>
<tr>
<td>Taunton River</td>
<td>12 (15%)</td>
<td>1,170.2</td>
<td>529.5</td>
<td>0.01</td>
</tr>
<tr>
<td>Total Narragansett Bay Watershed</td>
<td>78</td>
<td>3,578.3</td>
<td>1,704.9</td>
<td>0.02</td>
</tr>
</tbody>
</table>

(1) National Hydrography Dataset
sampled five to ten years ago, the results from this analysis should be considered as a view of stream macroinvertebrate conditions over that timeframe.

The Estuary Program quantified the number of sites for each of the three stream condition levels (Table 3) and summarized them by River Basins and HUC10 watersheds, including the percentage of sites in each stream condition level. This information characterizes the general stream conditions only in areas of the Narragansett Bay Watershed where stream macroinvertebrates communities have been used as an indicator of water quality; the information about stream conditions and water quality does not apply to other areas of the Watershed.

To provide a measure of how thoroughly the data represent each River Basin, the density of monitoring sites was calculated. The total stream miles were calculated to determine the density of sites per stream mile within each River Basin, which ranged from 0.01 to 0.05 sites per stream mile (Table 4). The results indicated that fewer data were available for streams in the Taunton River Basin and for coastal streams draining directly into Narragansett Bay. Methods for assessing stream invertebrates in Rhode Island are not applied to many of the coastal freshwater streams, as they do not present the appropriate conditions for sampling in riffle habitats, where flowing water tumbles over rocks and cobblestones in the stream. Many coastal streams have sandy, mucky bottoms and are in regions with low elevations that do not have riffle habitat. It is important to acknowledge that site density results are based on all stream miles in the Watershed, and not only the stream segments that are suitable for monitoring stream macroinvertebrates. Future work is needed to quantify and evaluate the length of the stream and the drainage area of which each site is representative.

**Status**

As discussed above, the dataset developed for this report covered a period from 2002 to 2014. The results provide a general representation of stream conditions for this period that is presumed to be reasonably indicative of the status of those wadeable streams that were monitored. MassDEP and RIDEM had a total of 78 sites in the Narragansett Bay Watershed where they monitored stream macroinvertebrates. The Blackstone River Basin had the highest (38 percent) number of sites and the Taunton River Basin had the lowest (15 percent), as a percentage of all sites monitored in the Narragansett Bay Watershed (Table 3). The density of sites in each River Basin showed that while the Blackstone River and Taunton River Basins have comparable areas and total number of stream miles, the density of monitoring sites in the Blackstone River Basin was three times that of the Taunton River Basin (Table 4).

Of the 78 stream sites in the Narragansett Bay Watershed, 62 sites had Good Macroinvertebrate Health and Good Habitat Quality (79 percent of classified stream sites), and fifteen sites (nineteen percent) had Poor Macroinvertebrate Health and Good Habitat Quality (Table 5; Figure 2). Only one site in the Watershed, in the Taunton River Basin, had Poor Macroinvertebrate Health and Poor Habitat Quality (Figure 2, partially obscured near Brockton).

At the River Basin and HUC10 watershed scales, the Pawtuxet River Basin and the Blackstone River Basins had 90 and 80 percent of their sites, respectively, showing good stream condition levels based on both macroinvertebrate health and habitat quality.

Overall, the high number and percentage of sites that had healthy stream conditions were expected from these results. Riffles are good habitats for stream macroinvertebrates, and most wadeable stream sampling occurs in small headwater streams where water quality and surrounding habitat are in good condition, thus leading to good stream condition. However, sites with poor macroinvertebrate health but good habitat may have factors such as water pollution affecting stream macroinvertebrates, causing species tolerant of degraded water quality conditions to dwell at these sites at the time of monitoring.

To compare stream condition among River Basins based on stream macroinvertebrates and habitat, the results for each stream condition level were summarized by the number of sites in each River Basin (Table 6). Most of the 62 sites with Good Macroinvertebrate Health and Good Habitat Quality were located in the Blackstone River Basin (39 percent) and the Pawtuxet River Basin (31 percent). Of the fifteen sites in the Watershed that had Poor Macroinvertebrate Health and Good Habitat Quality, 40 percent were in the Blackstone River Basin, followed by 27 percent in the Coastal Narragansett Bay Basin (Table 6).
Figure 2. Stream condition levels in the Narragansett Bay Watershed based on stream macroinvertebrate monitoring.

