# CHAPTER 15: SELECTION OF REFERENCE CONDITIONS

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## INTRODUCTION

The use of reference conditions is a necessary part of any restoration monitoring program. Without the use of appropriate reference conditions for comparison, individuals assigned to monitor restoration sites cannot evaluate, analyze, and/or interpret the data collected from a restored area. This is due to coastal habitats being very dynamic places, subject to a variety of factors that can dramatically influence their structural and functional characteristics. Seasonal and annual differences in rainfall patterns, water levels, the frequency of storms, the introduction of invasive species, and changes in upstream land use, to name just a few, are all factors can directly impact coastal communities and the progress of restoration projects. These factors are often outside of the control of restoration practitioners and their effects may be misinterpreted as resulting from the restoration activity unless data from reference sites under similar influences are available for comparison.

### ESTABLISH PROJECT GOALS AND DETERMINE REFERENCE CONDITIONS

Selecting reference conditions should take place early in the planning stages of the restoration project, before any construction or intervention takes place. Once restoration project goals are established and appropriate reference conditions identified, construction documents can then be prepared and practitioners can begin project implementation. The method for selecting reference conditions will vary from one monitoring effort to the next depending upon project goals, level of accuracy desired, the number of potential sites available, and the level of funding allocated to monitoring. In addition, a statistician should be consulted early in the planning process to help practitioners balance statistical needs with logistical constraints and help insure that the appropriate type and amount of information is collected to accurately assess the progress of the restoration project.

### DISTINGUISHING BETWEEN 'REFERENCE SITE' AND 'REFERENCE CONDITION'

Before methods to select reference sites or conditions can be discussed, a few definitions need to be established. The terms, 'reference site' and 'reference condition' have been used in many different ways, depending on the literature practitioners have been using. In the habitat assessment literature, for example, the term 'reference site' typically refers to the least impacted examples of a specific habitat[2] within a particular area. In the restoration literature, however, 'reference site' refers to any area to which a restored site is being compared, regardless of the level of impact.

- Reference conditions refer to any historical, predicted, existing condition or site against which a restored area is compared
- A reference domain encompasses all existing sites of a particular habitat type within a defined region (Brinson and Rheinhardt 1996). The full range of impact levels from 'pristine'[3] to degraded is included (see Figure 1).

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[2] Habitat, as defined in Volume One, is the sum total of all the living and non-living factors that surround and potentially influence an organism; a particular organism's environment.

[3] The term pristine is often used in restoration literature with quotes as it is recognized that truly pristine conditions rarely, if ever, exist. Virtually all sites, to some degree have been impacted by human development and can therefore not be considered pristine in the true sense of the word. It is used, however, to relate that these sites are the best-of-the-best available.

