Regional Ecosystem Indicators for the Gulf of Maine: Pre-Summit Draft

FISHERIES, CONTAMINANTS, AND COASTAL DEVELOPMENT

Prepared for the Gulf of Maine Summit

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Image Courtesy of NOAA

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Introduction

Work commenced on the development of regional ecosystem management indicators in 2003 with the formation of a US/Canada indicators work group. In January 2004, they convened 100 scientists and managers that ratified the following:

> *Vision for the region*: A sustainable northwest Atlantic ecosystem that ensures environmental integrity and that supports and is supported by economically viable, healthy human communities.
>
> *Mission for regional indicators*: To track the status and trends in ecosystem integrity throughout the northwest Atlantic region and to provide information for management decisions at regional and local scales.
>
> *2004 Indicators Workshop Goal*: To achieve consensus on a list of key indicators focusing on six major categories: fisheries, eutrophication, contaminants, coastal development, aquatic habitat, and climate change, for which regional data will be compiled and tracked to indicate changing trends in ecosystem integrity through the northwest Atlantic region (*i.e.* northeast U.S./Maritime Canada).

Leading Management Issues

To guide its deliberations, the work group developed and implemented an Indicators Web Survey in December 2004. Over 200 US and Canadian respondents completed the survey and identified key topics, goals, themes, and commented on straw indicators. Cross-tabulations were run on the respondent's job characterization, ocean scales studied (*e.g.* estuary, coastal zone, embayment, river, etc.), and the jurisdiction with which they were associated (*e.g.* state/province, NGO, etc.).

While the survey identified six management issues this report focuses on:

Fisheries

- What are the trends in and the status of exploited fisheries stocks?
- What are the effects of fishing on non-targeted species and their associated communities?
- What are the effects of fishing and non-fishing activities on marine habitat and fisheries productivity?
- What are the trends in the socioeconomic characteristics of fishing?

Contaminants

- How are contaminants in the region changing?
- How is the input of contaminants changing over time and space?
- Are management actions changing the extent and severity of human health effects?
- How well are contaminant management actions protecting ecosystem integrity?

Coastal Development

- What is the type, pattern, and rate of land use change?
- How are these changes impacting the integrity of coastal ecosystems?
- How is the region responding to changes in coastal ecosystems?

Regional Indicators

A regional indicator is a measurement (quantitative or qualitative) that provides useful information about the condition of the natural, cultural, or economic environment. They can be used to:

- Raise awareness of issues that need to be addressed
- Provide information about existing conditions
- Inform decision-making in strategy selection
- Monitor changes to measure performance and determine the effectiveness of actions

Report Contents

This report identifies regional ecosystem management indicators for the region's three leading management issues – fisheries, contaminants, and coastal development. These draft indicators are the result of six-months of volunteer effort to crystallize the January 2004 workshop recommendations into a set of "working indicators". In addition, draft indicators related to aquatic habitats, nutrients and climate change are also available at:

www.gulfofmainesummit.org.

In the appendix is a list of the individuals that have prepared these materials.

Fishery Indicators

FISHERY INDICATOR 1
Impact of Commercial Fish Landings on the State/Regional Economy

Purpose: This information is useful to fishery managers as a tool in examining the socioeconomic consequences of management action/alternatives. In the NW Atlantic Coastal Indicators Workshop web-based survey, this was a fishery indicator of interest to the respondents. At the state levels, this type of information can be used to help plan for infrastructure needed to support commercial fishing. Residential/tourism related development has created conflicts with the docks and marine support infrastructure required to support traditional economic endeavors such as fishing.

Ecosystem Objective: Supporting healthy socioeconomic communities and maintain traditional economic activities in coastal communities.

Measure: Scott Steinback (NOAA/NMFS/READ- Social Sciences Branch) has developed an input/output model (I/O) to assess the contribution of Maine's commercial fishing industry to the New England economy. This study will serve as an example of the multiplier effect (direct, indirect, and induced sales, income and employment) of commercial dockside landings in the wider economy. Direct impacts are sales, income, and employment directly related to commercial fishing, seafood dealers, and seafood processors. Indirect impacts are sales, income, and employment in industries that supply commercial fishers, seafood dealers, and seafood processors. Induced impacts are sales, income, and employment generated by employees of the direct and indirect sectors. Final demand sectors (restaurants, fish markets, etc.) are not included in this analysis. The indicator, total impacts, is the sum of direct, indirect, and induced impacts.

Total impacts on sales, personal income and employment are calculated for 12 different subregions in New England. Data from Northeast vessel trip reports, Northeast dealer weigh-out slips, Northeast permit applications, and County Business Patterns information was used to delineate the subregions. This data defines the regional distribution channels of seafood as it flows from harvesters to dealers and then to processors. Goods and services imported into New England from outside the region were not included in this analysis, since their economic impact occurs outside the region.

The default IMPLAN (Impact Analysis for Planning) model provides county-level estimates of business activity for up to 528 sectors in each subregion. Commercial fishing activities were classified by gear type and sales estimates (ex-vessel revenues) for each subregion. Production functions for seafood dealers in each subregion were developed from information in the Kearney/Centaur report (1986). A production function accounts for all expenditures required to produce one dollar of sales, and measures the additional value a seafood dealer must charge to cover their fixed and variable operating costs.

Outcome: For the year 2001 the total impact of Maine's commercial fish landings on all businesses in New England was $833.4 million. Of this total the Maine dockside value was $250.6 million, which generated $582.8 million for New England dealers and processors. A significant fraction of this impact ($438.5 million) accrued to New England businesses outside the state of Maine. Total income in coastal New England states was $317.8 million and total employment was roughly 11,000 jobs. Most of this income is in fishing, wholesaling and retailing.

Illustration: The 17 commercial fishing gear types examined had ex-vessel revenues of: inshore and offshore lobster pots ($171.7 million); small/medium/large bottom trawls ($25.0 million); diving gear ($16.4 million); hand gears ($12.7 million); small/medium/large scallop dredges ($9.0 million); mid-water trawl ($6.0 million); sink gillnets/other fixed gear ($5.5 million); etc. The coastal seafood processing manufacturer's generated sales of $148.3 million, while the revenue from seafood dealer trade was $100 million. For comparison, the revenues from some other industrial sectors included: services ($86.7 million); finance, insurance & real estate ($56.9 million); transportation, communication & public utilities ($22.6 million); construction ($13.0 million); agriculture ($5.3 million); etc. See Table 1.

Features: This illustration is only applicable to the state of Maine for the year 2001. The IMPLAN software model was implemented with the assumption that seafood prices and the quantity of imports are constant over time. Thus, this static analysis can't be extrapolated in space or time. The example shows what can be done with existing databases in the public domain utilizing an I/O model to estimate the regional economic impact of commercial dockside landings.

Limitations: The dockside ex-vessel revenues for the 17 gear types covered include those landed at ports in Maine. The IMPLAN model implementation assumed that 40% of the dealer sales value was exported out of the region and was thus not available to local seafood processors. Also, goods and services imported into New England from outside the region are not included in the economic impact analysis, since their benefits accrue to businesses outside the region. The final demand sectors (restaurants, fish markets, etc.) are not included in this analysis. This static analysis makes it difficult to evaluate how the harvesting sector and the rest of the New England economy would change over time.

Interpretation: Economic scientists would have to advise fishery managers on how to interpret the I/O model results and explain its use for evaluating management actions.

Comments: Obviously this analysis is too complex to be done on an annual basis, but it might be possible to conduct it at 3-5 year intervals if it provided information useful to fishery managers/policy makers. Proxy indicators (ex-vessel value, number of fishing licenses by port, employment estimates, etc.) could be produced on an annual basis. The recreational and commercial fishing revenues and their regional economic impacts (direct, indirect and induced) are generated using applications of the IMPLAN model software, but the total dollar values can't be compared with one another (apples versus oranges analogy). The IMPLAN model does allow a comparison of the economic impacts from commercial fishing in relation to other industrial sectors contributing to the state economy.

References

Kearney/Centaur. 1986. The economic impact of the commercial fishing industry in the United States. Prepared for National Marine Fisheries Service; Alexandria, VA.

Steinback, Scott. 2004. Economic impacts of Maine's commercial fishing industry. Personal Communication.

Table 1 (next page) Total New England Coastal Region Sales Impacts (2001 $).

Sector	Downeast ME	Upper Mid-Coast ME	Lower Mid-Coast ME	Southern ME	NH Seacoast	Gloucester MA	Boston MA	Cape & Islands MA	New Bedford MA	Rhode Island	CT Seacoast	Non-Maritime NE	New England
Commercial Fishing							Sales ($'s)						
Inshore Lobster Traps	15,600,000	97,200,000	47,300,002	10,300,000	0	0	0	0	0	0	0	0	170,400,002
Offshore Lobster Traps	469,000	374,000	430,000	0	0	0	0	0	0	0	0	0	1,273,000
Large Bottom Trawl	0	11,600	7,910,000	0	0	0	0	0	0	0	0	0	7,921,600
Medium Bottom Trawl	0	1,320,000	8,950,000	172,000	0	0	0	0	0	0	0	0	10,442,000
Small Bottom Trawl	0	1,400,000	4,810,000	497,000	0	0	0	0	0	0	0	0	6,707,000
Large Scallop Dredge	0	267	0	0	0	0	0	0	0	0	0	0	267
Medium Scallop Dredge	456	663,000	30,700	695	0	0	0	0	0	0	0	0	694,851
Small Scallop Dredge	4,720,000	3,150,000	301,000	14,600	0	0	0	0	0	0	0	0	8,185,600
Surf Clam, Ocean Quahog Dredge	2,590,000	0	0	0	0	0	0	0	0	0	0	0	2,590,000
Sink Gillnet	53,400	101,000	2,570,000	90,800	0	0	0	0	0	0	0	0	2,815,200
Diving Gear	2,630,000	10,200,000	3,500,000	58,500	0	0	0	0	0	0	0	0	16,388,500
Midwater Trawl	0	3,320,000	2,730,000	0	0	0	0	0	0	0	0	0	6,050,000
Fish Pots and Traps	2,890	22,200	867,000	0	0	0	0	0	0	0	0	0	892,090
Bottom Longline	0	21,400	521,000	0	0	0	0	0	0	0	0	0	542,400
Other Mobile Gear	0	266,000	50,900	0	0	0	0	0	0	0	0	0	316,900
Other Fixed Gear	115,000	971,000	765,000	845,000	0	0	0	0	0	0	0	0	2,696,000
Hand Gears	2,830,000	4,090,000	5,380,000	365,000	0	0	0	0	0	0	0	0	12,665,000
Agriculture	1,586,639	83,544	184,475	95,530	65,428	102,054	259,787	90,763	35,284	61,027	917,671	1,794,423	5,276,623
Mining	1	42	12	7	137	3,949	24,320	515	143	133	4,947	19,084	53,290
Construction	27,375	139,025	522,412	137,243	726,372	636,430	3,635,011	367,251	432,410	679,287	2,204,664	3,466,348	12,973,829
Manufacturing	17,173	163,253	1,080,853	161,123	978,311	1,236,124	5,565,347	120,805	1,002,076	3,011,179	5,814,385	7,624,731	26,775,360
Fresh and Frozen Seafood Processing	6,185,520	8,468,029	8,990,900	1,249,391	15,421,085	40,263,416	23,942,833	1,434,192	30,511,185	8,824,137	2,943,927	92,757	148,327,372
Manufactured Ice	0	0	0	0	3,049	26,900	279,668	20,884	238,408	128,231	14,699	161,932	873,771
Cordage and Twine	7,022	984	5,002	488	0	61	1,933	0	5,731	1,960	4,136	2,685	30,003
Paperboard Container and Boxes	0	0	231,071	215,439	173,500	552,639	1,191,985	0	518,638	860,311	1,450,108	3,766,739	8,960,431
Transportation, Communications, Public Utilities	27,538	98,559	775,318	113,321	1,158,012	820,534	7,225,896	338,916	603,452	1,585,514	4,755,590	5,128,624	22,631,275
Motor Freight Transport and Warehousing	56,351	74,398	683,270	73,350	630,628	419,285	2,730,297	99,792	389,044	718,658	1,458,473	3,405,608	10,739,156
Water Transportation	178,775	900,306	1,406,669	92,531	436,689	1,476,326	5,513,875	2,836,265	640,342	1,904,712	7,135,216	807,185	23,328,889
Trade	56,018	273,631	1,492,111	398,105	2,155,538	1,551,643	9,169,028	885,600	1,222,765	2,125,272	5,375,436	8,567,537	33,272,684
Seafood Dealers	11,300,000	48,599,999	35,000,000	4,580,000	131,000	188,000	47,700	116,000	15,600	118,000	0	0	100,096,298
Wholesale Trade	25,890	119,962	1,396,475	173,696	2,480,174	1,819,505	14,648,581	216,802	1,252,765	1,802,779	7,482,548	8,321,213	39,740,392
Finance, Insurance and Real Estate	25,021	175,837	1,739,517	198,825	2,386,731	2,093,149	19,757,489	700,523	901,984	2,773,684	11,365,553	14,733,327	56,851,641
Services	95,147	505,303	3,106,620	621,241	4,169,107	3,817,186	30,466,210	1,371,777	2,074,895	5,328,929	15,245,452	19,855,881	86,657,749
Governement	14,206	59,550	270,837	60,814	343,962	316,265	1,572,080	105,781	190,472	387,324	844,880	1,731,333	5,897,504
Other	598	8,918	14,624	4,243	13,520	20,240	101,914	8,481	6,050	17,564	97,244	88,006	381,402
Total	48,614,020	182,781,807	143,015,769	20,518,942	31,273,243	55,343,707	126,133,955	8,714,348	40,041,244	30,328,701	67,114,929	79,567,415	833,448,078

FISHERY INDICATOR 2
Days at Sea (DAS) for Fishing Vessels

Purpose: Fishery managers use DAS as a surrogate measure of fishing effort by commercial fishing vessels (i.e. bottom and mid-water trawls) and recreational fishing vessels (i.e. head and charter boats). In the Northeast Multispecies Fishery Management Plan, one of the management tools used is effort control based upon days-at-sea (DAS) allocations to different components of the fishing fleet. Technical interactions between the fishing fleet composition, management regulations and abundance of fish stocks leads to changes in the effort directed towards different fish stocks over time. For non-fishery policy makers, this can provide potential insights on the direct/indirect ecological impacts associated with fish harvesting (pressure component).

