Maryland and Virginia Benthic Monitoring Program Developments

1. Development of functional groups of macrobenthos used to determine the environmental health of marine and estuarine ecosystems. In assessing the ecological impacts of low dissolved oxygen events on the macrobenthic communities of Chesapeake Bay, two functional groups of species were proposed to discriminate stressed benthic communities of the Chesapeake Bay. These two groups were based upon life history characteristics and response to environmental stress and termed initially as opportunistic and equilibrium species groups. This approach is now widely adopted for use in the Chesapeake Bay and other estuaries and was the precursor to the pollution indicative and pollution sensitive metrics of the Chesapeake Bay benthic index of biotic integrity (See Weisberg et al. 1997 below).

Dauer, D.M., J.A. Ranasinghe, and A.J. Rodi, Jr. 1992. Effects of low dissolved oxygen levels on the macrobenthos of the lower Chesapeake Bay. *Estuaries* 15:384-391.

2. Development of criteria for determining the environmental health of benthic communities of Chesapeake Bay. Graphical models of macrobenthic community structure were presented to assess the environmental health of estuarine benthic communities. These models represent an easily understood depiction of complex biological data and were designed for presentation to environmental managers. Metrics used were community biomass, abundance of individuals, species diversity, depth distribution of biomass within the sediment, equilibrium species biomass and opportunistic species biomass. Each model displays the metric as a function of salinity. The development of multiple metrics of benthic community structure to assess the environmental health of benthic communities was another contribution leading to the development of the Chesapeake Bay benthic index of biotic integrity (See Weisberg et al. 1997 below). This publication is widely cited internationally by applied benthic ecologists in publications dealing with anthropogenic sources of environmental stress.

Dauer, D.M. 1993. Biological criteria, environmental health and estuarine macrobenthic community structure. *Marine Pollution Bulletin* 26:249-257.

3. Development of restoration goals for macrobenthic communities of the Chesapeake Bay. Habitat-specific goals for the major benthic communities of the Chesapeake Bay were developed for ten benthic community metrics at seven habitat types. This project resulted in the development of a practical and conceptually sound framework for assessing progress towards the attainment of environmental conditions that allow the establishment and maintenance of benthic communities of the highest ecological value.

Ranasinghe, J.A., S.B. Weisberg, D.M. Dauer, L.C. Schaffner, R.J. Diaz, and J.B. Frithsen. 1994. Chesapeake Bay Benthic Community Restoration Goals. Report for the U.S.

Environmental Protection Agency, Chesapeake Bay Office, and the Maryland Department of Natural Resources. 49 pp.

Ranasinghe, J.A., S.B. Weisberg, D.M. Dauer, L.C. Schaffner, R.J. Diaz, and J. B. Frithsen. 1998. Chesapeake Bay benthic community restoration goals. pp. 87-89, In: S.I. Hartwell (ed.), *Biological Habitat Quality Indicators for Essential Fish Habitat*. NOAA Technical Memorandum NMFS-F/SPO.

4. Development and application of trend analyses to benthic communities of the Chesapeake Bay. The Benthic Ecology Laboratory of Old Dominion University produced the first trend analyses conducted on macrobenthic communities of the Chesapeake Bay. This approach uses a series of powerful nonparametric trend tests that have been adopted bay-wide for trend analyses.

Dauer, D.M. 1991. Long-term trends in the benthos of the lower Chesapeake Bay. pp. 527-536, In: J.A. Mihursky and A. Chaney (eds.), *New Perspectives in the Chesapeake System. A Research and Management Partnership.* Chesapeake Research Consortium.

Dauer, D.M. 1994. Long-term trends in the Lower Chesapeake Bay (1985-1992): IV. Benthos. pp. 430-440, In: P. Hill and S. Nelson (eds), *Proceedings of the Chesapeake Research Conference. Toward a Sustainable Coastal Watershed: The Chesapeake Experiment.* Chesapeake Research Consortium Publication No. 149.

