ENVIRONMENTAL INDICATORS, INDICES AND HABITAT SUITABILITY MODELS [a]

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ABSTRACT

Both environmental indicators and multi-metric indices are useful for describing baseline conditions and qualitatively predicting the cumulative consequences of multiple actions. Several examples and case studies with indicators and/or indices are presented herein. They can be easily modified for usage in CEA. Habitat suitability models reflect special indices related to habitat needs and quality for specific species or broad habitat types. Such models have been used to address direct and indirect effects, and with some modification, they can be also used to address cumulative effects of multiple actions. This review of environmental indicators and indices, and habitat suitability models has indicated that there are numerous examples of such tools which have been or could be used in both EIA and CEA. Some key lessons from this review are: (1) in conducting CEA studies, it is useful to think from the mindset that "I am the VEC or indicator, and what is my historical and current condition and how have I, or will I, be affected by multiple past, present, and future actions?"; (2) due to the likely absence of detailed information on future actions, the described tools can still be used to "predict" future conditions by focusing on up-or-down changes in individual indicators or their aggregated displays; and (3) numerous regional and site-specific tools are currently being developed, with primary examples being indices of biological integrity for specific watersheds and water bodies. Such tools, even though they may not have been developed for CEA usage, can certainly benefit CEA studies and practice. Finally, usage of selected and appropriate tools as described herein can aid in conducting systematic and documentable CEA studies.

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INTRODUCTION

As the practice of cumulative effects assessment (CEA) is maturing, new tools are emerging along with the realization that existing tools can be used if their focus is shifted from environmental impact assessment (EIA) to CEA (Canter, 1997 and 1999). One important fundamental concept is the need to conduct CEAs for specific Valued Ecosystem Components (VECs). VECs are considered by stakeholders, professionals, or other interested parties to be important resources, ecosystems or human communities that deserve attention in impact assessment work. Many of the examples and case studies described herein are focused on specific VECs, although some highlight broad analyses for multiple VECs at regional or national levels. The three types of tools addressed herein encompass indicators, environmental indices, and habitat suitability models. They can be used to describe historical to current baseline conditions, and to evaluate both direct and indirect effects of single proposed projects as well as cumulative effects from multiple actions.

Several definitions are fundamental to the variety of tools addressed herein. The most basic definition relates to the term “indicator”; with associated definitions for an environmental index and a habitat suitability model. The definitions are:

> Indicator -- An indicator, comprising a single datum (a variable) or an output value from a set of data (aggregation of variables), can be used to describe a system or process such that it has significance beyond the face value of its components. It can communicate information on the system or process.
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> Environmental index -- While the above definition for an indicator encompasses the aggregation of multiple variables (metrics), an environmental index can be seen as referring to a numerical or descriptive categorization of a large quantity of environmental data or information involving multiple metrics, with the primary purpose being to summarize and simplify such data and information so as to make it useful to decisionmakers and various stakeholders (Canter, 1996a, p. 122).
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> Habitat suitability model – This type of model is actually a specialized environmental index which is focused on aggregated indicators of habitat quality for either fish and wildlife as a whole, or for specific species to be studied in either EIA or CEA studies.

The topics addressed herein can be divided into two themes – context information related to the usage of these tools in both EIA and CEA; and specific examples of the use of indicators, indices, and habitat suitability models in environmental studies and adaptation for usage in CEA. Context information encompasses an historical perspective, a three-part categorization, and special needs considerations related to their usage in CEA. The examples are divided into national and regional indicators (and indices), VEC-based and species-based local indicators, regional and site-specific indices, and habitat suitability models. The final section contains a brief summary and delineates lessons learned.

USE OF THESE TOOLS IN THE EIA AND CEA PROCESS – AN HISTORICAL PERSPECTIVE

Environmental indicators and various multi-metric indices have been used in document preparation under the National Environmental Policy Act (NEPA) process in the United States since NEPA's implementation in January, 1970. Section 102(c)(i) of NEPA itself called for a description of the "environmental impacts of the proposed action", although no details were provided on the media and resources which should be addressed. Further, the term "environmental indicator" was not included in the Act. However, early environmental impact statements (EISs) began to address selected characteristics related to physical-chemical, biological, cultural, and socioeconomic components of the environment. The components were typically sub-divided into specific "indicators", with the indicators used to describe both the environmental setting and the anticipated consequences (effects) of the proposed action and alternatives. Section 102 (c)(iii) of NEPA required a discussion of the "alternatives to the proposed action", and this section within early EISs was soon characterized by comparative information on the impacts of the alternatives. The impact analyses and displays were based on anticipated changes in the indicators of various environmental components.

In 1979, the Council on Environmental Quality (CEQ), which was created by NEPA itself, promulgated regulations for the NEPA process (Council on Environmental Quality, 1999). One feature of these regulations related to the specification of a typical format for EISs as found in 40 CFR 1502.10 to 1502.18. These sections have particular relevance to the use of environmental indicators; however, no definition for indicators was included in the regulations. Section 1502.15 (Affected Environment) encourages a succinct description, and indicators have been typically utilized across a broad range of projects, plans, and programs with differing geographical scales by compressing large amounts of data into succinct descriptions.

Section 1502.16 (Environmental Consequences) is focused on describing the direct, indirect, and cumulative effects of all analyzed alternatives, including the proposed action. Again, impact-related indicators have typically been utilized since 1979. Finally, Section 1502.14 (Alternatives Including the Proposed Action), which is described as the "heart of the EIS", summarizes the comparative impact information for the analyzed alternatives. Summary information from Sections 1502.15 and 1502.16 is typically used in Section 1502.14.

The early years of NEPA practice (the 1970s through the mid 1980s) were also characterized by the development of environmental impact assessment (EIA) methodologies (Canter, 1996). These matrix and checklist methodologies were typically characterized by the inclusion of environmental categories and lists of associated indicators. Such methodologies have long been used to plan and conduct impact studies, and to prepare EISs.

Another characteristic of NEPA practice since 1970 has involved litigation regarding inadequacies in the NEPA process or non-compliance with its spirit and intent against agencies that prepare NEPA documents. A theme from many court cases relates to whether or not the proponent agencies took a “hard look” at the impacts in relation to site-specific environmental conditions. Accordingly, Federal, District, and Appellate courts have typically upheld the use of environmental indicators in EISs and environmental assessments (EAs); however, the key issue is often associated with the careful documentation of why the indicators were chosen, and explanations of the importance of the findings associated therewith.

The 1990s were characterized by three CEQ reports related to expanding and/or improving NEPA practice. Each report includes reference to using environmental indicators. For example, a 1993 report related to incorporating biodiversity considerations, as appropriate, within the NEPA process and resulting EISs (Council on Environmental Quality, 1993). More specifically, Appendix B of the report included examples of biodiversity indicators for inventorying, monitoring, and assessing terrestrial biodiversity at four levels – regional landscape, community-ecosystem, population-species, and generic. For each level, potential indicators are listed in the appendix for addressing the relevant composition, structure, and function. The appendix also includes summary information on inventory and monitoring tools (Council on Environmental Quality, 1993, p. 27).

In 1997, the CEQ issued a report related to the effectiveness of NEPA after 25 years (Council on Environmental Quality, 1997b). Two of five elements identified as critical to the effective and efficient implementation of NEPA were: (1) the use of an “interdisciplinary place-based approach to decisionmaking that focuses the knowledge and values from a variety of sources on a specific place”; and (2) the use of “science-based and flexible management approaches once projects are approved” (Council on Environmental Quality, 1997b, p. ix).

The “interdisciplinary approach” requires comprehensive environmental, social, and economic data. Further, it was noted that many federal agencies are using existing or proposed new environmental, social, and economic indicators to provide more consistent information on the status of resources, ecosystems, and human communities over time and various spatial boundaries.

The use of follow-on “management approaches” comprised of both monitoring and adaptive management will necessitate the identification of management objectives (goals) and appropriate indicators which could be systematically monitored. To place these “management approaches” in context, it should be noted that the “traditional” NEPA model was based upon the concept of “predict, mitigate, and implement”. Accordingly, the traditional model was concluded upon the successful completion of an EIS and Record of Decision (ROD). Follow-on management approaches are based on a new NEPA model consisting of “predict, mitigate, implement, monitor, and adapt” (Council on Environmental Quality, 1997b, p. 32). This new model, which was advocated by CEQ, extends the NEPA process beyond document preparation (EIS) into longer-term project management. As noted above, indicators have been used in the traditional NEPA model. Follow-on activities associated with the new NEPA process will need to utilize indicators as a foundation element.