Ecosystem Objective: Effort is a pressure indicator for fisheries harvesting which has fishery management ramifications for restoring/maintaining exploited fishery resources at sustainable levels, while reducing the effects of bycatch on nontarget species and gear impacts on benthic habitats (ecosystem goals).

Measure: Effort for commercial fishing vessels can be obtained from Vessel Trip Report (VTR) database that provides information on the number of trips and days absent from port (DAFP). Recreational charter and head boats with federal licenses also report fishing activity to the VTR database. For other components of the saltwater angling community, the Marine Recreational Fisheries Statistics Survey (MRFSS) estimates effort from random phone surveys of fishers and nonfishers in geographically defined areas. The indicator would be annual changes in the DAS for different gear types/fisheries in the Gulf of Maine (GOM).

Outcome: For FMPs which employ effort controls the indicator can be interpreted against the plan standards. Fleet overcapitalization (too many boats, chasing too few fish) and unused licenses (latent effort) pose challenges to managers in matching fish abundance to catch capacity, especially when plans are underway to rebuild depleted fish stocks. The ecosystem impacts of effort changes are more difficult to interpret due to changes in effort levels and areas in which fishing occurs due to changes in fish stock levels, management regulations, fleet composition, etc. The type of fishing gear utilized and area fished lead to bycatch effects and potential gear impacts on benthic/pelagic. Habitat.

Illustration: Could show the relationship between abundance (fishery independent surveys), commercial catch, and effort over time for a depleted groundfish stock (i.e. cod). When the abundance is high, low levels of effort lead to good catches. Over time as abundance declines, the effort has to be increased to support good catches. Eventually excess harvest reduces abundance causing depleted stock sizes and declining catches, which requires greatly reduced effort in order to allow stock rebuilding.

Features: The VTR data is mandatory, so that the accuracy of trip and DAFP values as a relative measure of annual changes in fishing effort is probably good. Linkages to other indicators (stock status, size characteristics of exploited species, spatial distribution of fishing activity, effects of fish harvest on community structure) are important in interpretation of the effort indicator. DAFP data includes non-fishing time and could over-estimate fishing time in offshore regions, while trip data has a reverse bias, since it ignores steaming time to reach the fishing grounds.

DAS and other effort indicators (soak time for pot fisheries and deployment times for gillnets) can be computed on annual basis for the area occupied by the fishing fleet. These areas can be inferred from the home ports and ranges of the fishing vessels or can be measured directly in aggregate from the VMS (vessel monitoring system) on larger commercial vessels or at sea observers on a portion of the fishing fleet. Depleted fish stocks often only occupy a fraction of the historical range and management measures such as rolling closed areas and DAS limits can influence the geographic area occupied by the fishing vessels.

Limitations: The areas occupied by the fishing fleet vary with management regulations; fish abundance hot spots; and socioeconomic constraints (cost of fuel and ice versus price for catch). Thus, the temporal/spatial scales can be variable over time. Estimates of effort are costly to produce, so that this is likely to be beyond the capabilities of local management entities, which use the number of permits as a proxy.

Interpretation: Can be used to evaluate the success of FMPs employing effort control as a way to control fishing mortality or rebuild depleted fish stocks. FMPs are designed to control the behavior of fishermen/women in the hopes of matching the Total Allowable Catch (TAC) to the fishing fleet harvesting capacity. Supporting data from other indicators will enhance the value of DAS in order to infer the ecological effects associated with fish harvesting.

Comments: The influence of FMPs on the behavior of the fishing fleet is not well understood, so that this is an area that would benefit from an adaptive management approach, in which the management regulations could be altered as more experience is gained. Increased socioeconomic research on the behavior of fishers would also be beneficial. Many biological and socioeconomic components influence the level of effort and where it occurs.

Managers employ a variety of tools to protect fish stocks from being overharvested, while trying to obtain the optimum sustainable yield (OSY) from the fishery for the benefit of the nation. Since the maximum sustainable biological and maximum economic yields do not coincide, deciding how to evaluate OSY varies amongst constituencies. Ecosystems-based fishery management (EbM) approaches are being developed to approach this problem in a more holistic fashion, to include the effects of fish harvesting on non-target species and essential fish habitat (EFH).

Fisheries harvesting exerts impacts on biodiversity, structure/function of the marine food web from top-down removal of predators or bottom-up removal of prey; effects of fishing gear on benthic habitats; and other aspects that comprise the integrity of the Gulf of Maine ecosystem. We lack targets/reference points to evaluate these "ecosystem health" goals in relation to fishing effort, but future research or adaptive management experiments may provide insights on developing indicators in this area.

FISHERY INDICATOR 3
Changes in Community Structure

Purpose: Fishing and environmental changes directly and indirectly affect the community structure of marine ecosystems by altering species composition and the size/age distributions of target and non-target species. Changes in community structure influence ecological processes (e.g., food web dynamics) that determine how ecosystems function. This indicator will track changes in species, size, and trophic composition of marine communities.

Ecosystem Objective: Minimize impacts of fishing on community structure of the Gulf of Maine ecosystem

Measure: Species similarity, size spectra, and trophic composition of the fish community can be computed using data collected by fisheries independent surveys conducted by state/provincial and federal agencies.

Outcome: An increase in fishing pressure should be detected by a steeper slope of the size spectra, while changes in environmental conditions that affect productivity within the region will be reflected in the intercepts (i.e., higher productivity conditions should result in a higher intercept and vice versa) (Bianchi et al. 2000). Monitoring the trophic composition will enable detection of food web shifts, which may affect functioning of the biotic community. The aforementioned metrics are compiled for an aggregate community, but they will not detect shifts in the relative abundance of individual species. Similarity measures can quantify temporal variation in the relative abundance of species (Collins et al. 2000).

Illustration: Size spectra will be displayed as line graphs. Trophic composition can be presented as pie charts of biomass or numbers of organisms representing major trophic categories, or as line, graphs showing temporal changes in the mean trophic level of organisms collected in surveys. Similarity per se cannot be shown in a graphical form, but species composition is shown using bar graphs or pie charts.

Features: This indicator could be computed on an annual basis using data from fisheries independent surveys. However, responses might not be easily detected on an annual basis; computations every 3 to 5 years may be adequate and more sensitive. The indicator should be applied at a regional scale. Aspects of this indicator would be closely linked to the size composition and stock status indicators, which would be used to monitor changes in the abundance and structure of individual populations.

Limitations: It can be difficult to differentiate between the effects of fishing and environmental conditions if changes are noted in the community-level indicators. A change in the intercept of the size spectrum may signify that productivity in the ecosystem has changed. But while differences in intercepts have been observed and associated with productivity across systems, little research has been conducted to determine how reliable or responsive the intercept is to changing environmental conditions within a system. Particularly in nearshore waters, eutrophication and climate change may change community composition that affect the slope of the size spectra (i.e., eutrophication may promote growth of smaller organisms, such as plankton and planktivores) irrespective of fishing patterns.

The "community" encompassed by this indicator will be limited to those groups sampled by standardized fisheries independent surveys, typically juvenile and adult fish and commercially-harvested benthic macroinvertebrates. Some components of the community, such as plankton, jellyfish, squid, and benthic organisms may undergo substantial changes that will not be captured by this indicator. Data for elements that are not sampled by bottom trawl or hydroacoustic surveys could be provided by surveys for fish eggs and larvae or by plankton surveys.

Interpretation: The components of this indicator need to be interpreted over time; no interpretation can be offered after a single year because there is no target (or "correct") size spectrum or trophic composition for the Gulf of Maine fish community. Community similarity requires more than one year of information for its computation.

Comments: Existing time-series data from surveys in the Gulf of Maine region can be analyzed to 1) develop a historic context for changes in these community-level indicators and 2) determine an appropriate time scale for applying the indicator. In addition to data from federal fish (dating back to the 1960s) and plankton (for 1977-1987) surveys, inshore trawl surveys conducted by states could be incorporated into this indicator.

References

Bianchi, G. and 10 co-authors. 2000. Impact of fishing on size composition and diversity of demersal fish communities. ICES Journal of Marine Science 57: 558-571.

Collins, S. L., F. Micheli, and L. Hartt. 2000. A method to determine rates and patterns of variability in ecological communities. Oikos 91: 285-293.

Rice, J. C. 2000. Evaluating fishery impacts using metrics of community structure. ICES Journal of Marine Science 57: 682-688.

FISHERY INDICATOR 4
Fleet/Industry Composition

Purpose: The number of active participants/vessels comprising a fishery, size make-up of the fleet, activity level at fishing ports along the coast, etc. may be indicators of the socioeconomic status of the fishing community. As an example, there were over 3,000 licensed fishermen involved in the fishery for green sea urchins in Maine at its peak in 1994; now there are only a few hundred. The decline in numbers of active licenses in this case is directly the result of declines in resource abundance. The New England groundfish fleet is reduced in size. Factors include buy-outs, reduced number of fishing days, loss of permits, and overfished groundfish stocks.

Ecosystem Objective: To maintain a diverse and productive fishing industry and coastal economy.

Measure: Number of active license holders, distribution of licenses along the coast, vessel size composition of fleet, age of participants, number of landing trips by port.

Outcome: This indicator will detect changes in the human component of the ecosystem. Changes in numbers of participants/vessels over time may indicate changes in the amount of available resource to be harvested, resulting in changes in economic incentives to participate. Changes in this indicator may be reflected in the dockside value of landings, how those landings are distributed along the coast, in the shoreside infrastructure and processing sectors.

Illustration: Changes in numbers of license holders and/or vessels over time; changes in size composition of vessels over time; changes in spatial distribution of the fleet over time; number and location of active fishing ports over time.

Features: 5-year, and 10-year changes in numbers of license holders, age distribution of license holders, number of licensed vessels at specific locations throughout the range of the fishery.

Limitations: Changes in these indicators may not be a direct reflection of the status of the stocks. Management objectives and measures such as limited entry may restrict the number of entrants in a fishery. Detailed socioeconomic data may not be available in sufficient to detail for some measures.

Interpretation: The components of this indicator need to be analyzed in conjunction with such factors as management measures implemented during the same period, markets, and economic conditions such as the price of fuel, stock conditions, and other confounding influences.

Comments: Historically there has been a lack of socioeconomic information for most fisheries. Data are most available for federally managed fisheries.

FISHERY INDICATOR 5
Spatial Distribution of Exploited Resources

Purpose: The spatial distribution of exploited fishery resources reflects both abundance and the state of the ecosystem. The Gulf of Maine cod stock was formerly abundant throughout the Gulf, but is now concentrated in the western areas. Ames (2004) has proposed that depletions of cod stocks in coastal and eastern areas of the Gulf of Maine are the result of overfishing local stocks. Indices of spatial distribution provide insight into the nature of the distribution and abundance of the species in question (Halliday 2001). Current patterns of distribution and abundance must be compared to historical patterns, patterns of exploitation, and oceanographic patterns.

Ecosystem Objective: To restore/maintain the historical distribution of targeted marine resources over time.

Measure: Halliday (2001) proposed several potential measures derived from fishery independent trawl surveys:

1. An index of population concentration (the proportion of the total survey area occupied by the top nth percent of the total population)
2. An index of prevalence (the proportion of non-zero sets)
3. An index of local density (the average number per non-zero survey tow or CPUE where present)
4. The stratified mean catch per standard survey tow (Smith 1996).

Outcome: Changes in these indexes over time may reflect actual changes in abundance and distribution.

Illustration: Line graphs of indexes plotted over time. Maps of bubble plots of species distributions over time or averaged by 5-year intervals may indicate changes in distribution. These figures are available in the Essential Fish Habitat technical reports published by the National Marine Fisheries Service.

Features: The indicators should be calculated from fishery-independent trawl survey data that covers the geographic range of the stock. The indices for species are calculated annually and should be compared over time.

Limitations: Factors such as fishing and physical environmental conditions affect the abundance and resulting distribution of species. Therefore, one must consider fishing effort, temperature trends, climate change, predator-prey interactions, etc. as possible factors affecting changes in the spatial distribution of species.

Interpretation: Area occupied and abundance are positively correlated for a number of demersal fish populations (Winters and Wheeler 1985, Creco and Overholtz 1990, Rose and Leggett 1991, Swain and Wade 1993, Marshall and Frank 1994). These studies show generally that changes in distribution over a range of population abundance levels are the result of interactions between fish density and geographic area occupied, likely mediated through such density dependent processes as prey density and availability, and habitat preferences. Swain and Sinclair (1994) show that these processes may also be age or size dependent and that no single index will provide a satisfactory view of the spatial response of a demersal fish population to changes in population abundance.

Comments: This indicator would be examined on a species-by-species basis and not all species will react the same way or in concert. Thus, the change in an index for a single species does not necessarily reflect the health of the ecosystem. It is unlikely that all harvested marine resources will ever be maintained at high abundance throughout their historical range.

