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INTEGRATED WETLAND ASSESSMENT PROGRAM. Part 4: A Vegetation Index of Biotic Integrity (VIBI) and Tiered Aquatic Life Uses (TALUs) for Ohio Wetlands

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INTEGRATED WETLAND ASSESSMENT PROGRAM.
PART 4: VEGETATION INDEX OF BIOTIC INTEGRITY (VIBI) AND TIERED AQUATIC LIFE USES (TALUs) FOR OHIO WETLANDS

John J. Mack[1]

ABSTRACT

A Vegetation Index of Biotic Integrity (VIBI) for wetlands was previously developed using vascular plants as the indicator taxa group from sites sampled in Ohio between 1996-2000 representing different wetland types and ecological regions. This paper represents the second major evaluation of the VIBI since it was originally proposed (Mack et al. 2000, Mack 2001b) and the fourth iteration (Fennessy et al. 1998a and 1998b, Mack et al. 2000, Mack 2001b) in overall development of vegetation-based wetland assessment tools for the State of Ohio. Subsequent testing and refinement is an important step in the development of a robust IBI. The VIBI is actually three IBIs for use with emergent, forest, or shrub dominated wetlands (VIBI-E, -F, -SH). Data collected in 2001 and 2002 from additional wetland types and ecoregions was used to test the the VIBI (Mack et al. 2000, Mack 2001b). The VIBI continued to correlate significantly with the original disturbance gradient as well as an alternative disturbance gradient derived from land use percentages within a 1km radius of the wetlands. Analysis of individual metrics resulted in refinement and replacement of some metrics. The most serious metric problems occurred with the VIBI-Forest. New data from disturbed forests colonized by shade intolerant, native and adventive herbaceous and shrub species, exposed a previously unseen forest metric sensitivity to this disturbance-induced increase in diversity. This sensitivity resulted in over-performance of some metrics and inflated VIBI-F scores for these disturbed forests *vis-a-vis* intact forests. Metrics were refined or selected to only include forest (shade, facultative shade) and hydrophyte species. The VIBI was evaluated for significant differences due to ecological region, landscape position (HGM class), and dominant plant community. Significant ecoregional differences were observed for the first time. Wetlands, other than slope wetlands and bogs, located in the unglaciated Allegheny Plateau had, on average, significantly higher VIBI scores than similar types of wetlands in all other Ohio ecological regions. Hydrogeomorphic class and dominant plant community were also significant variables. Significant differences in some combinations of ecoregion, HGM class, and plant community were also observed. Tiered Aquatic Life Uses (TALUs) for wetlands are proposed with differing biological expectations based on landscape positions, plant communities, and ecoregions in Ohio. This represents the first time wetland TALUs applicable to all wetlands in a state have been published.

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INTRODUCTION

A Vegetation Index of Biotic Integrity (VIBI) for wetlands was previously developed using vascular plants as the indicator taxa group (Mack et al. 2000, Mack 2001b, Mack 2004a) using data from sites sampled in Ohio between 1996-2000 representing different wetland types and ecological regions. An important step in the development of an IBI is the subsequent testing and refinement with new data sets from the same or different regions and/or community types (Karr and Chu 1999). This paper represents the second major evaluation of the VIBI since it was originally proposed in Mack et al. (2000) and the fourth iteration in overall development of vegetation-based wetland assessment tools for the State of Ohio.

Initial efforts to develop vegetation sampling methods and useful indicators of wetland condition were based on 31 depressional and riparian wetlands sampled in 1996-1997 (Fennessy et al. 1998a and 1998b; Lopez and Fennessy 2002). The Floristic Quality Assessment Index (FQAI) (Andreas and Lichvar 1995) emerged as a particularly useful index for evaluating wetland condition and as a potential metric in IBI development (Fennessy et al. 1998b; Lopez and Fennessy 2002). Other plant community characteristics were shown to vary predictably with human disturbance (Fennessy et al. 1998a). Qualitative and semi-quantitative human disturbance gradients were developed and evaluated and were shown to be important steps in the development of wetland IBIs (Fennessy et al. 1998a and 1998b). In particular the Ohio Rapid Assessment Method for Wetlands (ORAM v. 3.0 - 4.1) was used and evaluated for use as a human disturbance gradient.

Additional data was collected in 1998 from natural and mitigation wetlands. Preliminary attempts at building a multi-metric wetland plant IBI revealed deficiencies in the data set (e.g. a lack of high quality emergent wetlands and highly disturbed forested wetlands). As a human disturbance gradient, ORAM (v. 3.0 - 4.1) underemphasized the evaluation of disturbances to wetlands as they affected overall ecosystem condition, and overemphasized habitat and certain functions or wetland types (e.g. riparian wetlands). (Mack et al. 2000, Mack 2001b). Sampling in 1999 focused on alleviating the deficiencies in the data set: high quality emergent communities were located and sampled; very disturbed forested wetlands that still had trees were sampled; and additional moderate and high quality emergent, forest, and shrub dominated wetlands were sampled. The ORAM had undergone relatively minor revisions in 1999 (v. 4.0 and 4.1) but was substantially recast to be a condition-based rapid assessment tool during the 1999 field season and before data collected during 1999 was analyzed.

The recast disturbance gradient (ORAM v. 5.0) and the additional data collected during 1999 provided the basis for developing a multimetric vegetation-based wetland IBI (Mack et al. 2000) using 48 forest, shrub and emergent wetlands in mostly depressional landscape positions and located in the Eastern Corn Belt Plains (till plains) ecoregion (Omernik 1987; Woods et al. 1998). In 2000, data was collected from wetlands in the the Erie-Ontario Drift and Lake Plains (glaciated Allegheny Plateau) ecoregion (Omernik 1987). The VIBI proposed in Mack et al. (2000) (VIBI 2000) was tested against this new data set. Some refinements and modifications of individual metrics were necessary but the overall performance of the VIBI was confirmed. Relatively little variation due to ecoregion was observed although hydrogeomorphic and plant community class were significant classification variables (Mack 2001b).

This paper represents a further evaluation and refinement of the 2001 VIBI with a substantially expanded wetland dataset that includes some data from all ecoregions and major wetland types occurring in Ohio. It also proposes Tiered Aquatic Life Uses (TALUs) for wetlands and equates these uses to wetland regulatory categories. To the author's knowledge, this is the first time this has been done using a large reference wetland data set with ecoregion, landscape position (HGM or hydrogeomorphic class) and dominant plant community as TALU categories.

This paper is the fourth in a series of papers documenting the development of an integrated wetland assessment program in Ohio. Summary and synthesis of earlier VIBI development efforts are found in Mack (2004a) (Part 1). A quantitative evaluation of the wetland classification scheme used here is found in Mack (2004b) (Part 2). The history and development of the Ohio Rapid Assessment Method for Wetlands is discussed in Mack and Fennessy (2004) (Part 3). Linkage of structural plant community attributes to wetland ecosystem processes, as well as use of plant community indicators to assess performance of created and restored wetlands can be found in Fennessy et al. (2004) (Part 5). Wetland IBIs have also been developed for amphibians (Micacchion 2002, 2004) (Part 7) and macroinvertebrates (Knapp 2004) (Part 8). In addition, a reevaluation of amphibian data from Ohio EPA data sets and development of predictive models for amphibian presence in natural wetlands and amphibian colonization of created wetlands was done by Porej (2004). Finally, a translation of the technical conclusions of these papers into standardized monitoring, design, and performance protocols for mitigation wetlands is found in Mack et al. (2004) (Part 6).

METHODS

Sampling Methods

Sampling methods are summarized in detail in Mack (2002, 2004a). Sites 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 in the data set (Karr and Chu 1999; Parker 2002, Fennessy et al. 2001). "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.

A plot-based vegetation sampling method was used to sample wetland plant communities (Peet et al. 1998; Mack 2002; Mack 2004a). At most sites, a "standard" plot was established consisting of a 2 x 5 array of 10m x10m modules, i.e. 20m wide by 50m long (1000m^2 or 0.1 ha), within the boundary of the wetland and within each vegetation community of interest. Location of the plot was qualitatively selected by the investigator based on site characteristics and rules for plot location (Mack 2002, 2004a). Presence and areal cover was recorded for herb and shrub stratums, stem density and basal area was recorded for all woody species >1m. Standing biomass (g/m^2 from 8 0.1m^2 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 subsequent analyses. A soil pit was dug in the center of every plot and soil color, texture, and depth to saturation was recorded and a sample was collected from the top 12 cm and analyzed for standard nutrient parameters and metals at the Ohio EPA laboratory. If standing water was present in the wetland, a grab sample of water was collected and analyzed for various water quality parameters.

Taxonomic identification

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). Positive identifications of species were made in the field although 2,365 voucher specimens have been collected of both easy and difficult to identify species. Since 1996, 647 vascular plant species have been encountered and identified (approximately 28% of the flora of Ohio) (Cooperrider et al. 2001).

Classification

Each wetland was classified using an *a priori* classification system. The classification was subsequently evaluated and refined (Mack 2004b). Wetland class is based on dominant landscape position dominant plant community. There are nine landscape positions identified: depression, impoundment, riverine, slope, fringing, Lake Erie coastal, bog and mitigation which correspond generally to the hydrogeomorphic classification system outlined by Brinson (1993) (see Table 1 in Mack 2004b). There are three main plant community divisions: forest, emergent, and shrub. Each of these types has several subtypes: forest (swamp forests, bog forests, forest seeps); emergent (marsh, fen, other sedge-grass communities, sphagnum bog); and shrub (buttonbush swamp, alder swamp, mixed shrub swamp, bog and fen shrub swamps). Refer to Mack 2004b for a detailed description of these classes.

Ecoregions of Omernik (1987) as revised by Woods et al. (1998) were used. To the extent that the large areas of the ecoregions present in Ohio extend into adjoining states including Indiana, Michigan, Pennsylvania, and West Virginia, the Vegetation IBI proposed here would be usable outside of Ohio's political boundaries within the ecoregional boundaries of the Eastern Corn Belt Plains, Huron-Erie Lake Plains, Erie-Ontario Lake Plains, and the Western Allegheny Plateau (Omernik 1987; Woods et al. 1998).

Attribute Selection and Scoring

Potential attributes were initially selected *a priori* and included aspects of the community structure (taxa richness, relative cover, density, dominance), taxonomic composition (species identity, floristic quality, diversity indices, tolerance or intolerance of particular species to disturbance, and ecosystem processes (productivity) (Mack et al. 2000, Mack 2001b, 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 three successive refinements of the Vegetation IBI (Fennessy et al. 1998a and 1998b; Fennessy and Lopez 2002; Mack et al. 2000, Mack 2001b, Mack 2004a). 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. A 0, 3, 7, or 10 metric scoring scheme was used (Mack et al. 2000, Mack 2001b, Mack 2004a).

Human disturbance gradient

The score from the Ohio Rapid Assessment Method for Wetlands v. 5.0 (ORAM) was used as human disturbance gradient (Mack et al. 2000, Mack 2001a, Mack 2001b, Mack 2004a, Mack and Fennessy 2004). The ORAM was designed to perform regulatory categorizations and to be used as a wetland disturbance scale (Mack 2001a). Questions in ORAM are designed to assess the condition of the wetland. 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, and spatial heterogeneity, amphibian habitat features. Because the "disturbance" questions in the ORAM correlate strongly with the total ORAM score (df=72, F=295.75, R^2=0.806, p<0.001), the total ORAM v. 5.0 score was used as a disturbance gradient.

The Landscape Development Intensity Index (LDI) (Brown and Vivas 2004), was also used as an alternative, quantitative human disturbance scale. The LDI is calculated by mulitplying land use percentages with 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 2004; Odum 1996). The equation for calculating the LDI is,

$$LDI_{Total} = \sum \%LU_i * LDI_i$$

where, LDI_{Total} = the LDI score, $\%LU_i$ = percent of total area in that land use *i*, and LDI_i = landscape development intensity coefficient for land use *i*. The %LU*i* was calculated with landscape composition 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 (2004) 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.

Evaluation of Earlier VIBI

The VIBI previously developed and reported (Mack 2000, Mack 2001b, Mack 2004a) was evaluated with new data collected in 2001 and 2002 from wetlands representing multiple plant communities and hydrogeomorphic classes and multiple ecoregions based on Omernik (1987) (Eastern Corn Belt Plains, Erie-Ontario Drift and Lake Plains, Michigan and Indiana Drift and Lake Plains, Huron-Erie Lake Plains and the Western Allegheny Plateau) (Table 1). Descriptive statistics, box and whisker plots, regression analysis, analysis of variance, multiple comparison tests, and t tests (Minitab v. 12.0) were used to explore and evaluate the biological attributes measured for VIBI development. Detrended Correspondence Analysis (DCA) (Hill and Gauch 1980; Gouch 1982) and Cluster Analysis (Sneath and Sokol 1973) were used to evaluate species presence and relative abundance data for patterns related to human disturbance. Principal Components Analysis (PCA) and DCA were used to evaluate metric performance. Multivariate analyses were performed with PC-ORD (McCune and Mefford 1999) using metric values or species abundance composition and abundance data (relative cover for herb and shrub strata; importance values, stem density and basal area for shrub, subcanopy and canopy strata). For the DCA, Euclidean distance was calculated and rare species were downweighted. For Cluster Analysis, Sorensen similarity and Ward's linkage method were used.

Ecoregional, HGM, and Plant Community Evaluation

Variation in average and achievable VIBI scores based on ecological region, hydrogeomorphic class, and plant community was evaluated. Results from Mack (2004b) demonstrated differences in dominant vegetation (forest, emergent, shrub) as well as some subcommunities: fens and other sedge-grass dominated communities, bogs, coastal marshes, marshes, swamp forests, shrub swamps. Mack (2004b) also found differences in four HGM classes (slopes, bogs, impoundments, coastal marshes) and that these four classes differed from riverine and depressional systems in the aggregate. Floristic composition alone did not clearly define riverine from depressional systems (Mack 2004b). Even given the relatively large data set in this paper (n = 168), grouping by ecoregion, HGM class, and plant community resulted in many small sample groups (n < 4). To avoid this, the data set was aggregated for analysis by ecoregion (all HGM class and plant communities), then HGM class (all ecoregions, plant communities), and then plant community (all ecoregions and HGM classes). Given the clear results of Mack 2004b on certain class distinctions (slope, bog, coastal, wet meadows including fens and prairies), subsequent analyses focused on depressional and riverine systems within the ECBP, WAP, and EOLP regions that were swamp forests, marshes, or shrub swamps (n = 109 sites). Of the 109 sites, 55 were reference standard sites). Differences were evaluated using analysis of variance, multiple comparison tests (Tukey's HSD), box and whisker plots, means, medians, and 25th, 75th, and 95th percentiles.

RESULTS

Disturbance effects in Ordination of Species Data

Analysis of site by species abundance matrices using DCA revealed clear separations in ordination space of moderately to severely disturbed plant communities from less disturbed to largely intact plant communities (Figures 1 and 2). Disturbed emergent marsh communities had distinguishable species assemblages and abundances from intact marsh communities (Figure 2). Most mitigation wetlands, i.e. created or restored wetlands, also ordinated with the disturbed communities, as did many Lake Erie coastal marshes (Figure 2). With regards to the coastal marsh communities, many of them are moderately to severely degraded or are subject to natural disturbances from daily, monthly, yearly, and/or decadal variations in water levels leading to a plant community with many species adapted to these natural disturbance cycles. Similar patterns emerged from a cluster analysis of the same data set, with disturbed inland and coastal marshes, mitigation wetlands, natural beaver impoundments, acid mine drainage impacted inland wetlands clustering apart from good to high quality inland and coastal marshes (Figure 3).

Disturbed forest and shrub dominated communities also showed a strong signature in their species assemblages and abundances (Figure 1). "Disturbed" forests often have high importance values for cottonwood (*Populus deltoides*) and black willow (*Salix nigra*) along with green ash (*Fraxinus pennsylvanica*), pin oak (*Quercus palustris*), and elms (*Ulmus rubra, U. americana*) that sets them apart from more typical canopy assemblages of Ohio wetland forests (Figure 4). Other degraded forest communities have canopy assemblages indistinguishable from intact forests due to the longevity of canopy species (Figure 4). Trends in woody dominated wetlands are not as apparent as with emergent communities because highly disturbed swamp forests and shrub swamps tend to have had trees and shrubs completely removed and thus have the appearance of emergent marshes. Given that the climatological climax landscape in Ohio is deciduous forest (Shane 1987; Webb et al. 1983), and that most of Ohio was forested at the time of settlement (Gordon 1966), it can be argued that degraded emergent marshes in known, previously forested areas constitute the bottom of the scale for forested wetlands.

*Evaluation of ORAM and the Landscape Development Index as disturbance gradient*s

The performance and behavior of the ORAM score as a disturbance gradient was compared to the Landscape Development Intensity Index (LDI). Despite the scale differences between them (ORAM addressing on-site disturbances and the LDI focusing on land use within a 1km radius circle of the wetland), the LDI score was a highly significant predictor of wetland category as defined by the ORAM score (Figure 5). As might be expected, there was considerable scatter in the plot of ORAM versus LDI scores (Figure 6), but the relationship was still significant. Much of the variability is explainable by the scale differences in the method or by the fact that on site circumstances caused degradations despite a relatively intact landscape or that on-site circumstances buffered the wetland from land uses which typically degrade wetlands.

Comparison of existing metrics and VIBIs with the ORAM and LDI scores

The performance and behavior of the VIBI 2001 and its component metrics of the Vegetation IBIs were reevaluated. Results for each VIBI (-E, -F, -SH) are presented below.

VIBI - Emergent Evaluation

The VIBI-E was calculated for sites sampled in 2001 and 2002 using the scoring ranges derived for the 2001 VIBI (VIBI 2001) (Mack 2004a). The VIBI-E 2001 continued to perform very strongly with significant correlations with the disturbance gradient (Figure 7) (df = 38, F = 97.6, R^2 = 72.5%, $p < 0.001$). The VIBI-E also correlated significantly with the independent, quantitative Landscape Development Index (LDI) (Figure 7) (df = 38, F = 54.5, R^2 = 52.6%, $p < 0.001$).

Individual metrics in the VIBI-E were reevaluated using the two disturbance scales (ORAM and LDI) and box and whisker plots of ORAM score tertiles. Overall metric performance with the additional sites from the EOLP and WAP ecoregions sampled in 2001 and 2002 remained good and correlations with the new LDI disturbance gradient were also observed for most metrics (Figures 8, 9, 10, 11, 12, 13, 14, 15, 16, and 17). Minor modifications are proposed for 3 metrics and 1 metric is replaced. These are discussed below.

Richness of *Carex* species continues to be a good predictor of wetland quality, although a few high quality sites had relatively low numbers of carices observed in the sample plots (Figure 8). This may be the result of where the plot was located at these sites (plot baselines at these sites did not include the shallow margin of the wetland), or that these sites tended to have strong submersed or floating aquatic communities and lower natural *Carex* richness. Cyperaceae richness and monocotyledon species richness were reevaluated as metrics but did not perform as well as the *Carex* metric (results not shown).

The dicot (dicotyledon species) metric continued to perform well with a few sites having higher or lower values than expected by the disturbance scales (Figure 9). The metric is improved by excluding adventive dicots from the totals since these are usually upland weeds that colonize disturbed sites ($dicot_{native}$ - ORAM: df = 38, F = 30.0, R^2 = 44.8%, p <0.001; LDI: df = 50, F = 19.1, R^2 = 28.0%, p < 0.001). There is also better separation of the ORAM tertiles using the $dicot_{native}$ modification.

The Rosaceae species metric is the only metric proposed for replacement in the VIBI-E. Although significant differences between mean Rosaceae richness still occur between the 1st and 3rd ORAM tertiles, there are many good to very good sites that have low Rosaceae richness and many disturbed sites with high Rosaceae richness leading to metric scores that are not correlated with disturbance (Figure 10). The ratio of annual to perennial species is proposed as a substitute metric with a threshold relationship to the ORAM disturbance gradient and better graphical separation of box and whisker plots of ORAM tertiles (Figure 11). Correlation with the LDI is significant but low (Figure 11), although sites in low intensity landscapes have low A/P ratios (dominated by perennials). Sites in higher intensity landscapes can have high or low A/P ratios, with site specific disturbances being the more important factor in predicting A/P ratio than intensive land use within the 1km radii of the site.

Performance of the shrub ratio (shrub spp./total species) metric declined substantially with the inclusion of additional data from 2001 and 2002 (Figure 12). Correlations with both disturbance gradients was low and there was poor separation of mean scores by ORAM tertiles (Figure 12). Partly this was due to the inclusion of adventive upland shrubs in the calculation but also the ratio calculation resulted in disturbed sites with relatively few total species having high ratio values. This metric was modified to a richness metric of native, wetland shrub species (as in the VIBI-F and -SH, see below). Performance improved significantly with the replacement metric (Figure 13).

Standing biomass (g/m^2, either mean or maximum sampled) has been a metric in the VIBI-E since it was initially proposed. Correlations have been imperfect with a few less disturbed sites having relatively high biomass, and some sites being so disturbed that they are sparsely vegetated and have low standing biomass (Figure 14 and 15). The maximum standing biomass metric is modified to mean standing biomass. Linear correlations of mean standing biomass to both disturbance gradients are low or absent (Figure 15), but an abrupt threshold relationship is observable in the ORAM scatterplot. There is significant separation in the box and whisker plots at least between the 1st and 3rd ORAM tertiles (Figure 15). Of note is the low standing biomass of mitigation sites which is function of poor soil conditions and construction practices rather than quality (Figure 15). Poor quality mitigation wetlands are dominated by unvegetated open water and unvegetated or sparsely vegetated ground that is often dominated by annual wetland species (Figure 16). A substitute metric for use when the VIBI is calculated for mitigation wetlands is proposed: relative cover of unvegetated ground plus relative cover of annual species (Figure 16). The LDI score is poorly correlated with the A/P ratio due to on-site factors that control standing crop versus land use in the 1km radius circle.

The hydrophyte species (FACW, OBL) richness metric, FQAI metric, and the relative cover of invasive graminoid species, tolerant species, and sensitive species metrics all continued to perform well and also showed significant and relevant correlations with both disturbance gradients (Figures 17, 18 19, 20, and 21). No changes to these metrics are proposed.

The VIBI-E was recalculated with the retained, modified and replacement metrics (Table 3) using scoring ranges in Table 2. Overall metric performance with modified and replaced metrics was evaluated using principle components analysis (Figure 22). All metrics performed as intended with "positive" metrics (carex, dicot native, shrub native, hydrophyte, %sensitive, FQAI) associating with good to high quality sites and "negative" metrics (A/P ratio, %tolerant, standing biomass, %invasive graminoids) associating with degraded sites and most mitigation wetlands (Figure 22). There is some suggestion of differential metric performance betweeen riverine, depression, and impoundment sites (Figure 22). The modified VIBI-E remained highly correlated with both disturbance gradients with significant separation between all three ORAM tertiles (Figure 23).

Lake Erie Coastal Marsh Evaluation

Lake Erie coastal marsh data was separately evaluated because of the strong separation observed in ordinations of emergent community data (Mack 2004b). The VIBI-E score as summarized above (Tables 2 and 3; Figure 23) was calculated for Lake Erie Coastal Marsh plots. Some annual dominated wetlands were under- and overperforming (Figure 24). This may be due to differences in the coastal marshes in the data set. Seven of the coastal marsh plots were in communities with > 10% relative cover of annual plant species (Figure 24). When the data set was split, correlations of the VIBI to the disturbance scales were highly significant for perennial dominated coastal marshes (ORAM: df = 9, F = 71.8, R^2 = 78.7%, p = 0.001; LDI: df = 8, F = 18.3, R^2 = 91.1, p < 0.001). This may point to a classification issue between perennial dominated coastal marshes (and their associated hydrogemorphic factors) and mudflat or annual dominated coastal marshes.

A complicating factor in this analysis was the lack of reference condition Lake Erie coastal wetlands in Ohio. Arguably, only North Pond (Kelleys Island, Erie County, Ohio) and possibly Arcola Creek (Lake County, Ohio) were undisturbed enough to count as "reference standard" wetlands. Data from separate and merged plots at North Pond resulted in VIBI-E scores comparable to high quality inland marshes (Figure 24).

Finally, Husat (2003) recommended substituting richness of Cyperaceae species for the *Carex* richness metric in the VIBI-E when it is used for Lake Erie coastal marshes. Cyperaceae richness does in fact perform better than the *Carex* richness metric. Other Cyperaceae genera including *Eleocharis, Schoenoplectus, Scirpus, Cyperus,* and *Bolboschoenus* are often more common components of the sedge flora of coastal marshes than *Carex* species.

Wet Meadow Evaluation

Fens, prairies, and other grass and/or sedge dominated emergent communities (wet meadows) clearly ordinated apart from emergent marsh communities (Mack 2004b). Although there are within community differences, these graminoid dominated wetlands have sufficiently similar assemblages to treat them as single class for IBI purposes (Mack 2004b and community evaluation below). Included in this analysis are two "tall shrub fens" (Mack 2004b) with sedge dominated understories.

The VIBI-E score as summarized above (Tables 2 and 3; Figure 23) was calculated for data from plots in these communities (Figure 26). Fens, deep soil prairie wet prairies and Oak Openings sand prairies exhibit a threshold relationship with both disturbance gradients (Figure 26). Moderate to moderately low levels of on-site disturbance result in an abrupt decrease in VIBI scores; similarly, moderate shifts in land uses with the 1 km radius of the site, generally leads to abrupt reduction in quality. Sites at the low end of these gradients tend to be dominated by reed canary grass (Figure 26). Degraded fens occupy somewhat intermediate positions, but these sites are generally receiving active management to maintain relict fen communities (Figure 26). One site, Daughmer Savannah, is a deep soil prairie sedge meadow located in the center of a 15ha relict prairie savannah patch which buffers it from the intensive row cropping elsewhere within the 1 km radius of the site (Figure 26). Reference standard condition fens (mean = 85.5) had on average significantly higher VIBI-E scores than reference standard marsh communities (mean = 77.0) (df = 26, t = 2.58, p = 0.016), although many (36% in this data set) of the best marsh communities can have VIBI-E scores in the 80s or 90s also.

VIBI - Forest Evaluation

The VIBI-F 2001 was calculated with additional wetland sites sampled in 2001 and 2002

(Mack 2001b, 2004a). The VIBI-F 2001 continued to perform strongly with significant correlations with the disturbance gradient (Figure 27). Although still significant, the strength of the correlation between the the VIBI-F with the LDI was relatively low (20.3%) (Figure 27) for two reasons: some forests are degraded by substantial local disturbances despite being located in a predominately forested landscape matrix. In this instance, land use within the 1 km radius as a predictor of wetland condition is "trumped" by strong on-site factors; or 2) high quality forested wetlands that are located within woodlots that buffer them from their intensively developed surrounding landscapes.

Individual metrics in the VIBI-F were reevaluated using the two disturbance scales (ORAM and LDI) and box and whisker plots of ORAM score tertiles. Overall metric performance with the additional sites from the EOLP and WAP ecoregions sampled in 2001 and 2002 remained good, although correlations with the new LDI disturbance gradient were sometimes low for the reasons noted above. Modifications are proposed for 3 metrics and 3 metrics are replaced. These are discussed below. The main cause underlying theses changes was metric sensitivity to colonization of moderately to highly disturbed forests by shade intolerant, native and adventive understory species. In some instances, a disturbed forest will retain some of its original flora plus add adventive upland or native shade intolerant species. This disturbance-induced increase in diversity resulted in over-performance on some metrics and an inflated VIBI-F score for these disturbed forests *vis-a-vis* intact forests (this is a conservative error which could result in over-protection of degraded wetlands but would not result in under-protection of high quality sites). The solution was to modify the calculation of the affected metrics to exclude non-forest and/or non-wetland species from the counts.

A second complicating factor in the development of a vegetation IBI for wetland forests is the longevity of the canopy; disturbed forests can fully retain their pre-disturbance canopy. This can lead to an apparent over-performance of otherwise disturbed forests on certain metrics (e.g. mean tree IV, Figure 41) which lowers the correlations with the disturbance gradient.

Several metrics developed substantial problems from the disturbance-induced diversity discussed above. The dicot (dicotyledon species) metric did not correlate significantly with either disturbance gradient with the addition of new sites in the data set (Figure 28). Mean scores for ORAM tertiles while exhibiting some graphical separation were also not significantly different (Figure 28). The metric was only marginally improved by excluding adventive dicots from the totals or by attempting to modify it by only including shade tolerant and/or hydrophytic species in the richness counts (results not shown). The dicot metric was failing to detect the effects of disturbance (increased energy/or nutrients and/or hydrologic drawdowns); however, intact wetlands still scored well on this wetland with their diverse shade intolerant floras. The metric was recast to include only shade intolerant understory species at a site, both monocotyledon and dicotyledon species. The shade species metric performs strongly with significant correlations with both disturbance gradients, and with highly significant differences between all three ORAM tertiles (Figure 29). Strength of the correlation with the LDI score, while significant, remained low for the reasons mentioned above.

Performance of the shrub metric declined with the inclusion of additional data from 2001 and 2002 (Figure 32), again due to inflated richness of degraded sites by the addition of adventive and/or shade intolerant shrub species to their floras. Metric performance was regained by modifying the metric to include only native, wetland (FACW, OBL) shrub species typical of forest understories (e.g. *Lindera benzoin, Ilex verticillata*) or species which are facultative with regard to shade tolerance (e.g. *Vaccinium corymbosum, Viburnum recognitum, Aronia melanocarpa*) (Figure 33). Correlations with both disturbance gradients were significant and there was significant separation of mean scores by ORAM tertiles (Figure 33).

Although performance was regained with relatively minor modifications to the shrub metric, the information content of the shrub metric was deemed to be overly redundant with the average importance value of native wetland subcanopy species (see below). Because of this, the shrub metric was replaced by a new metric focusing on the abundance of nonvascular plant taxa (mostly mosses along with the aquatic lichen genera *Riccia* and *Ricciocarpos*). Bryophytes are important and common components of forest ecosystems including forested wetlands. The relative cover of bryophytes exhibited a threshold relationship with the disturbance gradients, with bryophyte cover generally declining or disappearing with moderate to high distubance (Figure 35). Because of this threshold relationship, linear correlations were low but still significant (Figure 35).

Performance of the hydrophyte species (FACW, OBL) richness metric also degraded with the inclusion of additional data from 2001 and 2002 for the same reasons as the dicot metric: artificially inflated richness of degraded sites by the addition of adventive and/or shade intolerant shrub species to their floras. The metric was modified by including only shade or facultative shade tolerant species and converted to a dominance metric: relative cover of "shade" hydrophytes. Metric performance was regained. Correlations with both disturbance gradients were significant and there was significant separation of mean scores by ORAM tertiles (Figure 36).

The Rosaceae species metric is proposed for replacement for the same reasons as in the VIBI-E: many high quality sites with few species in the Rosaceae and many disturbed sites with high Rosaceae species richness (Figure 30). The richness of seedless vascular plants (vascular cryptogams) is proposed as a substitute metric. Seedless vascular plants (SVPs) have advantages as taxa group for a forest community metric. Most SVP species are “forest” species and SVPs generally disappear completely with moderate or greater disturbance (Figure 31). Richness of SVPs is significantly correlated with both disturbance gradients (Figure 31), although the the strengths of the correlations are lower as would be expected with a threshold relationship.

The shrub density metric began to behave inconsistently. Density dependent metrics in IBIs have potential problems related non-disturbance related variation: inter-year variation in recuitment, individualistic species responses, etc. (Karr and Chu 1999). As modification of this metric, the average importance value of subcanopy species was evaluated. Because of its averaging of relative frequency, density, and basal area, it is less sensitive to site-specific variability in density. Correlations with both disturbance gradients were significant and there was significant separation of mean scores by ORAM tertiles (Figure 40).

The mean of the importance values of trees in the canopy is substituted for the former maximum modified IV metric (Figure 41). As noted above, disturbed forests with intact canopies can perform as well as undisturbed forested wetlands which results in lower correlations with the disturbance gradients.

Finally, four metrics were retained with no changes: FQAI, %tolerant species, %sensitive species, and the relative density of small (pole timber) trees (10-25 cm dbh) (Figures 33, 35, 36, and 37). All continued to have significant correlations with the disturbance gradients and well defined separation of box and whisker plots. No changes to these metrics are proposed.

The VIBI-F was recalculated with the retained, modified and replacement metrics (Table 3) using scoring ranges in Table 2. Overall metric performance with modified and replaced metrics was evaluated using principle components analysis (Figure 42). All metrics performed as intended with “positive” metrics (shade, shrub, SVP, FQAI, %hydrophyte, %sensitive, shrub IV, tree IV) associating with good to high quality sites and “negative” metrics (%tolerant, small tree density) associating with degraded sites (Figure 42). Riverine, depression, and slope forested wetlands clustered based on the their metric performance indicating a difference due to dominant landscape position (Figure 42). The modified VIBI-F remained highly correlated with both disturbance gradients with significant separation between all three ORAM tertiles (Figure 43).

VIBI -Shrub Evaluation

The VIBI-SH was calculated for sites sampled in 2001 and 2002 using the scoring ranges derived for the 2001 VIBI (Mack 2004a). The VIBI-SH 2001 continued to perform strongly with significant correlations with the ORAM disturbance gradient (Figure 44). There were no linear correlations with the LDI, although the threshold pattern of high and low quality groups with some sites under- or over-performing based on land use patterns was apparent (Figure 44).

Individual metrics in the VIBI-SH were reevaluated using the two disturbance scales (ORAM and LDI) and box and whisker plots of ORAM score tertiles. Overall metric performance with the additional sites from the EOLP and WAP ecoregions sampled in 2001 and 2002 remained good. However, most metrics did not have linear correlations with the new LDI disturbance gradient. This can be attributed to on-site factors providing buffers from intensive surrounding land uses or on-site disturbances degrading a site despite low-intensity surroudning land uses. Minor modifications are proposed for 4 metrics and 2 metrics are replaced. These are discussed below.

No changes are proposed for the *Carex*, hydrophyte, FQAI or %tolerant metrics. Correlations with the ORAM disturbance scale remain significant and there is significant separation between ORAM tertiles (Figures 45, 46, 47, and 48). As with the VIBI-F, the Rosaceae metric is replaced with richness of seedless vascular plants (SVPs) (Figure 49). The dicot metric was slightly modified to include only native dicot species (Figure 50), and the shrub richness metric was modified to include only native, wetland species (Figure 51). As with the VIBI-F, the shrub density metric became sensitive to non-disturbance related variability. It was modified to the average subcanopy species importance value (Figure 52). The small tree density metric, while useful in the VIBI-F, failed with the addition of new data in the VIBI-SH. It was replaced with the %bryophyte metric (Figure 53). Finally, the performance of the %sensitive species metric declined. The metric was overly sensitive to high coverages of buttonbush at moderately to highly degraded sites. The metric was modified by deducting relative cover of buttonbush from the summation of relative covers of "sensitive species", e.g. species with coefficients of conservatism of 6, 7, 8, 9, or 10 (Andreas et al. 2004) (Figure 54).

The VIBI-SH was recalculated with the retained, modified and replacement metrics (Table 3) using scoring ranges in Table 2. Overall metric performance with modified and replaced metrics was evaluated using principle components analysis (Figure 55). All metrics performed as intended, and there was some clustering of depressional versus riverine sites due to metric performance (Figure 55). The modified VIBI-SH remained highly correlated with both disturbance gradients with significant separation between all three ORAM tertiles (Figure 56).

Ecoregional, HGM, and plant community variation in Vegetation IBI

VIBI scores varied significantly due to the ecological region of the wetland. Wetlands located in the EOLP region had, on average, significantly higher VIBI scores than wetlands located elsewhere in the state (Tables 4 and 5). However, no ecoregional variation in total VIBI scores was noted for certain plant community types (bogs, fens, wet meadows) and HGM classes (slopes, bogs). Prior evaluations (Mack 2001b) had only noted minor ecoregional variation between ECBP and EOLP wetlands for a few individual metrics but not for the overall VIBI scores. These ecoregional differences were also observed when the data set was partitioned by plant community types and HGM classes (Table 6 and 7, Figures 60, 61).

An ordination of the species composition and abundance data (Mack 2004b) confirmed many recognizable wetland communities due to differences in floristic composition; but, only some of these types had significantly different in VIBI scores (Table 6 and 7, Figure 60). Reference standard condition fens, weakly ombrotrophic bogs ("rich" bogs), and wet meadow communities had higher VIBI scores than marshes, swamp forests, forest seeps, shrub swamps and strongly ombrotrophic bogs ("poor" bogs) (Table 6, Figure 60). Statistical significance when comparing mean scores for these classes was obscured by uneven group sizes and small sample sizes for some groups. Detrended correspondence analysis of selected shared metrics across plant community types showed clustering of plant community types caused by differential metric performance based on plant community (Figure 58). Similar patterns were observed with regards to HGM class: ordinations of species abundance data confirmed multiple classes (Mack 2004b) but only certain classes had noticeable or significant differences in VIBI scores (Table 7, Figure 60). Riverine mainstem depressions and strongly ombrotrophic bogs had the lowest average scores, and weakly ombrotrophic bogs and slopes had the highest scores; coastal, depression, riverine headwater, and impoundments had average scores intermediate between these groups (Figure 60). There was also variation within classes due to ecoregion (Table 7). Detrended correspondence analysis of shared metrics showed clustering or pattern based on HGM class indicating differential performance on certain metrics because of landscape position (Figure 59). Scatterplots of VIBI scores for all sites showed a general intermixing of depressional and riverine wetlands although many riverine wetlands (mostly mainstem depressions) trended along the bottom of the distribution especially at the "undisturbed" end of the disturbance gradients (ORAM or LDI) (Figure 62).

DISCUSSION

As a potential indicator taxa to measure the biological integrity of wetlands, vascular plants are large, obvious, important components of wetland ecosystems with a well understood taxonomy, that can be cost effectively sampled using well-developed sampling methods (Fennessy et al. 2001). Plant-based IBIs have been developed in other states and regions (Carlisle et al. 1999; Gernes and Helgen 1999, Simon et al. 1999, DeKeyser et al. 2003). In terms of their role in ecosystem processes of wetlands they can almost be considered a physical feature like soil or water in addition to being living organisms Cronk and Fennessy 2001).

The Vegetation IBI as developed and proposed in Mack (2001b) continued to work very well with the addition of new IBI testing data (Figures 7, 27, and 44). Although the overall VIBIs continued to work well, a metric by metric analysis revealed some problems. Metrics were refined by excluding adventive species, e.g. dicot richness to native dicot richness, or by modifying the metric calculation, e.g. maximum biomass to average biomass, maximum canopy IV to average canopy IV, shrub density to average subcanopy IV. In a few instances, metrics were simply replaced because they failed with the addition of new data, e.g. the Rosaceae metric, or developed a consistent problem, e.g. over-scoring of disturbed sites like some VIBI-F metrics. The final suite of metrics for the Vegetation IBI (Table 8) includes metrics relating to taxonomic composition, community structure, and ecosystem processes (Barbour et al. 1995). The Vegetation IBI consistently and reliably assesses wetland condition across the whole range of wetland types and throughout Ohio ecological regions (Figure 60). The most substantial problems occurred with the forest IBI which had the most metrics replaced or modified.

Although the VIBI-F 2001 continued to work very well for undisturbed wetland forests (Figure 27), data from additional disturbed wetland forest revealed a recurring metric sensitivity to disturbance-induced increases in diversity. In forested wetlands a major artifact of disturbance is the addition to their floras of non-wetland or wetland native or adventive plant species adapted to full sun conditions resulting in over-performance of some disturbed sites. The correction for this problem required modifying or replacing several metrics so that only forest dependent species were included in metric values. Forested wetlands are clearly much more difficult to work with than emergent communities in developing an IBI. Disturbance can affect the herb, subcanopy, and canopy layers differentially resulting in different "information-content" in defining metrics which respond consistently and predictably with disturbance. The final VIBI-F includes metrics which address ground layer (%bryophyte), herb layer (shade or SVP species), shrub layer (subcanopy IV, relative density of young trees), canopy (canopy IV), and all vertical strata (FQAI score, %hydrophytes, %sensitive, %tolerant) (Table 8).