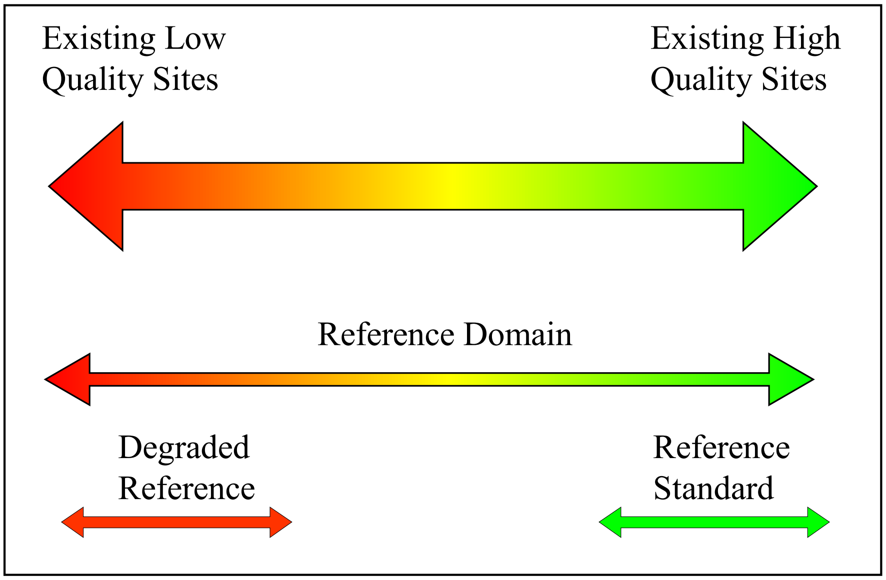


Figure 1. The relationship between different types of existing reference sites. Out of all the existing sites of high and low quality, the reference domain is a subset. The reference domain can be further subdivided into degraded reference sites or reference standards. What type of sites are used for restoration monitoring will depend upon such factors as project goals, available funds, and the availability of different types of sites to name a few. Graphic by David Merkey, NOAA GLERL.

- Reference standards represent all existing sites that are of the highest quality under current conditions. The structural and functional characteristics of reference standards may be used to set goals for restoration projects (Brinson 1993a).
- Degraded reference sites are areas that have undergone similar types and levels of human impact as areas to be restored but are left in an unrestored condition. They are similar to controls used in laboratory experiments.

Reference conditions for use in restoration monitoring projects can be derived from historical information about the site to be restored, existing sites with similar structural characteristics, and predicted conditions based on computer models. Regardless of the type, location, or number of reference sites or conditions the practitioner selects, emphasis must be placed on the similarity of structural characteristics. Structural characteristics are those that define the physical, chemical, and biological composition of a habitat. Without the similarity of primary structural characteristics such as geomorphology, sediment grain size, hydroperiod, and salinity between restored and reference areas, comparison of functional characteristics such as presence and abundance of specific groups of organisms or nutrient cycling dynamics is inappropriate. A complete listing of the primary structural and functional characteristics of marine and freshwater coastal habitats of the United States is provided in Appendix II of *Science-Based Restoration Monitoring of Coastal Habitats, Volume One: A Framework for Monitoring Plans Under the Estuaries and Clean Waters Act of 2000 (Public Law 160-457)*. The importance of these characteristics to restoration monitoring is described for each habitat in *Volume Two: Tools for Monitoring Coastal Habitats*. These lists and descriptions can aid practitioners in determining which site characteristics to use when selecting reference conditions for a restoration project.

This chapter does not present a step-by-step method for selecting reference conditions for a particular restoration project. There is no universal formula to do that. Instead, the strengths, weaknesses, and effectiveness of different approaches to selecting reference conditions and examples of how each has been used in research and restoration efforts are described. Practitioners should be able to build upon this information and, with the help of a statistician and knowledge of the similar coastal habitats as those being restored, select the appropriate type and number of reference conditions for their particular project.

## HISTORICAL REFERENCE CONDITIONS

Historical conditions depicted in aerial photos, previous studies, historical accounts such as land surveys, nautical charts, newspaper accounts, or diaries can be useful in making the case for restoration projects (Figure 2). These resources may, however, not be of sufficient detail to set specific restoration targets or success criteria. For example, an aerial photo may show that a marsh once existed in a particular spot but offer little or no information about its hydrodynamic characteristics, substrate elevations, and/or soil chemistry. Without knowing this level of detail about a site, one cannot determine what plant species are appropriate to plant, what density or species of animals should be able to use the marsh, or what water chemistry processes may have occurred. Even in cases where detailed historical data are available, the site may be so altered or degraded that it cannot be restored to some previous condition. The use of historical conditions as reference conditions under these circumstances would not be effective. Therefore, the use of existing reference sites to help set project goals and compare the development of the restoration over time is almost essential.

