United States
Environmental Protection
Agency

A Manager's Guide to Indicator Selection

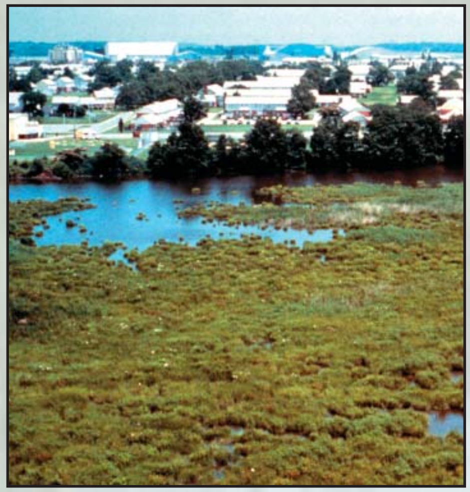

Photo: NOAA, Department of Commerce

Humans are part of—not apart from—ecological systems. Individual and collective choices within a watershed determine land use patterns, such as forested, agricultural, or urban, that in turn affect aquatic ecosystems. As a society, we want to derive valuable ecosystem services from our aquatic resources. These services include drinking water, recreation, habitat, or other amenities. Conflicts arise when social choices (land use patterns) adversely affect these desired services. Government managers are charged with managing the protection or achievement of these ecosystem services; to be effective, their decision-making processes must be done within the context of society's choices.

New Tools for Monitoring Our Waters

The original intent of the Clean Water Act of 1972—to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters"—has yet to be realized. While natural resource and science communities have continued to pursue this goal, two major road blocks have hindered their efforts: 1) a lack of useful ecological indicators for monitoring, diagnosing, and predicting conditions; and 2) the difficulty of choosing relevant benchmarks against which to compare their own resources. To decrease these barriers, the U.S. EPA Estuarine and Great Lakes (EaGLe) Program established five regional centers to develop integrated ecological indicators for use by local resource managers and scientists (shown on page 8).

To assist resource managers and scientists in the Mid-Atlantic region, the Atlantic Slope Consortium (ASC), based at Pennsylvania State University, has developed more than 30 biological, chemical, physical, and socioeconomic indicators tailored to the region's aquatic resources, landscapes, and watersheds. The suite of indicators can be used to assess water resource conditions, monitor trends, diagnose causes of problems, and target critical management activities. While some indicators can be used in a variety of ways, few indicators perform all of these activities equally well; therefore, understanding the features and limitations of indicators is critical to their appropriate usage.

This publication describes a framework developed by the ASC to guide managers in selecting ASC indicators and benchmarks with which indicator values can be compared. In essence, the framework is a question-and-answer process that defines the parameters of a task. It incorporates factors that are common to most managerial situations:

- ***Type of question***—the problem
- ***Spatial scale***—the size of the resource
- ***Temporal scale***—the length of time or timescale being considered
- ***Context***—the type of land use and landscape surrounding the resource

After considerable field testing, all ASC indicators were categorized according to these same factors, so that users could readily see which indicators and benchmarks apply to their situation.

A Framework for Indicator Selection

The Type of Question: defining the problem

Choosing an indicator begins with the type of question being asked. What is the problem? What is causing it? Is management making a difference? A relevant indicator should give managers the answers to their specific questions, and it should help them communicate the answers to the public in an understandable and pertinent way. The ASC framework (depicted in Table 1) categorizes managerial questions according to the following types.

Condition Assessment: What is the current condition of the resource?
Evaluation: Are management actions effective?
Stressor Diagnosis: What is causing the undesirable condition?
Communication: What will help decision makers and the public comprehend the problem?
Forecast/Restore: What will happen in the future if the problem isn't corrected? Will restoration efforts be effective?

Table 1. Indicator Selection Framework. This table summarizes the questions that frame the selection of an appropriate ASC indicator. Answers can then be matched with the indicators in Table 2 on pages 6-7.

