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Research paper

# Adaptation and application of multivariate AMBI (M-AMBI) in US coastal waters

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## ABSTRACT

The multivariate AMBI (M-AMBI) is an extension of the AZTI Marine Biotic Index (AMBI) that has been used extensively in Europe, but not in the United States. In a previous study, we adapted AMBI for use in US coastal waters (US AMBI), but saw biases in salinity and score distribution when compared to locally calibrated indices. In this study we modified M-AMBI for US waters and compared its performance to that of US AMBI. Index performance was evaluated in three ways: 1) concordance with local indices presently being used as management tools in three geographic regions of US coastal waters, 2) classification accuracy for sites defined *a priori* as good or bad and 3) insensitivity to natural environmental gradients. US M-AMBI was highly correlated with all three local indices and removed the compression in response seen in moderately disturbed sites with US AMBI. US M-AMBI and US AMBI did a similar job correctly classifying sites as good or bad in local validation datasets (83–100% accuracy vs. 84–95%, respectively). US M-AMBI also removed the salinity bias of US AMBI so that lower salinity sites were not more likely to be incorrectly classified as impaired. The US M-AMBI appears to be an acceptable index for comparing condition across broad-scales such as estuarine and coastal waters surveyed by the US EPA's National Coastal Condition Assessment, and may be applicable to areas of the US coast that do not have a locally derived benthic index.

## 1. Introduction

Macrobenthic invertebrate communities are a central part of estuarine and coastal condition assessment programs (Diaz et al., 2004; O'Brien et al., 2016). The interpretation of benthic community composition, particularly for a management audience, is typically achieved using indices that distill complex species composition data into easily communicated condition scores (Pinto et al., 2009). The AZTI-Marine Biotic Index (AMBI; Borja et al., 2000), an abundance-weighted, tolerance value index that assesses habitat condition based upon the relative abundance of taxa in different tolerance value groups, is one of the most frequently used indices in Europe (Borja et al., 2015).

This index is popular because it responds to human pressures (Borja et al., 2003; Muxika et al., 2005), does not require extensive calibration and validation datasets, and uses a generalized conceptual reference definition (sensu Stoddard et al., 2006), which includes indicators commonly used by experts when assessing the status (Borja et al., 2014). However, in a pan-European study, Grémare et al. (2009) showed some weaknesses in its way of assessing sensitivity/tolerance levels (i.e. existence of a single sensitivity/tolerance list) and recommended clarification of the sensitivity/tolerance levels for individual species. Reflecting this, shortly after the publication of AMBI (Borja et al., 2000) several authors published variants of AMBI (BENTIX (Simboura and Zenetos, 2002), and MEDOCC (Pinedo and Jordana, 2007)) to address discrepancies in the assignment of tolerance groups and differences in the disturbance gradient compared to the theoretical

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model it was based on.

In the years after AMBI and other variants have been published, several authors have illustrated that AMBI performance can be improved when using tolerance values tailored to the local setting (Rodil et al., 2013; Gillett et al., 2015; Robertson et al., 2016). In addition, AMBI performance is less robust when there are few individuals and species present in the sample, as would be expected in the low salinity portions of an estuary (Borja and Muxika, 2005). To address this problem, Muxika et al. (2007) combined AMBI scores with habitat measures of species richness and diversity to producing multivariate AMBI (M-AMBI).

In a previous study, Gillett et al. (2015) modified and expanded the ecological group (EG) classifications to create an integrated list of benthic species found along the west, gulf and east coasts of the US. Using this new and expanded list to calculate AMBI for US waters (US AMBI) improved performance of this index. US AMBI was able to differentiate between *a priori* good and bad sites from three different areas of the country, and was correlated with the local indices from these areas. However, it tended to compress scores towards moderate condition. In addition, the index was correlated with grain size and salinity. The correlation with salinity resulted in a misclassification of reference sites as degraded in oligohaline and tidal freshwater habitats (Gillett et al., 2015).

In this study, we addressed these issues by adapting the M-AMBI framework of Muxika et al. (2007) for the conterminous US coast. We then examined whether the US M-AMBI improved upon the AMBI using the same data sets previously used by Gillett et al. (2015) to evaluate US AMBI.

## 2. Materials and methods

### 2.1. Approach

US AMBI was combined with two additional metrics to create US M-AMBI. The National Coastal Assessment (NCA) datasets used to develop the ecological group species list in our initial study (Gillett et al., 2015) was used to derive the High and Bad thresholds for each habitat (salinity zone) needed for the M-AMBI algorithm. These datasets were also used to select the additional metrics used in US M-AMBI. US M-AMBI was evaluated using the three regional datasets used to evaluate US AMBI in a previous study (Gillett et al., 2015). US M-AMBI was assessed for 1) concordance with local indices presently being used as management tools in three geographic regions of US coastal waters, 2) classification accuracy for sites defined *a priori* as good or bad and 3) insensitivity to natural environmental gradients.

