A Vegetative Index of Biotic Integrity for Lake Erie's Coastal Wetlands: Addition of Eastern Ohio Sites

Vegetation IBI and Lake Erie Marshes

A Final Report to The Ohio Lake Erie Commission, Lake Erie Protection Fund

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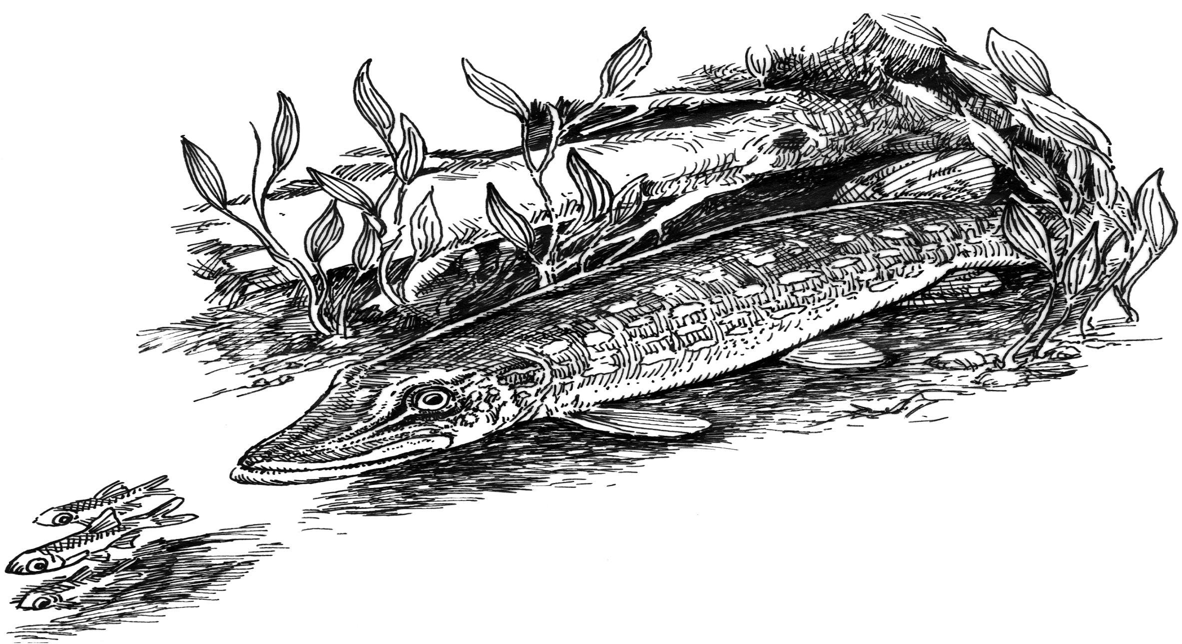

June 2007
Grant LEQI 03-11

THE OHIO STATE UNIVERSITY

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ABSTRACT

Substantial effort in recent years has been invested in developing monitoring protocols and indicators for assessing the health of coastal wetlands of the Great Lakes. Most efforts have collected data exclusively in Great Lakes coastal wetlands and have not evaluated coastal wetland indicator development in the context of other wetland types in the state, province, or region. “Inland” freshwater wetlands are also subject to multiple hydrologic cycles of differing time scales and in some landscape contexts may be as hydrologically variable as Great Lakes coastal wetlands. The Ohio Environmental Protection Agency developed a Vegetation Index of Biotic Integrity (VIBI) for wetlands based on vascular plants as the indicator taxa group. The extension of the VIBI to Lake Erie coastal marshes was evaluated. Least-impacted Lake Erie marshes did not have significantly lower (or higher) scores ($p < 0.001$) although the upper 75th percentile of coastal wetland scores was not as high as the upper 75th percentile of inland wetland VIBI scores. Significant correlations ($p < 0.01$) were observed with two different human disturbance gradients in a combined data set of inland and coastal wetlands. Simultaneous metric evaluation using Principal Components Analysis showed some separation in metric performance between inland and coastal wetlands but also clear overlap, especially between reference-quality inland and coastal systems. Ordination of species presence and abundance data revealed similar patterns with some separation between inland and coastal wetlands but considerable overlap in species composition. Lake Erie coastal marshes represent another type of emergent marsh system. With minor modifications, the VIBI, developed with inland wetland data sets, worked well for assessing Lake Erie coastal wetlands in Ohio. The analysis of data from Ohio coastal wetlands with a larger inland reference data set shows the advantages of treating Great Lakes coastal wetlands as a type of freshwater wetland and working toward indicator development in the context of an overall state or provincial wetland classification and assessment program.

INDEX WORDS: vegetation IBI, coastal wetlands, Lake Erie, Ohio

INTRODUCTION

Substantial effort in recent years has been invested in developing monitoring protocols and indicators for assessing the health of coastal wetlands of the Great Lakes (SOLEC, 2005; Shear et al., 2003). These efforts have often focused on the development of indices of biotic integrity (IBI) using various taxa groups including fish, macroinvertebrates, and vascular plants (SOLEC, 2005). The ability to develop workable IBIs for Great Lakes coastal wetlands has been questioned because of the natural hydrologic variability intrinsic to these systems (Wilcox et al., 2002). However, many Great Lakes IBIs and other assessment protocols have been or are being developed (e.g. Niemi et al. 2006, Crewe and Timmerman, 2004, Grabas and Pernanen, 2004, Uzarski et al. 2004, 2005; Howe et al., in press; Bhagat et al., in review. Invertebrate and fish IBIs have addressed changes in lake levels by sampling within vegetation zones (e.g. Uzarski et al., 2004; Bhagat, in review). Since the assessment method is calibrated for particular types of vegetation, as lake levels change, sample locations to assess a wetland would also "move" as the vegetation zones migrate (e.g. Uzarski et al., 2004). Practical sample location rules for sampling in consistent locations for vegetation-based indicators have also been proposed (e.g. Niemi et al. 2006; Mack, 2004c).

Most of Great Lakes assessment efforts have collected data exclusively in Great Lakes coastal wetlands and have not evaluated coastal wetland indicator development in the context of other wetland types in the state, province, or region. "Inland" freshwater wetlands are also subject to multiple hydrologic cycles of differing time scales and in some landscape context (e.g., riverine) may be as hydrologically variable as Great Lakes coastal wetlands. The Ohio Environmental Protection Agency (Ohio EPA) developed a Vegetation Index of Biotic Integrity (VIBI) for wetlands based on vascular plants as the indicator taxa group (Mack et al., 2000; Mack, 2001b; Mack, 2004a; Mack and Micacchion, 2006, Mack, in press) and using data from inland freshwater wetlands in Ohio. Beginning in 2000, data collection efforts in undiked Lake Erie coastal marshes were begun. This effort was significantly expanded by Husat (2003), who proposed an IBI specific to Lake Erie coastal wetlands based on an analysis of data collected in coastal wetlands. Mack (2004b) and this paper evaluate data from Lake Erie coastal marshes in the context of Ohio EPA's larger inland reference wetland data and propose the extension of the Vegetation IBI, originally developed for inland wetlands to Lake Erie coastal marshes. The subsequent testing and refinement of IBIs with new data sets from different wetland types is an important step in the IBI development process (Karr and Chu, 1999).

METHODS

Site selection

As part of its wetland IBI development process, Ohio EPA sampled several coastal wetlands in 2000 and 2001. In conjunction with Ohio EPA staff, Husat (2003) identified and sampled nine coastal wetlands. Since most sites were located in the western basin of Lake Erie, several coastal wetlands in eastern Ohio were sampled in 2004. Coastal sites were selected to represent the full gradient of disturbed to least-impacted, undiked Ohio coastal wetlands (Table 1). Given the scarcity of least-impacted Ohio coastal wetlands, special care was given to obtain data from the few relatively unimpacted wetlands remaining. Inland wetland sites in Ohio EPA's existing wetland database were selected using a targeted selection approach to ensure that wetlands representing a gradient of disturbance, different plant communities and hydrogeomorphic classes, and different ecoregions were adequately represented (Karr and Chu, 1999; Fennessy et al., 2001; Parker, 2002) (Table 2). "Reference standard" (Smith et al., 1995) sites were used to set biological expectations, and are defined as sites lacking obvious human cultural influence or the least-impacted systems available.