5. Development of inferential links between water quality trends and benthic community trends. Dauer and Alden (1995) were the first to relate in a quantitative manner long-term trends in water quality to long-term trends in benthic communities of the Chesapeake Bay. Trends in indicators of benthic biological community health were inferentially related to trends observed in water quality conditions in the tributaries and mainstem of Chesapeake Bay. All major water quality and biotic trends appeared to correspond in an ecologically meaningful manner. Dauer (1997) was an invited presentation at an International Symposium entitled *Long-term Changes in Marine Ecosystems: Methods of Analysis, Case Studies and Between-site Comparisons*, held in Arcachon, France in 1994. Both studies concluded that trends in opportunistic and equilibrium species composition of the benthic community were the best indicators of the ecological significance of the trends observed.

Dauer, D.M. and R.W. Alden III. 1995. Long-term trends in the macrobenthic communities of the lower Chesapeake Bay (1985-1991). *Marine Pollution Bulletin* 30:840-850.

Dauer, D.M. 1997. Dynamics of an estuarine ecosystem: Long-term trends in the macrobenthic communities of the Chesapeake Bay, USA (1985-1993). *Oceanologica Acta* 20:291-298.

6. Development of a benthic community index for assessing attainment of restoration goals for macrobenthic communities of the Chesapeake Bay. An index of biotic integrity (B-IBI) was developed for assessing in a quantitative manner whether benthic communities of the Chesapeake Bay have met restoration goals. The B-IBI provides a means for comparing relative condition of benthic invertebrate communities across habitat types. Seven benthic habitat types were identified and community metrics were selected for each habitat type. Scoring thresholds for each metric were determined based on the distribution of metric values from samples considered to represent reference conditions, i.e., unaltered by anthropogenic sources of stress. The index is scaled from 1 to 5 where a value of 3.0 or greater indicates attainment of restoration goals.

Weisberg, S.B., J.A. Ranasinghe, D.M. Dauer, L.C. Schaffner, R.J. Diaz, and J.B. Frithsen. 1997. An estuarine benthic index of biotic integrity (B-IBI) for Chesapeake Bay. *Estuaries* 20:149-158.

7. Testing the effectiveness of approaches to assessing the environmental quality of marine systems using benthic communities. In this study a widely used graphical approach, the abundance-biomass comparison method (ABC method) for assessing the environmental quality of marine systems, was tested using data from an estuary. Estuaries have strong gradients of environmental factors that produce high levels of natural stress. The ABC approach assumed that naturally unstressed communities would have high dominance in biomass by a few species (long-lived, equilibrium species) and few, if any, species greatly dominating abundance patterns. Conversely, highly stressed communities would have a high dominance in abundance by a few species (short-lived, opportunistic species) and no species dominating biomass patterns. The use of the ABC method in estuaries is limited by the presence of many species adapted to high levels of natural stress. Alternate and multiple approaches for assessing the environmental quality of benthic communities of estuaries were proposed. Multiple approaches increase the statistical robustness of environmental assessments.

Dauer, D.M., M.W. Luckenbach, and A.J. Rodi, Jr. 1993. Abundance biomass comparison (ABC method): Effects of an estuarine gradient, anoxic/hypoxic events and contaminated sediments. *Marine Biology* 116:507-518.

8. Pioneering development of relationships between benthic community condition, water quality, sediment quality, and watershed stressors on a bay-wide scale for the Chesapeake Bay. In this study, associations between macrobenthic communities, measures of pollution of the water column and sediment, and measures of anthropogenic activities throughout the watershed were examined for the Chesapeake Bay, USA. Correlation analysis was used to examine associations between sites with poor benthic condition and measures of pollution exposure in the water column and sediment with three major associations identified: (1) Benthic community condition was strongly correlated with low dissolved oxygen events. Low dissolved oxygen events were spatially extensive occurring in 32 of the 61 spatial segments studied of the Chesapeake Bay. (2) Benthic community condition was negatively related to sediment contamination. Sediment contamination was spatially limited to a few specific locations including Baltimore Harbor and the Southern Branch of the Elizabeth River, and only seven of 61 segments had any contaminants exceeding levels considered detrimental to benthos. (3) After removing the effects of low dissolved oxygen events, the residual variation in benthic community condition was weakly correlated with surrogates for eutrophication – water column concentrations of total nitrogen, total phosphorus, and chlorophyll *a.* In addition, associations between benthic condition and anthropogenic inputs and activities in the watershed were also studied, with four major associations identified: (1) Benthic condition was negatively correlated with measures of urbanization (*i.e.*, population density, point source loadings, and total nitrogen loadings) and positively correlated with watershed forestation. (2) At the tributary level, the frequency of low dissolved oxygen events and levels of sediment contaminants were positively correlated with population density and percent of urban land use. Sediment contaminants were also positively correlated with point source nutrient loadings. (3) Water column total nitrogen concentrations were positively correlated with nonpoint nutrient loadings and agricultural land use while total phosphorus concentrations were not correlated with land use or nutrient loadings. (4) Chlorophyll *a* concentrations were positively correlated with nitrogen and phosphorus concentrations in the water column and with agricultural land use but were not correlated with nutrient loads.