Framework	Factors to Address	Criteria and Considerations
Type of Question A relevant indicator must be able to address the type of managerial question being asked. An indicator can answer more than one type of question, but not necessarily all types.	**Condition Assessment:** What is the state of the system?	A relevant benchmark must be chosen to indicate if a system is in good or poor condition. For example, a forested watershed may not provide relevant benchmarks for an urban one. Depending on the question, more appropriate references might be drawn from indicators derived from a restored urban river.
	Evaluation: Are management actions effective?	This is usually a subset of a condition indicator. The indicator must be responsive to management actions. For example, a Benthic Index of Biotic Integrity (IBI) should reflect improvements of in-stream habitat.
	Stressor Assessment: What is causing the problem?	For a stressor diagnosis, the indicator should demonstrate a cause and effect relationship with the stressor. An example is density of submerged aquatic vegetation with light availability.
	Communication to the public: What is the best way to communicate status to public and decision makers?	The indicator should encourage comprehension of the environmental condition in a way that the public can understand, based on concepts relevant to their own experiences and ethics.
	Futures forecast or restoration assessment: What is the outlook for the condition of the resource, either with or without action?	Indicators that forecast future conditions are used mostly for large areas over longer time periods, such as the regional impact of climate change on agricultural production or the composition of aquatic biological communities.
Spatial Scale (Size)	What is the extent of the targeted resource?	The scale of the ecosystem characteristic or process being measured should match the scale at which management actions are taken. For example, a Fish Index of Biotic Integrity (IBI) reflects conditions in an entire watershed and should be responsive to changes in land management over the entire watershed. In contrast, the habitat value of an individual wetland is responsive to local actions in the area immediately surrounding the wetland itself.
Temporal Scale (Timescale)	What is the relevant timeframe over which to monitor trends?	The selected indicator must be able to confidently detect change over the timeframe of interest.
Context (Land Use & Landscape)	What is the predominant land cover around the resource? What type of landscape is it? What is a useful comparison?	Measuring progress requires a realistic benchmark that is appropriate to the type of land use and physical landscape. For example, in an urbanized watershed, restoration to a pristine condition is neither possible nor sustainable. What is needed is a relevant benchmark for an urban watershed.

Spatial Scale: how extensive is the resource?

Indicators have been developed for specific spatial scales. Therefore, it is important that the scale of the ecological process being measured is similar to the extent of the resource being managed. Is the resource a local lake, a small watershed, or a portion of an estuary? Managers need to define the scale in terms that make sense, ecologically and/or politically.

The ASC indicators were developed according to the scale at which most management decisions in the Mid-Atlantic region are made. All of the indicators can be used for estuarine segments and small watersheds. An “estuarine segment” represents a downstream area composed of deepwater areas, shallows, tidal marshes, creeks, and adjacent uplands. A “small watershed” is equivalent to an upstream area that encompasses several streams and river banks, wetlands, water bodies, and the contributing drainage basin. As can be seen from the indicators listed in Table 2 (page 6), some are useful for smaller areas, such as sites (for example, a riparian area along a headwater stream) or reaches (a short section of a lower order stream).

Temporal Scale: how long and when?

Does the project in question need to look at the seasonal variations of a fish species? Does it need to compare improvements over a 5-year period? The ASC indicators apply to the timescales that managers most often consider—seasonal variations, annual comparisons, and long-term trends. All indicators are developed for specific temporal scales and may not work at other scales.

Context: land use and landscape

To determine the feasibility of management or restoration plans, the activities must be considered in context with the surrounding land use and landscape. Does the resource in question lie in a protected forest or in a rural watershed undergoing rapid urbanization? Does it lie in a coastal plain or in an area with steep hills and valleys?

The issue of context leads into the use of ecological benchmarks. To set realistic management goals, a resource should be compared to a relevant benchmark, in other words, to the best attainable condition for the region and the type of landscape. Traditionally, environmental benchmarks have been taken from systems devoid of human impact. As most landscapes are managed with the intention of supporting continued human use, this is neither practical nor realistic. When developing the ASC indicators, the researchers determined benchmarks for each indicator that reflect the types of land uses, landscapes, and geological characteristics prevalent in the Mid-Atlantic region. Managers can refer to Figure 1 to determine the context for their site.