Sampling methods

A plot-based vegetation sampling method was used to sample wetland plant communities (Peet et al., 1998; Mack, 2004c). At most sites, a "standard" plot was established consisting of a 2 x 5 array of 10 m x10 m modules (i.e., 20 m wide by 50 m long with an area of 0.1 ha), within the boundary of the wetland. Location of the plot was qualitatively selected by the investigator based on site characteristics and rules for plot location (Mack, 2004c). Presence and areal cover were recorded for herb and shrub strata, stem density and basal area were recorded for all woody species >1 m tall. All species encountered in a plot were identified to the lowest taxonomic level possible (usually species). The nomenclature and species concept generally followed Gleason and Cronquist (1991) with recent changes proposed by Flora of North America. Standing biomass (g/m2 from eight 0.1 m2 clip plots) and various physical variables (% open water, % bare ground, % litter cover, depth of litter, depth of inundation, depth to saturated soils, number of tussocks, number of hummocks, amount of coarse woody debris, standing dead trees, and overall microtopographic complexity) were also recorded. Percent cover was estimated using cover classes of Peet et al., (1998) (solitary/few, 0-1%, 1-2.5%, 2.5-5%, 5-10%, 10-25%, 25-50%, 50-75%, 75-90%, 90-95%, 95-99%). The midpoints of the cover classes were used in all quantitative analyses. A soil pit was dug in the center of every plot, and soil color, texture, and depth to saturation were recorded. A sample was collected from the top 12 cm and analyzed for pH, particle size, ammonia-N, total phosphorus, total organic carbon and metals (aluminum, barium, calcium, chromium, copper, iron, magnesium, manganese, lead, nickel, potassium, sodium, strontium, zinc) at the Ohio EPA laboratory. If standing water was present in the wetland, a grab sample of water was collected and analyzed for pH, ammonia-N, total Kjeldhal N, Nitrate-Nitrite-N, total phosphorus, total organic carbon, total suspended solids, total solids, chloride and metals (aluminum, barium, calcium, chromium, copper, iron, magnesium, manganese, lead, nickel, potassium, sodium, strontium, zinc) at the Ohio EPA laboratory.

Prior development of VIBI

Potential attributes for the VIBI were initially selected a priori and included aspects of the community structure (e.g., taxa richness, relative cover, density, and dominance), taxonomic composition (e.g., species identity, floristic quality, and diversity indices), tolerance or intolerance of particular species to disturbance, and ecosystem processes (e.g, productivity) (Mack, 2004a). Successful attributes had ecologically meaningful linear, curvilinear, or threshold relationships to a human disturbance gradient. Attributes and metrics were selected and evaluated in four successive refinements of the VIBI (Mack et al., 2000; Mack, 2001b; Mack, 2004a; Mack and Micacchion, 2006; Mack, in press). Attributes selected as metrics for the VIBI were scored by quadrisecting the 95th percentile of the metric values or graphically sectioning the score distributions into four parts and scores of 0, 3, 7, or 10 were assigned (Mack and Micacchion 2006).

Human disturbance gradients

The score from the Ohio Rapid Assessment Method for Wetlands v. 5.0 (ORAM) was used as human disturbance gradient (Mack, 2001a). The ORAM was designed to perform regulatory categorizations and to be used as a wetland disturbance scale. The score ranges from 0 (very poor condition) to 100 (excellent condition). Questions are mostly site specific and include buffer width, dominant land use outside of the buffer, and intactness of natural hydrologic regimes, intactness of natural substrates, and intactness of natural wetland habitats (disturbance questions) as well as size, water sources, hydroperiod, connectivity, microtopography, spatial heterogeneity, and amphibian habitat features. The Landscape Development Intensity Index (LDI) (Brown and Vivas, 2005; Mack, 2006), was also used as an alternative, quantitative human disturbance scale. The LDI is calculated by multiplying land use percentages by a weighting factor derived from the amount of supplemental emergy needed to maintain that use, where emergy has a unit of solar emergy joule (sej) or sej/ha*yr-1 (Brown and Vivas, 2005; Odum, 1996). The equation for calculating the LDI is,

$$LDI_{Total} = 3\ \%LUi * LDIi$$

where, LDI_{Total} = the LDI score, %LUi = percent of total area in that land use I, and LDIi = landscape development intensity coefficient for land use I. The %LUi was calculated with landscape data from the National Land Cover Database (NLCD) using ArcView v. 3.2 (ESRI, 1999) to obtain land composition percentages within a 1 km radius circle of each wetland sampled. Brown and Vivas (2005) report emergy coefficient for 27 land use classes using a Florida land use classification system. This is many more classes than are used in the NLCD classification. Emergy coefficients were assigned to the NLCD classes as follows: forest, wetland forest, emergent wetland = 1.00; water = 1.00; pasture = 3.41; row crop = 7.00; suburban 7.55; rock, transitional = 8.32, urban = 9.42.

Data analysis

Descriptive statistics, box and whisker plots and regression analysis were used to explore and evaluate the biological attributes used in the VIBI. Mean VIBI scores of coastal and inland were compared using ANOVA followed by Tukey's multiple comparison test after arcsine transforming the VIBI scores. All analyses were performed using Minitab v. 12.0 except multivariate tests were performed with PC-ORD v. 4.0 (McCune and Mefford, 1999). Nonmetric Multidimensional Scaling (NMS) was used to evaluate species presence and relative abundance data for patterns related to human disturbance and differences in wetland plant communities between inland and coastal wetlands. The final NMS model stress (21.22) is considered high (McCune et al. 2002) and was likely due to the floristic diversity in the data set. This could produce different results after running the model again. To address this potential problem, results from NMS were compared to the results from Correspondence Analysis. The position of sites in ordination space was very similar after comparing results from NMS and CA and the NMS analysis was retained given the other advantages of NMS (McCune et al., 2002). Because of the general linear behavior of metric values, Principal Components Analysis (PCA) was used to evaluate simultaneous metric performance. Data sets were edited using the ordination space partitioning procedure outlined in Gouch (1982) and Mack (2004a).

RESULTS

The plant community composition of inland and coastal wetlands was evaluated using Nonmetric Multidimensional Scaling (Figure 1). A strong grouping between less-disturbed and more disturbed inland marshes is apparent along Axis 1, suggesting Axis 1 may be interpretable as a human disturbance gradient. A scatterplot of Axis 1 scores versus VIBI scores showed sites with high VIBI scores generally having Axis 1 scores of 0 to -1 and sites with low VIBI scores having Axis 1 scores of 0 to +1 (Figure 2). Coastal sites clustered in three broad groups (lower, middle, and upper) along Axis 2 and were somewhat or very intermixed with inland wetland sites (Figure 1). Coastal sites towards the right side of these three clusters (more degraded side of Axis 1) also tended to be more disturbed and have higher dominance of *Typha* spp. or *Phragmites* (Figure 1).

Using metrics and scoring procedures in Mack (2004b) (Tables 3 and 4), VIBI scores of Lake Erie coastal marshes were evaluated with scores from multiple types of inland marshes (e.g., depressions, riverine mainstem, riverine headwater, and impoundments) located in other Ohio ecoregions. Least impacted Lake Erie marshes did not have significantly different scores than reference condition inland marshes, although non-reference (moderately to highly disturbed) Lake Erie coastal marshes in this data set had significantly higher VIBI scores on average than non-reference inland marshes (df = 61, F = 21.5, p <

0.001) (Figure 3A). This is likely due to the fact that data from extremely disturbed coastal wetlands was lacking, even though a goal of site selection for this study was to include sites representing the full gradient of disturbance. This may also reflect an intrinsic capacity of coastal marshes to buffer disturbance not available to inland systems, e.g., flushing of the system or propagule dispersion or recolonization by lake waters, such that the lowest condition of coastal marsh is higher than the lowest condition of inland marsh.

Parsing the data set by ORAM score tertiles reveals a somewhat more refined picture of attainable expectations in VIBI scores (Figure 3B). The third-tertile of inland and coastal marshes was significantly different from 2nd and 1st tertile inland and coastal sites using ANOVA followed by Tukey's multiple comparison test (df = 61, F = 30.1, $p < 0.001$). However, the upper 75th percentile of coastal wetland scores tend not to be as high as the upper 75th percentile of inland wetland VIBI scores although this difference was not significant. The 2nd tertile of coastal wetland scores was also not significantly different than 2nd tertile inland scores. Figure 3B also suggests very highly disturbed coastal wetlands were not sampled.