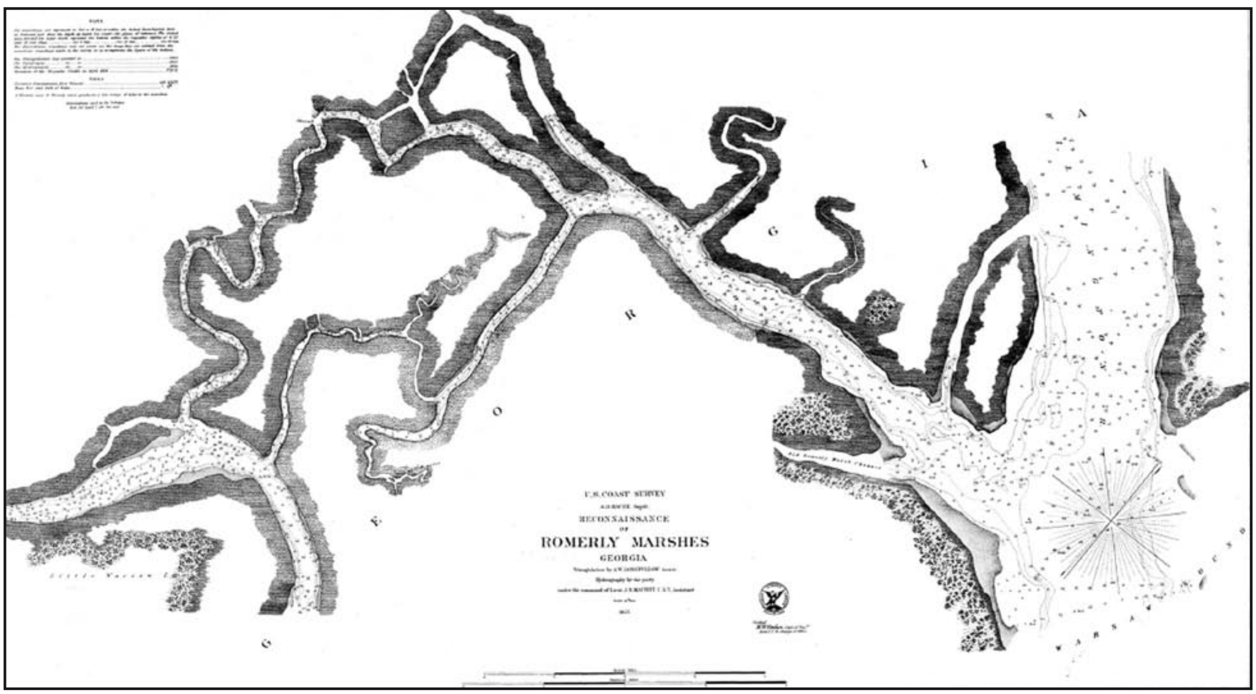


Figure 2. A historical chart of Romerly Marshes in Georgia, circa 1855. Historical documents such as this allow practitioners to begin planning restoration projects by identifying areas were marshes previously occurred. Chart from the NOAA Historical Map and Chart Project Library.

## EXISTING REFERENCE SITES

Although historical reference conditions are often used to justify restoration projects, only data collected at the restoration site before and after the project is implemented can be used to demonstrate the effects of a restoration project. Differences in gear required to sample habitats and differences in sampling effort before and after implementation of the restoration project may, however, occasionally make comparison of pre- and post-implementation data difficult (Able et al. 2000). Data should therefore be collected simultaneously from the restored site and one or more reference sites (standard or degraded) whenever possible. Only through the comparison of the restoration site to other existing sites can practitioners document which changes are caused by restoration activities and which are perhaps attributable to natural variability; variability that may be due to broader regional influences or other confounding variables[4]. Confounding variables may include natural, seasonal and annual differences in climate and hydroperiod, changes in water sources, and variability in organism populations, phenomena that are larger than site-scale and often beyond the control of a restoration practitioner. Large scale phenomena such as regional weather patterns and changes in river discharge, for example, have been shown to have tremendous effects on the presence, absence, and community composition of submerged aquatic vegetation (SAV) communities (Carter et al. 1994). Without the use of existing reference sites to compare to the restored site, changes in habitat characteristics caused by these larger-than-site-scale factors could be misinterpreted as resulting from restoration activities.

