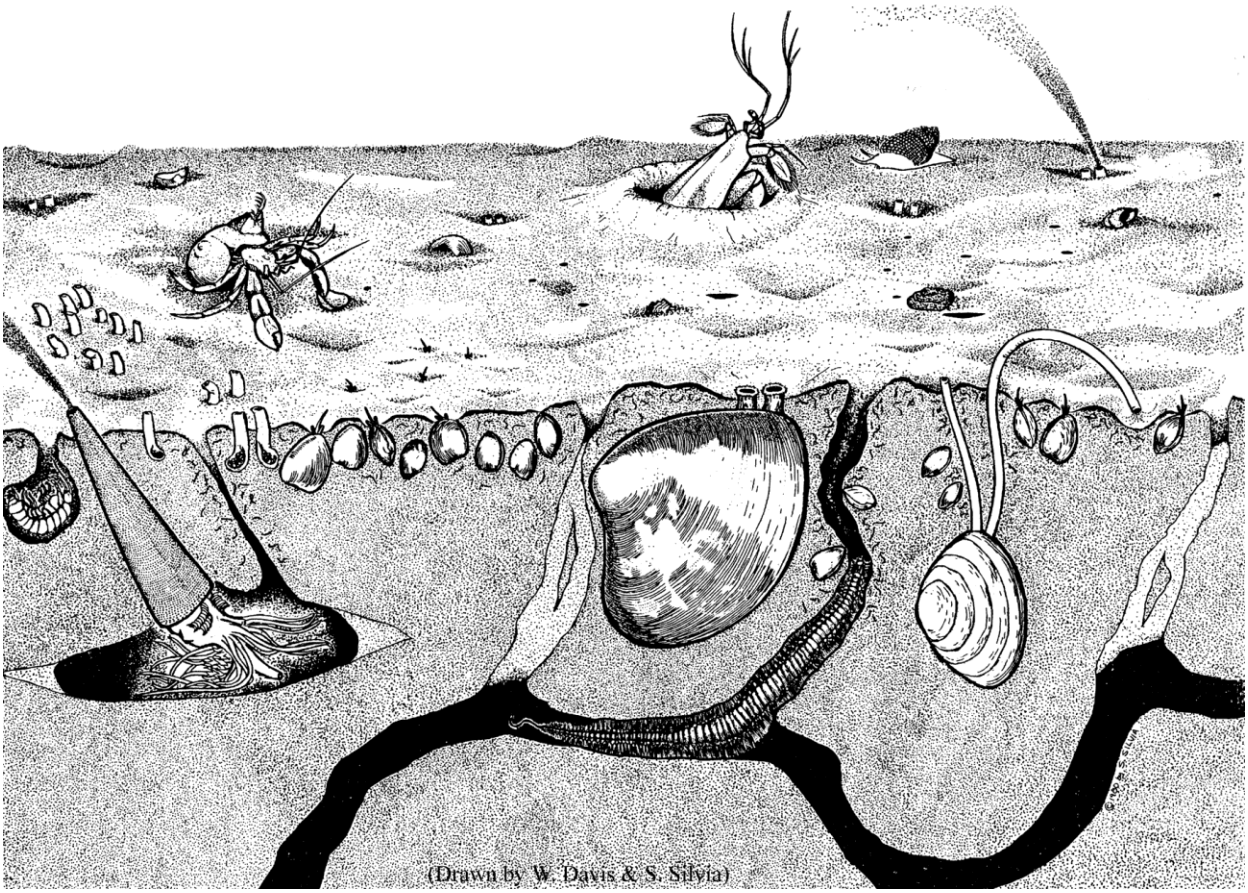
A Database of Historical Benthic Invertebrate Biodiversity Spanning 182 Years in Narragansett Bay (Rhode Island and Massachusetts)



A Database of Historical Benthic Invertebrate Biodiversity Spanning 182 Years in Narragansett Bay (Rhode Island and Massachusetts)

Stephen S. Hale[1], Melissa M. Hughes[2], Henry W. Buffum[2]

[1]Atlantic Ecology Division, National Health and Environmental Effects Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, 27 Tarzwell Drive, Narragansett, RI, USA 02882. hale.stephen@epa.gov. [2]CSRA, U.S. Environmental Protection Agency, Narragansett, RI, USA 02882

Data presented here were used by the following articles:

Hale, S.S., M.M. Hughes, and H.W. Buffum. 2018. Historical trends of benthic invertebrate biodiversity spanning 182 Years in a southern New England estuary. *Estuaries and Coasts*. http://link.springer.com/article/10.1007/s12237-018-0378-7

Hale, S.S., H.W. Buffum, and M.M. Hughes. (in review). Six decades of pollution-related benthic biodiversity trends in a southern New England estuary.