Strongly sedge and/or grass dominated communities tend to be emergent communities *par excellence*: intact fens, wet prairies, prairie sedge meadows, and Oak Openings sand prairies incorporate floristically the "best of" the emergent vegetation class. The VIBI-EMERGENT works well when evaluating these communities apart from more emergent marsh communities, but a threshold relationship with local disturbance or landscape factors is clearly apparent: beyond a certain level or local disturbance or intensity of surrounding land use, these communities degrade quickly (Figure 26). This is consistent with other research on the fate of sedge-grass communities after human disturbance (Woo and Zedler 2002, Werner and Zedler 2002).

Lake Erie coastal marshes represent another type of emergent marsh system. Husat (2003) evaluated the VIBI-E for use in Lake Erie coastal marshes using data previously collected by Ohio EPA, as well as data from additiona coastal sites sampled with the author using methods outlined in this paper. She concluded that six of 10 VIBI-E 2001 metrics developed using inland marsh data were usable as is or with minor modifications to the metric or metric scoring (*Carex* richness modified to Cyperaceae richness, dicot richness, shrub richness, hydrophyte richness, FQAI score, and %invasive graminoids). She proposed perennial species richness as an additional new metric for a 7 metric VIBI-COASTAL (Husat 2003).

The data used by Husat (2003) was reanalyzed with the larger inland marsh data set and VIBI-E 2004. Only one coastal site (North Pond, Kelleys Island) was definitely a "reference standard" site, with Arcola Creek being another possible "reference standard" site. North Pond was sampled twice, with one plot located in the strongly emergent to floating leaved zone (2001) and a second plot which included the shrubbier margins at the south side of the lagoon. VIBI scores were calculated for the plots separately and combined and all of the scores were competitive with reference standard condition inland marshes (combined = 84, 2001 plot = 78, 2002 plot = 81). The Arcola Creek site scored a 67. The majority of other sites 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 reference standard condition Lake Erie coastal sites can perform as well as similarly intact inland marshes shows that the VIBI-E 2004 can be used for coastal marsh evaluation. As Husat (2003) recommended a Cyperaceae richness metric is proposed for use in lieu of the *Carex* richness metric for coastal marshes. Also a replacement metric, annual/perennial species was proposed for all emergent sites. This is closely akin to the perennial richness metric that Husat (2003) found effective for coastal marshes.

Husat (2003) also rejected the %tolerant and %sensitive species metrics. While correlations within just the coastal marsh data set were low or lacking, a reanalysis of coastal marshes with the inland marsh data set indicated that these metrics were still working as part of an overal VIBI-E (Figure 25). In addition, the lack of correlation was due to annual dominated coastal wetlands (Figure 24). High annual coverage may be reflective of past disturbances or be a classification issue for coastal marsh systems where natural hydrologic variability results in a more annual dominated wetland.

Finally, a clear distinction appeared between types of bog communities. Relatively species poor bogs (leatherleaf bogs, sphagnum bogs, tamarack bogs) dominated by bog-obligate species had significantly lower VIBI scores than species rich bogs (tamarack-hardwood bogs, tall shrub bogs). It is suggested that the former are moderately to strongly ombrotrophic bogs and the latter are weakly ombrotrophic late-successional bogs (Moore and Bellamy 1974).

Ecoregion, Landscape position (HGM class), and Dominant Plant Community

As any plant ecologist of the last 150 years would tell you, landscape position is a significant variable for determining plant community type. Significant variation from ecoregion, HGM class, or dominant vegetation can occur at multiple levels of community organization and data synthesis: at the community level with an analysis of species compositon and abundance data; at the individual metric level with some types of wetlands scoring better or worse on average than other types; or at the level of composite index scores with significant differences in achievable biological expectations as measured by the IBI score. Ultimately, the variation that "matters," for the applied purposes that IBIs are developed, is variation that causes significant differences in the IBI score. Classification helps to control and partition variation into meaningful bundles of like sites; but where ever possible, the goal is to merge classes that have similar biological expectations. The working hypothesis is that while certain wetland types may differ in their floras at the species or community level, these species or communities behave in a similar manner in response to human disturbance (Premise 11, Karr and Chu 1999).

Evaluation of significant variation for developing a vegetation-based wetland assesssment tool was undertaken in several ways. Community level data (species composition and relative abundance) was ordinated to evaluate the *a priori* classification schemes previously developed (Mack 2004b). It confirmed the broad recognition of emergent, forest, and shrub dominated wetlands as well plant community subclasses: bog communities, fen communities, other sedge-grass dominated communities (wet prairies, prairie sedge meadows, sand prairies, reed canary grass meadows), Lake Erie coastal marshes, impoundment marshes (beaver, human), and types of shrub swamps and swamp forests (Mack 2004b). The ordination of community level data also confirmed differences due to landscape position (HGM class) (Mack 2004b). Slopes, Lake Erie Coastal, impoundments, Bogs (including weakly to strongly ombrotrophic) and a broad but relatively poorly defined depression and riverine (mainstem, headwater) depression group (Mack 2004b) The distinction between riverine and non-riverine "depressional" systems was poorly defined at the level of community data (by depression, it means wetlands dominated by evapotranspiration and precipitation during the growing season after spring precipitation and/or seasonal spring flooding have ceased and the wetlands shift to a vertical hydrologic pathway).

The next level evaluated was at the level of individual metrics that make up the the VIBI-E, -F, and -SH. Differential metric performance was observed at all levels: ecoregion, dominant plant community, and HGM class (Figures 57, 58, and 59; also see plots of metrics for all three IBIs). Most importantly the distinction between depressional and riverine systems, which was poorly defined at with community-level data, became well defined at the level of IBI metrics.

Resolving the issue of the importance of HGM class is important from for the purposes of developing a valid wetland vegetation IBI; but, it is also important from a public policy perspective. Hydrogeomorphic functional assessments have been encouraged, if not mandated, as the assessment approach for Section 404 wetland regulatory programs by the Army Corps of Engineers since the early 1990s (Brinson 1993, Smith et al. 1995 and others). It is asserted here, that a properly developed wetland IBI, which includes landscape position in its classification is a clearer and purer enunciation of wetland condition than a system which mixes biological, physical and landscape variables in what are called by HGM practioners as "crude" (and almost always untested) logic models. The IBI has the advantage of keeping biological information (the IBI and its component metrics) separate from chemical (soil chemistry, water chemistry), physical (microtopography, basin morphometry, etc.), and landscape level information, allowing relationships between all of these to be explored before an untested homogenization of these differing information contents and levels are mixed in *a priori* developed HGM logic models.

In addition the term HGM "functional" assessment is, at best, a misnomer since few, if any HGM functional assessment models measure ecoystem processes (functions) or even ecological services (values) directly (the exceptions are functions or values like flood retention or water quality improvement where basically civil engineering or environmental chemistry modeling allow a reasonable quantification). Instead, the same as IBI approaches, HGM models measure structural variables and purport to infer "function" or "functional levels" from these structural variables. Stevenson and Hauer (2003) in their synthesis paper exploring the commonalities and differences between

IBI and HGM approaches apparently accept the HGM at its face-value that it actually measures functions even though a review of most attempts at developing HGM functional assessments shows that structural parameters are far and away the most frequently measured variables (Rheinhardt et al. 2002, Stutheit et al. 2004). Even the seminal HGM functional assessment papers (e.g. Rheinhardt et al. 1997) take an approach indistinguishable from the one used here and collect primarily quantitative vegetation data and a few other related physical variables (e.g. microtopography, coarse woody debris, etc.) to develop there "HGM" models.

While landscape is clearly significant variable for IBI developent (as well as any other assessment method) not every conceivable landscape type and subtype is important (the same can be said and is shown here for ecoregion and dominant vegetation). Hydrogeomorphic class, at least on its surface, considers wetland vegetation to be "green stuff" on the ground. While hydrology and landscape position can drive what grows, what grows can be markedly different within the same HGM class, cf. slopes = calcareous fens, fens, forest seeps; cf. depressions = marshes, forests, sedge meadows, shrub swamps. A myopic focus on HGM class alone can result in homogenization of very distinct wetland communities and create a likely insuperable problem in developing wetland assessment tools. For example, dominant vegetation (tree-dominated, shrub-dominated, herbaceous-dominated) is a more important driver of wetland differences than an inclusive "depressional" landscape position class that homogenizes these florally and faunally distinct community types. This is true not just for a vegetation-basded tool described here but also tools using faunal assemblages (Micacchion 2004).

The point here is not to denigrate assessment methodologies which take an "HGM" approach but only to make clear function is rarely if at all measured directly in such approaches despite the use of the word "function" in the HGM system. In this regard, as Stevenson and Hauer (2003) state, there is probably little difference between an IBI approach which measures "structural" variables and assumes that if the structure deviates little from "reference" condition that the functions supporting that structure are also operating at reference levels; and and an HGM approach, which measures structural variables and attempts to infer functional level directly by measuring the deviation of "structural" variables from "refernce standard" condition (Smith et al. 1995).

Evaluation and Corroboration of Wetland Disturbance Gradients

An important step in VIBI development taken in this paper was the use of a second, complementary disturbance scale based on quantitative land use information. Earlier versions of the Vegetation IBI were developed using ORAM v. 5.0 as the disturbance gradient, a semi-qualitative human disturbance scale (Mack et al. 2000, Mack 2001b, Mack 2004a). The the VIBI was evaluated with Landscape Development Index (Brown and Vivas 2004) and had a significant and ecologically interpretable relationship to this quantitative disturbance index (Figures 7, 27, 44, and 60).

This relationship between the VIBI and LDI provides and important, independent validation of the VIBI (and also the ORAM): that they are sensitive to and actual able to measure, wetland condition. In addition to the overall VIBI score, many individual metrics also had similar relationships to the LDI, although of note is a pattern of metrics that are more sensitive to on-site disturbances, or lack thereof, and metrics that also vary predictably with land uses. Using ORAM with its focus on on-site disturbances the overall trend in VIBI scores is linear, but a more threshold relationship occured when the LDI was used as a disturbance gradient. Brown and Vivas (2004) actually found the best correlations when land use within 200 m of the wetland boundary was used to calculate the LDI. To obtain land use percentages so near to the wetland requires georeferenced wetland perimeter which was not available for our sites.

Looking at land uses within a 1 km radius of the wetland center, a more complex relationship to land use appears. Land use as quantitified by the LDI did not predict condition of two classes of wetlands: wetlands which had higher VIBI scores than would be expected by the land uses within a 1 km radius of the wetland, and wetlands which had lower VIBI scores than expected based on land uses within a 1 km radius. These under- and over-performing sites are explainable by on-site or near-site factors (disturbances, nearby buffers, wetland type) that "trump" the usual and expected effects of surrounding land uses. In effect, in the often fragmented landscape in Ohio, remotely sensed land use information (at least at the 1 km radius level) may be insufficient as sole predictor where lingering effects of past disturbance, or massive influence of on-site degradation swamp predictive power of the landscape. In regions where the overall landscape matrix is more intact, indexes like the LDI alone may be sufficient as disturbance scales.

Wetland Tiered Aquatic Life Uses (TALUs)

A main wetland program goal in developing wetland specific IBIs is to be able to specify numeric biological criteria for wetlands that correspond to various wetland designated uses. At the present time, Ohio law lists a single designated use for wetlands, the "wetland designated use" (OAC Rule 3745-1-52) which a wetland has merely by meeting the definition of a wetland in OAC Rule 3745-1-50. The development of a numeric IBI based on wetland vegetation is sufficiently advanced to propose tiered wetland aquatic life uses with associated numeric criteria. Ultimately, standards like these will be incorporated into the State of Ohio's water quality standards just as standards for streams have been previously promulgated. Tiered Aquatic Life Uses (TALUs) for wetlands are proposed with differing biological expectations based on landscape positions, plant communities, and ecoregions in Ohio. This represents the first time wetland TALUs applicable to all wetlands in a state have been published.

Using the results of the ecoregional, HGM, and plant community evaluation, as well as the classification and ordination in Mack 2004(b), significant categories for wetland TALU development were identified. Tiered Aquatic Life Uses were derived by calculating the 95th percentile of the VIBI score distribution for that category using reference standard (Smith et al. 1995) and other reference sites (sites with some disturbance) as recommended by USEPA (1990, 1998, 1999). The 95th percentiles were compared and classes with similar scores were grouped, and the 95th percentile partitioned into sextiles. The sextiles were then compared to disturbance scores (LDI, ORAM) for the sites and combined into 4 aquatic life use categories proposed in Mack (2001b): limited quality wetland habitat (LQWLH) (1st and 2nd sextiles), restorable wetland habitat (RWLH) (3rd and 4th sextiles), wetland habitat (5th sextile), and superior wetland habitat (SWLH) (6th sextile).

Narrative wetland Tiered Aquatic Life Uses (TALUs) categories were proposed in Mack (2001b) (Table 8). Special uses (values or ecological services) provided by wetlands were also proposed (Mack 2001b) (Table 9). The previously developed numeric TALUs (Mack 2001b) were revised based on the results discussed above as well as the ordinations performed in Mack (2004b, Tables 1A and 1B) (Table 9). Numeric TALUs (biological criteria) for Ohio wetlands are proposed based on VIBI scores, ecoregion, landscape position, and plant community (Table 10). Using Tables 9 to 11, a wetland TALU can be assigned as described in the following example: the wetland being evaluated is a pumpkin ash (*Fraxinus profunda*) swamp in Fowler Woods State Nature Preserve. This is a swamp forest in a depressional landscape position. After a detailed vegetation survey, a Vegetation IBI score of 76 is calculated. Referring to Tables 1A and 1B in Mack (2004b), this wetland is classified as "surface water depression/swamp forest" and receives the use code "IA1a". Referring to Table 11, a Vegetation IBI score of 76 is in the SWLH (Superior Wetland Habitat) use range. Finally, Table 10 is consulted and it is determined that the wetland has educational uses as a state nature preserve that is open to the public. The Wetland Aquatic Life use designation can then summarized as, "SWLH-IA1a$_B$", where SWLH = means Superior Wetland Habitat, IA1a = surface water depression swamp forest, and the subscript $_B$ = a special use of "educational." The wetland TALUSs generally correspond to the three antidegradation categories (Category 1, 2, 3) listed in

Ohio Administrative Code (OAC Rule 3745-1-54). However, there may be some instances where a wetland shows moderate to substantial impairment but is still categorized as a Category 2 or 3 wetland under the antidegradation rule because it exhibits one or more residual functions or values at moderate to superior levels, e.g. water quality improvement or flood retention. Where a "special use" is assigned to a moderately or severely degraded wetland under the wetland TALUs proposed here, it serve as an "alert" for antidegradation review purposes that the wetland has a residual function or value that should be protected.

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Table 1. Summary of numbers of separately analyzable sample plots by major hydrogeomorphic and plant community classes and ecoregions 1996-2002. 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	73	Swamp forests (all types)	41	ECBP	62
Impoundments	10	Marshes (all types)	63	EOLP	73
Riverine headwater depressions	10	Wet meadows - Fens	14	HELP	12
Riverine mainstem depressions and Riverine channel	24	Wet meadows - Other (prairie sedge meadows, lake plains sand prairies, reed canary grass meadows)	8	MIDP	4
Slope (excluding lacustrine fens)	20	Shrub swamps (all types)	31	WAP	15
Fringing (lacustrine fens)	2	Bog Forests, Tall shrub bogs	5		
Coastal (Lake Erie fringing)	14	Fen Shrub Swamps	2		
Mitigation	13	Sphagnum bogs	2		
TOTAL	166				

Table 2. Scoring ranges for assigning metric scores for Vegetation IBIs. Descriptions of metrics are found in Table 3. E = Emergent, SH = Shrub, F = Forest, $E_{COASTAL}$ = Lake Erie Coastal Marshes, MITIGATION = emergent mitigation wetlands. For metric values that are decimals and occur between classes, scoring ranges should be rounded up starting at 0. For example, in the bryophyte metric, if the metric value is 0.0106 and the scoring ranges are 0 - 0.01 = 0 and 0.01 - 0.03 = 3, the scoring range should be interpreted as 0 - 0.0109 and a score of 0 assigned.

metric	community	score 0	score 3	score 7	score 10
Carex	E, SH	0 - 1	2 - 3	4	≥5
Cyperaceae	$E_{COASTAL}$	0 - 1	2 - 3	4 - 6	≥7
dicot	E	0 - 10	10 - 17	18 - 25	≥25
	SH	0 - 9	10 - 14	15 - 23	≥24
shade	F	0 - 7	8 - 13	14 - 20	≥21
shrub	E, SH	0 -1	2	3 - 4	≥5
hydrophyte	E	0 -10	11 - 20	21 - 30	≥31
	SH	0 -9	10 - 14	15 - 20	≥21
A/P ratio	E	>0.48	0.32 - 0.48	0.20 - 0.32	0.0 - 0.20
SVP	F, SH	0	1	2	≥3
FQAI	E, SH	0 - 9.9	10.0 - 14.3	14.4 - 21.4	≥21.5
	F	0 - 14.0	14.1 - 19.0	19.1 - 24.0	≥24.1
%bryophyte	F, SH	0 - 0.01	0.01 - 0.03	0.031 - 0.06	≥0.06
%hydrophyte	F	0 - 0.1	0.1 - 0.15	0.151 - 0.28	≥0.281
%sensitive	E	0 - 0.025	0.025 - 0.10	0.10 - 0.15	0.15 - 1.0
	F	0 - 0.035	0.035 - 0.12	0.21 - 0.3	0.31 - 1.0
	SH	0 - 0.02	0.021 - 0.06	0.061 - 0.13	0.131 - 1.0
%tolerant	E	0.60 - 1.0	0.40 - 0.60	0.20 - 0.40	0 - 0.20
	F	0.45 - 1.0	0.30 - 0.45	0.15 - 0.30	0 - 0.15
	SH	0.15 - 1.0	0.10 - 0.15	0.05 - 0.10	0 - 0.05
%invasive graminoids	E	0.31 - 1.0	0.15 - 0.3	0.03 - 0.15	0 - 0.03
small tree	F	0.32 - 1.0	0.22 - 0.32	0.11 - 0.22	0 - 0.11
subcanopy IV	F	0 - 0.02	0.02 - 0.072	0.072 - 0.13	≥0.131
	SH	0 - 0.02	0.02 - 0.05	0.05 - 0.1	≥ 0.11
canopy IV	F	0.21 - 1.0	0.17 - 0.21	0.14 - 0.17	0 - 0.14
%unvegetated	MITIGATION	≥0.46	0.31 - 0.46	0.15 - 0.31	0 - 0.15
biomass	E	≥801	451 - 800	201 - 450	0 - 200

Table 3. Description of metrics used in 2004 version of VIBI-E, VIBI-F, VIBI-SH. "E" = emergent, "$E_{coastal}$" = Lake Erie Coastal Marsh, "$E_{MITIGATION}$" = Mitigaiton Marshes, "F" = forested", "SH" = shrub.

metric	E, F, SH	code	type	metric increase or decrease w/ disturbance	description
number of *Carex* spp.	E, SH	carex	richness	decrease	Number of species in the genus *Carex*
number of cyperaceae spp.	$E_{coastal}$	cyperaceae	richness	decrease	Number of species in the Cyperaceae family
number of native dicot spp.	E, SH	dicot	richness	decrease	Number of native dicot (dicotyledon) species
number of native shade spp.	F	shade	richness	decrease	Number of native shade[2] tolerant or shade facultative species
number of native, wetland shrubs	E, SH	shrub	richness	decrease	Number of shrub species that are native and wetland (FACW, OBL) species
number of hydrophyte spp.	E, SH	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.	E	A/P	richness ratio	decrease	Ratio of number of nonwoody species with annual life cycles to number of nonwoody species with perennial life cycles. Bienniel species excluded from calculation
number of seedless vascular plant spp.	F, SH	SVP	richness	decrease	Number of seedless vascular plant (ferns, fern allies) species
FQAI score	E, F, SH	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 bryophytes	F, SH	%bryophyte	dominance ratio	decrease	Percent cover of all bryophyte species divided by total percent cover of all plant species (mosses and aquatic lichens *Riccia* and *Ricciocarpos*
relative cover of shade tolerant hydrophyte spp.	F	%hydrophyte	dominance ratio	decrease	Percent coverage of shade or partial shade tolerant FACW and OBL plants in the herb and shrub stratums divided by total percent coverage of all plants
relative cover of sensitive plant spp.	E, F, SH	%sensitive	dominance ratio	decrease	Percent coverage of plants in herb and shrub stratums with a Coefficient of Conservatism (C of C) of 6,7,8,9 and 10 (Andreas et al. 2004) divided by total percent coverage of all plants

1 Shade tolerance and other codes to calculate VIBI metrics are available in Mack (2004d).

Table 3. Description of metrics used in 2004 version of VIBI-E, VIBI-F, VIBI-SH. "E" = emergent, "$E_{coastal}$" = Lake Erie Coastal Marsh, "$E_{MITIGATION}$" = Mitigaiton Marshes, "F" = forested", "SH" = shrub.

metric	E, F, SH	code	type	metric increase or decrease w/ disturbance	description
relative cover tolerant plant spp.	E, F, SH	%tolerant	dominance ratio	increase	Percent coverage of plants in herb and shrub stratums with a C of C of 0, 1, and 2 (Andreas et al. 2004) divided by total percent coverage of all plants
relative cover of invasive graminoid spp.	E	%invgram	dominance ratio	increase	Percent coverage of *Typha* spp., *Phalaris arundinacea,* and *Phragmites australis* divided by total percent coverage of all plants
relative density of small trees (pole timber)	F	pole timber	density ratio	increase	The density (stems/ha) of a tree species in size classes between 10 and 25 cm dbh divided by the density of all trees
mean importance value of native shade subcanopy spp.	F, SH	shrub IV	importance value	decrease	The mean of importance values for native, shade and facultative shade shrub species where importance value calculated by averaging relative size class frequency[3], relative density, and relative basal area of native shade or facultative shade tolerant shrub and small tree species
mean of impor-tance values of canopy spp.	F	mean IV	importance value	decrease	The mean of the importance values of trees in the canopy of the forest where importance value is calculated by averaging relative size class frequency, relative density, and relative basal area
sum of relative cover of annual spp. and cover of unvegetated areas	$E_{MITIGATION}$	%unvegetated	dominance ratio	increase	The sum of the relative cover of annual plant species (percent annual spp. cover divided by total spp. cover) and the percent cover of unvegetated areas.
mean standing biomass	E	biomass	primary production	increase	The average grams per square meter of clip plot samples collected at each emergent wetland

2 Size class frequency is the number of size classes in which there is at least one stem for that woody species. There are 11 size classes 0-1, 1-2.5, 2.5-5, 5-10, 10-15, 15-20, 20-25, 25-30, 30-35, 35-40, and >40 cm.

Table 4. Comparison of average VIBI scores by ecoregion for reference and reference standard wetlands. ECBP = Eastern Corn Belt Plains, EOLP = Erie-Ontario Drift and Lake Plains, WAP = Western Allegheny Plateau, COASTAL = Lake Erie coastal wetlands, OO = Oak Openings subregion sand prairies. Means without shared letters are significantly different (p < 0.05).

ecoregion	reference standard wetlands	n	all sites	n
ECBP	70.4 (14.2)a	22	43.1 (26.2)a	64
EOLP	80.4 (11.3)b	46	47.0 (27.6)bc	72
WAP	63.8 (12.2)ac	8	55.8 (24.0)ac	16
COASTAL	75.5 (12.2)ac	2	45.2 (14.4)a	12
OO	90.3 (8.3)a	3	91.0 (--)b	4

Table 5. Comparison of average VIBI scores for wetlands located in the Eastern Corn Belt Plains (ECBP) and Erie-Ontario Drift and Lake Plains (EOLP) ecoregions for reference and reference standard wetlands. Fen and bog wetlands excluded. There are no ecoregional differences in fen and bog scores and inclusion of these sites masks significant differences between depression, riverine, and impoundment wetlands. Means without shared letters significantly different (p < 0.05).

ecoregion	reference standard wetalnds	n	reference wetlands	n
ECBP	64.1 (13.4)a	15	29.1 (20.1)c	28
EOLP	79.1 (11.2)b	31	38.6 (23.9)c	18

Table 6. Comparison of average VIBI scores by dominant plant community for all sites (reference and reference standard) (df = 165, F = 5.46, p < 0.001). Because of uneven groups and small group sizes in some classes, multiple comparison test not performed.

plant community	reference standard wetlands	n	all sites	n
fen meadow	85.5 (8.3)	12	79.3 (14.4)	16
wet meadow	88.8 (7.5)	3	67.0 (35.8)	5
forest seep	78.7 (18.6)	18	74.4 (19.7)	5
"rich" bog	96.7 (3.5	4	96.0 (3.2)	4
"poor bog"	67.8 (4.1)	3	67.8 (4.1)	4
marsh	78.1 (9.0)	19	47.7 (26.1)	62
shrub swamp	67.1 (15.4)	17	57.3 (22.6)	33
swamp forest	73.9 (12.2)	4	52.4 (26.5)	36

Table 7. Summary statistics for wetlands by reference condition (reference, reference standard), HGM class, and ecological region (df = 165, F = 15.5, p < 0.001). non = reference, ref = reference standard. COAST = Lake Erie coastal wetlands, ECBP = Eastern Corn Belt Plains, EOLP = Erie-Ontario Drift and Lake Plains, WAP = Western Allegheny Plateau, OO = Oak Openings subregion. dep = depression, main = riverine mainstem, head = riverine headwater, impound = impoundment. Bog, mitigation, and slope wetlands were grouped statewide.

condition	mean	SD	median	Min	Max	N
Bog	82.6	17.9	93	53	100	7
non-Slope	60.3	13.7	48	48	74	4
non-COAST	46.0	14.0	48.5	20	63	12
non-ECBP-depression	30.5	22.7	31.0	0	84	22
non-ECBP-impoundment	19.0	---	19.0	---	---	1
non-ECBP-mainstem	21.0	6.3	18.0	16	29	6
non-ECBP-headwater	23.0	---	23.0	---	---	1
non-EOLP-depression	47.7	29.8	45.0	10	87	7
non-EOLP-mainstem	21.6	16.3	17.0	9	50	5
non-EOLP-headwater	35.8	14.9	38.5	16	50	4
non-slope (all regions)	66.8	18.8	70.0	48	93	5
non-WAP-impoundment	57.2	30.4	68.0	3	75	5
non-WAP-mainstem	53.3	12.4	60.0	39	61	3
OAK OPENINGS (sand prairies)	90.5	6.8	92.0	81	97	4
ref-COAST	75.5	12.0	75.5	67	84	2
ref-ECBP-depression	64.8	14.2	67.0	46	87	12
ref-ECBP-mainstem	55.0	12.7	55.0	46	64	2
ref-ECBP-headwater	71.0	---	71.0	---	---	1
ref-EOLP-depression	79.8	11.6	80.5	54	97	18
ref-EOLP-mainstem	81.3	6.7	78.5	77	91	4
ref-EOLP-headwater	74.7	14.5	82.0	58	84	3
ref-slope (all regions)	82.8	10.6	85.0	58	97	16
ref-WAP-mainstem	57.0	16.1	58.5	36	75	4
ref-WAP-headwater	74.0	4.2	74.0	71	77	2
ref-HELP-mainstem	67.0	---	67.0	---	---	1

Table 8. Summary of metrics for final Vegetation IBIs. See Table 3 for definitions.

VIBI-E	VIBI-$E_{COASTAL}$	VIBI-$E_{MITIGATION}$	VIBI-SH	VIBI-F
---	Cyperaceae	---	---	---
Carex	---	*Carex*	*Carex*	---
Dicot, native	Dicot, native	Dicot, native	Dicot, native	---
Shrub, native, wetland	Shrub, native, wetland	Shrub, native, wetland	Shrub, native, wetland	---
Hydrophyte, native	Hydrophyte, native	Hydrophyte, native	Hydrophyte, native	---
A/P ratio	A/P ratio	A/P ratio	---	---
FQAI score	FQAI score	FQAI score	FQAI score	FQAI score
%tolerant	%tolerant	%tolerant	%tolerant	%tolerant
%sensitive	%sensitive	%sensitive	%sensitive	%sensitive
%invasive graminoids	%invasive graminoids	%invasive graminoids	---	---
biomass	biomass	---	---	---
---	---	%unvegetated	---	---
---	---	---	---	Shade
			SVP	SVP
---	---	---	---	%hydrophyte
---	---	---	%bryophyte	%bryophyte
---	---	---	---	pole timber density
---	---	---	subcanopy IV	subcanopy IV
---	---	---	---	canopy IV

Table 9. General Wetland Aquatic Life Use Designations.

code	designation	definition
SWLH	Superior Wetland Habitat	Wetlands that are capable of supporting and maintaining a high quality community with species composition, diversity, and functional organization comparable to the vegetation IBI score of at least 83% (five-sixths) of the 95th percentile for the appropriate wetland type and region as specified in Table 11.
WLH	Wetland Habitat	Wetlands that are capable of supporting and maintaining a balanced, integrated, adaptive community having a species composition, diversity, and functional organization comparable to the vegetation IBI score of at least 66% (two-thirds) of the 95th percentile for the appropriate wetland type and region as specified in Table 11.
RWLH	Restorable Wetland Habitat	Wetlands which are degraded but have a reasonable potential for regaining the capability of supporting and maintaining a balanced, integrated, adaptive community of vascular plants having a species composition, diversity, and functional organization comparable to the vegetation IBI score of at least 33% (one-third) of the 95th percentile distribution for the appropriate wetland type and region as specified in Table 11.
LQWLH	Limited Quality Wetland Habitat	Wetlands which are seriously degraded and which do not have a reasonable potential for regaining the capability of supporting and maintaining a balanced, integrated, adaptive community having a species composition, diversity, and functional organization comparable to the vegetation IBI score of less 33% (one-third) of the 95th percentile for the appropriate wetland type and region as specified in Table 11.

Table 10. Special wetland use designations.

subscript	special uses	description
A	recreation	wetlands with known recreational uses including hunting, fishing, birdwatching, etc. that are publicly available
B	education	wetlands with known educational uses, e.g. nature centers, schools, etc.
C	fish reproduction habitat	wetlands that provide important reproductive habitat for fish
D	bird habitat	wetlands that provide important breeding and nonbreeding habitat for birds
E	T or E habitat	wetlands that provide habitat for federal or state endangered or threatened species
F	flood storage	wetlands located in landscape positions such that they have flood retention functions
G	water quality improvement	wetlands located in landscape positions such that they can perform water quality improvement functions for streams, lakes, or other wetlands

Table 11. Wetland Tiered Aquatic Life Uses (WTALUs) for specific plant communities and landscape positions. tbd = to be developed. LQWLH = limited quality wetland habitat, RWLH = restorable wetland habitat, WLH = wetland habitat, SWLH = superior wetland habitat. Equivalent antidegradation categories as specified in Ohio Administrative Code Rule 3745-1-54 are indicated in parentheses below the TALU category.

HGM class	HGM subclass	plant community	ecoregions	95th percentile	LQWLH (Category 1)	RWLH (modified Category 2)	WLH (Category 2)	SWLH (Category 3)
Depression	all	Swamp forest, Marsh, Shrub swamp	EOLP	91	0 - 30	30 - 60	61 - 75	76 - 100
			all other regions	75	0 - 24	25 - 50	51 - 62	63 - 100
	all	Wet Meadow (incl. prairies and sedge/grass dominated communities that are not slopes)	all regions	91	0 - 29	30 - 59	60 - 75	76 - 100
Impoundment	all	Marsh, Shrub Swamp	EOLP	80	0 - 26	27 - 52	53 - 66	67 - 100
			all other regions	71	0 - 24	25 - 47	48 - 63	64 - 100
		Wet Meadow (incl. prairies and sedge/grass dominated communities that are not slopes)	all regions	91	0 - 29	30 - 59	60 - 75	76 - 100
Riverine	Headwater	all	EOLP	84	0 - 27	28 - 56	57 - 69	70 - 100
			all other regions	71	0 - 23	24 - 47	47 - 59	60 - 100
	Mainstem	all	EOLP	89	0 - 29	30 - 56	57 - 73	74 - 100
			all other regions	64	0 - 20	21 - 41	42 - 52	53 - 100
	Headwater or Mainstem	Wet Meadow (incl. prairies and sedge/grass dominated communities that are not slopes)	all regions	91	0 - 29	30 - 59	60 - 75	76 - 100
Slope	all	Wet meadow (fen), tall shrub fen, forest seep	all regions	92	0 - 29	30 - 59	60 - 75	76 - 100
Fringing[1]	Natural Lakes (excluding lacustrine fens) and reservoirs	tbd	tbd	tbd	tbd	tbd	tbd	tbd
Coastal[2]	closed embayment, barrier-protected, river mouth	all	all regions	75	0 - 24	25 - 49	50 - 61	62 - 100
	open embayment, diked (managed unmanaged failed)	tbd	tbd	tbd	tbd	tbd	tbd	tbd
Bog	weakly ombrotrophic	Tamarack-hardwood bog, Tall shrub bog	all regions	100	0 - 32	33 - 65	66 - 82	83 - 100
	moderately to strongly ombrotrophic	Tamarack forest, Leatherleaf bog Sphagnum bog	all regions	72	0 - 23	24 - 47	48 - 59	60 - 100

1. Depending on the circumstances, scoring breaks for depression, impoundment, or riverine may be used.
2. Scoring breaks for coastal embayment, barrier-protected, and river mouth may be usable.

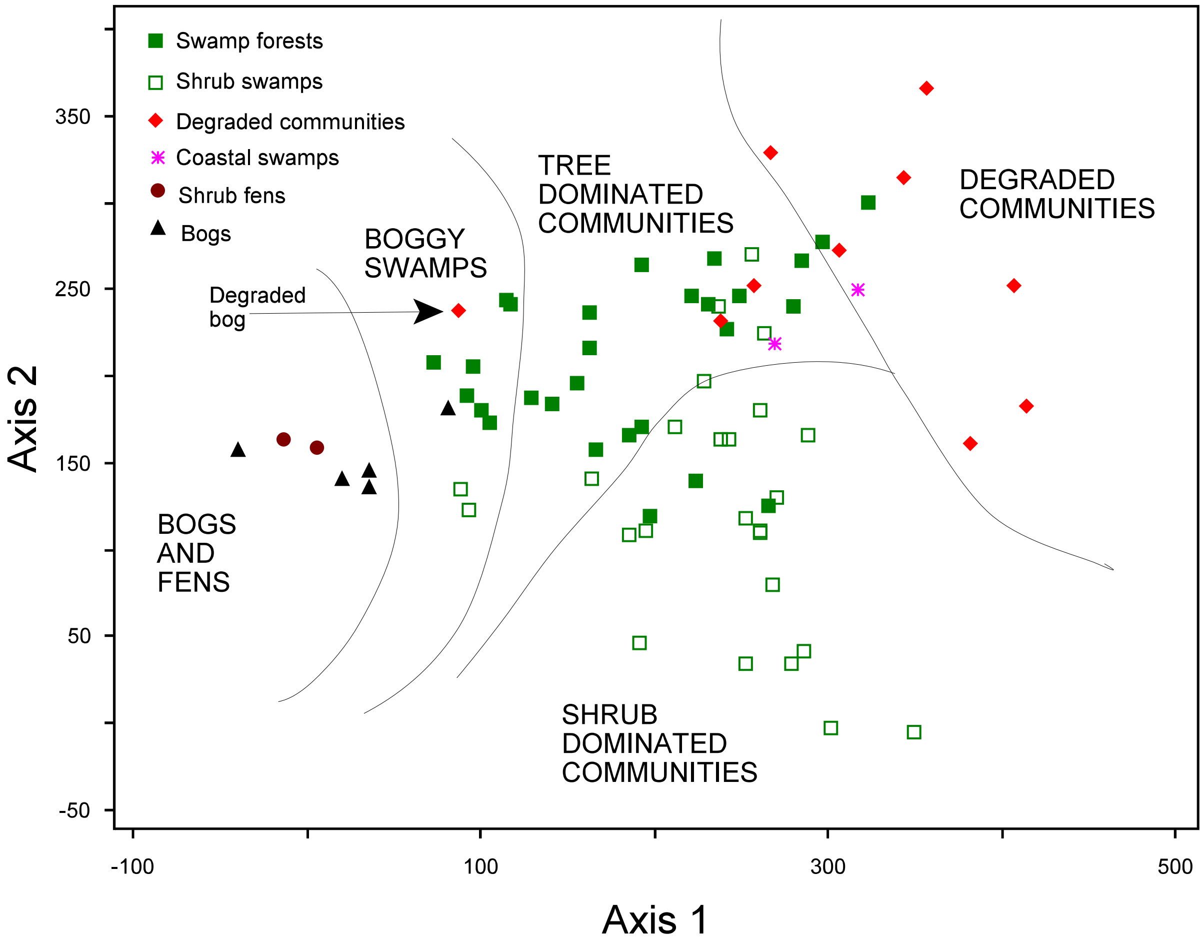


Figure 1. Detrended correspondence analysis of wetlands dominated by woody species from 1999-2002 (n=72 plots, 300 species). Total inertia (variance) in species data = 9.05; eigenvalues = 0.557, 0.433, 0.291 axes 1, 2, and 3, respectively.

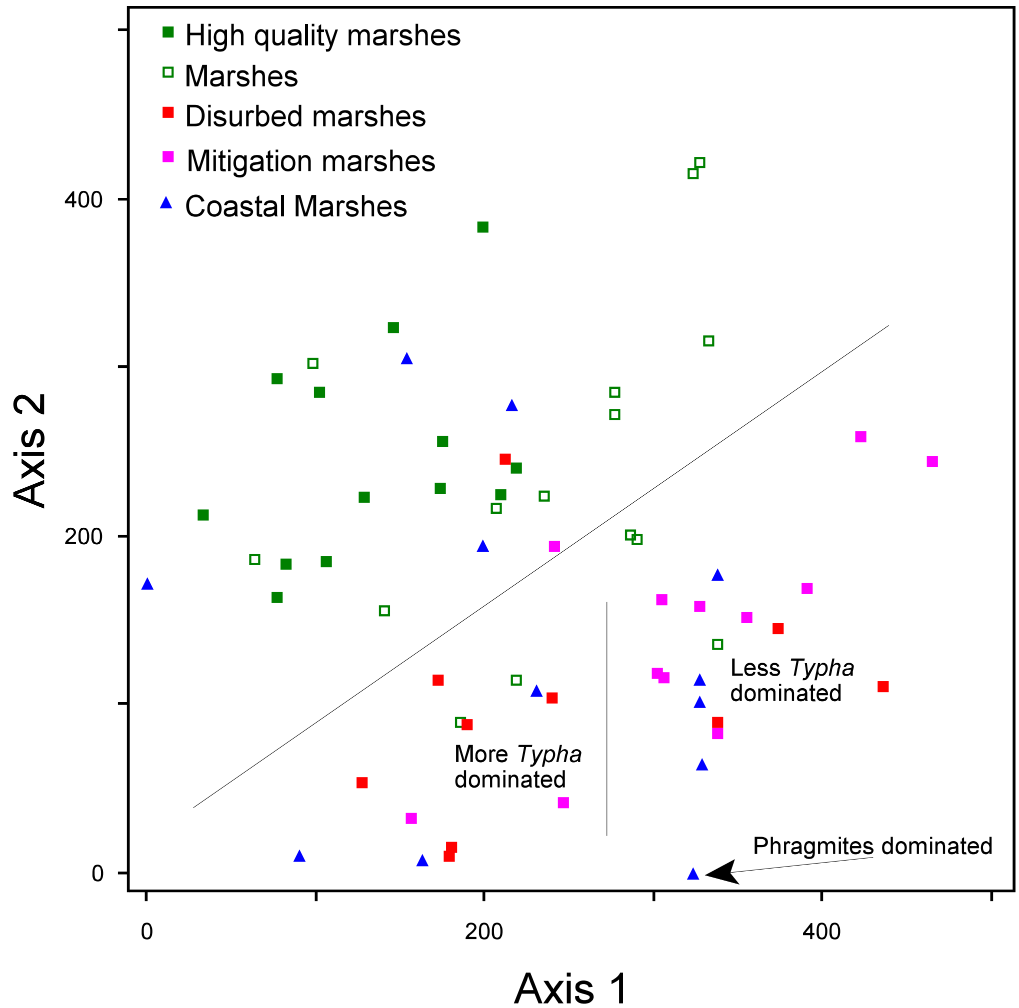


Figure 2. Detrended correspondence analysis of marsh wetland vegetation data from 1999-2002 (n=62 plots, 234 species). Total inertia (variance) in species data = 12.48; eigenvalues = 0.608, 0.550, 0.458 axes 1, 2, and 3, respectively. Most good to high quality natural marshes ordinate in the upper left of the plot with disturbed natural marshes, mitigation marshes and most coastal marshes ordinating towards the bottom right.