### REFERENCE DOMAIN

The most important factors in selecting reference conditions for a restoration monitoring effort are to ensure that the sites in question are of similar ecological setting and have similar site-level structural characteristics. Depending on the particular goals of the restoration project, ecological settings can be derived through the use of ecoregions or watersheds. Ecoregions are defined as areas within which biotic, abiotic, terrestrial, and aquatic capacities and potentials are similar (Brinson 1993b; McMahon et al. 2001). Among others, Bailey (1983), Omernik (1995), and the Commission for Environmental Cooperation (1997) have presented ecosystem classifications for the United States that can be used for managing natural resources. The North America ecoregions delineated by the Commission for Ecological Cooperation (1997) are shown in Figure 3.

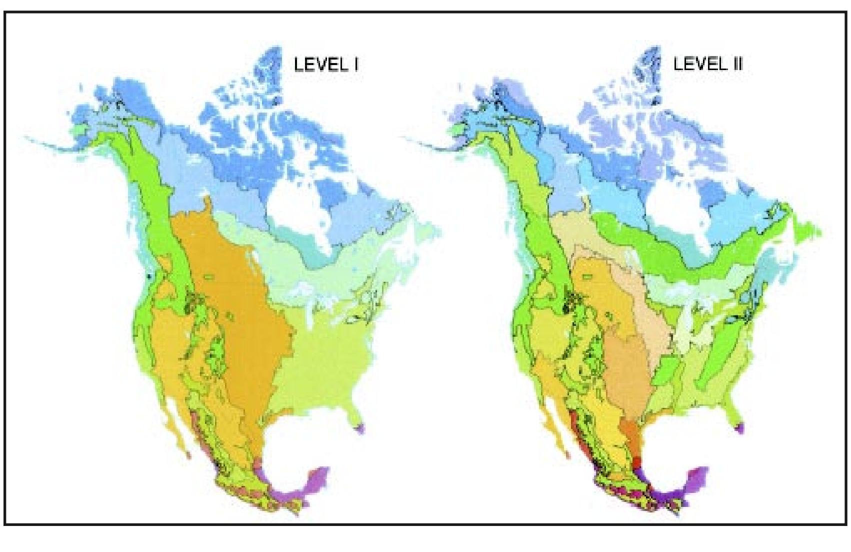


Figure 3. Level I and Level II ecoregions for North America. Taken from Commission for Environmental Cooperation 1997.

[4] Confounding variables are natural phenomena beyond the control of the restoration practitioner that can affect the outcome of the project but are often unseen or unobserved.

One limitation of these regional classifications is that the scale can be quite large for restoration monitoring purposes. Other authors have noted that smaller, state-level ecosystem classifications (e.g., Albert 1995) can be useful in differentiating plant communities in coastal habitats (Minc 1998; Minc and Albert 1998). Albert's (1995) ecosystem classification of Minnesota, Wisconsin, and Michigan is a hierarchical system similar to the ones described by Bailey (1983), Omernik (1995), and McMahon et al. (2001). This similarity occurs at the largest scale (based on climate and geology) but then delineates smaller units based on physiography, soils, and vegetation patterns (Figure 4). Many other states also have finer-scale ecoregion classification systems that practitioners can use to narrow down the search for appropriate reference conditions. Selecting sites within the same watershed or a nearby watershed with similar characteristics such as slope, soil texture, and land cover is another method of ensuring that large-scale external forces influencing reference and restored sites are similar. Once the ecological setting of restored and reference sites has been established, comparison of structural characteristics can be used to further reduce the number of potential reference sites.