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FISHERY INDICATOR 6

Status of a Targeted Fishery Resource

Purpose: U.S. federal and interstate fishery management plans contain biological reference points for spawning stock biomass (SSB) and harvesting rate (as fishing mortality-Fmsy, F10, etc.) that allows managers to evaluate the status of stocks and establish appropriate management measures. These biological reference points provide an operational definition for "sustainable fisheries harvesting" and attainment of these targets should reduce the impact of fishing on the health of the Gulf of Maine ecosystem.

Ecosystem Objective: Maintain harvested fishery resources at target levels.

Measure: Fishing mortality rates, estimates of SSB, and other parameters are derived from stock assessments. Some stocks are managed using indices of abundance (numbers or biomass). The stock assessments utilize data on catch per unit effort (CPUE) based upon commercial harvest data or fishery independent surveys (bottom trawl surveys for demersal fish or acoustic surveys for pelagic fish) to produce indices of relative abundance.

Outcome: Increases or decreases in fish stocks depend on the value of these measures relative to the target biological reference points in the FMP. If one plots the ratio of the stock assessment F/target F on an ascending scale versus the ratio of the stock assessment SSB/target SSB value on an ascending scale, well-managed fish stocks should occupy the lower right quadrant (no overfishing and not overfished). Many of the New England fish stocks lie outside this lower right quadrant. This graph would make it apparent whether managers needed to reduce fishing mortality (F) or increase spawning stock biomass (B), or some combination of the two in order to achieve "sustainable fish harvesting".

Illustration: Annual reports to Congress from the National Marine Fisheries Service (NMFS) list regionally the number of stocks that are being harvested sustainably; stocks harvested that are experiencing overfishing; overfished stocks with a rebuilding plan; stocks recovered from an overfished condition; and those harvested stocks for which assessments are lacking. One could plot this data as a percentage of the harvested stocks in each category over time in order to get a picture on the success of the management measures.

NEFSC (2002) provides a Table for 20 groundfish stocks in the Northeast which provides information on: current F, Fmsy, percent F reduction to achieve Fmsy, current B, Bmsy, and percent current B of Bmsy for each stock.

Features: Fishing mortality and SSB estimates are calculated annually or periodically over the geographic range of the fish stock in either state (0-3 miles) or federal (3-200) jurisdictional waters. Even though the fishery independent surveys are often done annually, the stock assessments for a species are updated on different time scales depending upon the stock and its status. The fish stocks in the GOM region are usually designated as either GOM or GB (Georges Bank) and the supporting bottom trawl survey strata are combined to provide indices of relative abundance based upon the stock boundaries. The Canadians define some of these geographical stock areas differently; care needs to be taken when comparing the stock assessment F and B values with those from the U.S.

Limitations: There are some species harvested inshore (bay scallops, hard and soft shell clams) that are managed by local/state officials with systems not utilizing biological reference points. Part of the reason for this is resource constraints (dollars and people) on gathering fishery dependent or independent data and processing these into stock assessments. These species will not be considered in this indicator.

Interpretation: Fishery managers can use this information to assess whether the biological reference points in the FMP are being met. There are control rules in the FMP that provide response options, such as limited entry, effort control (Days at Sea), large scale closed areas (seasonally or annually), larger mesh sizes in nets and larger minimum fish size; vessel/fishing license buybacks; etc. Management considers political, legal, and socioeconomic factors in addition to the stock's biological reference points.

Fish stock size is a function of recruitment to the fishery and natural mortality which vary due to many environmental factors and predator/prey interactions and fishing mortality which varies with the regulatory actions and technological interactions within the fishing fleet. Thus, this indicator can be evaluated more effectively by examining trends over a number of years.

Comments: Many FMPs are for single species or small groups of species and thus don't consider interactions (predation and competition) between harvested/non-target species in determining the optimum sustainable yield (OSY) from the ecosystem. The summed maximum sustainable yield (msy) for these individual species/small groups is likely to exceed the OSY from the ecosystem. For example, harvested forage species (Atlantic herring) are prey for other harvested species (cod and haddock), used as bait (lobsters) and contribute to the food web for other living marine resources (LMRs), such as marine mammals, sea birds, sea turtles, and non-targeted fish species. Ecosystems-based fisheries management (EbM) approaches are being considered to address these concerns.

Since there has been long term harvesting of the fishery resources in the Gulf of Maine (GOM), the present biological reference points may not reflect the historical reference points. This is referred to as the "shifting baseline phenomenon" where fishery managers base their decisions on sustainable stock size on the population sizes that have occurred in more recent times. These stock levels may be much lower that the sizes which occurred historically before quantitative fishery science was developed. To operationally define sustainable fishery harvesting in the context of the integrity of the GOM ecosystem, these historical reference points might be more applicable, but we lack information on these levels.

References

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FISHERY INDICATOR 7
Incidental Mortality of Species of Concern in Fisheries

Purpose: In the U.S. the Marine Mammal Protection Act (MMPA) forbids the intentional killing of marine mammals, but allows incidental mortality in the pursuit of such activities as commercial fishing (bycatch). Based upon the population size of the marine mammal population in relation to its optimum sustainable population (OSP) level and the incidental mortality from commercial fishing in relationship to the potential biological removal rate (PBR) for the marine mammal population, sixteen strategic marine mammal stocks have been designated in the Northeast (Waring et al., 2004). Fisheries that exert incidental mortality on these strategic marine mammal stocks are categorized as being in Category 1 (high) to Category 3 (minimal) based on their level of impact.

The Canadian Species at Risk Act (SARA) came into effect in June 2004 and the List of Wildlife Species at Risk included: 17 extirpated species, 105 endangered species, 68 threatened species, and 43 species of concern. SARA is similar to the U.S. Endangered Species Act (ESA) in listing other aquatic species beyond marine mammals. SARA develops recovery strategies and action plans (including protection of critical habitat) for listed species and is similar to the U.S. MMPA in providing permits for incidental mortality of endangered/threatened species affected as fisheries bycatch.

Ecosystem Objective: Rebuild populations of species of concern (endangered, threatened, etc.- refers to a gradient of risk of extinction/extirpation of the species unless adverse human impacts are removed/ameliorated).

Measure: The MMPA Stock Assessment Reports (SAR) list the annual human-induced total mortality and the mortality due to fishing. The data comes from observers on commercial fishing vessels or reports by the captain for fishing mortality. Observers are placed on the Category 1 fishing gear vessels: Northeast sink gillnets, Atlantic offshore long line fisheries, American lobster trap/pot fisheries, and squid, mackerel, butterfish trawl fisheries. The non-fishing mortality is usually obtained from the Marine Mammal Stranding Network data.

The aim of the MMPA is to achieve the zero mortality rate goal (zmrg) for the incidental mortality of marine mammal populations from commercial fishing activities. The zmrg is defined as a percentage of the PBR value. This may not be zero takes for some MMPA strategic stocks (harbor porpoises), even though this would be the value for North Atlantic right whales, which are critically endangered (listed in ESA).

Outcome: The total and fishing mortality values are compared to the PBR value (which is a fraction of the OSP level- the fraction is based upon whether the marine mammal stock is listed under the ESA or is a strategic versus non-strategic stock under the MMPA) and managers use a variety of tools to reduce this incidental mortality. These tools include: dynamic area management (DAM) or seasonal area management (SAM) to remove fishing gear in specific areas; modification of fishing gear; notifying ships of North Atlantic right whales in shipping lanes in order to reduce ship strikes; etc.

Illustration: The annual MMPA SAR includes tables showing the trends in marine mammal population size, PBR standard, total annual mortality and fishing mortality, strategic status, etc. The first SAR was published in 1995 and the strategic stock status is revised annually. The 2003 Atlantic and Gulf of Mexico SAR revised the population assessments for 43 of 60 marine mammal stocks (Waring et al., 2004). Trends from the tables for the population size of the marine mammal stock, total and fishing mortality could be shown on a graph, even though this time series is of short duration.

Features: The MMPA SAR is revised annually for strategic stocks and every three years for non-strategic stocks over the spatial distribution range for the marine mammal species. For many of the cetaceans (whales and dolphins) these geographic ranges can extend beyond the Gulf of Maine (GOM) region and include both continental shelf and slope waters. Many of the seals in the GOM are strategic stocks in the U.S. waters, but quite abundant in Canadian waters where the ice seals are harvested. The mortality estimates in the SAR reports include both U.S. and Canadian waters for some species of marine mammals. The fishing gears classified in Category 1 or 2 can have spatial distributions that differ (often smaller) from that of the marine mammal stocks. Thus it is difficult to make categorical definitions on the spatial area covered by the indicator, since it involves the range of the marine mammal species coupled to the spatial distribution of the fishing fleet.

Limitations: Since many of the ship strikes of whales occur far offshore, they often don't appear in the Marine Mammal Stranding Network data, while nearshore fishing gear-induced strandings may be disproportionately sampled. Since observers are only placed on a fraction of the commercial fishing vessels by gear type/size, incidental mortality estimates from fishing are based upon variable sample sizes in relation to the size of the fishing fleet for different gear types.

In Canada, the government changed the location of the shipping channel in the Bay of Fundy to reduce the ship strike mortality for North Atlantic right whales. These whales exhibit scars from ship propellers that lead the National Marine Fisheries Service (NMFS) to establish a program to warn ships of when this whale species is in shipping lanes. Recently NMFS released a proposal for public comment that envisioned possible changes in shipping lanes. The direct number of right whale deaths attributed to ship strikes is low, so that much of this management action is based upon a precautionary approach. The same management philosophy underlies the removal of lobster pots and gillnets in areas occupied by North Atlantic right whales for short time periods (DAM) or seasonal occupation of their critical habitat (SAM).

For harbor porpoises, time/area closures have been incorporated into the sink gillnet fishery with good success in reducing incidental mortality. There is obviously a tradeoff between protecting species of concern and maximizing the harvesting of fish species. The observer coverage of the fishing fleet required to minimize the bycatch mortality of target fish species differs from that required to reduce the incidental mortality of species of concern from commercial fishing. Thus tradeoffs need to be made in how to allocate the sea sampling budget between these two observer functions. The high cost of observers limit the application of sea sampling to fishing vessels with federal permits.

Interpretation: Fishery managers have tools under SARA, ESA, MMPA, and the Magnuson-Stevens Sustainable Fisheries Act (SFA) to implement regulations to reduce incidental mortality on species of concern. For some of the challenges faced in implementing SARA, one can read the paper by Hutchings and Reynolds (2004). The ESA covers sea turtles, other fish species (Atlantic salmon, shortnose sturgeons), etc. which are threatened by other human activities (often habitat loss/degradation) and not just fishing. This discussion focused on the MMPA because NMFS has greater regulatory authority over fishing than for example changing shipping lines that requires approval by the International Maritime Organization (IMO).

Comments: One has to know the population status of the species of concern (marine mammals, sea turtles, seabirds, etc.) and the incidental mortality exerted by commercial fishing in relation to other human caused sources. This information is not available in some cases that provides a constraint in implementing an ESA or SARA recovery plan or MMPA Take Reduction Team. Since the historical abundance of whale populations before harvesting is not known, the OSP calculation provides the stock recovery target. The "shifting baseline phenomenon" applies to the historical abundance of species of concern and their roles in the larger ecosystem, both of which are unknown. Thus, it is difficult to relate the MMPA/ESA recovery goals to the health of the wider ecosystem.

There are often socioeconomic and political constraints to achieving these recovery targets. SARA tries to achieve these goals by voluntary stewardship programs, financial compensation, and education. There are user conflicts between fishers and environmentalists/animal rights activists in implementing the ESA and MMPA in order to protect species of concern in the ocean.

Reference

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FISHERY INDICATOR 8

Fish Habitat Protection Through Marine Protected Areas Closed to Fishing

Purpose: Area closures are tools that can promote increased production of exploited fish populations, reduce bycatch, and preserve undisturbed fish habitat. Such Marine Protected Areas (MPAs) can achieve multiple objectives and can therefore serve as indicators for a variety of purposes. A well-designed MPA can be an effective way to simultaneously achieve a number of fisheries, habitat conservation, and biodiversity objectives. However, the ecosystem effects of particular MPAs vary and assessing their effectiveness requires data and information that are often lacking for individual sites. In such instances, MPAs are an application of the precautionary approach and indicate a willingness to forego the benefits that, in the case of fishery-closure MPAs, would have been derived from fishing in that area in exchange for another desired goal.

Ecosystem Objective: To protect ecologically significant habitat to a scientifically based optimum level (currently not known). Where the extent of ecologically significant habitat and the optimum level of protection are unknown, the objective is pursued through the application of the precautionary approach.

Measure: As a proxy for optimum habitat protection, periodically monitor the number of square kilometers and the percentage of the total area in the Gulf of Maine that are closed year-round to mobile, bottom-tending fishing gears, and to all fishing gears by habitat type if available. In the same terms, monitor shifts in effort to open areas.

Outcome: General indicator of protected habitat.

Illustration: This indicator would use maps and tables indicating the location, size, and significant features of existing closed areas and any areas that have been added, eliminated, or modified during the year. In the US, this information is maintained and up-dated periodically by NOAA and efforts are underway to include sites in Canada. Information on shifts in fishing effort attributable to a closure would be more difficult to obtain.

Features: Important features of each closure that should be included in the inventory include the following:

- Size
- Date it was created (or eliminated/modified)
- How it was modified (if relevant)
- Known habitat characteristics (e.g., substrate, depth, biological resources)
- Types of fishing activities and other activities that are prohibited and/or allowed in the area
- Management authority and jurisdiction
- Purpose of closure

This indicator would link to the proposed stock status/DAS and spatial distribution of fishing indicators.