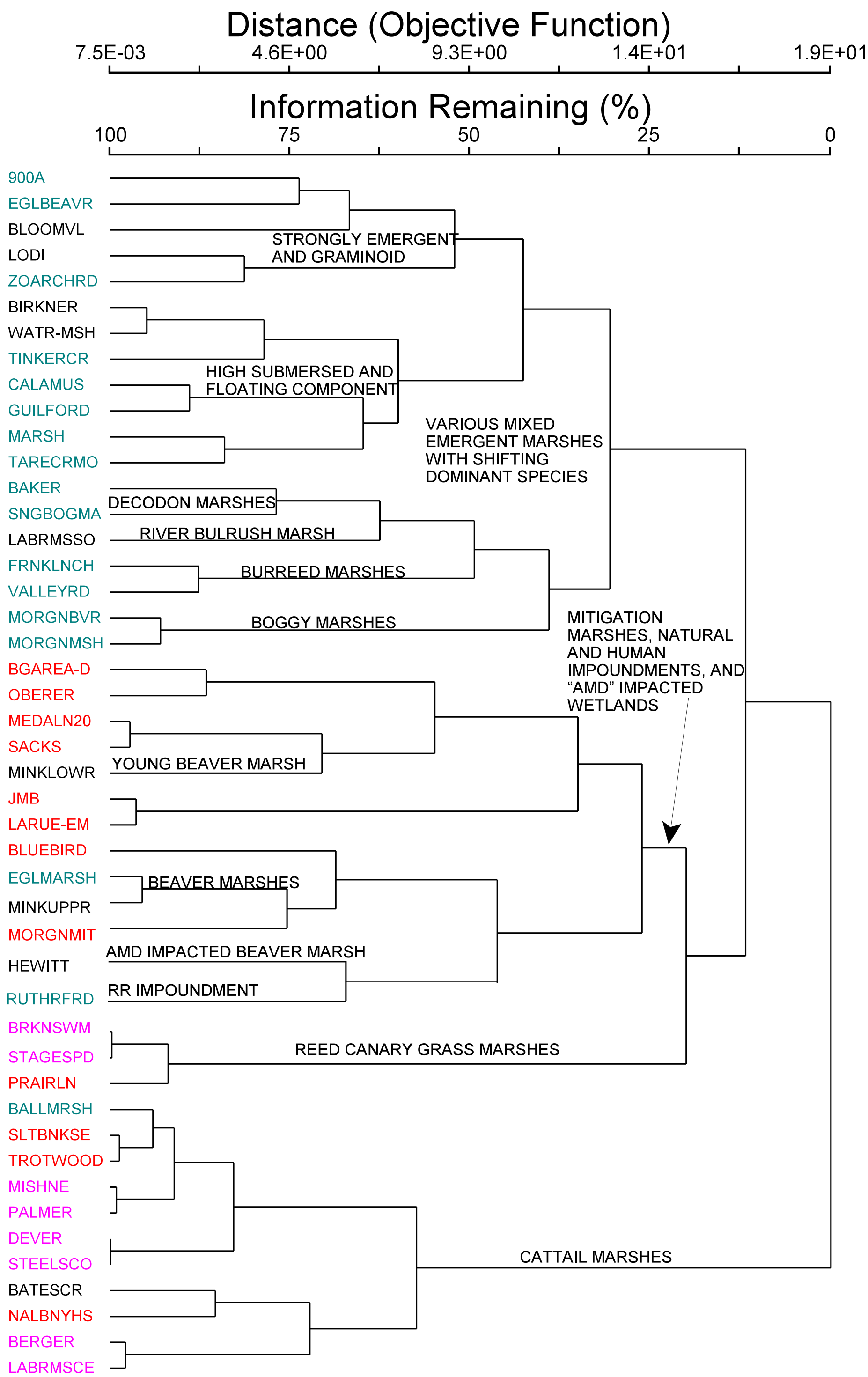


Figure 3. Cluster analysis of inland marsh data wetland vegetation data from 1999-2002 (n=47 plots, 213 species). Red=mitigation marshes, magenta=highly disturbed natural marshes, teal=undisturbed, high quality natural marshes, black=somewhat disturbed to moderately disturbed natural marshes.

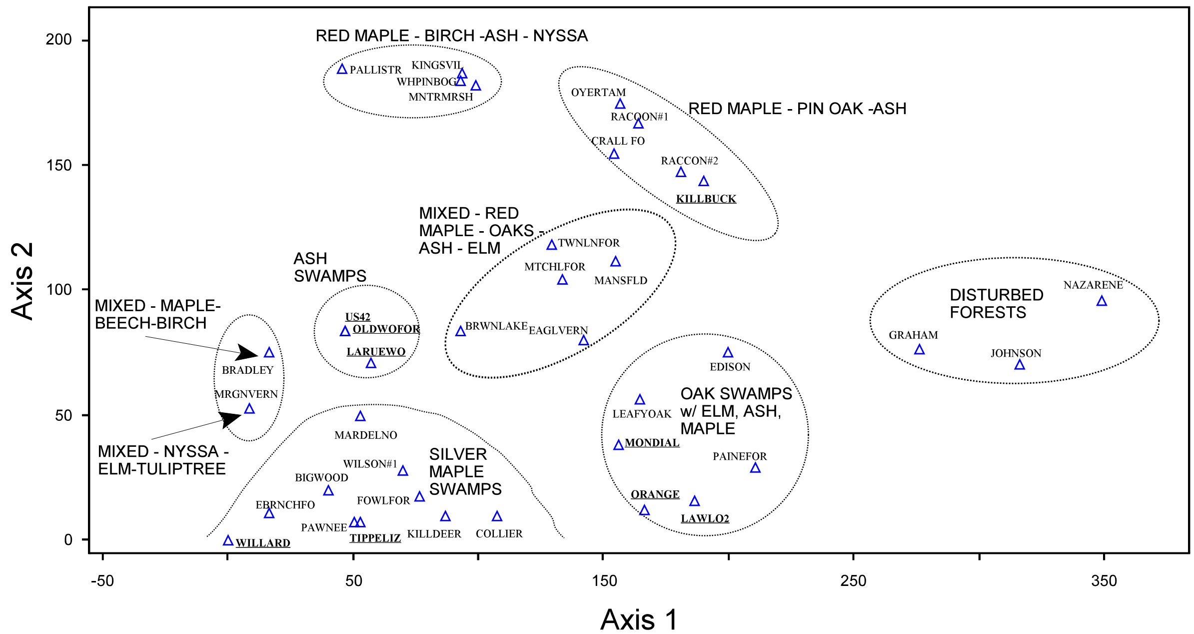


Figure 4. Detrended correspondence analysis of tree canopy species of forested wetlands from 1999-2002 (n=55 plots, 243 species). Total inertia (variance) in species data = 2.91; eigenvalues = 0.524, 0.347, 0.192 axes 1, 2, and 3, respectively. Degraded forests with canopy assemblages indistinguishable from more intact forest are in bold face and underlined.

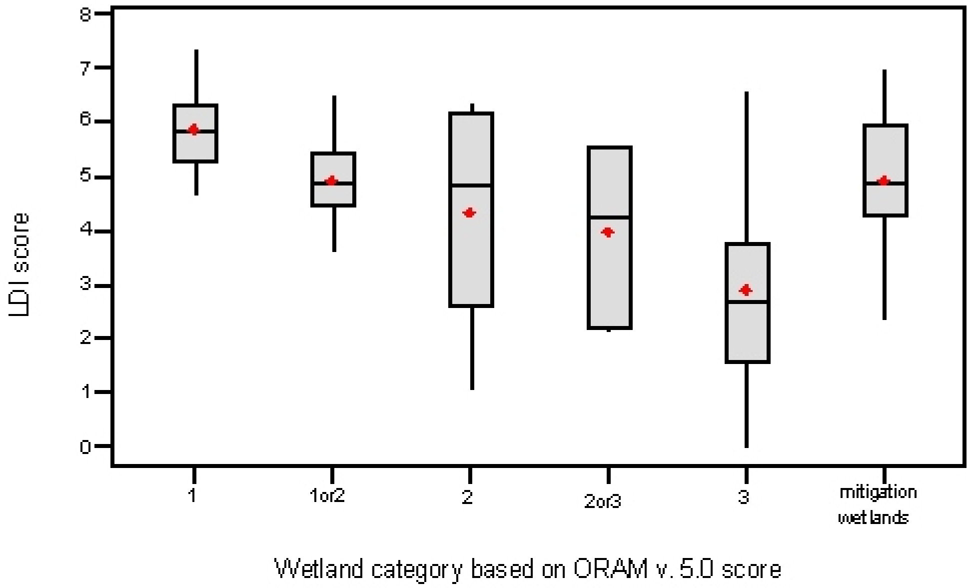


Figure 5. Landscape Development Intensity Index (LDI) score using land use from 1 km radii circle with from point located in center of the wetland versus wetland regulatory category using ORAM v. 5.0 scores. Mean LDI scores for Category 1, 2, and 3 wetlands significantly different after analysis of variance followed by Tukey's multiple comparison test (df= 199, F=10.99, p<0.05). Note that mitigation wetlands tend to be placed in intensively developed landscape positions similar to Category 1 (low quality) natural wetlands. ORAM v. 5.0 scoring categories (Mack 2000) are Category 1 = 0 - 29.9, Cateogory 1 or 2 = 30.0 - 34.9, Category 2 = 35.0 - 59.9, Category 2 or 3 = 60.0 - 64.9, Category 3 = 65.0 - 100. Category 1 wetlands are low quality with minimal functions, Category 2 wetlands are of moderate quality with moderate functions, and Category 3 wetlands are of high quality with high functions (Ohio Administrative Code Rule 3745-1-54).

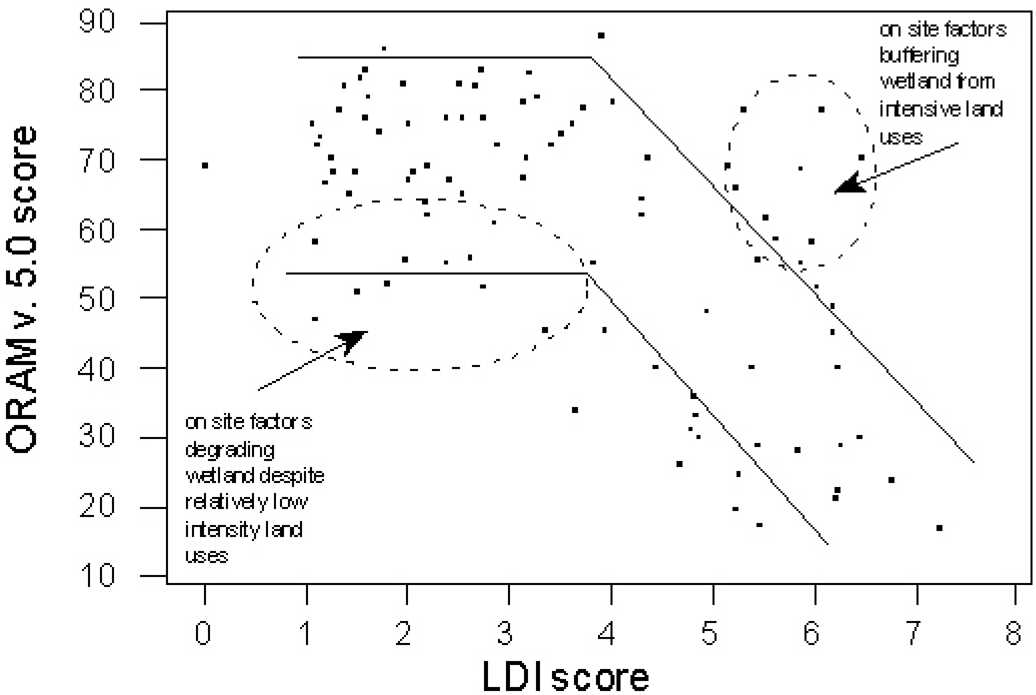


Figure 6. Landscape Development Intensity Index (LDI) score using land use from 1 km radii circle with from point located in center of the wetland versus ORAM v. 5.0 scores. Significant correlation after polynomial regression (df = 108, F = 29.9, R^2 = 36.1%, $p < 0.01$). Solid lines included to show pattern in data and do not represent confidence limits.

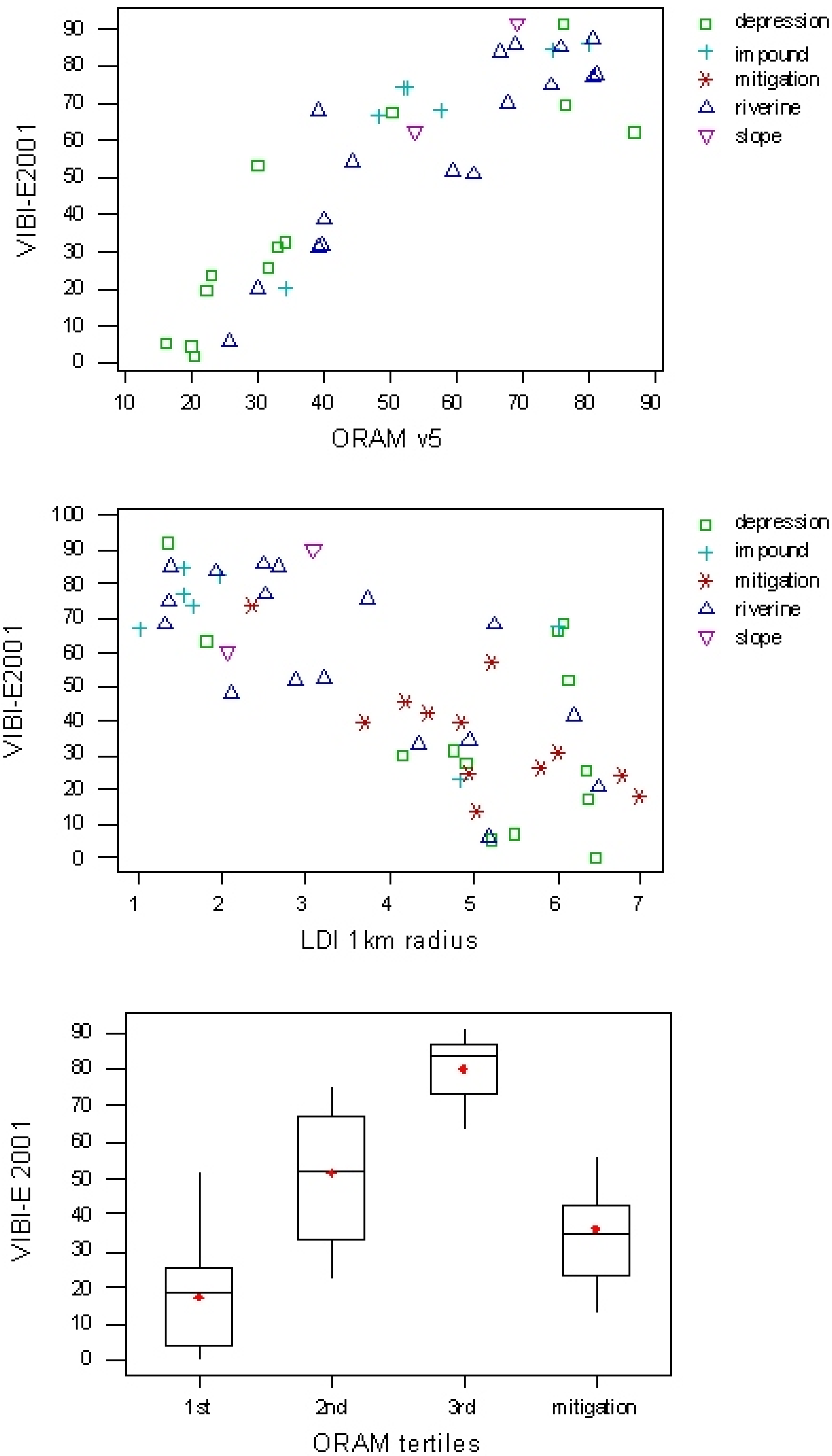


Figure 7. Summary plots of 2001 VIBI-EMERGENT (Mack 2001b, 2004a). Scatterplots are VIBI score versus ORAM v. 5.0 score or LDI score. Box and whisker plots represent ORAM score tertiles (thirds). All means of VIBI-E scores for ORAM tertiles significantly different ($p < 0.05$); mitigation significantly different from 3rd tertile ($p < 0.05$).

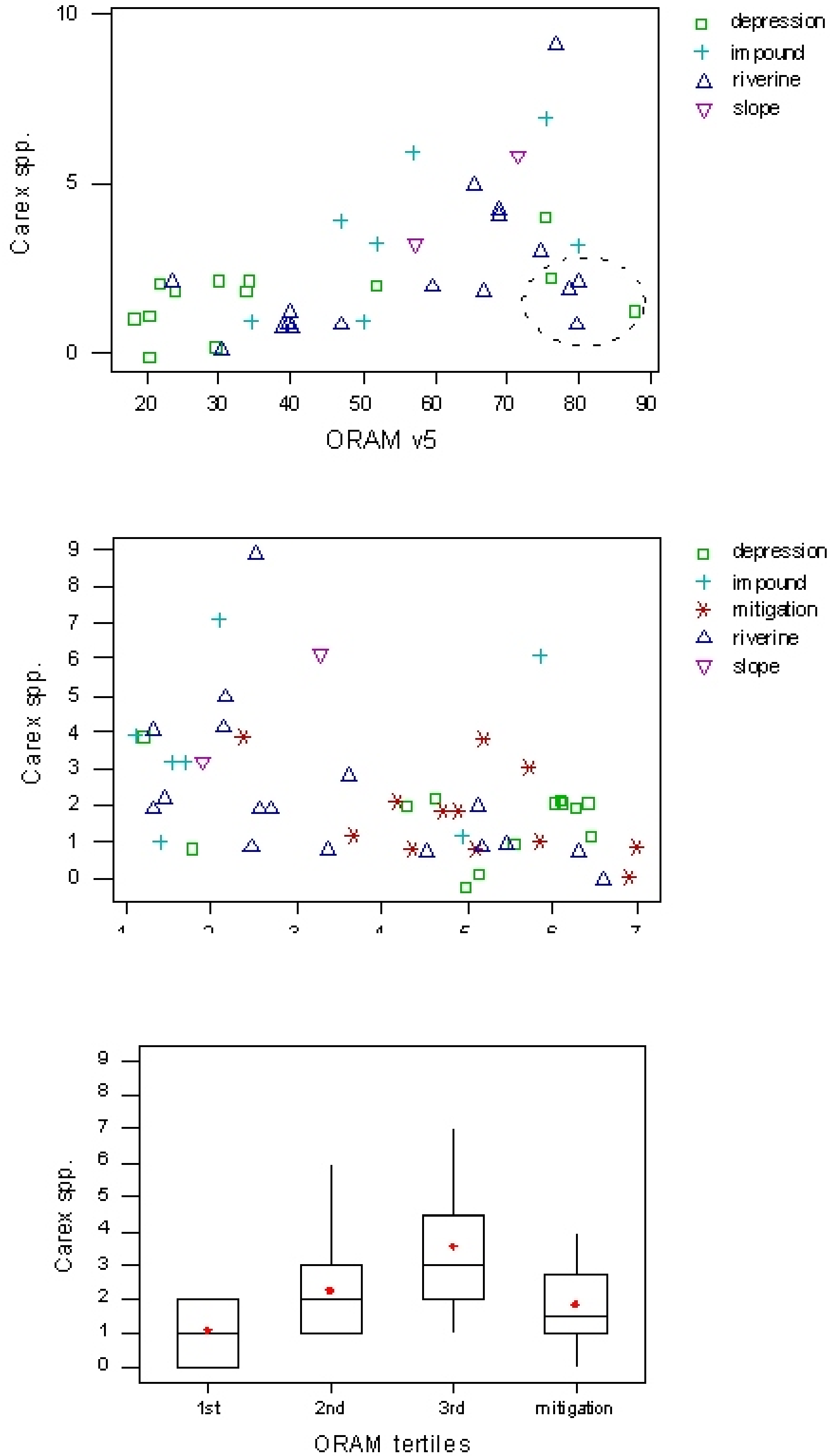


Figure 8.Summary plots of *Carex* metric for VIBI-EMERGENT. Scatterplots are *Carex* richness versus ORAM v. 5.0 score (df = 38, F = 12.7, R^2 = 25.6%, p = 0.001) or LDI score (df = 50, F = 12.4, R^2 = 20.4%, p = 0.001). High quality marshes with strong submersed or floating aquatic communities indicated by circle (R^2 increases to 52.8% and 26.9% with ORAM and LDI scores, respectively, when these sites are removed from the regression). Box and whisker plots represent ORAM score tertiles (thirds). 3rd tertile significantly different from 1st (p < 0.05).

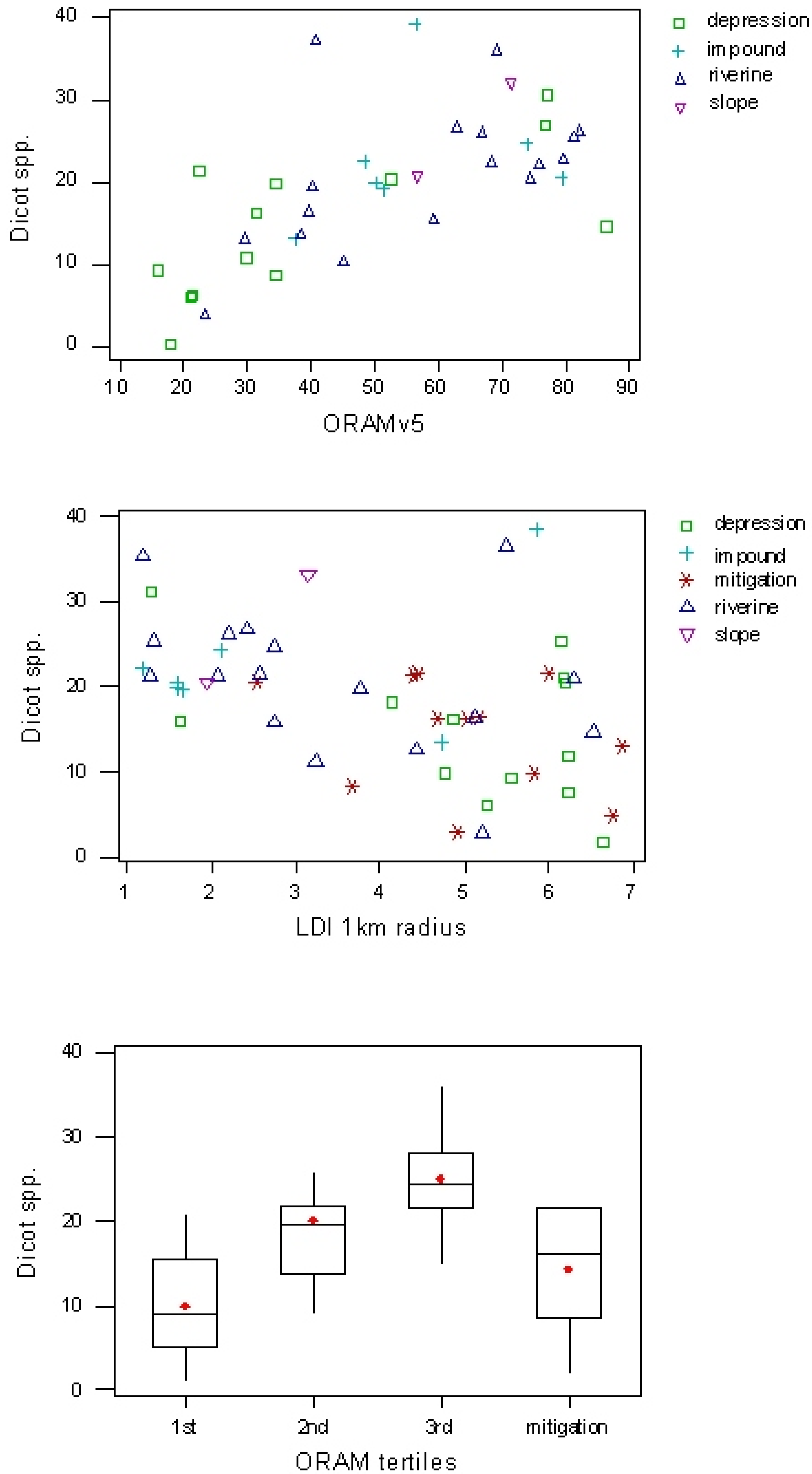
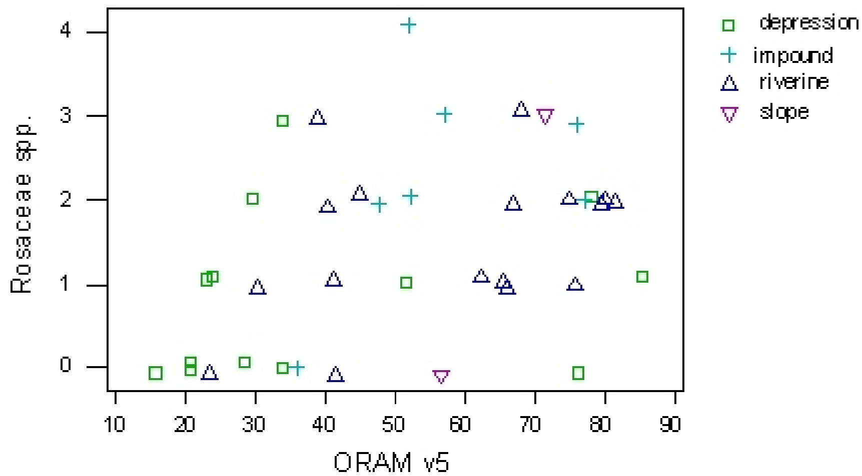
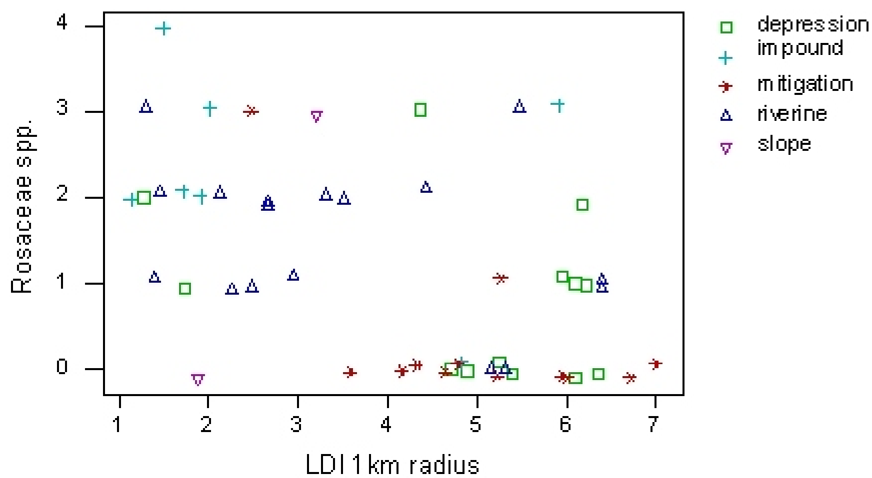


Figure 9. Summary plots of dicot metric for VIBI-EMERGENT (metric modified by excluding nonnative dicots, see text). Scatterplots are dicot species richness versus ORAM v. 5.0 score (df = 38, F = 30.0, R^2 = 44.8%, $p < 0.001$) or LDI score (df = 50, F = 19.1, R^2 = 28.0%, $p < 0.001$). Box and whisker plots represent ORAM score tertiles (thirds). 3rd tertile significantly different than 1st and mitigation, 2nd tertile significantly different than 1st ($p < 0.05$).





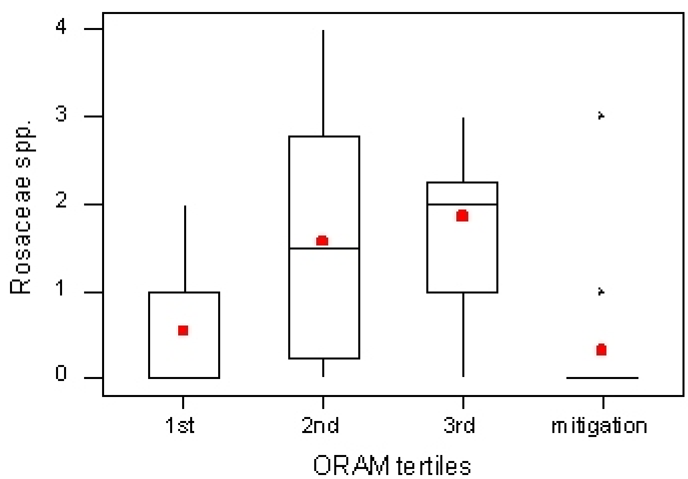


Figure 10. Summary plots of Rosaceae metric for VIBI-EMERGENT. Scatterplots are Rosaceae species richness versus ORAM v. 5.0 score (df = 38, F = 7.0, R^2 = 16.0%, p = 0.012) or LDI score (df = 50, F = 7.3, R^2 = 26.3%, p < 0.001). Box and whisker plots represent ORAM score tertiles (thirds). 3rd tertile significantly different from 1st and mitigation and 2nd significantly different from mitigation (p < 0.05).

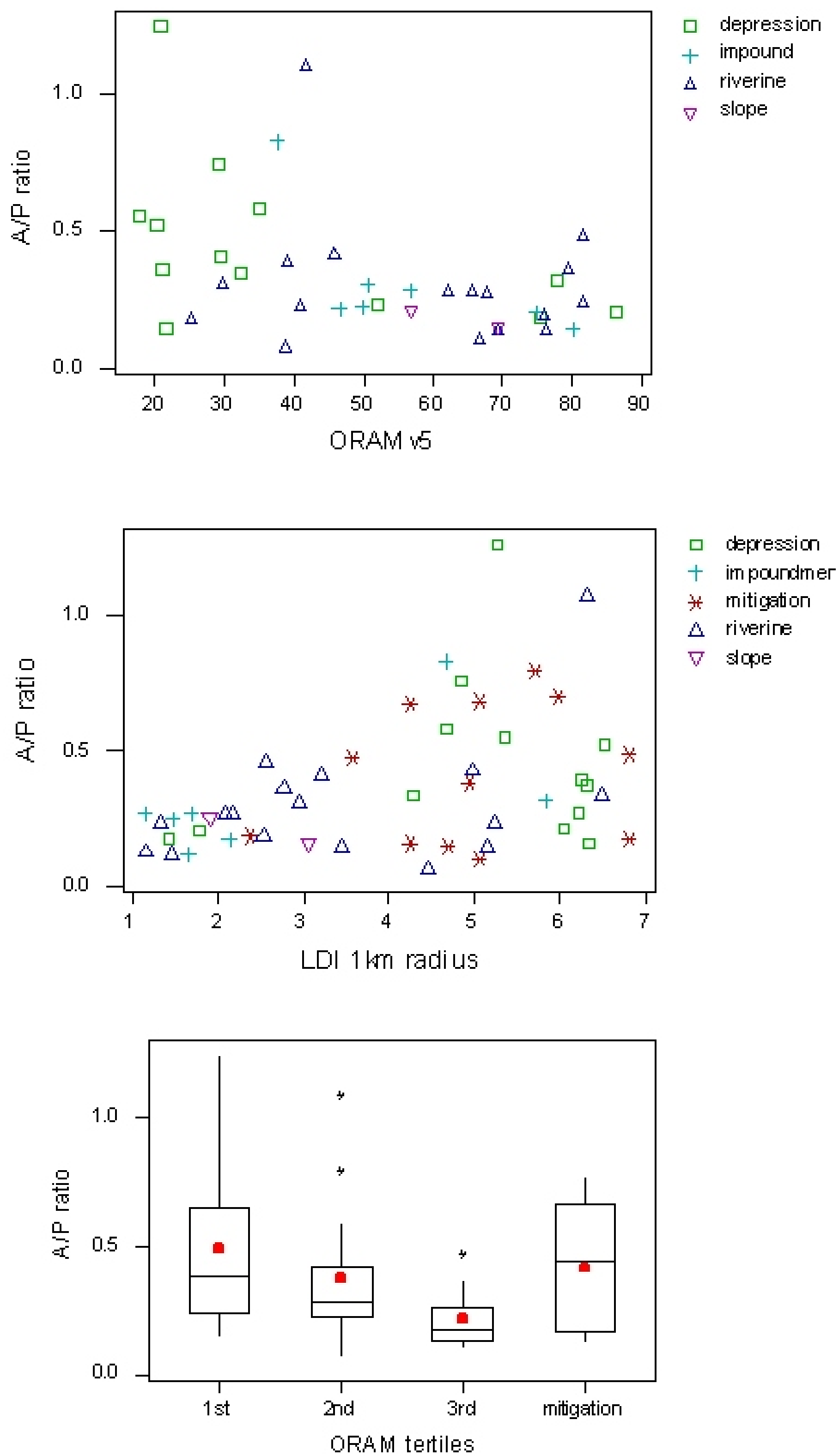


Figure 11. Summary plots of annual/perennial ratio for VIBI-EMERGENT. Scatterplots are ratio of annual species richness to perennial species richness versus ORAM v. 5.0 score (df = 38, F = 10.8, R^2 = 22.7%, p = 0.002) or LDI score (df = 50, F = 11.0, R^2 = 18.3%, p = 0.002). Box and whisker plots represent ORAM score tertiles (thirds). 3rd tertile significantly different from 1st (p>0.05).

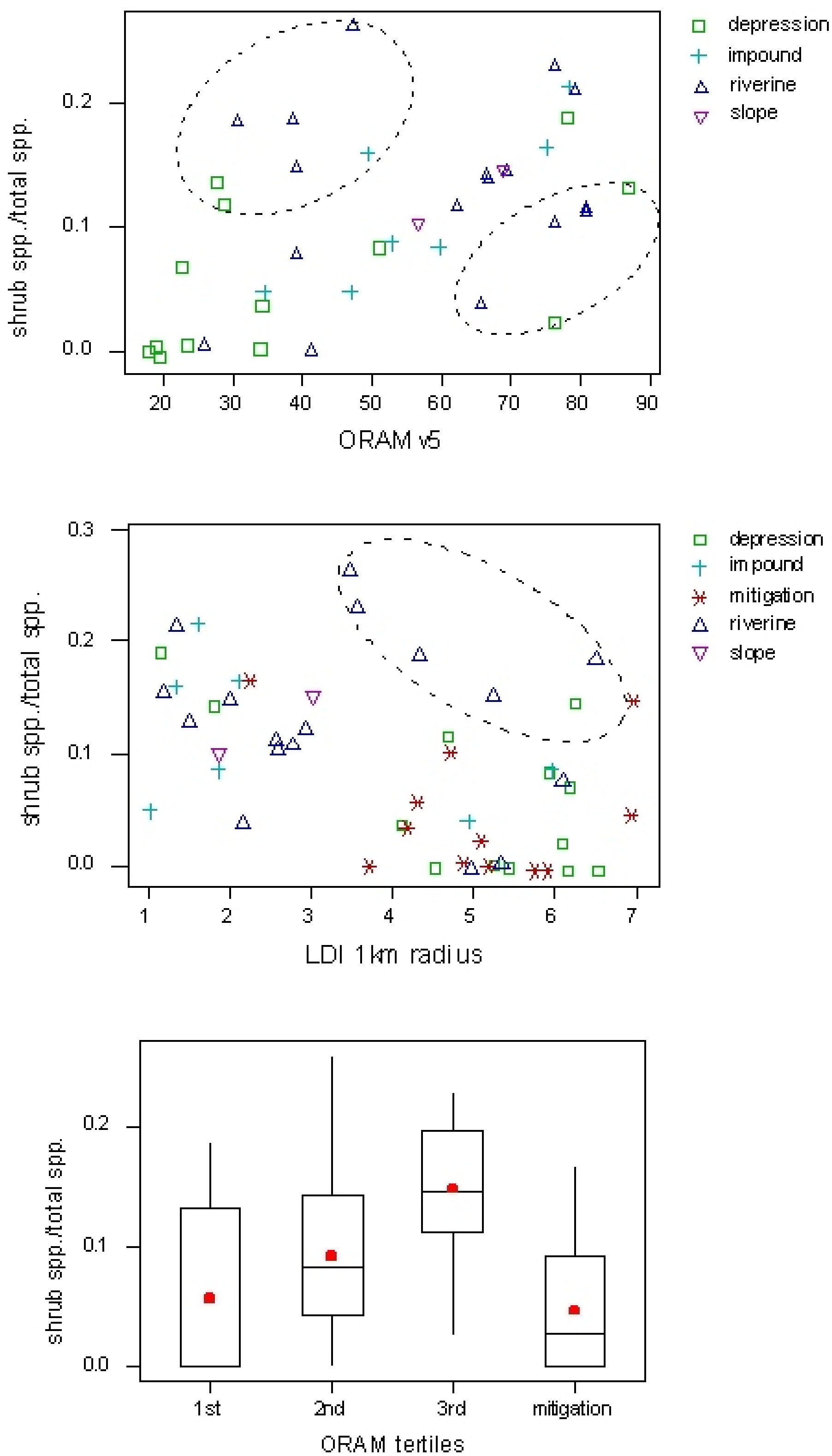


Figure 12. Summary plots shrub ratio metric for VIBI-EMERGENT. Scatterplots are ratio of shrub species richness to total species versus ORAM v. 5.0 score (df = 38, F = 11.3, R^2 = 23.4%, p = 0.002) or LDI score (df = 50, F = 13.0, R^2 = 20.9%, p = 0.001). Box and whisker plots represent ORAM score tertiles (thirds). 3rd significantly different from 1st and mitigation ($p < 0.05$). Sites circled in scatterplots indicate sites that under- or overperformed on the metric.