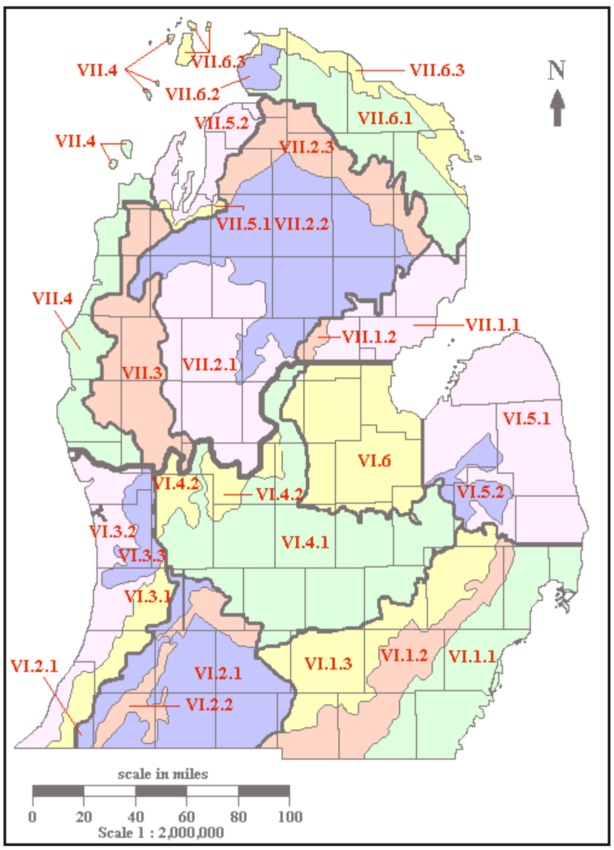


Figure 4. Albert (1995) has devised a classification of regional ecosystems for Michigan (Lower peninsula shown), Wisconsin, and Minnesota. Differences in dominant vegetation of coastal habitats are present between the smallest ecoregions. These smaller scale ecoregions are also used by state resource management agencies for maintaining habitat diversity within the state of Michigan. Taken from Albert 1995.

## Adjacent Sites

The similarity of two sites decreases with increasing distance between them (Tobler 1970). Thus many restoration projects have used adjacent areas for comparison to restored sites (Havens et al. 1995; Dawe et al. 2000; Stolt et al. 2000; Tupper and Able 2000; Tanner et al. 2002). Sites that are close to one another also have the advantage of convenience when it comes to fieldwork and data collection. For example, if migratory bird usage is a monitored parameter, there may only be a short period of time when the birds will be present in the restored and reference marshes. Having the marshes in close proximity facilitates completion of sampling within this short time period. If adjacent areas are used as reference sites they should be totally independent of the restored area so that restoration-related activities do not affect their characteristics as well.

Simply using adjacent sites for reference, however, is often not enough. While it is true that adjacent sites should have large-scale influences in common, site-scale structural parameters such as topographic diversity, sediment grain size, salinity levels, water temperature, and wind and wave energy may not be similar. Sites with different structural characteristics are less likely to have similar functional capabilities and should therefore not be used for comparison in restoration monitoring (Brinson 1993a). For example, Havens et al. (1995) compared a created marsh with two other adjacent natural marshes. By using adjacent marshes as references, structural variables such as climate, tidal regime, and access by marine animals were assumed to be similar across all three marshes. While dissolved oxygen concentration and temperature were similar between the three marshes, structural differences in freshwater inputs, substrate topography, surrounding habitats, salinity, soil organic carbon, and vegetation density led to significant differences in marsh functions as measured by zooplankton abundance, and fish, crab, and bird utilization. Thus even though the marshes were in close proximity, differences in structural characteristics lead to differences in functions between the restored and reference marshes.

