Issue Paper

Development of Santa Monica Bay Habitat Health Indices

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Abstract

This paper presents the results of recent evaluation conducted by staff of the SMBRC (the author) on the feasibility of developing and using system-wide index to assess the ecological health of major habitats in Santa Monica Bay. The evaluation revealed that despite it's being imperfect due to its qualitative nature, the new ranking system used in our latest State of the Bay report is among the first in the Country to do so on the level of habitat/ecosystem and it is a critical first step toward the development and adoption of a more quantitative, scientifically viable index for assessing the habitat's ecosystem health. While development of such index is feasible for all major types of habitats in the Bay, it can be done easier and sooner for some habitats than others, depending on the availability of monitoring data, history of involvement, and extent of progress to date. .

Background

An index, if well-designed, provides a consistent measure to periodically assess the health of a habitat and allow resource managers to track changes over time, attribute causes to these changes, and ultimately provide policy makers with information they need to evaluate the effectiveness of current resource protection policies and plan for the future. An index is also a friendly and objective way to communicate the results of scientific evaluation/assessment to the general public.

While the use of habitat health index is highly desirable, not many have been developed and widely used, primarily due to the lack of data and the difficulty in reaching consensus on how to include and weigh multiple factors of a complex ecosystem associated with any type of habitat. One way to put it is that people, even the most brilliant scientists in the world can be intimidated by the complexity of the natural system and are afraid that no matter how many metrics are incorporated, an index will still too simple to accurately interpret the results and characterize the condition of a habitat. On the other hand, the more information gained on more aspects of a complex system, and the more that scientific community understands the complexity of the system, there tend to be stronger resistance to deduct the information in a simple form as what an index inherently exhibit.

In contrast to the lack of habitat health indices, various indicators have been widely used to characterize and report on almost all things related to the environment. Few would argue that environmental indicators are the second best thing in the absence of good indices. Besides, data used by environmental indicators often provide what needed to fill matrices of a habitat index. It is not a stretch to say that an index is a composite of a suite of environmental indicators; or to say that the development and use of environmental indicators lay foundation and make it possible for construction of the metrics needed by an index. For these reasons, in order to determine the feasibility for developing habitat health indices, it is important to examine the history and current use of environmental indicators as well as the scale and status of current monitoring programs.

The purpose of this research project is to assess the feasibility and evaluate viable approaches for development of ecosystem-based health indices for all major types of habitats in Santa Monica Bay and its watershed. During the course of this research project, the author compiled and analyzed information on existing environmental indicators and habitat health indices developed elsewhere with the focus on how these indices deal with the data gap issue. The author also conducted survey and interviews of members of the SMBRC Technical Advisory Committee (TAC) members, scientific staff of other National Estuary Programs, and other outside experts to gain their insight on the status of existing indices, the main limitations, constraints, and obstacles encountered in the index development processes, and what approach should be taken to facilitate index development for our purposes.

Review of Existing Programs and Information

Comprehensive Monitoring Program Development in Santa Monica Bay

The first effort to develop a comprehensive monitoring program for Santa Monica Bay began more than 20 years ago, shortly after the establishment of the Santa Monica Bay Restoration Project (SMBRP, the Santa Monica Bay NEP). During the process for developing the first comprehensive monitoring program, the SMBRP first devised a Regional Monitoring Comprehensive Framework and then detailed sampling designs for eight of 16 monitoring components identified in the Framework. Four major types of habitats, pelagic, wetlands, kelp, and intertidal were included in the initial eight components. Although not included in the initial eight, detailed monitoring design for soft bottom habitat completed during the Bight-wide regional monitoring was adopted for Santa Monica Bay and incorporated into the Bay comprehensive monitoring program.

Prompted by new requirements adopted in the NPDES permit for the City of Los Angeles' Hyperion Waste Water Treatment Plant, the SMBRC initiated a new process in 2005 to accelerate the implementation of the Comprehensive Bay Monitoring Program. This process included a review of implementation efforts to date and an update of monitoring objectives and designs for the original five habitat-related monitoring components. A noteworthy change from the original plan and design principle is that the underlying goal of the new program is to address all elements of the Comprehensive Framework at a regional scale (i.e., the scale of the Bay) and in a coordinated manner that fosters data integration and regional interpretation and assessment. In addition, the newly updated program emphasizes several key features in its monitoring designs in particular and of the Program as a whole:

- First, monitoring designs focus on the status of the overall Bay system, rather than on individual discharges and their associated impacts. Thus, the characteristic monitoring approach is to distribute monitoring sites throughout a habitat, using randomized or systematic designs, or a combination of both.
- Second, the Program does not include all possible monitoring, but focuses on the status of key resources at the scale of the Bay as a whole. By the same token, the program incorporates higher-level, derived data products that aid in the interpretation of monitoring data to the greatest extent possible
- Third, the Program defines "monitoring" broadly to include the acquisition and integration of data from a wide range of other sources. An important aspect of the Program is its focus on taking maximum advantage of existing data gathering and analysis efforts being conducted by other parties.