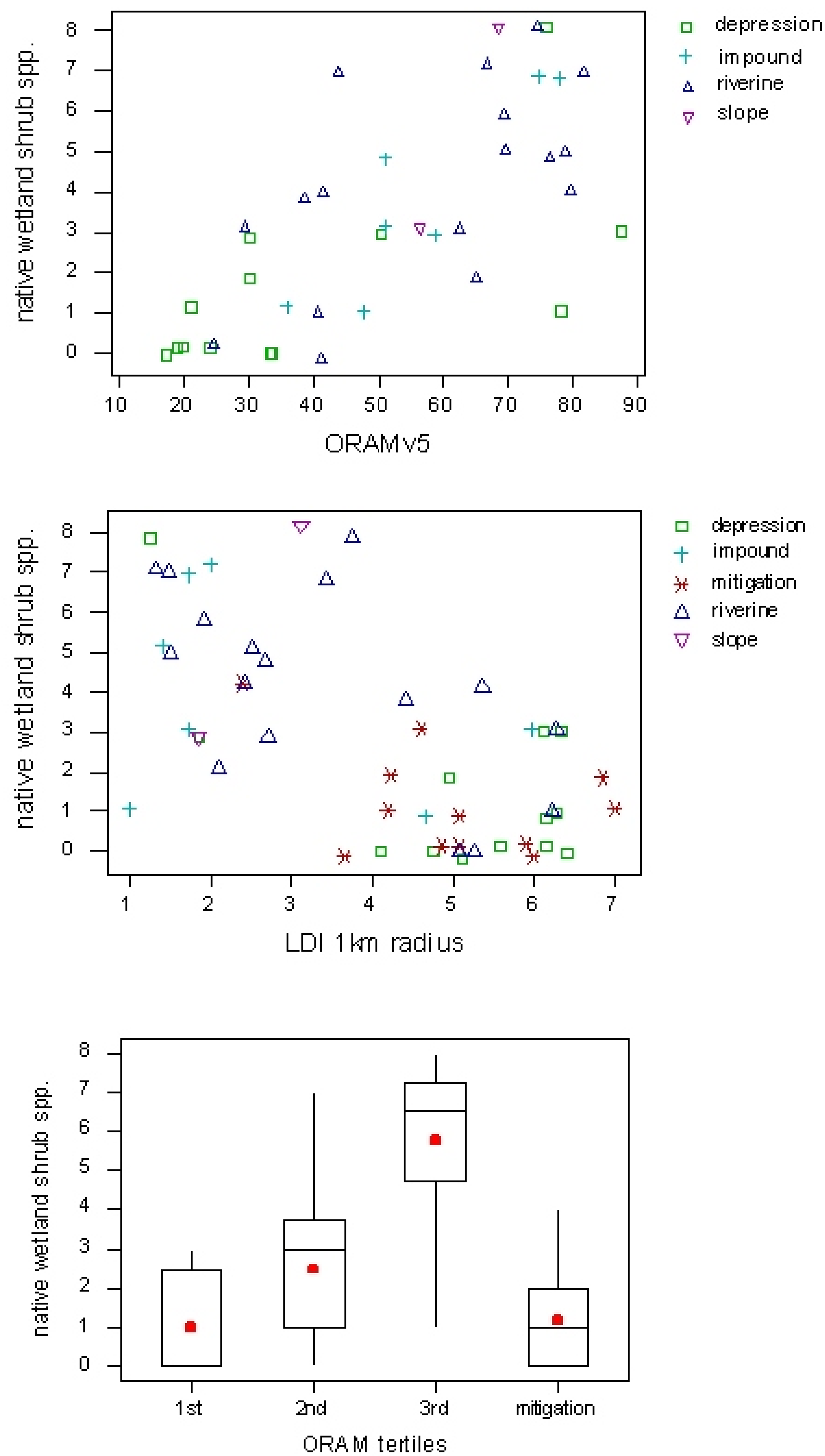


Figure 13. Summary plots shrub metric for VIBI-EMERGENT (replacement metric for shrub ratio metric, see text). Scatterplots are species richness of native wetland shrubs versus ORAM v. 5.0 score (df = 38, F = 38.9, R^2 = 51.2%, $p < 0.001$) or LDI score (df = 50, F = 37.2, R^2 = 43.2%, $p < 0.001$). Box and whisker plots represent ORAM score tertiles (thirds). 3rd tertile significantly different except 1st and 2nd tertiles and mitigation ($p < 0.05$).

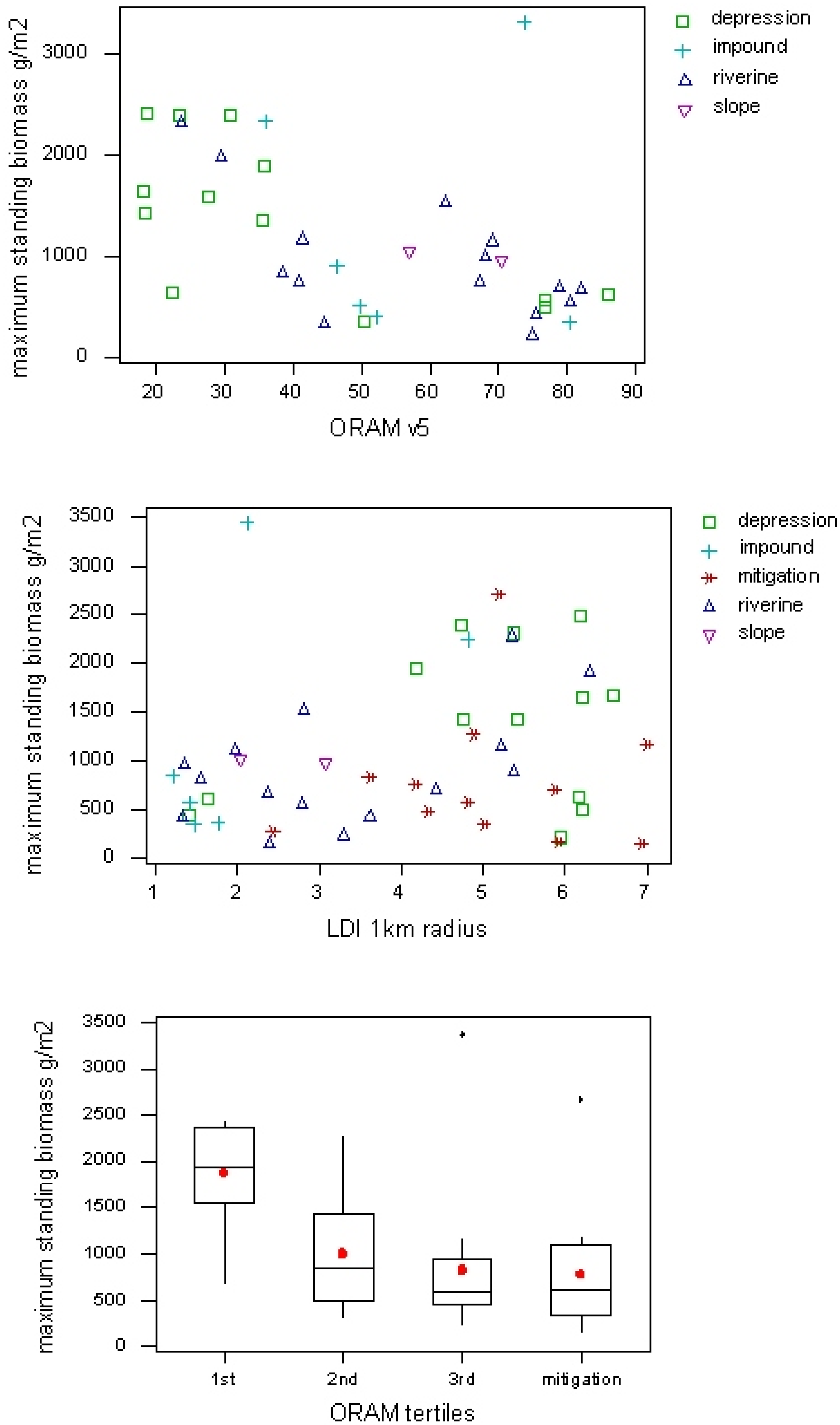


Figure 14. Summary plots for maximum biomass metric for VIBI-EMERGENT. Scatterplots are maximum standing biomass (g/m^2) versus ORAM v. 5.0 score (df = 35, F = 7.7, R^2 = 18.5%, p = 0.009) or LDI score (ns). Box and whisker plots represent ORAM score tertiles (thirds). 1st tertile significantly different from 3rd and mitigation (p<0.05).

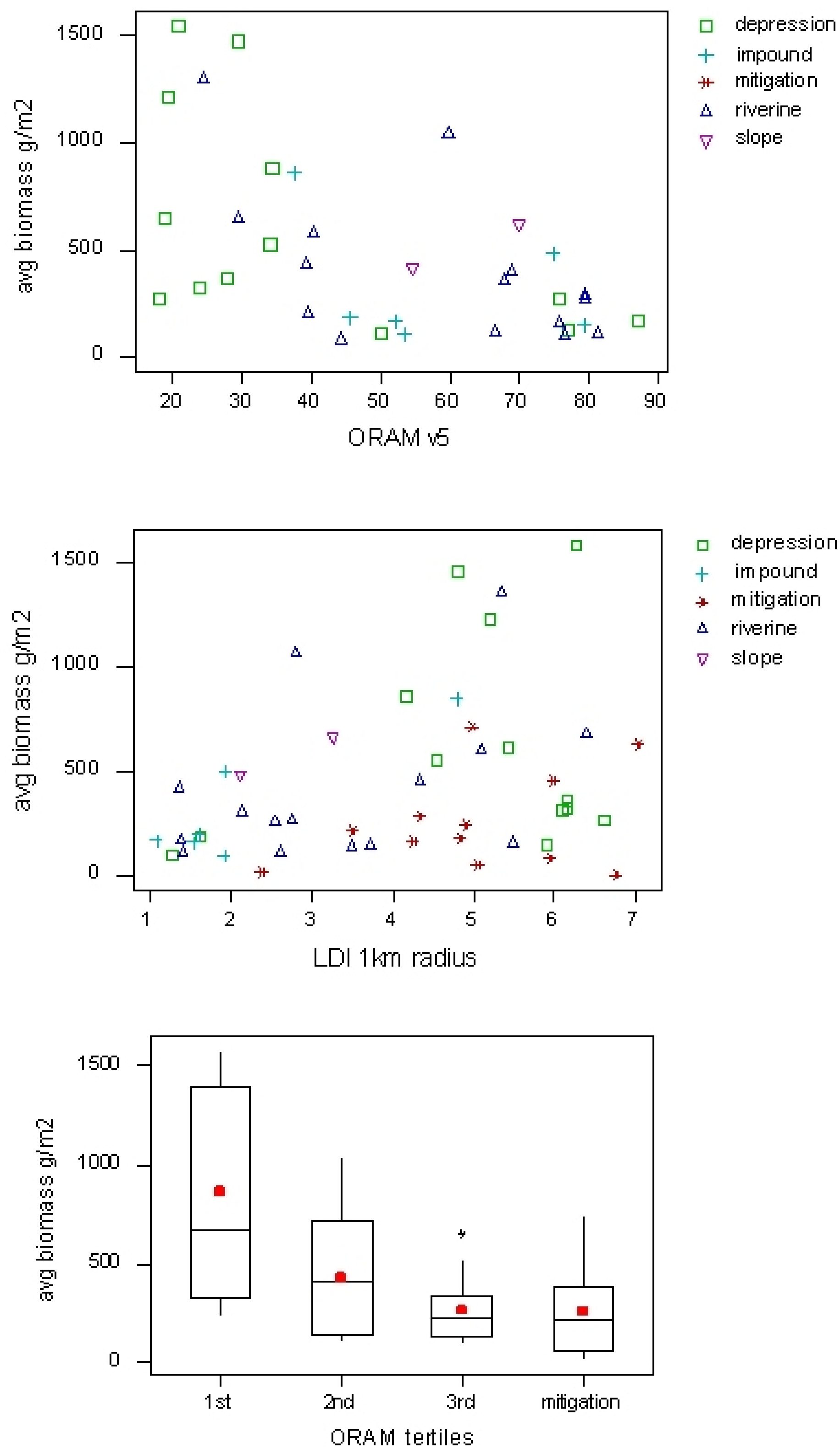
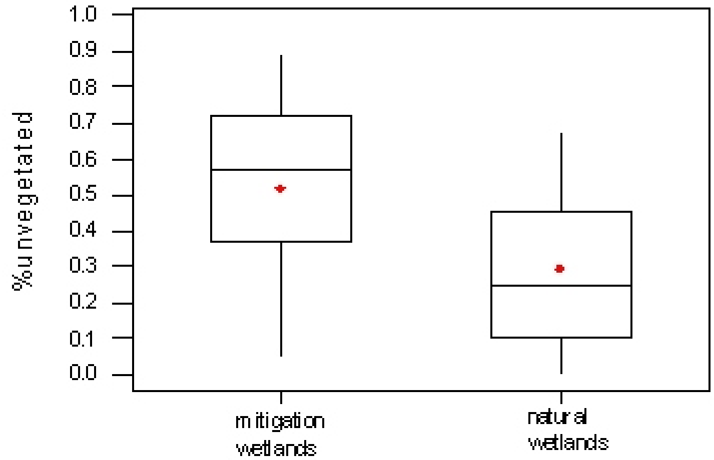


Figure 15. Summary plots average biomass metric for VIBI-EMERGENT (modification of maximum standing biomass metric, see text). Scatterplots are average standing biomass (g/m^2) versus ORAM v. 5.0 score (df = 35, F = 4.9, R^2 = 12.6%, p = 0.003) or LDI score (ns). Box and whisker plots represent ORAM score tertiles (thirds). 1st tertile significantly different than 3rd and mitigation ($p < 0.05$).



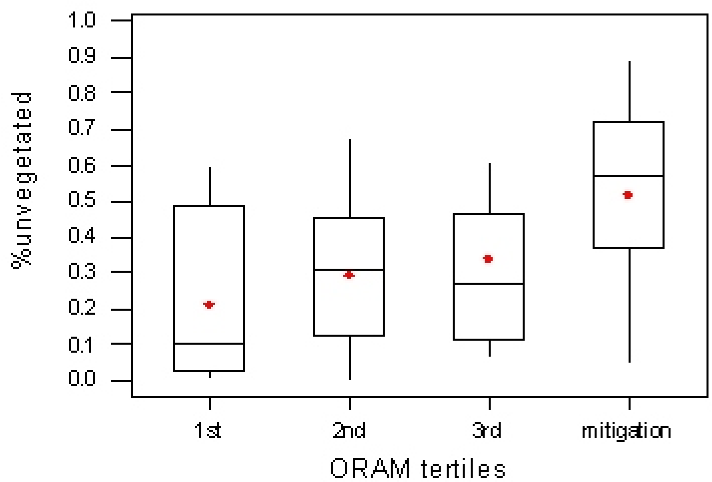


Figure 16. Box and Whisker plots %unvegetated metric for mitigation sites (substitute metric for average standing biomass when using VIBI-E at mitigation wetlands. Plots are the sum of relative cover of annual species and unvegetated areas (bare ground, open water) comparing (1) mitigation (52%) versus natural (29%) wetlands (df = 46, t = 6.72, p = 0.013), and (2) mitigation (52%) wetlands versus 1st (21%), 2nd (29%), and 3rd (34%) ORAM tertiles (df = 46, F = 2.7, p = 0.061). Some mitigation sites well-vegetated and others sparsely vegetated which reduces average for mitigation wetlands.

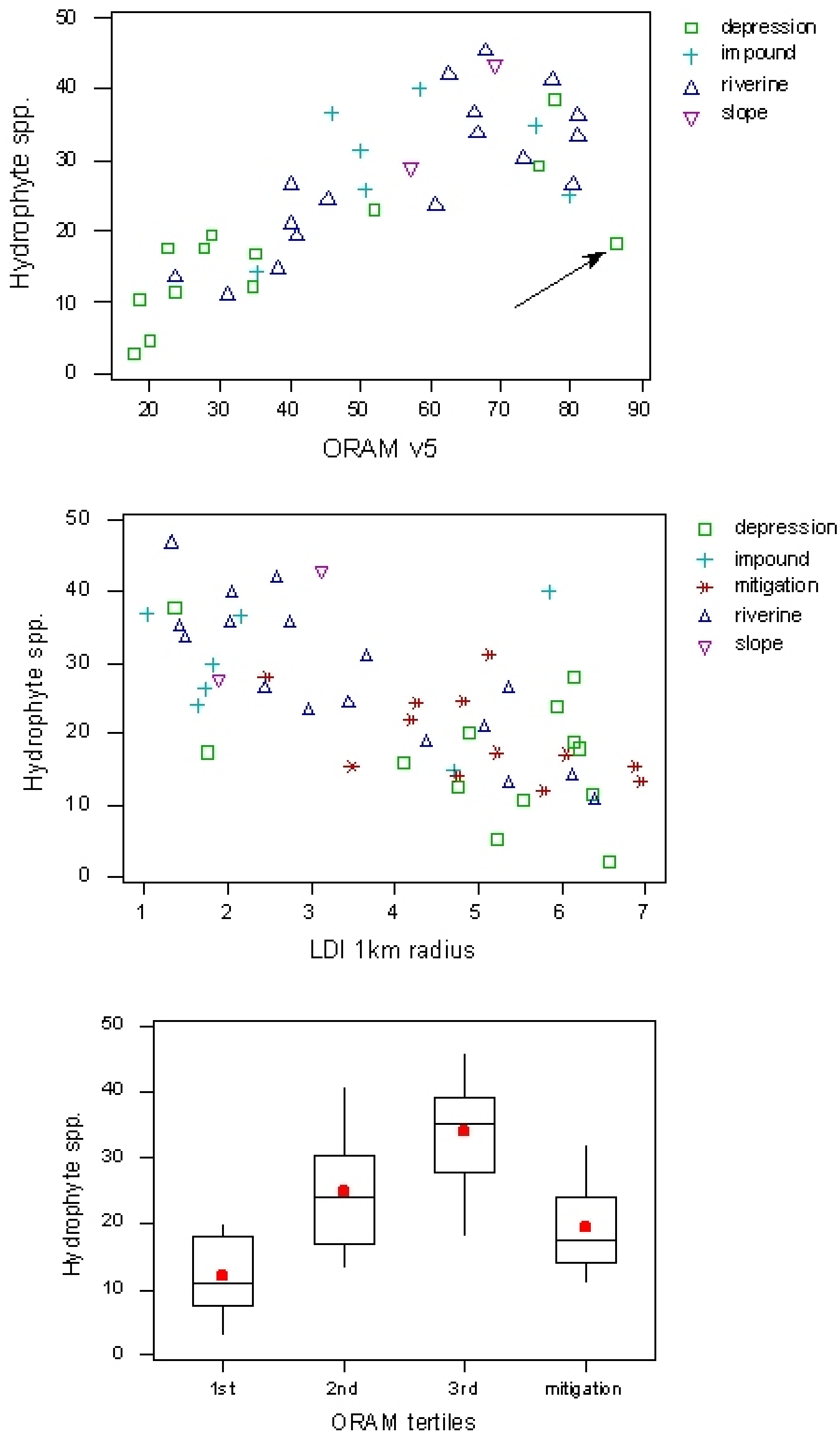


Figure 17. Summary plots hydrophyte metric for VIBI-EMERGENT. Scatterplots are richness of FACW and OBL plant species versus ORAM v. 5.0 score (df = 38, F = 48.3, R^2 = 56.6%, $p < 0.001$) or LDI score (df =50, F = 42.2, R^2 = 46.3%, $p < 0.001$). Box and whisker plots represent ORAM score tertiles. 3rd tertile signficantly different from 1st, 2nd, and mitigation; 2nd significantly different from 1st ($p < 0.05$). Site with arrow is floating leaved marsh located in species poor ombrotrophic bog complex.

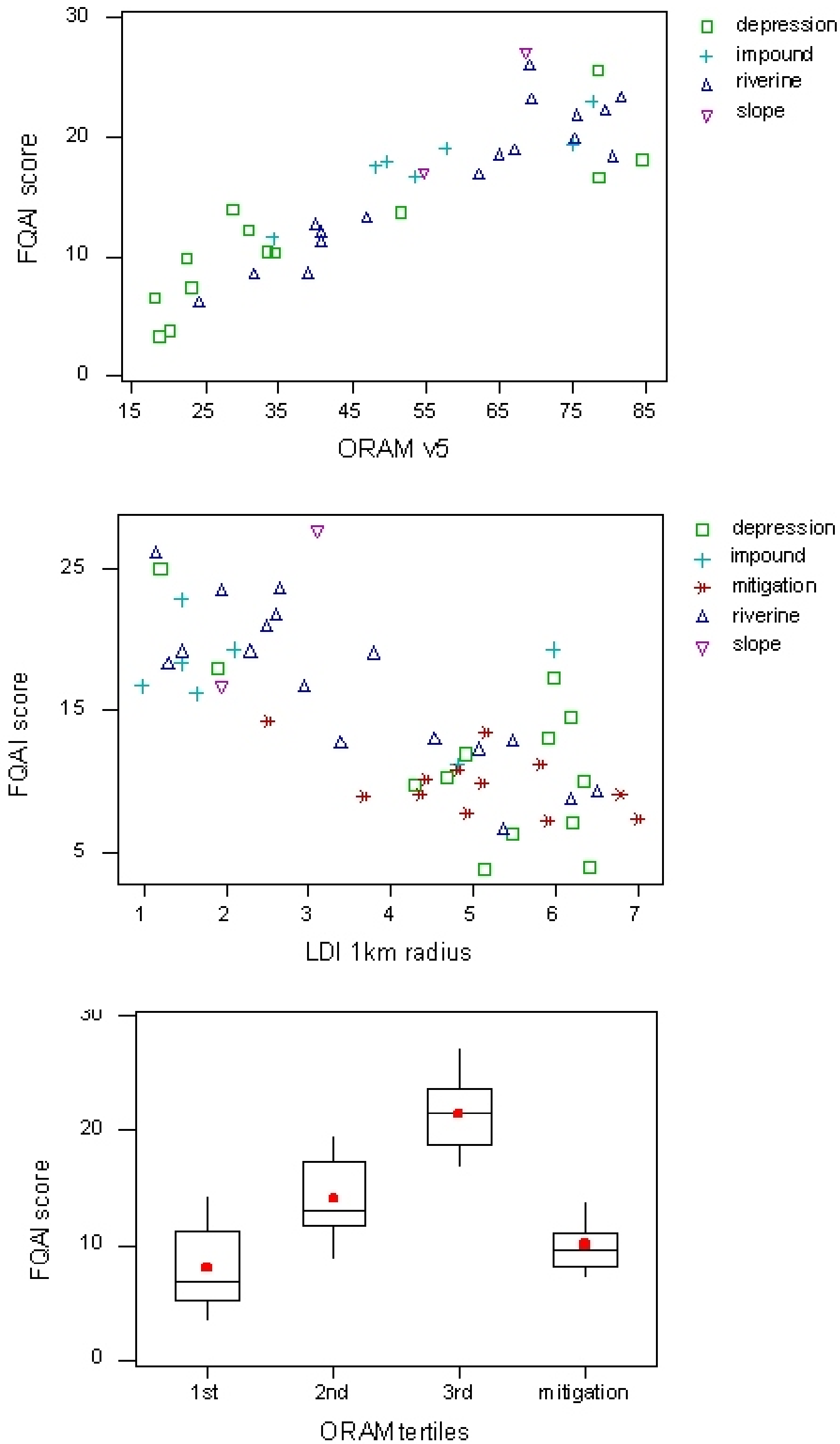


Figure 18. Summary plots of FQAI metric for VIBI-EMERGENT. Scatterplots are FQAI score calculated using Eqn. 7 and coefficients in Andreas et al. (2004) versus ORAM score (df = 38, F = 137.9, R^2 = 78.8%, $p < 0.001$) or LDI score (df = 50, F = 54.5, R^2 = 52.7%, $p < 0.001$) . Box and whisker plots are ORAM score tertiles. All means significantly different except 1st tertile and mitigation ($p < 0.05$).

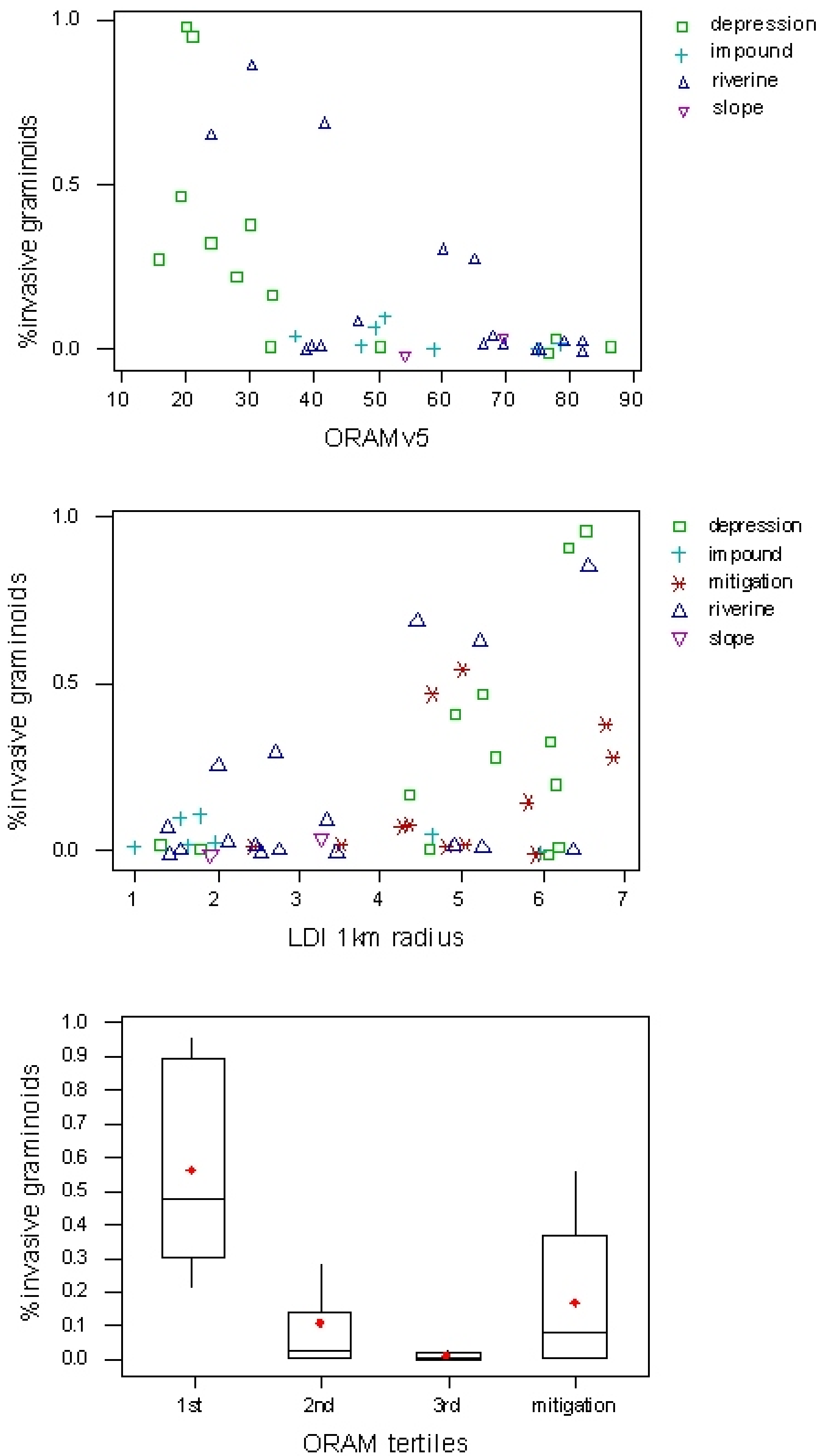


Figure 19. Summary plots of %invasive graminoids metric for VIBI-EMERGENT. Scatterplots are relative cover of invasive graminoids (*Typha* spp., *Phalaris arundinacea, Phragmites australis*) versus ORAM v. 5.0 score (df = 38, F = 21.1, R^2 = 36.4%, $p < 0.001$) or LDI score (df = 50, F = 12.6, R^2 = 20.5%, $p = 0.001$). Box and whisker plots represent ORAM score tertiles (thirds). 1st tertile significantly different from 2nd, 3rd and mitigation ($p < 0.05$).

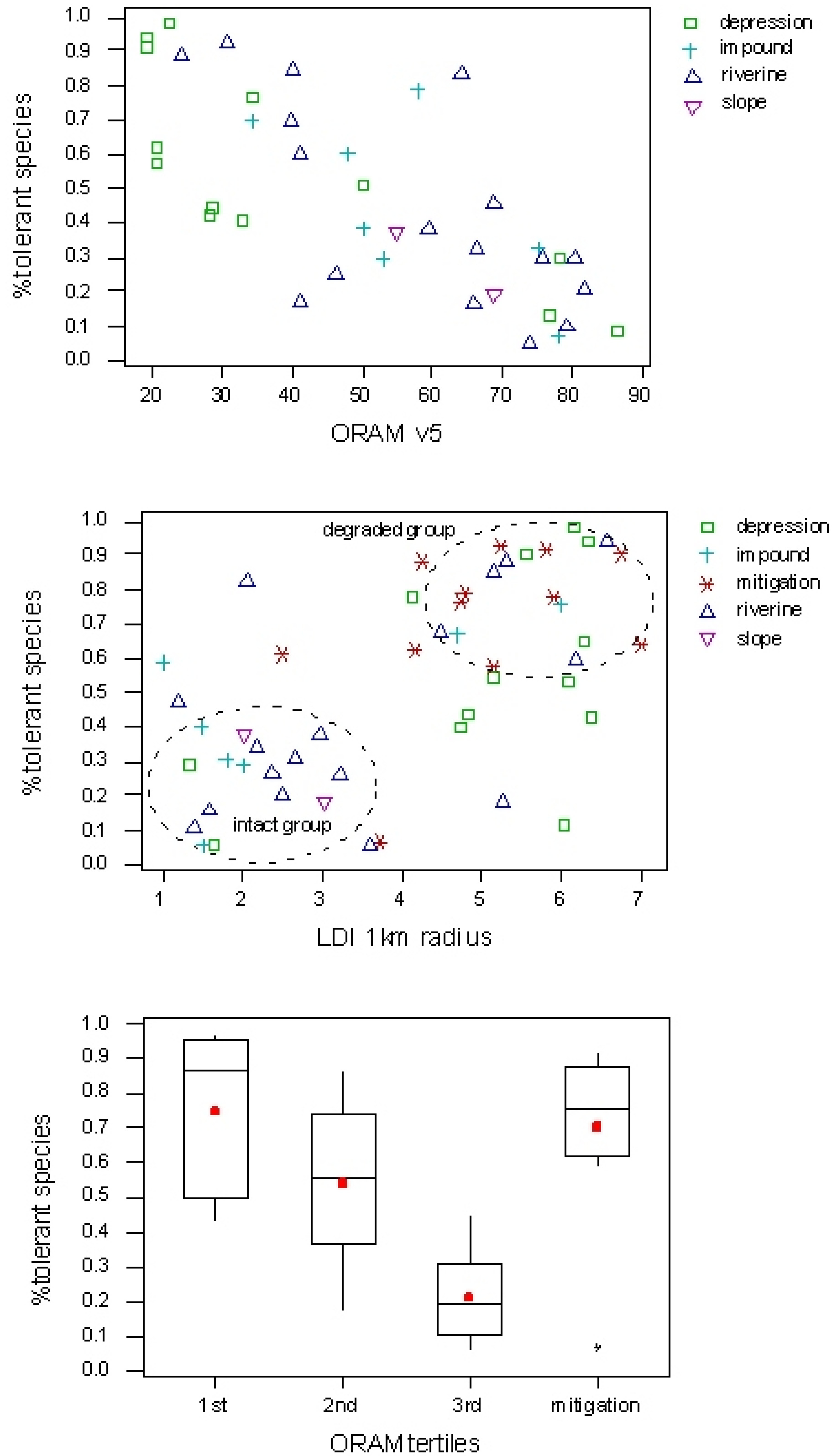


Figure 20. Summary plots of %tolerant metric for VIBI-EMERGENT. Scatterplots are relative cover of tolerant species (plants with Coefficients of Conservatism of 0, 1, 2) versus ORAM v. 5.0 score (df = 38, F = 40.0, $R^2 = 51.3\%$, $p < 0.001$) or LDI score (df = 50, F = 24.1, $R^2 = 33.0\%$, $p < 0.001$). Box and whisker plots are ORAM tertiles. 3rd tertile significantly different from 1st, 2nd, and mitigation ($p < 0.05$).

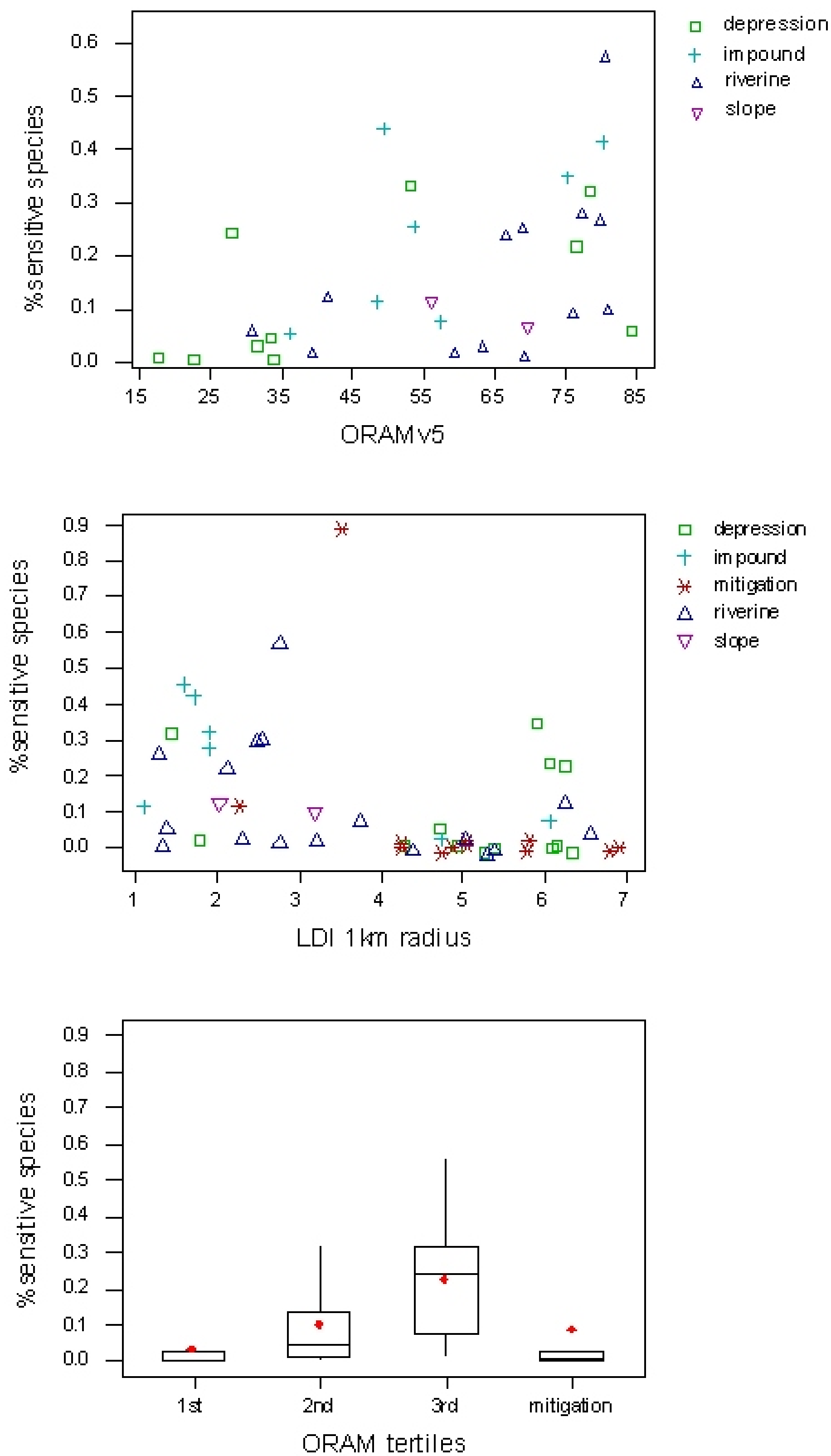


Figure 21. Summary plots of %sensitive metric for VIBI-EMERGENT. Scatterplots relative cover of sensitive species (Coefficients of Conservatisum = 6 -10) versus ORAM v. 5.0 score (df = 38, F = 15.3, R^2 = 29.3%, $p < 0.001$) or LDI score (df = 50, F = 10.4, R^2 = 17.5%, p = 0.002). Box and whisker plots are ORAM tertiles. 3rd tertile significantly different from 1st ($p < 0.05$).

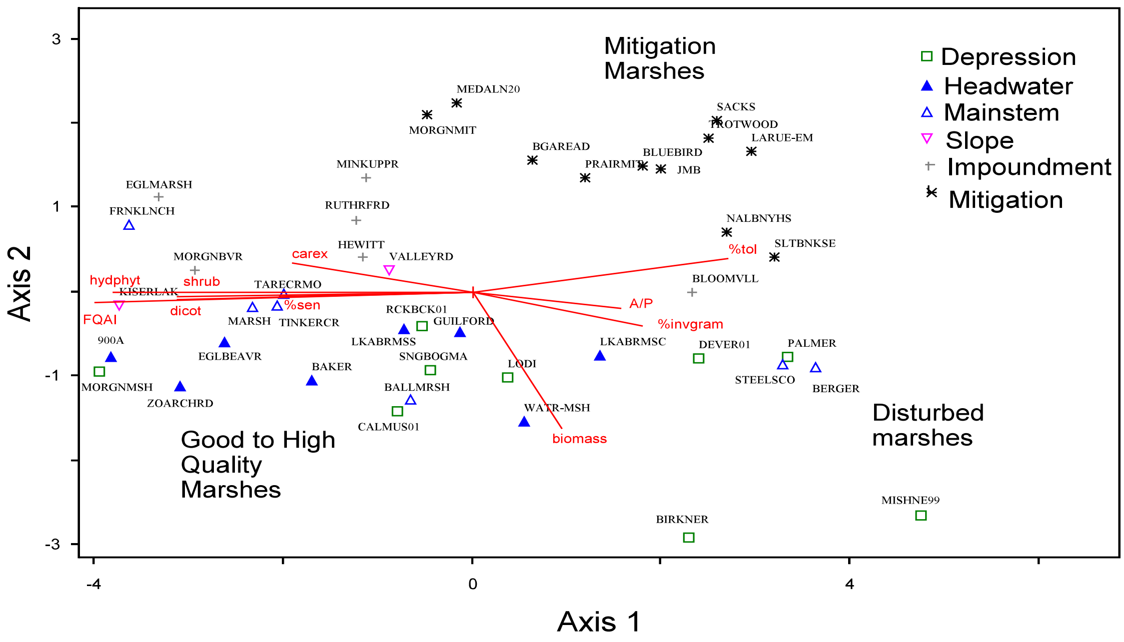


Figure 22. Principal components analysis of VIBI-EMERGENT metrics. Percent variance explained by first three eigenvalues 51.1, 13.8, and 10.0, respectively. Headwater = riverine, headwater; mainstem = riverine, mainstem.