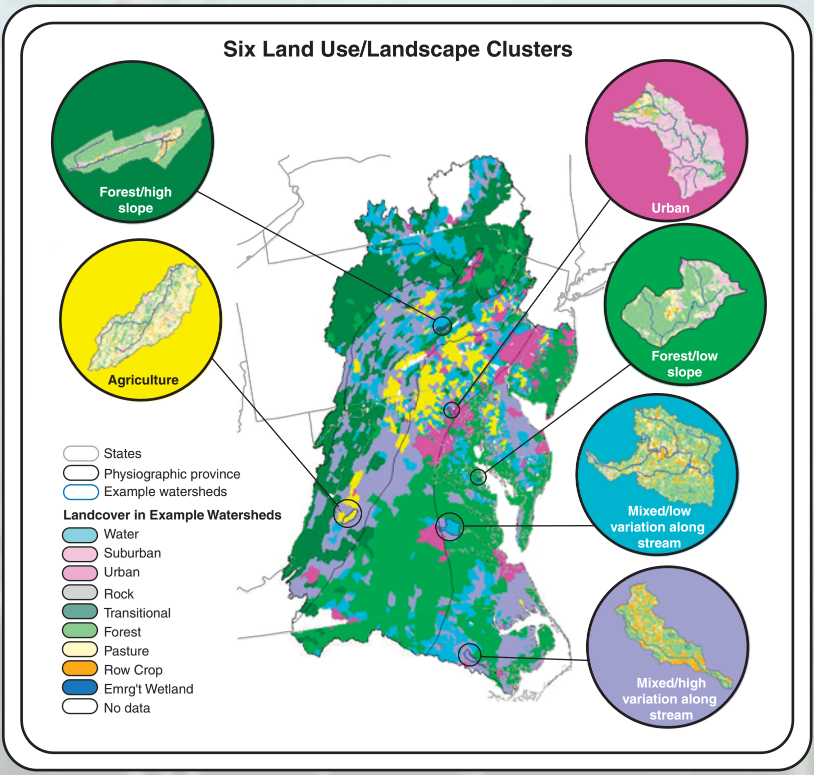

Figure 1. Determining ASC Indicator Context. All small watersheds in the region (14-digit Hydrologic Unit Code watersheds) were classified according to land use patterns—forested, urban, agriculture, and mixed. This information was further delineated by additional landscape parameters (for example, high or low slope), resulting in these six land use/ landscape clusters. ASC indicators were benchmarked according to the land use/landscape clusters in this map of the Atlantic Slope region.

Photo: Donna Marie Bilkovic

When the Fish Community Index was compared with measures of habitat conditions, the index scores were poorest in areas with highly altered shoreline conditions and minimal subtidal habitat.

Putting the Framework to Work

Once users have answered the questions in the ASC framework, they can select appropriate indicators from the list of ASC indicators in Table 2 (pages 6-7). The table is provided to simplify the initial selection process. Further information on each indicator can then be obtained from the Atlantic Slope Consortium website, www.asc.psu.edu.

The following hypothetical scenarios illustrate how managers can use the ASC framework (Table 1) and the table of indicators (Table 2) to select indicators best suited for the resource question at hand.

Situation #1: *Professional and recreational fishers have reported declines of fish in an estuary in a county in Maryland. The county has undergone rapid urbanization of agricultural and forested land for the past five years. Resource managers want to learn if and what land use changes may be affecting nearshore estuarine fish communities. They need to convey their findings to interested environmental and fishing groups and local decision makers.*

In this situation the managers want to answer the following *types of questions*. What is the relative biological integrity of the nearshore environment? How will future development affect fish communities? Can this indicator clarify environmental connections to the public? These questions fit into the categories of condition assessment, futures forecast/restore, and communication with the public, respectively. Looking at the list of ASC indicators in Table 2, the most applicable indicator is the Fish Community Index for Estuaries, since it can be used to address all three of these questions.

It also appears that the *spatial scale* of the Fish Community Index—site to small watershed—would be appropriate, as would the *temporal scale*—days to years. The initial step of the selection process is done.