Data from coastal wetlands were not used in the derivation of the present VIBI (Mack 2004b). Despite this, inclusion of coastal wetland scores with the inland data set still resulted in very strong and significant correlations between the VIBI scores and the disturbance gradient (R2 = 0.779, $p < 0.001$) (Figure 4). In addition to correlations with the ORAM disturbance gradient, VIBI scores of inland and coastal wetlands were also significantly correlated with the Landscape Development Index, an alternative human disturbance gradient (R2 = 0.513, $p < 0.001$) (Figure 3) and also the scores from Axis 1 of the NMS ordination (Figure 5).

The individual metrics in the VIBI were individually evaluated (Table 5). All metrics were significantly correlated with the disturbance gradient when inland and coastal marsh metric values were evaluated together (Table 5). In fact, these correlations are nearly identical to correlations of just inland metrics alone (Mack 2004a). The behavior of all 10 metrics was evaluated simultaneously using PCA (Figure 6) and the metrics performed as intended with less disturbed sites scoring high on positive metrics (and low on negative metrics) and more disturbed sites doing the opposite. There was some separation in metric performance between inland and coastal wetlands with many coastal wetland sites ordinating in an intermediate position between high quality and degraded inland marshes, but least impacted coastal sites had similar metric performance as high quality inland sites (Figure 6).

DISCUSSION

Lake Erie coastal marshes represent another type of emergent marsh system. With minor modifications, the VIBI, developed with inland wetland data sets, worked well for assessing Lake Erie coastal wetlands in Ohio. Successful IBIs have been developed for vascular plants across the United States in multiple wetland types, and it is therefore, not unexpected that they should also work as an indicator taxa group for Great Lakes coastal wetlands (Carlisle et al., 1999 (tidal marshes in Massachusetts); Gernes and Helgen, 1999 (depressional emergent wetlands in Minnesota); Simon et al., 2001 (northern Indiana Lake Michigan coastal marshes); Lillie et al., 2002 (multiple inland wetland types in Wisconsin); DeKeyser et al., 2003 (prairie pothole marshes); Miller et al., 2004 (multiple inland wetland types in Pennsylvania)).

Husat (2003) evaluated the VIBI-Emergent (VIBI-E) for use in Lake Erie coastal marshes using only data from the coastal marshes sampled from 2000-2002. She concluded that 5 of 10 VIBI-E metrics in Mack (2001b) were usable "as is": dicot richness, shrub richness, hydrophyte richness, FQAI score, and % invasive graminoids. Husat (2003) recommended a Cyperaceae richness metric be used for 190 coastal marshes in lieu of the Carex richness metric. Cyperaceae richness does in fact perform better than 191 the Carex richness metric in coastal marshes (Mack 2004b). Various Cyperaceae genera including *Eleocharis*, *Schoenoplectus*, *Scirpus*, *Cyperus*, and *Bolboschoenus* are often more common components of the sedge flora of coastal marshes than Carex species. She also proposed perennial species richness as an additional new metric for a 7 metric VIBI-COASTAL (Husat, 2003). Mack (2004b) evaluated this proposed metric as well as other variations on annual and perennial species richness and eventually adopted an annual/perennial species ratio metric applicable to all emergent wetlands, inland and coastal. Husat (2003) rejected the % tolerant and % sensitive species metrics because correlations within the coastal marsh data set alone were lacking; the reanalysis of Ohio coastal wetlands with the larger inland data set shows significant correlations and these metrics are retained as is (Table 5, Figure 3).

Although Lake Erie coastal wetlands definitely present some hydrologic characteristics that differ from inland wetlands, inland wetlands in riverine contexts are also subject to often dramatic hydrologic events of differing scalesm (e.g., 5-, 10-, 50-, 100-, 500- year floods, ice scour, temporary to long-term impoundment from beaver activity, drought, etc.). These riverine hydrologic events are qualitatively as "variable" as many hydrologic conditions faced by Great Lakes coastal wetlands. Even other apparently "stable" inland wetland types experience yearly and decadal length hydrologic cycles that induce changes in dominant flora and fauna. For example, in areas where beavers are active, a complex chronosequence of wetlands types develops. Recently flooded areas that are sparsely vegetated in deeper zones develop into older impoundments with strong emergent and floating-leaved marsh components. These marsh systems eventually convert to sedge meadows as beaver dams fail, are abandoned, or as ponds fill with sediment. Finally, shrub swamps and swamp forests can complete the cycle.

Coastal marshes in Ohio have significant floristic similarities to inland systems. Although clear distinctions are present, they do not present insurmountable hurdles to application of a plant-based IBI to coastal wetlands. Other types of Great Lakes wetlands also have floristic similarities to inland systems. For example, inland calcareous fens on slopes or around glacial kettle lakes and certain types of Great Lakes coastal wetlands (e.g., some Lake Superior coastal wetlands) have clear floristic similarities (Minc and Albert, 1998).

The analysis of data from Ohio coastal wetland with a larger inland reference data set shows the advantages of treating Great Lakes coastal wetlands as a type of freshwater wetland and working toward indicator development in the context of an overall state or provincial wetland classification and assessment program. When data from Ohio coastal marshes are viewed in the context of Ohio EPA's larger inland marsh data set, much of their perceived uniqueness becomes manageable with the same metrics and scoring procedures developed for inland systems. The majority of Ohio coastal wetlands sampled had VIBI-E scores in the 40-60 range which is reflective of their past disturbance history (generally moderate to moderately-severe) and degree of recovery (partial to none). The fact that least impacted Lake Erie coastal sites are structured similarly to intact inland marshes shows that the VIBI-E can be used for coastal marsh evaluation. Differences in biological expectations between coastal and inland systems can be dealt with by setting different aquatic life use cut-points for coastal wetlands. In deriving Wetland Tiered Aquatic Life Uses (WTALU) for Ohio wetlands using the VIBI, separate standards were developed for Lake Erie coastal wetlands (poor = 0-24, fair = 25-49, good = 50-61, very good >61) (Mack and Micacchion, 2006). In contrast, inland marshes in the unglaciated Allegheny Plateau region of northeast Ohio had significantly higher biological expectations and higher WTALU cut points (poor = 0-30, fair = 31-60, good = 61-75, very good >75).

Although frequently claimed to be a problematically unique class of wetlands, that makes IBI development extremely difficult or impossible (e.g., Wilcox et al., 2004), coastal wetlands of Lake Erie are not inherently more difficult to monitor and assess than other types of wetland ecosystems. Problems associated with migration of plant communities during high- or low-water cycles can be addressed with practical sample location or sampling window rules similar to those outlined for inland systems (Mack, 2004c) or by the development of alternative IBIs that will work in the various marsh successional phases. Of course during extreme high-water level periods, when certain wetlands can simply disappear and become shallow lake habitats, practical sampling procedures would prohibit sampling these areas to collect data for a "wetland" IBI. This may be just an issue of having alternative IBIs or indicators for evaluating this phase of the coastal wetland cycle (e.g., a near-shore fish IBI might then be the appropriate assessment tool) (Kleber and Johnson, 2006). In Ohio EPA's stream assessment program it is not uncommon to forgo sampling certain rivers because of unusually large flood events or continuously high water levels because representative data of the quality of fish assemblages cannot be collected.

Although sometimes criticized as simplistic or unable to account for natural disturbance cycles in certain ecosystem types, the evaluation presented here suggests the robustness of the IBI approach in allowing for the development of usable, scientifically sound assessment protocols for disparate aquatic resource types. Although the State of Ohio is unfortunately lacking in sufficient numbers of intact examples of the many types of Great Lakes coastal wetlands, future work elsewhere in the Great Lakes basin should be able to evaluate whether further refinement by coastal marsh sub-classes is necessary (Albert et al., 2003; Chow-Fraser and Albert, 1998), especially if these evaluations are undertaken in the context of larger freshwater wetland data sets.

ACKNOWLEDGMENTS

This work was funded by Lake Erie Protection Fund Grant No. LEQI 01-06 and several U.S. EPA Wetland Program Development Grants including CD995927, CD995761, CD985276 and CD985875. Special thanks to Michael Wisnewski, Katherine Kleber, Lauren Glockner, Joseph Bishop, Jen Wilson, Deni Porej, Chad Kettlewell and Joni Lung for their assistance in this project.