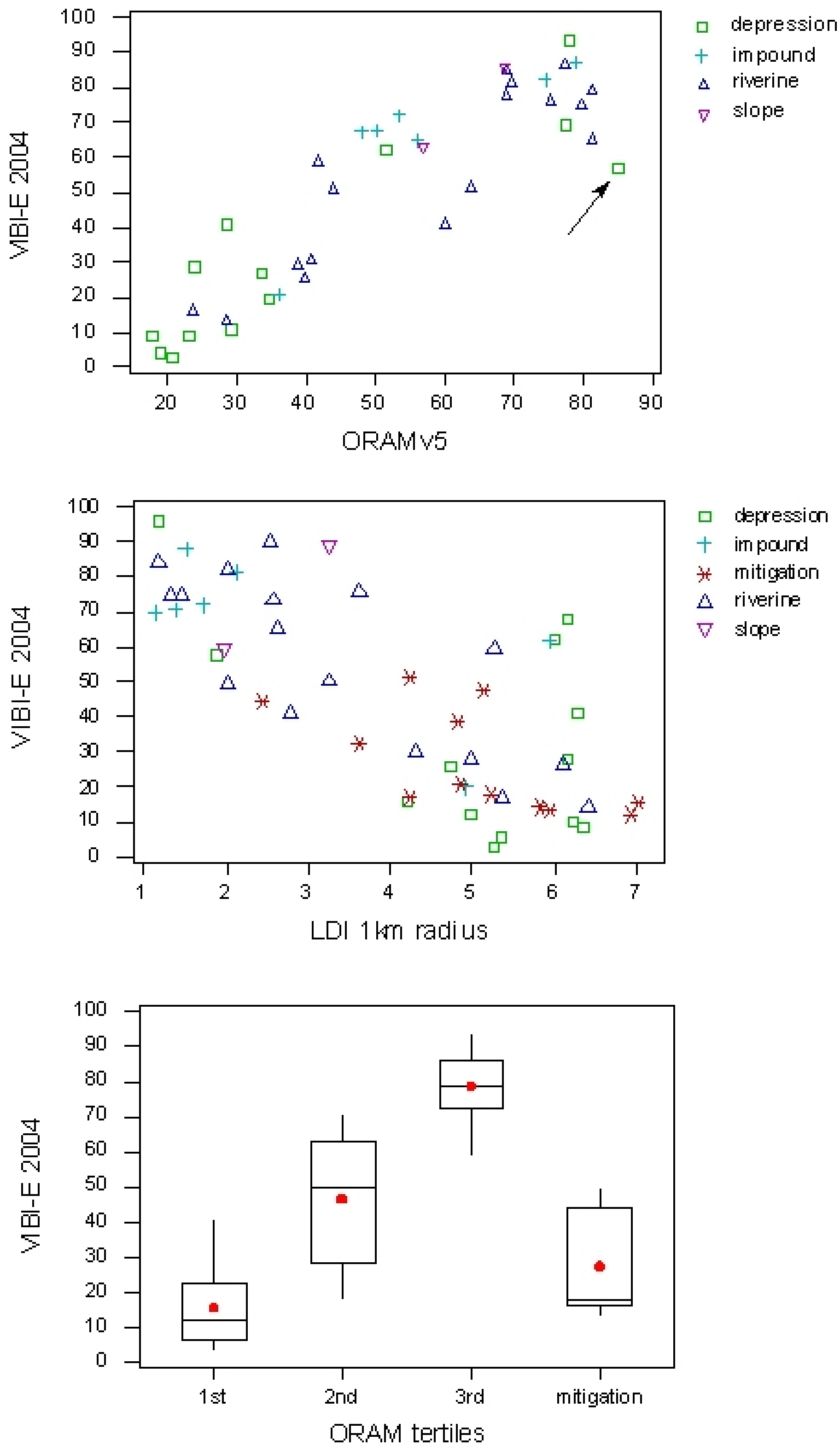


Figure 23. Summary plots of VIBI-EMERGENT as modified (see text for discussion). Scatterplots are VIBI-E score versus ORAM v. 5.0 score (df = 40, F = 117.1, R^2 = 75.0%, $p < 0.001$ or LDI score (df = 52, F = 61.0, R^2 = 54.5%, $p < 0.001$). Box and whisker plots represent ORAM score tertiles (thirds). 1^{st}, 2^{nd} and 3^{rd} tertiles significantly different ($p<0.05$) and mitigation category signifantly different from 2^{nd} and 3^{rd} tertiles ($p < 0.05$). Site with arrow is marsh located in strongly ombrotophic bog complex.

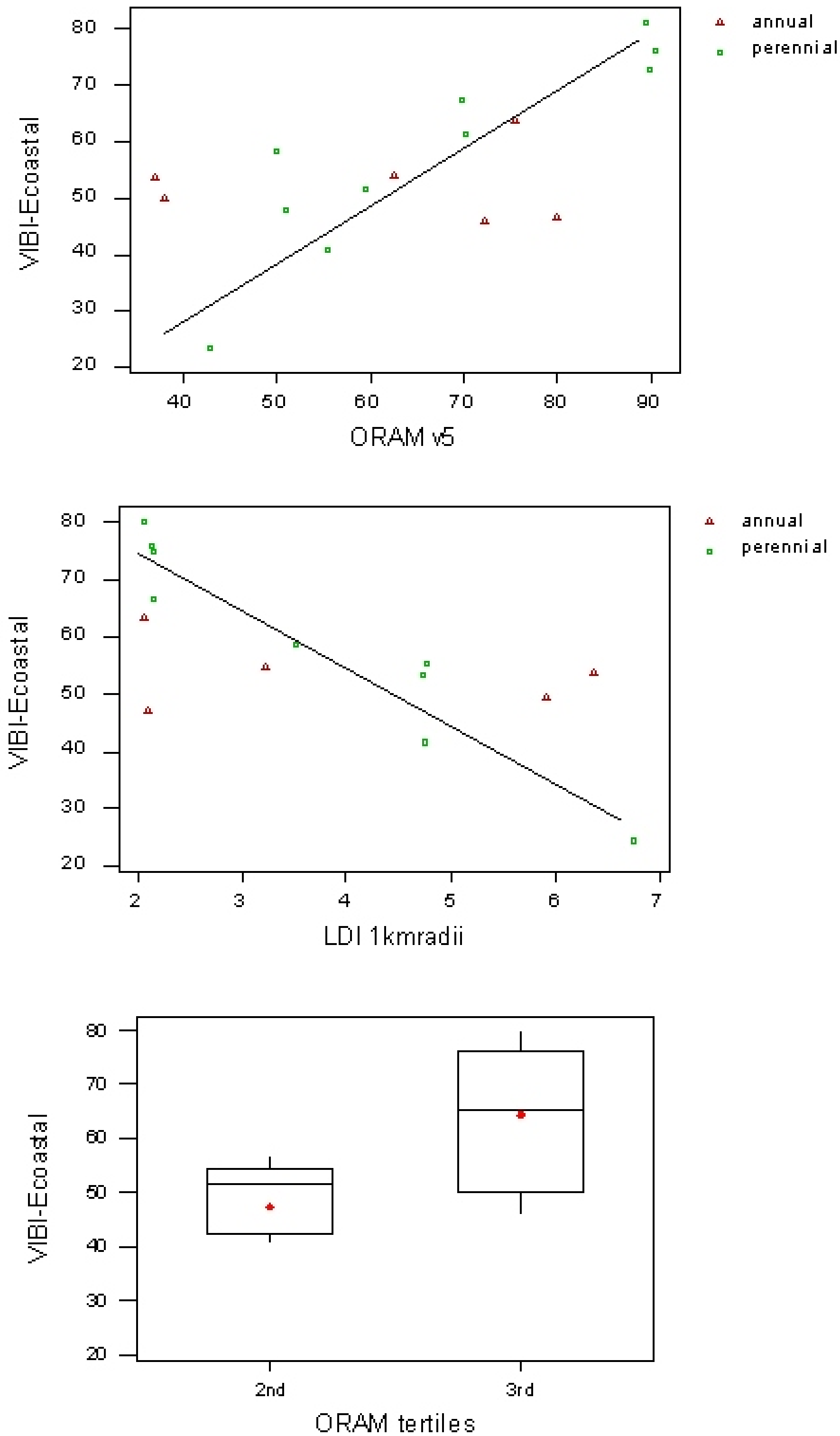
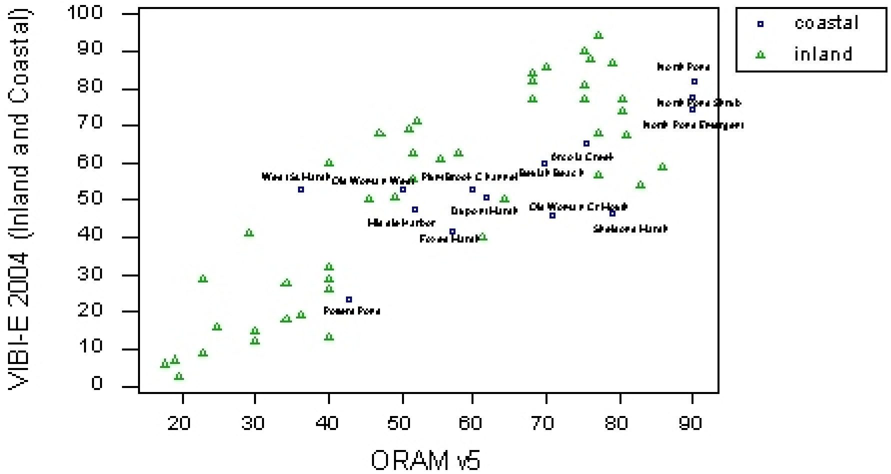


Figure 24. Summary plots of VIBI-$E_{COASTAL}$ (same as VIBI-EMERGENT with Cyperaceae species richness substituted for *Carex* richness metric). Scatterplots are VIBI-E scores for Lake Erie Coastal Marshes versus ORAM v. 5.0 score (df = 15, F = 14.3, R^2 = 50.5%, p = 0.002) or LDI score (df = 13, F = 14.5, R^2 = 54.7%, p = 0.002) (two sites missing LDI scores). Box and whisker plots represent ORAM score tertiles (thirds). 2^{nd} and 3^{rd} tertiles significantly different (p = 0.013) . NOTE: North Pond sampled with two separate plots (Far upper right of ORAM scatterplot; Plots analyzed separately and together). Line is not a regression line but only represents general trend of perennial sites VIBI scores. "annual" refers to wetlands with >10% relative cover of annual plant species; "perennial" refers to wetlands with <10% relative cover of annual plant species.



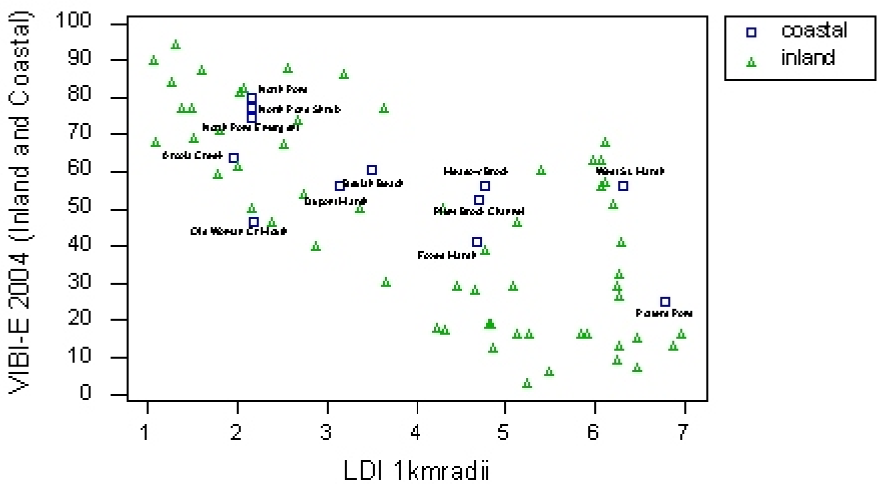


Figure 25. Summary plots of VIBI-E$_{COASTAL}$ and VIBI-E for inland natural marshes and mitigation sites. Scatterplots are VIBI-E scores versus ORAM v. 5.0 score and LDI scores. Arcola Creek and North Pond are arguably the only "reference standard" marshes in the data set. Note how the two reference standard coastal marshes have comparable scores and are grouped with high quality inland marshes. Also note how, in general, coastal sites intermix with inland sites in the overall distribution.

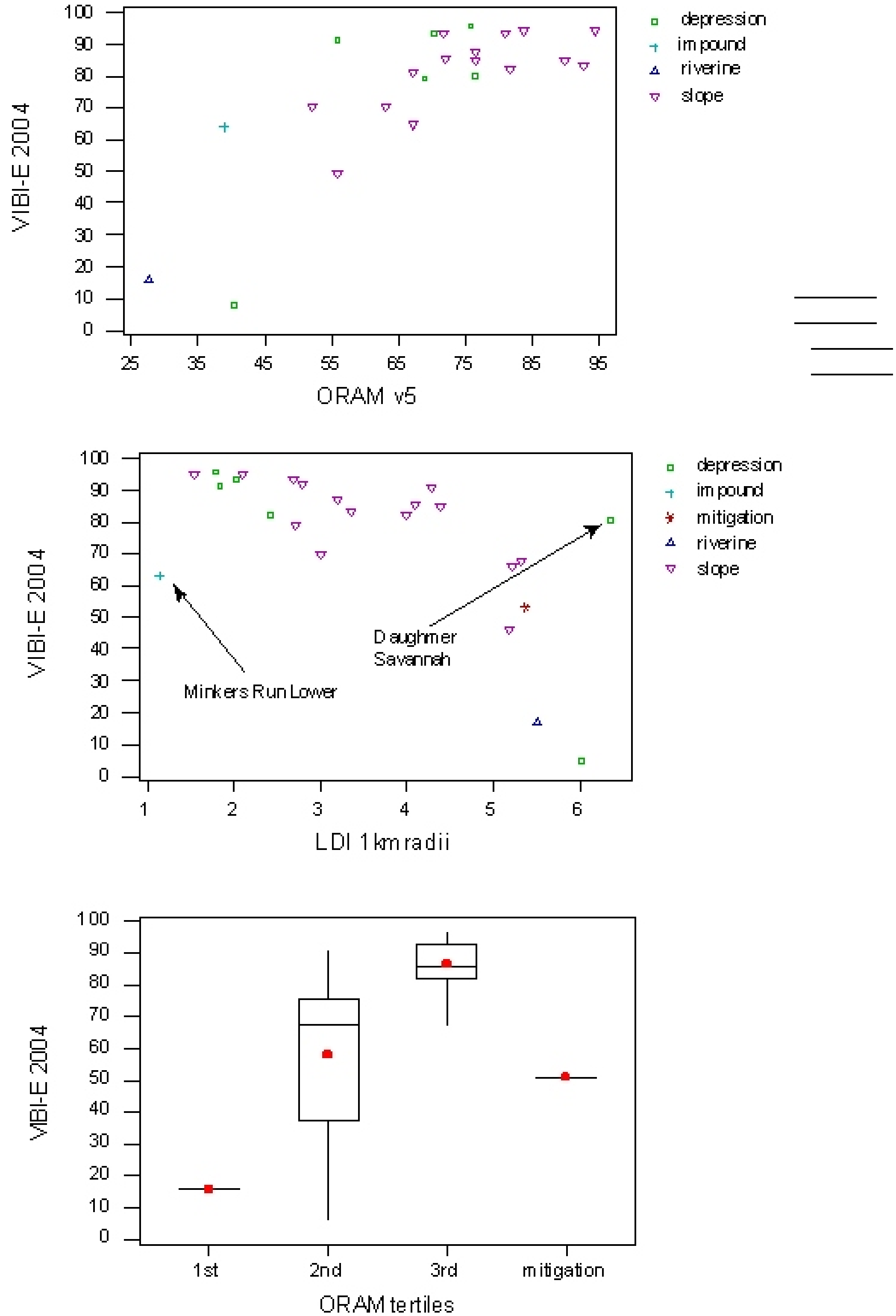


Figure 26. VIBI-EMERGENT scores of sedge-grass dominated wetlands (fens, wet prairies, reed canary grass meadows, etc.). Scatterplots of VIBI-E scores versus ORAM score and LDI score. Box and whisker plots by ORAM quartiles. There is one mitigation wetland, a fen restoration. Note in LDI scatterplot, the AMD impacted/created wet meadow that is located in a strongly reforested valley (Minkers Run) and Daughmer Savannah, a prairie sedge meadow, that is buffered from an intensive agricultural landscape by 30 ha of upland prairie and savannah.

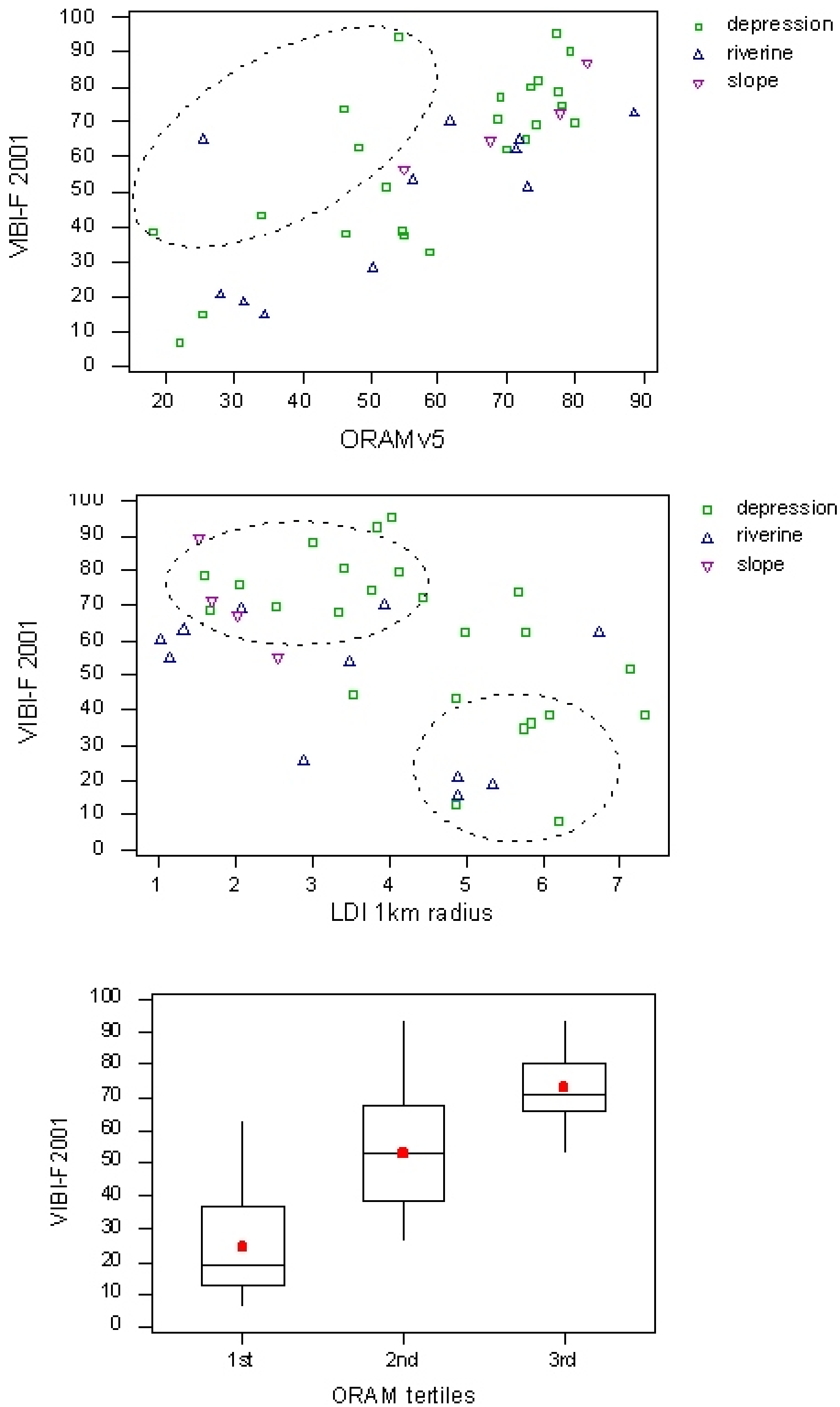


Figure 27. Summary plots of the 2001 VIBI-FOREST calculated in accordance with Mack (2001b, 2004a). Scatterplots are VIBI score versus ORAM v. 5.0 score (df = 38, F = 49.7, R^2 = 57.3%, p <0.001) or LDI score (df = 38, F = 9.4, R^2 = 20.3%, p = 0.004). Box and whisker plots represent ORAM score tertiles (thirds). N = 39 reference sites, of these n = 20 are " reference standard" forests. All means of VIBI-F scores for ORAM tertiles are significantly different (p <0.05) after ANOVA and Tukey's multiple comparison test. Sites circled in LDI scatterplot are bimodally distributed undisturbed and disturbed sites. Note circled sites (1) in VIBI v. ORAM scatterplot that are doing much better than predicted and (2) in VIBI v. LDI scatterplot that are doing better or worse than predicted by landscape factors because of site specific disturbances or buffers.

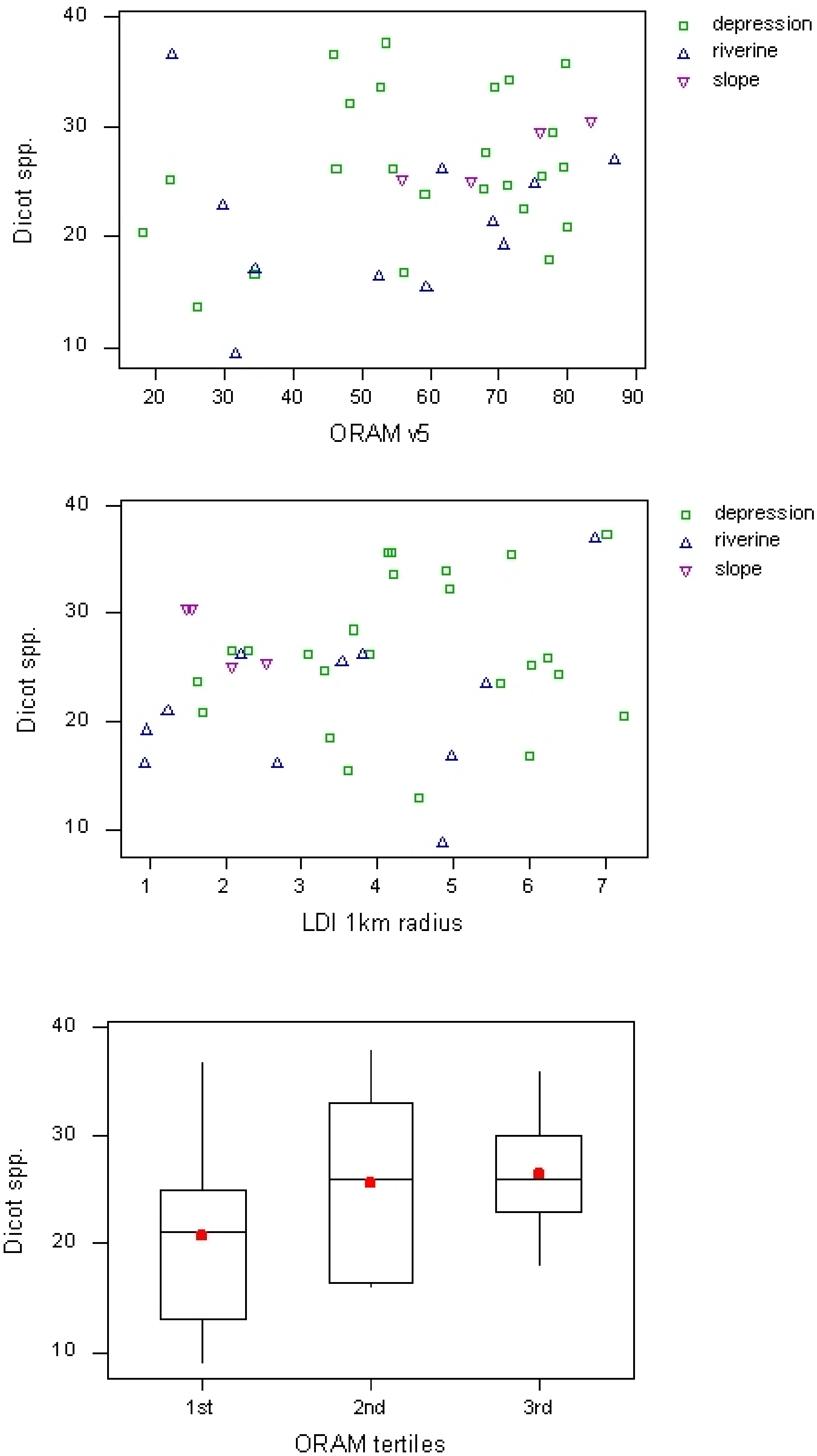


Figure 28. Summary plots of the dicot metric for VIBI-FOREST. Scatterplots are number of dicot species versus ORAM v. 5.0 score (ns) or LDI score (ns). Box and whisker plots represent ORAM score tertiles (thirds). Means are not significantly different.

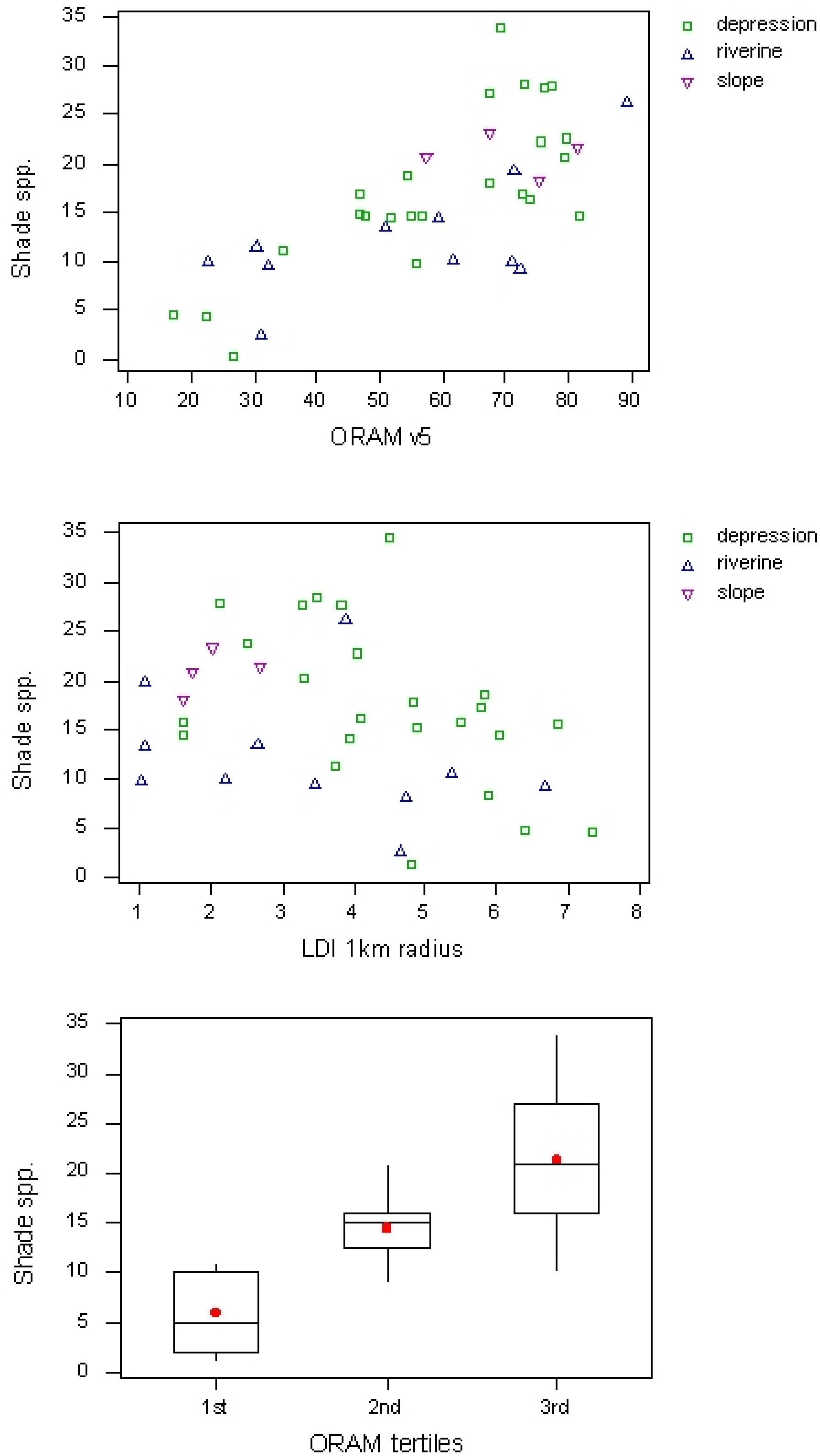


Figure 29. Summary plots of the shade metric for VIBI-FOREST (replacement metric for Rosaceae metric). Scatterplots are number of shade or facultative shade species versus ORAM v. 5.0 score (df = 38, F = 41.1, R^2 = 52.6%, $p < 0.001$) or LDI score (df = 38, F = 4.8, R^2 = 11.5%, p = 0.035). Box and whisker plots represent ORAM score tertiles (thirds). 3rd tertile significantly different from 1st ($p < 0.05$).

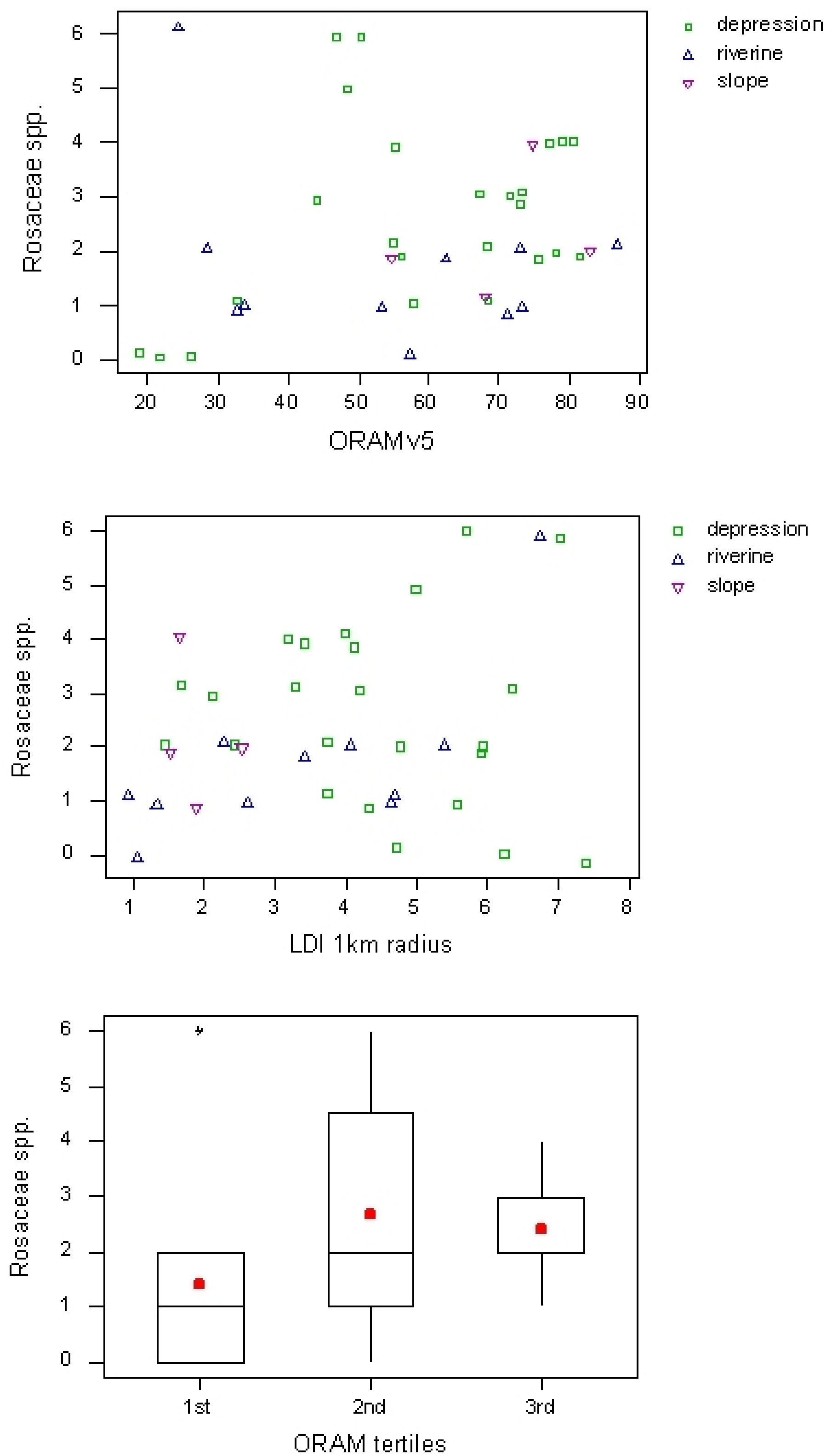


Figure 30. Summary plots of the Rosaceae metric for VIBI-FOREST. Scatterplots are number of Rosaceae species versus ORAM v. 5.0 score (ns) or LDI score (ns). Box and whisker plots represent ORAM score tertiles (thirds). Means not significantly different.

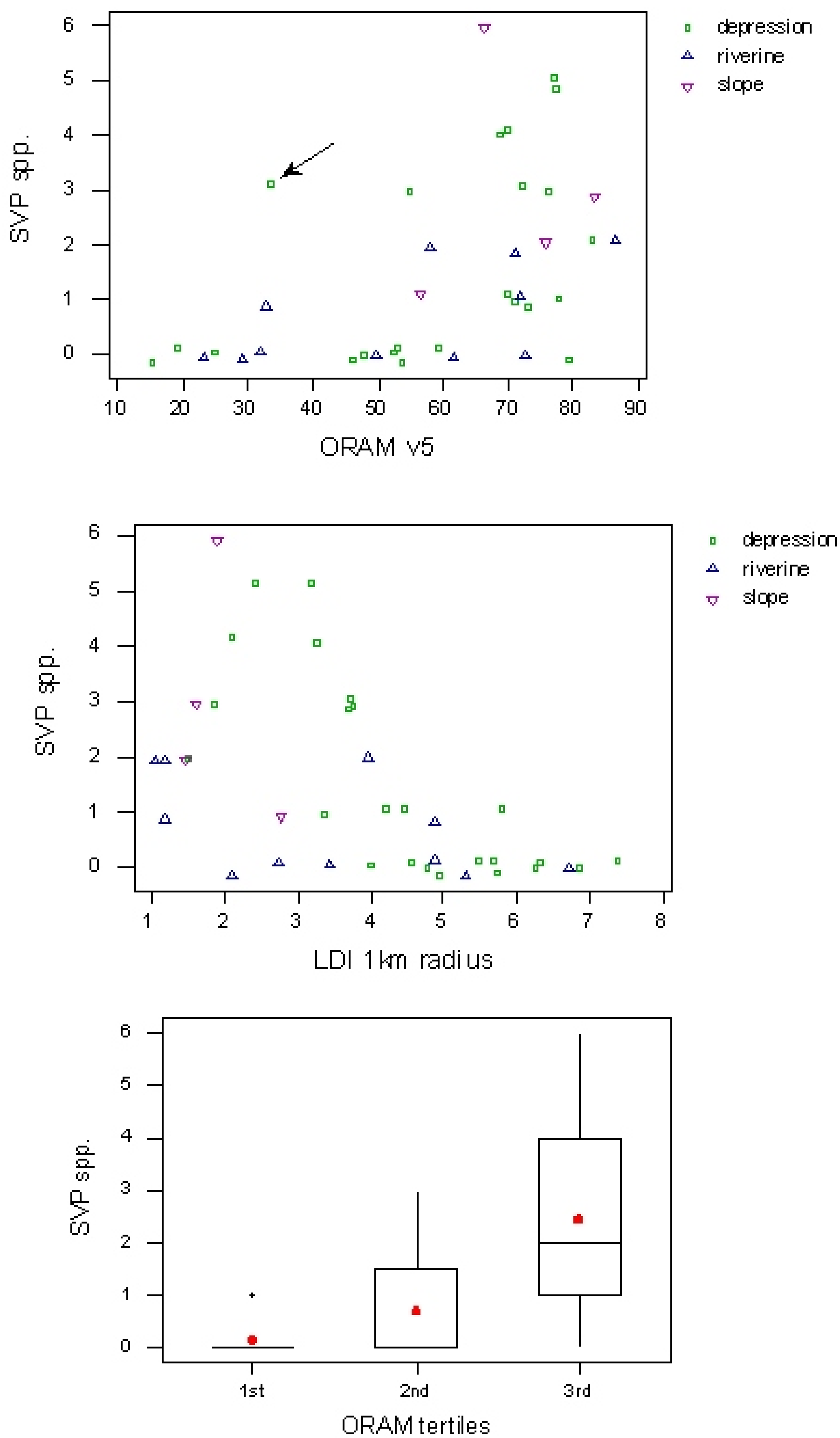


Figure 31. Summary plots of SVP metric for VIBI-FOREST. Scatterplots are number of the SVP species (seedless vascular plants i.e. cryptogams or ferns and fern allies) versus ORAM v. 5.0 score (df = 38, F = 12..1, R^2 = 24.6%, p = 0.001) or LDI score (df = 38, F = 5.2, R^2 = 33.2%, p < 0.001). Box and whisker plots represent ORAM score tertiles (thirds). 3rd tertile significantly different from 1st and 2nd tertiles (p < 0.05). Site with arrow is area of recovering swamp forest at south side of Mentor Marsh, a now *Phragmites* dominated wetland where brine spills from salt mining destroyed a rich swamp forest complex in the 1960s.

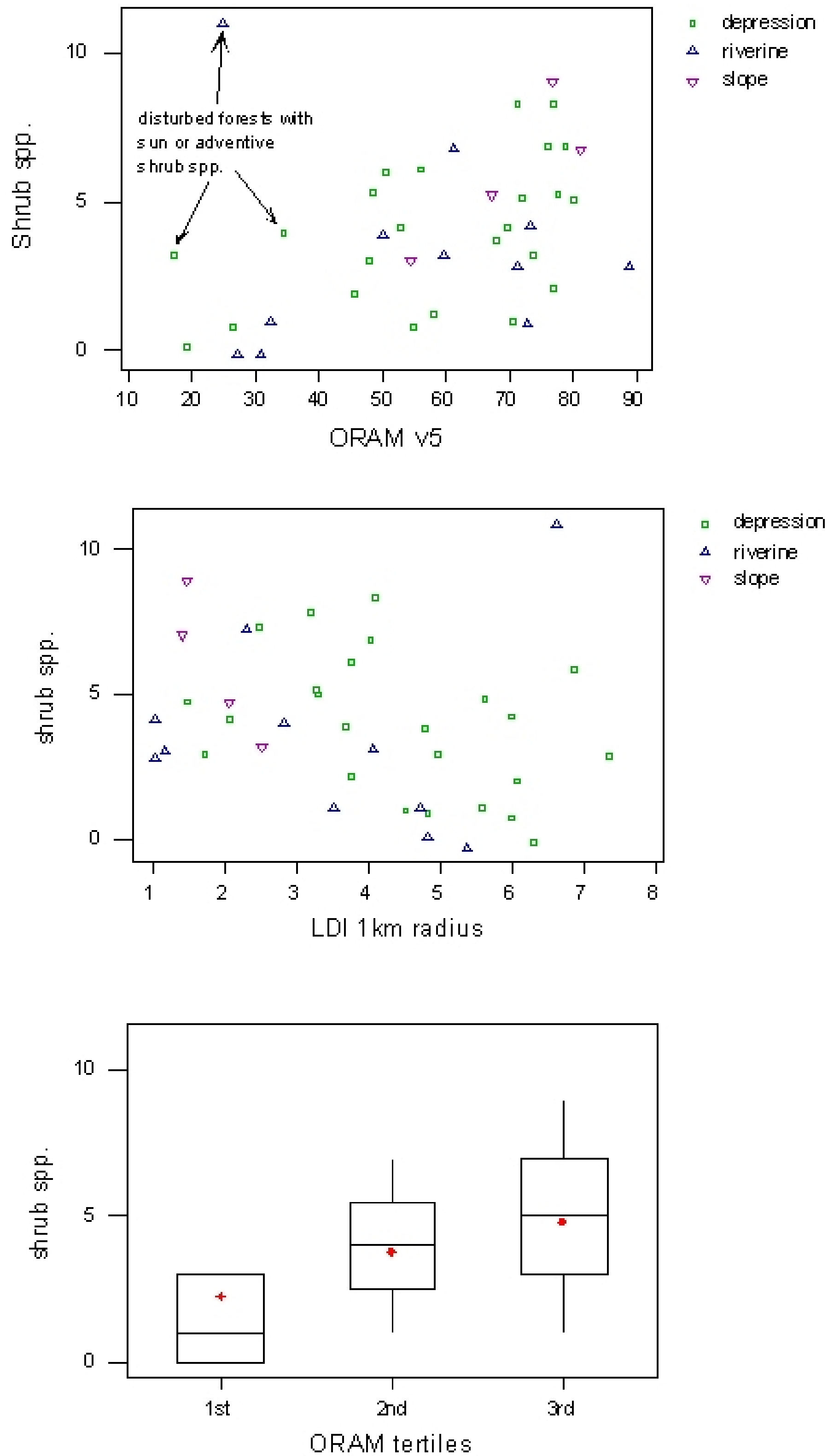


Figure 32. Summary plots of the shrub species metricfor VIBI-FOREST. Scatterplots are shrub species versus ORAM v. 5.0 score (df = 38, F = 4.9, R^2 = 11.7%, p = 0.033) or LDI score (ns). Box and whisker plots represent ORAM score tertiles (thirds). Means not significantly different.