Besides the original five habitats, the updated monitoring program also for the first time added monitoring design for sandy intertidal habitat. However, several other habitat types, including creeks and streams, coastal dunes and bluffs, and seagrass beds were still left out of the Program. Ironically, one reason for overlooking some of these habitats (dunes, bluffs, and seagrass beds) was the complete absence of any monitoring at these places, which made it difficult to define monitoring objectives and attribute for these

habitats. As an alternative, the new Program did recommend special (reconnaissance) studies be conducted for these habitats first before development of specific mornitoring designs.

Development and Application of Environmental Indicator in Santa Monica Bay

The effort to develop environmental indicators for the Bay began in the early 1990s. It was initially folded into the Bay Comprehensive Monitoring Program because indicators were considered first and foremost as key attribute and parameters recommended for long-term monitoring (see discussion above); and later, for good reason, has coincided with development of the State of the Bay reports. Although the list of environmental indicators has evolved over the years, what can be called "core indicators" have remained relatively the same, such as pollutant loading from POTWs, bacterial indicator counts and number of beach closures, etc. This high level of fidelity can be attributed partly to the fact that the Bay Restoration Plan, which defined the key management questions to be addressed by the environmental indicators, had not been updated for more than fifteen years. For historical reasons, the original BRP placed more emphasis on pollution prevention and reduction with conventional mechanisms rather than habitat restoration and resource protection. Those actions included in the BRP for addressing resource and habitat issues were a hodgepodge at best. There was neither discussion nor action recommended to address issues related to many major habitat types, including subtidal rocky reef, intertidal, dunes and bluffs, among others. As a result, there were no indicators developed to measure the health of these habitats.

The Bay Restoration Plan underwent a major update in 2008. One of the key changes was a revamped section on natural resource protection. The new natural resource protection section took a systematic, ecosystem-based approach and identified key issues and objectives for addressing those issues one by one for every major habitat in the Bay and the Bay watershed.

Designed and organized to mirror the structure of the updated BRP, the 2010 State of the Bay report provided an assessment on the status and trend of environmental conditions of every major habitat in the Bay and Bay watershed. In addition to continuously use a suite of environmental indicators, the report for the first time presented an assessment for all major type of habitats. The assessments were presented graphically on a standardized, easy to understand scale. Because it was the first time the Commission have attempted to assess all habitat conditions in a standardized way, the TAC gave a lot of thought on developing a matrix that can be used for all habitats, and determining a method of displaying the conclusion graphically without oversimplifying the information. However, the basis for the status and trend graphics was by all means still largely qualitative instead of quantitative.

Despite the limitations, the new matrix and graphic presentation for assessing the ecological condition of the Bay's habitat was a great step forward. It also raised the awareness for the need, and support for the effort to develop a more robust and objective index for these habitats so that future reports on the state of the Bay will be more

concrete, less controversial, and easier to write. For these reasons, one of the first tasks given to Commission staff by the TAC was to conduct a review, report to the TAC, and lay out next steps to support and facilitate index development efforts.

Indicators and Indices Used by other NEPs and Local Programs

Most of the 28 NEPs (including us) have adopted a list of environmental indicators and used these indicators in their periodic state of the estuary reporting. The number of indicators on these lists varies greatly, from less than ten to more than 30. These indicators report on a broad range of issues including relatively new and emerging issues such as watershed/land use, climate change, and socioeconomics (Table 1). Understandably habitat is one of the most populated categories, only second to water quality. The most common indicator is the acreage of seagrass beds, reflecting the prominence of this habitat along the U.S coast. However, given the importance of this habitat, it is a bit puzzling that no index seems to have been developed or applied for measuring the health of this ecosystem as a whole.