Cover illustration by W. Davis and S. Silvia

Abstract

Benthic invertebrate biodiversity of Narragansett Bay supports influential ecosystem functions and services including shellfish production, energy flow to fishes, and crucial processes for biogeochemical cycles. To examine biodiversity trends over time, a master list was compiled of all benthic invertebrate species collected from the bay beginning with Totten's 1834 descriptions of mollusks, Leidy's collections in 1855, Verrill and Smith's surveys beginning in 1871, and studies at Alexander Agassiz's Marine Zoological Laboratory in Newport, 1873–1910. The list, spanning 182 years, was compiled from 104 sources and includes invertebrate macrofauna (>0.5 mm) and more limited studies of meiofauna. It currently holds over 1,200 unique taxa from 21 phyla. A permuted estimator of number of species suggested about 300 more are yet to be discovered. This report describes the master species list, chronicles how it was compiled, and includes the database and accompanying documentation.

Data acquisition

We compiled a master species list of Narragansett Bay (Fig. 1) benthic invertebrates, beginning with the first known sampling of the bottom communities in 1834 and continuing through 2015. We obtained species records from published articles, published and unpublished reports, U.S. Environmental Protection Agency (USEPA) and other federal agency studies, national monitoring programs, State of Rhode Island and Commonwealth of Massachusetts studies, website downloads, museum collections, Master's theses and Ph.D. dissertations (from the University of Rhode Island, Brown University, and University of Massachusetts), and unpublished data sets collected by various researchers. The list includes species records from 166 stations extracted from a USEPA national monitoring program (EMAP 2017; NCA 2017; NCCA 2017). We incorporated 20 studies with data from a previous compilation of benthic invertebrate studies conducted in Narragansett Bay between 1951 and 1986 (Frithsen 1989). Altogether, we obtained species records from 104 sources (98 studies and 6 biodiversity databases.

Early scientific records began with Joseph Totten's collections in 1834 and 1835 (Totten 1834, 1835; Photo 1), August Gould's report on invertebrates of Massachusetts (Gould 1841), Joseph Leidy's collections of 1855 (Leidy 1855), surveys by Addison Verrill and the US Fish Commission on the *Fish Hawk* and other research vessels the in the 1870s and 1880s on (Verrill and Smith 1874; Tanner 1880; USBF 1880–1899; Photo 2, Photo 3), studies at Alexander Agassiz's Newport Marine Zoological Laboratory at Castle Hill, 1873–1910 (Agassiz 1865, 1879; Fewkes 1881; Photo 4, Photo 5), reports from the Rhode Island Commissioners of Inland Fisheries (1899), Barnes (1906) list, and the survey of Sumner and colleagues (Sumner et al. 1911). Four databases provided most of the early historical data: the Invertebrate Zoology Collections of the Yale Peabody Museum of Natural History (2017), the Collections Database of the Harvard Museum of Comparative Zoology (2017), the Invertebrate Zoology Collections of the Smithsonian National Museum of Natural History (2017), and logbooks of the *Fish Hawk* (Biodiversity Heritage Library 2017; MBL-WHOI 2017; USBF 1880–1899). Additional records were obtained from the Ocean Biogeographic Information System (OBIS 2017) and the Global Biodiversity Information Facility (GBIF 2017). Books and reports digitized by the Biodiversity Heritage Library (Biodiversity Heritage Library 2017) provided access to crucial historical documents. The 1,160 stations of the studies that gave latitude/longitude coordinates are shown on Fig. 1. Altogether, there were 1,985 stations but some of the historical studies only referred to a general geographic area of the bay. A species discovery curve (Fig. 2) shows the surges in taxa discovered in the late 1800s and beginning in the 1970s.

The master species list was restricted to invertebrate animals that live part or all of their life stages on the seafloor. Most records are of species from samples processed with a sieve mesh size of 0.5 mm and larger, but there are some from 0.3 mm and smaller meshes. Invertebrate parasites were not included. We gathered records from all habitats; however, the bulk of the records are from grabs of soft-bottom sediments; rocky bottoms are not common in most of the bay. There are some records from intertidal and salt marsh habitats. We used records from any time of the year and from any method—bottom grabs, cores, dredges, bottom fish trawls, collections by hand in the intertidal zone, and records from fish gut analyses.