Dauer, D.M., J.A. Ranasinghe, and S.B. Weisberg. 2000. Relationships between benthic community condition, water quality, sediment quality, nutrient loads, and land use patterns in Chesapeake Bay. *Estuaries* 23:80-96.

9. Statistical verification of the Chesapeake Bay benthic index of biotic integrity. In this study a series of multivariate statistical and simulation techniques were employed to evaluate and verify properties of the B-IBI. The evaluation process focused on verifying various aspects of the B-IBI: (1) whether the threshold values employed to calculate scores for B-IBI metrics are effective; (2) whether the sets of metrics comprising the B-IBI can detect statistically significant differences between sites known to be degraded and sites known to be unstressed (reference); (3) which of the metrics provide the greatest discriminating power; (4) the minimum and optimal sets of metrics that should be used to produce defensible B-IBIs for each habitat; (5) confidence limits of B-IBI scores for reference areas and degraded areas in each habitat; and (6) assessment of the sensitivity of the B-IBIs to changes in the raw values of individual metrics. Overall, the B-IBI was verified as being sensitive, stable, robust, and statistically sound.

Alden, R.W. III, D.M. Dauer, J.A. Ranasinghe, L.C. Scott, and R.J. Llansó. 2002. Statistical verification of the Chesapeake Bay Benthic Index of Biotic Integrity. *Environmetrics* 13:473- 498.

10. Probability-based sampling and areal estimates of degradation. Biological monitoring programs traditionally use fixed-point stations for the collection of field data. Such stations are useful for long-term trend analyses but spatial extrapolation to larger bodies of water is not possible. Knowing the areal extent of degradation is particularly useful in assessing the effectiveness of restoration efforts at different spatial scales – segments, tidal creeks, rivers, the Bay. After careful and quantitative consideration of the effects of reducing temporal sampling frequency on the statistical power to detect long-term tends at fixed stations (Alden et al. 1997), the number of cruises each year to the fixed stations was reduced to allow the addition of a probability-based sampling program bay-wide in 1996. In this program the Chesapeake Bay was divided into 10 sampling strata and each stratum was sampled at 25 random locations selected by a GIS system. A total of 250 random locations are sampled each year. Such random sampling allows the program to estimate, with a known confidence interval, the actual area of benthic bottom of each stratum that fails or attains the Benthic Restoration Goals as indicated by the value of the B-IBI. This pioneering effort to combine probability-based sampling, the Benthic Restoration Goals, and the B-IBI has since been applied in other benthic studies of the Chesapeake Bay from spatial scales ranging from small tidal creeks with a benthic bottom area of less than 0.1 km^2 to the entire 11,607 km^2 of benthic bottom of Chesapeake Bay (Dauer and Llansó 2003). This combined approach has been successfully applied to each of 67 Chesapeake Bay tidal water segments providing information at spatial scales never before available (Llansó et al. 2003).

Alden, R.W. III, S.B. Weisberg, J.A. Ranasinghe, and D.M. Dauer. 1997. Optimizing temporal sampling strategies for benthic environmental monitoring programs. *Marine Pollution Bulletin* 34:913-922.

Dauer, D.M. and R.J. Llansó. 2003. Spatial scales and probability based sampling in determining levels of benthic community degradation in the Chesapeake Bay. *Environmental Monitoring and Assessment* 81:175-186.

Llansó, R.J., D.M. Dauer, J.H. Vølstad, and L.S. Scott. 2003. Application of the Benthic Index of Biotic Integrity to environmental monitoring in Chesapeake Bay. *Environmental Monitoring and Assessment* 81:163-174.