In 1997, the CEQ also issued guidance on addressing cumulative effects in the NEPA process (Council on Environmental Quality, 1997a). Addressing cumulative effects requires the consideration of larger study areas, longer time frames, and effects contributions from past, present, and reasonably foreseeable future actions. The use of selected indicators can facilitate the analysis of cumulative effects on resources, ecosystems, and human communities. For example, such indicators can be used to describe the historical and current conditions of the affected environment; establish qualitative and/or quantitative connections between various actions and affected resources ecosystems, and human communities; and identify collaborative mitigation measures. Further, environmental sustainability may need to be considered relative to potential cumulative effects on already stressed environmental components, thus the use of “sustainability indicators” may be appropriate.

Finally, in 2003 a Task Force of CEQ issued a report entitled “Modernizing NEPA Implementation” (Council on Environmental Quality, 2003). One chapter addressed adaptive management and monitoring, thus further advocating the integration of “follow-on” activities in the new NEPA model. To provide a perspective, it is instructive to consider the typical elements of an adaptive management program, whether it is applied to natural resources management or within the NEPA process, or both. Further, in planning a related monitoring program, the selection of key indicators is required.

CATEGORIZATION OF THESE TOOLS

The conceptual framework which has been frequently used for the development of these three tools has been the “pressure-state-response” model (PSR). The PSR model considers that human activities exert “pressures” on the environment and affect its quality and the quantity of natural resources (“state”); society responds to these changes through environmental, general economic and sectoral policies and through changes in awareness and behavior (“societal response”). The PSR model has the advantage of highlighting these links, and helping decisionmakers and the public see environmental and other issues as interconnected (although this should not obscure the view of more complex relationships in ecosystems, and in environment-economy and environment-social interactions) (Organisation for Economic Cooperation and Development, 1998, p. 108).

The concept of pressure indicators, state indicators, and societal response indicators can also be used in CEA and related management. Pressure indicators could be used to reflect measures of impacts from specific types of projects; for example, they could include air pollutant emission factors, wastewater loadings as expressed by constituents and flows, losses of habitat per unit of project, etc. These indicators could be useful for comparing alternatives in terms of their relative impacts. State indicators are routinely used in describing historical and current conditions of selected VECs; further, they can be used as a framework for identifying and assessing direct, indirect, and cumulative effects from the proposed actions and other actions in the study area. Several examples of these types of indicators, and their combination into indices, are included herein. Finally, response indicators could address local area mitigation measures associated with the proposed actions, and regional management measures for significant cumulative effects. Essentially all of the indicators, indices, and habitat suitability models described herein fall within the pressure, state and response categories, or combinations thereof.

If indicators and indices are to be used for various purposes within EIA and CEA, a systematic and documented process should be used in their selection and/or development. For example, the following questions could be considered in selecting indicators:

- Are they measurable and scientifically valid?
- Can various stakeholders understand the measurement results and their interpretation?
- Can the measurement results be used in decision making, including the evaluation of progress relative to policy goals?
- Are quantitative or qualitative thresholds available for use in interpreting measurement results?
- Have the indicators been used in other environmental impact studies, or in adaptive management programs?

- Is it cost-effective to monitor the indicators?

CONSIDERATIONS RELATED TO THE CURRENT USAGE OF THESE TOOLS IN CEA

The three types of tools addressed herein (indicators, indices, and habitat suitability models) can be used in several ways in CEA studies. For example, they can be used: (1) to summarize and communicate information on historical to current conditions and trends for selected VECs and their indicators; (2) to increase the study team's understanding of the VEC and pertinent features (for example, the life cycle of selected species and their resiliency or susceptibility to changes from various stressors); (3) to provide an analytical framework for evaluating the individual and combined effects of past, present, and proposed actions on the selected VECs; (4) to provide a basis for considering the effects of future actions and their influence on the component indicators (that is, will indicator measures go up or down; if so, this information could be needed to make qualitative but structured predictions; (5) as a surrogate tool for evaluating VEC sustainability over time; and (6) for planning follow-up monitoring and adaptive management programs.

Regarding monitoring program indicators, three types of indicators have been proposed – compliance indicators, diagnostic indicators, and early warning indicators (Cairns, et al., 1993, pp. 6-8). Compliance indicators are those chosen to judge the attainment and maintenance of management objectives (goals) for environmental quality, natural resources sustainability, and social acceptability (quality of life). Diagnostic indicators are those used to identify causal factors related to environmental degradation and non-attainment of management objectives. Causal factors could be related to the adverse environmental consequences of projects, plans, programs, and/or policies. Further, diagnostic indicators can be used in the development of mitigation measures or management responses to preclude further degradation or worsening of non-attainment conditions. Finally, early warning indicators could be a subset of compliance indicators, or be based on more frequent usage of all compliance and diagnostic indicators. These indicators should focus on warning signs which could then be addressed with a preventive maintenance strategy.

Determination of the actual usage of environmental indicators, indices, and habitat suitability and related models in CEA is somewhat problematic. For example, in professional practice it is always useful to find case studies which can be adapted to new site-specific conditions or needs. Conversely, it should be recognized that the majority of the tools described herein were developed for non CEA-related purposes. Such purposes have included general environmental monitoring and management, meeting requirements for evaluating national and regional resources, and prioritization of resources relative to their spatially-driven conditions and vulnerability.

For the CEA practitioner who is faced with the need to both systematically and quantitatively address cumulative effects on specific VECs subject to multiple stressors, there may be several pragmatic challenges to overcome. Examples include:

- The identification of tools for addressing the specific study VECs rather than generic tools or generic frameworks.

- The evaluation of the applicability of such tools for usage at the site or in the local or regional study area.

- The need for creative thinking to determine <u>how</u> the tool could be used for CEA. Such creative thinking could be based on questions related to specific steps in a CEA process. To illustrate, consideration could be given to which, if any, of the 11-steps in the CEQ's CEA process could be accomplished. Such thinking could encompass specific questions related to usage of the tool for: (1) describing historical and current conditions for the VEC; (2) identifying multiple stressors could contribute to cumulative effects on the VEC, and their relative contributions; (3) determining the significance of such effects on the VEC (does the tool incorporate quantitative or descriptive thresholds or information which would aid the user in interpreting results); and (4) delineating potential project mitigation measures for reducing local cumulative effects, and regional measures which could be used to more effectively manage VEC-specific cumulative effects.

- Determining how to modify a tool developed for one location or VEC to make it useable for a different location and a similar but different VEC, or a completely new VEC.

An important concept, which can be used for each of the above challenges, is to develop the "mindset" of the VEC itself. In other words, does the tool (selected indicators, developed indices, habitat suitability models, or other models) appropriately focus on key information related to the VEC?

Finally, developers of indicators, indices, and habitat suitability models often use one or more conceptual models to represent the developers' understanding of how systems operate, and help integrate the different fields of science relevant to an issue that cuts across environmental disciplines, such as minimization of incremental and cumulative impacts.

EXAMPLES OF NATIONAL AND REGIONAL INDICATORS (AND INDICES)

The purpose of this section is to provide several examples of types of indicators which have been, or could be, used in EIA and CEA. The section begins with attention to sustainability. This is followed by referrals to two USA books, with one focused on ecological indicators and the other on social and economic indicators related to transportation projects. Regional indicators related to watershed vulnerability analyses are then described followed by VEC-focused regional indices for watersheds. Finally, examples of specific watershed and landscape indicators are presented.

Sustainability or Sustainable Development Indicators

In recent years, various governmental levels have defined environmental indicators for specific management purposes. One example is the increasing attention to “sustainability indicators” or “sustainable development indicators”. These types of indicators are most frequently utilized at national or international levels; however, they can also be used regarding specific national or regional resources, or in the evaluation of development plans for local communities or urban areas. For example, over the last decade several states and numerous cities in the United States have developed indicators for use in environmental evaluations and determining the effectiveness of various management programs.

One international example is from a report on the use of a 21-indicator environmental sustainability index (ESI) applied to 146 countries (Esty, et al., 2005). The focus of the ESI is on the ability of nations to protect the environment over the next several decades. Five topical categories encompass the 21 indicators; the categories include understanding environmental systems, reducing environmental stresses, reducing human vulnerability to environmental stresses, evaluating societal and institutional capacity to respond to environmental challenges, and participating in global stewardship.

The 21 indicators relate to the topical categories as follows: (1) air quality, biodiversity, land, water quality and water quantity are associated with environmental systems; (2) reducing air pollution, reducing ecosystem stress, reducing population pressure, reducing waste and consumption pressures, reducing water stress, and natural resource management are associated with reducing environmental stresses; (3) environmental health, basic human sustenance, and reducing environment-related natural disaster vulnerability are associated with reducing human vulnerability; (4) environmental governance, eco-efficiency, private sector responsiveness, and science and technology are related to social and institutional capacity; and (5) participation in international collaborative efforts, greenhouse gas emissions, and reducing transboundary environmental pressures are measures related to global stewardship. A total of 76 variables represent specific metrics used to define the 21 indicators. A point system is then used to characterize the metrics, indicators, and categories; the additive total score reflects the ESI for each evaluated country.