To learn more about the usefulness of the Fish Community Index (FCI), the managers could turn to the ASC website, where a summary and final report of each indicator is provided. They would learn that the FCI was developed for application in the Chesapeake Bay watershed's nearshore estuarine environment (< 2m depth). The FCI incorporates measures of fish community integrity, such as taxonomic richness and diversity, trophic composition, and nursery function. When the FCI was compared with measures of habitat conditions, such as shoreline alteration and subtidal structures, FCI scores were lowest in areas with highly altered shoreline conditions and minimal subtidal habitat. In addition, FCI scores were lower in developed and agriculture watersheds than in watersheds dominated by forests. In other words, biotic responses correlated with habitat condition measures in nearshore, shoreline, and watershed environments.

Resource managers in this situation could use the FCI to explore its relationship among nearshore habitat condition and existing shoreline conditions at specific sites or in small watersheds in their county. They also could use it to evaluate future development scenarios. Additionally, the FCI would be useful in communicating their findings to the public, particularly since the index is expressed as an easily understood score.

Situation #2: The setting is a rapidly developing semi-urban county through which two large, brackish rivers flow. Public groups and environmental managers are concerned with declining aquatic conditions, and the county is considering various shoreline restoration efforts. Project managers want to determine which efforts would most improve habitat condition.

In this situation, the managers need to address the following *types of questions*: What is the current status of aquatic habitat quality? What land-use or land-cover changes could improve aquatic habitat condition? They have chosen the Macrobenthic Community Indices in Estuaries (Table 2) as one of their assessment tools, because these indices can be used to assess the problem (condition assessment), to evaluate different scenarios (forecast/restore), and to communicate outcomes with the public (communication). The indices also are applicable in terms of *scale* and *context.*

Photo: Dave Stanhope

A sampling of the macroinvertebrate organisms from the nearshore benthic environment of the Chesapeake Bay

Photo: Donna Marie Bilkovic

Samples for the Macrobenthic Community Indices are collected with relative ease.

In the summary provided on the ASC website, the managers learned that the Macrobenthic Community Indices involves two indices. While both indices are measures of biotic integrity that can be correlated with habitat conditions, one index is applicable at the site level, the other at a watershed level. In combination, the indices can reflect ecological thresholds of biotic response to developed land use impacts at both the site and watershed scales. For example, the indices' scores were significantly reduced when the amount of developed shoreline at the site level exceeded 10%, and when developed land use at the watershed level exceeded 12%. However, researchers also found that forests and wetlands in the riparian zone have the potential to diminish the effects of urban land use in localized areas.

Not only could the information provided by the Macrobenthic Community Indices help the managers in this situation prioritize and target sites or small watersheds for restoration or protection, it also could help them communicate goals to the public. Even so, the information provided by the Indices is just one layer of an overall condition assessment. ASC researchers recommend adopting an ecosystem approach incorporating various indicators that measure different scales or types of stressors.

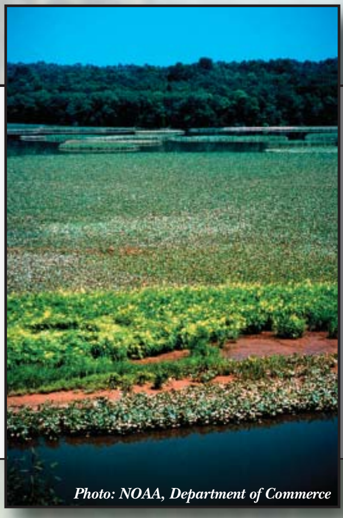

Photo: NOAA, Department of Commerce

The impact of shoreline and watershed land use on nearshore biotic communities is a fundamental ecosystem management question. Shallow-water tidal habitats provide essential nursery, spawning, and foraging areas for numerous fish, shellfish and crustacean species. These critical resources are under intense pressure from a variety of users. Both the Fish Community Index and Macrobenthic Community Indices are useful assessment tools for these areas.

Table 2. Ecological Indicators Developed for the Mid-Atlantic Region. All ASC indicators have been categorized according to the factors in the ASC framework. Their applicable uses are shown in the middle column below. A full list of indicators and further information is available at: www.asc.psu.edu.