Limitations: Closed fishing areas are often implemented for reasons other than habitat protection and may not encompass an ecologically sensitive or valuable habitat in terms of biodiversity. A prime example of this is an area that is closed to protect spawning aggregations of fish. These areas are closed to help restore over-exploited fishery resources. Areas closed to bottom fishing would not necessarily protect habitat if that effort becomes concentrated in more sensitive or valuable habitat areas as a result, or concentrated in excess of some recoverability threshold.. Areas that were once closed to fishing and subsequently reopened following the recovery of stocks that occupy the area are at once an indicator of an improving ecosystem condition (stock rebuilding) and possibly a reduction in habitat protection, which would complicate the interpretation of this indicator.

Also, without knowing what habitat types, and how much of each are included in each closure and what is their ecological value or importance to particular species of concern or the ecosystem, it would be difficult to draw definitive conclusions about the overall ecosystem effects provided by a given amount, or percent change, of closed area. And finally, MPAs are regulatory measures and not indicators of any ecosystem property per se, and serve as a substitute indicator for unavailable data.

Interpretation: Use of this indicator would require interpretation. For instance, one logical extreme is to interpret the "best score" to be 100 percent closure, which is clearly not the case. Neither is it necessarily true that fishing is always a negative impact and that reducing it provides any benefit at all. Ideally, only well designed MPAs with clear and measurable objectives informed by knowledge of the value of the specific habitat would be used.

Supporting data that would enhance the value of this indicator would be provided by information on changes in the condition of exploited fishery resources, i.e., have they been restored to the point that area closures designed to protect them have been eliminated or modified? If so, then a decline in the amount of area closed to fishing should be interpreted as a positive indicator of ecosystem health from a fishery resource perspective, but not from a habitat protection perspective. Monitoring the number of closed square kilometers without an analysis of the impact of transferred effort would also confuse interpretation of the indicator. Other information linking the value of habitat type to a biological goal (growth, recruitment, productivity, etc.) is also needed.

Comments: Use of GIS mapping and analysis tools will be very helpful in implementing this indicator.

FISHERY INDICATOR 9

Role of Recreational Fishing Expenditures in State/Regional Economy

Purpose: As recreational fishing undergoes increased management oversight, the collection of economic information allows managers a tool for assessing the socioeconomic effects of regulation. By monitoring trends in saltwater angler expenditures, state and government agencies can more effectively plan for the expansion of infrastructure needed to support recreational fishing. These agencies can also pursue policies that support healthy coastal communities and local/ regional economies when they better understand the multiplier effect from recreational fishing expenditures.

Ecosystem Objective: To assess the role of recreational fishing in supporting healthy communities and economics in the Gulf of Maine region.

Measure: A recent NOAA Professional Paper (Steinback et al. 2004) on the economic importance of marine recreational angler expenditures outlined a methodology for estimating the direct, indirect, and induced effects of recreational fishing expenditures by residents and non-residents. Direct impacts are sales, income, and employment directly related to supporting recreational fishing. Indirect impacts are sales, income, and employment in industries that supply services/products to the recreational fishers. Induced impacts are sales, income, and employment generated by employees of the direct and indirect sectors. The indicator would be changes in the Total Impacts over time (or multiplier effect which is the sum of direct, indirect and induced impacts) where the 1998 value would be the baseline.

Outcome: For the Northeast states the fishing expenditures model output is on a state-by-state basis, indicating the recreational fishing expenditures, sales, income, employment and tax impacts that could be followed over time. Only a proportion of the recreational dollars spent in a particular state actually have an economic impact in that state. This reflects the amount of goods and services that have to be imported into the state to support saltwater anglers.

Illustration: Given the way the Steinback (2004) model was developed, it is not possible to compute a regional value for the GOM. In 2000, the national total recreational expenditures were $30.5 billion, which was partitioned into: $13 billion for direct, $6.7 billion for indirect, and $10.7 for induced. These angler expenditures generated $12.0 billion in personal income and supported almost 350,000 jobs. The national economic impact gives an idea of the relative magnitude of the different components of the Total Economic Impact. For values for particular states, see the Tables in Steinback et al. (2004) paper. The output of the model could be plotted as line graphs to show changes over time in the Total Economic Impact or its components (direct, indirect, and induced).

Features: The New England data were for 1998 on a state-by-state basis in the Steinback et al. (2004) report. Steinback et al. (2004) point out that it would not be correct to sum the state values to obtain a regional total for the Gulf of Maine (GOM) region because of the way the IMPLAN PRO (Impact Analysis for Planning) model was implemented. One could formulate the model in a different way to obtain a regional total. Thus, the geographic scale is at the state level and one could update the supporting databases and revise the model estimates every 3-5 years.

There is a separate indicator for commercial fishing expenditure economic impacts that could be examined for comparison. The IMPLAN PRO model provides information on other economic sectors and their associated contributions to healthy coastal communities and the state economy.

Limitations: Even though the databases for estimating the recreational fishing economic impact are available in the public domain, this analysis could probably not be updated on an annual basis like the often used proxy indicator (number of recreational fishing trips from the Marine Recreational Fisheries Statistics Survey or MRFSS). The MRFSS effort information is based upon random surveys of fishers and nonfishers in defined geographic regions. It is available on an annual basis, even though there is a time lag in reporting the results. The IMPLAN PRO model could be improved by conducting a sensitivity analysis of the potential effects of fishery management regulations or infrastructure improvement on sales, income, employment, and taxes. Other economic tools like forecast research could be utilized to examine changes in recreational fisher behavior to management regulations or infrastructure improvement on a state-by-state basis or regional basis. Steinback's paper (2004) focuses on the economic impacts associated with recreational fishing in the context of fishery management.

Interpretation: Economists would have to advise on how to interpret the results of this indicator, especially the effects of the assumptions on the model output; interpretation of sensitivity analysis of the IMPLAN model for each state; and required databases to support this analysis. This information could be placed in the context of regional economic development plans or similar plans at the town or county level. This would help policy makers and political leaders develop strategies to preserve traditional occupations such as fishing and the associated support industries in the face of the expansion of tourism and residential development.

Comments: Commercial fishing landings are often reported as dockside value, but these are not comparable to the state recreational fishing impacts reported in the NOAA Professional Paper (Steinback et al., 2004). One would have to incorporate the value-added components of the fish processors, wholesale fish dealers, and retail markets to the dockside value to get a comparable economic impact value. This is developed as a separate socioeconomic indicator. The web-based survey for the NW Atlantic Coastal Indicators Workshop indicated that the "multiplier" effect of commercial landings and recreational fishing expenditures were of interest to the respondents.

Reference

Steinback, Scott et al. 2004. The economic importance of marine angler expenditures in the United States. NOAA Professional Paper, NMFS 2:1-169.

FISHERY INDICATOR 10

Availability of Habitat to Anadromous Fishes in Rivers of the Gulf of Maine Watershed

Purpose: This indicator will enable managers and the public to monitor changes in habitat available to anadromous fishes and in programs to maintain anadromous populations by stocking in Gulf of Maine Rivers.

Ecosystem Objective: Increase spawning success and populations of anadromous fishes in Gulf of Maine rivers.

Measure: Number of unobstructed river miles, % of historical habitat that is available to each species, and the status of stocking programs for anadromous fishes on major rivers in the Gulf of Maine watershed.

Outcome: As habitat increases, either by removal of dams or increased use of fishways, reproductive success of anadromous fishes should increase and stocking programs may decline.

Illustration: This indicator should be presented spatially. Appropriate portions of rivers could be color-coded as "accessible" vs. "inaccessible" for each anadromous species. Tables could show where active stocking programs exist and which species are stocked.

Features: The indicator should be derived on a river-by-river and species-by-species basis throughout the region. Updates every 3-5 years should be adequate, as this indicator is unlikely to change dramatically on an annual basis.

Limitations: Data for computing this indicator may not be available for all rivers in the region, but it can be compiled for major rivers.

Populations of anadromous fishes are influenced by a number of human activities: fishing, coastal development, and habitat alteration. This indicator focuses strictly on habitat availability and stocking efforts. Population trends should be monitored at a regional scale as part of the "status of the stocks" indicator.

Interpretation: Increases in the number of unobstructed river miles and the percentage of historical habitat available to each species will indicate progress towards restoring spawning access to anadromous fishes.

Stocking programs enhance anadromous stocks upstream of dams. Cessation of a stocking program does not necessarily indicate that a species is doing well in a river, as stocking decisions may be driven by funding constraints or by management priorities. On the other hand, it may indicate that natural reproduction is adequate to sustain a population and that stocking is no longer necessary. Caution should be applied when interpreting this aspect of the indicator.

This indicator will likely change only if management decisions are made to remove or construct dams, incorporate or remove fish passages, or modify stocking programs. Thus, changes in the indicator can be interpreted in a context of management actions.

Comments: This indicator will draw upon available information to determine the status of habitat areas and stock enhancement efforts for anadromous fishes. Further research may contribute to a more refined evaluation of passable dams and habitat accessibility for each species.

FISHERY INDICATOR 11
Size/Age Structure of Species From Surveys or Landings

Purpose: Fishery scientists utilize information on the size and age structure in fish stocks to prepare stock assessments that identify the spawning stock biomass (B) and fishing mortality (F). Fish harvesting selectively removes larger, mature members, while trying to protect the juveniles. Some juveniles are killed through bycatch in commercial fisheries or from catch and release mortality in recreational fisheries. The size and age structure of the landed catch provides an insight on the impacts of commercial fishing on targeted species, while the fishery independent surveys provide information on the effects of bycatch on non-target species. One goal of "sustainable fisheries" is to minimize the impacts of fish harvesting on the population structure of target and non-target fish species with the ultimate aim of improving ecosystem health.

Ecosystem Objective: Minimize the impacts of fish harvesting on the population structure of target and non-target fish species, while maintaining yield to the fishery and reducing bycatch to the extent practicable.

Measure: Port and sea sampling of the landed catch provides samples for age and size determination from the commercial fishing fleet (fishery dependent data), while fishery independent surveys (bottom trawl surveys or hydroacoustic surveys) provide samples from the demersal and pelagic fish communities (both target and non-target species). Size can be measured on shipboard, while age is determined back in the laboratory from analysis of the otoliths. The size-at-age matrix or catch curve would provide the basis for this indicator.

Outcome: For fishery management plans (FMPs) which lack biological reference points for overfishing (fishing mortality) and overfished condition (spawning stock biomass), data on the age and size structure f the target population provides a method for evaluating the impact of harvesting. Fish harvesting concentrates on smaller, rapidly growing, mature size classes in order to maximize production. For non-target species the goal might be a stable age distribution with a full range of sizes and age classes (greater percentage of older fish size classes than in target species).

The "surplus production" concept defines the population size/age structure, which can be harvested without depleting the stock, while at the same time maximizing yield. Since larger, older females often produce more and better quality eggs, some FMPs (i.e. lobsters) set goals for egg production by establishing a maximum size for harvesting to protect these older females. In a stable age structure births equal deaths (predominately due to natural mortality) and this distribution might be a baseline for non-target species. An analogy would be biotic integrity indices for fish community health that use a natural community as the baseline for comparison.

Illustration: For a specific fish species, one could plot fishing mortality rate versus the age class and compare the mortality rate of landings and discards for each age class (at older age classes the landings fishing mortality rate exceeds that from discards, while the opposite is true at younger age classes). Alverson et al. (1994) discuss a variety of approaches to compare the biological characteristics of landings, discards, and bycatch.

Changes in the size-at-age for the target species can be plotted on line graphs showing changes in the annual values over time and % changes in size for different age classes in a specific cohort (following a recruitment year class through time). Plots of the percentage of the population in different age (or size as a proxy variable) classes can be used to examine changes in the population structure for non-target species and see if a stable age distribution has been attained and continued through time.

Features: State/interjurisdictional FMPs cover the 0-3 mile jurisdictional zone, while federal FMPs cover the 3-200 miles Exclusive Economic Zone (EEZ). In the U.S. Georges Bank (GB) and the Gulf of Maine (GOM) are treated as separate fish stocks for cod and haddock, while they are treated as single stocks for these geographic regions in Canada. Thus, the FMPs define the spatial area covered by the stock (operational definition), even though these stocks may not be reproductively isolated (biological population).

The temporal scale would be constrained depending upon the frequency of the fishery independent surveys, sea sampling, or landings data and the time required to process the biological samples. The temporal scale is often constrained by the updating of the stock assessment that is based upon abundance information and biological data on size and age. The size data is available sooner than the age information, so that the otolith analysis is the limiting step. Federal fishery agencies have production ageing groups to conduct this work and do the appropriate quality control.

Limitations: Nicholson and Jennings (2004) pointed out that long term monitoring can detect changes in the length, weight, and age of a fish population, but the low power of these monitoring programs for change detection make it hard to incorporate this information into management measures with a 2-3 year time horizon. The authors concluded that even after 10 years of bottom trawl surveys in the North Sea, there was a low probability of detecting change.

Port sampling of the landed catch, doesn't measure the size and age of the catch discarded at sea. Observers on commercial fishing vessels can collect biological samples at sea (sea sampling) for a portion of the commercial fleet deploying selected gear types, but this is a costly program generally only conducted at the federal level. Fishery independent gear can differ in catchability from the commercial gear, but it offers the advantage of long term, scientifically designed data collection. The commercial vessels go where the fish are likely to be concentrated, unlike the randomly, stratified federal surveys which are designed to sample fish stocks over large areas. This can lead differences in the size and age distribution of the fish population sampled.