Table 1. Types of environmental indicators adopted and/or used by the 28 National Estuary Programs

Program	Human Health				Watershed							Water Quality													Habitat														
	SFC	TC	BC	BI	ImP	LU	OS	Pop	H&B	WU	Prg	Cnv	PLP	PLN	Tox	WC	SC	MW	Bio	FD	Nu	EC	WQL	Prg	OS	OW	Ben	SAV	Man	HAB	Int	Est	Wet	Up	R&S	FI	Mci	Inv	Shl	Fsl
Albemarle-Pamlico Sounds (n/a)																																								
Barataria-Terrebonne Estuary	X			X					X	X						X					X			X										X				X	X
Barnegat Bay	X		X			X																			X			X		X						X				
Buzzards Bay	X					X															X							X					X		X					X
Casco Bay	X		X		X			X					X	X			X	X				X	X		X			X						X						
Charlotte Harbor	X						X		X		X	X				X	X				X	X	X			X	X	X	X	X	X	X	X	X	X			X	X
Coastal Bend Bays and Estuaries	X	X		X												X	X				X		X					X		X	X		X	X		X				X
Lower Columbia River Estuary (n/a)																																								
Delaware Inland Bays	X					X		X				X	X						X		X							X												
Delaware Estuary						X	X	X		X		X							X		X	X	X										X	X			X		X	X
Galveston Bay (n/a)																																								
Indian River Lagoon (n/a)																																								
Long Island Sound			X			X	X	X			X			X	X	X	X	X			X			X				X					X		X					X
Massachusetts Bay				X									X				X	X			X																			
Mobile Bay	X	X	X	X	X	X	X	X	X			X		X	X	X	X	X			X		X	X				X					X							X
Morro Bay	X			X	X							X									X					X		X												X
Narragansett Bay (n/a)																																								
New York/New Jersey Harbor	X	X	X	X										X		X	X				X					X	X			X		X	X							X
Peconic Estuary	X		X		X							X			X	X	X				X				X	X		X		X			X							X
Piscataqua Estuary			X	X	X		X					X				X	X	X			X				X		X	X												X
Puget Sound	X	X		X	X	X							X				X	X	X	X		X	X	X				X												X
Puget Sound	X			X	X					X						X	X								X	X		X						X						X
Puget Sound	X		X		X	X				X							X		X							X		X												X
San Francisco Bay (n/a)																																								
San Juan Bay (n/a)																																								
Sarasota Bay (n/a)																																								
Tempa Bay																X					X							X												
Tillamook Bay	X			X												X		X										X							X					X

Findings from Indicators Used by NEP Programs

- It seems that larger, more established programs have made more efforts to use indices, instead of, or in addition to environmental indicators. However, none of the ones used are for habitat as a whole, or in other words, ecosystem-based.

- Lack of data appears to be the main reason (or excuse) for not using index. Most existing indices are for assessment of water quality, where more monitoring data exist and data are more quantifiable, or comparable against established standards. The few rankings used for habitats status and trend assessment are, like us, based on professional judgment of a panel of experts.

- Three reports adopted bar graphics similar to the habitat health index we used in our latest State of the Bay report. Delaware Estuary uses a bar-shaped gauge, so is bar graphics used by Puget Sound in their reports. However unlike our report, the bar graphics in all these cases are primarily used to show status and trend of an indicator, rather than overall condition of a habitat (Puget Sound did have additional bar graphics for overall marine water quality and marine and fresh water health).

  Coastal Bends uses a colored (orange to blue) status and trend bar to show whether the indicator data is in a positive (healthy, dot placed to the right, in the blue) or negative state (dot placed to the left, in the orange). Arrows indicate the direction of any trends the data reveals. The length of the arrow reveals the rate of change. The graphics are based on CBBEP's interpretation of the data. In addition showing status and trend of each indicators, a

- One of Charlotte Harbor program’s objectives is to develop and meet site-specific criteria which are protective of living resources. The types of criteria under consideration for parameters that affect living resources and are not sufficiently addressed existing water quality standards are stream and lake condition index, fish species index, and trophic state index using TP, TN and chlorophyll a with and without phosphorus.

- Buzzards Bay uses an index of ecological capacity to rank the state of the Bay on a 0-100 scale. The index integrates scores assigned to eight indicators in three categories: pollution, watershed health, and living resources. The current state of the Bay is measured against the healthiest Buzzards Bay in recorded history (1602).

- Piscataqua Estuary uses a sign (symbol, positive, negative, or caution) to show the status of each indicator.

- Most programs include an indicator on the extent of seagrass or eelgrass beds.