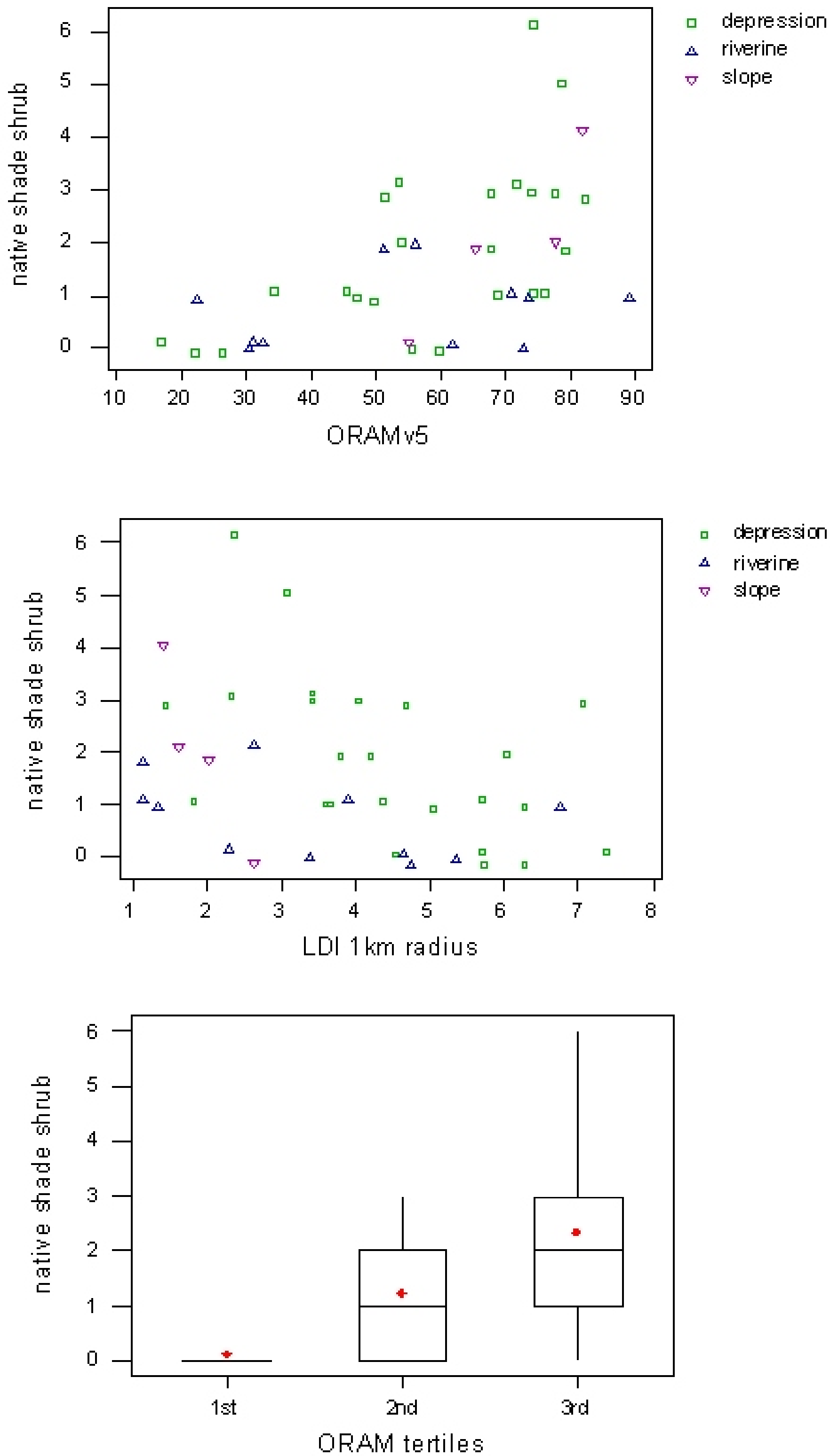


Figure 33. Summary plots of the native shade shrub species (considered as a modification of shrub metric, see text). Scatterplots are native, shade shrub species versus ORAM v. 5.0 score (df = 38, F = 16.0, R^2 = 30.2%, $p < 0.001$) or LDI score (df = 38, F = 5.2, R^2 = 12.3%, p = 0.029). Box and whisker plots represent ORAM score tertiles (thirds). 3rd tertile significantly different from 1st tertile ($p < 0.05$).

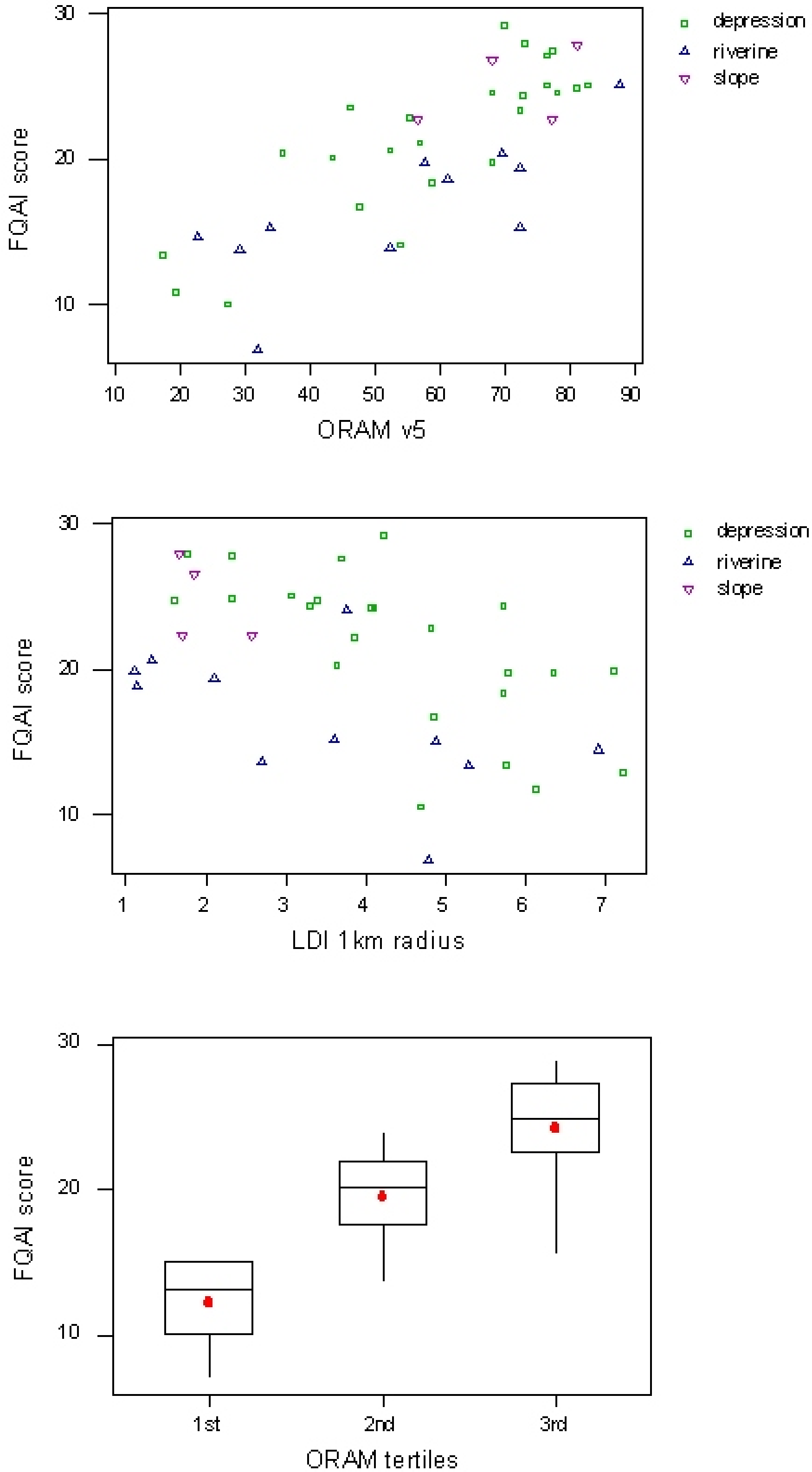


Figure 34. Summary plots of the FQAI score metric for VIBI-FOREST. Score calculated using Eqn. 7 and with the coefficients in Andreas et al. (2004). Scatterplots are FQAI score versus ORAM v. 5.0 score (df = 38, F = 58.1, R^2 = 61.1%, $p < 0.001$) or LDI score (df = 38, F = 12.0, R^2 = 24.4%, $p = 0.001$). Box and whisker plots represent ORAM score tertiles (thirds). All means significantly different ($p < 0.05$).

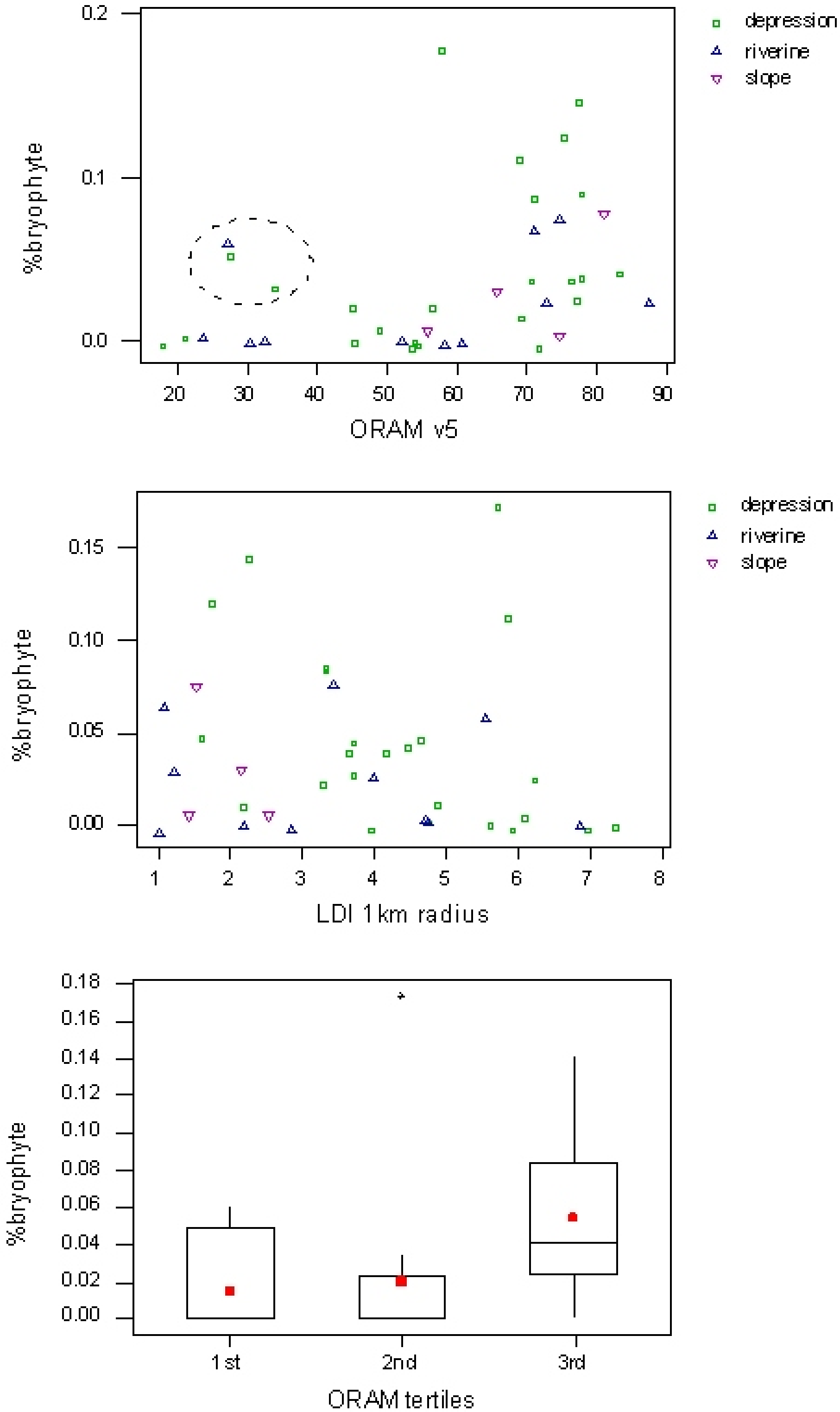


Figure 35. Summary plots of the %bryophyte metric for VIBI-FOREST (replacement for shrub richness metric, see text). Scatterplots are relative cover of bryphytes versus ORAM v. 5.0 score (df = 38, F = 6.02, R^2 = 14.0%, $p < 0.019$) or LDI score (ns). Box and whisker plots represent ORAM score tertiles (thirds) (df = 38, F = 3.68, $p < 0.035$). Note three disturbed circled in ORAM scatterplot with unusually high bryophyte cover. These sites all sampled in 1999 during the first year of sampling using the Peet et al. (1998) methodology and this may be due to sampling error.

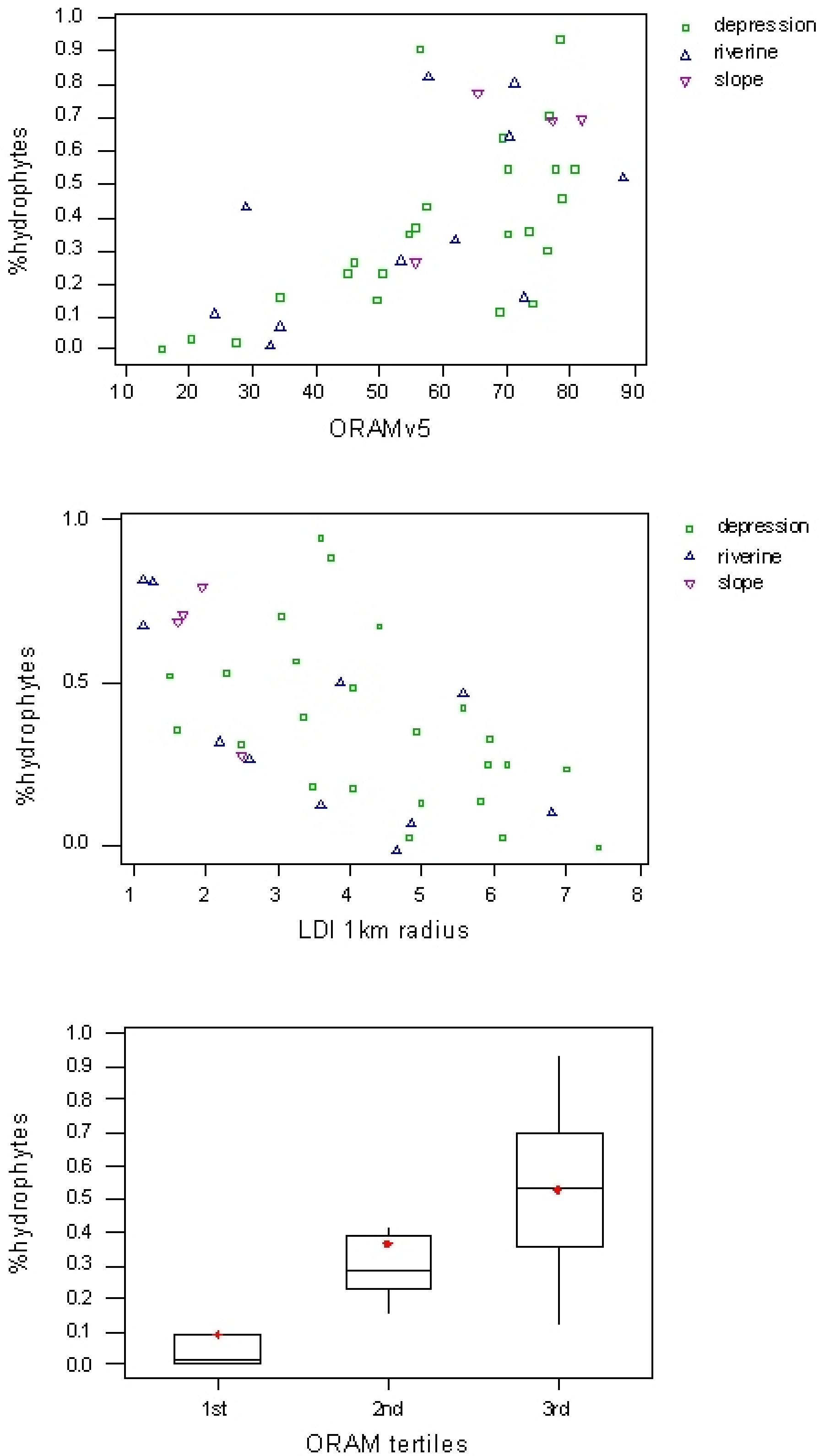


Figure 36. Summary plots of the %hydrophyte metric for VIBI-FOREST. Scatterplots are relative cover of shade and facultativel shade hydrophyte species (FACW, OBL) versus ORAM v. 5.0 score (df = 38, F = 24.9, R^2 = 40.3%, $p < 0.001$) or LDI score (df = 38, F = 23.2, R^2 = 38.6%, $p < 0.001$). Box and whisker plots represent ORAM score tertiles (thirds). 3rd and 2nd tertiles significantly different from 1st tertile ($p < 0.05$).

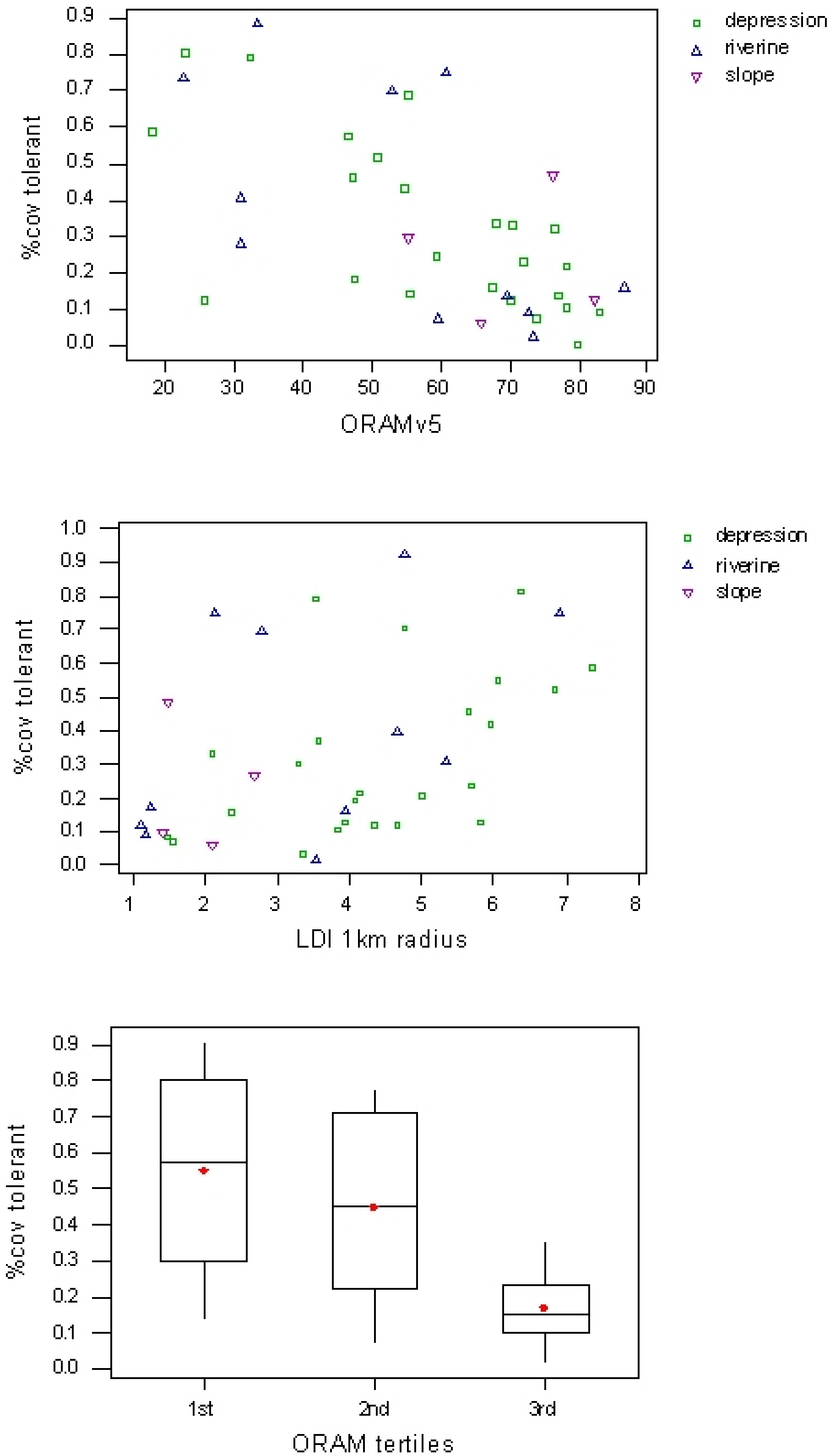


Figure 37. Summary plots of the %tolerant metric for VIBI-FOREST. Scatterplots are relative cover of tolerant species (Coefficients of Conservatism = 0, 1, 2) versus ORAM v. 5.0 score (df = 38, F = 24.2, R^2 = 39.6%, p < 0.001) or LDI score (df = 38, F = 8.9, R^2 = 19.4%, p = 0.005). Box and whisker plots represent ORAM score tertiles (thirds). 3rd tertile significantly different from 1st and 2nd tertiles (p < 0.05).

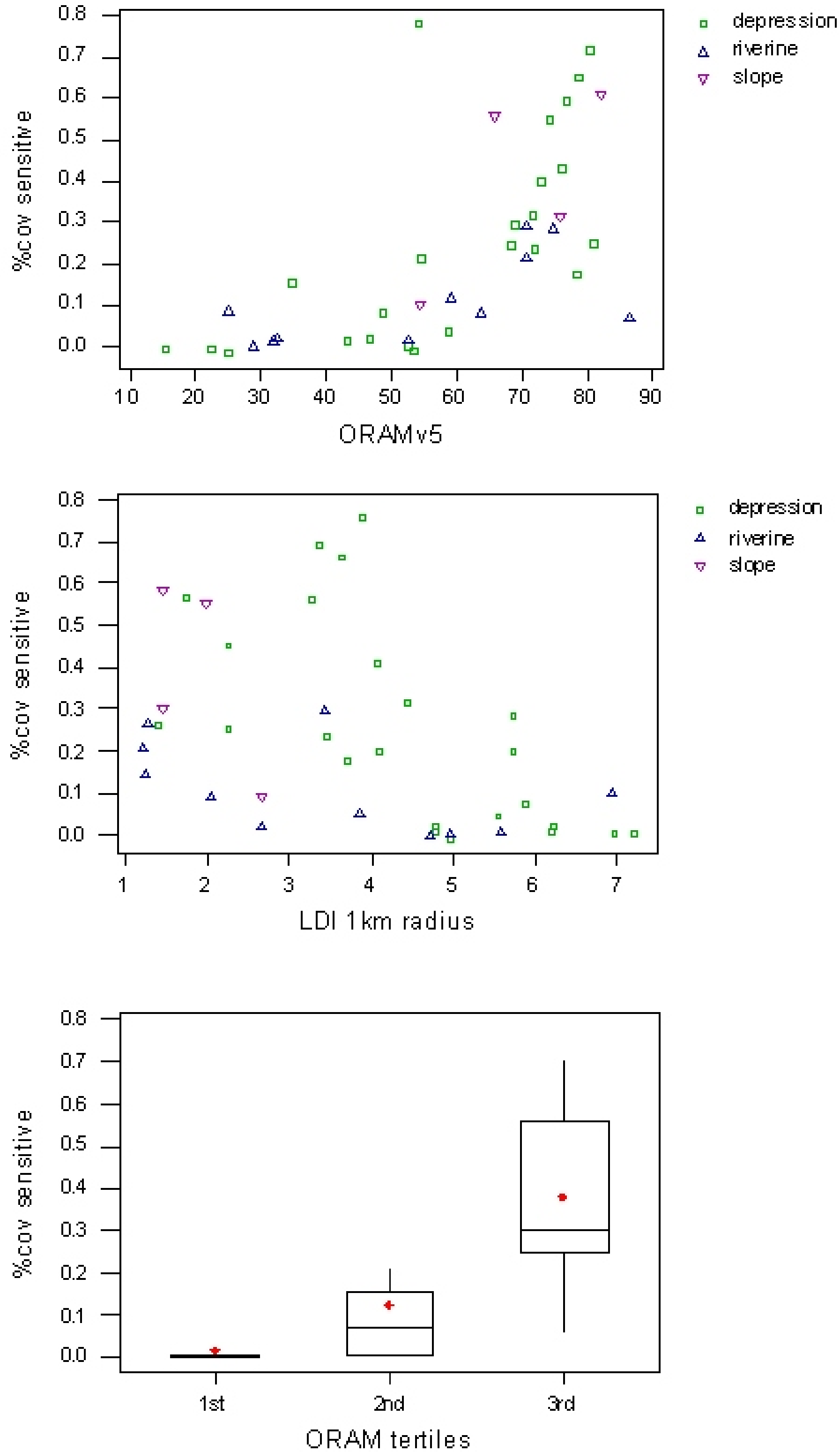


Figure 38. Summary plots of the %sensitive metric for VIBI-FOREST. Scatterplots are relative cover of sensitive species (Coefficients of Conservatism = 6 - 10) versus ORAM v. 5.0 score (df = 38, F = 23.8, R^2 = 39.1%, $p < 0.001$) or LDI score (df = 38, F = 10.9, $p = 0.002$). Box and whisker plots represent ORAM score tertiles (thirds). All means significantly different ($p < 0.05$). N = 39 reference sites, of these n = 20 are "reference standard" forests. Note riverine forested wetlands with relatively low abundance of sensitive species.

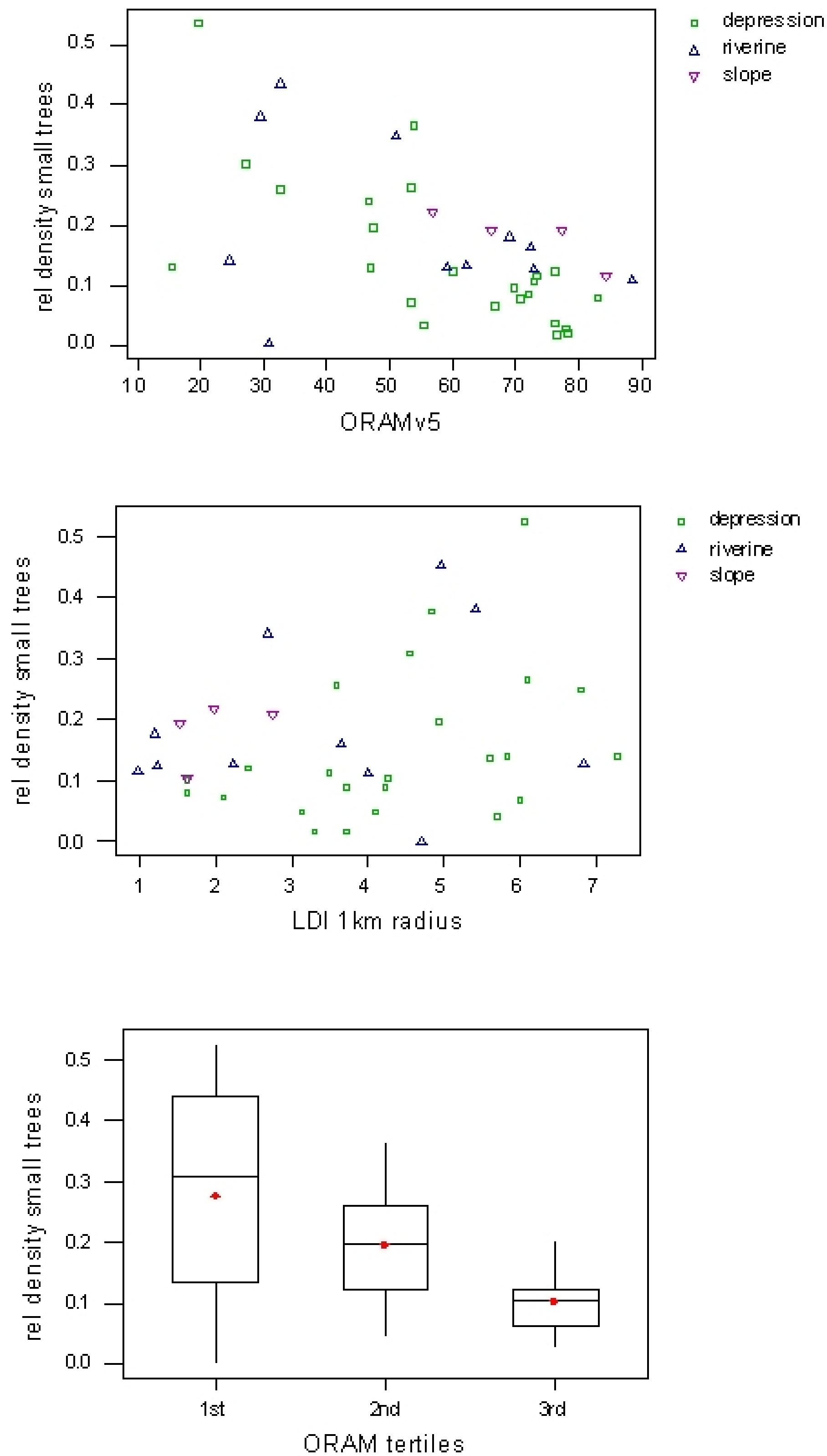
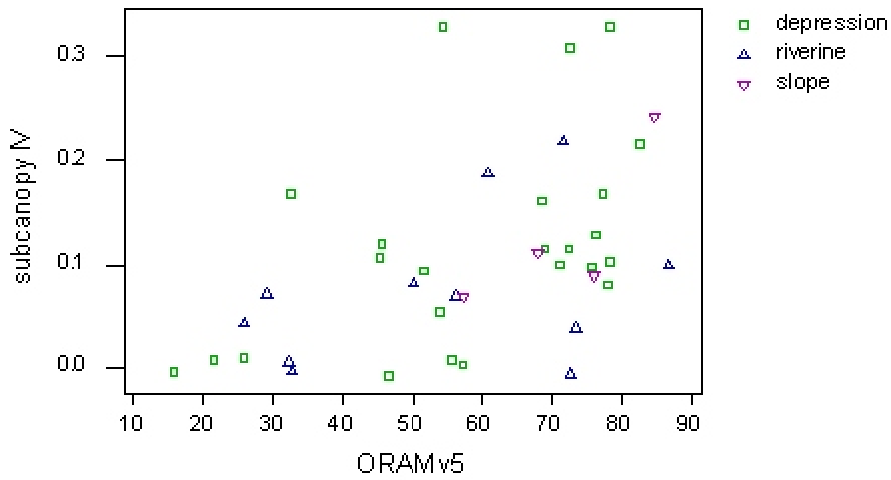
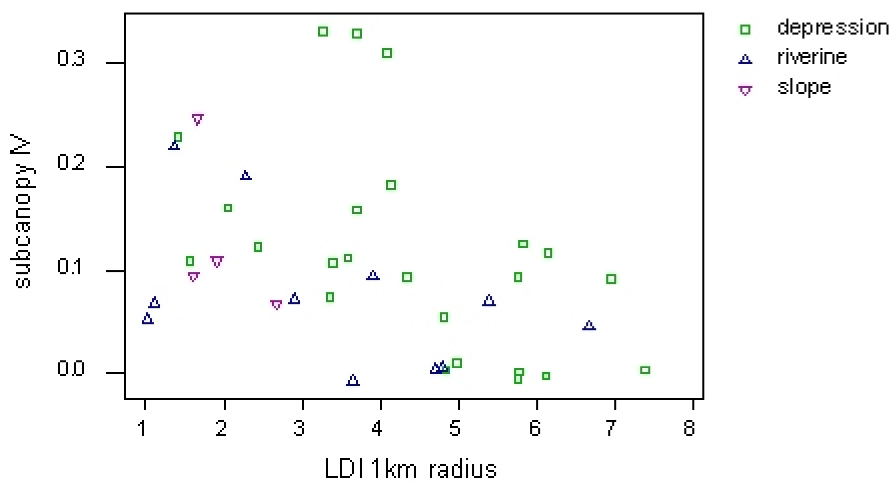


Figure 39. Summary plots of pole timber metric for VIBI-FOREST. Scatterplots are the relative density of small trees (10-25 cm dbh) versus ORAM v. 5.0 score (df = 38, F = 18.8, R^2 = 33.7%, $p < 0.001$) or LDI score (ns). Box and whisker plots represent ORAM score tertiles (thirds). 3rd tertile significantly different from 1st and 2nd ($p < 0.05$).





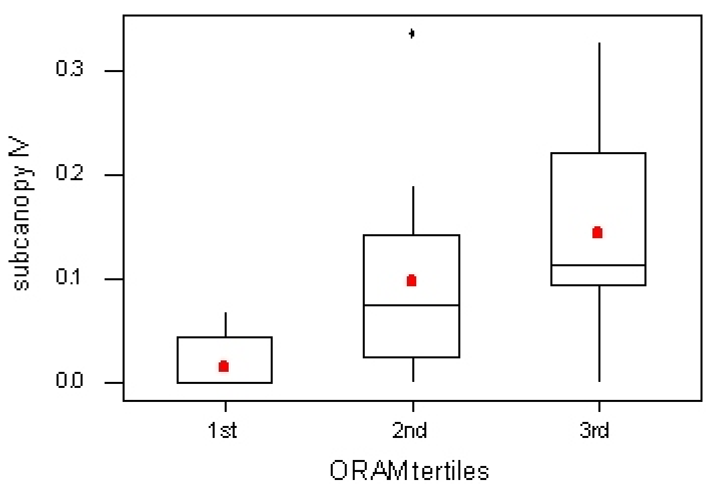


Figure 40. Summary plots of the subcanopy IV metric for VIBI-FOREST. Scatterplots are average importanc value of native, shade and facultative shade tolerant subcanopy (small tree and shrub) species versus ORAM v. 5.0 score (df = 38, F = 11.9, R^2 = 24.3%, p = 0.001) or LDI score (df = 38, F = 6.9, R^2 = 15.8%, p = 0.012). Box and whisker plots represent ORAM score tertiles (thirds). 3rd tertile significantly different from 1st and 2nd tertiles ($p < 0.05$).

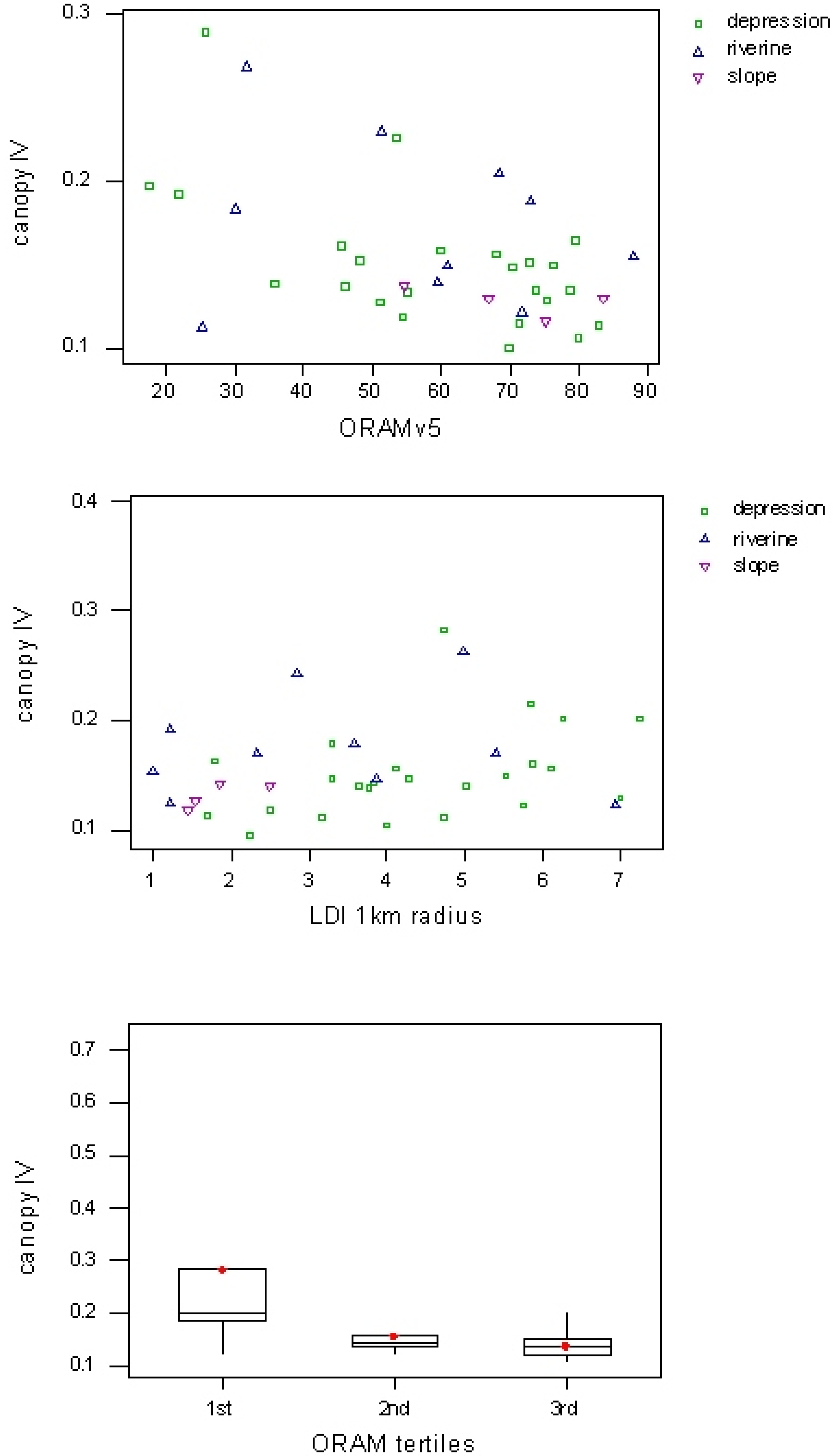


Figure 41. Summary plots of the canopy IV metric for VIBI-FOREST. Scatterplots are average importance value of canopy tree species versus ORAM v. 5.0 score (df = 38, F = 7.4, R^2 = 16.7%, p = 0.01) or LDI score (ns). Box and whisker plots represent ORAM score tertiles (thirds). 1st tertile significantly different from 2nd and 3rd ($p < 0.05$).