Recreational fishing catch and effort data (Marine Recreational Fisheries Statistical Survey) use random phone surveys for effort and intercept surveys for catch characteristics. The biological characteristics of the recreational fishery are collected during intercept surveys in the field. The Commercial catch biological characteristics information is developed from port sampling and sea sampling and this data is reported sooner than that for recreational fishing on a common fish stock.

Comments: When one has size-at-age matrices (fishery independent surveys) and catch curves (fishery dependent data), it is possible to compute growth rates and instantaneous mortality rates. Halliday (2001) converted fishery independent and dependent data into growth rates and instantaneous mortality rates as proxy indicators of secondary production in groundfish stocks. These computations make assumptions about equilibrium conditions, following a cohort through time, and require development of protocols for defining acceptable rates or goals. More research is required on how to define the optimum growth rate for a target species for a time series and the same is true for the instantaneous mortality rate (combines fishing and natural mortality)

Inshore one faces the challenge of separating the impacts of fishing on size and age distribution in fish populations from those due to eutrophication, habitat loss/degradation, and toxic contamination. Offshore, one faces the time scale constraint; long term monitoring required to detect an effect versus the shorter management time horizons. Since fisheries management is based upon the best available science on the biological status of the fish populations coupled with political, socioeconomic, and legal factors, the long time periods required for monitoring programs to detect changes can conflict with the shorter time scale required for management decisions.

Thus, a "precautionary" approach is used in fisheries management to accommodate scientific uncertainty in order to achieve the goal of sustainable fisheries. Achieving the "sustainable fisheries" goals in FMPs should reduce the direct and indirect impacts of fish harvesting on the health of the Gulf of Maine ecosystem. The size/age structure in a fish stock required to maximize production differs from the natural, unstressed fish community used as a reference in "ecology integrity" measurements (a mature fish population with a stable age distribution would have a greater percentage of older, larger individuals).

References

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FISHERY INDICATOR 12
Spatial Distribution of Bottom Fishing

Purpose: Mobile, bottom-tending fishing gear (trawls and dredges) are known to adversely impact benthic habitats that provide food and shelter for bottom-dwelling fish and invertebrates by reducing habitat complexity, altering benthic community structure (abundance and species composition), and reducing productivity (NRC 2002). Offshore benthic habitat types in the Gulf of Maine region have been ranked in terms of their vulnerability to trawling and dredging, with rocky and gravel bottom types (especially those with emergent epifauna) being the most vulnerable (NRC 2002, NREFHSC 2002). Changes in the intensity and distribution of trawling and dredging activity that increase the degree of disturbance to vulnerable benthic habitats will reduce habitat quality and suitability for a variety of marine organisms.

Ecosystem Objective: Protect vulnerable benthic habitats from the effects of mobile, bottom-tending fishing gear.

Measure: Monitor changes in the intensity and distribution of bottom trawling and dredging activity in relation to benthic habitat types using GIS mapping and analysis techniques and georeferenced fishing activity information.

Outcome: Increased bottom fishing activity in offshore areas of high structural and biological complexity (e.g., rocky substrates with attached epifauna, deep-water coral and sponge habitats, deep-water mud and sand substrates) will reduce habitat quality and suitability for marine organisms.

Illustration: GIS maps and spatial analysis of year-to-year changes in the intensity and distribution of fishing activity for mobile, bottom-tending fishing gears in relation to benthic habitat features such as depth and substrate type.

Features: Regional geographic scale, annual time scale. To be useful, this indicator will require region-wide bottom habitat and fishing activity data at the same spatial scale (1-10 km) – see below. In the U.S., the information that is available to implement this indicator is archived in the vessel trip report (VTR) database. VTR data are provided for each commercial fishing trip made by federally permitted vessels and indicate, for about 75% of all trips, a geographic location (latitude/longitude) that best describes where most of the fishing during each trip took place. VTR data are collected by gear type. Because the spatial distribution of fishing is affected by changes in fishery management measures such as area closures, this indicator is closely linked to the Area Closed to Fishing indicator.

Limitations: This indicator will have limited utility until more detailed, higher-resolution maps of benthic habitat features are available for the entire GOM region. Geological features of nearshore habitats have been mapped along the Maine coast, but there are currently no comprehensive maps of bottom habitats for U.S. offshore waters in the region. Available information is limited to a 1989 U.S.G.S. map of nine surficial sediment types which – in offshore areas – are based on a very limited number of sampling points (Poppe et al. 1989). Recent sediment composition data are available as geo-referenced point data in an up-dated U.S.G.S. database that also includes the original digitized sediment data layers (USGS 2003). Some smaller areas like Stellwagen Bank, portions of the Great South Channel, and Browns Bank (Canada) have been surveyed using side-scan and multi-beam sonar and sediments in scallop fishing grounds on Georges Bank have been characterized using bottom video imagery.

There are similar problems with the available fishing activity information. Maps showing the location of individual trips or the number of trips or days at sea within ten minute squares of latitude and longitude (approx 260 km^2) are available in U.S. waters for years starting in 1995. However, not all fishing trips in the vessel trip report (VTR) database are reported by lat/long and for trips that are reported by location, entire trips are assigned to a single point location.

Even though the quality of existing U.S. data needed to support this indicator needs to be improved, existing data are sufficient to show annual shifts in fishing intensity for bottom-tending gears at moderate to small-scale geographic scales and to draw conclusions about the nature of bottom types that are being subjected to intensified fishing effort.

Comments: Geospatial analysis of annual VTR trip point data overlaid on depth and substrate data layers would make this a more quantitative indicator. Application of this methodology to existing 1995-2003 VTR data (for selected bottom trawl and dredge gear types) would indicate whether this approach should be developed any further.

References

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Coastal Development Indicators

COASTAL DEVELOPMENT INDICATOR 1

Increase in Area of Habitat Types Resulting from Habitat Restoration

Purpose: To measure location, effort and success of habitat restoration projects.

Ecosystem Objective: To maintain or increase the availability of natural habitats (nesting, rearing, foraging areas) for native flora and fauna.

Measure: Acres of restored habitat (categories to be determined – salt marsh, riparian edges, etc.) reported by state/province based on remote sensing data or other methods.

Outcome: Gap analysis highlighting areas with little to no restoration. Correlations between hectares restored and other environmental attributes (e.g. Migratory species).

Illustration: Maps with overlying graphs and tables (visual display always better than text).

Features: Reassessment every 5-10 years. Possible data sources are reports from restoration projects, related databases (NMFS/NOAA, Long Island Sound, Atlantic Canada Data Centre), aerial photography, and ground truthing.

Limitations: Definition of restoration – how to know if the habitat type restored is 'fully functioning'. Data may be difficult and labour intensive to find.

Interpretation: This indicator will put a tangible number on restoration effort and show the human response of changes in coastal ecosystems. This will compliment land management and land conservation indicators – restored acres is an 'on the ground' response, and the other two might be at higher levels (policies, programs and legislation).

COASTAL DEVELOPMENT INDICATOR 2

Trends of Invasive Plants in Coastal Wetlands

Purpose: To document the impacts of coastal development on coastal brackish water wetland plant habitats and the spread of invasive species such as phragmites and purple loosestrife.

Ecosystem Objective: Maintain and restore natural tidal flows of salt water into coastal wetlands to preserve healthy habitat for native species. Identify potential coastal development practices and impacts that may contribute to invasive species intrusion into native habitats.

Measure: Acreage of phragmites observed, occurrence and abundance of invasive plants, and measurement of brackish salinities conducive to invasive plants. Measure impervious surface of adjacent coastal development and develop an associated ratio to invasive plants.

Outcome: The way the indicator is interpreted. Coastal wetlands with surrounding development and impervious surfaces of greater than XX % stress native plants and enhance conditions for invasive species.

Illustration: Areal photography and ground truthing of invasive plants by town and region. Develop GIS overlays for invasive species areas, native species, developed areas, and impervious areas. Color maps and charts are effective visual communicators as well as picture inlays for reports.

Features: Areal photography and remote sensing of coastal wetlands vegetative cover at 5-year intervals. Should be done in conjunction with ground truthing of species and overlaying data layers of impervious surfaces and stormwater management of surrounding developed areas.

Limitations: Possibility of stressors to native species that are unrelated to development. Salt marsh subsidence and sea level rise may impact coastal wetland salinity regimes as well as climatological and meteorological events.

Interpretation: Supporting water quality & tidal flow data, and introduction of non-native species used in landscaping practices in coastal communities will verify the validity of using invasive species as a biological measure of the impacts of development on coastal wetland systems.

Comments: Special analytical techniques, supporting information, multiple interpretations, etc.

COASTAL DEVELOPMENT INDICATOR 3
Conserved Land

Purpose: This measure is a surrogate for land that will be forever maintained in its natural state. This is a valuable indicator since a wide variety of anthropogenic alterations to the land within a watershed have detrimental environmental impacts to estuaries. This will include the overall acreage of preserved land as well as the percentage of preserved land within the watershed.

Ecosystem Objective: The objective is to limit development within the coastal municipalities and watershed as a means of preventing habitat and water quality degradation in the downstream estuary.

Measure: The measure is *acreage* preserved and *percentage* of preserved land within the watershed.

Outcome: The greater the acreage and percentage of preserved land, the less likely that land will contribute to estuarine habitat and water quality degradation.

Illustration: Maps delineating the preserved land and accompanying tables of acreage and percentages will provide graphic representation of the indicator.

Features: Five-year time intervals indicating the changes in preserved land will reveal progress overall. It will also reveal rate of progress within specific towns as a mechanism for using adaptive management strategies to target areas within the watershed where progress is slow. If the indicator is refined in a way that the preserved land is identified as state owned, municipal, private land trusts (fee ownership), private land with conservation easements, then the indicator reveals which mechanisms for land conservation are progressing and which are moving more slowly. This also lends itself to adaptive management strategies such as: open space bonds for state use, open space bonds that can be granted to municipalities or land trusts with matching municipal or private funds etc. The indicator will also reveal if the land is preserved in areas most likely to protect the estuarine habitats and water quality. Priorities can be established at the state, municipal, and land trust level to protect high priority areas.

Limitations: The success of this indicator is dependent upon the appropriate information being provided to the agency responsible for maintaining and reporting the data. This will be easily achieved at the state level but can also be achieved at the municipal level and land trust level using appropriate strategies. State funds awarded to municipalities and land trusts for land preservation can require that the location and acreage be provided as well as GIS coverages with the land delineated. Municipal and private land trusts can be required by statute to provide appropriate documentation of their preserved land to the state agency responsible for managing the data.

Another factor to be considered is the relative value of the preserved land with regard to protecting the estuary. Preserved land farther from a river or stream may be less critical than land adjacent to a tributary. Likewise, the type of land cover on the preserved land is also a factor in determining the value in estuary protection since forested land is more effective at preventing nutrients from entering waterways than is land in field or barren of vegetation. Therefore, a prioritization of lands based on land cover type, distance from a watercourse etc could be established to refine the indicator.

Interpretation: This indicator could be used in conjunction with other indicators such as amount of impervious surface in the watershed, population growth, population density, miles of roads, etc to obtain a fuller picture of what is happening within the watershed and how such changes might impact the estuary.

Comments: Much of the data is already available in some states and in some coastal municipalities. Some states are even in a position to easily compile the data. Others may need to ramp up for this, but they could obtain technical assistance from states that are further along in the process. A data rescue process would provide useful information going back decades, making this indicator even more valuable since the value of an indicator increases as the time series lengthens.

This indicator was identified in Ecological Indicators for Narragansett Bay and its Watershed (August 26, 2003) produced by Kleinschmidt for the Partnership for Narragansett Bay. The report suggested that this indicator be applied at the watershed level and noted that it is already being used as an indicator for Puget Sound, Chesapeake Bay, and Long Island Sound.

COASTAL DEVELOPMENT INDICATOR 4

Number of Comprehensive Local Government Land Development Ordinances in Coastal Watersheds

Purpose: To document local government commitment to controlling the impacts of development on coastal waters.

Ecosystem Objective: To reduce the impacts of development on coastal and Gulf waters.

Measure: Number of ordinances being implemented.

Outcome: Development is more likely to have less impact on coastal waters if local governments are implementing comprehensive land development ordinances.

Illustration: Maps of local government jurisdiction by watershed.

Features: Collected at same frequency as water quality measures to indicate whether local commitment is having intended impact.

Limitations: Local commitment is difficult to measure due to lack of detailed information about implementation and enforcement.

Interpretation: Data would need to be analyzed alongside supporting information, such as, population change, development levels, density of impervious surfaces, etc.

Comments: None.

COASTAL DEVELOPMENT INDICATOR 5

Land Protected Through Acquisition or Permanent Conservation Easement

Purpose: To identify lands permanently protected from urban development.

Ecosystem Objective: To reduce the impacts of land development and subsequent occupancy on coastal and gulf resources.

Measure: Acres of land under public control with restrictions that prohibit urban development.

Outcome: Lands that will not have urban development will have fewer impacts on adjacent coastal and Gulf resources.

Illustration: Maps of lands under governmental ownership and easement

Features: Periodic inventory of federal, state/province, and local government conservation land holdings.

Limitations: Ownership may not ensure parcels of sufficient size or location for maintaining species diversity, water quality, or other goals.

Interpretation: Supporting data such as location of development will enhance the indicator.

Comments: None.

COASTAL DEVELOPMENT INDICATOR 6

Status of the Populations of Migratory Species as a Measure of Coastal Ecosystem Integrity

Purpose: Assess the population status of selected coastal migratory species (i.e. birds, marine mammals, marine and diadromous fishes, and marine invertebrates), and any historic and/or recent trends for these populations.