### Multiple Sites

This is not to say that restored and reference sites need to be identical in all biological, geological, and physical aspects. In fact, finding even one or two reference sites with the exact same characteristics as a site being restored is not possible (Hurlbert 1984). The use of a reference domain can help address this problem by describing the range of conditions and natural variability typical of the habitat being restored. The use of multiple sites in the reference domain or reference standard (see below) also allows a 'bound of expectation' to be developed (Weinstein et al. 2000; Weinstein et al. 2001). For example, the goal of a particular restoration effort may be to reintroduce SAV with growth rates comparable to other non-impacted sites in the area (i.e., reference standard sites). Turbidity affects the ability of SAV to grow by altering the amount of light available to plants. An assessment of other SAV beds in the general area may find several that have many structural characteristics in common with the restored area but with higher or lower turbidity levels and corresponding lower or higher levels of SAV growth. This range of conditions could then be used to set up a range of expectations for the restored area. As long as turbidity levels and SAV growth rates are within the range exhibited by the reference standards, the restoration effort could be considered successful. If not, then corrective action can be identified and implemented in an attempt to increase growth rates to the level characteristic of sites in the reference standard.

The selection of a reference domain does not have to be a time consuming and expensive process. Many automated techniques are now available using powerful statistical procedures (Morgan and Short 2002) and geographic information systems (GIS) (Russell et al. 1997; Palik et al. 2000; Wiley et al. 2000) to make selection of potential reference sites more efficient. For example, statistical techniques such as principle components analysis (PCA) or cluster analysis can be used to identify groups of sites. This helps maximize the structural similarity among sites for comparison. Morgan and Short (2002) compared several constructed salt marshes to a large pool of potential reference sites. They used PCA techniques to identify areas that had structural characteristics most similar to the constructed sites and then selected their reference conditions from this smaller number of areas. By using this technique, they were able to minimize the amount of variability among restored and reference sites by comparing only those sites that had the greatest amount of structural similarities. Information about a particular site to be restored can also be entered into a GIS that can then be queried to identify areas with similar attributes to identify reference sites (Russell et al. 1997; Palik et al. 2000; Wiley et al. 2000). The use of these or similar techniques, however, requires access to a sufficiently large, existing database of information on coastal habitats. Research institutions and universities along with federal, state, Tribal, and local units of government assigned to manage coastal resources may be good sources of this information.

## REFERENCE STANDARDS

Once a reference domain has been established, reference standards can be selected from it. Reference standards represent the highest quality sites within a reference domain. Once reference standards are identified, their structural and functional characteristics can be used to set a range of acceptable goals for a restoration project. Establishing which specific sites are of the highest quality, however, requires that all of the sites in the reference domain be assessed. Although highly valuable, this can be a costly and time-consuming process and most restoration-monitoring programs are too financially constrained to sample multiple areas. To address this issue, resource managers and scientists have recently started to organize coast-wide data sharing around standardized monitoring protocols (Neckles et al. 2002; Steyer et al. 2003). Sharing information across a variety of sites in an area allows practitioners to incorporate a range of conditions in restoration project planning and goal setting. Thus restoration practitioners can utilize existing information to select an acceptable range of site characteristics without the expense of additional sampling and have access to a suite of reference sites that encompass a range of ecological conditions. Data sharing arrangements of this type have only recently been introduced. Until they are fully functional, restoration practitioners may rely on previous monitoring and assessment efforts conducted by private consultants, universities, non-governmental agencies such as watershed councils, and/or local, state, federal, Tribal, and regional resource management agencies. Each of these parties should have considerable experience in coastal habitats in their region and should be able to help select high quality sites for use as reference standards.

The standardized protocols and data sharing efforts now being planned on coastal and regional scales may also provide restoration practitioners with a readily available list of parameters and monitoring techniques that may be adapted to their own purposes. This data sharing process ensures the comparability of data from one restoration monitoring effort to the next. The National Oceanic and Atmospheric Administration (NOAA) has developed a database of coastal monitoring programs for the entire United States and its protectorates. This searchable web-based database is designed to help restoration practitioners identify and locate other monitoring efforts in their area to facilitate cooperation and collaboration between monitoring efforts. Links to the database can be found at NOAA's restoration monitoring website: http://coastalscience.noaa.gov/ecosystems/estuaries/restoration_monitoring.html or http://restoration.noaa.gov.

