**Estuary Delineation Assessment EDA 2.1 Summary**

## *Methods*

Based on feedback from MassBays Science and Technical Advisory Committee (STAC) and regional coordinators, we made the following modifications to the estuary delineation assessment (EDA 2.0):

1. we calculated resource and stressor attributes for Salem Sound (22) and included it as one of the embayments in the region;
2. with the addition of Salem Sound, we removed and replaced four component embayments with overlapping areas – Manchester Harbor (17), Danvers River (19), Forest River / South River / Salem Harbor (20), and Marblehead Harbor (21);
3. we removed Black Rock Creek (1) because it does not constitute an embayment, according to the definition used for this project
4. we incorporated water transport time data generated by Woods Hole Group and compiled by Todd Callaghan (Office of Coastal Zone Management) to assess the role of tidal flushing in embayment categorization;
5. we added a standardized measure of natural shoreline unsuitable for hardening (ESI codes 1A, 1C, 2A, 2B, 3B, 8A, and 8D, which refer primarily to rocky shoreline, vertical escarpments, etc.) – hereafter ‘unhardenable’ – calculated as (km shoreline unhardenable

/ km total shoreline) \* 100 to account for the proportion of rocky shoreline in each embayment

## *Results*

Based on partitioning around mediods (PAM) using the updated dataset, there are two separate clusters. However, we visualize the results of the multidimensional PCA using ordination diagrams depicting two, four, and six clusters to allow examination of the different clusters and to facilitate comparison between EDA 2.1 clusters and ecotypes identified to inform the Biological Condition Gradient (BCG).

In all cases, the first two axes of the principal component analysis (PCA) explain 55.9% of the total variation in embayment characteristics, with axes 1 and 2 explaining 37.6% and 18.3%, respectively. In addition, axis 3 explained 15.3% of the total variation, but additional axes explained <10% each. Positive axis 1 values were associated with a greater proportion of hardened shoreline, high intensity land use, bacterially-impaired water, more severe CAPS tidal restriction, larger population density, and greater tidal flushing, whereas negative axis 1 values were associated with a larger proportion of population using septic systems, as well as more tidal flats and greater salt marsh extent and shoreline (Table 1). Positive axis 2 values corresponded to a greater proportion of hardened shoreline, high intensity land use, and higher tidal flushing, as well as more natural shorelines, including tidal flats, seagrass beds, and rocky (i.e., unhardenable) shorelines, while negative axis 2 values corresponded to bacterially-impaired water and more severe CAPS tidal restriction, as well as greater salt marsh extent and shoreline (Table 1).

Table 1. Contribution of stressor and resource variables to the three components used in the PCA analysis. Bolded values (absolute value > 0.1) represent a substantial contribution of that variable to that component. The sign of the value represents the direction of the contribution.

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Component 1** | **Component 2** | **Component 3** |
| Tidal Flushing | **0.1773** | **0.2025** | **0.1022** |
| Rocky (unhardenable) | -0.0007 | **0.3181** | 0.0041 |
| Shoreline Hardened | **0.3856** | **0.4388** | 0.0993 |
| High Intensity Land Use | **0.1921** | **0.1389** | 0.0123 |
| Annual Stormwater Discharge | -0.0035 | 0.0088 | 0.0285 |
| Population Density | **0.1409** | 0.0565 | -0.0739 |
| % Population Using Septic System | **-0.6086** | -0.0248 | **0.5151** |
| Septic System Use | -0.0345 | 0.0251 | 0.0730 |
| Nutrient Impairment (Estuary, 303(d)) | -0.0531 | 0.0196 | -0.0680 |
| Bacterial Impairment (Estuary, 303(d)) | **0.3928** | **-0.2467** | **0.3949** |
| CAPS Tidal Restriction | **0.3165** | **-0.5285** | **-0.2878** |
| Salt Marsh Shoreline | **-0.1247** | **-0.4129** | -0.0583 |
| Salt Marsh Extent | **-0.2615** | **-0.1003** | -0.2075 |
| Seagrass | -0.0314 | **0.2217** | 0.0870 |
| Tidal Flat | **-0.2220** | **0.2669** | **-0.6365** |

Figure 1. Principal Component Analysis (PCA) grouping the 39 embayments into ***two*** clusters based on analysis of combined stressor and resource data and partitioning around mediods (PAM). Bay numbers correspond to embayments ordered from North (lowest number) to South (highest number); see Table 2 for embayment IDs and cluster assignments.