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Table 1. Summary table of Lake Erie Coastal wetlands sampled, 2000-2004. Sites with * = reference sites. EOLP = Erie-Ontario Drift and Lake Plains, HELP = Huron-Erie Lake Plains.

Table 2. Summary of numbers of separately analyzable sample plots in Ohio EPA's referenc wetland database by major hydrogeomorphic and plant community classes and ecoregions 1996-2004. ECBP = Eastern Corn Belt Plains, EOLP = Erie-Ontario Drift and Lake Plains, HELP = Huron-Erie Lake Plains, MIDP = Michigan-Indiana Drift and Lake Plains, WAP = Western Allegheny Plateau.

Table 3. Scoring ranges for assigning metric scores for VIBI-Emergent. Descriptions of metrics are found in Table 4. Cyperaceae metric used in place of Carex metric for Lake Erie coastal wetlands.

Table 4. Description of metrics used in Vegetation IBI-Emergent.

Table 5. Correlation coefficients from regression analysis of inland and coastal wetland metric values versus ORAM score. * p value = 0.001, ** p value < 0.001

Figure 1. Nonmetric Multidimensional Scaling of inland and coastal wetland species abundance data (stress = 21.22, p = 0.0323). Data set edited following procedures in Mack (2004a) and Gouch (1982). The two circles (long-dash) representative clusters of high and low quality inland wetlands. The three ovals (short-dash) show clusters coastal wetland sites grouped with inland sites.

Figure 2. Scatterplot of VIBI scores versus NMS Axis 1 scores (R2 = 0.203, p = 0.001). Circled sites were outliers in an analysis of residuals versus fits.

Figure 3. Box and whisker plots of Vegetation IBI scores of Lake Erie and inland marshes in Ohio. A: reference condition inland and coastal marshes and non-reference condition inland and coastal marshes. B: inland and coastal marshes grouped by ORAM score tertiles (0-32, 33-65, >65). 1st, 2nd and 3rd refer to inland coastal marshes in the first, second, or third ORAM tertiles; 2nd- coast and 3rd-coast refer to Lake Erie coastal marshes in the second and third ORAM tertiles.

Figure 4. Scatterplot of VIBI scores versus the human disturbance gradient (ORAM v 5.). Metric 5 of ORAM assigns extra points for the purposes of regulatory categorization (and not related to disturbance). Undiked coastal wetlands consistently receive 10 extra points on Metric 5 and coastal wetlands are more fairly compared to inland wetlands by excluding Metric 5 from the ORAM score. Category 1, 2, and 3 refer to the antidegradation category in Ohio Administrative Code (OAC) Rule 3745-1-54, which assigns increasing levels of regulatory protection the higher the Category. SWLH, WLH, RWLH, and LQWLH refer to superior wetland habitat, wetland habitat, restorable wetland habitat, and limited quality wetland habitat, respectively. These are proposed wetland tiered aquatic life use categories for Ohio (Mack 2004b, Mack and Micacchion 2006).

Figure 5. Comparison of inland and coastal wetland VIBI scores to Landscape Development Index, an alternate human disturbance gradient. Land use data to calculate the LDI score was not available for sites sampled in 2004.

Figure 6. Simultaneous evaluation of metric performance of inland and coastal wetlands using PCA. Square = high quality inland wetlands, circle = fair to good quality inland wetlands, asterisk = low quality inland wetlands, triangle = coastal wetlands, solid circle = least impacted coastal wetlands. Refer to Table 4 for description of metrics.

Table 1. Summary table of Lake Erie Coastal wetlands sampled, 2000-2004. Sites with * = reference sites. EOLP = Erie-Ontario Drift and Lake Plains, HELP = Huron-Erie Lake Plains.

Site Code	Site Name	Sample date	County	Latitude	Longitude	Ecoregion	Subregion	HGM Subclass	Plant Community
ARCOLA	Arcola Creek*	12-Jul-2001	Lake	41.8497	-81.0058	EOLP	Erie Lake Plain	drowned river mouth	mixed emergent marsh
BEULAH	Beulah Beach	7-Aug-2002	Erie	41.3928	-82.4397	EOLP	Erie Lake Plain	drowned river mouth	mixed emergent marsh
CDRPT-NE	Cedar Pt. NE	7-Jul-2004	Ottawa	41.7011	83.3285	HELP	Maumee Lake Plains	diked-managed	mixed emergent marsh
CDRPT-SW	Cedar Pt. Swale	8-Jul-2004	Ottawa	41.7037	83.3384	HELP	Maumee Lake Plains	beach swale	mixed emergent marsh
COWLESCR	Cowles Cr Swale	27-Jul-2004	Ashtabula	41.8576	80.9694	EOLP	Erie Lake Plain	beach swale	mixed emergent marsh
DUPONT	Dupont Marsh	2-Jul-2001	Erie	41.3633	-82.5567	EOLP	Erie Lake Plain	drowned river mouth	mixed emergent marsh
FOXMARSH	Foxes Marsh	18-Sep-2002	Ottawa	41.7114	-82.8281	HELP	Marblehead Drift/Limestone	barrier-beach lagoon	mixed emergent marsh
MEADWBRK	Meadow Brook	12-Aug-2002	Ottawa	41.5086	-82.7733	HELP	Marblehead Drift/Limestone	closed embayment	mixed emergent marsh
MIDHARBR	Middle Harbor	12-Aug-2002	Ottawa	41.5483	-82.8178	HELP	Marblehead Drift/Limestone	closed embayment	mixed emergent marsh
NORPND-E	North Pond Emergent*	3-Jul-2001	Erie	41.6114	-82.7011	HELP	Marblehead Drift/Limestone	barrier-beach lagoon	mixed emergent marsh
NORPND-S	North Pond Shrub*	14-Aug-2002	Erie	41.6114	-82.7011	HELP	Marblehead Drift/Limestone	barrier-beach lagoon	mixed shrub swamp
OLDWO-IN	Old Woman Cr Inlet	15-Aug-2001	Erie	41.3766	-82.5092	EOLP	Erie Lake Plain	drowned river mouth	mixed swamp forest
OLDWO-MO	Old Woman Cr Mouth	2-Jul-2001	Erie	41.3814	-82.5153	EOLP	Erie Lake Plain	drowned river mouth	mixed emergent marsh
OLDWO-WE	Old Woman West	7-Aug-2002	Erie	41.3844	-82.5167	EOLP	Erie Lake Plain	closed embayment	buttonbush swamp
PLUMBRK	Plum Brook Channel	6-Aug-2002	Erie	41.4267	-82.6406	HELP	Marblehead Drift/Limestone	drowned river mouth	mixed emergent marsh
PTRSPOND	Potters Pond	14-Aug-2002	Lucas	41.6794	-83.3092	HELP	Maumee Lake Plains	closed embayment	cattail marsh
SHELDON	Sheldons Marsh	22-Sep-2000	Erie	41.4179	-82.6026	HELP	Marblehead Drift/Limestone	barrier-beach lagoon	mixed emergent marsh
WESTSTMA	West St. Marsh	7-Aug-2002	Erie	41.3981	-82.5586	EOLP	Erie Lake Plain	drowned river mouth	mixed emergent marsh
WHEELMD	Wheeler Cr Meadow	26-Jul-2004	Ashtabula	41.8541	80.9908	EOLP	Erie Lake Plain	drowned river mouth	blue joint meadow
WHEELMSH	Wheeler Cr Marsh*	26-Jul-2004	Ashtabula	41.8536	80.9895	EOLP	Erie Lake Plain	drowned river mouth	mixed emergent marsh

Table 2. Summary of numbers of sample plots in Ohio EPA's reference wetland database by major hydrogeomorphic and plant community classes and ecoregions 1996-2004. ECBP = Eastern Corn Belt Plains, EOLP = Erie-Ontario Drift and Lake Plains, HELP = Huron-Erie Lake Plains, MIDP = Michigan-Indiana Drift and Lake Plains, WAP = Western Allegheny Plateau.