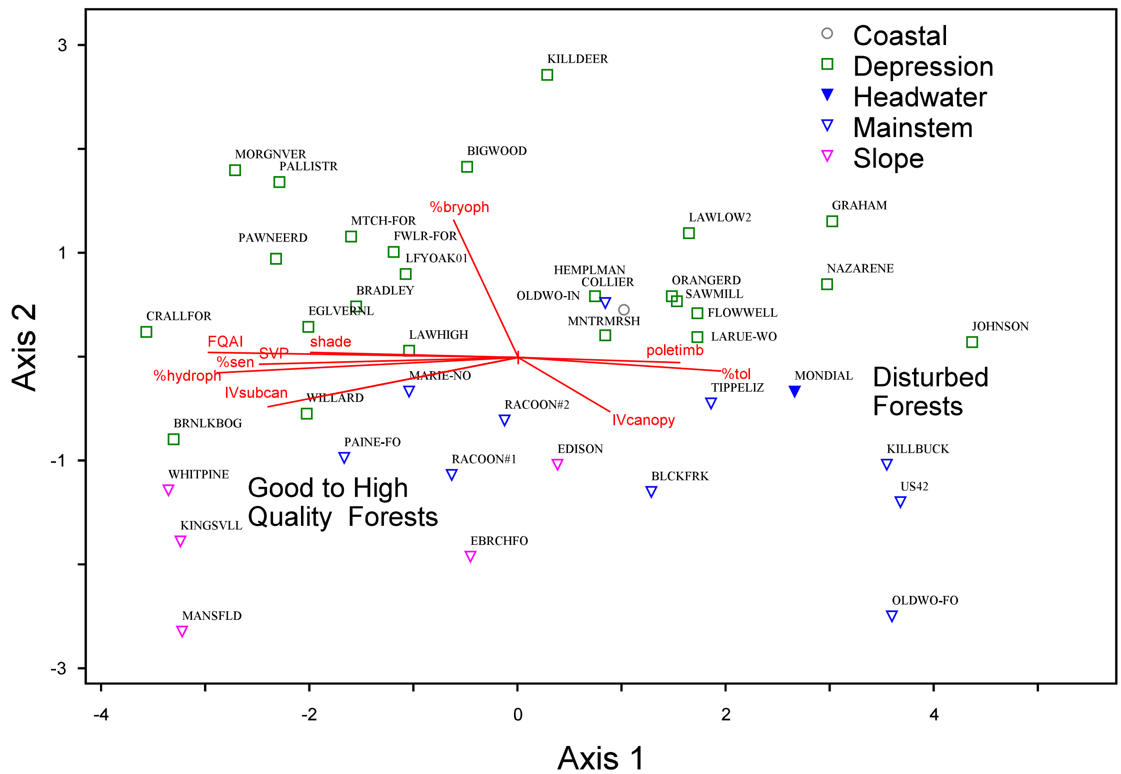


Figure 42. Principal components analysis of VIBI-FOREST metrics. Percent variance explained by first three eigenvalues 44.3, 12.9, and 10.2, respectively. Headwater = riverine, headwater; mainstem = riverine, mainstem.. Bog forests excluded due to strong influence on ordination. Note effect of HGM class on metric performance with clustering of slope, depression, and riverine wetlands.

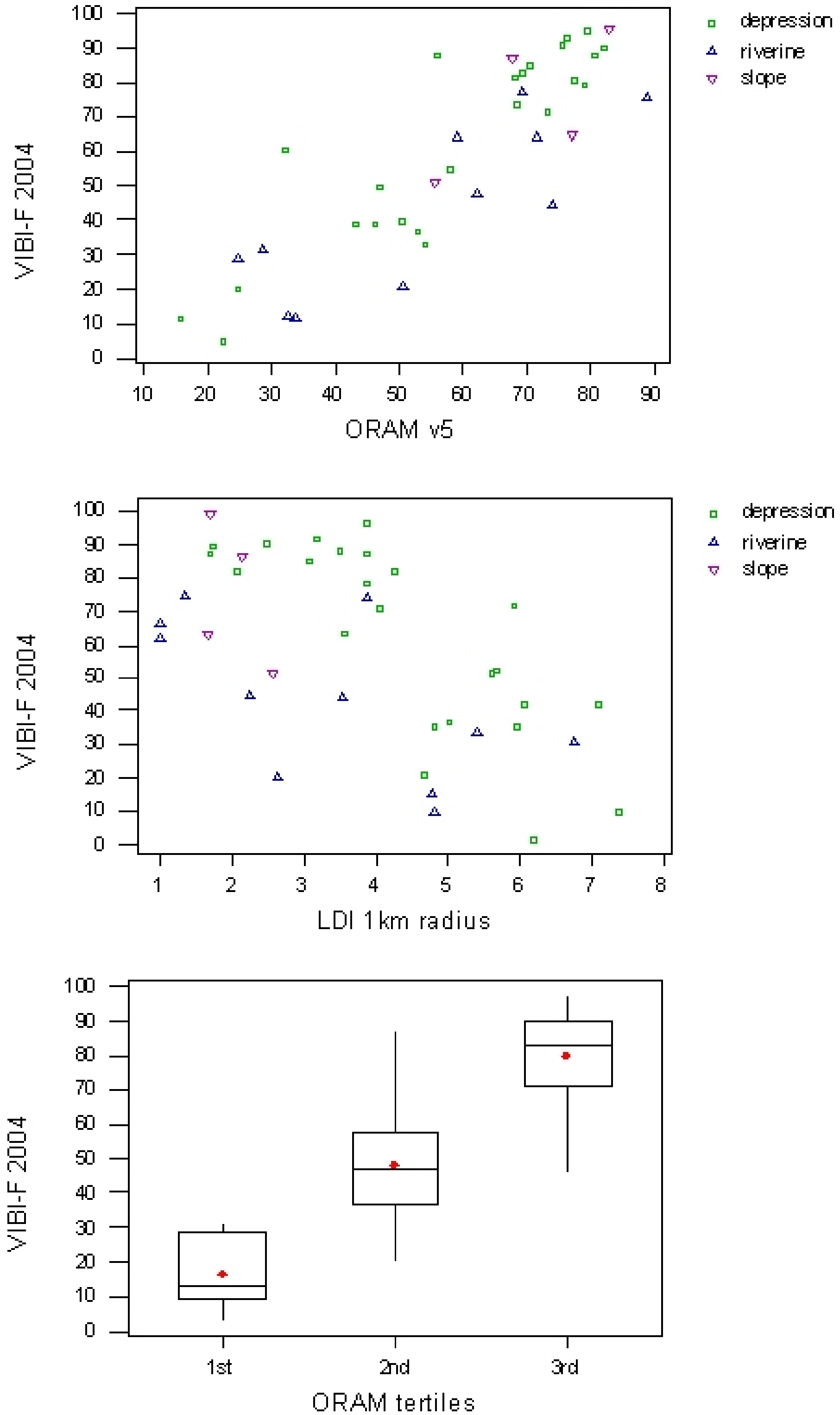


Figure 43. Summary plots of the VIBI-FOREST 2004 (with refined or changed metrics discussed in text). Scatterplots are VIBI-F 2004 scores versus ORAM v. 5.0 score (df = 38, F = 95.8, R^2 = 72.1%, $p < 0.001$) or LDI score (df = 38, F = 22.0, R^2 = 37.3%, $p < 0.001$). Box and whisker plots represent ORAM score tertiles (thirds). All means are significantly different ($p < 0.05$).

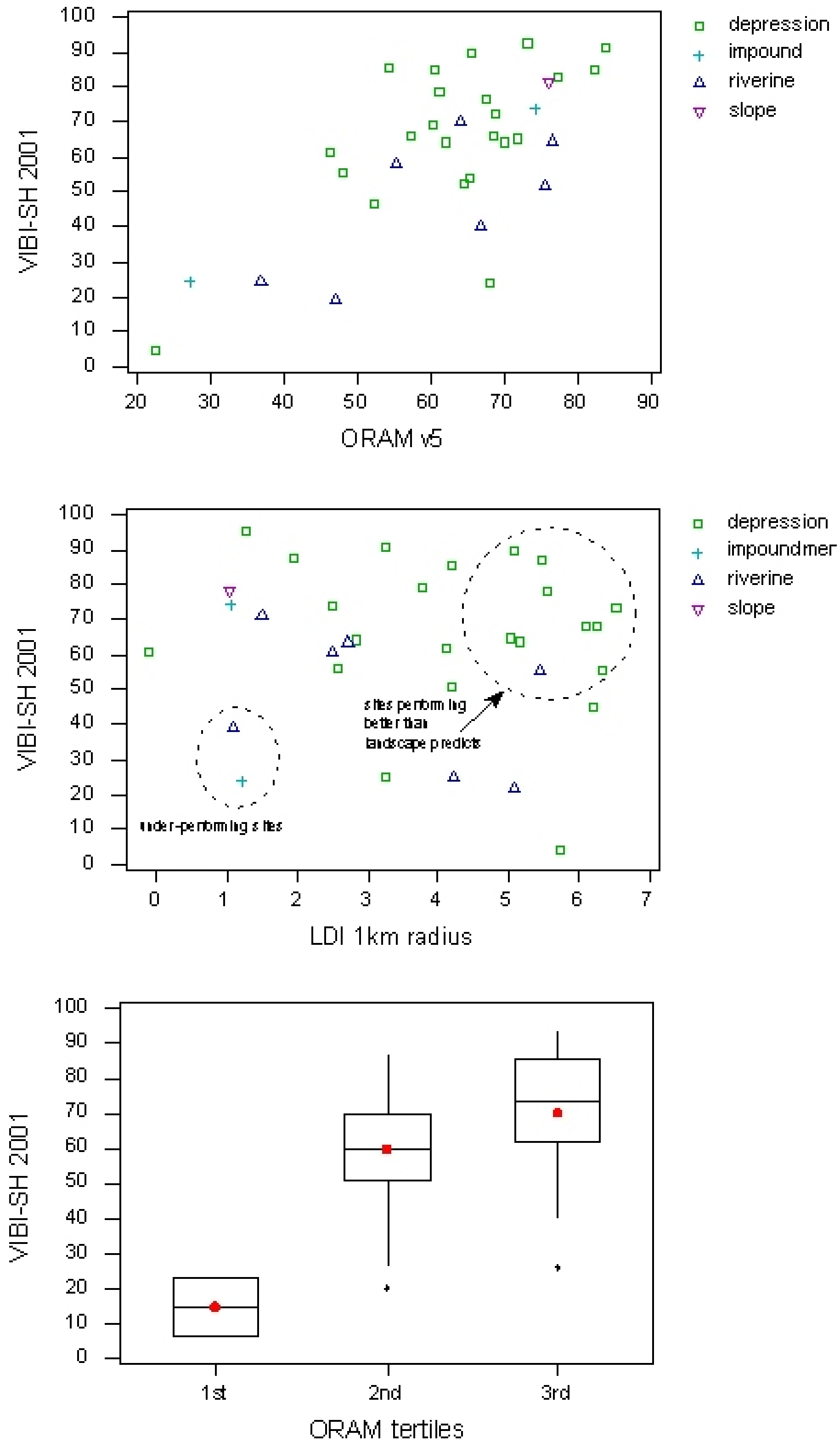


Figure 44. Summary plots of the VIBI-SHRUB 2001. Scatterplots are VIBI-SH 2001 scores versus ORAM v. 5.0 score (df = 32, F = 8.1, R^2 = 48.0%, $p < 0.001$) or LDI score (ns). Box and whisker plots represent ORAM score tertiles (thirds). 2nd and 3rd tertiles significantly different from 1st tertile ($p < 0.05$).

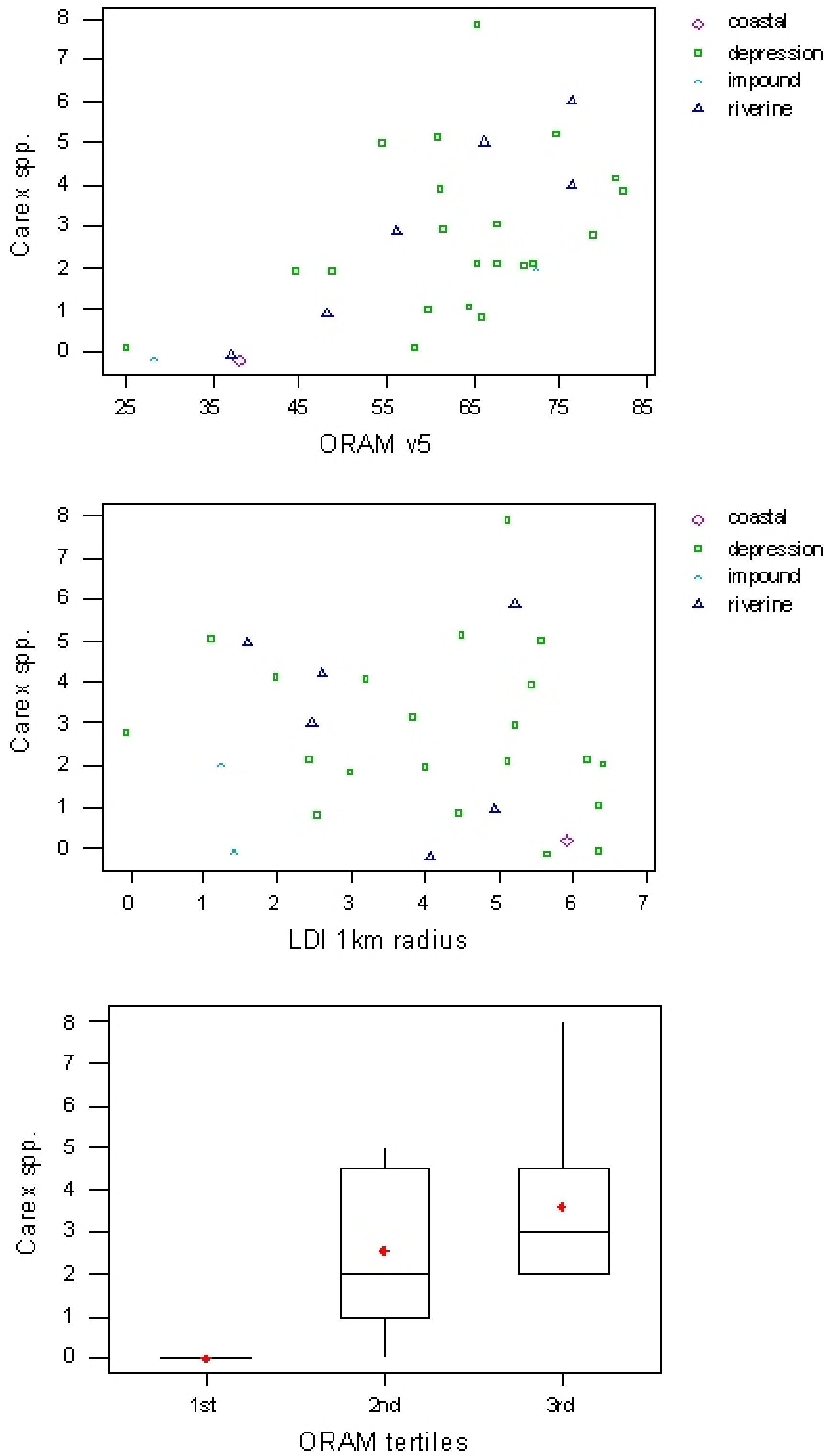


Figure 45. Summary plots of the *Carex* metric for the VIBI-SHRUB. Scatterplots are number of *Carex* species versus ORAM v. 5.0 score (df = 29 , F = 14.1, R^2 = 33.4%, p = 0.001) or LDI score (ns). Box and whisker plots represent *Carex* richness by ORAM tertiles (thirds). 2nd and 3rd tertiles different from first ($p < 0.05$). Note 1st ORAM tertile includes two sites with ORAM scores of 37.5 and 39 in order to have a 1st tertile group size of 4 for ANOVA results.

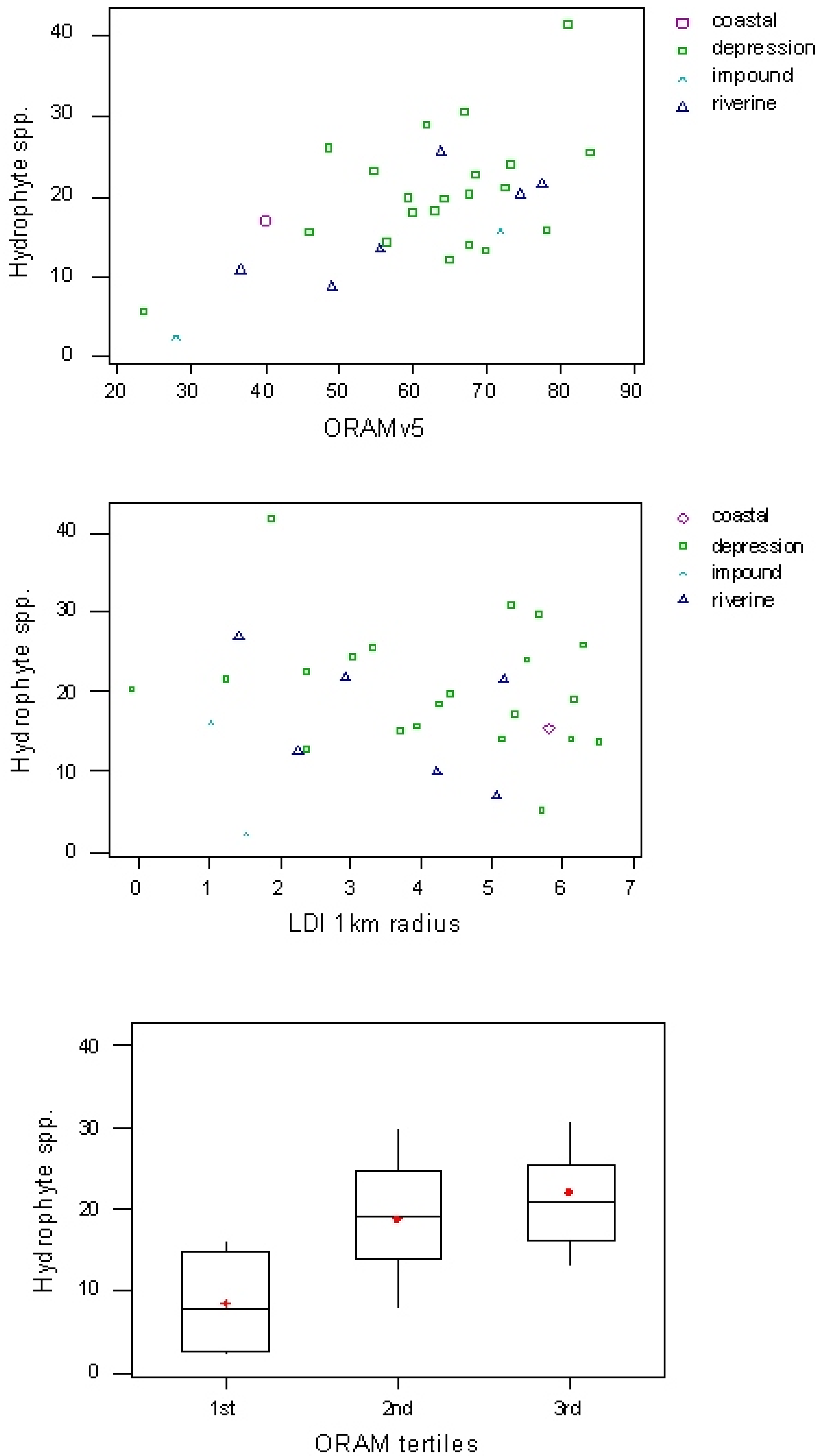


Figure 46. Summary plots of the hydrophyte metric for VIBI-SHRUB. Scatterplots are number of hydrophyte species (FACW, OBL) versus ORAM v. 5.0 score (df = 29, F = 16.8, R^2 = 37.5%, $p < 0.001$) or LDI score (ns). Box and whisker plots represent hydrophyte richness by ORAM tertiles (thirds). 2nd and 3rd tertiles significantly different from 1st tertile ($p < 0.05$). Note 1st ORAM tertile includes two sites with ORAM scores of 37.5 and 39 in order to have a group size of 4 for ANOVA results.

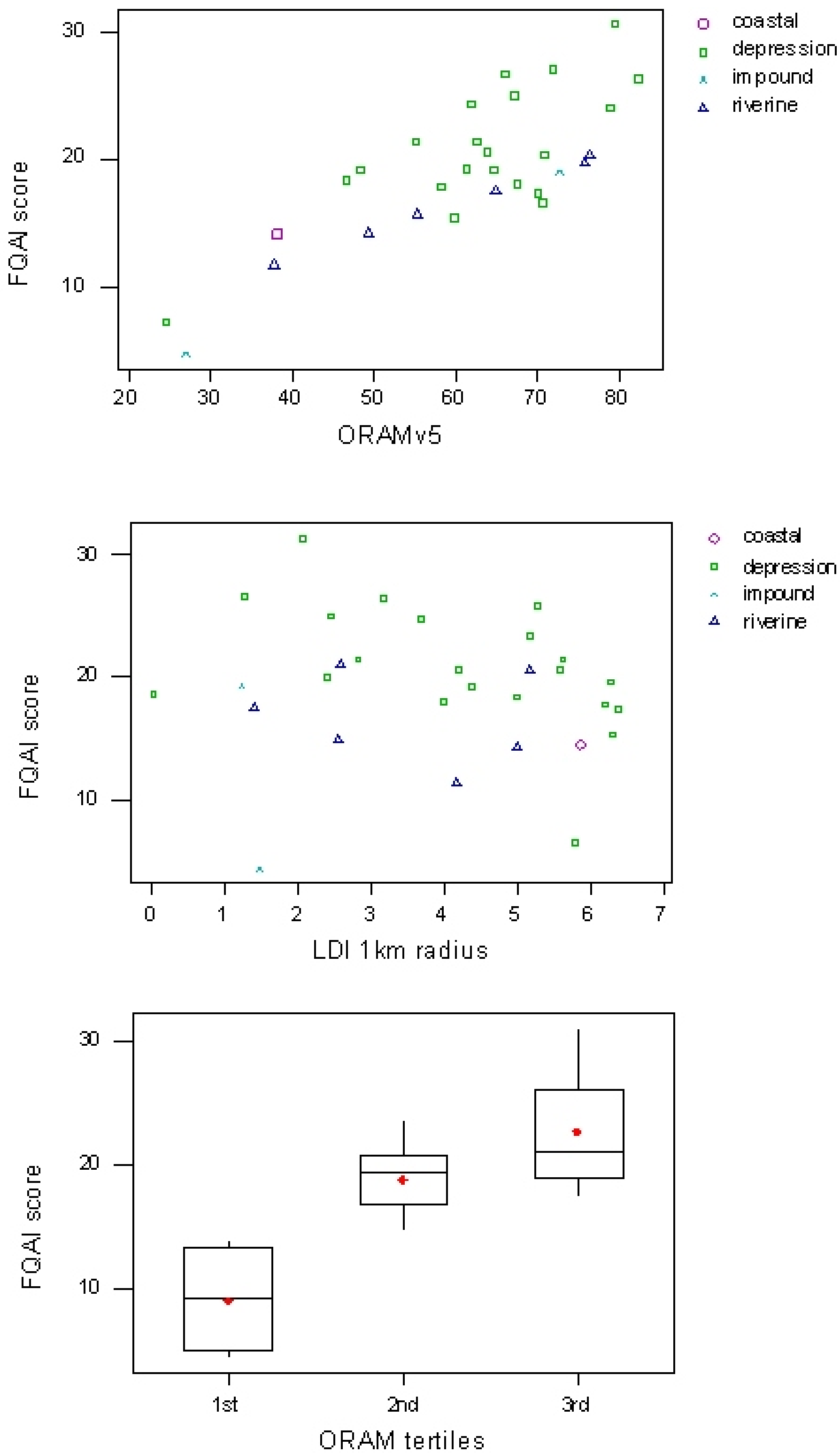


Figure 47. Summary plots of the FQAI metric for VIBI-SHRUB. Scatterplots are FQAI score calculated using Eqn. 7 and coefficients in Andreas et al. (2004) versus ORAM v. 5.0 score (df = 29, F = 59.6, R^2 = 68.0%, $p < 0.001$) or LDI score (ns). Box and whisker plots represent FQAI score by ORAM tertiles (thirds). All means are significantly different ($p < 0.05$). Note 1st ORAM tertile includes two sites with ORAM scores of 37.5 and 39 in order to have a group size of 4 for ANOVA results.

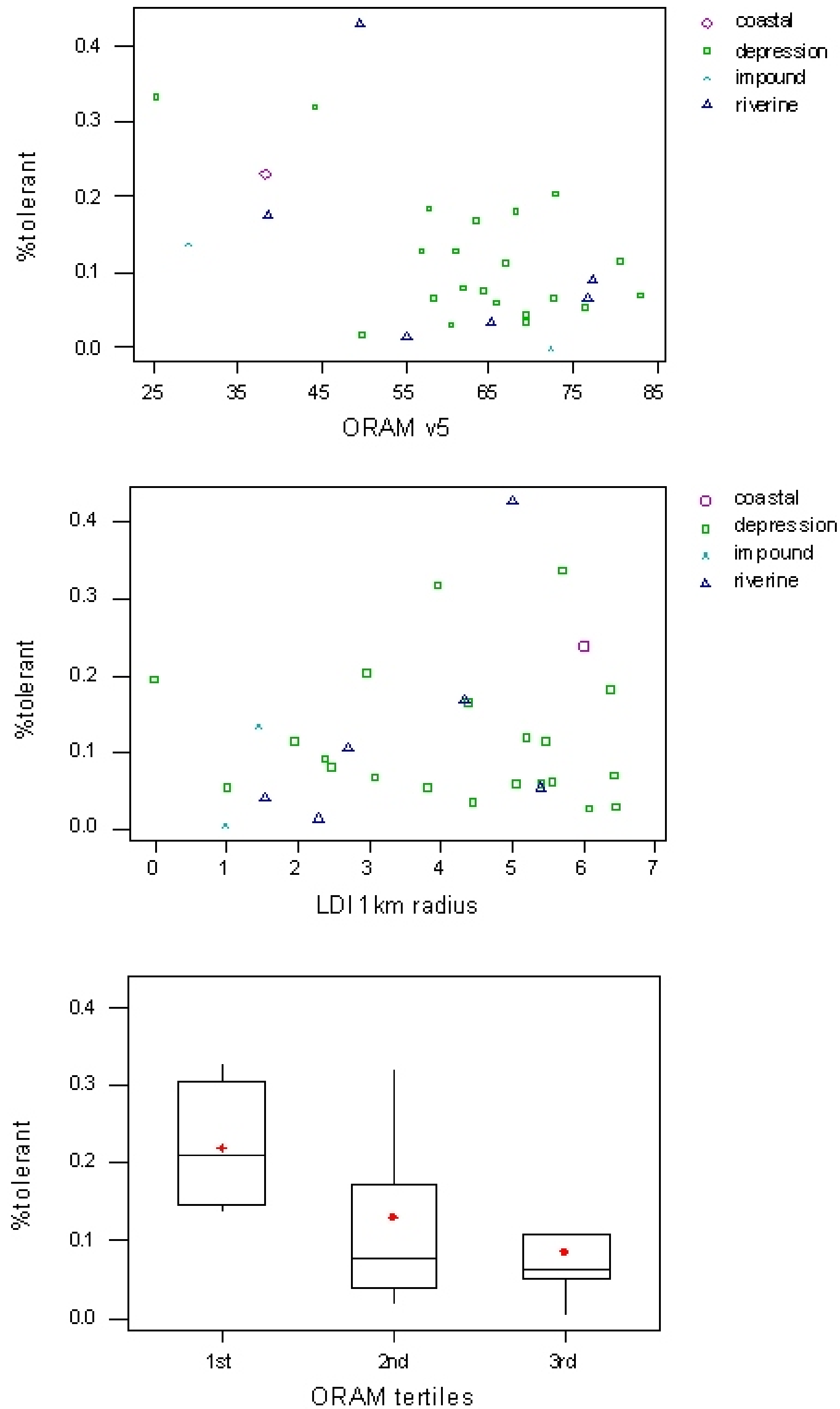


Figure 48. Summary plots of the %tolerant metric for VIBI-SHRUB. Scatterplots are relative cover of tolerant plant species (coefficients of conservatism = 1, 2, or 3) versus ORAM v. 5.0 score (df = 29, F = 12.2, R^2 = 30.3%, $p = 0.002$) or LDI score (ns). Box and whisker plots represent %tolerant species by ORAM tertiles (thirds). 3rd tertile significantly different from 1st ($p < 0.05$). Note 1st ORAM tertile includes two sites with ORAM scores of 37.5 and 39 in order to have a group size of 4 for ANOVA results.

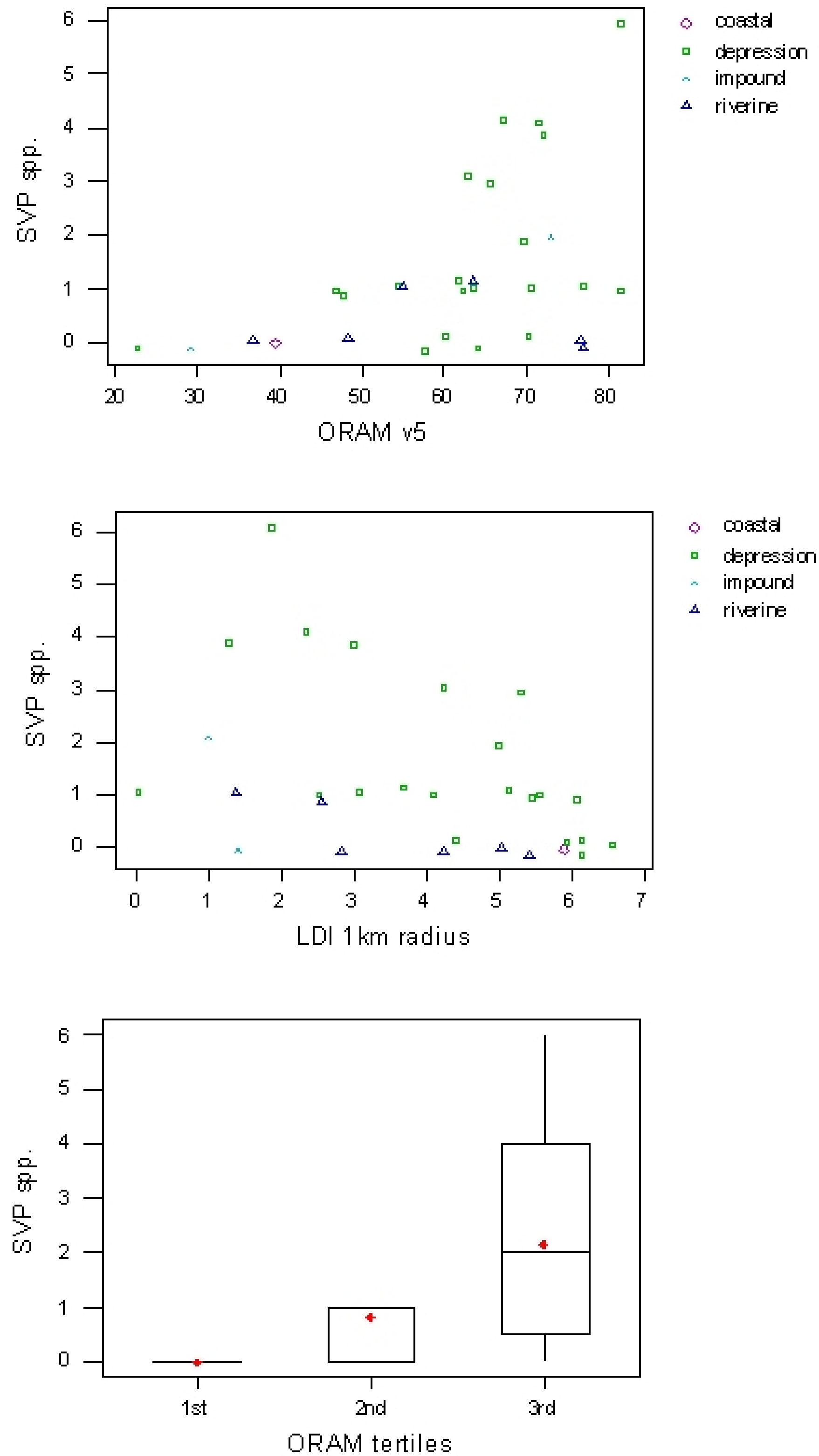
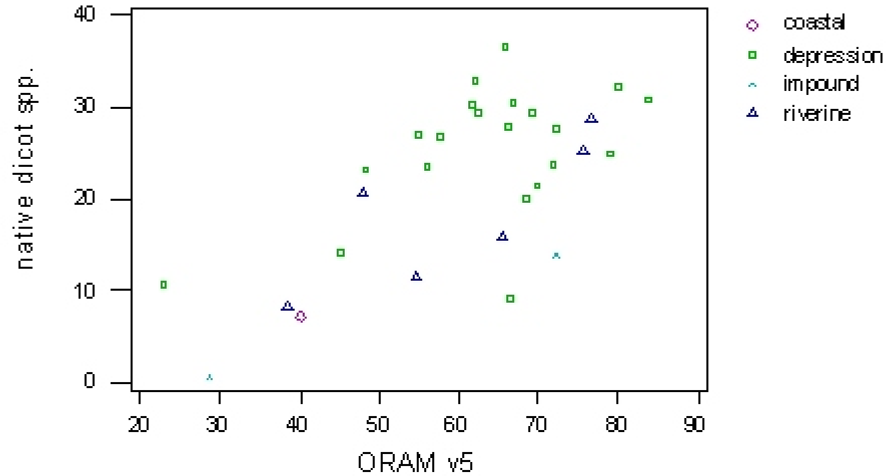
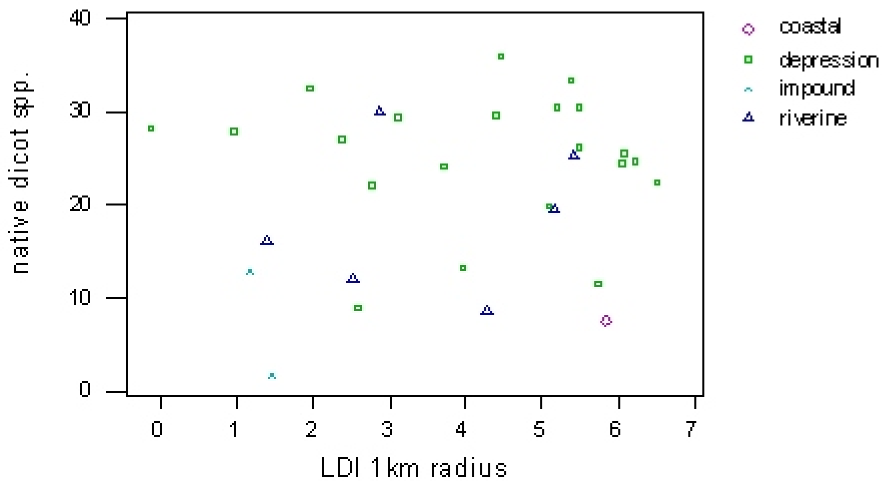


Figure 49. Summary plots of the SVP (seedless vascular plant) metric for VIBI-SHRUB. Scatterplots are number of SVP species versus ORAM v. 5.0 score (df = 29, F = 7.5, R^2 = 21.1%, p = 0.011) or LDI score (df = 29, F = 5.6, R^2 = 16.8%, p = 0.025). Box and whisker plots represent SVP species by ORAM tertiles (thirds). 3rd tertile significantly different from 1st ($p < 0.05$). Note 1st ORAM tertile includes two sites with ORAM scores of 37.5 and 39 in order to have a group size of 4 for ANOVA results.





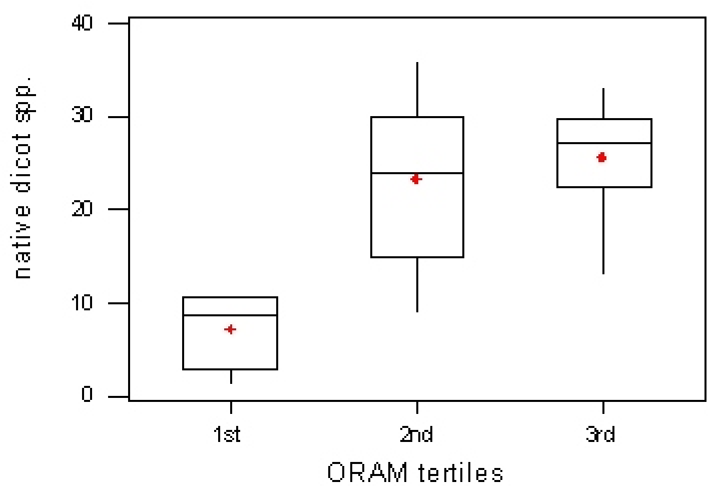


Figure 50. Summary plots of the dicot metric for VIBI-SHRUB. Scatterplots are number of native dicot species versus ORAM v. 5.0 score (df = 29, F = 20.2, R^2 = 41.9%, $p < 0.001$) or LDI score (ns). Box and whisker plots represent dicot species by ORAM tertiles (thirds). 1st tertile significantly different from 2nd and 3rd tertiles ($p < 0.05$). Note 1st ORAM tertile includes two sites with ORAM scores of 37.5 and 39 in order to have a group size of 4 for ANOVA results.

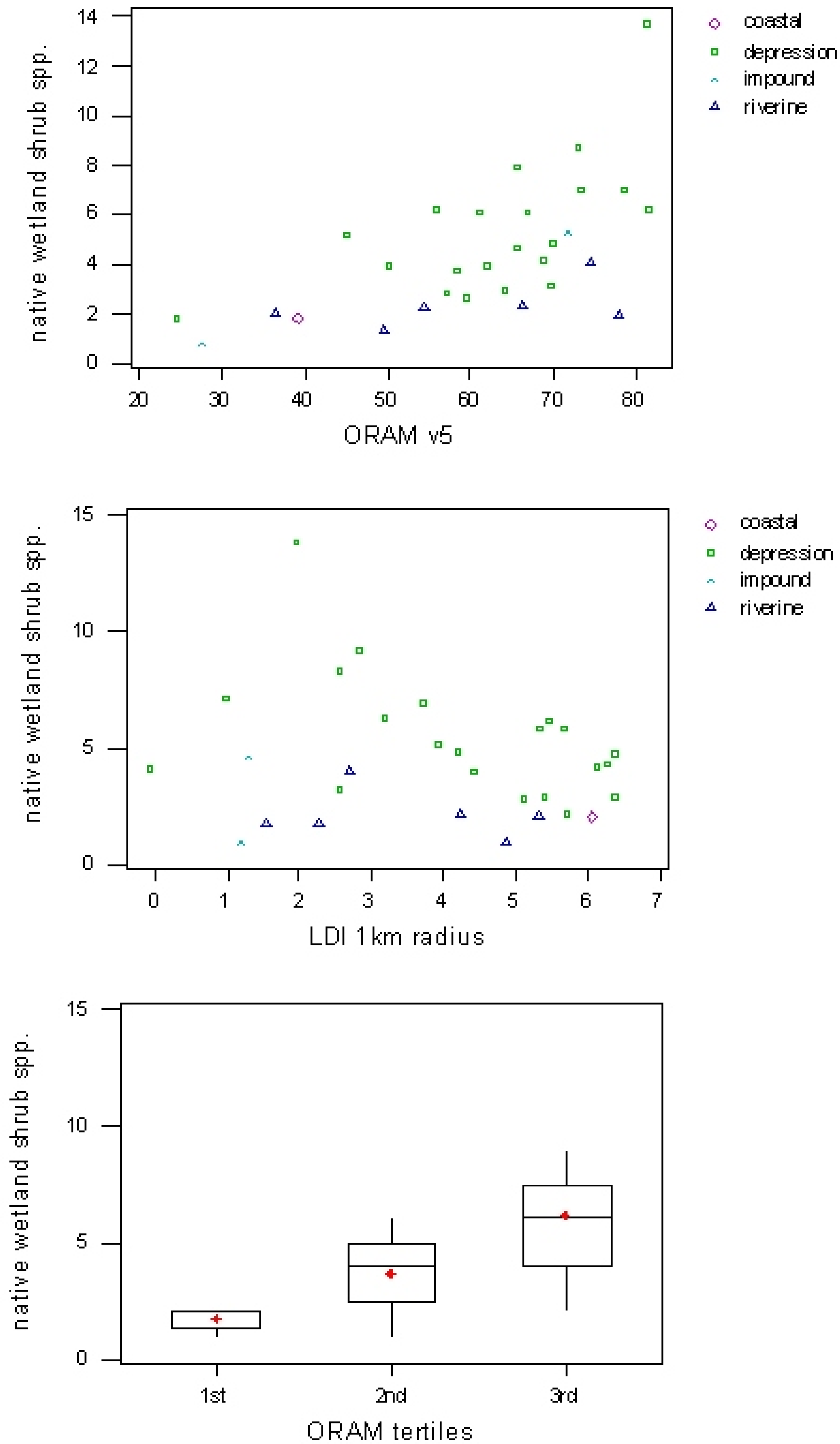


Figure 51. Summary plots of the shrub metric for VIBI-SHRUB. Scatterplots are number of native, wetland (FACW, OBL) shrub species versus ORAM v. 5.0 score (df = 29, F = 13.9, R^2 = 33.1%, p = 0.001) or LDI score (ns). Box and whisker plots represent shrub species by ORAM tertiles (thirds). 3^{rd} tertile are significantly different from1st and 2^{nd} ($p < 0.05$). Note 1^{st} ORAM tertile includes two sites with ORAM scores of 37.5 and 39 in order to have a group size of 4 for ANOVA results.