0.4

10

45

13

hard.of.hard

65

68

unhard.std

41

tidalflat.openwater

seagrass

61

57

59

percent.septic

56

53 55 39

60

40

tidal.flushing

high.intensity

pop.d3en3sity

27

22

26

29

30

sSneutoptrrtimiecn.watacrte STD

8

34

smacres.km

36

50

52

66

28

31 25

2

bacteria

percen7t.sm

51

5

37

tidal.restrict

4

3

6

0.2



0.0

Comp.2 (18.3%)

−0.2

−0.2 0.0 0.2

Comp.1 (37.59%)

Table 2. Bay numbers, embayment IDs, and assigned clusters based on PCA analysis in Figure 1, ordered from North to South.

|  |  |  |
| --- | --- | --- |
| **Id** | **Embayment** | **Cluster** |
| 2 | MERRIMACK RIVER | 1 |
| **3** | **PARKER RIVER** | **2** |
| **4** | **ROWLEY RIVER** | **2** |
| **5** | **IPSWICH RIVER** | **2** |
| **6** | **PLUM ISLAND SOUND** | **2** |
| **7** | **ESSEX RIVER / ESSEX BAY** | **2** |
| **8** | **ANNISQUAM RIVER** | **2** |
| 10 | ROCKPORT HARBOR (SANDY BAY) | 1 |
| 13 | GLOUCESTER HARBOR | 1 |
| 22 | SALEM SOUND | 1 |
| 25 | SAUGUS RIVER / PINES RIVER / LYNN HARBOR | 1 |
| 26 | BELLE ISLE CREEK / WINTHROP BAY | 1 |
| 27 | CHELSEA CREEK / MYSTIC RIVER / CHARLES RIVER | 1 |
| 28 | NEPONSET RIVER / DORCHESTER BAY | 1 |
| 29 | BLACKS CREEK / QUINCY BAY | 1 |
| 30 | BACK RIVER / FORE RIVER / HINGHAM BAY | 1 |
| 31 | WEIR RIVER / STRAITS POND | 1 |
| 33 | LITTLE HARBOR | 1 |
| **34** | **COHASSET HARBOR** | **2** |
| 36 | SCITUATE HARBOR | 1 |
| **37** | **NORTH RIVER/ SOUTH RIVER** | **2** |
| **39** | **BLUEFISH RIVER / BACK RIVER / DUXBURY BAY** | **2** |
| **40** | **JONES RIVER / KINGSTON BAY** | **2** |
| 41 | EEL RIVER / PLYMOUTH HARBOR | 1 |
| **45** | **ELLISVILLE HARBOR** | **2** |
| **50** | **SANDWICH HARBOR** | **2** |
| **51** | **SCORTON CREEK** | **2** |
| **52** | **BARNSTABLE HARBOR** | **2** |
| **53** | **CHASE GARDEN CREEK** | **2** |
| **55** | **SESUIT CREEK / SESUIT HARBOR** | **2** |
| **56** | **QUIVETT CREEK** | **2** |
| **57** | **PAINE'S CREEK / STONY BROOK** | **2** |
| **59** | **NAMSKAKET CREEK / LITTLE NAMSKAKET CREEK** | **2** |
| **60** | **BOAT MEADOW CREEK / ROCK HARBOR** | **2** |
| **61** | **HERRING RIVER / HERRING POND** | **2** |
| **65** | **WELLFLEET HARBOR** | **2** |
| **66** | **PAMET RIVER / LITTLE PAMET RIVER** | **2** |
| **68** | **PROVINCETOWN HARBOR** | **2** |

Figure 2. Principal Component Analysis (PCA) grouping the 39 embayments into ***four*** clusters based on analysis of combined stressor and resource data. Bay numbers correspond to embayments ordered from North (lowest number) to South (highest number); see Table 3 for embayment IDs and cluster assignments.