Hydrogeomorphic Classes	N	Plant Community Classes	N	Ecoregion	N
Depressions	74	Swamp forests (all types)	47	ECBP	64
Impoundments	10	Marshes (all types)	59	EOLP	74
Riverine headwater depressions	10	Wet meadows - Fens	16	HELP	27
Riverine mainstem depressions and Riverine channel	34	Wet meadows - Other (prairie sedge meadows, lake plains sand prairies, reed canary grass meadows)	14	MIDP	4
Slope (excluding lacustrine fens)	34	Shrub swamps (all types)	33	WAP	22
Bog	9	Bogs	9		
Coastal (Lake Erie fringing)	20	Fen Shrub Swamps	3		
Mitigation Bank	103	Forest seeps	10		
Mitigation Individual	13				
TOTAL (excluding mitigations)	191		191		191

Table 3. Scoring ranges for assigning metric scores for VIBI-Emergent. Descriptions of metrics are found in Table 4. Cyperaceae metric used in place of *Carex* metric for Lake Erie coastal wetlands.

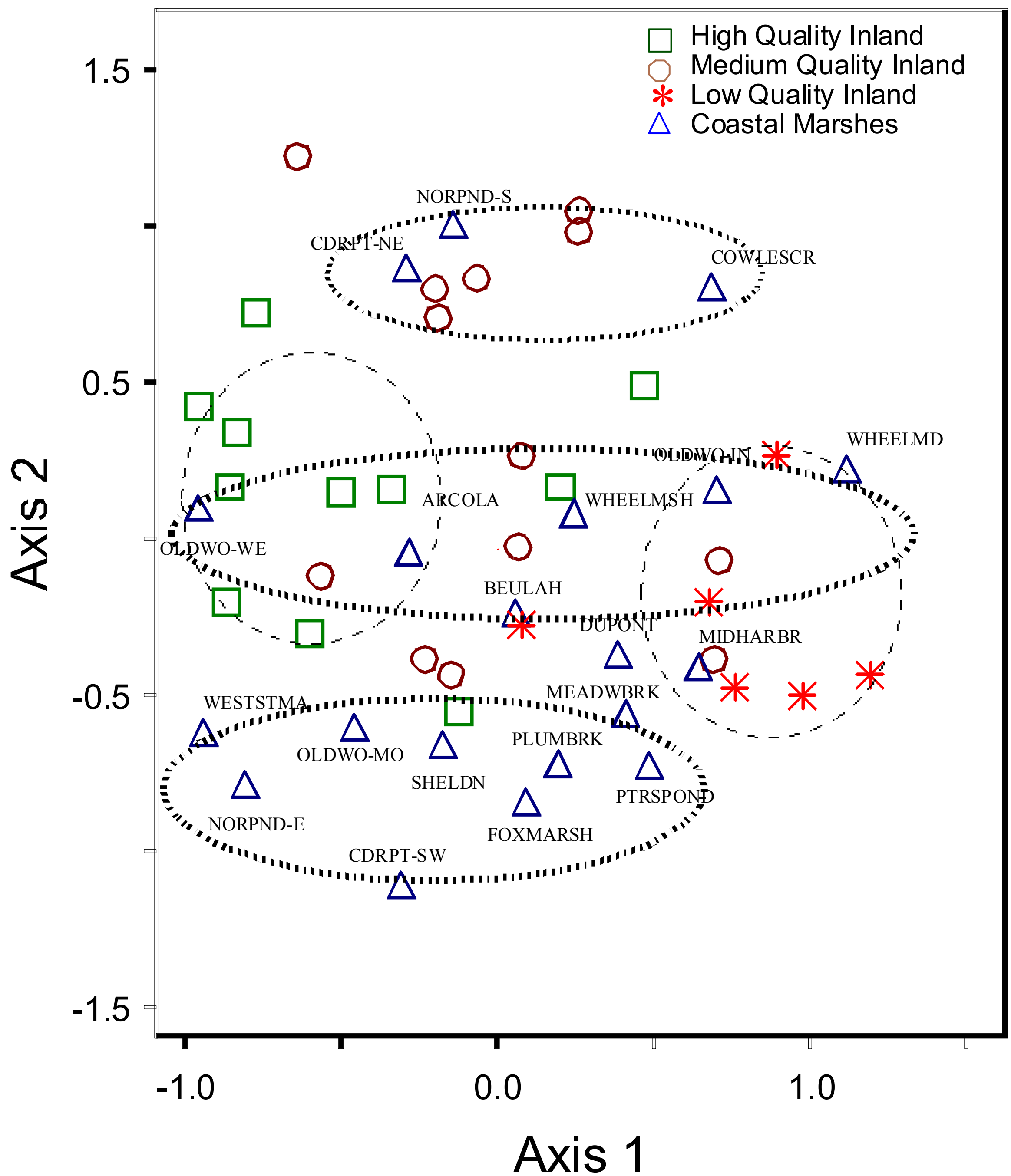
Metric	Score 0	Score 3	Score 7	Score 10
Carex	0 - 1	2 - 3	4	≥5
Cyperaceae	0 - 1	2 - 3	4 - 6	≥7
Dicot	0 - 10	11 - 17	18 - 24	≥25
Shrub	0 -1	2	3 - 4	≥5
Hydrophyte	0 -10	11 - 20	21 - 30	≥31
A/P ratio	>0.48	0.32 - 0.48	0.20 - 0.32	0.0 - 0.20
FQAI	0 - 9.9	10.0 - 14.3	14.4 - 21.4	≥21.5
%Sensitive	0 - 0.025	0.025 - 0.10	0.10 - 0.15	0.15 - 1.0
%Tolerant	0.60 - 1.0	0.40 - 0.60	0.20 - 0.40	0 - 0.20
%Invasive Graminoids	0.31 - 1.0	0.15 - 0.3	0.03 - 0.15	0 - 0.03
Biomass	≥801	451 - 800	201 - 450	0 - 200

Table 4. Description of metrics used in Vegetation IBI-Emergent.