- Growing numbers of NEPs use extent of impervious surfaces in the watershed as an indicator.

- Paconic Estuary Program identified and listed clearly their indicators up front in the document, which make compilation of information from its program far easier. Piscataqua Estuary Program also clearly summarized their twelve indicators in a table form. Moreover, they linked each indicator to specific CCMP goals albeit the goals vary greatly in their specificity. Charlotte Harbor Program identified indicator(s) specifically for a CCMP goal and for each indicator. It identified the available products, gaps, and target. Barataria-Terrebonne Program associated each of its 34 indicators to 10 focus questions up front as well.

- Only one program, Paconic Estuary, uses indicators of groundwater contamination.

- It is somehow difficult to categorize the indicators involving fish especially when a subject report apparently intended (but did not make it clear) to use and interpret the data for measuring both the health of a fishery and the health of the habitat/ecosystem. In that case, a rule of thumb is adopted to categorize the indicator: unless the report made it specifically clear, if the data is about the abundance of the fish population, it is categorized as a habitat/ecosystem health indicator; if the data is primarily on fishing landing or CPUE, it is categorized as an indicator of fishing.

- Some programs adopted and reported on some indicators even though there seem to be no or very little data to report on.

- Long Island Sound and Puget Sound Programs have indicators on marine mammals (Seals and Orca). Puget Sound also has an indicator on concentration of toxics in marine mammals (harbor seal). Casco Bay has an indicator for concentration of contaminants of emerging concern in tissue sample of seals.

- Puget Sound is also the only program that includes oil spill as an indicator.

- Delaware Estuary and Puget Sound included indicators of climate change.

- Barataria-Terrebonne is the only program that has an indicator on reptiles (alligator).

The preliminary results of the review have shown that most, if not all NEPs rely primarily on environmental indicators, rather than ecosystem health index for their state of the bay/estuary reporting. We do see that various types of “index” were used by several NEPs in their reporting. But a closer examination of these “indices” reveals that they take

into account a few metrics at most, mostly are a set of water quality parameters without biological attributes al all.

The only relatively widely adopted and used one is benthic community (or response) index. Interestingly, all of the benthic indice used by those NEPs were based on the same index developed by EPA under its EMAP program. This index was modeled after the benthic response index first developed during the Southern California Bight-wide regional monitoring program, which was first implemented in 1994 and participated by the Santa Monica Bay Restoration Project.

Assessment of Index Development Feasibility

Definition and Categorization of Environmental Indices

The dictionary definition of the term "index" varies, depending on the circumstance of its usage (from meaning "pointing" in index finger to "an alphabetical listing" in an index in a book). The closest definition of "index" to its use in biological and environmental science is its usage in mathematical science to mean "a number or ratio indicating a specific characteristic, property," or more accurately, "a numerical scale by means of which variables, such as levels of the cost of living (in environmental science, the equivalent would be fish population or assemblage), can be compared with each other or with some base number." (http://www.thefreedictionary.com/index). However, in environmental management practice, the usage of this term does not always adhere to this definition. In fact, they do not most of the time. Most often the term is used interchangeably with the term "indicator." In many other cases, it is just used to refer to a simple numerical ranking scale.

While many would consider the graphic presentation we used in our latest State of the Bay report a type of index already, the type that the SMBRC TAC is working on, which is the topic subject of this paper, are indices that abide by the more strict definition and that must be developed in accordance with a standard protocol and be able to withstand rigorous scientific scrutiny.

It is also important to point out that the focus of SMBRC TAC's effort is to develop indices that can be used to assess the ecological health for all major types of habitats in the Bay and its watershed, not a certain characteristic or attributes of a habitat. This is where we draw the line to distinguish an indicator from an index, for an index that can indicates the overall ecological health of a habitat most likely would need to integrate data on characteristics of multiple attributes of that habitat. This being said, we do recognize that in the initial stage we may need to start with a simpler index that incorporates only few, or even just one attribute. This type of simple index is generally called response index and they are usually developed first when the amount of available data is limited. The strategy is to take a tiered approach: as more data become available, we can upgrade the existing simpler index by incorporating new metrics, step by step, or combine multiple indices into a composite index (Figure 1).