Ecosystem Objective: Maintain and/or restore healthy and productive coastal migratory species populations. Many of these species represent important recreational and commercial fisheries, as well as possible indicators for the integrity of the ecosystem that coastal species depend for various life history requirements.

Measure: Population indices (e.g. stock assessments, landings, surveys, observations/counts) may illustrate which species or geographic areas have shown the greatest amount of change.

Outcome: Specific species and/or geographic areas that show the greatest degree of change in population indices may be identified for further analysis. This may include correlation with coastal land-use change indices for coastal communities.

Illustration: Selection of various population indices could be illustrated in a tabular and graphical form (e.g. percent change in stock assessment variables, landings, observations/counts); these indices could be illustrated geographically to assess if there are "problem" areas and whether these relate to specific coastal land-use changes.

Features: Because of the nature of migratory species, various spatial scales for the indicator may be required. Although most migratory species ranges involve at least a region-wide scale, some inferences may be possible on a local scale by assessing the specific habitat requirements of each species. For example, the range of Atlantic herring encompasses inshore, coastal areas from Nova Scotia to Cape Hatteras, as well as offshore portions of the Gulf of Maine, Georges Bank, and the Mid-Atlantic Bight. However, inshore, coastal areas are identified as the most critical habitats for larval and juvenile life stages, which are most affected by coastal land-use changes. Correlation may be possible between population indices of some migratory species and land-use indices. Other water quality indices of specific watersheds or estuaries could be compared with population indices of migratory species.

Limitations: The use of migratory species as indicators of ecosystem integrity may be difficult and complicated due to the large geographic range of many migratory species. Coastal land-use changes are likely affecting species at a number of spatial and temporal levels, confounding the correlation with population changes. Additionally, many migratory species are affected directly or indirectly by recreational and commercial fishing harvests. This complicates any "cause and effect" determination for population changes in migratory species. For example, changes in fishery regulations can have significant direct and indirect impacts on a population and possibly masking other non-fishing effects on the species.

Interpretation: Some caution should be applied to inferences made with population indices of migratory species and land-use change. It may be necessary to limit the analysis to species that are not directly exploited in an existing fishery, have relatively restricted geographic ranges, or have some site fidelity in their migrations (e.g. river herring). Other data may be used that supports the interpretation of the migratory species indicator. For example, population indices of non-migratory species utilizing the same geographic area could be compared for similar trends.

Comments: This indicator could be used to infer effects to the ecosystem from land-use changes. Although it may not be the best biological indicator to assess ecosystem integrity, it may be one that data is available. For example, good time-series data is available from marine mammal and bird surveys, and historical data is available for some recreationally or commercially exploited migratory fish.

COASTAL DEVELOPMENT INDICATOR 7
Demographic Changes in Municipalities That Border Saltwater

Purpose: To track changes in the rate and location of population change in municipalities that border saltwater as an indicator of a significant pressure that drives coastal land conversion.

Ecosystem Objective: None.

Measure: Percent change in population in municipalities that border saltwater (potentially delineated into permanent and seasonal populations).

Outcome: Coastal municipalities with population growth (over _ %) will more likely experience increased land development as natural areas are converted to residential and seasonal homes, and commercial venues and infrastructures are built to support increased residential and seasonal residents' needs.

Illustration: Map with different color dots/shading for municipalities according to their percent population change.

Features: Population change by coastal watershed, instead of municipality, may be a more useful scale and could still be done using census data. The scale would need to be consistent with the percent change in land cover (and perhaps other indicators) so that the changes in land cover could be discussed in the context of population changes.

Limitations: May need to complement with other indicators of demographic changes such as housing units, lot sizes, vehicle miles, etc, to get a more detailed picture of the demographic changes that are driving coastal land development.

Interpretation: Comparative data on the percent population change in non-coastal municipalities (or counties/watersheds) would give a sense of statewide or region-wide population growth (i.e. tell how growth in coastal areas compares to growth in non-coastal areas).

Comments: None.

COASTAL DEVELOPMENT INDICATOR 8
Types and Rates of Land Use/Land Cover Change in the Gulf of Maine

Purpose: To document and display not only that Land Use/Land Cover is changing but what and where are the changes occurring.

Ecosystem Objective: Changing land use/land cover from natural state to developed or disturbed is a source of stress for habitats and biota and has other socioeconomic effects.

Measure: Remotely sensed areas of land use/land cover types, classified as Natural Condition, Disturbed Open, Maintained Open, Agricultural, Residential (High and Low?), Urban, at discrete points in time (time periods TBD).

Outcome: More discussion and examples from data sets needed to establish interpretations and outcomes.

Illustration: Maps and graphs.

Features: 5 to 10 year intervals, depending on data source and availability.

Limitations: Inconsistent time periods, data sources and resolution, land use/cover class systems.

Interpretation: More discussion and examples from data sets needed to establish interpretations and outcomes.

Comments: Recommend 2 scales:

1. Baseline coarse scale, for one organization/entity to conduct a region-wide analysis using LandSat TM satellite imagery and available interpreted Land Use/Land Cover.
2. For states and provinces or other organizations to conduct more specific and finer analyses depending on their available data and info (most likely relying on aerial photography and GIS layers).

Contaminants Indicators

CONTAMINANTS INDICATOR 1
Area of Contaminated Sediment

Purpose: To document how contaminant levels are changing.

Ecosystem Objective: Maintain high sediment quality.

Measure: Area of sediments that have contaminant levels above sediment quality guidelines or are elevated with respect to contaminant levels observed elsewhere in sediments of similar character (i.e., grain size, carbon content, AVS, etc.) Data sources include USGS sediment database, NCA, NOAA Status & Trends, EPA National Estuary Programs, U.S. Army Corps of Engineers (e.g., DAMOS), state and provincial databases, pipeline projects, dredging projects, wastewater outfall monitoring program.

Outcome: Areas with elevated contaminant levels may experience ecosystem degradation, contamination of local seafood, and difficulty in disposing of dredged material.

Illustration: Maps of surficial sediment contamination. Periodic "State of the Environment" reports.

Features: Annual to decadal measurements of surficial sediment contamination, average for water bodies. Supplement with cores in focusing areas to get long-term temporal context. Generally, more temporal and spatial resolution is needed where gradients are high. Consider speciation/sorption. Use transport models, where appropriate/available.

Indicators should be chosen to represent classes of contaminants/pollutants (e.g. metals); however, the specific contaminants measured may change as more is learned about that class of contaminants. Include classes of inorganic and organic chemicals with known biological effects. Include those with a specific mode of action, as well as those whose effects are more general. Link to sediment triad indicator, chemical loads, contaminant availability (e.g., TOC levels, AVS), marine organism disease incidence.

Limitations: Basic understanding of transport and fate, sediment physical characteristics is needed. Need to standardize methods. Costs can be very high, depending on scale of evaluations and because of environmental variability. There are also many unknowns that may require research, particularly to understand the broad physical, chemical, and biological effects and their synergy.

Interpretation: This indicator will help determine where are contaminants (location, ecosystem compartment); where contaminants are going (time, space, trophic level); and effectiveness of regulatory actions (and effects of other human activities, e.g. coastal development).

Comments: An incomplete list of data sources is above. The question of who can take the lead in aggregating data, and what process to use, may be difficult questions because of cost concerns and parochialism.

Archive sediments and tissues for future analysis of emerging contaminants. There are existing archives (EPA, USGS) but the networks between them need to be strengthened, and someone needs to fund the archival.

CONTAMINANTS INDICATOR 2
Contaminant Levels in Sentinel Organisms

Purpose: Document how contaminant levels are changing

Ecosystem Objective: Understand trophic transfer, effects at different trophic levels

Measure: Level of contaminants in representative, relatively non-migratory organisms at various trophic levels that might be considered "sentinel" organisms. For example, macroalgae, mussels, lobster, flounder, colonial seabirds, harbor seals (and, on an opportunistic basis, beached marine mammals) have been suggested as sentinels at several trophic levels. Measure tissue burdens in high-risk human populations (high background levels from diet) as modeled in the Great Lakes, The Netherlands, the Arctic). Include emerging contaminants of concern (e.g., estrogens, brominated compounds (e.g., PBDE)) in addition to the traditional suite. Data from fisheries agency monitoring programs, NCA, NOAA Mussel Watch, Gulfwatch (blue mussels), Canadian Wildlife Service (sea birds), the MEDEP SWAT program, and others. Consider use of government health advisories as a component of this measure.

Outcome: Organisms with elevated contaminant levels may have higher disease incidence or reproductive problems; contaminants may be transferred from one trophic level to another.

Illustration: Maps of contamination levels in sentinel organisms. Temporal trends in contamination levels. Periodic State of the Environment reports.

Features: Measure tissue body burdens in same season each time, but may not need to be measured every year. Generally, more temporal and spatial resolution is needed where gradients are high. Consider contaminant speciation/sorption, the life stage and age of the indicator organism, and the range and movement of mobile species. Use transport models, where appropriate/available. Monitoring across trophic scales would incorporate biomarkers of exposure and effects in indicator species at key points in the food chain. Link to measures of sediment contamination, disease incidence.

Indicators should be chosen to represent classes of contaminants/pollutants (e.g. metals); however, the specific contaminants measured may change as more is learned about that class of contaminants. Include classes of inorganic and organic chemicals with known biological effects. Include those with a specific mode of action, as well as those whose effects are more general. Monitoring should be sensitive enough to provide early warning of unexpected effects.

Limitations: Need to standardize methods. In motile organisms, body burden could represent exposure to contamination anywhere in their range. Analysis of higher trophic levels complicates assessments of management actions. Sources can be a complex mix of active and historical cycling. Effects on organisms are often poorly known and priority pollutant list is rarely modified. Analyses are expensive and public release of data must be carefully handled to ensure there are not unwarranted scares that could have multiple economic ramifications, e.g., closures of fisheries.

Interpretation: This indicator will help determine where contaminants are (location, ecosystem compartment); where contaminants are going (time, space, trophic level); and effectiveness of regulatory actions (and effects of other human activities, e.g. coastal development). Certain classes of organic contaminants and metals readily bioaccumulate in aquatic food chains and become increasingly concentrated from seawater to plankton to shellfish, fish, seabirds, marine mammals, and humans. Compared with levels in seawater, these contaminants are biomagnified by several orders of magnitude in fatty tissues of top predators. Could help to determine if current "margin of safety" limitations are appropriate, i.e., too large or small.

Comments: Data sources include NOAA, USGS, and EPA programs, Corps of Engineers (?), State/provincial environmental and health agencies, researchers, NGOs.
Need to measure emerging contaminants—especially those increasing in US, e.g., brominated flame retardants in fish, human breast milk. Archive sediments and tissues for future analysis of emerging contaminants. There are existing archives (EPA, USGS) but the networks between them need to be strengthened, and someone needs to fund the archival.

CONTAMINANTS INDICATOR 3
Area of Shellfish Bed Closures

Purpose: To document how bacterial contamination is changing, and to determine whether management actions are changing the extent and severity of human health effects.

Ecosystem Objective: Protect public health and availability of safe seafood.

Measure: Area of shellfish bed closure by state and province by year provided it is carefully interpreted to reflect actual impact, rather than bias from administrative closures, resource values and accessibility, or natural sources of bacteria. Use data from state and provincial shellfisheries/health agencies.

Outcome: Shellfish bed contamination due to sewage inputs may result in contamination of local seafood, disease in shellfish consumers, and loss of the resource use.

Illustration: Maps of shellfish bed closure areas; graphs of number (percent?) of acres closed over time. See the attached summary of recent data.

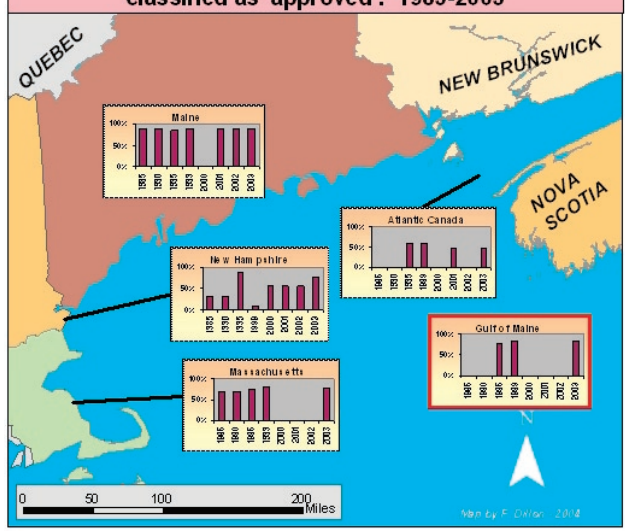
Features: Event-specific measure (not temporally averaged) for each water body. Generally, more temporal and spatial resolution is needed where gradients are high. Link to beach closures. Link to climate change/rainfall?

Limitations: Shellfish beds may also be due to administrative closures, resource values and accessibility, or natural sources of bacteria. Interpretation must take into account variation in rainfall. Human, animal, and bird waste enters the environment by different pathways but consumption of shellfish contaminated by bacterial pathogens (natural and fecal-borne), viruses, and parasites can result in human disease regardless of the source. Because indicators are not direct measures of the presence of pathogens, they may lead to needless closures. Research to develop new indicators that are more relevant to pathogens, or to use DNA typing techniques to separate sources which may have different risks (e.g. human vs. wildlife), is likely needed. Costs of routine DNA typing and true pathogen analyses are high, but are coming down.

Interpretation: This indicator will help determine the location and source of contaminants (location, ecosystem compartment); the transport and persistence of contaminants (time, space); and effectiveness of regulatory/management actions (and effects of other human activities, e.g. coastal development).