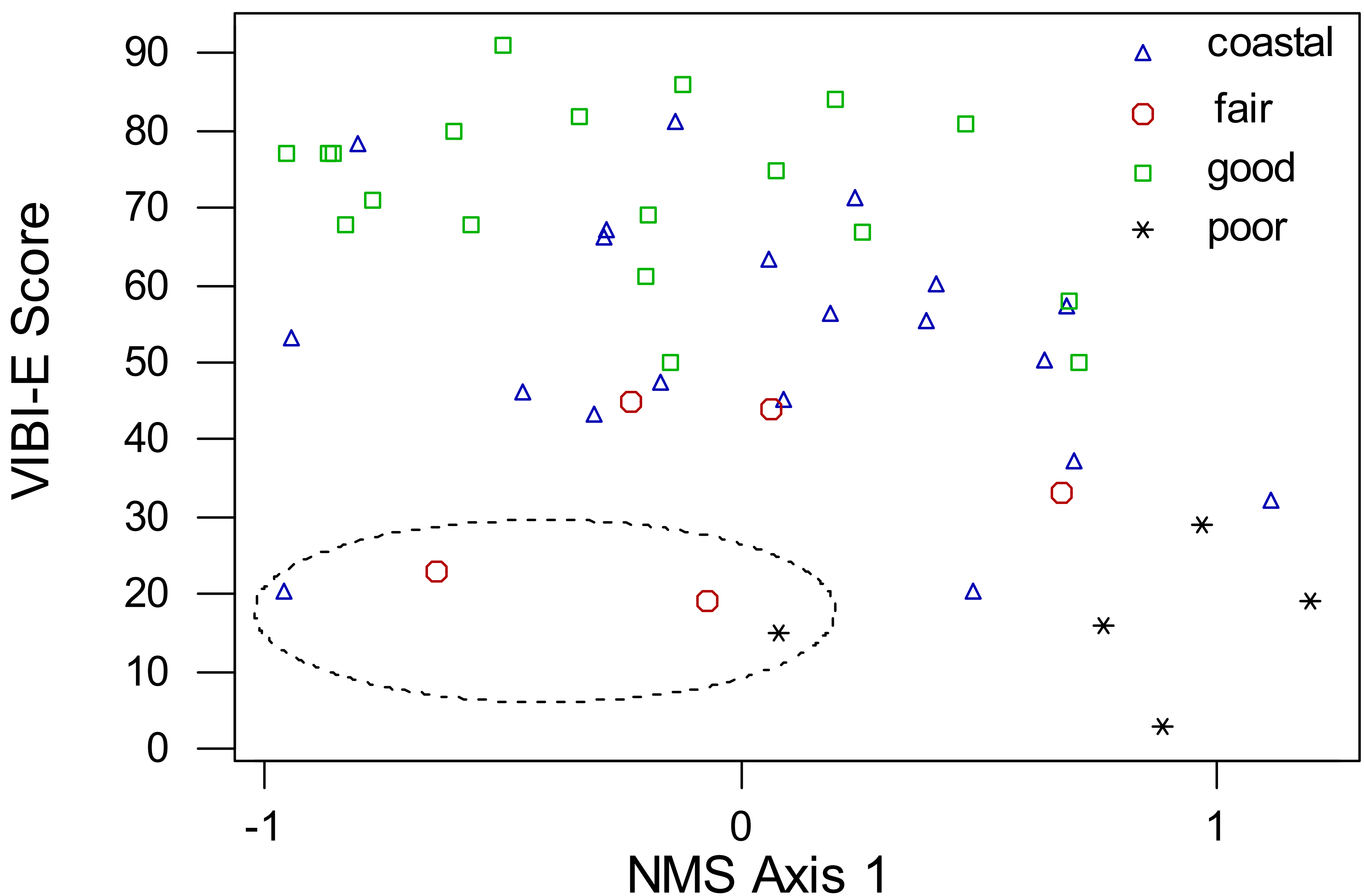
Metric	Code	Type	Metric increase or decrease w/ disturbance	Description
Number of *Carex* spp.	carex	Richness	Decrease	Number of species in the genus *Carex*
Number of cyperaceae spp.	cyperaceae	Richness	Decrease	Number of species in the Cyperaceae family
Number of native dicot spp.	dicot	Richness	Decrease	Number of native dicot (dicotyledon) species
Number of native, wetland shrubs	shrub	Richness	Decrease	Number of shrub species that are native and wetland (FACW, OBL) species
Number of hydrophyte spp.	hydrophyte	Richness	Decrease	Number of vascular plant species with a Facultative Wet (FACW) or Obligate (OBL) wetland indicator status (Reed 1988, 1997; Andreas *et al.* 2004).
Ratio of annual to perennial spp.	A/P	Richness ratio	Decrease	Ratio of number of nonwoody species with annual life cycles to number of nonwoody species with perennial life cycles. Biennial species excluded from calculation
FQAI score	FQAI	Weighted richness index	Decrease	The Floristic Quality Assessment Index score calculated using Eqn. 7 and the coefficients in Andreas *et al.* (2004)
Relative cover of sensitive plant spp.	%sensitive	Dominance ratio	Decrease	Sum of relative cover of plants in herb and shrub strata with a Coefficient of Conservatism of 6,7,8,9 and 10 (Andreas *et al.* 2004)
Relative cover tolerant plant spp.	%tolerant	Dominance ratio	Increase	Sum of relative cover of plants in herb and shrub strata with a Coefficient of Conservatism of 0, 1, and 2 (Andreas *et al.* 2004)
Relative cover of invasive graminoid spp.	%invgram	Dominance ratio	Increase	Sum of relative cover of *Typha* spp., *Phalaris arundinacea,* and *Phragmites australis*
Mean standing biomass	biomass	Primary production	Increase	The average grams per square meter of clip plot samples collected at each emergent wetland

Table 5. Correlation coefficients from regression analysis of inland and coastal wetland metric values versus ORAM score. * p value = 0.001, ** p value < 0.001

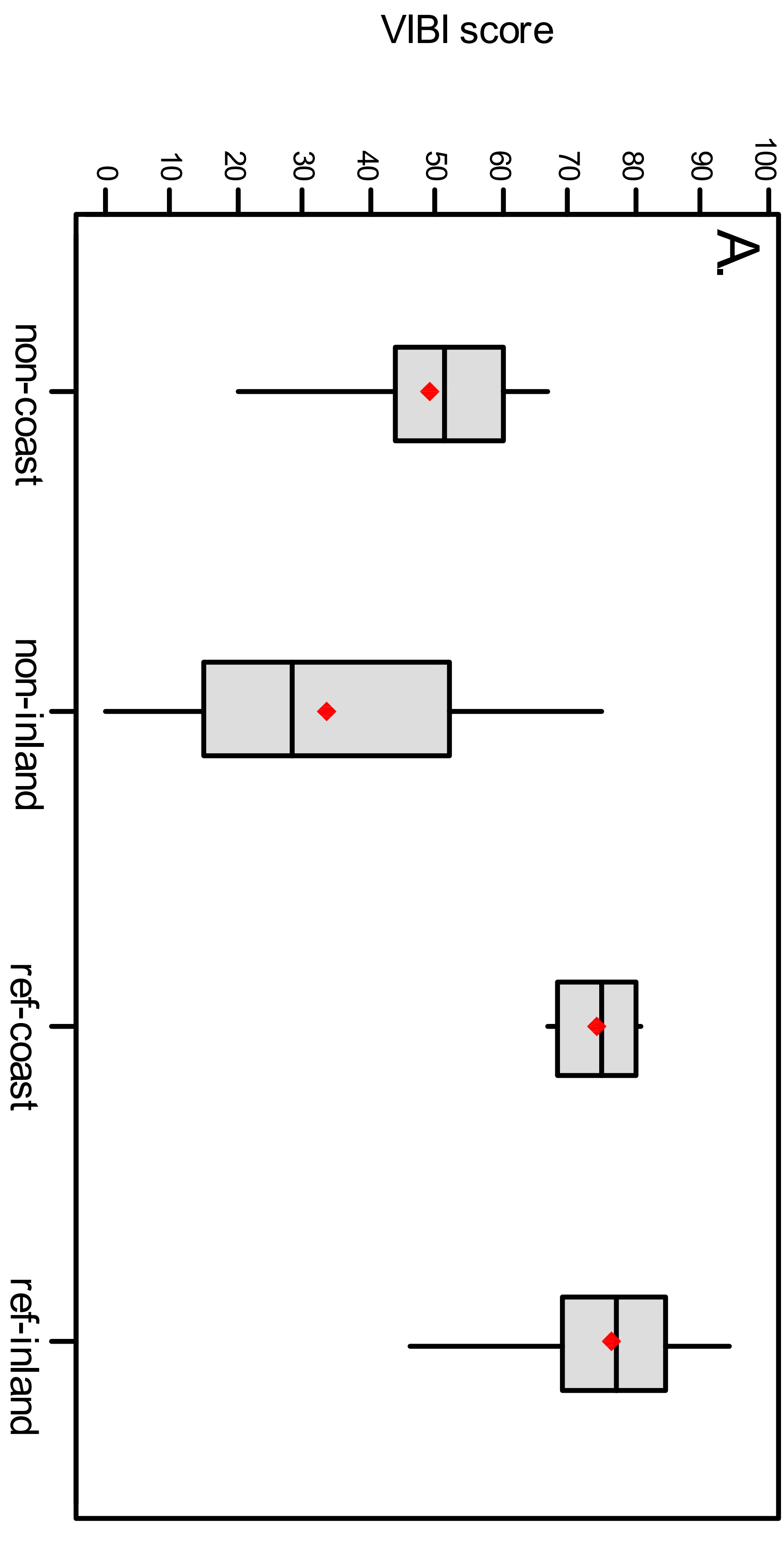
Metric	R^2
Carex spp. richness	26.9%**
Cyperaceae spp. richness	23.7%**
native wetland dicot spp. richness	52.3%**
native hydrophyte spp. richness	51.0%**
native, wetland shrub spp. richness	38.3%**
Floristic Quality Assessment Index score	64.9%**
Annual/Perennial spp. ratio	17.3%*
relative cover of invasive graminoids	33.3%**
relative cover of tolerant plant spp.	35.4%**
relative cover of sensitive plant spp.	19.2%**
averaging standing biomass (g/m^2)	16.1%**
VIBI -E score	77.9%**