Stream Invertebrates and Habitat Quality

Monitoring Sites: Stream Condition Levels

- Invertebrate Health: Good; Habitat Quality: Good
- Invertebrate Health: Poor; Habitat Quality: Good
- Invertebrate Health: Poor; Habitat Quality: Poor
Discussion

For the period from 2002 to 2014, available data on stream condition levels in the Narragansett Bay Watershed, including many headwater streams, reflected a positive finding in that a majority of the streams sampled indicated good ecological conditions for macroinvertebrates. However, the results should be interpreted with caution to avoid extrapolating this characterization of conditions to all streams across the Watershed. The findings of this indicator do not necessarily apply to all wadeable streams in the Narragansett Bay Watershed, but only those with appropriate riffle habitat. In addition, data were not available from many portions of coastal streams because the data collection methods are not suitable as these streams tend to have lower gradients, slow-moving water, silty bottoms, and deeper water depths. Because many of these lowland streams lack the appropriate riffle habitat required for the assessment, coastal streams are poorly represented in the assessment.

Therefore, the results are specifically reflective of the type of small, shallow, wadeable streams that were sampled in the Watershed by the state agencies, MassDEP and RIDEM. Given land use patterns in the Watershed, sampling locations in upstream parts of the Watershed would in general be expected to be located in less-developed areas and to support better habitat and water quality. Based on these criteria and factors that influence stream invertebrate sampling and also the results as presented, it is important to note that the Watershed characteristics vary among River Basins, topographically and hydrologically, not to mention the different characteristics driven by human uses in the landscape. The Blackstone River Basin is characterized by higher elevations and fragmented streams and rivers, primarily by dams, whereas the Taunton River Basin is generally characterized by low-lying lands, and where estuarine waters meet freshwaters in approximately 20 miles of an unobstructed Taunton River. Coastal areas tend to be more developed, and the Pawtuxet River Basin is characterized by moderate elevations with a forested landscape, mainly in the upper reaches of the watershed.

Despite the disparate and low number of sampling sites within and across River Basins (Table 5), the

<table>
<thead>
<tr>
<th>River Basins</th>
<th>Stream Condition Level</th>
<th>Total Number of Sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>HUC10 Watershed Name</td>
<td>Good Macroinvertebrate Health and Good Habitat Quality</td>
<td>Poor Macroinvertebrate Health and Poor Habitat Quality</td>
</tr>
<tr>
<td>Blackstone River Basin</td>
<td>80% (24 sites)</td>
<td>20% (6 sites)</td>
</tr>
<tr>
<td>Upper Blackstone River</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>Lower Blackstone River</td>
<td>16</td>
<td>4</td>
</tr>
<tr>
<td>Coastal Narragansett Bay Basin</td>
<td>73% (11 sites)</td>
<td>27% (4 sites)</td>
</tr>
<tr>
<td>Ten Mile River</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Palmer River</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Narragansett Bay</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Woonasquatucket-Moshassuck Rivers</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Pawtuxet River Basin</td>
<td>90% (19 sites)</td>
<td>10% (2 sites)</td>
</tr>
<tr>
<td>Taunton River Basin</td>
<td>67% (8 sites)</td>
<td>25% (3 sites)</td>
</tr>
<tr>
<td>Upper Taunton River</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Lower Taunton &amp;</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Frontal Mt. Hope Bay</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Three Mile River</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Total Narragansett Bay Watershed</td>
<td>79% (62 sites)</td>
<td>19% (15 sites)</td>
</tr>
</tbody>
</table>
findings by River Basin indicate, in terms of the geography and topography of the Watershed, that riffle habitat is primarily found in the upper reaches of the Watershed. These sites provide suitable conditions for healthy stream macroinvertebrates, whereas the lowlands, such as the coastal areas (Table 5 and Figure 2), are less likely to provide the geomorphological conditions for riffles or habitat conditions have been deteriorated by development pressures. In the Taunton River, it is assumed there are fewer monitoring sites because of its flattened watershed, thus providing fewer sites with suitable riffle habitat, or sampling effort is simply small compared with other River Basins.