NOAA's Restoration Center has also prepared a database of restoration projects for the United States and its protectorates. This online, searchable database can be used to help those interested in planning a restoration project contact others in the area and share information. Individual projects or a description of all restoration efforts in the database can be downloaded from: http://neri.noaa.gov. The U.S. Environmental Protection Agency also maintains a restoration project database (http://yosemite.epa.gov/water/restorat.nsf/rpd-2a.htm). This database, however, is not exclusively devoted to coastal habitat restoration projects. Restoration efforts for inland waterways and terrestrial habitats are also listed there.

## DEGRADED REFERENCE SITES

Degraded reference sites may also be used as reference conditions when standards are not available. Degraded sites can be used to describe progress away from the degraded condition and determine which restoration techniques[5] have

[5] Restoration is a relatively young science and many methods and techniques are still experimental. There are also unique aspects to every proposed restoration effort requiring innovative solutions. Experimenting with different techniques and disseminating results is strongly encouraged to further the science and increase the efficiency of future restoration projects

the greatest effect. Ideally, reference sites should be separate and independent of the restored area, however, areas within or near the habitat being restored may be acceptable for use as degraded reference sites when areas to be restored are unique or other acceptable reference sites cannot be identified. This approach was used in the restoration of riverine forests and deepwater swamps along the Pen Branch of the Savannah River (Kolka et al. 2000; Nelson et al. 2000). Vegetation communities along the Savannah River were impacted by hot water discharges from an upstream power plant. No non-impacted riverine forests or deepwater swamps were available in the area for comparison so researchers subdivided the river into a series of cross sections where different planting treatments could be tried and compared to areas left untreated. A variety of structural and functional characteristics were then monitored at the treated and non-treated areas to assess the effects of various restoration techniques (Barton et al. 2000; Bowers et al. 2000; Buffington et al. 2000; Fletcher et al. 2000; Kolka et al. 2000; Lakly and McArthur 2000; Nelson et al. 2000; Paller et al. 2000; Wike et al. 2000).

One draw back of using only degraded sites as the reference condition, is that practitioners may be unable to set appropriate restoration goals. For example, for the Pen Branch project described above, only other impacted areas were used for comparison with the restoration effort. Monitoring results show that some vegetation change occurred in the restored area. Without the benefit of historical data, however, researchers could not determine if the restored area was truly a representative of high quality riverine forest along the Savannah River. Without the use of reference standards to set goals for restoration projects, changes observed in 'restored' areas may be just 'changes' and not true restoration of the characteristic structures and functions of the habitat.

## PREDICTING REFERENCE CONDITIONS

If data from a variety of monitored locations are available, the data can also be used in computer models to predict reference standard conditions given various restoration scenarios. This approach has been successfully demonstrated using hydrologic and fish community data from rivers in southeastern Michigan (Wiley and Seelbach 1997) and could be adapted to coastal areas as well. For a single restoration project this would be an expensive endeavor. On the other hand, it could be useful in areas that have undergone extensive research and assessment such as the Chesapeake Bay, the gulf coast of Louisiana, or the San Francisco and San Pablo Bays.

As young as the science of restoration is, the science of modeling ecosystems is even younger. Although the science is advancing rapidly, current models cannot account for all of the factors that influence habitat development (Oreskes et al. 1994). Natural, random events such as hurricanes, floods, and large fires as well as man-made impacts such as industrial accidents, nutrient enrichment, or introduction of invasive species can have tremendous, and sometimes even devastating, impacts on coastal habitats. These cannot as yet be included reliably in ecosystem modeling. In areas where high quality sites are not available for use as reference standards, however, computer modeling may be the only method available to set realistic restoration project goals.