0.4

10

45

13

hard.of.hard

65

68

unhard.std

41

tidalflat.openwater

seagrass

61

57

59

percent.septic

56

53 55 39

60

40

tidal.flushing

high.intensity

pop.d3en3sity

27

22

26

29

30

sSneutoptrrtimiecn.watacrte STD

8

34

smacres.km

36

50

52

66

28

31 25

2

bacteria

percen7t.sm

51

5

37

tidal.restrict

4

3

6

0.2



0.0

Comp.2 (18.3%)

−0.2

−0.2 0.0 0.2

Comp.1 (37.59%)

Table 3. Bay numbers, embayment IDs, and assigned clusters based on PCA analysis in Figure 2, ordered from North to South.

|  |  |  |
| --- | --- | --- |
| **Id** | **Embayment** | **Cluster** |
| **2** | **MERRIMACK RIVER** | **4** |
| **3** | **PARKER RIVER** | **4** |
| **4** | **ROWLEY RIVER** | **4** |
| **5** | **IPSWICH RIVER** | **4** |
| **6** | **PLUM ISLAND SOUND** | **4** |
| **7** | **ESSEX RIVER / ESSEX BAY** | **4** |
| **8** | **ANNISQUAM RIVER** | **4** |
| 10 | ROCKPORT HARBOR (SANDY BAY) | 1 |
| 13 | GLOUCESTER HARBOR | 1 |
| **22** | **SALEM SOUND** | **3** |
| **25** | **SAUGUS RIVER / PINES RIVER / LYNN HARBOR** | **3** |
| **26** | **BELLE ISLE CREEK / WINTHROP BAY** | **3** |
| **27** | **CHELSEA CREEK / MYSTIC RIVER / CHARLES RIVE** | **R 3** |
| **28** | **NEPONSET RIVER / DORCHESTER BAY** | **3** |
| **29** | **BLACKS CREEK / QUINCY BAY** | **3** |
| **30** | **BACK RIVER / FORE RIVER / HINGHAM BAY** | **3** |
| **31** | **WEIR RIVER / STRAITS POND** | **3** |
| **33** | **LITTLE HARBOR** | **4** |
| **34** | **COHASSET HARBOR** | **4** |
| **36** | **SCITUATE HARBOR** | **4** |
| **37** | **NORTH RIVER/ SOUTH RIVER** | **4** |
| **39** | **BLUEFISH RIVER / BACK RIVER / DUXBURY BAY** | **4** |
| **40** | **JONES RIVER / KINGSTON BAY** | **4** |
| 41 | EEL RIVER / PLYMOUTH HARBOR | 1 |
| **45** | **ELLISVILLE HARBOR** | **2** |
| **50** | **SANDWICH HARBOR** | **4** |
| **51** | **SCORTON CREEK** | **4** |
| **52** | **BARNSTABLE HARBOR** | **4** |
| **53** | **CHASE GARDEN CREEK** | **4** |
| **55** | **SESUIT CREEK / SESUIT HARBOR** | **4** |
| **56** | **QUIVETT CREEK** | **2** |
| **57** | **PAINE'S CREEK / STONY BROOK** | **2** |
| **59** | **NAMSKAKET CREEK / LITTLE NAMSKAKET CREEK** | **2** |
| **60** | **BOAT MEADOW CREEK / ROCK HARBOR** | **4** |
| **61** | **HERRING RIVER / HERRING POND** | **2** |
| **65** | **WELLFLEET HARBOR** | **2** |
| **66** | **PAMET RIVER / LITTLE PAMET RIVER** | **4** |
| 68 | PROVINCETOWN HARBOR | 1 |

Figure 3. Principal Component Analysis (PCA) grouping the 39 embayments into ***six*** clusters based on analysis of combined stressor and resource data. Bay numbers correspond to embayments ordered from North (lowest number) to South (highest number); see Table 4 for embayment IDs and cluster assignments.