Within the Narragansett Bay Watershed, the Pawtuxet River and the Blackstone River Basins have 65 percent of the sampling sites in the Watershed, reflecting that they contain most of the riffle habitat within the entire Watershed, and correspondingly they contain most of the sites with good macroinvertebrate health and good habitat quality (Tables 5 and 6). These sites and others throughout the Watershed with both good macroinvertebrate health and good habitat quality should continue to be routinely tracked and targeted for enhanced watershed protection if warranted. While the Blackstone River Basin is represented by good macroinvertebrate health and good habitat quality, it also contains 20 percent of the sampled sites classified as poor macroinvertebrate health and good habitat quality. As previously noted, this may indicate water quality problems such as nutrient enrichment or other pollution issues (Plafkin et al. 1989). Macroinvertebrate health may improve at these sites following implementation of appropriate best management practices aimed at water quality improvement.

MassDEP and RIDEM have found that water quality degradation is more likely to be occurring in the densely developed watersheds. Results from landscape stressor indicators developed by the Estuary Program show that watersheds and subwatersheds (HUC10 and HUC12 respectively; see the Appendix for definitions, lists, and maps) within the Coastal Narragansett Bay Basin are highly populated (see “Population” chapter) and intensively urbanized (see “Land Use” chapter) with the highest percentages of impervious cover (see “Impervious Cover” chapter). While all but one site had good habitat quality, and fifteen sites were found as having poor macroinvertebrate health, the effects of urbanization and other landscape, chemical, and climatic stressors may be contributing to the degradation of water quality.

Efforts by other partners are producing new information about stream invertebrates and other biological indicators in the Narragansett Bay Watershed. For example, EPA’s Atlantic Ecology Division (AED) monitored macroinvertebrates in streams at 105 sites across the Watershed in 2012 and 2013. The sites encompassed an impervious cover gradient in which fifteen reference sites had less than one percent impervious cover and 90 sites had varying percentages of cover (Anne Kuhn, personal communication; a report is in preparation). Future collaborative partnerships should be sought to continue using stream macroinvertebrates as biological indicators to augment the understanding of and track changes in stream conditions in the Narragansett Bay Watershed.

Table 6. Percentage of all sites in the Narragansett Bay Watershed in each stream condition level that were located in each River Basin.

<table>
<thead>
<tr>
<th>River Basins</th>
<th>Percent of Sites by Stream Condition Level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Good Macroinvertebrate Health</td>
</tr>
<tr>
<td>Good Habitat Quality</td>
<td>Good Habitat Quality</td>
</tr>
<tr>
<td>Blackstone River</td>
<td>39</td>
</tr>
<tr>
<td>Coastal Narragansett Bay</td>
<td>18</td>
</tr>
<tr>
<td>Pawtuxet River</td>
<td>31</td>
</tr>
<tr>
<td>Taunton River</td>
<td>13</td>
</tr>
</tbody>
</table>

(1) A monitoring site in the Taunton River Basin was the only one in the Narragansett Bay Watershed with both poor macroinvertebrate health and poor habitat quality.
Data Gaps and Research Needs

- Existing macroinvertebrate sampling protocols are not appropriate for all rivers and streams in the Watershed. To address coastal streams left unassessed, a multi-year effort of data collection and evaluation is needed and should be conducted at a regional scale to sample a sufficient number of locations in the lowland ecoregion streams. The data should be used to develop a robust biotic index for use in the lowland ecoregions for which the current rapid bioassessment protocol is not appropriate.

- Further analysis of existing data is needed to evaluate how well the existing monitoring strategies represent the conditions of the wadeable rivers and streams throughout the entire Watershed.

- Characterization of stream segments (by calculating stream miles) and drainage area (by defining the contributing catchment area to the site) is needed to study the influences of landscape stressors and other factors on stream conditions. The characterization should focus on sites where macroinvertebrate health was poor but habitat conditions were good. The findings could be used to help identify and ameliorate potential threats at sites with good macroinvertebrate health and good habitat quality that need protection.

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References