## SOME STATISTICAL ISSUES

As stated previously, the use of a small number of independent, adjacent reference sites minimizes many of the logistical issues associated with monitoring. Shortcomings with this approach, however, do exist. Restoration projects are essentially experiments and for the results of experiments to be statistically valid, they need to be replicated. It has been argued that it is not possible to calculate statistically significant differences between restored and reference sites when only one or two reference sites are used (Hurlbert 1984). Through a variety of statistical techniques, however, is issue may be overcome (Eberhardt 1976; Skalski and McKenzie 1982; Stewart-Oaten et al. 1986; Carpenter 1989; Carpenter et al. 1989; Stewart-Oaten et al. 1992). Through repeated and simultaneous sampling at the restored site and at one or more reference sites, before and after the implementation of the restoration project, effects can be statistically detected (Schroeter et al. 1993). The Before After Control Impact (BACI)[6] study design and the statistical analyses associated with it can be used to statistically assess the effect of impacts and restoration projects on coastal habitats (Schroeter et al. 1993). This further highlights the need for a statistician to be consulted early on in project planning so appropriate statistical practices and models can be incorporated into the sample design.

Statistics alone, however, should never be the used as the sole means for understanding ecological processes and phenomena or for making decisions about restoration progress, particularly where biology is involved. Plants and animals can be remarkably adaptive and resilient to a variety of circumstances. Therefore, a strong understanding of ecology and the use of multiple species and measurements should be a part of any interpretation of statistics derived from restoration monitoring projects before conclusions are drawn (Schroeter et al. 1993).

When monitoring restored and reference sites, it is particularly important to consider temporal variability and monitor sites for several years. Seasonal and annual patterns in climate and water level can change structural and functional characteristics at the site level that may be misinterpreted as restoration-related if monitoring is done without the use of reference sites or only for a short period of time (Simenstad and Thom 1996; Simenstad and Cordell 2000). For example, a monitoring project that only sampled water quality for one year after project construction might conclude that changes in suspended sediment and nutrient concentrations were a result of restoration activities. Yet these changes may be the result of regional hydrologic patterns relatively unaffected by any particular restoration activity. Only through monitoring for multiple years after restoration, within an appropriately selected reference domain, can practitioners distinguish the effects of the restoration activity from the background effect of large-scale, non-restoration related, variables. This is particularly true in highly dynamic environments such as those along the coast of the Great Lakes where annual differences in lake levels can completely alter the dominant vegetation communities (Keddy and Reznicek 1982; Keddy and Reznicek 1986; Wilcox and Whillans 1989; Reznicek 1994; Wilcox et al. 2002). Additional information on the timing and duration of monitoring can be found in *Science-Based Restoration Monitoring of Coastal Habitats: Volume One*.

[6] More thoroughly discussed in several of the citations listed above.

## CONCLUSIONS

The specific type and number of reference conditions will vary from one restoration project to another depending upon project goals and constraints, such as available funding. Whether they are in the form of historical records, existing sites, or computer simulations, reference conditions are the guidepost against which the progress of a restoration project is measured. The general scientific consensus is that reference conditions should be developed using multiple existing, independent sites of similar structure to the area to be restored. Use of reference sites and sharing of information with other researchers and restoration practitioners makes sense from the long-term economic view of restoration as well as it increases the efficiency of current and future restoration and monitoring projects (Wilcox, USGS, pers. comm.). That said, constraints dictate that not every restoration project will be able to monitor multiple reference sites as part of their restoration monitoring project. Restoration practitioners should allow an adequate budget for monitoring reference sites or conditions and are encouraged to seek out and create collaborative efforts to share data and information with other affiliated agencies. These efforts will increase the efficiency of restoration and restoration monitoring as well as the over-all amount of information on the structural, functional, ecological, and economic importance of our coastal habitats.

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