National Research Council – Two Examples

In recent years, the National Research Council (NRC) of the National Academies, has conducted several studies and generated publications related to the use of environmental indicators. To understand the "intellectual significance" of the resulting books, a description of the Council process is helpful. The process typically begins in response to a request from a federal agency, and the establishment of a contractual relationship. The professional staff of the pertinent Board within the NRC then identifies an appropriate independent "committee of experts" to actually conduct the study and prepare the resultant book. The committee members may be from academia, industry, state or local government, or non-governmental organizations. The committee and pertinent professional staff hold several meetings and gather pertinent information. Following "information gathering" and the input of pertinent knowledge and experience by the committee members, a plan is developed for a resultant "book" to be published by the National Academy Press. The book is prepared via the collaborative writing efforts of the committee members, and it is subjected to external peer review. Based upon this description, it can be stated that NRC books do have appropriate policy and scientific foundations; they are prepared using a systematic process; and they are subject to peer review.

In 2000, Ecological Indicators for the Nation was published (Committee to Evaluate Indicators for Monitoring Aquatic and Terrestrial Environments, 2000). The study objective involved the critical scientific evaluation of indicators to monitor ecological changes from either natural or anthropogenic causes. Although the emphasis is on national indicators, their usage at community, watershed, regional, state, and even international scales is advocated. General criteria for evaluating potential indicators are delineated; further, it can be stated that they are similar to numerous other lists of evaluation criteria. Specific recommendations are included for national ecological indicators in three categories (Committee to Evaluate …, 2000, p. 7):

- As indicators of the extent and status of the nation's ecosystems – land cover and land use.

- As indicators of the nation's ecological capital – total species diversity, native species diversity, nutrient runoff, and soil organic matter.

- As indicators of ecological functioning or performance – carbon storage, production capacity, net primary production, lake trophic status, and stream oxygen; and for agricultural ecosystems, nutrient-use efficiency and nutrient balance.

The above "national indicators" could also be adapted to regional and local (site-specific study areas) scales. Other types of regional and local indicators could include productivity indicators, and indicators of species diversity, including more localized indices of biotic integrity. In addition, the use of "ecosystem conceptual models" as a basis for indicator identification was also mentioned.

The second NRC example involved data needs for community participation in informed decisionmaking. This study was commissioned by the Bureau of Transportation Statistics and the U.S. Department of Transportation. The focus was on the identification of data, including geo-spatial data, and performance measures needed to make informed local and regional decisions on transportation, land use planning, and economic development (Committee on Identifying Data Needs for Place-Based Decision Making, 2002). An underlying theme related to encouraging broad and effective stakeholder participation in the planning of "livable communities" which are based upon local goals and community-derived indicators. A balanced set of "livability indicators" could include those related to social, environmental, and economic sectors. Examples of social indicators related to place and connectivity could include community involvement (e.g., volunteerism), number and locations of parks and recreational areas, and access to health care and social services. Many of the identified indicators could be used for addressing potential cumulative social and economic impacts of proposed local or regional projects, plans, or programs.

In summary, these two NRC examples uphold the "indicator concept" and support the use of various types of indicators for a variety of environmental management purposes. An underlying theme was the careful evaluation of indicators and documentation of the resulting rationale for their selection. Finally, environmental indicators can be used for several purposes in both the EIA process for a single action, and CEA studies within the EIA process. Examples of such purposes include identifying potential impacts, describing the affected environment, prediction of environmental impacts, comparing the impacts of analyzed alternatives, selecting the preferred alternative, and evaluating mitigation and cumulative effects management measures.

Multiple VEC Regional Indicators (and Indices)

A nationwide watershed vulnerability analysis tool has been developed by the U.S. Army Corps of Engineers (Jenicek, et al., 2005). The tool contains a subset of indicators used by the U.S. Army for evaluating Army installations, natural and ecological resources conditions, land usage, area population growth, infrastructure, and numerous other factors. The installation-focused method, referred to as the Sustainable Installations Regional Resource Assessment (SIRRA) Tool, includes 48 indicators. The watershed tool includes 23 of the 48 indicators, and Table 1 lists the selected 23, their data sources, and their spatial scale (Jenicek, et al., 2005, p. 11).

Specific information sources, including pertinent websites, are delineated for each of the 23 indicators. Further, the logic for including each indicator and its related measurements or metrics is described. An integrating feature of the

Table 1: **Indicators Comprising the Watershed Vulnerability Analysis Tool (Jenicek, et al., 2005, p. 11).**

Indicator	Data Source	Data Level
	Issue Area: Air Sustainability	
Criteria Pollutant Non-Attainment	Environmental Protection Agency (EPA)/Energy Information Administration (EIA)	County
	Issue Area: Urban Development	
Regional Population Density	USCB – 10 yrs	County
Incr. Regional Growth Rate	USCB – 10 yrs	County
Regional Population Growth	USCB – 10 yrs	County
State Smart Growth Plans	American Planning Association (APA) web site	State
Proximity to MSA	USCB	Installation
	Issue Area: TES Sustainability	
# TES in State	USFWS	State
Species at Risk	Journal of American Water Resources Association (JAWRA)	Watershed
Federally Listed TES by Ecoregion	NatureServe	Ecoregion
TES of Concern	NatureServe	Ecoregion
	Issue Area: Locational Sustainability	
Federally Declared Floods	Federal Emergency Management Agency (FEMA) database	County
Seismic Zones	U.S. Geological Survey (USGS) maps	Zone
Weather-Related Damage	National Weather Service (NWS)/National Oceanic and Atmospheric Administration (NOAA)	State
Federally Declared Disasters	FEMA database	County
Tornadoes	NOAA	County
	Issue Area: Water Sustainability	
Level of Development	JAWRA	Watershed
Ground Water Depletion	JAWRA	Watershed
Flood Risk	JAWRA	Watershed
Low Flow Sensitivity	JAWRA	Watershed
Water Quality	JAWRA	Watershed
	Issue Area: Infrastructure Sustainability	
Proximity to Interstate	Intelligent Road/Rail Information Server (IRRIS)	Installation
Roadway Congestion	2002 Urban Mobility & Federal Highway Administration (FHWA)	State
Traffic Volume	Travel Time Index (TTI) & FHWA	State

Notes: USCB = U.S. Census Bureau
TES = Threatened and Endangered Species
USFWS = U.S. Fish and Wildlife Service
FEMA = Federal Emergency Management Agency
MSA = Metropolitan Statistical Area

overall watershed tool is the inclusion of sustainability ratings for each of the 23 indicators. The ratings have been divided into five categories -- very low vulnerability, low vulnerability, moderate vulnerability, vulnerable, and high vulnerability. Specific instructions are included on how to classify the data on each indicator into its proper vulnerability classification. In general, higher vulnerability ratings would reflect greater concerns relative to cumulative effects. Such concerns could be used to trigger more aggressive local effects mitigation, and regional cumulative effects management measures.

VEC-Focused Regional Indices

Regional studies of specific VECs are being increasingly utilized, with one common feature being the identification and use of several individual indices and one or more combined indices. Brief information from a Canadian freshwater fish biodiversity study is described next. The study results could be used as siting considerations for proposed major regional developments; in evaluating the direct, indirect, and cumulative fish-related effects of both single and multiple developments and other future actions; and for development and evaluation of regional cumulative effects management measures for freshwater fish. Watersheds were used as the basic spatial units within the study.

The objective of the Canadian study was to assess both natural and societal pressures on freshwater fishes at the watershed level across the whole country; the study itself was based on using existing data and information (Chu, et al., 2003). A fish biodiversity index was developed based upon both species commonness (richness) and rarity data, statistical analyses, standardization, and ranking of the findings. The fish data were originally organized by ecodistricts and later presented via watersheds.

Watershed-related environmental indices were also calculated, with the key variables associated with climate metrics such as growing degree-days above 5ºC, mean annual sunshine hours, annual precipitation, and mean annual vapor pressure. The range of elevation within each watershed was also considered (Chu, et al., 2003). A number of stress indicators were compiled and used in a composite index to reflect historical and current pressures on aquatic ecosystems, including fish biodiversity. Examples of stress indicators included the number of crop farms, forestry activities, waste management facilities, and petroleum refining facilities. Further, road and dwelling densities, and densities of atmospheric and wastewater discharges were also incorporated.