Data curation and quality control

Taxonomic information for all taxa was brought up to date using first the Integrated Taxonomic Information System (ITIS 2017) and next the World Register of Marine Species (WoRMS 2017). Records for taxa that were unique names, but were not identified down to species level were examined to see if they represented a unique taxon; if not, they were eliminated. For example, records for "Bivalvia" were eliminated because there were other taxa, such as *Mercenaria*, that belonged to that class. Original scientific names were kept along with the updated names. The list includes the ITIS Taxonomic Serial Number and taxonomic hierarchy (species, genus, family, order, class, phylum). The list also includes the accepted WoRMS scientific name and taxonomic hierarchy. The column 'ITIS_WoRMS_Accepted_Name' is the updated scientific name that we used to establish unique taxa. When the original name did not appear in ITIS, but appeared in WoRMS, the latter appears under 'ITIS_WoRMS_Accepted_Name'. In instances where the accepted 'ITIS_Name' was at the genus or higher level, if there was an accepted WoRMS name at the species level, that name appears under 'ITIS_WoRMS_Name'. In a few cases, the original name was neither in ITIS nor in WoRMS, but was found in another database. Names not found in any database were not added to the list. Sieve mesh size assigned to a taxon was based on the smallest sieve size found in the studies in which the taxon was identified. Latitude and longitude coordinates and geographical names were checked for consistency against a GIS map of the bay.

Description of the data

The master species list of all benthic invertebrates captured from Narragansett Bay since the first sampling in 1834 includes 1,214 unique taxa, of which 1,087 were identified to species level (Table 1). They belong to 21 different phyla (Table 2), representing 62% of all animal phyla on Earth and 72% of all non-symbiont animal phyla (Snelgrove 1998). The species count is certainly an underestimate—given the availability of data, the restrictions we used on size classes and taxa and habitat sampled, and the likelihood that some of the 127 taxa identified to a higher taxonomic level than species (e.g., Tubificidae) included more than one species. We had another 74 records of taxa that we could not verify and did not add to the list. The Narragansett Bay benthos is taxonomically quite distinct: over the 182 years in the master species list, on average, every 2-3 species were in a different family. Meiofauna captured on sieve meshes < 0.5 mm (that were not also captured on meshes > 0.5 mm as adults) contributed 93 unique taxa, with 62 identified to species level (Table 1). Numbers of unique fauna by phylum for all taxa found show that Annelida comprised 29%, Arthropoda 27%, and Mollusca 23% (Table 2).

Tabs in the accompanying spreadsheet (HaleStephen_A-j3vh_Data_20180322.xlsx) are as follows:

Report. Title page

Abstract

AppTable1. Sources of data for Narragansett Bay master species list of benthic invertebrate taxa, 1834–2015

AppTable2. Checklist of Narragansett Bay benthic invertebrate master species list, 1834–2015. Phyla are listed by the phylogenetic order of the Integrated Taxonomic Information System; lower levels are sorted alphabetically on the ITIS-WoRMS_Accepted_Name

AppTable3. Spreadsheet of Narragansett Bay benthic invertebrate taxa in alphabetical order of the ITIS-WoRMS_Accepted_Name, master species list, 1834–2015
AppTable4. Supporting documentation for Appendix Table 3
AppTable5. Information on studies that collected benthic invertebrates from Narragansett Bay, 1834–2015
AppTable6. Stations with latitude and longitude from studies that collected benthic invertebrates from Narragansett Bay, 1834–2015
Addendum. Records of Narragansett Bay benthic invertebrate taxa found after publication of the journal article

Limitations of the data

The master species list is a function of who happened to sample the bay's benthos, what expertise they had, what taxa they focused on, what gear they used, and what habitats they sampled. The uneven sampling of taxa, areas of the bay, and habitats (mainly soft bottom sediments, with some salt marshes, and little sampling of rocky coasts) limited our efforts to detect more than broadly meaningful changes in the communities (Hale et al. 2018). The absence of a long-term, consistent benthic community monitoring program with broad spatial coverage throughout all habitats of the entire Narragansett Bay prior to 1990 affected our ability to link changes in benthic biodiversity to stressors such as organic over-enrichment, hypoxia, and sediment contaminants.

We were not able to obtain records of all the data we knew had been collected. For example, the mollusks from the 1800s that had been stored in the "Lost Museum," the former Jenks Museum of Natural History at Brown University (Duffy 2016). Exact location of studies was often uncertain for the early historical data, particularly where geographic coordinates were rough estimates.

It is difficult to evaluate the proficiency of the people doing the taxonomic identifications throughout the 182-year record. Many of the early naturalists were experts in particular taxa and it is unlikely they made many misidentifications (although some names were later changed because of precedence rules). They described several previously-unknown species (e.g., Totten 1834, 1835; Leidy 1855; Agassiz 1865; Verrill and Smith 1874; Fewkes 1881). Voucher specimens from this time are available for study at museums such as the Yale Peabody Museum of Natural History, the Harvard Museum of Comparative Zoology, and the National Museum of Natural History. The USEPA survey (EMAP 2017; NCA 2017; NCCA 2017), covering the entire range of invertebrate species biodiversity, requires adherence to quality assurance standards for taxonomic identifications (USEPA 2010).