11. Relating benthic habitat quality to benthic community condition. In this study, several ecological hypotheses relating habitat quality and benthic biotic integrity were tested. An independent measure of habitat quality was obtained using the SPI (Sediment Profile Imaging) approach in which a specially designed camera system penetrates the sediment and creates an image that is assessed for habitat quality. Benthic habitat quality is assessed by calculation of the Organism-Sediment Index (OSI). The OSI defines quality of benthic habitats by evaluating images for depth of the apparent color RPD layer, successional stage of macrofauna, the presence of gas bubbles in the sediment (an indication of high rates of methanogenisis), and the presence of reduced sediment at the sediment-water interface that would indicate current or recent low dissolved oxygen conditions. This study examined the relationship between patterns of habitat quality and benthic biotic integrity as measured by the B-IBI at 200 probability-based stations from Virginia's tidal waters. Four possible relationships between the habitat quality and biotic integrity were examined: (1) Both habitat quality and biotic integrity are high. A strong positive relationship was found supporting the hypothesis that when habitat quality is restored biotic integrity improves. (2) Both habitat quality and biotic integrity are low. Again a strong relationship was found supporting the hypothesis that when habitat quality deteriorates biotic integrity will degrade. These two cases of direct relationships between habitat quality and biotic integrity accounted for 51% of the sites studied. There are two possible cases of an inverse relationship between habitat quality and biotic integrity. (3) High habitat quality but low biotic integrity occurred in 39% of the sites studied. This result is consistent with the hypothesis that a lag time may exist between restoration of habitat quality and the attainment of high biotic integrity through such ecological processes as rates of recruitment and community succession. (4) The existence of low habitat quality but high biotic integrity does not make ecological sense and this was the rarest case with only 10% of the sites placed into this category.

Diaz, R.J., G. R. Cutter, Jr., and D. M. Dauer. 2003. A comparison of two methods for estimating the status of benthic habitat quality in the Virginia Chesapeake Bay. *Journal of Experimental Marine Biology and Ecology* 285-286:371-381.

12. Development of a Sediment Contaminant Diagnostic Tool. The objective of this study was to develop analytical tools that are capable of classifying regions in Chesapeake Bay identified as having degraded benthic communities into categories distinguished by the type of stress experienced by those communities. Sediment contaminants and bottom low dissolved oxygen concentrations were identified as the primary sources of anthropogenic stress on benthic communities and an attempt was made to develop multivariate statistical tools that could distinguish between these sources of stress. In this initial diagnostic project a statistical procedure was developed in order to assess when sediment contaminants were most likely the cause of benthic community degradation. A linear predictive discriminant function was developed using the probability-based samples of the Maryland and Virginia Benthic Monitoring Programs. There were insufficient samples to develop a tool including low dissolved oxygen as a stressor. However, the developed function was capable of discriminating contaminated sites from sites affected by all other potential sources of stress in any of the seven benthic habitat types of Chesapeake Bay. Future efforts to include additional stressor groups such as low dissolved oxygen are anticipated.

Dauer, D.M., M.F. Lane, and R.J. Llansó. 2002. Development of Diagnostic Approaches to Determine Sources of Anthropogenic Stress Affecting Benthic Community Condition in the Chesapeake Bay. Final Report to the US. Environmental Protection Agency. 64 pp. [View Presentation] [Download Report]

13. Contributing to the development of Basin Summaries. Basin Summaries synthesize monitoring information from watershed, ambient water quality, habitat, and living resource components. This information is linked to nutrient and sediment pollution sources and is intended to provide Tributary Teams with resources to assist in setting Tributary Strategy Goals. The development of Basin Summaries is preceded by workshops that have as an objective the review, interpretation, and short-term analysis of monitoring information to help in developing or strengthening management recommendations. The Maryland Benthic Monitoring Program contributes to this effort by summarizing benthic community condition and the links to water quality for each of eight major basins in the Maryland Chesapeake Bay.