Finally, the biodiversity indices, environmental indices, and stress indices were combined into integrated categorical indices, by watershed. The integrated indices were divided into conservation priority categories as follows (Chu, et al., 2003):

- High conservation priority – high biodiversity index (BI) with high environmental index (EI) and high stress index (SI); and low BI, low EI, and high SI.

- Intermediate conservation priority – high BI, high EI, and low SI; high BI, low EI, and high SI; and low BI, high EI, and high SI.

- Low conservation priority – high BI, low EI, and low SI; low BI, high EI, and low SI; and low BI, low EI, and low SI.

The conservation priority categories can be used to develop guidelines for management actions in Canadian watersheds. The categories are not suggestive of the importance of the individual watersheds; rather, they can be used to identify which watersheds might require more intensive management efforts for future cumulative effects.

Inventory of Watershed Indicators

In 1997, the USEPA published an inventory of watershed indicators which could be used in national comparisons of watershed conditions and vulnerability (U.S. Environmental Protection Agency, 2002). Watersheds were defined in accordance with the U.S. Geological Survey's "eight-digit scale" associated with their Hydrologic Unit Classification (HUC) System. The inventory includes seven "condition indicators" and eight "vulnerability indicators". The condition indicators incorporate: (1) assessed rivers meeting all designated uses established by state or tribal water quality standards (Section 305b of the Clean Water Act); (2) fish and wildlife consumption advisories; (3) indicators of source water quality for drinking water systems; (4) contaminated sediments; (5) ambient water quality data for four toxic pollutants (copper, hexavalent chromium, nickel, and zinc); (6) ambient water quality data for four conventional pollutants (ammonia, dissolved oxygen, phosphorus, and pH); and (7) a wetland loss index (percentage losses in specified time periods). The vulnerability indicators are comprised of: (1) aquatic/wetland species at risk; (2) toxic pollutant loads discharged above permitted limits; (3) conventional pollutant loads discharged above permitted limits; (4) urban runoff potential; (5) index of agricultural runoff potential (composed of a nitrogen runoff potential index, modeled sediment delivery to rivers and streams, and a pesticide runoff potential index); (6) population growth rate; (7) relative reservoir impoundment volume in the watershed; and (8) an estuarine pollution susceptibility index. Finally, flowcharts delineating information sources and requisite analyses for the indicators are included in Version 1.3 of the inventory (U.S. Environmental Protection Agency, 2002).

Landscape Indicators for Aquatic Impacts

Traditional approaches for predicting or evaluating the impacts of projects, plans, and programs on riverine systems have included the use of chemical and biotic indicators and indices; instream flow methods which integrate flows, water quality, and habitat information with aquatic ecological measures; and physical habitat measures based on hydrogeomorphic features. A common theme of these traditional approaches is their specific focus on the aquatic environment.

To “bridge the gap” regarding the potential impacts of proposed developments on riverine systems, Gergel, et al., (2002) proposed the use of “landscape indicators” as complements to traditional approaches. Landscape indicators derive from landscape ecology, with the latter relating to interactions between spatial patterns and ecological processes. Examples of watershed-level landscape indicators for monitoring of human impacts on various components of riverine systems include: amount of urban land cover and percentage of impervious surfaces; percentages of various land uses (forest, agriculture, non-forest, wetlands, etc.); average buffer width; average frequency of gaps in the buffer zone; percentages of developed riparian zones; and patch width in riparian zones.

Some potential advantages of the use of landscape indicators are that they can be linked to other chemical and biotic indicators and indices, and they provide direct measures of human use in a watershed. Landscape indicators can be used to assess local to regional areas, and the communication of this information can be facilitated by the use of geographic information systems (GIS). Further, land usage information throughout the United States is typically available and readily accessible.

EXAMPLES OF VEC-BASED AND SPECIES-BASED LOCAL INDICATORS

This section provides two examples of indicators; one is for functional analyses of wetlands and streams/rivers; and the other is for indicators for two species (freshwater mussels and Sonoran pronghorn). The use of simple matrix tables for relating the indicators to past, current, proposed, and future actions is also addressed.

Functional Analyses of Wetlands and Streams/Rivers

As the body of knowledge has increased on the structure and functions of specific aquatic ecosystems, it has become possible to use this knowledge as a basis for identifying potential effects of multiple stressors. For example, Table 2 displays nine widely verified functions of wetlands, along with brief descriptions of how wetlands accomplish each of the functions (after Kusler, et al., 1983, p. 7). These functions can be used as indicators. The next seven columns in the table – as specified in Note a (historical conditions, past actions, present actions, current cumulative effects, proposed action(s), reasonably foreseeable future actions, and future cumulative effects) could provide a structure for describing and evaluating the impacts of various actions on the functions. The x-y cells in the matrix could be populated by descriptive information and/or quantitative

Table 2: Example of a Functional Analysis Matrix for Wetlands (after Kusler, et al., 1983, p. 7)

Function	How Wetlands Perform the Function	Other Columns [a, b, c]
Flood conveyance	Some wetlands (particularly those immediately adjacent to rivers and streams) serve as floodway areas by conveying flood flows from upstream to downstream points	
Wave barriers	Wetland vegetation, with massive root and rhizome systems, bind and protect soil. Vegetation also acts as wave barriers.	
Flood storage	Some wetlands store and slowly release flood waters.	
Sediment control	Wetland vegetation binds soil particles and retards the movement of sediment in slowly flowing water.	
Pollution control	Wetlands act as settling ponds and remove nutrients and other pollutants by filtering and causing chemical breakdown of pollutants.	
Fish and wildlife habitat	Wetlands provide water, food supply, and nesting and resting areas. Coastal wetlands contribute nutrients needed by fish and shellfish to nearby estuarine and marine waters.	
Recreation (water-based)	Wetlands provide wildlife and water for recreational uses.	
Water supply (surface)	Some wetlands store flood waters, reducing the timing and amount of surface runoff. They also filter pollutants. Some serve as sources of domestic water supply.	
Aquifer recharge	Some wetlands store water and release it slowly to ground water deposits. However, many other wetlands are discharge areas for a portion or all of the year.	

a: Additional columns which could be added include – historical (reference) conditions for the function, past actions contributing to cumulative effects on the function, present actions contributing to cumulative effects on the function, current cumulative effects on the function, proposed action(s) contributing to cumulative effects on the function, reasonably foreseeable future actions contributing to cumulative effects on the function, and future cumulative effects.

b: In addition to changes in wetland functions, the area of the wetland or wetlands in the study area should also be considered.

c: The x-y cells in the matrix could include descriptive information as well as quantitative data, if available.

information on indicators reflective of numbers and sizes of all the actions. Finally, the concepts displayed in Table 2 could be used for one wetland, multiple individual wetlands, or all wetlands in the CEA study area.

To serve as a second example, Table 3 lists eight indicators of bottomland hardwood ecosystems which were proposed for use in CEA studies of related wetlands (Lee and Gosselink, 1998). Again, a table structured like Table 2 could be developed for a study area involving bottomland hardwood ecosystems. The first column could blend together the two columns in Table 3. Then, the right-most seven columns could be the same as those suggested for Table 2, and completed accordingly. In so doing, alterations of the indicators via past, present, and future projects could be qualitatively predicted and used to address cumulative effects on the identified indicators. As noted above, the size of the ecosystems could also be incorporated in the analysis.

A third example involves the structure and functions of streams and rivers (Allan, 1995). In the USA, this impact analysis is a requirement under the Section 404(b)(1) dredge and fill material guidelines of the Clean Water Act (U.S. Environmental Protection Agency, 2008). Briefly, stream functions include: (1) “treatment” of pollutants via degradation, adsorption and deposition of suspended materials, chemical oxidation or reduction or precipitation, evaporation, etc.; (2) nutrient cycling as represented by the various forms of nitrogen; (3) modulation and control of water temperature; (4) maintenance of a genetic diversity of organisms, including fish; (5) provision of a dynamic stability (sustainability conditions within seasonal flow patterns); (6) transport of water and sediment; and (7) maintenance of a water balance and retention of organic matter. Again, using these examples of stream functions, a functional analysis of potentially impacted streams could be conducted; that is, structure a tabular format similar to Table 2, complete the x-y cells in the table, and discuss the implications of the results. This approach would be useful for addressing the factual determinations portion of the Section 404(b)(1) guidelines. For example, 40 CFR 230.11(e) addresses aquatic ecosystem and organism determinations as follows (U.S. Environmental Protection Agency, 2008):

> Determine the nature and degree of effect that the proposed discharge will have, both individually and cumulatively, on the structure and function of the aquatic ecosystem and organisms.

Further, once the functions of estuaries are identified, the Table 2 structure could also be used to address cumulative effects on these functions.