Gould (1841), in his species compilation *Report on the Invertebrata of Massachusetts, comprising the Mollusca, Crustacea, Annelida, and Radiata* noted:

> "The extent and difficulty of this work have very far exceeded my expectations. The unsettled state of our nomenclature,—the scattered state of the materials of which it must be constructed, have raised almost interminable doubts and difficulties. It is the first work of the kind attempted in this country; and it were presumptuous to hope that it is free from error. It is not a difficult thing to settle, satisfactorily, the proper

> genera and species of nine tenths of the shells and other objects we may find. But when an attempt is made to give *the whole*, the other tithe will require an equal amount of study, and, after disposing of it in the best way we can, we must leave it, mortified that we have perhaps settled nothing, but have merely given an opinion. It is easy enough see errors and difficulties in these cases, but it is not easy to adjust them."

Similarly, as in any endeavor that aims to compile a master list of benthic invertebrate taxa, we experienced the inevitable issues of trying to find all the records that existed, obtaining the records that we knew existed, and trying to verify with incomplete information those that we did find. We recognize that the list is incomplete and subject to some uncertainty. Nevertheless, in the spirit of Gould (1841) who asked that "Corrections and remarks relating to the facts or opinions given in the Report are respectfully solicited," we are making our list—with all of its acknowledged and unacknowledged blemishes and deficiencies—available in the hope that others will find it useful. Accordingly, we view this list, almost impossible for one group to bring to a higher standard, as an ongoing project of the collective Narragansett Bay scientific community to fill in omissions, correct errors, and add as they are found records of species previously unknown in the bay.

Acknowledgments

We are grateful to Sheldon Pratt of the Graduate School of Oceanography at the University of Rhode Island (GSO-URI) who over many years has been an unparalleled fount of data and information on the Narragansett Bay benthos. Eric Lazo-Wasem and Lourdes Rojas at the Yale-Peabody Museum of Natural History, Patrick Randall at the Harvard Museum of Comparative Zoology, and William Moser at the Smithsonian's National Museum of Natural History provided expert assistance with the historical data and access to their online databases was invaluable. Kathrinne Duffy and Steven Lubar of Brown University provided information on the "Lost Museum" of Brown. The availability of historical books and reports from the Biodiversity Heritage Library was essential to our task. We are grateful for the assistance of Joyce Downey at Pell Marine Science Library, Hope Lappen at Brown University Library, David Remsen at Marine Biological Laboratory-Woods Hole Oceanographic Institution Library, and Dale Sheehy at the USEPA Atlantic Ecology Division library. We appreciate the generosity of those that gave us access to their unpublished records of Narragansett Bay benthic invertebrates:; Deborah French McCay and Melanie Schroeder of Applied Science Associates, Inc. – Mount Hope Bay data from MRI and the Weaver Cove LNG project; Candace Oviatt (GSO-URI) - Marine Ecosystems Research Laboratory data; Jeremy Collie (GSO-URI) - the invertebrate data from the bottom trawl time series; Daisy Durant – species from her survey at the Narragansett Bay National Estuarine Research Reserve; and our colleagues at the USEPA lab (Peg Pelletier from her surveys in 2012 and 2013, Rick McKinney, Marty Chintala, Cathy Wigand, as well as historical data collected by Ken Perez, and Wayne Davis). Chuck Audette helped with finding historical data. Review comments by G. Cicchetti, W. Berry, and J. Kiddon improved this report.

References

Agassiz, A. 1865. North American Acalephae. Museum of Comparative Zoology at Harvard College, Cambridge, Massachusetts.

Agassiz, A. 1879. A zoological laboratory. *Nature* 19:317–319.

Barnes, E.W. 1906. A preliminary list of the marine Mollusca of Rhode Island. Annual Report of the Rhode Island Commissioners of Inland Fisheries 36: 30–37. Providence, R.I.

Biodiversity Heritage Library. 2017. http://www.biodiversitylibrary.org/ Accessed October 2016.

Coe, W.R. 1929. Biographical memoir of Addison Emery Verrill, 1839–1926. National Academy of Sciences 14: 18–66.

EMAP [Environmental Monitoring and Assessment Program]. 2017. Office of Research and Development, U.S. Environmental Protection Agency. http://www.epa.gov/emap.

Fewkes, J. W. 1881. Studies of the Jelly-fishes of Narragansett Bay. Bulletin of the Museum of Comparative Zoology, Harvard University. Vol. 8. No. 8.

Frithsen, J.B. 1989. The benthic communities within Narragansett Bay. An assessment completed for the Narragansett Bay Project, Report #NBP-90-28. Marine Ecosystems Research Laboratory, Graduate School of Oceanography, University of Rhode Island, Narragansett, RI.