Comments: Most states and provinces have regulatory authorities over shellfish beds, or delegate them to local shellfish commissions. They collect the data. The methodologies are "mature" under the National Shellfish Sanitation Act protocols. A possible HAB indicator could measure how effective HAB monitoring is in protecting public health. Furthermore, epidemiological studies/research would help quantify the risk better.

Figure 5.2. Percent of shellfish acreage classified as 'approved': 1985-2003



CONTAMINANTS INDICATOR 4
Days of Beach Closure

Purpose: Document how bacterial contamination is changing, and determine whether management actions are changing the extent and severity of human health effects.

Ecosystem Objective: Protect public health, maintain usability of beaches.

Measure: Days of beach closure due to bacterial contamination by state or province by year, but with careful interpretation to ensure closures reflect an anthropogenic effect from pathogens or relevant indicator organisms. Data from state and provincial health agencies, recreational beach managers. The Natural Resources Defense Council compiles data from states into an annual report. Data can be interpreted in many ways, so careful use of this indicator is warranted to ensure risks are realistically quantified.

Outcome: Swimming beach contamination due to sewage inputs may result in loss of the resource use.

Illustration: Graphs of miles of shoreline, or number or percent of beaches closed over time. See attached figure showing percent of beaches with closures.

Features: Event-specific measure (not temporally averaged) for each water body. Generally, more temporal and spatial resolution is needed where gradients are high. Link to shellfish bed closures. Link to climate change/rainfall? Variability is high and the interplay of human vs. wildlife sources must be carefully studied to ensure effective management direction. Also, wet and dry weather play important roles and confound trend/improvement analyses.

Limitations: Swimming beach closures may also be due to administrative closures, resource values and accessibility, or natural sources of bacteria. Because the data will inevitably be used to compare risks among jurisdictions, it must be very carefully interpreted. A jurisdiction with no beach closures may simply not be monitoring or monitoring inadequately. Thus, data only from areas where consistent monitoring occurs should be used, or an alternative measure such as percent of samples above the swimming standard. Interpretation must take into account variation in rainfall. Human, animal, and bird waste enters the environment by different pathways but exposure to water contaminated by bacteria, viruses, and parasites can result in human disease regardless of the source. Statistical comparability among jurisdictions will require a uniform level of monitoring and include each individual beach to provide valid relationships among jurisdictions.

Probably the most important limitation of this indicator is that it is based on bacterial measurements that take at least one day to read, causing a delayed response to actual water quality conditions that can result in unnecessary closures or, more importantly, no closure under unhealthy conditions. Modeling of environmental conditions can be helpful, and more timely measurements are needed. Standardization of water quality indicators should be pursued, as *E. coli* is used in Canada and enterococci used in the US.

Interpretation: This indicator will help determine the location and sources of contaminants; the persistence and transport of contaminants; and effectiveness of regulatory/management actions (and effects of other human activities, e.g. coastal development). For microbes, total annual load is not meaningful, so need to use measurements from routine and short-term, high-intensity event monitoring. In urbanized, coastal areas "no" closures is probably a laudable, albeit unattainable goal.

Comments: Most data are collected by state, provincial, and local agencies. NRDC, as noted above, compiles US data. Perhaps build upon that effort to iron out any wrinkles. EPA's new "Beach" initiative should be looked at for whatever support and data it might provide.

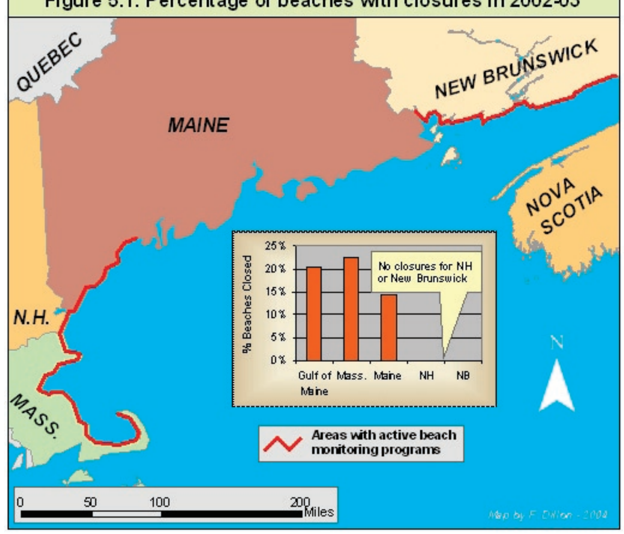


Figure 5.1. Percentage of beaches with closures in 2002-03

CONTAMINANTS INDICATOR 5
Annual Chemical Load

Purpose: Document how the input of contaminants is changing over time and space.

Ecosystem Objective: Maintain high water and sediment quality.

Measure: Annual chemical load to water bodies by state or province by source (point sources, CSO, runoff, atmospheric, tributaries, spills, groundwater, flux from "legacy" contaminated sediments). May have to use surrogate analyses, e.g., use of lawn chemicals, area in suburban/urban/commercial development, areas of imperviousness, stream/river gauging station data. Data from NPDES permits/permit applications, Canada's NPRI, Air/Toxics releases/permitting, NEP studies, Sea Grant studies, EPA Toxic Release Inventory.

Outcome: Areas receiving high loads of chemical contaminants may experience sediment and water contamination and contamination of local seafood.

Illustration: Maps of loads. Graphs of time variation in loads. Periodic "State of the Environment" reports.

Features: Spatial scale: water bodies, region wide. Temporal scale: annual to source specific (should measure at least seasonally, but aggregate to annual average). Include "emerging" contaminants such as pharmaceuticals, estrogenic compounds.

Indicators should be chosen to represent classes of contaminants/pollutants (e.g. metals); however, the specific contaminants measured may change as more is learned about that class of contaminants. Include classes of inorganic and organic chemicals with known biological effects. Include those with a specific mode of action, as well as those whose effects are more general. Link to sediment contamination indicators. Link to climate change - warming can affect contaminant cycling, as can changes in redox due to cultural eutrophication. Variability will be high, and effects concentrations can be exceedingly low (e.g., mercury or PCBs in water) given high biomagnification levels.

Limitations: Indirect relationship to water and sediment quality - need to understand dilution/focusing, "carrying capacity". Low effect thresholds making analysis and tracking difficult. Costs may be high; some contaminants, e.g. dioxin, can exceed $1000 per sample. Research is needed on "emerging" contaminants, e.g., it's unclear how PBDE's get into the environment and how they change forms.

Interpretation: This indicator will help determine the overall scope of the problem, as well as determining improvements due to regulatory actions vs. stresses from population growth and development. Data analysis should integrate the source data with information on coastal development, data on distribution of tissue and sediment contamination, and understanding of transport (e.g. from OOS buoys). Also consider the residence time for various contaminants.

Comments: Data are being collected by federal, state/provincial, local, research, NGOs. Tracking of microbial sources (human/wildlife/livestock, runoff/POTW/ballast water) is an important related issue for which indicators should be developed.

CONTAMINANTS INDICATOR 6

Source Investigations and Eliminations

Purpose: To document how the input of contaminants is changing over time and space.

Ecosystem Objective: Limit the input of contaminants to maintain high water and sediment quality.

Measure: Number of bacterial/viral source investigations and sources eliminated by year by state/province (e.g. TMDLs completed, CSOs eliminated, failed septic systems replaced, stormwater BMPs implemented). Data from state/provincial environmental protection agencies, NEPs, coastal zone management?

Outcome: Source investigations should lead to elimination of contaminant sources.

Illustration: Number of sources investigated and eliminated.

Features: Spatial scale - water bodies, region wide. Link to shellfish and beach closures, annual chemical loads. Include "emerging" contaminants such as pharmaceuticals, estrogenic compounds.

Limitations: This "human response" indicator is an indirect measure of improvements in environmental quality. If tracking of sources is included in monitoring for the other contaminant indicators, the methodologies may accommodate source elimination as a logical outcome. If problems are identified using the above indicators, but we are unprepared to recommend management actions, money and time are wasted.

Interpretation: This indicator will help determine the overall scope of the problem, as well as determining improvements due to regulatory actions vs. stresses from population growth and development.

Comments: Over time, move toward more direct measures of health risk (fecal coliform --> *Enterococcus* --> viruses).

CONTAMINANTS INDICATOR 7

Inventory of Contaminant Problems

Purpose: To document how the input of contaminants is changing over time and space.

Ecosystem Objective: Limit the input of contaminants to maintain high water and sediment quality.

Measure: A simple inventory or list of contaminant problems affecting coastal waters throughout the region. The list would grow or shrink with each renewal, giving an overview of contamination problems and their character. Each contaminant could also be evaluated for level of understanding – e.g., emerging, known problem, thoroughly researched and understood, under management, resolved. Data from state/provincial environmental protection agencies, NEPs, coastal zone management, and from all of the above federal, state/provincial, research, and NGO groups previously identified.

Outcome: Overview of contamination problems and their character.

Illustration: [From recent press] Forty-four states have consumption advisories because of high mercury levels in fish tissue. Put it in a matrix that identifies this problem, i.e., check the boxes under priority pollutant and fish tissue, and other relevant media, i.e., check the box for known sediment storage relationship, and sources, i.e., check the box for stack emissions. Need to think more about all the relevant categories.

Features: Spatial scale - water bodies, region wide. Include sources of "emerging" contaminants such as pharmaceuticals, estrogenic compounds. There is a need to establish what we know or don't know about various contaminants – some are well understood and/or regulated, others not. The list is always changing along with the level of understanding. Some contaminant problems are resolved while new contaminants or effects are added. Link to indicators of source investigations chemical loads, shellfish and beach closures? For this indicator, variability would be very low if the literature and regulatory review is complete. Either a contaminant is listed, researched, an identified problem, etc. or not.

Limitations: Provides qualitative information only. Cost is likely fairly cheap. Can probably be built upon national summaries of consumption advisories, impaired water lists, etc. Reviews for "emerging" problems will be most difficult and controversial.

Interpretation: This indicator will help determine the overall scope of the problem, as well as determining improvements due to regulatory actions vs. stresses from population growth and development.

Comments: Aggregation of data could start with national summaries of health advisories (e.g., mercury because contamination in fish is widespread) or impaired waters (e.g., PAH in sediments because it causes fish abnormalities).

CONTAMINANTS INDICATOR 8
Tissue Body Burden in Seafood and High-Risk Humans

Purpose: To determine whether management actions are changing the extent and severity of human health effects.

Ecosystem Objective: Protect public health and the availability of safe seafood.

Measure: Tissue body burden in seafood species (bivalves, lobster, flounder) and in high-risk human populations. Contaminants on this list would be updated regularly to reflect continuing and new concerns, such as emerging contaminants. Consumption advisories are one example of how this information might be translated into potential human health effects. Data from fisheries agencies, NCA, other? Public health agencies have data on humans? Consider use of government health advisories as a component of this measure.

Outcome: Contaminants in seafood can cause adverse human health effects.

Illustration: Maps of body burden in seafood species and high-risk human populations. Graphs of body burden over time.

Features: Annual to decadal measurements on water body and regional scales. Measure tissue body burdens in same season each time, but may not need to be measured every year. Indicators should be chosen to represent classes of contaminants/pollutants (e.g. metals); however, the specific contaminants measured may change as more is learned about that class of contaminants. Include classes of inorganic and organic chemicals with known biological effects. Include those with a specific mode of action, as well as those whose effects are more general. Monitoring should be sensitive enough to provide early warning of unexpected effects.

Limitations: It may be difficult to relate body burden to adverse health effects. Costs are likely to be high.

Interpretation: This indicator will help determine effectiveness of management actions in protecting human health, and effects of other human activities, e.g. coastal development. Fish consumption advisories are related to this question, but are imperfect indicators because they are not necessarily based on current data and/or may be politically influenced.

Certain classes of organic contaminants and metals readily bioaccumulate in aquatic food chains and become increasingly concentrated from seawater to plankton to shellfish, fish, seabirds, marine mammals, and humans. Compared with levels in seawater, these contaminants are biomagnified by several orders of magnitude in fatty tissues of top predators.

Comments: A possible HAB indicator could measure how effective HAB monitoring is in protecting public health. This indicator is closely related to the indicator of contaminant levels in sentinel organisms and the same comments and limitations apply.

CONTAMINANTS INDICATOR 9
Human Disease From Fish Consumption and Swimming

Purpose: To determine whether management actions are changing the extent and severity of human health effects.

Ecosystem Objective: Protect public health and the availability of safe seafood.

Measure: Human disease due to fish/shellfish consumption and swimming – including infectious disease (microbial infections), cancer, neurological, endocrine and immune disruption (primarily due to chemical exposure). Need participation of epidemiologists/public health experts to develop appropriate indicator. Data from public health agencies (?).

Outcome: Contaminants in seafood, and exposure of swimmers to pathogens, can cause human health effects.

Illustration: Graphs showing relationship of human disease incidence with fish consumption or incidence of swimming in contaminated water.

Features: Annual to decadal measurements on water body and regional scales. Link to tissue body burdens (seafood and human).

Limitations: Determining whether disease is caused by fish consumption or swimming, rather than other exposure routes, requires epidemiological study.

Interpretation: This indicator will help determine effectiveness of management actions in protecting human health, and effects of other human activities, e.g. coastal development.

Comments: These studies are difficult to conduct because of potential multiple sources of pathogens, which further weakens the relationship between indicators and pathogens. Some working group members felt this indicator would be too difficult to develop -- needs more research, scientists and managers don't have the right expertise for interpretation, and too many complicating factors.