Species-Based Indicator Analyses (Freshwater Mussels and Sonoran Pronghorn)

Two examples of the identification and use of species-specific indicators will be summarized – one is for freshwater mussel populations in the Ohio River

Table 3: **Indicators of Bottomland Hardwood (BLH) Landscape Structure and Function (after Lee and Gosselink, 1988)**

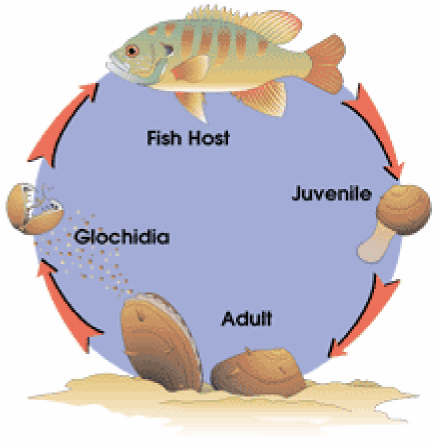
Indicator	**Definition**
Fraction of BLH remaining	BLH remaining as % of historical or potential
BLH patch size distribution	Size-frequency distribution of BLH patches
Contiguity: a. BLH to stream b. GLH to upland forest	a. Length of BLH-stream interface/2 x stream length b. Length of BLH-upland forest interface/total BLH-upland interface
Water quality	Historical change in flow-adjusted concentration of phosphorus
Nutrient loading	Total nutrient input/water flux
Stage-discharge relations	Historical changes in stage-discharge rating curves
Water detention	Volume of water stored on floodplain/ discharge
Balanced indigenous populations	Old growth stands; endangered/ threatened species; presence/absence of indicator species; change in bird species richness

and the other relates to the endangered Sonoran pronghorn in the southwestern USA.

In a navigation infrastructure modernization study associated with the mainstem of the Ohio River, cumulative effects were used as the integrator for addressing multiple impacts of numerous projects/actions over past and future time periods. In so doing, it was determined that a key VEC was freshwater mussels. To examine cumulative effects on associated mussel beds and mussel populations, the CEA study team examined available information on the species' life cycle, and they utilized an Interagency Working Group (IWG) to delineate key indicators of sustainable conditions. A synopsis of the life cycle is as follows (Harrell, 2005, pp. 5-6):

> "Freshwater mussels typically aggregate into mussel beds in the benthic environment. They exhibit --- a complex life cycle involving various stages during which important conditions must be met in order to sustain their populations. Sexual reproduction is stimulated by changes in water temperature. As Figure 1 illustrates, after female eggs are fertilized by male sperm, the embryo undergoes metamorphosis into a larval form known as the glochidium. These glochidia are released over varying time periods depending on the mussel species and local water conditions. The released glochidia of most species are obligate parasites of fish and must become attached to the fins or gills of a suitable fish host within 24 to 48 hours or they will die."
>
> "Fish may become infested with glochidia by directly coming into contact with them in the water column, on the substrate, or by attempting to ingest them, depending on the mussel species and where the glochidia are released in the water column. Females of several mussel species mimic prey fish or insects to lure fish hosts before they release their glochidia. Other mussel species secrete a protective gelatinous matrix around the mature glochidia before they are released."
>
> "The glochidia stay attached to their fish hosts for varying time periods, again depending upon the mussel species, local water quality, and factors related to the fish host. During their attachment, the glochidia metamorphose into juvenile mussels, and then the juveniles detach from the hosts and burrow into suitable benthic substrate. In contrast to mussels, which lack mobility, fish hosts can swim to potential new habitats and, thus, aid in mussel distribution. As can be seen from this brief description, native mussels also are highly dependent on water quality and sediment quality, as well as on fish."

<u>FIGURE 1:</u> **Life Cycle of Freshwater Mussels (Harrell, 2005, p. 6)**



SOURCE : North Carolina Mussel Atlas http://www.ncwildlife.org

It is important to note that while the life cycle of native mussels is known in terms of broad connections and relationships, specific details are not well known relative to the influence of water depths and flows, water turbidity, the various time periods associated with each part of the cycle, the mechanisms of glochidia-fish host attraction, and the influence of fish behavioral patterns on the conversion stage to juvenile mussels. As noted above, freshwater mussels typically aggregate into mussel beds. These beds refer to areas where mussels are consistently found in greater abundance than in surrounding areas, and where several mussel species and young animals are present.

Based on the life cycle information, the study team and the IWG (which included several experts on mussels) brainstormed the delineation of pertinent sustainability indicators; they included (Harrell, 2005, p. 9):

- the amount of habitat with stable substrates, suitable depths, suitable currents and connectivity to other mussel populations;

- measures of water quality parameters important to mussel populations;

- extent of food supplies to help ensure good growth rates and reproduction;

- availability and mobility of fish hosts to ensure reproductive success and maintain species diversity; and

- extent of disturbance from biotic stressors, such as zebra mussels, and from abiotic stressors such as river traffic.

These five indicators of diverse and sustainable mussel communities in the Ohio River could be included in a table structured like Table 2. In so doing, completion of the x-y cells in the table would provide a systematic approach for analyzing cumulative effects on freshwater mussels.

In addition to fulfilling NEPA requirements, indicators are routinely used to meet the analysis requirements of the Endangered Species Act (ESA). In some cases, EISs will need to address the impacts of proposed projects, plans, and programs, on listed species. Further, cumulative effects may need to be considered. To accomplish this, indicators for the species may need to be utilized for appropriate analyses. The Sonoran pronghorn case study described herein provides an illustration of the use of species-specific (ESA) listing criteria and scientific information to identify pertinent indicators, and to then use the indicators to describe the affected environment and analyze direct, indirect, and cumulative effects. This case study arose as a result of remand from court litigation.

In February 2001, the U.S. District Court for the District of Columbia ruled that the Yuma Training Range Complex (YTRC) Final Environmental Impact Statement (FEIS) prepared by the U.S. Marine Corps in 1997, failed to adequately address the cumulative impacts of range activities on the endangered Sonoran pronghorn located on YTRC in southern Arizona. To remedy this deficiency, the court remanded to the Marine Corps, that portion of the YTRC FEIS that addressed cumulative impacts on the Sonoran pronghorn. In accordance with the court order, the Marine Corps/Navy prepared a Supplemental EIS (U.S. Department of the Navy, 2001) reconsidering the cumulative impacts of the proposed actions and alternatives, together with other relevant past, present, and reasonably foreseeable future actions, on the Sonoran pronghorn.

Nine ESA screening criteria, which also reflect indicators for the Sonoran pronghorn population, were identified based upon the listing criteria for the species, related scientific research studies, and an existing recovery plan. The nine criteria were (U.S. Department of the Navy, 2001, pp. 2-6 and 2-7):

(1) Habitat loss or curtailment, including barriers or impediments to movement or access to habitat

(2) Habitat modification or diminished quality of habitat, including habitat fragmentation and degraded air quality

(3) Overutilization (e.g., hunting and research activities) of Sonoran pronghorn

(4) Disease and predation, including the potential of increasing predator populations or opportunities for predators to prey on Sonoran pronghorn

(5) Management or regulatory conflicts

(6) Death or injury of Sonoran pronghorn, including potential death or injury from collisions with vehicles and munitions delivery or detonations

(7) Harassment of Sonoran pronghorn, including surface vehicles, human presence, surface noise sources, overflight noise and visual presence of aircraft

(8) Diminished fawn recruitment

(9) Exposure to toxic substances or materials, including toxins found in forage plants or surface water and exposure to harmful radio frequency energy

The screening criteria were then used to identify which Marine Corps' actions would affect the pronghorn habitat and/or population. The criteria were also used to identify other past, present, and reasonably foreseeable future actions which have or would contribute to cumulative effects on the species. The criteria were then used to provide a species focus to the description of the historical and current affected environment. Finally, they were used to develop individual interaction matrices to display cumulative effects. Each matrix was focused on one criterion; e.g., habitat loss or curtailment. A final composite matrix for all nine criteria (indicators) was then developed and utilized to identify the Marine Corps' responsibilities for mitigation, as well as needed collaborative mitigation efforts from multiple contributors to the regional cumulative effects problem.

EXAMPLES OF REGIONAL AND SITE-SPECIFIC ENVIRONMENTAL INDICES

This section includes examples of environmental indices which have been or could be used in CEA. The examples range from summaries of a type of index to their specific applications. The topics range from water quality indices, to indices of biological integrity, to benthic indices of integrity, to multiple watershed indices, to multiple indices for wetland functions.