GBIF [Global Biodiversity Information Facility]. 2017. http://www.gbif.org/

Gould, A.A. 1841. Report on the Invertebrata of Massachusetts, comprising the Mollusca, Crustacea, Annelida, and Radiata. Commissioner on the Zoological and Botanical Survey of the State, Cambridge, MA.

Hale, S.S., H.W. Buffum, and M.M. Hughes. (in review). Six decades of pollution-related benthic biodiversity trends in a southern New England estuary.

Hale, S.S., M.M. Hughes, and H.W. Buffum. 2018. Historical trends of benthic invertebrate biodiversity over 182 years in a southern New England estuary. Estuaries and Coasts. http://link.springer.com/article/10.1007/s12237-018-0378-7

Harvard Museum of Comparative Zoology. 2017. MCZ Collections Database. www.mcz.harvard.edu/Departments/InvertZoo. Accessed March 2017.

ITIS [Integrated Taxonomic Information System]. 2017. http://www.itis.gov

Leidy, J. 1855. Contributions toward a knowledge of the marine invertebrate fauna of the coasts of Rhode Island and New Jersey. Journal of the Academy of Natural Sciences of Philadelphia 3(2):3–18.

MBL-WHOI [Marine Biological Laboratory-Woods Hole Oceanographic Institute] Library Biodiversity Heritage Library at: http://www.mblwhoilibrary.org/ and http://biodiversitylibrary.org/

NCA [National Coastal Assessment]. 2017. Office of Research and Development, U.S. Environmental Protection Agency, Washington, DC. http://www.epa.gov/emap/nca

NCCA [National Coastal Condition Assessment]. 2017. Office of Water, U.S. Environmental Protection Agency, Washington, DC. http://water.epa.gov/type/oceb/assessmonitor/ncca.cfm

NOAA Photo Library. 2018. National Oceanic and Atmospheric Administration. www.photolib.noaa.gov

OBIS [Ocean Biogeographic Information System]. 2017. Data downloaded from: http://www.iobis.org/

Rhode Island Commissioners of Inland Fisheries. 1899. [needs more]

Smithsonian National Museum of Natural History. 2017. Invertebrate Zoology Collections. http://collections.nmnh.si.edu/search/iz/ Accessed October 2016.

Snelgrove, P.V.R. 1998. The biodiversity of macrofaunal organisms in marine sediments. Biodiversity and Conservation 7:1123–1132.

Sumner, F.B., R.C. Osborn, and L.J. Cole. 1911. A Biological Survey of the Waters of Woods Hole and Vicinity. Part 1. Section I. Physical and Zoological. Bulletin of the Bureau of Fisheries 31, Washington, DC.

Tanner, Z.L. 1880. Report on the construction and work in 1880 of the Fish Commission Steamer *Fish-Hawk*. U.S. Fish Commission, Washington, DC.

Totten, J.G. 1834. Description of some new Shells, belonging to the coast of New England. The American Journal of Sciences and Arts 26:366–369.

Totten, J.G. 1835. Description of some Shells, belonging to the Coast of New England. The American Journal of Sciences and Arts 28:347–353.

USBF [United States Bureau of Fisheries]. 1880–1899. Original logbooks of the "Fish Hawk", U.S. Fish Commission dredging records. Series SIA RU007184. http://www.mblwhoilibrary.org

USEPA [U.S. Environmental Protection Agency]. 2010. National Coastal Condition Assessment's Quality Assurance Project Plan https://www.epa.gov/sites/production/files/2013-11/documents/ncca-qapp.pdf

Verrill, A.E., and S.I. Smith 1874. The invertebrate animals of Vineyard Sound and the adjacent waters, with an account of the physical features of the region. Chapt. VIII in Baird, S.F. 1873. Report on the Condition of the Sea Fisheries of the South Coast of New England in 1871 and 1872. United States Commission of Fish and Fisheries, Washington, D.C.

WoRMS [World Register of Marine Species]. 2017. http://www.marinespecies.org

Yale Peabody Museum of Natural History 2017. Invertebrate Zoology Collections. http://collections.peabody.yale.edu/search. Accessed October 2016.

