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Experimental ecosystem accounting for coastal and marine areas: A pilot application of the SEEA-EEA in Long Island coastal bays

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ABSTRACT

Recent international efforts have focused on the development of metrics to supplement or adjust Gross Domestic Product (GDP) to better account for the broader environmental and social impacts of economic development. In this regard, the United Nations System of Environmental-Economic Accounting, through its Experimental Ecosystem Accounting (EEA) work, is developing a standardized approach to accounting for the value of ecosystem services generated by ecosystems and documenting the relationships between ecosystem services and economic activity. Limited examples exist of the application of the EEA approach to coastal and marine habitats. The purpose of the current paper is therefore to develop a pilot process for applying the EEA within a coastal area, using South Shore Long Island Bays as a case study. Indicators of ecosystem condition and ecosystem services are proposed, data are compiled for the study site, and population of EEA tables as proposed by the United Nations is undertaken. Results indicate significant data gaps for marine and coastal areas that may limit the immediate ability to compile these ecosystem accounts. However, based on identified data gaps and implementation challenges, the process undertaken at the pilot site also provides guidance for potential future research activities.

1. Introduction

Gross Domestic Product (GDP) measures the economic output of a country and is a de facto means of comparing performance across countries. Given its importance in political and economic discussions, standardization of the methodology for its calculation was needed to ensure the integrity of the GDP estimates provided by countries. The System of National Accounts (SNA) provides an international standard for estimating GDP to facilitate inter-country comparisons of economic output and growth trends [1]. For several decades, and despite its widespread usage, the limitations of GDP in providing a full assessment of the overall well-being of a country have been documented (World Bank 1997), particularly critiquing its narrow focus on income generation and neglect of social, environmental, and sustainability considerations.

Various efforts are underway to address the challenges associated with relying on GDP, not intended to be a metric of well-being, as the sole indicator for international comparisons of economic development. The Sustainable Development Goals of the United Nations represent one international approach to tracking thematic indicators of well-being that are broader than GDP (https://sustainabledevelopment.un.org/), with many of the goals and their associated targets emphasizing economic linkages to social and environmental measures. Other strategies have emphasized inclusion of social and health-related measures and/or information on the scarcity of natural resources and the implications of that scarcity for economic sustainability into aggregate indices. These efforts broadly include development of a Genuine Progress Indicator (GPI), Inclusive Wealth Index (IWI), and Human Development Index (HDI), among others [2,3]. Of these three highlighted indices, GPIs and IWIs have focused most specifically on incorporation of ecosystem assets into index development.

GPIs have been calculated internationally as well as for states within the United States. While approaches for GPI are not consistent, most include an incorporation of social elements (e.g., income inequality) into the evaluation of city/region/country performance as well as the environmental and sustainability costs (e.g., loss of natural capital stocks) associated with economic activity. For example, recent work in Baltimore, Maryland (Talberth 2017) included social elements such as the value of leisure time and value of unpaid labor as well as environmental considerations such as services from protected natural capital and costs of pollution. In the same study, authors argued for a GPI 2.0, to increase consistency in its calculation, and to focus GPI on benefits and costs of economic activity (as opposed to GDP's focus on economic output) and on current welfare rather than long-run sustainability concerns.

Development of an IWI by the United Nations and associated experts has focused on a range of issues in its research agenda, but included assessment of sustainability of natural capital stocks over time and their association with well-being [4,5]. The IWI provides several potential strategies for incorporating ecosystem services, including shadow prices and use of an adjusted Net Domestic Product (NDP) that considers the role of changing benefits as a consequence of development impacts