Water Quality Indices (WQIs)

Water quality indices (WQIs) have been used for several decades in EIA practice. The most common usage is to summarize historical and existing water quality conditions at multiple locations within the study area. They have also provided a framework for considering the changes in the indicators and resultant indices resulting from the direct and indirect effects of the proposed action (project). Relative to CEA, WQIs provide the opportunity to consider the effects of other past, present, and future actions, along with the effects of the proposed action, on the specific indicators and resultant indices.

An early WQI used in the USA, and one which continues to be used in both in the USA and internationally, was originally developed by the National Sanitation Foundation (NSF) (Ott, 1978). The WQI was focused on water usage for public consumption. Nine indicators were included (dissolved oxygen, fecal coliforms, pH, 5-day biochemical oxygen demand – BOD, nitrates, phosphates, temperature deviation from normal, turbidity, and total solids), and functional curves were used to convert field data into subjective value scores. Each of the nine indicators were assigned relative importance weights, thus an overall arithmetically averaged WQI could be calculated as follows (Canter, 1996, p. 133):

WQI_a = Sum of product of importance weight for each indicator times its subjective value score

This weighted sum, which would be reflective of the composite water quality, could range from 0 to 100, with the higher scores reflecting better overall quality. This WQI could also be used in CEA, with the simplest example involving the construction of a table similar to Table 2 (the nine indicators being placed in the left-hand column, and past, present, and future actions shown in additional columns to the right. Descriptive information could be used to complete the x-y cells. In so doing, it would be possible to surmise the potential directional changes in the WQI both for the proposed action and cumulatively.

In both EIA practice and for the conduction of environmental monitoring, periodic modifications have been made to the NSF WQI. For example, the Department of Ecology in the State of Washington (2002) in the USA has reduced the number of indicators to eight (temperature, dissolved oxygen, pH, fecal coliforms, total nitrogen, total phosphorus, total suspended solids, and turbidity). Functional curves similar to those in the NSF WQI are provided, and the relative importance weights have been adjusted. A new feature was added; that is, adjustments for varying flow conditions were included. Again, a table analogous to Table 2 could be developed and the Washington WQI indicators could be used in the left column.

A third example involves WQI indicator calculations which are ratio values based on applicable standards or guidelines. This WQI approach was used in a regional study of CEA in three northern rivers in Canada; the Peace, Athabasca, and Slave River Basins (Dube, et al., 2006). Further, specific environmental effects monitoring was conducted in the study area and utilized in determining the WQIs.

Indices of Biological Integrity (IBIs)

Quantitative indices of the biological integrity (IBIs) of aquatic ecosystems began to be developed in the early 1980s. A generic definition of an IBI is that it – "represents a synthesis of diverse biological information which numerically depicts associations between human influence and biological attributes. It is composed of several biological attributes or "metrics" that are sensitive to changes in biological integrity caused by human activities. The multi-metric (a compilation of metrics) approach compares what is found at a monitoring site to what is expected using a regional baseline condition that reflects little or no human impact" (Columbia Basin Research, 2008). The individual metric measurements from each monitoring site are typically converted into metric scores of 1, 3, or 5. A score of 5 is assigned if the metric value is at or near the value expected at a nearby reference site which has been minimally altered by humans. A score of 3 is assigned if the monitoring site is moderately degraded from the reference site, and 1 is assigned if it is severely degraded (Ecosystem Management and Restoration Research Program, 2005). The reference site condition (sometimes referred to as the baseline condition) refers to "the condition at a site with a biota that is the product of evolutionary and biogeographic processes in the relative absence of the effects of modern human activity" (Ecosystem Management and Restoration Research Program, 2005).

The term "metrics" refers to biological indicators which have been chosen for inclusion in the IBI. The original IBI from the early 1980s was comprised of 12 indicators (Karr, 1981). These fish-related indicators reflected taxonomic richness, habitat and trophic guild composition, and individual health and abundance. Numerous variations of the original indicators have been included in IBIs for different types of streams and rivers; accordingly, the IBI is now frequently considered as a family of related indices (Mebane, et al., 2003).

To serve as a specific example of an IBI, the following 10 indicators (metrics) were included in an IBI for Pacific Northwest Rivers in the USA. The ecological rationale for the inclusion of each indicator, along with their expected responses to environmental degration, was provided. The fish-related indicators included (Mebane, et al., 2003, pp. 243-245): number of native coldwater species, percentage of coldwater individuals, number of alien species, percentage of sensitive native individuals, percentage of tolerant individuals, percentage of common carp individuals, number of sculpin age classes or percentage of sculpin individuals if the number of sculpin age classes is not available, number of selected salmonid age classes, percentage of individuals with DELT (deformities, eroded fins, lesions, or tumors) anomalies, and catch per unit effort of coldwater individuals (number of coldwater individuals per minute of electrofishing).

Fish-related IBIs can be used to describe historical and current conditions for streams and rivers, particularly within the recent past which has sufficient monitoring data. The potential contributions of broad types of past actions to degraded aquatic conditions could also be examined. Further, and again using the structure of Table 2, descriptive information on the relationship between past, present, and future actions and their effects on the IBI metrics could be examined.

A regional index of fish assemblage biotic integrity (IBI) has been proposed for usage in the Occoquan River watershed in northern Virginia (Teels and Danielson, 2001). Further, the IBI could be used for other watersheds in northern Virginia and, with appropriate regional and local adjustments, could be used elsewhere in the United States. A key feature of the proposed IBI is that it relates land use and stream habitat information into a "human disturbance gradient". Fish community data are then summarized into attributes, and attribute performance across the human disturbance gradient is evaluated. The best performing attributes are then aggregated into a fish assemblage IBI. The IBI scores can be used to evaluate stream zones with minimal to maximum historical human disturbances, and they can also be used in a "predictive" mode related to the potential impacts of land use changes resulting from proposed projects. Identified indicators were used to develop human disturbance gradients and fish community attributes based on specified metrics and scores. Based upon this case study, it can be concluded that the IBI integrates both impact-related information and environmental resource information. According, it could be a useful “model” for use in the NEPA process.

Benthic IBIs (B-IBIs)

Benthic IBIs (B-IBIs) are typically based on metrics involving benthic macroinvertebrate assemblages. Reasons for focusing on benthic macroinvertebrates are that they are resident in aquatic ecosystems during some or all periods of their life histories. Benthic macroinvertebrates are useful indicators of stream and ecosystem conditions because they respond to both short-term episodic events, such as flooding or toxic discharges, and to longer-term cumulative effects of multiple land-based development projects (Stribling, et al., 1998).

As was noted above for the IBIs, unique sets of indicators, with some commonality, are typically used for specific streams and rivers. In like manner, B-IBIs are comprised of multi-metrics (indicators) appropriate for given locations. Further, the included indicators are typically identified following benthic macroinvertebrate monitoring and pertinent statistical testing. The systematic process actually used in the development of two B-IBIs for streams and rivers in Maryland is described elsewhere (Stribling, et al., 1998). The B-IBI for low gradient coastal plain streams and rivers included seven indicators – total number of taxa, number of EPT taxa (denotes number of taxa in the insect orders Ephemeroptera – mayflies, Plecoptera – stoneflies, and Tricoptera – caddisflies), percentage Ephemeroptera, percentage Tanytarsina of Chironomidae, Beck’s Biotic Index, number of herbivorous scraper taxa, and percentage of clingers (cling to surfaces in fast moving water). The B-IBI for high-gradient non-coastal streams and rivers included nine indicators, with four being duplicates from above – total number of taxa, number of EPT taxa, percentage Ephemeroptera, and percentage Tanytarsina. The new indicators included the number of Ephemeroptera taxa, number of Diptera taxa, number of intolerant taxa, percentage tolerant, and percentage collectors (detrivores). Again, the indicators for the B-IBIs could be displayed as per Table 2, and the effects of past, present, and other actions on each indicator could be analyzed.

Three additional brief examples of B-IBIs will be noted. One B-IBI was developed to assess benthic community health and environmental quality in Chesapeake Bay (Llanso, et al., 2003); it could be used in CEA-related studies associated with multiple stressors in the Bay watersheds and the Bay itself. A B-IBI for the Virginian Biogeographic Province (from Cape Cod, Massachusetts to the mouth of the Chesapeake Bay in Virginia) has also been developed based on monitoring data from the U.S. Environmental Protection Agency’s Environmental Monitoring and Assessment Program (Paul, et al., 2001). Finally, a B-IBI has been developed for estuaries in the southeastern USA (from Cape Henry, Virginia, to the St. Lucie Inlet in Florida) (Van Dolah, et al., 1999).