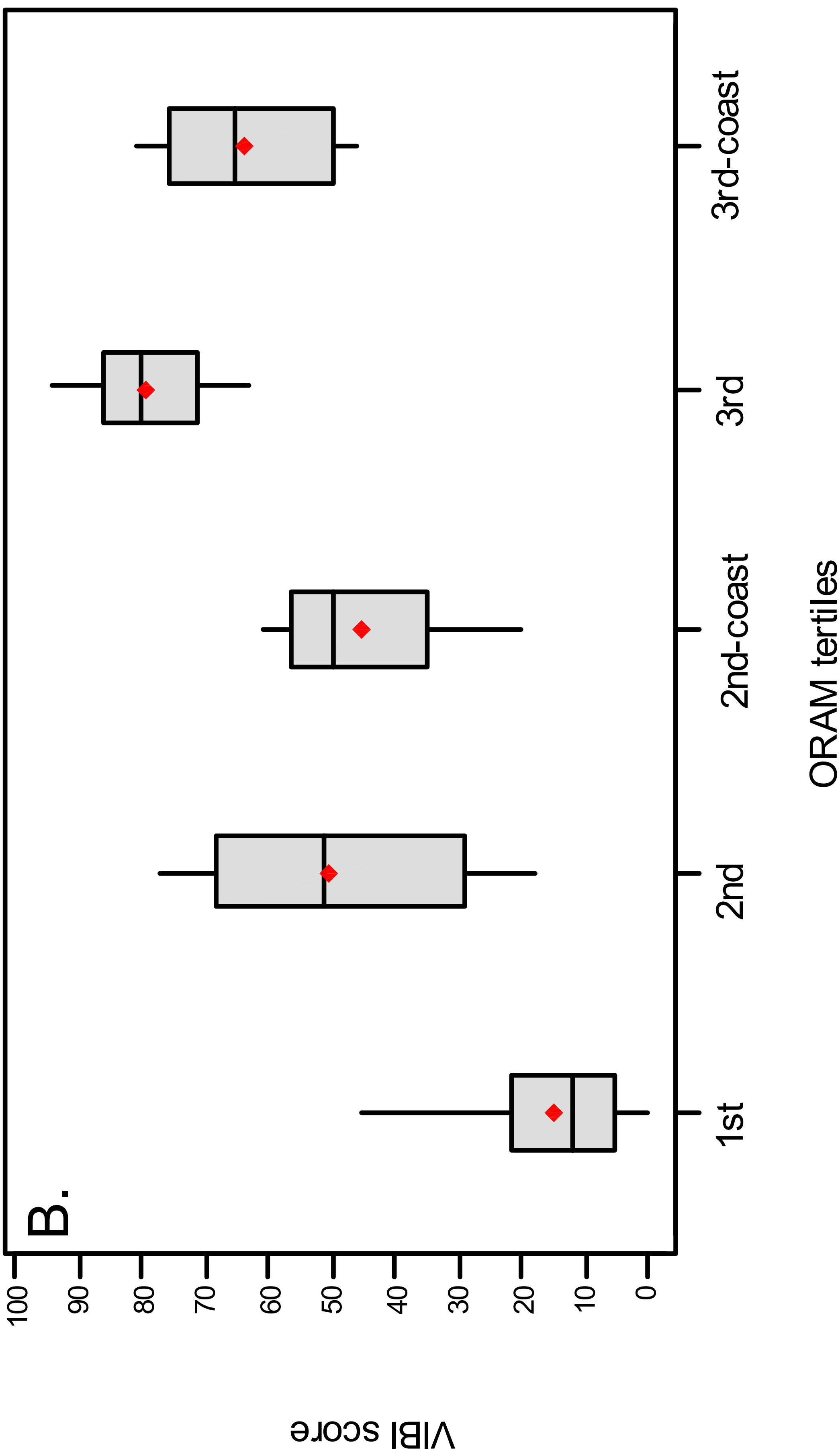


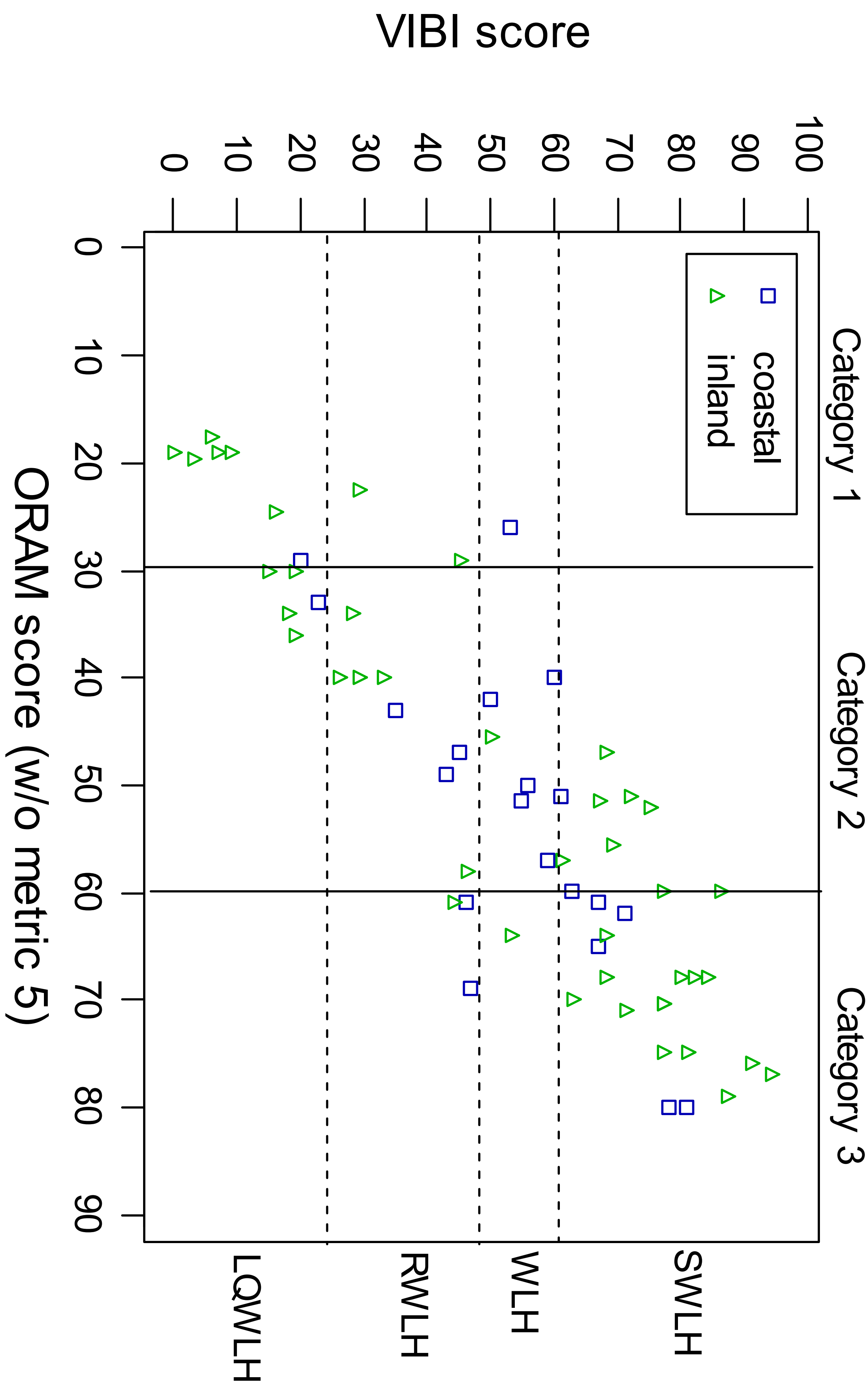
High Quality Inland
Medium Quality Inland
Low Quality Inland
Coastal Marshes
Axis 2
Axis 1
1.5
0.5
-0.5
-1.5
-1.0
0.0
1.0
NORPND-S
CDRPT-NE
COWLESCR
OLDWO-IN
WHEELMD
ARCOLA
WHEELMSH
OLDWO-WE
BEULAH
DUPONT
MIDHARBR
MEADWBRK
WESTSTMA
OLDWO-MO
PLUMBRK
SHELDN
PTRSPOND
NORPND-E
FOXMARSH
CDRPT-SW