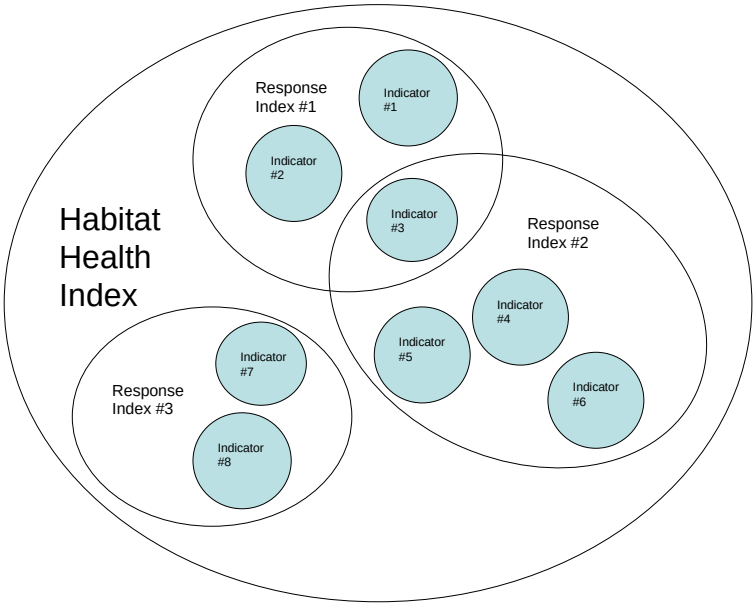

Figure 1. Relationship among environmental indicators (or individual attribute), response indices, and the habitat health index.

While there will always be variation on the theme, an index development process generally follows five basic steps, or phases, each next phase depends on the outcome of the earlier phase, every phase requires rigorous data processing and analysis

- Identify indicators and/or major attributes of the habitat's ecosystem
- Collect and assemble monitoring data set on the identified attributes. The data must exhibit a quantifiable gradient, correspond to a range of environmental impacts, and be calibrated among data collected from different locations.
- Define thresholds of biological responses, especially a reference threshold in order to place index values in perspective. Other thresholds involved define deviation from the reference condition.
- Standardize the scale of the index values to ensure that a particular index value indicates the same level of effect.
- Validate the index, normally by using a data set independent of the calibration data

There is no doubt that because of this multiple-phase process and rigorous requirements in every phase, index development, especially the index for health of a habitat's ecosystem remains extremely challenging. The fact that that many in the scientific community believe the challenge is so daunting contribute to their strong resistance to any attempt to use a standard metric in reporting habitat conditions, such as the one used in the 2010 State of the Bay report. However, there is also growing recognition that development and use of such index are feasible in our region, in light of the progress

made to date, including those made by the SMBRC as well as other research institutions and organizations in Southern California.

History and Status of Habitat Health Index Development in Southern California

By all account, Southern California leads the nation in developing and applying indices of environmental conditions, especially scientifically-validated indices aimed at assessing the habitat health at the ecosystem levels. This advantage can be largely attributed to the long history that monitoring agencies and research institutions in Southern California have in collaborating to develop and conduct regional monitoring which provide the range and depth of data sources and institutional platform indispensable for development of such indices. The earliest, and perhaps still the most successful effort is the benthic response index (BRI) developed during Bight 98, the first Southern California Bight-wide regional survey which the SMBRP had significant involvement.

The BRI is an objective, quantitative index that measures the condition of a benthic assemblage, with defined thresholds for levels of environmental disturbance. Thresholds were established for reference condition as well as for four levels of biological response. The four response levels were established as the index values at which key community attributes were lost. Although using benthic assemblage moved the index development beyond the level of individual species, and it was considered even better than a multi-metric approach, the BRI, strictly speaking, is still an indicator for the condition of the benthic habitat instead of an index of the habitat ecosystem health. As it is true for probably all types of habitat, while the infaunal assemblage maybe the best measure of biological response to the effects of pollution, there are many other physical, chemical, and biological attributes/metrics such as fish assemblage, floral assemblage that may have various types and levels of effects on the overall condition of the ecosystem.

Since the introduction of the BRI, new regional monitoring initiatives as well as more index development efforts have sprout up. Similar indices have been developed for benthic habitat using fish assemblage and megabenthic invertebrate. Regional monitoring consortium were formed and standard protocols were developed and adopted for monitoring of subtidal rocky reef, rocky intertidal, and steam habitats. Taking advantage of the plethora of data collected through these regional monitoring programs, several research institutions and programs in the region, including SMBRC has begun discussion and in several cases supported research initiatives to develop new indices. Overall, the extent and pace of the progress is encouraging. Although it may take relatively long time for some habitats (such as sandy beach, and ocean pelagic system), it is close to be done for some habitats (such as coastal wetlands) and can be done much sooner for several other habitat types (streams, soft bottom, and rocky subtidal).