Accordingly, in a CEA study, a useful thing for the study planners to do would be to ascertain if IBIs and/or B-IBIs exist for the study area. If they do, they could possibly be used in the CEA study. For example, both an IBI and a B-IBI was used in a recent CEA study conducted on an eastward expansion of the Craney Island Dredged Material Management Area (CIDMMA) located in the Hampton Roads area near Norfolk, Virginia. Such an expansion would extend the useful life of the CIDMMA, provide additional acreage for long-term berthing and landside port facilities, and possibly serve as a logistical and tactical area supporting deployment of national defense forces. The feasibility study involved, among other things, an evaluation of the impacts to about 600 acres of shallow bottom habitat eastward of the existing CIDMMA. Cumulative impacts from the potential expansion action, and other nearby past, present, and reasonably foreseeable future actions had been identified as a concern. The study itself evaluated 17 types of actions that may contribute to cumulative effects in the Hampton Roads area. These actions include those that have occurred since the mid-1950s, are now taking place, or are anticipated to occur by the year 2050 (Canter, 2004).

Use of an IBI and B-IBI in a Mined Appalachian Watershed

To illustrate the use of fish and macroinvertebrate indices in a specific area of West Virginia which has been subject to both deep coal mining and mountaintop removal, brief information will be provided. A fish-based index, called the Mid-Atlantic Highlands IBI, or MAH-IBI, has been utilized along with a benthic invertebrate-based index (the West Virginia Stream Condition Index – WV-SCI) for evaluating the cumulative effects of acid mine drainage and other area stressors (Tetra Tech, Inc., 2000; and Freund and Petty, 2007).

Actual case studies involving use of these indices for evaluating cumulative effects have been conducted. One study examined stream water chemistry and the response of fish and macroinvertebrate indices in the Cheat River watershed (Freund and Petty, 2007). The key findings from this study indicate that … “biomonitoring programs in mined watersheds should include both benthic invertebrates, which are consistent indicators of local conditions, and fishes, which may be indicators of regional conditions. In addition, remediation programs must address the full suite of chemical constituents in acid mine drainage and focus on improving linkages among streams within drainage networks to ensure recovery of invertebrate and fish assemblages” (Freund and Petty, 2007, p. 707).

The second study involved surveys of the B-IBI, water chemistry, and thermal regime in the Cheat River watershed (Merovich and Petty, 2007). The study was focused on quantifying the interactive effects of multiple stressors (acid mine drainage and thermal effluent from a coal-fired power plant). A key finding was that the acid mine drainage was over two times more responsible than heat alone for the observed ecological losses based on the changes in the B-IBI. Finally, it should be noted that these two Cheat River watershed studies involved substantial monitoring programs followed by detailed data analyses and interpretations.

Fish and Macroinvertebrate Indices for the Ohio River

An index for assessing the condition of fish assemblages within the 981 mile mainstem of the Ohio River was recently developed. Because of the river length and associated flows, along with 20 locks and dams used for navigation purposes, no fish-based IBIs had been developed prior to 2003 (Emery, et al., 2003). To provide a scientific basis for such indices, a 10-year sampling program (1991-2001) was conducted for 55 candidate metrics (indicators) within 709 river reaches. These indicators were based on attributes of fish assemblage structure and function and examined relative to their spatial and temporal variability and their responsiveness to anthropogenic disturbances resulting from municipal and industrial effluents, turbidity from nonpoint sources and highly embedded contaminated substrates. Based upon the aggregated results and statistical testing, the resultant Ohio River Fish Index (ORFin) is comprised of 13 metrics. The 13 metrics included two from Karr's original IBI (the number of intolerant species and the number of sucker species) and six modified metrics from upper Ohio River IBIs (the number of native species; number of great-river species; number of centarchid species; the number of deformities, eroded fins and barbels, lesions, and tumors; percent individuals as simple lithophils; and percent individuals as tolerant species). The five remaining metrics included three trophic metrics (the percent of individuals as detritivores, invertivores, and piscivores), one metric based on catch per unit effort, and one metric based on the percent of individuals as nonindigenous fish species.

A computer software program was also developed for entering fish data and calculating ORFin scores (Ohio River Valley Water Sanitation Commission, 2005). Resultant testing of ORFin demonstrated that it declined significantly in river reaches where man-made effects on substrate and water quality were pronounced (Lorenz, et al., 2006). Further, information related to the sampling level for a large river to determine an appropriate fish IBI has also been released (Blocksom, et al., 2008). Finally, a B-IBI is currently being developed for the Ohio River Mainstem (Applegate, et al., 2008).

Information related to the fish VEC in the recent Ohio River Mainstem CEA study included summary results from the ORFin (U.S. Army Corps of Engineers, 2006). Further, and as noted numerous times herein, the ORFin metrics could be displayed in the left column of a table patterned after Table 2, and actions included in other columns. Descriptive information related to cumulative effects could be included in the x-y cells.

Watershed Analysis with Multiple Indices

The U.S. Army Corps of Engineers has generated several tools which can be integrated for usage in CEA studies at the watershed level. For example, the System-Wide Water Resources Program (SWWRP) of the Corps developed a watershed assessment tool for five watersheds in three southern California counties (Smith, et al., 2005). This tool is focused on three sophisticated integrity indices – one for hydraulic conveyance, one for water quality, and one for habitat integrity. Each of the indices is based upon information gathering and analysis for up to 15 specific parameters (metrics). Accordingly, the influence of single project proposals, along with the combined effects of other past, current, and future actions, on the three indices could be examined.

Hydrogeomorphic Approach for Wetlands

Section 404 of the Clean Water Act in the USA directs the Army Corps of Engineers to administer a regulatory program for permitting the discharge of dredged or fill materials into "waters of the United States". This program, which is conducted in consonance with the U.S. Environmental Protection Agency, involves the issuance of "Section 404 permits" to applicants. As part of the permit review process, the impacts of discharging dredged or fill material on the functions of nearby wetlands must be assessed.

To provide a more quantitative and systematic process for evaluating such impacts on wetland functions, the Corps has promulgated the Hydrogeomorphic (HGM) Approach (Clairain, 2002). This Approach encompasses a collection of concepts and methods for developing functional indices, and subsequently using them to assess the capacity of a wetland to perform functions relative to similar wetlands in a region. Some features of the HGM Approach involve the determination of the types of wetlands in a study area, the identification of the functions of each of the types of wetlands, the calculation of the Average Annual Functional Capacity Units (AAFCUs) currently in the area, the determination of the changes in AAFCUs over time as a result of the project (the changes will most likely be reflected in losses of AAFCUs), and the determination and evaluation of appropriate mitigation requirements for the wetland losses.

Information is also available on how the results of an HGM analysis can be used to compare multiple wetlands of the same subclass, compute present and future potential project impacts, and determine mitigation requirements (Clairain, 2002). Further, it should be noted that while the HGM Approach was initially developed for addressing the impacts of single projects, the Approach could be easily adapted to multiple current and future projects and their cumulative effects on the wetland resources.

To provide a more specific illustration, the HGM Approach has been applied to riverine wetlands (Brinson, et al., 1995). Project-specific impacts could occur from proposed dams and impoundments, as well as other types of future actions such as nearby land development proposals. Riverine wetlands refer to a class of wetlands characterized by their occurrence in a floodplain or riparian geomorphic setting. Application of the Method involves both a development and an application phase. In the development phase, wetlands are classified into regional subclasses based on hydrogeomorphic factors. A functional profile is developed to describe the characteristics of the regional subclass, identify the functions that are most likely to be performed, and discuss the characteristics that influence how those functions are performed. As noted in Table 2 above, only nine general functions were identified. However, the actual number for a class or subclass could be higher. For example, a riverine wetland guidebook includes 15 functions classified into four major categories (Brinson, et al., 1995, p. 8):

- Hydrologic

    - Dynamic Surface Water Storage
    - Long-Term Surface Water Storage
    - Energy Dissipation
    - Subsurface Storage of Water
    - Moderation of Groundwater Flow or Discharge

- Biogeochemical

    - Nutrient Cycling
    - Removal of Imported Elements and Compounds
    - Retention of Particulates
    - Organic Carbon Export

- Plant Habitat

    - Maintain Characteristic Plant Communities
    - Maintain Characteristic Detrital Biomass

- Animal Habitat

    - Maintain Spatial Structure of Habitat
    - Maintain Interspersion and Connectivity
    - Maintain Distribution and Abundance of Invertebrates
    - Main Distribution and Abundance of Vertebrates

For each of the 15 functions, definitional information is included on the identified indicators to be used to assess specific riverine wetlands. Further, a numerical index is then delineated and calculations are illustrated for each of the 15 functions. In concept, these indices are analogous to those used in Habitat Suitability Index (HSI) models for evaluation species in the U.S. Fish and Wildlife

Service's Habitat Evaluation Procedures (HEPs) (described below). In effect, the functional indices are based on function-specific conceptual models.