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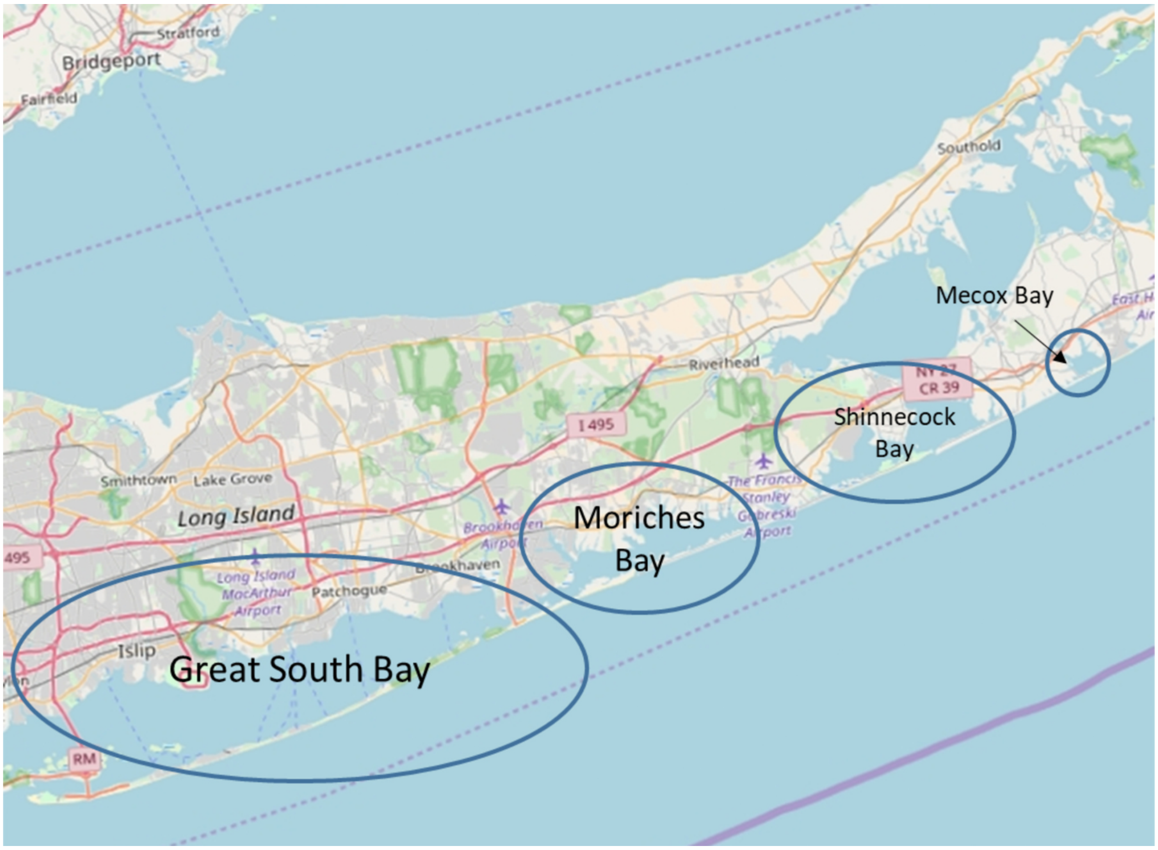

Fig. 1. Map of the broader study area with labeled study bays.

upon natural capital stocks. Data limitations across countries and the complexities of measuring ecosystem (as well as social) capital stocks and benefit flows have proven to be challenges in developing a comprehensive international IW measure that can track progress in meeting sustainable development objectives [6,7]. Examples of application include evaluation of resilience related to agriculture in southeastern Australia [8] and as a comparator against comprehensive wealth measures across multiple countries [2].

Ecosystem services, or the benefits that humans receive from ecosystems [9], have been the subject of intensive evaluation since the release of the Millennium Ecosystem Assessment and it associated reports. Though the United Nations System of Environmental-Economic Accounting (UNSEEA) has an internationally accepted Central Framework that proposes an accounting approach for selected individual environmental assets (e.g., water, minerals, land) [10], there is no currently accepted international standard similar to the SNA that focuses holistically on ecosystems and can therefore provide guidance for accounting for ecosystem services within the context of environmental-economic accounting. To standardize an approach for including the environment as a measure of national performance, UNSEEA initiated the development of its Experimental Ecosystem Accounting (EEA) approach [11]. This approach has been further elaborated in more recent technical recommendations [12].

The nature of accounting for ecosystem services poses unique challenges. These include the need to select and apply an appropriate classification system for ecosystem and their services (the Common International Classification for Ecosystem Services (CICES) is one example, the US Environmental Protection Agency's Final Ecosystem Goods and Classification System, another), the need to select consistent, relevant spatial habitat types and delineate spatial boundaries for accounting units, and the need to choose ecosystem indicators that can track its condition or health as well as the ecosystem services that it generates. Understanding of ecological models and processes therefore become important considerations when attempting to apply the EEA approach, requiring an interdisciplinary perspective in development of accounting system within a pilot region or country.

A standard, international set of indicators for ecosystem condition and ecosystem services is not the goal of the SEEA EEA; rather different geographies and systems would be expected to have different indicators that are critical to them given the complex environment-economy interactions involved. For example, if a community uses fish for subsistence rather than catch-and-release recreation, additional consumption-based indicators of fish health may be appropriate. Instead, the SEEA EEA provides an accounting structure for compiling statistics on indicators relevant to specific local, regional and national contexts. Though not the subject of this paper, it is also unlikely that a global valuation measure for monetary accounting by habitat would be appropriate. Through a compilation of pilot studies of the EEA approach researchers and decision makers will be able to better understand alternative approaches to compiling the SEEA tables to match their programmatic and policy needs.