Table 2 summarizes the status of indicator and index development for each main habitat found in Santa Monica Bay. The following section provides a brief overview of the progress as well as remaining challenges/obstacles for index development for creeks and streams, coastal wetlands, sandy beaches, rocky intertidal, rocky reefs, and soft bottom. There is no discussion regarding index development for coastal dunes and bluffs,

seagrass beds, and open ocean at this time because no effort appears exist in these areas. More research is needed to determine the feasibility of index development in these areas.

Table 2. Status of indicator and index development for main habitats of Santa Monica Bay

Habitat	Indicator	Response Index	Habitat Health Index	Next Steps
Creeks and Streams	Miles of stream restored; # of fish passage barriers removed (miles of creek reopened for fish migration)	Index of biotic integrity (IBI), benthic macroinvertebrate assemblage based; algal IBI is under development	Integration of multiple communities (macroinvertebrate, fish, and algae is being discussed	Develop an algal Index of Biotic Integrity.- Integrate multiple communities (e.g. Fish and algae).Conduct regional monitoring of riparian habitats in the Bay watershed to collect data that can be used for IBI ranking
Coastal Wetlands and Lagoons	Inlet condition; tidal range, plant species and abundance; hydrology; soil characteristics; benthic infauna; sediment chemistry; sediment toxicity, water quality, animal taxa		California Rapid Assessment Method (CRAM) Index developed. CRAM index scores calculated based on average of four attribute scores: landscape context, physical structure, hydrology, biological structure.	Improve and modify the existing index to make it more applicable to small wetlands/lagoons
Coastal Dunes and Bluffs	N/A			
Sandy Beaches	Grunion, surf-zone fish survey, bird estuary survey, bird rare species survey	On-going pre-development discussion		Form a workgroup to jumpstart development of a regional standard monitoring program
Rocky Intertidal	Abundace of core (13) and optional species of invertebrates and seaweeds, biodiversity	A habitat health index is under development (primarily biodiversity based attributes)		Evaluate new data sets to get wider range of human disturbance; complete the index development
Seagrass Beds	Development of a regional monitoring program is in progress	No initiative		
Rocky Reefs	Kelp canopy estimate, Invertebrates, fish, algae using CRANE protocol, fish density and biomass, recreational and commercial catch estimates	Rocky reef health index primarily based on fish assemblage. The Assemblage is quantified based upon feeding guild, density, and fidelity		Expansion of existing index to involve other data sets (algae, invertebrate)
Soft Bottom	Sediment chemistry, benthic infauna, demersal fish & invertebrate, fish tissue; commercial bottom fishing	Benthic Response Index (BRI), Fish Response Index (FRI), Megainvertebrate response index (MIRI)	Integration of BRI, FRI, MIRI was recommended	Integrate BRI, FRI, and MIRI., develop effective inner and outer shelf indices

Open Ocean		No initiative		

Creeks and Streams

An index of biological integrity (IBI) has been developed and widely applied. This IBI, specifically designed for coastal creeks and streams in Southern California, compares and ranks changes in riparian conditions against conditions at reference area. It is a composite index that combines scores of a selected set of metrics measuring the condition of macroinvertebrate communities. The metrics selected to include in the IBI are considered most responsive to the stressor gradients for a specific stream class. A similar IBI is under development for measuring the condition of the periphyton communities.

The main drawback if the existing IBI is that it is based primarily on benthic macroinvertebrate assemblages and does not necessarily capture all type of impacts such as the impact to algal-based food web changes from nutrient over-enrichment. Also, the threshold used in the current IBI may not be robust because it is not ecosystem function based. There is also concern that the current IBI may be overridden by biocriteria developed by the State in the next few years. The current IBI is also limited in its applicability to all types of stream due to the difficulty in defining reference condition under certain hydrological regime such as flood plains.

One logical next step would be to develop an algal IBI, which not only appears to be feasible but is already in the pipeline planned by researcher at SCCWRP. The next step would be to integrate multiple communities (macroinvertebrate, fish, algae, and others) to produce a composite index that captures most, if not all type of impacts and measures the overall health of the ecosystem. On the other hand, in order to apply the IBIs for reporting the conditions of creeks and streams in the Santa Monica Bay watershed, a regional monitoring program of riparian habitats in the Bay watershed need to be established and carried out to collect and supply adequate data for calculating IBI ranking.