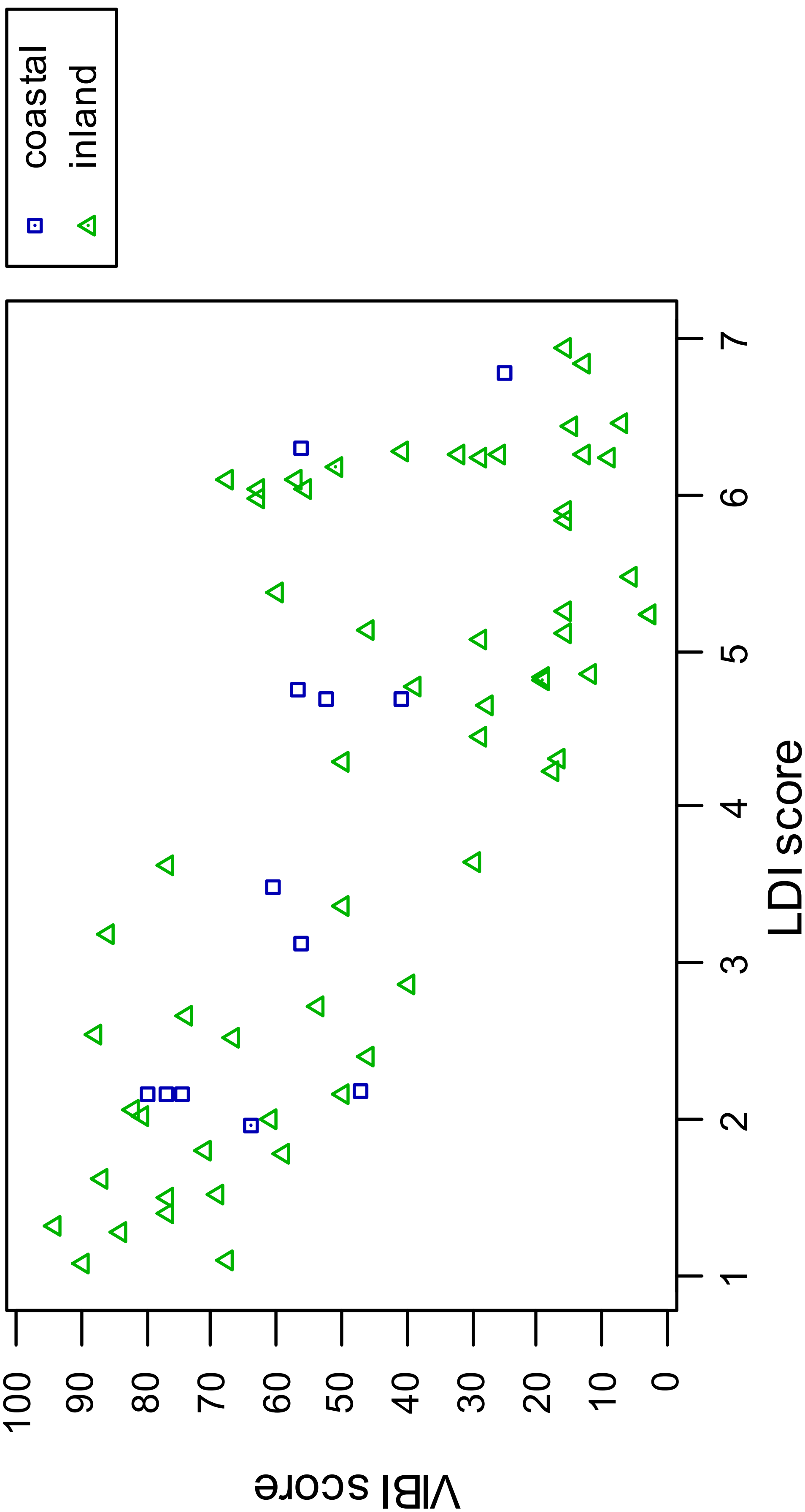


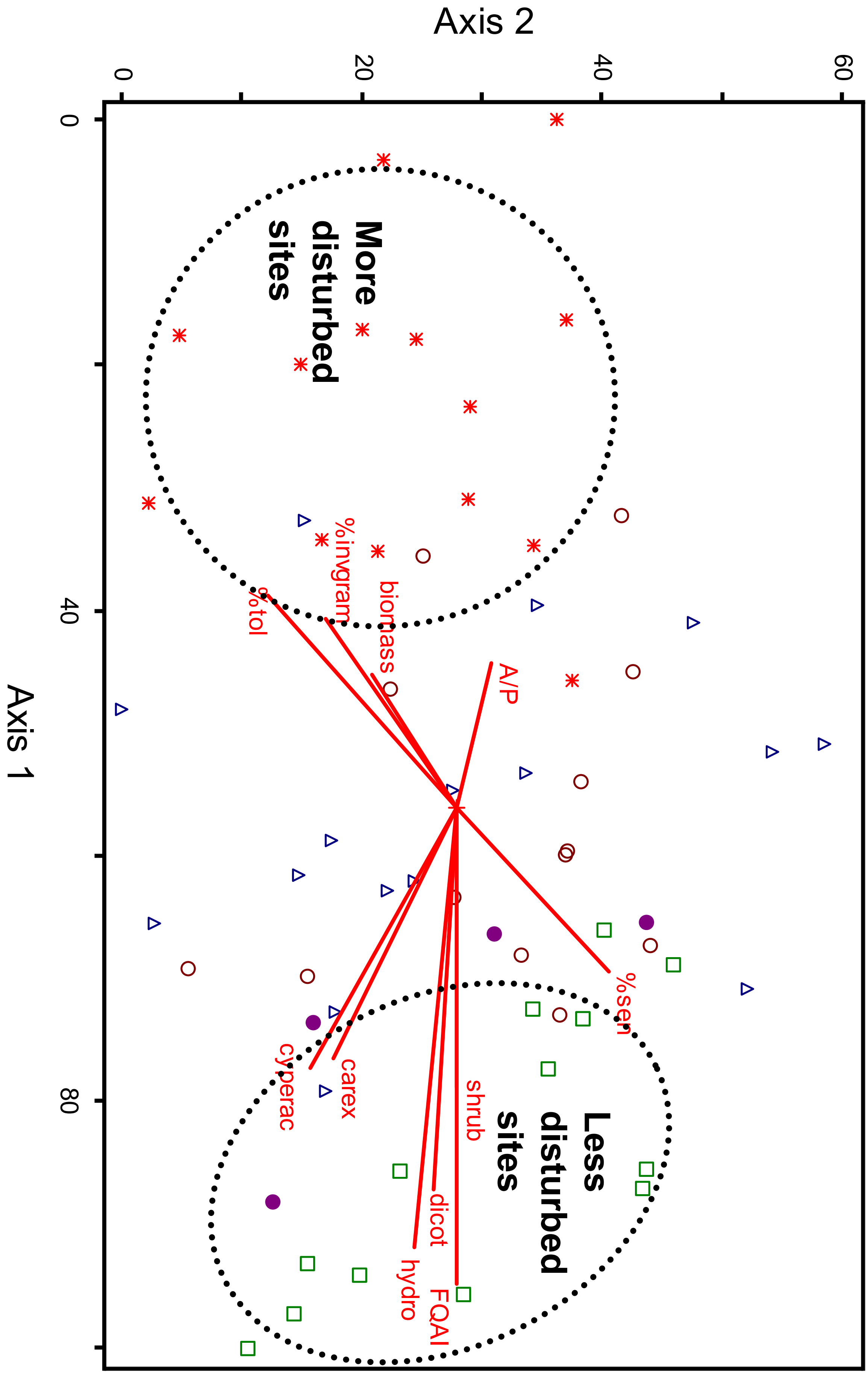
VIBI-E Score
90
80
70
60
50
40
30
20
10
0
-1
0
1
NMS Axis 1
coastal
fair
good
poor


VIBI score
A.
0
10
20
30
40
50
60
70
80
90
100
non-coast
non-inland
ref-coast
ref-inland


B.
VIBI score
0
10
20
30
40
50
60
70
80
90
100
1st
2nd
2nd-coast
3rd
3rd-coast
ORAM tertiles


VIBI score
ORAM score (w/o metric 5)
Category 1
Category 2
Category 3
coastal
inland
LQWLH
RWLH
WLH
SWLH
0
10
20
30
40
50
60
70
80
90
100


coastal
inland
VIBI score
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
LDI score


Axis 2
0
20
40
60
Axis 1
0
40
80
More disturbed sites
Less disturbed sites
%invgram
biomass
%tol
A/P
%sen
carex
cyperac
shrub
dicot
hydro
FQAI