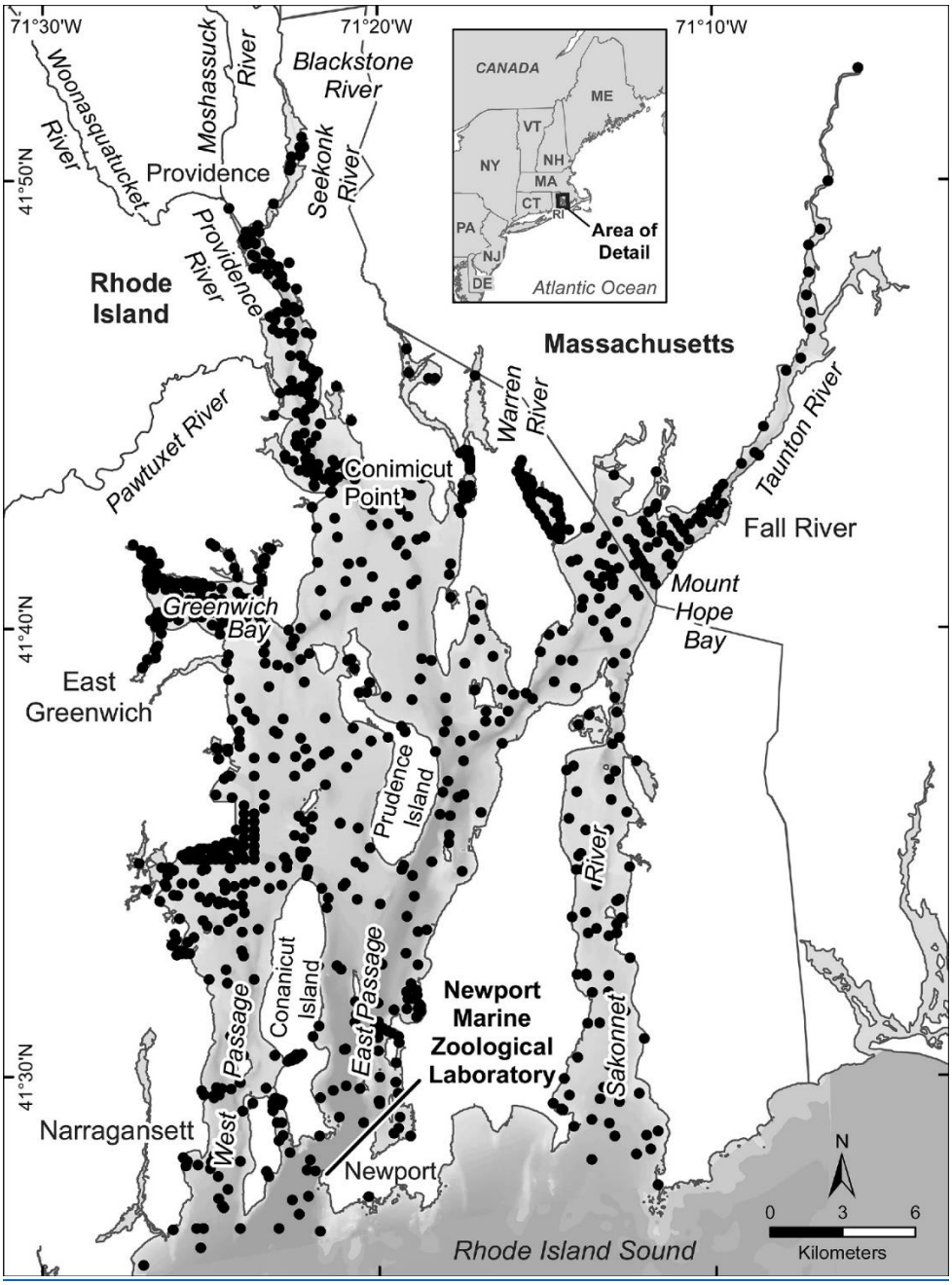


Fig. 1 Map of Narragansett Bay, Rhode Island and Massachusetts, showing stations from all studies that provided latitude/longitude, 1834–2015. For the sake of clarity, not all stations of a study are shown. Some stations were sampled more than once. Location of Alexander Agassiz's Newport Marine Zoological Laboratory is shown at the mouth of the East Passage