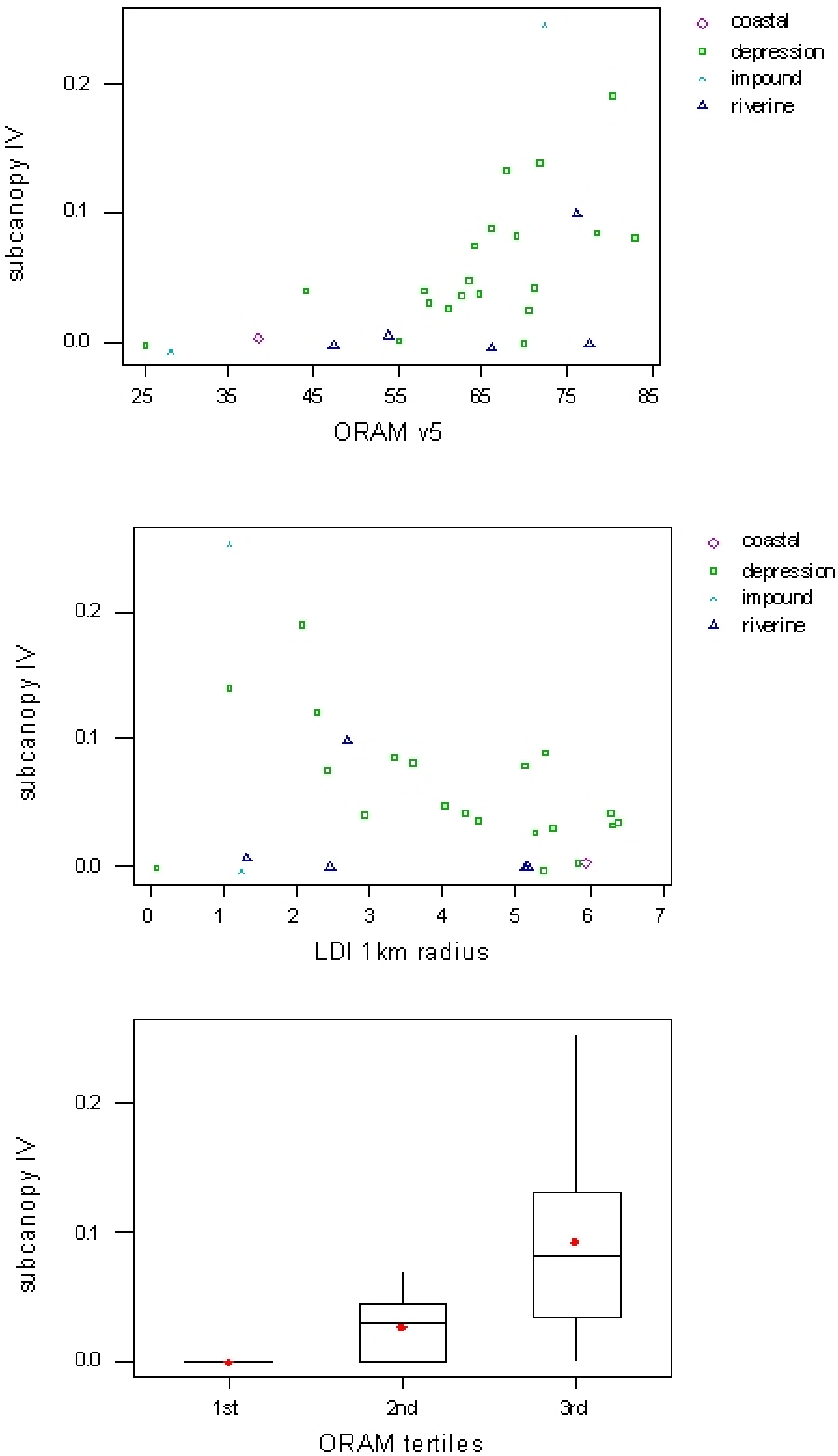


Figure 52. Summary plots of the subcanopy IV metric for VIBI-SHRUB. Scatterplots are average importance value of native, wetladn subcanopy woody species (small trees and shrubs) versus ORAM v. 5.0 score (df = 29, F = 10.6, R^2 = 29.0%, p = 0.003) or LDI score (df = 29, F = 4.6, R^2 = 15.1%, p = 0.041). Box and whisker plots represent relative cover of subcanopy IV by ORAM tertiles (thirds). 3rd tertile significantly different from 1st and 2nd ($p < 0.05$). Note 1st ORAM tertile includes two sites with ORAM scores of 37.5 and 39 in order to have a group size of 4 for ANOVA results.

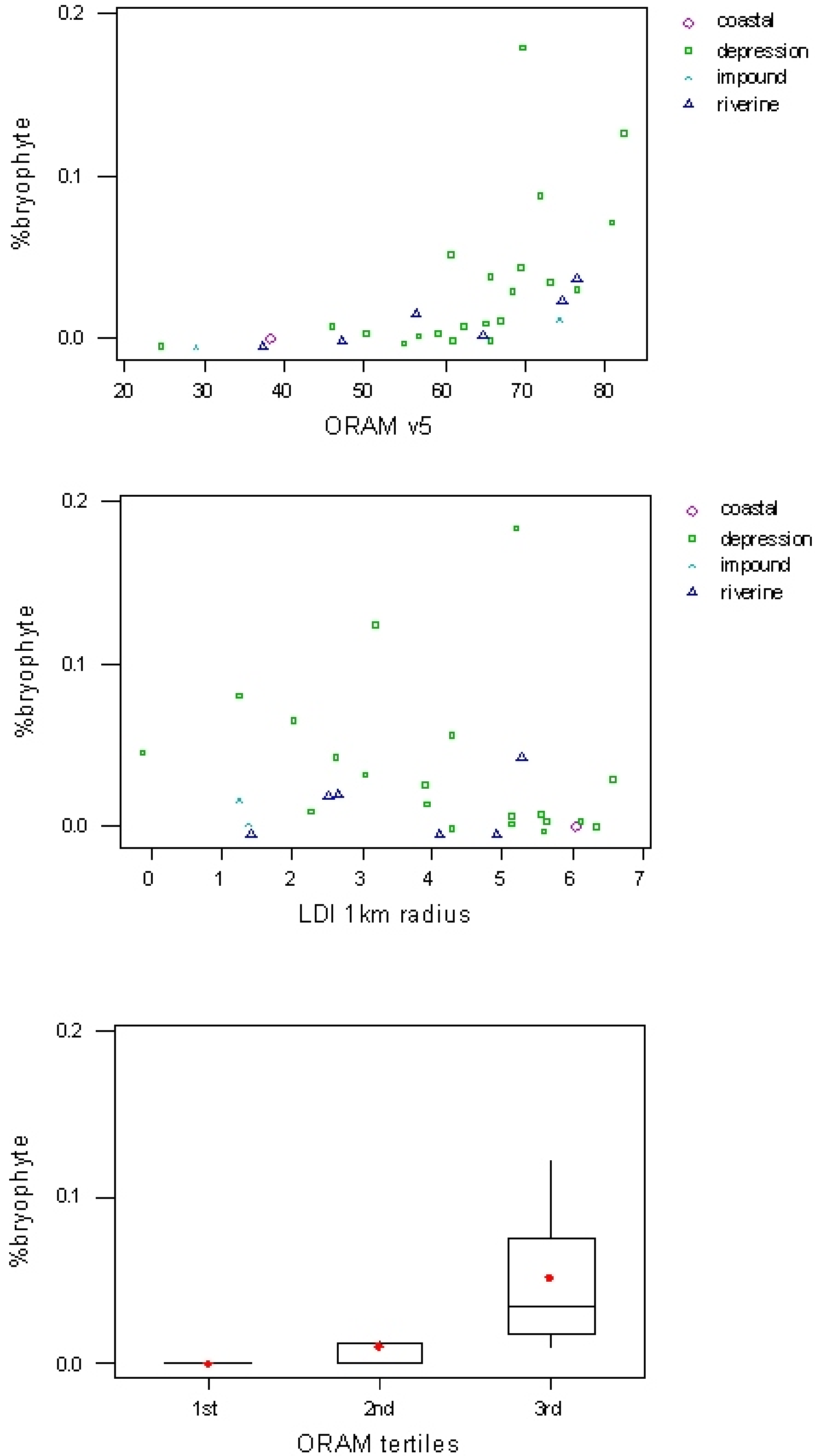


Figure 53. Summary plots of the %bryophyte metric for VIBI-SHRUB. Scatterplots are relative cover of byophytes (mosses and aquatic lichens *Riccia* and *Ricciocarpus*) versus ORAM v. 5.0 score (df = 29, F = 9.8, R^2 = 25.9%, p = 0.004) or LDI score (ns). Box and whisker plots represent %bryophyte cover by ORAM tertiles (thirds). 3rd tertile significantly different from 1st and 2nd ($p < 0.05$). Note 1st ORAM tertile includes two sites with ORAM scores of 37.5 and 39 in order to have a group size of 4 for ANOVA results.

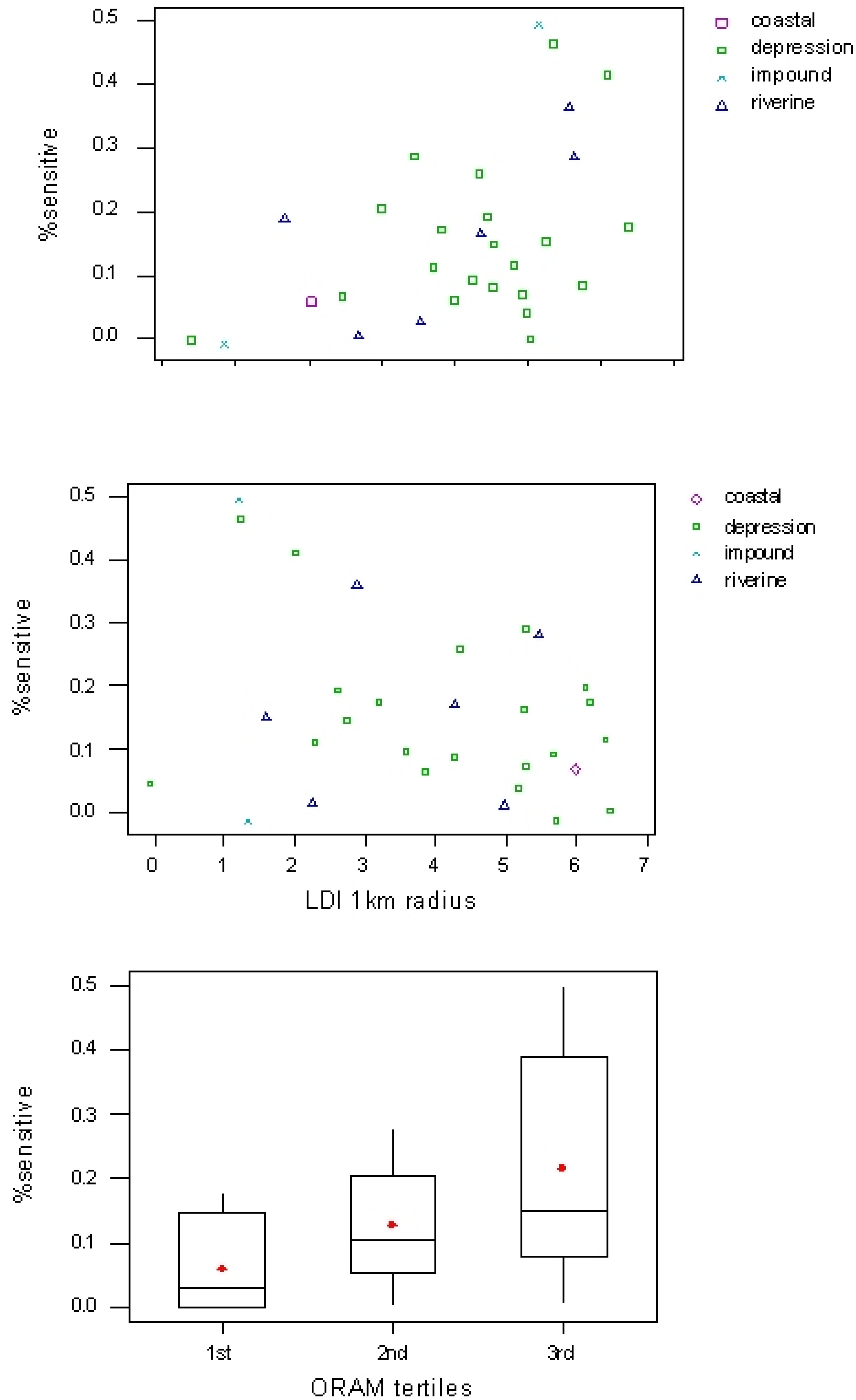


Figure 54. Summary plots of the %sensitive metric for VIBI-SHRUB. Scatterplots are relative cover of sensitive plant species (coefficients of conservatism = 6, 7, 8, 9 or 10) versus ORAM v. 5.0 score (df = 29, F = 9.5, R^2 = 25.3%, p = 0.005) or LDI score (df = 29, F = 3.5, R^2 = 11.1%, p = 0.072). Box and whisker plots represent %sensitive species by ORAM tertiles (thirds). ANOVA results marginally significant (df = 29, F = 2.8, p = 0.077). Note 1st ORAM tertile includes two sites with scores of ORAM 37.5 and 39 in order to have a group size of 4 for ANOVA results.

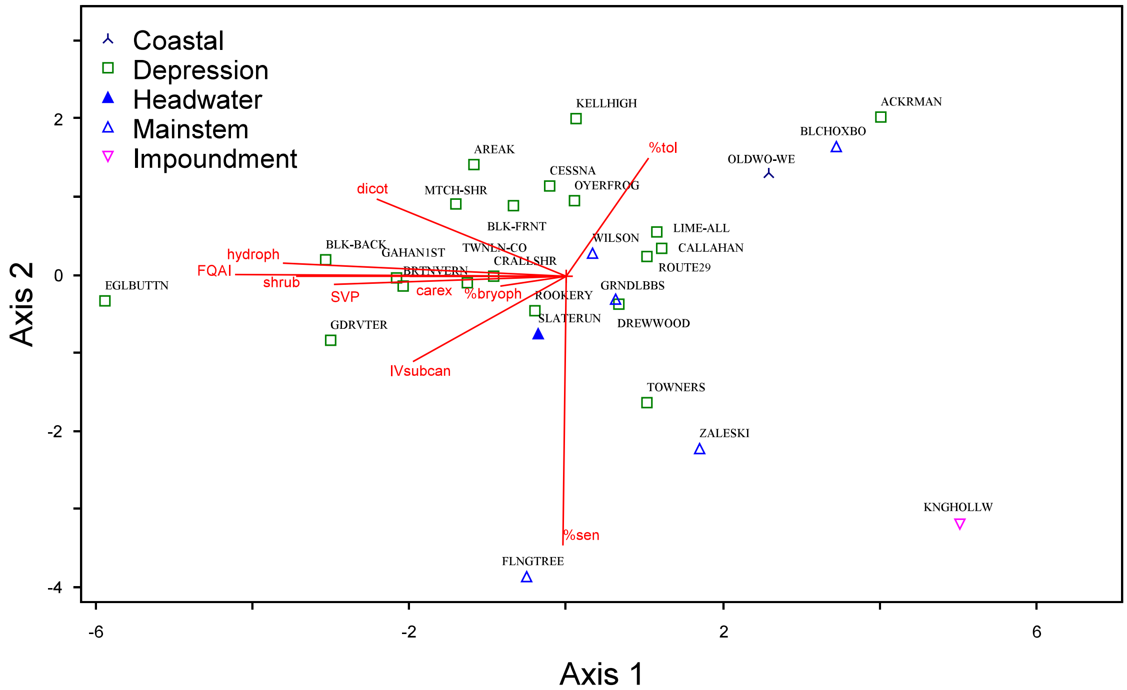


Figure 55. Principal components analysis of VIBI-SHRUB metrics. Percent variance explained by first three eigenvalues 44.6, 17.2, and 11.2, respectively. Headwater = riverine, headwater; mainstem = riverine, mainstem.. Bog and Fen shrub swamps excluded due to strong influence on ordination. Note effect of HGM class on metric performance with clustering of slope, depression, and riverine wetlands. Most disturbed shrub swamps towards upper and lower right areas of plot.

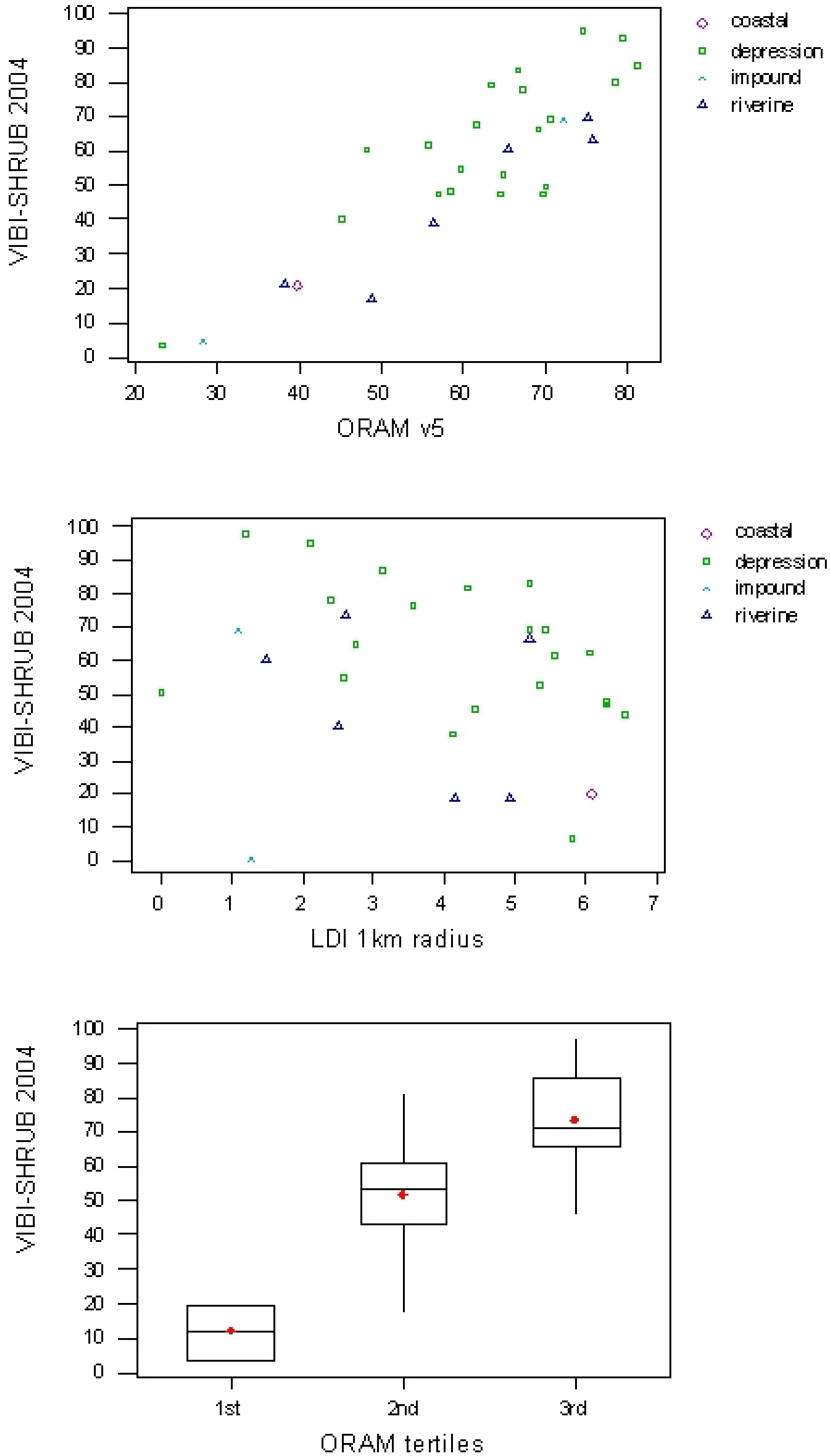


Figure 56. Summary plots of the VIBI-SHRUB 2004 (with refined or changed metrics discussed in text). Scatterplots are VIBI-SH 2004 scores versus ORAM v. 5.0 score (df = 29, F = 84.4, R^2 = 74.4%, $p < 0.001$) or LDI score (ns). Box and whisker plots represent ORAM score tertiles (thirds). All means are significantly different ($p < 0.05$). Note 1st ORAM tertile includes two sites with scores of ORAM 37.5 and 39 in order to have a group size of 4 for ANOVA results.

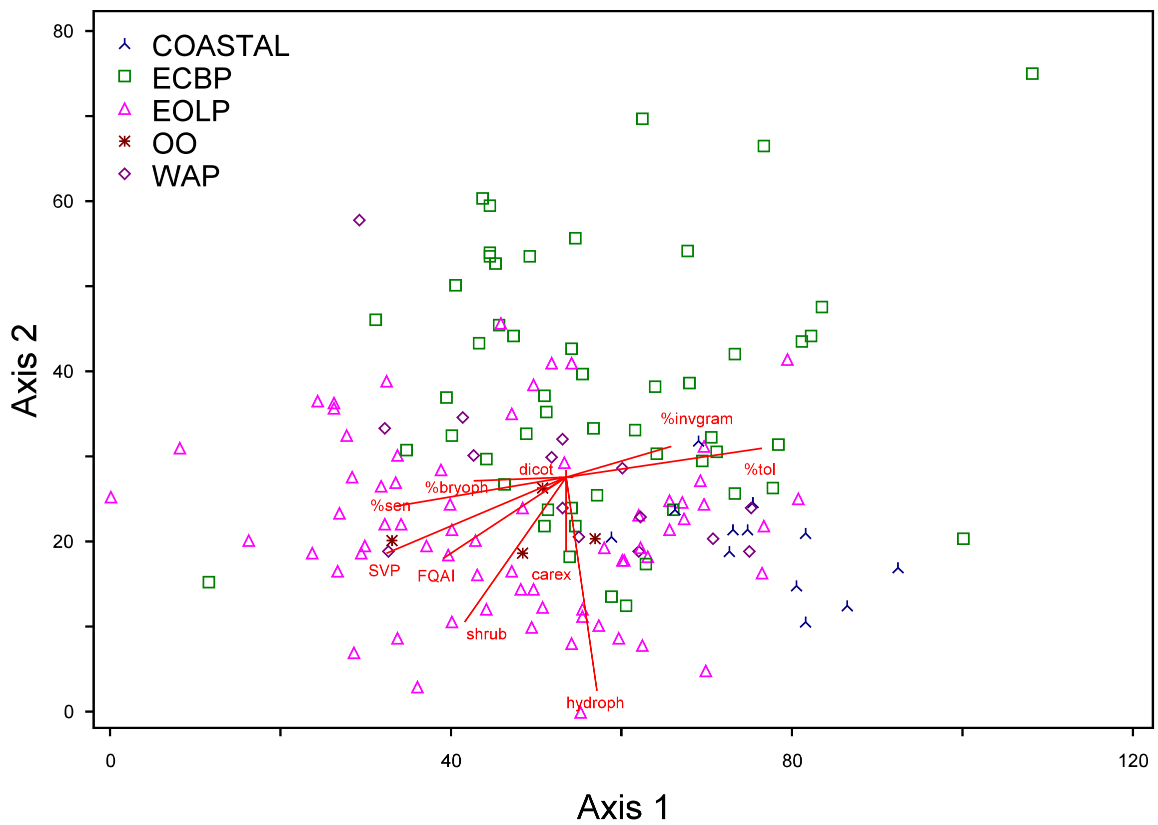


Figure 57. Detrended correspondence analysis of shared VIBI metrics for all sites excluding mitigation wetlands with ecological region of wetland location. COASTAL = Lake Erie coastal wetlands, ECBP = Eastern Corn Belt Plains, EOLP = Erie-Ontario Drift and Lake Plains, OO = Oak Openings subregion wetlands, WAP = Western Allegheny Plateau. Note general separation of ECBP wetlands from EOLP wetlands, although some better quality ECBP interspersed with EOLP wetlands. Also note, relatively distinct coastal wetland group. Four wetlands located in Michigan-Indiana Drift Plains (MIDP) included in ECBP.

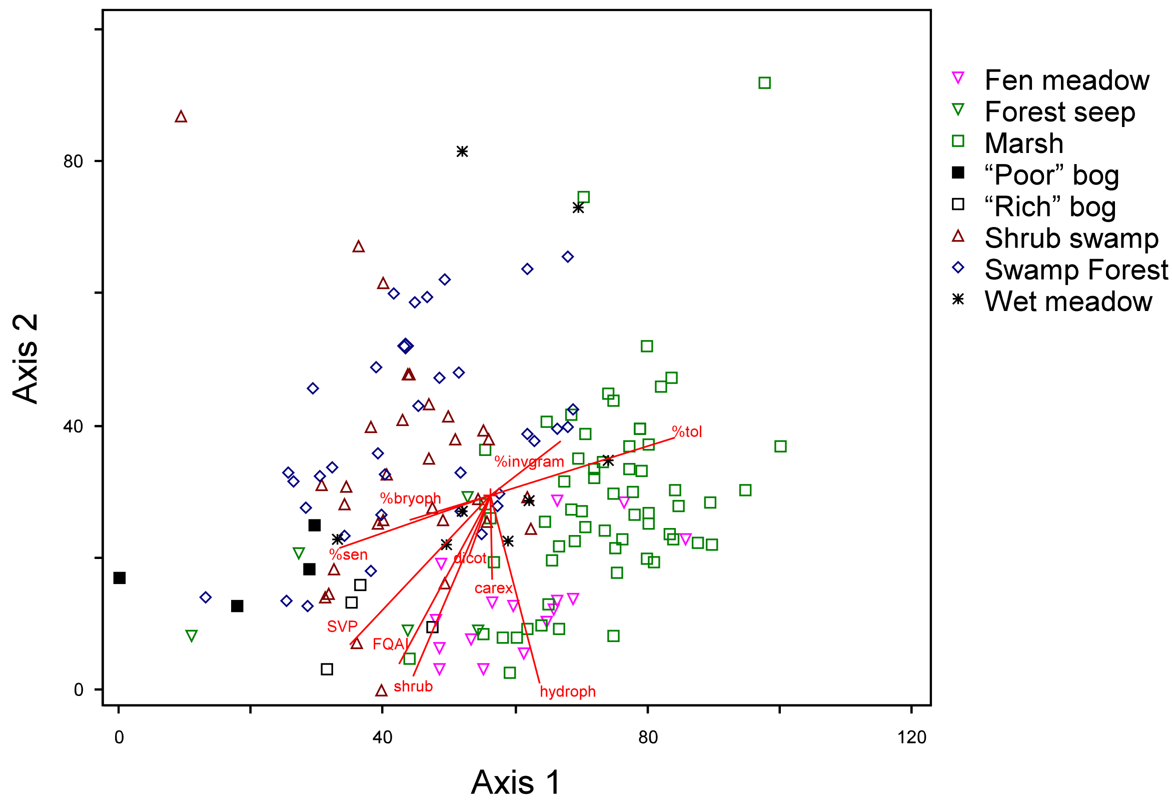


Figure 58. Detrended correspondence analysis of shared VIBI metrics for all sites excluding mitigation wetlands by dominant plant community. Fen meadow = all fens (slope wetlands with emegent sedge-grass communities), Forest seeps = slope wetlands with closed canopies of trees, Wet meadow = other grass/sedge dominated wetlands without significant ground water hydrologies (i.e. not slopes), Marsh = various mixed emergent marshes, Shrub swamp = shrub dominated wetlands that are not bogs or fens, and Swamp forest = wetlands with closed canopies of trees that are not bogs or fens.

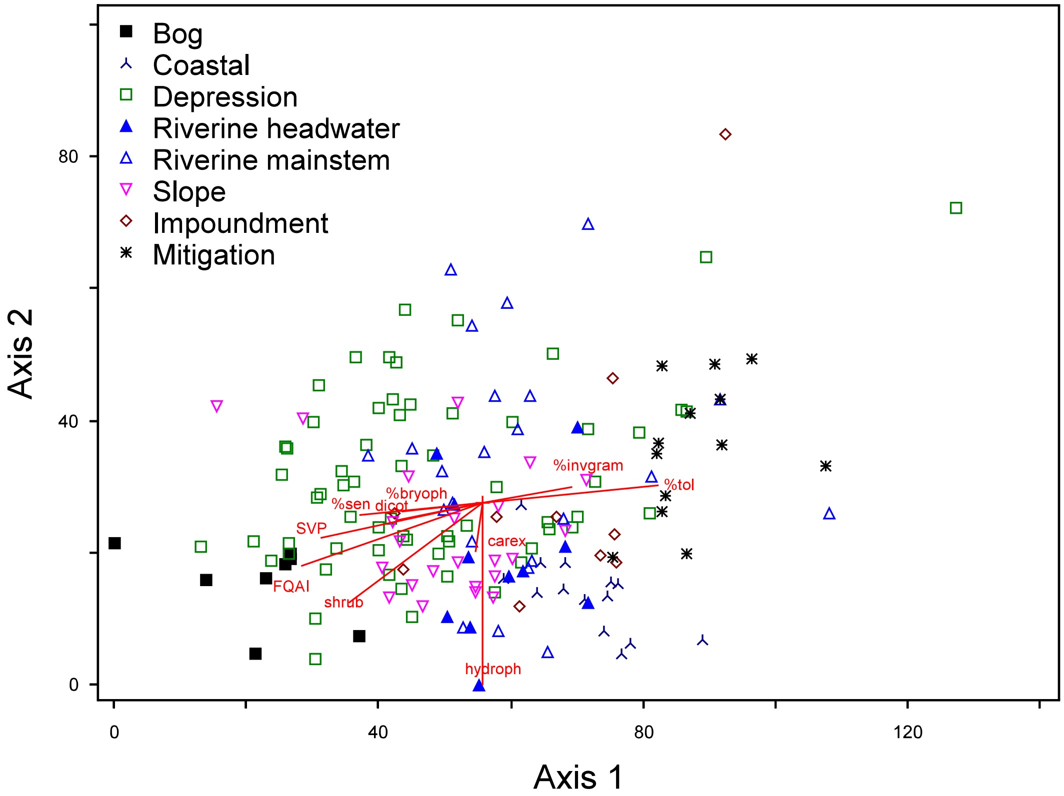


Figure 59. Detrended correspondence analysis of shared VIBI metrics for all sites by HGM class. Note differing metric performance due to HGM class from general grouping of bog, slope, coastal, depression, riverine, and mitigation classes.

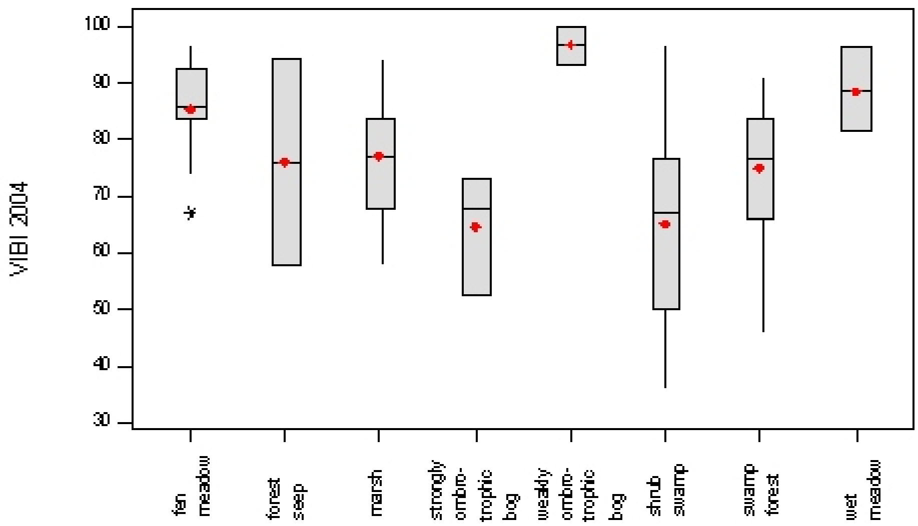


Figure 60. Box and whisker plots of VIBI 2004 score for reference standard wetlands only by plant community class (Mack 2004b). Box represents 25th and 75 percentile, bar is median, and circle is mean.

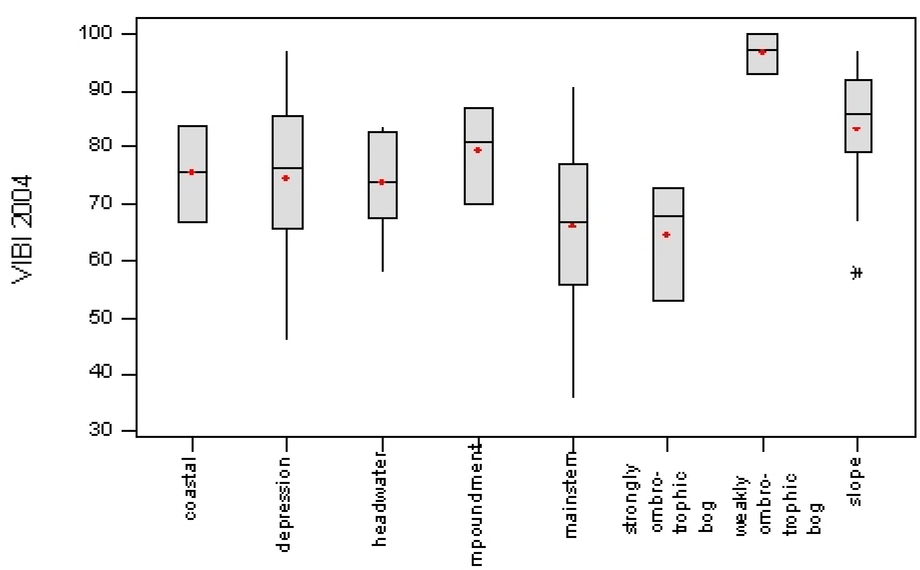


Figure 61. Box and whisker plots of VIBI 2004 score for reference standard wetlands only by HGM class (Mack 2004b). Box represents 25th and 75 percentile, bar is median, and circle is mean.

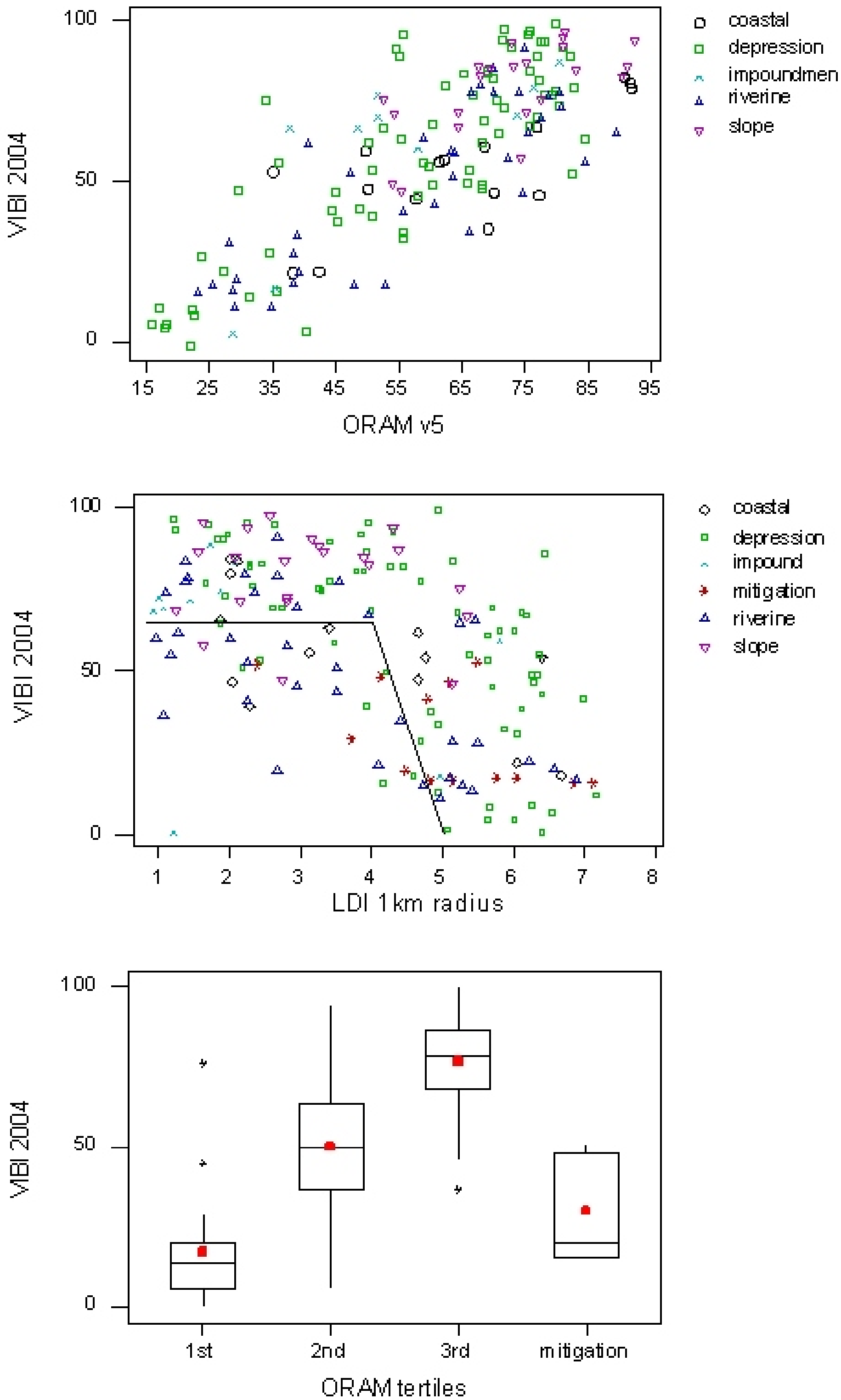


Figure 62. Summary plots of the VIBI2004 (with refined or changed metrics discussed in text). Scatterplots are VIBI 2004 scores versus ORAM v. 5.0 score (df = 154, F = 280,9, R^2 = 64.7%, $p < 0.001$) or LDI score (df = 167, F = 60.9, R^2 = 26.8%, $p < 0.001$). Relatively low correlation with land uses reflects threshold relationship of VIBI score and LDI score with wetland condition significantly declining where LDI score is greater than 4. Note sites that under- and over-perform from expected condition based on land uses because of on-site disturbances or buffers. Box and whisker plots represent ORAM score tertiles (thirds). All means are significantly different ($p < 0.05$) except 1st tertile and mitigation.