0.4

10

45

13

hard.of.hard

65

68

unhard.std

41

tidalflat.openwater

seagrass

61

57

59

percent.septic

56

5355 39

tidal.flushing

high.intensity

27

22

60

40

29

Ssnteuoptrrtmicew.naatctreerSTD

pop.d3e3nsity

26

30

8

34

smacres.km

36

50

52

66

28

31 25

2

bacteria

percen7t.sm

51

5

37

tidal.restrict

4

3

6

0.2



0.0

Comp.2 (18.3%)

−0.2

−0.2 0.0 0.2

# Comp.1 (37.59%)

Table 4. Bay numbers, embayment IDs, and assigned clusters based on PCA analysis in Figure 3, ordered from North to South.

|  |  |  |
| --- | --- | --- |
| **Id** | **Embayment** | **Cluster** |
| 2 | MERRIMACK RIVER | 1 |
| **3** | **PARKER RIVER** | **3** |
| **4** | **ROWLEY RIVER** | **3** |
| **5** | **IPSWICH RIVER** | **3** |
| **6** | **PLUM ISLAND SOUND** | **3** |
| **7** | **ESSEX RIVER / ESSEX BAY** | **3** |
| 8 | ANNISQUAM RIVER | 1 |
| **10** | **ROCKPORT HARBOR (SANDY BAY)** | **6** |
| **13** | **GLOUCESTER HARBOR** | **6** |
| **22** | **SALEM SOUND** | **5** |
| **25** | **SAUGUS RIVER / PINES RIVER / LYNN HARBOR** | **5** |
| **26** | **BELLE ISLE CREEK / WINTHROP BAY** | **5** |
| **27** | **CHELSEA CREEK / MYSTIC RIVER / CHARLES RIVE** | **R5** |
| **28** | **NEPONSET RIVER / DORCHESTER BAY** | **5** |
| **29** | **BLACKS CREEK / QUINCY BAY** | **5** |
| **30** | **BACK RIVER / FORE RIVER / HINGHAM BAY** | **5** |
| 31 | WEIR RIVER / STRAITS POND | 1 |
| 33 | LITTLE HARBOR | 1 |
| 34 | COHASSET HARBOR | 1 |
| 36 | SCITUATE HARBOR | 1 |
| **37** | **NORTH RIVER/ SOUTH RIVER** | **3** |
| **39** | **BLUEFISH RIVER / BACK RIVER / DUXBURY BAY** | **4** |
| **40** | **JONES RIVER / KINGSTON BAY** | **4** |
| **41** | **EEL RIVER / PLYMOUTH HARBOR** | **6** |
| **45** | **ELLISVILLE HARBOR** | **2** |
| **50** | **SANDWICH HARBOR** | **4** |
| **51** | **SCORTON CREEK** | **3** |
| **52** | **BARNSTABLE HARBOR** | **4** |
| **53** | **CHASE GARDEN CREEK** | **4** |
| **55** | **SESUIT CREEK / SESUIT HARBOR** | **4** |
| **56** | **QUIVETT CREEK** | **4** |
| **57** | **PAINE'S CREEK / STONY BROOK** | **2** |
| **59** | **NAMSKAKET CREEK / LITTLE NAMSKAKET CREEK** | **2** |
| **60** | **BOAT MEADOW CREEK / ROCK HARBOR** | **4** |
| **61** | **HERRING RIVER / HERRING POND** | **2** |
| **65** | **WELLFLEET HARBOR** | **2** |
| **66** | **PAMET RIVER / LITTLE PAMET RIVER** | **3** |
| **68** | **PROVINCETOWN HARBOR** | **6** |