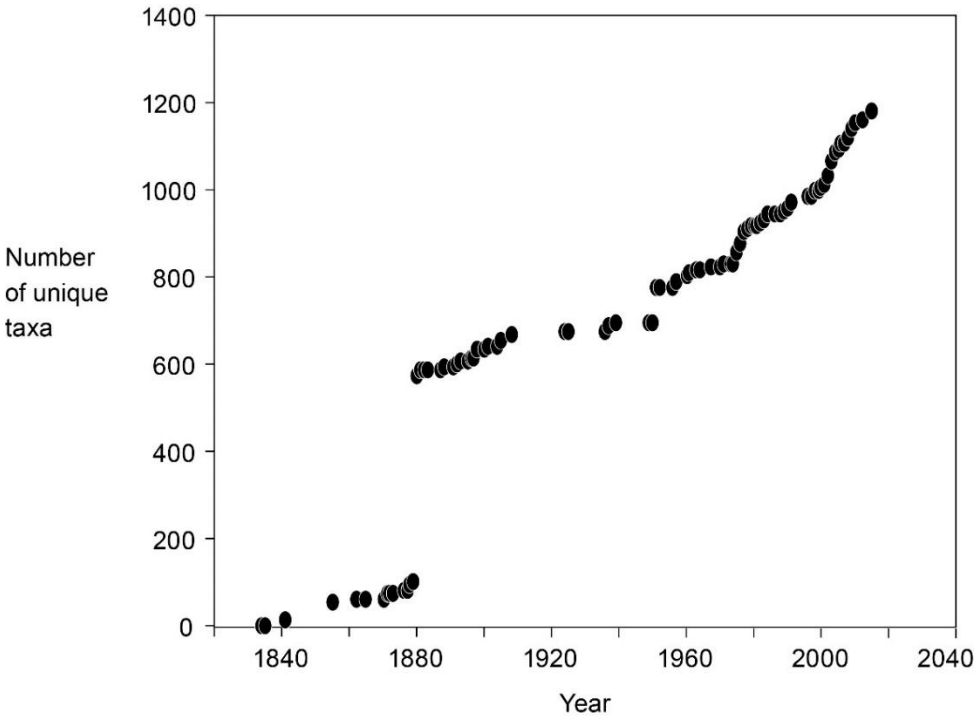


Fig. 2 Species discovery curve for Narragansett Bay benthic invertebrates showing the cumulative number of taxa that had been found in the bay in the 111 years with data, 1834-2015

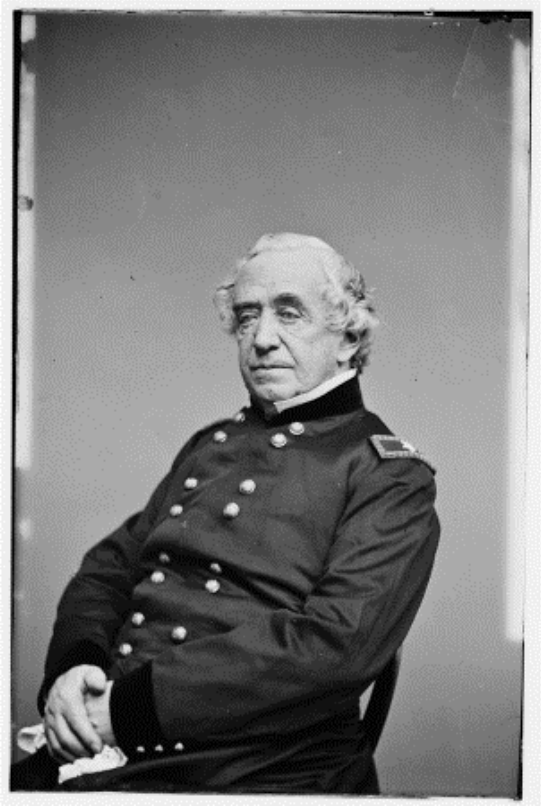


Photo 1 Joseph G. Totten, U.S. Army Corps of Engineers. Collected first scientific samples of benthic invertebrates in Narragansett Bay.

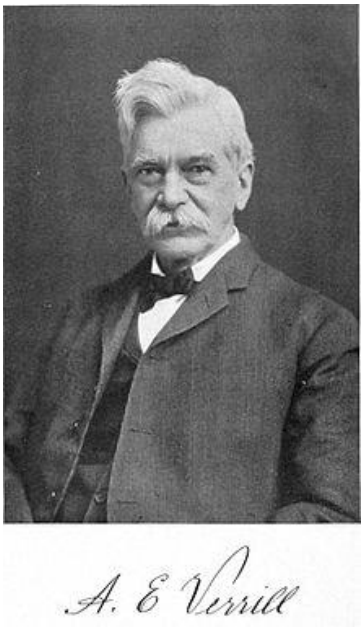


Photo 2 Addison E. Verrill, Yale University. Collected benthic invertebrates from the U.S. Fish Commission's steamer *Fish Hawk*. Credit: Coe (1929)