Llansó, R.J. 2004. Basin Summary for Benthos. Report to Maryland Department of Natural Resources, Tidewater Ecosystem Assessments. Versar, Inc., Columbia, Maryland. [Download Report]

14. Testing depth-related patterns in benthic community condition. In the Chesapeake Bay, the estuary has been stratified based on designated water use criteria. A shallow-water designated use category from the intertidal to the 2 m depth contour is designed to protect underwater bay grasses and the many fish and crab species that depend on seagrass bed habitats. Alternatively, a shallow water zone down to the 4 m depth threshold has also been defined as the zone of maximum anthropogenic impact upon natural ecosystem functions. In this study, the question of whether separate shallow-water strata should be created within the existing Chesapeake Bay benthic monitoring program strata was examined. Benthic community condition differences between shallow water and deep water regions were tested by comparing depth strata for each of two depth thresholds, and three Chesapeake Bay regions: (1) the York River entire estuarine gradient from the tidal freshwater to the polyhaline zone, (2) the Southern Branch of the Elizabeth River, and (3) the Virginia mainstem portion of the bay. These last two polyhaline regions were characterized as having the best and worst benthic community condition in Chesapeake Bay. Depth strata were defined by the 2 m and 4 m thresholds that are intended to emphasize (1) restoration of submerged aquatic vegetation, or (2) the zone of maximum anthropogenic impact. No significant depth-related differences in benthic condition were found at the scale of the entire tidal York River. Differences with depth were manifested only in the low mesohaline and polyhaline zones. No differences were found in the Southern Branch of the Elizabeth River or in the Virginia mainstem. The study suggested that an adaptive monitoring change of stratification into shallow and deeper regions is not required for the probability-based benthic monitoring program.

Dauer, D.M., R.J. Llansó, and M.F. Lane. 2008. Depth-related patterns in benthic community condition along an estuarine gradient in Chesapeake Bay, USA. *Ecological Indicators* 8:417-424. [Link to Journal]

15. Developing biological criteria for impaired waters assessments. To meet the requirements of the Clean Water Act, the States of Maryland and Virginia are using benthic biological criteria for identifying impaired waters in Chesapeake Bay and reporting their overall condition, ***i.e.*** 305(b)/303(d) reporting. The Chesapeake Bay benthic index of biotic integrity (B-IBI) is the basis for these biological criteria. The objectives of this project were to (1) develop a method for deciding whether Chesapeake Bay tidal waters are biologically impaired based on the B-IBI, and (2) produce assessments for each of 85 Chesapeake Bay segments and sub-segments containing benthic community data. The method uses reference conditions to identify degradation and designate impairment, but unlike most biological listing methods, it incorporates uncertainty into the impairment decision. Consideration of habitat specificity and uncertainty in reference conditions produces results with fewer Type I errors (calling a segment impaired when it is not). Fewer type I errors avoids unnecessary listing and remediation and helps focus restoration efforts where they are most needed. Uncertainty arises from natural stressors that mask the signal from pollution effects, patchiness in the distribution of macro-invertebrates, and small sample size. The assessments of Chesapeake Bay segments using this method produced impairment classifications that were generally consistent with expectations based on known patterns of human disturbance in the watershed. This is taken as confirmation of the general utility of the method in estuarine management decisions.

Llansó, R.J., D.M. Dauer, and J.H. Vølstad. 2009. Assessing ecological integrity for impaired water decisions in Chesapeake Bay, USA. *Marine Pollution Bulletin* 59: 48-53. [Link to Journal].

16. Contributing to the development of the Bay health Index (BHI). Benthic monitoring program scientists contributed to the development of a spatially-explicit index of Chesapeake Bay health. Three water quality and three biological measures were combined to formulate the BHI. The benthic index of biotic integrity (B-IBI) is a key component of the BHI, providing characterization of bay bottom conditions for each of 15 reporting regions in the Chesapeake Bay. Each of the thresholds used in the BHI, including those derived from the B-IBI, are rooted in the concept of ecosystem health and used to quantify the status of metric components relative to water quality and biotic conditions. A post-development evaluation of the BHI found significant correlations between the BHI and regional river flow, nitrogen, phosphorus, sediment loads, and the sum of developed and agricultural land use in most reporting regions, and provided an accurate representation of conditions in Chesapeake Bay that is the basis for an annual, publicly released environmental report card.