Indicator	Uses by ASC Indicator-selection Framework	Description
Abundance of Common Reed (*Phragmites australis*) in Brackish Wetlands of Chesapeake Bay	*Type of Question:* Condition assessment *Spatial Scale*: Wetland and subestuary *Temporal Scale*: Seasonal to annual *Context*: Forested, agricultural, urban, and mixed	Correlates the abundance of Common Reed and the nitrate concentrations in leaves with developed land.
Bio-optical Model for Determining Habitat Suitability for Submerged Aquatic Vegetation (SAV) in Estuarine Segments of Chesapeake Bay	*Type of Question:* Condition assessment; communication; forecast/restore *Spatial Scale:* Estuarine segment *Temporal Scale:* Seasonal to annual *Context:* Land-use decisions in coastal zone	Determines the level of suspended solids that allows SAV survival; gives level in relationship to land use.
Blue Crab (*Callinectes sapidus*) Abundance	*Type of Question:* Condition assessment; communication *Spatial Scale:* Shoreline segment, watershed, and regional level *Temporal Scale:* Seasonal *Context:* All land covers	Correlates juvenile crab abundance with shoreline wetlands, forested watersheds, and subestuaries with average salinity.
Fish Community Index (FCI) for Estuaries	*Type of Question:* Condition assessment; communication; forecast/restore *Spatial Scale:* Site to small watershed *Temporal Scale:* Days to years *Context:* Low-slope forested, agricultural, urban	Biotic integrity index for fish communities for application in the nearshore estuarine environment.
Index of Marsh Bird Community Integrity (IMBCI)	*Type of Question:* Community integrity assessment; stressor diagnosis; communication *Spatial Scale:* Marsh to subestuary *Temporal Scale:* Years to decades *Context:* Marshes within any land-cover context	Scores for marsh birds are compared to wetland habitat and land use to identify wetland stressors.
Index of Waterbird Community Integrity (IWCI)	*Type of Question:* Community integrity assessment; stressor diagnosis; communication *Spatial Scale:* Subestuary *Temporal Scale:* Years to decades *Context:* Subestuaries and associated watersheds with any land cover	Scores for waterbird communities in subestuaries are compared to indicators of estuarine condition to identify stressors and their pathways.
Inverse-distance Weighted Cropland	*Type of Question:* Condition assessment; stressor diagnosis *Spatial Scale:* Reach to watershed *Temporal Scale:* Seasons to decades *Context:* Agricultural, urban, and mixed watersheds	Watershed measure that gives greater weight to croplands closer to water bodies while including effect of more distant croplands.
Inverse-distance Weighted Developed Land	*Type of Question:* Condition assessment; stressor diagnosis *Spatial Scale:* Reach and watershed *Temporal Scale:* Seasons to decades *Context:* Urban and mixed watersheds	Watershed measure that gives greater emphasis to nearby developed land than to distant developed land.
Inverse-distance Weighted Impervious Cover	*Type of Question:* Condition assessment; stressor diagnosis *Spatial Scale:* Reach and watershed *Temporal Scale:* Seasons to decades *Context:* Urban and mixed watersheds	Watershed measure that gives greater emphasis to impervious land near a resource than to distant impervious land.