### 2.2. NCA calibration dataset

Benthic invertebrate macrofaunal samples from 4061 stations located in coastal waters of the conterminous US were collected during the summer months from 1999 to 2006 in the Atlantic, Gulf of Mexico, and Pacific waters of the US by the U.S. Environmental Protection Agency's National Coastal Assessment (NCA; U.S. EPA, 2016). Following local conventions, stations from the Pacific coast were sampled with a 0.1 $m^2$ grab and sieved on a 1-mm screen. In contrast, stations from the Atlantic and Gulf of Mexico coasts were sampled with a 0.04 $m^2$ grab and sieved on 0.5-mm screen. All specimens were identified to the lowest possible taxonomic level (typically species) and followed standard NCA QA/QC protocols for identification. They were further harmonized for taxonomy using the WoRMS (WoRMS Editorial Board, 2016) and ITIS (2016) databases.

All of the stations sampled for macrobenthos were also sampled for sediment chemistry (grain size, total organic carbon (TOC), heavy metals, PAHs, PCBs, etc.), sediment toxicity, and water quality (salinity, dissolved oxygen (DO), etc.) with sampling and laboratory protocols detailed in U.S. EPA (2015).

### 2.3. Calculation of indices

M-AMBI is calculated by combining the AMBI score, Shannon-Weiner Diversity (H'), and species richness (S). The value of each metric for each sample is standardized and then combined via a factor analysis; factor scores are then placed along orthogonal gradients of condition created from a user-defined reference (High) and highly degraded (Bad) anchor points for each habitat. The resultant position in Euclidean space is the index score of the sample (Muxika et al., 2007). This approach allows the user to create local-specific expectations of condition and interpret benthic samples using a best attainable reference condition definition (sensu Stoddard et al., 2006).

In this study, habitat was defined as salinity zone, following the Venice Classification System (1958), as was done by Borja et al. (2008) to remove the salinity bias seen in US AMBI (Gillett et al., 2015). High and Bad thresholds were calculated for each of the metrics (Table 1). The Bad threshold was the worst possible value for that metric (e.g., AMBI score of 6, diversity score of 0). The High threshold was based on the 95th percentile of the data for a metric that was higher at unimpacted sites (richness, diversity), and the 5th percentile for a metric that was higher at impacted sites (AMBI, % oligochaetes). West coast sites in both the NCA dataset and Southern California dataset (Ranasinghe et al., 2012) were sampled using a larger grab size which would be expected to inflate the species richness compared to smaller samples. Because of this, High thresholds were calculated separately for the polyhaline and euhaline habitats on the west coast. Higher species richness in lower salinity habitats on the west coast relative to similar habitats for the rest of the US was not observed, likely due to the low number of lower salinity samples from the west coast. For this reason, the lower salinity expectations were calculated for the entire US.

Although the ecological group classifications from Gillett et al. (2015) were used for this study, US AMBI was recalculated for all stations using raw rather than natural log transformed abundance, as transformation dampened the relationship between AMBI and chemical stressors, so that contaminated stations (Effects Range Median Quotient (ERMQ) > 1) were classified primarily as slightly to moderately disturbed rather than moderately to highly disturbed (Fig. 1).

**Table 1**
Reference (High) and highly degraded (Bad) anchor points for each habitat used to calculate M-AMBI scores.

| Salinity Bin | Region | Scale | AMBI | Species Richness | Diversity (H') | % Oligochaetes |
|---|---|---|---|---|---|---|
| All | NE, SE, Gulf, West | Bad | 6 | 0 | 0 | 100 |
| Tidal Freshwater | NE, SE, Gulf, West | High | 0.15 | | 1.93 | 0.00 |
| Oligohaline | NE, SE, Gulf, West | High | 0.53 | 16.0 | 2.12 | |
| Mesohaline | NE, SE, Gulf, West | High | 0.85 | 26.0 | 2.48 | |
| Polyhaline | NE, SE, Gulf | High | 0.72 | 44.0 | 2.96 | |
| Polyhaline | West | High | 0.18 | 76.8 | 3.30 | |
| Euhaline | NE, SE, Gulf | High | 0.56 | 61.0 | 3.29 | |
| Euhaline | West | High | 0.66 | 92.0 | 3.62 | |
| Hyperhaline | NE, SE, Gulf, West | High | 0.32 | 55.0 | 3.45 | |