Williams, M., B. Longstaff, C. Buchanan, R.J. Llansó, and W. Dennison. 2009. Development and evaluation of a spatially-explicit index of Chesapeake Bay health. *Marine Pollution Bulletin* 59:14-25 [Link to Journal]

17. Evaluating and comparing indices of benthic condition applicable to Chesapeake Bay. Three indices of benthic condition developed for different regions of the U.S. Atlantic coast are applicable to Chesapeake Bay. The implementation of these indices have been carried out by the agencies that developed them, and thus, because of overlapping responsibilities, the indices are being applied to the same geographical region, and the question arises as to how the results of these indices compare. In this study, the results of three indices (the B-IBI, EMAP-Virginian Province, and MAIA benthic indices) calculated on the same data, and the assessments of two monitoring programs that employed these indices (the Chesapeake Bay Program, and the Mid-Atlantic Integrated Assessment) were compared. Level of agreement of index results, sampling designs, and statistical estimation methods were evaluated, and differences between assessments using each of the 3 indices, were tested for significance. The study revealed a moderate to high level of agreement between the ratings of individual sites classified into degraded and non-degraded categories by the indices and by separate categories of water and sediment quality based on dissolved oxygen, sediment contaminant, and toxicity data. However, the assessments that employed these indices produced significantly different estimates of degradation that were due to unbalanced type I and II errors and differences in estimation methods. The study concluded that the greatest challenge in applying estuarine and coastal indices of biological condition is to accurately estimate condition above or below restorative thresholds, and that choice among existing indices does matter.

Llansó, R.J., J.H. Vølstad, D.M. Dauer, and J.D. Dew. 2009. Assessing benthic community condition in Chesapeake Bay: does the use of different benthic indices matter? *Environmental Monitoring and Assessment* 150:119-127. [Link to Journal]

18. Assessment of the relative role of hypoxia and other environmental factors upon changes in density, biomass, and diversity of macrobenthic communities by depth in Chesapeake Bay. Recent concerns of increasing hypoxia in Chesapeake Bay prompted us to analyze benthic program data to determine benthic community patterns by depth in association with dissolved oxygen (DO) changes relative to changes in other environmental factors. Environmental factors such as temperature, salinity, median grain size, and organic carbon content of sediments influence benthic communities in estuaries to a large extent. DO also influences benthic community structure, but its significance in Chesapeake Bay has not been evaluated at large spatial scales (i.e., the entire Chesapeake Bay). In this study, the influence of DO upon benthic density, biomass, and diversity relative to other physical variables was determined. Using regression models and an information-theoretic approach (Akaike's Information Criteria), the study found that DO was an important predictor of benthic density, biomass, and diversity by depth. Though other physical variables affected benthic density, oxygen was the single best predictor for benthic density in Chesapeake Bay in the summer. Biomass and diversity patterns were also directly related to DO. At low oxygen levels, biomass was extremely low, suggesting loss of foraging habitat for fish and crabs and substantial loss of benthic production in mesohaline and polyhaline habitats below 4.5 mg l^{-1} DO.

Seitz, R.D., D.M. Dauer, R.J. Llansó, and W.C. Long . 2009. Broad-scale effects of hypoxia on benthic community structure in Chesapeake Bay, USA. *Journal of Experimental Marine Biology and Ecology* 381:S4-S12. [Link to Journal]

19. Evaluating the relationships between hypoxia and macrobenthic production in Chesapeake Bay. The interaction of hypoxia and energy in Chesapeake Bay was evaluated using the 1996-2004 Maryland and Virginia benthic random samples collected in summer. Dissolved oxygen data measured at the time of sampling were assumed to be representative of the stations' annual condition. Daily production was estimated from individual species ash-free dry weights and Edgar's (1990) equation $P = 0.0049 * B^{0.80} * T^{0.89}$, where B is ash-free dry weight and T is water temperature. The production of the macrobenthic community was strongly related to dissolved oxygen. On a daily basis, hypoxia reduces secondary production in Chesapeake Bay by 90%.

Sturdivant, S.K., R.J. Diaz, R. Llansó, and D.M. Dauer. 2014. Relationship between hypoxia and macrobenthic production in Chesapeake Bay. *Estuaries and Coasts*, 37:1219-1232. [Link to Journal]

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