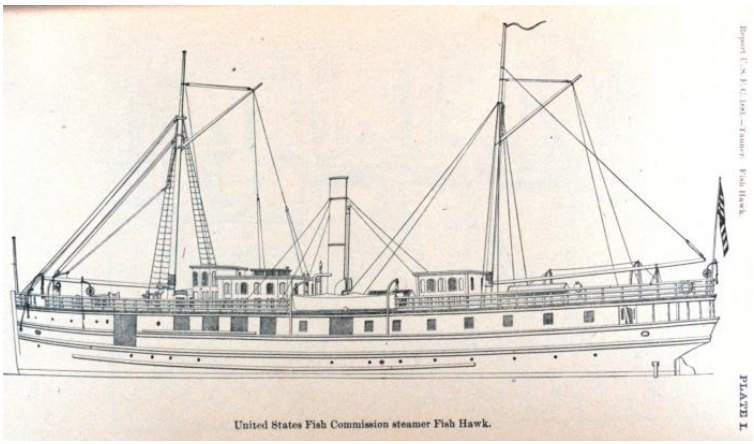


Photo 3 A.E. Verrill's survey ship, U.S. Fish Commission steamer *Fish Hawk*. Credit: NOAA Photo Library

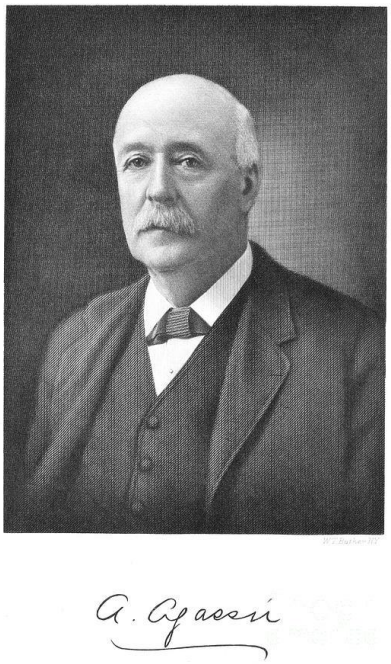


Photo 4 Alexander E.R. Agassiz, founder of the Newport Marine Zoological Laboratory in Newport, Rhode Island. Credit: NOAA Photo Library

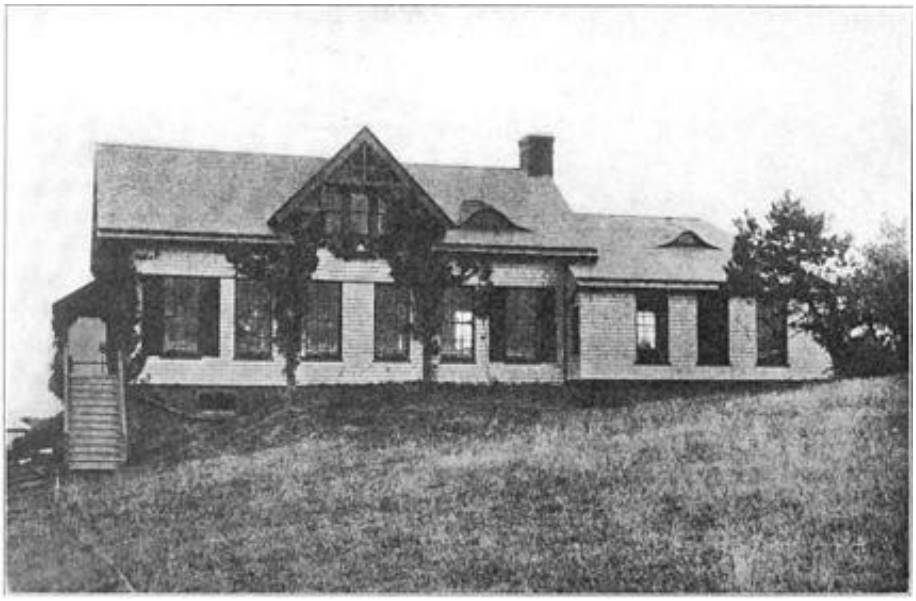


Photo 5 Alexander Agassiz's Newport Marine Zoological Laboratory, 1873-1910. Credit: Museum of Comparative Zoology Archives, Harvard University

Table 1 Number of benthic invertebrate taxa at different taxonomic levels in Narragansett Bay, master species list, 1834–2015

Taxon level	All sizes	> 0.5 mm
Phyla	21	18
Classes	47	47
Orders	131	130
Families	430	424
Genera	774	753
Species	1,087	1,025

Table 2 Number of unique benthic invertebrate taxa and number identified to species level in each phylum, Narragansett Bay, master species list, 1834–2015

Phylum	# taxa	# species
Annelida	346	320
Arthropoda	322	278
Mollusca	283	254
Cnidaria	100	96
Bryozoa	33	30
Echinodermata	28	25
Chordata	26	25
Platyhelminthes	21	12
Nemertea	19	19
Porifera	12	11
Nematoda	6	4
Sipuncula	5	4
Hemichordata	2	2
Kamptozoa	2	1
Phoronida	2	2
Xenacoelomorpha	2	2
Gastrotricha	1	0
Kinorhyncha	1	0
Nematomorpha	1	1
Priapulida	1	0
Tardigrada	1	1