The development phase also includes the selection of reference riverine wetlands to represent the range of variability exhibited in the study area. Data from the reference wetlands reflect the conditions exhibited by the undisturbed, or least disturbed, wetlands and landscapes in the study area. The functional indices resulting from the assessment models provide a measure of the capacity of a wetland to perform functions relative to other wetlands in the regional sub-class. The application phase of the Approach includes characterizing selected wetlands, assessing their functions, analyzing the results of the assessment, and applying them to evaluate the effects of a specific project or multiple projects. Detailed information on how to calculate AAFCUs for the various functions is available elsewhere (Brinson, et al., 1995; and Clairain, 2002). Once the losses in AAFCUs are determined, then specific elements of a mitigation plan can be determined. Further, proposed regional cumulative effects management measures could also be evaluated.

Development of GIS Layers

Geographic information systems (GIS) are frequently used to aggregate spatial information on various indicators into composited layers. For example, interpretive ratings or scales for the indicators can be multiplied by their assigned relative importance weights, with the product being displayed in a spatial context. As evidenced by several papers at the IAIA's Special Topic Meeting on Assessing and Managing Cumulative Environmental Effects held in Calgary (November 6-9, 2008), GISs have become a valuable tool in CEA. One example of several papers addressed multiple uses of GIS in EIA and CEA (Atkinson, et al., 2008).

EXAMPLES OF HABITAT SUITABILITY MODELS

Habitat suitability models have been used for almost three decades in EIA practice in the USA. Two examples are the Habitat Quality Index (HQI) models associated with the Habitat Evaluation System (HES) of the U.S. Army Corps of Engineers, and the Habitat Suitability Index (HSI) models within the Habitat Evaluation Procedures (HEPs) of the U.S. Fish and Wildlife Service. Further, a newer model for determining mitigation requirements is called Habitat Equivalency Analysis (HEA). These three examples are briefly summarized herein.

Habitat Evaluation System

The HQI models are based on the identification, measurement, and evaluation of specified indicators for seven types of habitat – streams, lakes, wooded swamps (wetlands), upland forests, bottomland hardwood forests, open lands, and the terrestrial wildlife value of aquatic habitat. Aggregation of the measurement values is accomplished via their conversions into index scales and their multiplication by assigned relative importance weight factors. These products are aggregated into overall HQI scores. These scores are then multiplied by the size of each type of habitat to yield Habitat Unit Values (HUVs). Changes in HUVs resulting from proposed projects are used as measures of impact. Further, they can serve as the basis for identifying and planning mitigation measures (U.S. Army Corps of Engineers, 1980; and Canter, 1996b, pp. 390-400).

It should be noted that the HES addresses habitat conditions for fish and wildlife as a whole; that is, it is not focused on specific indicator species. The concepts of HES can be utilized to develop habitat suitability models for other types of habitats; and such adaptations have been made in the USA and internationally. As noted above, the HES is primarily oriented to the prediction and evaluation of direct and indirect effects of single proposed projects on the indicators of HQIs and the changes in size of each affected habitat type. In addition, the HES can be utilized to address the cumulative effects of multiple past, current, and future actions on the indicators of HQIs, and on the sizes of each affected habitat type. Further, mitigation measures can be developed for the incremental impacts of the proposed project as well as other actions in the CEA study area.

The HES method can be used for describing historical and current conditions for aquatic and terrestrial ecosystems, and for predicting changed conditions resulting from proposed water resources and other types of projects. Usage of the HES method requires field data on identified indicators, the use of associated functional curves, and the calculation of resultant HQIs and HUVs. It can also be useful for identifying key indicators and impacts associated with proposed projects. Further, functional curves are available for 52 indicators comprising the HQI models for the seven types of habitat (U.S. Army Corps of Engineers, 1980).

Habitat Evaluation Procedures

The HSI models for the HEPs are also based on the prior identification of indicators, and their subsequent measurement and evaluation. However, the HEPs are focused on specific species in the study area rather than fish and wildlife as a whole (as per the HES). For the specific species, HSI models have been developed. These models include specified indicators which are related to key life requisites such as food, water, and habitat needs. The measured values for the indicators are converted into quality scales based on the use of functional curves (analogous to those used in the HES). Then, aggregation calculations for the curve scores are based on unique mathematical models developed for each species. These aggregated values represent the species’ HSIs; these data are then multiplied by the sizes of the specified habitats for each species, and a final total of Habitat Units (HUs) is produced (U.S. Fish and Wildlife Service, 1980; and Canter, 1996b, pp. 400-415).

It should be noted that the HEPs and the resultant species-specific HUs, as they were originally perceived, were focused on the prediction and evaluation of the direct and indirect effects of single proposed projects. In addition, the HEPs can be utilized to address the cumulative effects of multiple actions on the indicators of HSIs, and on the sizes of relevant habitat for the species. Further, mitigation measures can be developed for the proposed project as well as regional cumulative effects management measures for other actions in the CEA study area.

HEP can be used for describing historical and current habitat-related conditions for selected specific species, and can be used for predicting changed conditions and impacts from single to multiple proposed projects and actions. Usage of HEP requires field data on identified indicators, the use of functional curves, and the calculation of HSIs and HUs. A basic guidance manual for the HEPs is available (U.S. Fish and Wildlife Service, 1980). The manual describes how a habitat-based approach can be used for impact assessment and project planning. Further, the quantification method based on determining HSIs for selected species, the total area of available habitat, and the resultant HUs, is also described. Over 150 HSI models have been developed; and they can be procured on-line from the USFWS or from a Corps of Engineers website and related CD (U.S. Army Corps of Engineers, 2007). This site includes HSI models for 7 aquatic invertebrates, 57 fishes, 2 amphibians, 4 reptiles, 31 waterfowl/shorebirds, 7 upland game birds, 5 raptors, 20 songbirds, and 20 mammals. A specific citation for the HSI model for the pronghorn antelope is Allen, et al. (1984). Finally, it should be noted that numerous modifications and simplifications of HSI models have been made (Canter, 1996b, pp. 415-427).

Habitat Equivalency Analysis

A relatively recent concept involving the replacement of “lost ecological services” as a mitigation planning tool has been developed. For example, earlier habitat-related mitigation measures have focused on restoration via the replacement of lost or damaged habitat on a physical area (e.g., acres) basis. Such replacements have often included the use of ratios; for example, replace each lost acre with two acres or more. Such ratios are used to account for many uncertainties, including recovery times and the potential for success. In contrast, the Habitat Equivalency Analysis (HEA) method is focused on the replacement of “lost ecological services”, thus the necessary studies may include the identification and quantification of indicators of such services. Early attention was given to this approach as a means of calculating compensation required for habitat damage resulting from oil spills and other contaminant-related effects (National Oceanic and Atmospheric Administration, 2006; and Thur, 2007).

Applications of the HEA method are currently being examined by the U.S. Army Corps of Engineers (Ray, 2008). Case studies are also being developed; for example, Penn and Tomasi (2002). An excellent discussion of practical steps associated with the use of the HEA method is available (Ray, 2008). Further, due to the emphasis on evaluating ecological services, the method holds promise as a tool for CEA, including the development of site-specific mitigation measures and regional cumulative effects management measures.

SUMMARY AND LESSONS LEARNED

This review of environmental indicators and indices, and habitat suitability models, has demonstrated that there are numerous examples of such tools which have been or could be used in both EIA and CEA. The majority of the included examples and case studies have noted tools that are in the "state" or "response" categories. The term state denotes that the focus is on historical and current environmental conditions, while the term response relates to the response of VECs and their indicators to changes (effects) resulting from past, current, and future actions in defined study areas. Some key lessons learned from this review are:

- In conducting CEA studies, it is useful to think from the mindset that "I am the VEC or indicator, and what is my historical and current condition and how have I, or will I, be affected by multiple past, present, and future actions?"

- Due to the likely absence of detailed information on future actions, the described tools can still be used to "predict" future conditions by focusing on up-or-down changes in individual indicators or their aggregated displays.

- Numerous regional and site-specific tools are currently being developed, with primary examples being IBIs and B-IBIs for specific watersheds and water bodies. Such tools, even though they may not have been developed for CEA usage, can certainly benefit CEA studies and practice.

- Usage of selected appropriate tools described herein can aid in conducting a systematic and documentable CEA study.

- Retrospective analyses based on organizing historical information on environmental conditions for selected VECs and their indicators, along with information on past actions which have affected these conditions, can provide a foundation for prospective analyses related to future cumulative effects.

- Indicators, indices, and habitat suitability models can also be useful in planning follow-up monitoring and adaptive management programs.

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