CONTAMINANTS INDICATOR 10
Sediment Triad

Purpose: To determine whether contaminant management actions are protecting ecosystem integrity.

Ecosystem Objective: Maintain sediment quality sufficient to protect ecosystem integrity.

Measure: Sediment quality measured by triad approach (contaminant levels, sediment toxicity, and infaunal community structure). Not clear whether existing monitoring efforts provide all the data needed for this approach.

Outcome: Elevated contaminant levels may or may not reduce biodiversity or cause direct toxicity to benthic organisms in any particular area. Develop sediment quality triad index?

Illustration: Maps of surficial sediment contamination. Periodic "State of the Environment" reports.

Features: Annual to decadal measurements of sediment quality triad, average for water bodies. More temporal and spatial resolution is needed where gradients are high. Consider speciation/sorption. Use transport models, where appropriate/available. Relate to indicators of Area of contaminated sediment and Habitat quality impairment.

Limitations: Alterations in benthic communities can be caused entirely or partly by differences in depth, sediment texture, salinity, predation, and other factors. The data from the three components may not necessarily parallel each other.

Interpretation: This indicator will help determine effectiveness of management actions (and effects of other human activities, e.g. coastal development).

Comments: This is closely related to (or could be one component of) the sediment contamination indicator above, and could likely be folded into that other indicator.

CONTAMINANTS INDICATOR 11

Marine Organism Disease Incidence

Purpose: To determine whether contaminant management actions are protecting ecosystem integrity.

Ecosystem Objective: Prevent disease in marine organisms caused by anthropogenic chemical inputs and pathogenic organisms.

Measure: Incidence of disease (microbial infections) and health problems associated with chemical exposure (immune suppression, disease susceptibility, endocrine disruption, reproductive impairment) at various trophic levels (seals, birds, fish, mollusks, crustaceans) Reproductive success (or growth or productivity, as appropriate to the species.) Data from NOAA - NMFS, EPA, states/provinces, researchers.

Outcome: Organisms with elevated contaminant levels, or exposed to anthropogenic microorganisms, may have higher disease incidence or reproductive problems. Should be paired with other biological effects indicators above to aid interpretation.

Illustration: Maps of disease incidence in organisms. Temporal trends in disease. Periodic State of the Environment reports.

Features: Annual measurements in same season. Link to measures of sediment contamination, contamination levels in sentinel organisms. Monitoring across trophic scales, incorporating biomarkers of exposure and effects in indicator species at key points in the food chain. Apply new available technologies to measure biomarkers of exposure and effects (molecular and cellular diagnostics, reporter gene technology, genotyping, hepatic enzyme induction, lymphocyte proliferation) – these indicators provide rapid early warning signals of ecosystem health risks at various trophic levels (prior to frank disease or population-level impacts). These new technologies are rapid, straightforward, relatively inexpensive, and some are applicable to diverse tissues.

Limitations: More discussion/development of new biomarker technologies may be needed. The stressors responsible for increased disease incidence may be difficult to identify, or involve a complex mix of natural and anthropogenic factors. Regional/national/global change, e.g. warming, may have disproportionate consequences that can mask more subtle stressors. Cost depends on intensity.

Interpretation: This indicator will help identify changes in living aquatic resource health, allowing for treatment or prevention of epizootics, and may help determine effectiveness of management actions (and effects of other human activities, e.g. coastal development).

Comments: Few research labs and EPA/NOAA-NMFS efforts collect data on disease factors. [New York State DEC and CT's Aquaculture Bureau have full-time pathologists that study and monitor disease in some resource organisms in Long Island Sound.] Need to measure emerging contaminants—especially those increasing in US, e.g., brominated flame retardants in fish, human breast milk. Archive sediments and tissues for future analysis of emerging contaminants. There are existing archives (EPA, USGS) but the networks between them need to be strengthened, and someone needs to fund the archival.

CONTAMINANTS INDICATOR 12

Habitat Quality Impairment by Contaminants

Purpose: To determine whether contaminant management actions are protecting ecosystem integrity.

Ecosystem Objective: Protect marine habitat quality from direct effects of contaminant inputs.

Measure: Quality of habitats as affected by contaminants, including

- Low DO due to organic material input
- Turbidity of anadromous fish runs due to excessive solids input

Data from state/provincial environmental protection agencies, NPDES permits/permit applications, NEP studies, Sea Grant studies, fisheries agencies.

Outcome: Habitat quality may be impaired by direct physical or chemical alterations due to contaminant inputs (as distinguished from the effects of toxic and microbial contaminants discussed under other indicators, and from indirect effects of cultural eutrophication.)

Illustration: Maps of habitat quality. Periodic "State of the Environment" reports.

Features: This indicator relates to habitat quality measures (see habitat indicators) related to dissolved oxygen and solids. This indicator also relates to indicators of Area of contaminated sediment and Sediment quality triad.

Limitations: It may be difficult to distinguish effects of toxic contaminants from those of solids or organic matter inputs.

Interpretation: This indicator will help determine effectiveness of management actions (and effects of other human activities, e.g. coastal development).

Comments: Besides indicating direct effects of solids or organic matter inputs, measurements under this indicator can serve as another level or mechanism for interpreting the earlier indicators on sediment contamination, etc. plus the contributory effects of nutrient enrichment, global warming, etc. Habitat quality has to be quantified for many factors, in order to accurately interpret the above indicators.

APPENDIX ONE

Aquatic Habitats: Framework for Indicators and Monitoring

The long-term scope of effort should encompass regionally significant habitats within three general zones:

- Coastal watersheds above high-tide, including anadromous fish habitat
- Intertidal and nearshore estuarine habitats, including tidal marshes, sand beaches, sand and mud flats, rockweeds, seagrass beds, and kelp beds
- Marine systems (extending from nearshore subtidal to the 60-m depth contour)

Indicator selection was guided by the following monitoring questions:

Q1. How is the extent, distribution, or use of coastal habitats changing over time?
Q2. How is the ecological condition of coastal habitats changing over time?
Q3. What are the causes of coastal habitat change?

To be most effective, a regional monitoring program must answer these questions at multiple scales while addressing multiple pressures on coastal resources and environmental processes. A hierarchical framework for northeastern aquatic habitat monitoring was modeled after strategies developed for integrated research and monitoring on a national scale (National Science and Technology Council, 1997, Integrating the Nation's Environmental Monitoring and Research, http://www.epa.gov/cludygxb/Pubs/framewrk.pdf; Coastal Research and Monitoring Strategy Workgroup, 2000, Clean Water Action Plan: Coastal Research and Monitoring Strategy, http://www.cleanwater.gov/coastalresearch). Indicator-based monitoring will be implemented in a nested, three-tiered approach to document regional status and trends as well as diagnose causes of environmental change. When coordinated and integrated across tiers, this monitoring strategy will provide data needed to identify coastal habitat problems, suggest management solutions, and assess the effectiveness of management actions and environmental policies. Indicators will be monitored at the following scales:

Tier 1, Broad-scale characterizations. Measurements that characterize properties of large areas by simultaneous and spatially intensive measurements across the entire region. Indicators are measurable by remote sensing or automated data collection at mapping scales.

Tier 2, Broad-scale diagnosis. Issue- or resource-specific surveys focused on certain properties of a region. Surveys are designed to sample a subset of the total area using rapid assessment methods. Data are generated on ecological condition of ~100-300 sites throughout the region.

Tier 3, Intensive diagnosis. High-resolution monitoring of a greater number of indicators and at a higher frequency than either Tiers 1 or 2 but at a much smaller number of locations, or index sites (~10-30). Monitoring at this level is focused on diagnosing cause-effect relationships. Ideally, indicators measured at each index site relate to the major potential causes of environmental change as well as to ecosystem responses of concern to society.

Proposed Indicators

Indicators for addressing Monitoring Question 1 (Q1) are broadly relevant to all habitat types within the long-term scope of effort, and those for addressing Q2 are relevant to most. However, effective indicators for diagnosing the causes of habitat change (Q3) are quite habitat-specific. Initial indicators identified for Q3 relate to habitats that are most threatened by human activities and are areas of high management priority: seagrass beds, salt marshes, and soft-bottom subtidal habitats. Ultimately, indicators will be selected for the other aquatic habitats as well. Indicators for Q3 were identified to address the primary pressures on target habitats. The table below relates indicators to specific monitoring questions and scale of implementation. Indicators that are relevant to more than one Monitoring Question appear more than once in the table.

Monitoring Question	Indicator	Measure*	Scale of Implementation		
*[Habitat Relevance: ALL=all habitat types; SG=seagrass; SM=salt marsh SB= soft bottom subtidal habitats			Tier 1	Tier 2	Tier 3
Q1: How is the extent, distribution, or use of coastal habitats changing over time?	Extent and distribution of habitat types	Area of identified habitat types (habitat classification scheme to be determined) [All]	X		
		Mapped sizes and locations of identified habitat types [ALL]	X		
	Extent and distribution of habitat in protected status	Proportion protected [ALL]	X		
		Mapped sizes and locations of land use/land cover classes [ALL]	X		
Q2: How is the ecological condition of coastal habitats changing over time?	Community structure	Percent cover by species [ALL]		X	
		Vegetation canopy height [SG, SM]		X	
		Biomass by species [ALL]			X
		Photo stations [ALL]			X
	Trophic structure	Number of trophic levels with rapid assessment of proportional abundance (0, low, high) within target taxonomic groups [ALL]		X	
		Actual abundance of individuals within taxonomic groups/trophic levels [ALL]			X
	Invasive species	Presence or aerial cover of target species within certain habitats (e.g. invasive tunicates, Codium, Phragmites, purple loosestrife) [ALL]		X	
		Quadrat-based measurements of target species within certain habitats (metric varies with species, e.g. density, percent cover, vegetation canopy height) [ALL]			X
	Habitat boundaries relative to elevation	Location, depth of shallow edges of seagrass beds [SG]		X	
		Location, depth of deep edges of seagrass beds [SG]			x
		Location, relative elevation of high marsh and low marsh zones [SM]		X	
Q3: What are the causes of coastal habitat change? Have physical & hydrologic alterations contributed to coastal habitat change?	Direct alterations	Area of tidally restricted marsh [SM]	X		
		Width of tidal creek above and below restriction [SM]		X	
		Tidal regime above and below restriction [SM]			X
		Area impacted by dredging and dragging (aerial photography plus field verification) [SG]	X	X	
		Area impacted by dredging and dragging (side-scan sonar) [SB]			X
		Number and location of coastal and marine structures (e.g. hardened shoreline, docks, piers, ramps, floats, moorings, aquaculture pens, sunken debris; Mapping scale plus field verification of more use categories) [SG, SM, SB]	X	X	
	Indicator species	Abundance of certain maldanid polychaetes that are intolerant of dragging disturbance; presence of diatom layer; abundance of isopods and amphipods with known narrow salinity tolerances [SB]			X
Q3: What are the causes of coastal habitat change? Have nutrient & organic enrichment contributed to coastal habitat change?	Adjacent Land Use Index	Index based on septic tanks, agricultural land, urban/industrial use, residential use, and other human uses (mapping scale plus field verification of more use categories) [ALL]	X	X	
	Light transmission	Light attenuation coefficient (Kd) [SG]			X
		Location of deep edge of bed [SG]			X
	Plant growth and nutrient assimilation	Eelgrass Nutrient Pollution Indicator [SG]			X
		Nuisance macroalgae, epiphyte cover – rapid assessment (presence/absence) [SG]		X	
		Nuisance macroalgae, epiphyte cover – quantified metric [SG]			X
	Indicator species	Abundance of Capitella capitata [SB]			X
	Physicochemical sediment characteristics	Redox potential discontinuity, total organic content of sediments, sulfide concentration of sediments [SB]			X
Q3: What are the causes of coastal habitat change? Has contaminant input contributed to coastal habitat change?	Indicator species	Abundance of certain fauna with known narrow tolerance to contaminant input [SB]			X
	Sediment contaminants	PAH concentration in sediments [SB]			X

Monitoring Question	Indicator	Measure*	Scale of Implementation		
*[Habitat Relevance: ALL=all habitat types; SG=seagrass; SM=salt marsh SB= soft bottom subtidal habitats			Tier 1	Tier 2	Tier 3
Q3: What are the causes of coastal habitat change? Has global climate change contributed to coastal habitat change?	Phenology	Timing of flowering (rapid classification of data and percent flowering) [SM]		X	
		Emergence of first leaves [SM]			X
		Timing of flowering & seed production SG]			X
	Habitat boundaries relative to elevation	Location, depth of shallow edges of seagrass beds [SG]		X	
		Location, depth of deep edges of seagrass beds [SG]			X
		Location, relative elevation of high marsh and low marsh zones [SM]		X	
	Relative sediment elevation	Sediment elevation measured with surface elevation tables [SM]			X
	Indicator species	Abundance of certain fauna with known narrow salinity or temperature tolerance [SB]			X
Q3: What are the causes of coastal habitat change? Have erosion and/or sediment deposition contributed to coastal habitat change?	Relative sediment elevation	Sediment elevation measured with surface elevation tables [SM]			X
		Depth of depositional layer [SB]			X
	Light transmission	Light attenuation coefficient (Kd) [SG]			X
	Habitat boundaries relative to elevation	Location, depth of shallow edges of seagrass beds [SG]		X	
		Location, depth of deep edges of seagrass beds [SG]			X
		Location, relative elevation of high marsh and low marsh zones [SM]		X	
Q3: What are the causes of coastal habitat change? Has disease contributed to coastal habitat change?	Wasting disease	Eelgrass Wasting Index [SG]		X	

APPENDIX TWO

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