Coastal Wetlands and Lagoons

The California Rapid Assessment Method (CRAM) index used for assessing wetland condition is probably the first and by far the only “true” index by our definition, i.e. an index for measuring ecosystem health of a habitat. The CRAM index assesses wetland condition based on four attributes: landscape context, hydrology, physical structure, and biotic structure. Each of the four attributes has associated metrics, which are scored by matching the correct score from a list of descriptive narrative conditions for each metric to what is observed in the wetland. Metric scores are then compiled into numerical scores for each attribute and an overall score for the wetland. The overall score for a wetland indicates condition relative to the best achievable condition for that wetland type in the state.

One issue with the current CRAM index is that it may favors large, structurally complex wetlands within each wetland class and the scoring system may not best reflect or be

applicable to smaller wetlands, such as Malibu Lagoon, Zuma Lagoon, and Topanga Lagoon in the Santa Monica Bay watershed. Also, the scoring used by CRAM index still relies primarily descriptive narratives rather than numerical values derived from rigorous data analysis and calibration. These issues can be resolved gradually through calibration and adjustment of the scoring criteria with more field testing.

Sandy Beaches

Several constraints make development of health index for sandy beach rather difficult, and may be more difficult than for other types of habitats. To begin with, there are very few people working on beach ecology locally or even countrywide. Most of those who do focus on study of single species and not at the level of ecosystem. There are also theoretical and methodological challenges. The massive human impacts on sandy beach makes it almost impossible to separate human impacts from the natural setting, and the mobile nature of the sandy substrate makes monitoring of a permanent transit very difficult.

Nonetheless, seeing how indices were being developed and used for other types of habitats after overcoming similar or different kinds of obstacles, more sandy beach researchers now think it is doable, and there is growing interest to participate if someone can initiate and get the ball rolling. Set up a working group with people having experience in index development, people with knowledge of beach ecology and involve beach managers would be a good way to jumpstart the index development. But committing more resources to carry out baseline monitoring of key physical, chemical, and biological attributes would be even more important.

Rocky Intertidal

The establishment of MARINe, the Multi-Agency Rocky Intertidal Network greatly facilitated regional, long-term monitoring of the rocky intertidal habitats in Southern California. In addition to supporting collection and sharing of long-term data under a standard protocol, MARINe has organized a group of experts who are working to develop biological indices of health, based on the long-term data set and decades of collective experience analyzing rocky intertidal systems. Based on what have been worked out to date, the index will likely to be based on biodiversity-associated attributes, either all species or a handful of indicator species, that correspond to various degrees of disturbance. MARINe is working toward publishing a "State of the Rocky Shore" report which would use these bioindices to provide information on the health of the communities for the public.

Main remaining obstacles include the difficulty to define what disturbance means, because different group interpret disturbance differently. It is also difficult to differentiate natural from anthropogenic disturbance. Once the definition of disturbance and reference conditions is finalized, the remaining steps would include development of indicators, selection of metrics and formula for scoring, ranking, etc.

Rocky Reefs

A rocky reef habitat health index was developed in 2009 as part of the study on the status of nearshore rocky reef habitat in Santa Monica Bay and the regional survey conducted during the Bight 08. The index is based on a three parameter model where fish assemblages are quantified based upon feeding guilds (using mean size as a surrogate for biomass), density, and fidelity. The three parameters are treated equally. Habitat value for a sampling site is the sum of the values calculated for each depth zone at the site.

The development of this new index is made possible largely by the high quality and inclusive data collected following a standard survey protocol established under the Cooperative Research and Assessment of Nearshore Ecosystems (CRANE) statewide research program. Yet the habitat health index is based on fish assemblages only and has not considered, nor has it taken into account other matrices such as vegetation (primarily algae), and invertebrate.

Next steps could include expansion of existing index to involve other data sets. Analyze how the existing index respond to other parameters, such as kelp density, algal cover styles density. As for fish assemblage parameters used in the current index, conceivably the fish mean size can be replaced with direct biomass measurement.

Soft Bottom

Three benthic response indices have been developed which compare and rank changes in benthic macroinvertebrate (BRI), fish assemblage (FRI), and megabenthic invertebrate (MIRI), respectively, against conditions at reference areas. The benthic macroinvertebrate BRI was the earliest index ever developed in the region, probably in the Country and has been widely used. It has also been modified and adapted to soft bottom habitats in harbors and estuaries. The BRI, is an abundance weighted average pollution tolerance score of organisms occurring in a sample. It sets thresholds that can be used to assess whether species occurring in a sample meet reference condition criteria and whether they are impaired in terms of biodiversity, community function, or defaunation.