Table 2. Continued

Indicator	Uses by ASC Indicator-selection Framework	Description
Macrobenthic Community Indices in Estuaries (B-IBI, W-value)	*Type of Question:* Condition assessment; communication; forecast/restore *Spatial Scale:* Site to small watershed *Temporal Scale:* Days to years *Context:* Low-slope forested, agricultural, urban	Gives two measures of invertebrate biotic integrity of the nearshore estuarine environment.
Nitrate, Total N and Total P Concentrations in Subestuaries of Chesapeake Bay	*Type of Question:* Condition assessment *Spatial Scale:* Subestuary *Temporal Scale:* Short-term to seasonal *Context:* Forested, agricultural, urban and mixed	Examines relationships between watershed characteristics and nitrate, nitrogen, and phosphate.
Polychlorinated Biphenyls (PCBs) in White Perch	*Type of Question:* Condition assessment; communication *Spatial Scale:* Watershed level *Temporal Scale:* Seasonal to annual *Context:* Urban	Shows probability of high PCB levels in White Perch in subestuaries near commercial land.
Shoreline Condition	*Type of Question:* Condition assessment; stressor diagnosis; communication; forecast/restore *Spatial Scale:* Site to small watershed *Temporal Scale:* Days to years, resample every 5 years to assess change *Context:* Applicable in estuarine tidal areas	Reports riparian land use, bank characteristics, and structural modifications intended to reduce shoreline erosion. GIS format allows spatial assessment and analysis.
Source Land Proportion Weighted by Inverse Riparian Buffer Width	*Type of Question:* Condition assessment; stressor diagnosis *Spatial Scale:* Reach to watershed level *Temporal Scale:* Months to decades *Context:* Agricultural, urban, and mixed watersheds	Estimates effective proportion of land-cover type in the watershed draining to a stream response point.
Source-specific Mean Riparian Buffer Width	*Type of Question:* Condition assessment; stressor diagnosis *Spatial Scale:* Reach to watershed *Temporal Scale:* Seasons to decades *Context:* Agricultural, urban, and mixed watersheds	Quantifies the potential of riparian buffers to reduce the impact of a specific land cover on aquatic systems.
Spot Sampled Average Stream Nitrate Concentration	*Type of Question:* Condition assessment; performance evaluation; stressor diagnosis *Spatial Scale:* Reach to large river *Temporal Scale:* Seasons to decades *Context:* All watersheds	Spot sampling is a cost-effective predictor of nitrate and total nitrogen.
Stream–Wetland–Riparian (SWR) Index	*Type of Question:* Condition assessment *Spatial Scale:* Site to small watershed *Temporal Scale:* Days to years *Context:* All land covers	Site index of condition for streams and associated wetlands and riparian areas. Average of sites in watershed gives estimate of watershed condition.

Wardrop, D.H., Bishop, J.A., Easterling, M., Hychka, K., Myers, W.L., Patil, G.P., and Taille, C. 2005. Characterization and classification of watersheds by landscape and land use parameters in five mid-Atlantic physiographic provinces. *Journal of Environmental and Ecological Statistics* 12(2): 209-223.

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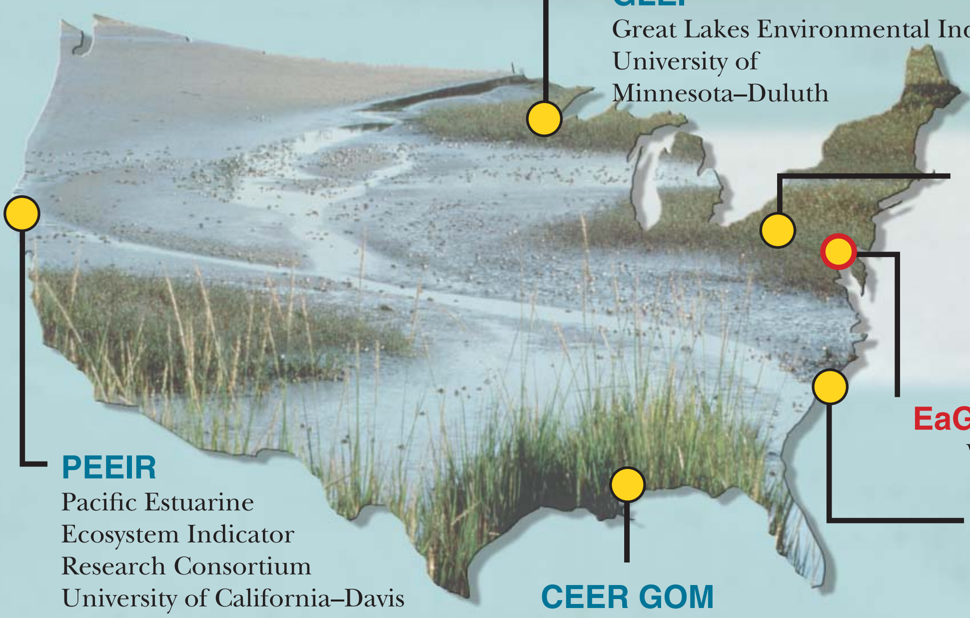

Direct and indirect effects of human activities have taken a toll on the nation's estuaries, yet few direct linkages have been identified between human activities on land and responses in estuarine ecosystems. The Atlantic Slope Consortium is one of five national projects funded by EPA's EaGLe program. The goal of the EaGLe program is to develop the next generation of ecological indicators that can be used in a comprehensive coastal monitoring program.

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