The newer FRI and megabenthic community indices have not been widely used. The SMBRC used the FRI last time in its 2004 State of the Bay report. However, researchers who developed the FRI still has difficulty in differentiating chemically-based effects and food supply effects, It also has only one threshold instead of four as the BRI. Judging from the significant progress made, the logical next step should be to integrate all response indices into a system-wide index to measure the general health and integrity of the soft bottom ecosystem.

Conclusion

The review of the existing programs, including other NEPs around the country and programs located in Southern California reveals that almost all NEPs have adopted and

primarily rely on the use of a suite of environmental indicators to assess and report on the environmental conditions of their bays and estuaries. A few of them have also developed and used a graphic grading system to present the status and trend of various issues of concern measured by the indicators, whether it is water quality, health of a certain type of habitat, fishery, or institutional/programmatic action implementation. Either by default or coincidence, the graphics used by most of these programs are strikingly similar to what we used in our latest State of the Bay report. (They all use a colored bar, either horizontal or vertical, to layout the gradient, position of a dot to indicate where on the gradient the condition of the subject is, and the direction of an arrow to indicate the trend). Aside from the similarity in visual presentation, our program is the only one that used this kind of grading system for assessment of ecosystem health of every major type of habitats in our project area (including both the Bay and the Bay watershed).

Despite the wide use of environmental indicators, only few programs have used indices for assessing and reporting the environmental status and trend in very limited areas. The area where an index is most likely to be used is water quality, while sediment quality/response index appears to be the only scientifically-validated index in use. Probably because of its scientific validity, it also appears to be the most widely accepted and used index everywhere.

None of the graphic grading systems found during this research assign numerical scores, neither are they based on any type of indices. Like the grading system adopted in our 2010 State of the Bay report, most, if not all, explicitly noted that the graphics/grades were based on staff's/scientists' subjective interpretation of the available information and may not fully reflect the view of contributing staff/scientists. Clearly, because of the lack of either the necessity or monitoring data, development and application of science-based indices have not been high on most program's project list. This presents us with the opportunity to be the first to lead the way on one hand. It also poses the challenge for cutting a new trail without readily available guidance.

Recommendations:

The Bay Commission should boost its effort and invest more resources to support development and application of ecosystem health-based indices for all major types of habitats in the Bay and the Bay watershed. The graphic grading system developed and used in the latest (2010) State of the Bay report provides the Commission with a good starting point to make the next move. The Bay Commission is also well-positioned to take a lead in this index development effort given the development work already initiated, underway, or completed by the Commission and various research institutions in the Southern California region. The Bay Commission should take advantage of the extensive monitoring data and existing index development efforts, boosting our support to, and strengthening collaborations with these institutions. For habitats where no index development effort exists, the Bay Commission should play a more active role to help jumpstart such effort.

Because of the extensive quantity and quality specificity for the data required, developing a scientifically-validated index for ecosystem health will indubitably a very time-consuming process. Besides convincing everyone be patient and persevere, the Commission TAC should consider taking a phased approach. Under this approach, phase one is the grading system that was already in use for the 2010 State of the Bay report, in which the grades were given based entirely on non-discretional interpretation of existing monitoring data and other evidence. In phase two, in time for the next State of the Bay report, or calling it the interim phase before the scientifically-validated index is ready, we should consider adopting a numerical grading system in which numerical scores are assigned based on available monitoring data compared against existing standard or threshold, or roughly defined reference conditions. Because the status of index development will undoubtedly differ from one habitat type to another, rather than synchronizing the index development effort for all habitats, we should set realistic goals and milestones for each habitat separately. The graphic below (Figure 2) shows the recommended timeline for index development based on information compiled and analyzed during the preparation of this report.

Habitat	**Timeline**										
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Creeks and Streams											
Coastal Wetlands and Lagoons											
Coastal Dunes and Bluffs											
Sandy Beaches											
Rocky Intertidal											
Seagrass Beds											
Rocky Reefs											
Soft Bottom											
Open Ocean											

Figure 2. Phased approach recommended for development of ecosystem health indices for major habitats in Santa Monica Bay

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Appendix A

Summary of Environmental Indicators Used by NEP programs

Appendix B

Examples of Habitat Condition Grading Systems