In this vein, the focus of this paper is on the pilot coastal application of the SEEA-EEA within the United States. Given the limited existing attempts to apply the SEEA EEA within a coastal and marine context [13,14], this research specifically focuses on the SEEA EEA process for coastal bays on Long Island, including proposal of potential indicators for ecosystem condition and population of ecosystem accounting tables as promulgated by the 2012 SEEA EEA. Although SEEA EEA accounts are targeted for eventual national level application, pilot testing at local and regional levels, as in this study, is important to building an understanding of the process for populating these tables; local and regional scale tables will eventually be needed to build up to national level tables. To our knowledge this is the first attempt to populate the SEEA EEA tables within the United States and one of the first globally to focus on the coastal and marine context. An important objective of this project was to evaluate the extent of data limitations as roadblocks for

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applying the SEEA EEA within the marine context as well as evaluating the strategies and potential drawbacks associated with scaling up local level estimates to the national level. This paper does not seek to draw conclusions about trends in the selected indicators resulting from the population of the SEEA EEA table, which is better accomplished through review of data trends by relevant technical experts. To focus the analysis on a context that might be used in regional decision-making, the research evaluated developing an EEA system focused on ecosystem services associated with coastal beach recreation and commercial fisheries, two drivers of economic activity on Long Island.

2. Study area

The study area for this pilot evaluation of the application of SEEA EEA principles to the marine environment consisted of the following South Shore Long Island coastal bays: Great South Bay, Moriches Bay, Shinnecock Bay, and Mecox Bay (See Fig. 1). These bays range from more densely settled areas closer to New York City (e.g., Western Great South Bay) to less densely populated bays of Eastern Long Island (e.g., Mecox Bay). Bays were initially evaluated on an individual basis and then combined to evaluate potential procedures for scaling up from multiple individual Ecosystem Accounting Units (EAUs).

3. Data and methods

3.1. Designation of ecosystem accounting unit

EAUs are designated by the SEEA EEA as the administrative unit for tracking of the changes in ecosystem characteristics and ecosystem condition over time. As such, one typical objective in selecting the EAU is that its boundaries remain consistent over time; this ensures that like EAUs are accounted for as accounts are compiled and compared over multiple time periods. For the purposes of this paper, 12-digit hydrologic unit codes (HUCs) as developed by the United States Geological Survey defined the EAU boundaries. Another benefit of HUCs is that they typically encompass both terrestrial and aquatic elements of the nearshore environment, allowing for an understanding of how terrestrial management actions and development within the watershed may impact indicators within the targeted bay. Each bay may be composed of more than one HUC (for example, the Great South Bay encompasses 5 HUCs). While each HUC may be viewed as its own EAU, this paper uses the common geographic designator (e.g., Moriches Bay) as the EAU for which data are collated and reported across the various component HUCs within a designated bay. There are a total of 10 12-digit HUCs within the study area (see Table 1 for a crosswalk between HUCs and common geographic designators (bay names)).

The EEA also defines a Land Cover Ecosystem Unit (LCEU) to track areas within an EAU of a specific land cover type. From these land cover types, as in most ecosystem services analysis, the ecosystem services emerge based on supporting scientific literature describing ecosystem functions present within and performed by these varied land cover types [15–19]. Complex classification systems for marine habitats are available [20,21] but existing bay-level data at this level of detail are limited. For the purposes of this research, therefore, broad scale common habitat designations related to the marine environment are used. Since this pilot analysis focuses on the coastal and marine context and services associated with beach recreation and commercial fisheries, the initial targeted LCEUs are (1) barren/beach areas, (2) wetland areas, (3) seagrass areas, (4) benthic habitats, and (5) water column.

Table 1
12-Digit HUCs by Pilot Suffolk County Bays.

Bay Name	12-Digit HUC
Great South	020302020406
	020302020407
	020302020405
	020302020305
	020302020304
Moriches	020302020601
	020302020602
Mecox	020302020605
Shinnecock	020302020603
	020302020604

3.2. Data compilation

As an explicitly spatial approach, the SEEA EEA requires spatial datasets that ideally connect ecosystem condition indicators and ecosystem service indicators to each defined LCEU and, consequently to the larger EAU. Spatial environmental and socioeconomic data available for the targeted bays were compiled for evaluation and application within to the proposed EEA tables (see Fig. 2) included in the EEA framework document [11]. These tables require data including ecosystem extent, characteristics, and services. As noted previously, the services (and, as a result, associated indicators) targeted for this pilot exercise were commercial fisheries and beach recreation. The datasets available for targeted habitats within New York State are shown in Table 2.

3.3. Indicator elaboration

Based on the data currently collected consistently across Long Island's coastal bays, indicators (both of ecosystem condition and ecosystem services) are proposed that measure ecosystem condition, ecosystem services, or ecosystem service benefits. These indicators are mapped across each of the EAUs and then scaled up as a measure for the overall region (i.e., the South Shore Bays of Suffolk County) depending upon the nature of the indicator. For certain indicators summation across regions is used (e.g., extent measures), while for others (e.g., *E. coli*, *Aureococcus* concentrations) averages across all bays were considered most appropriate as an initial estimate.

3.4. Population of example SEEA-EEA Tables

SEEA-EEA Tables (as shown in Fig. 1) were populated based on the identified datasets (Table 2), proposed association of indicators with LCEUs and ecosystem services (Fig. 3), and assumed ecosystem services consequences (reduction or improvement in condition) of a change in the indicator. Challenges in connecting indicators to specific LCEUs were noted in the tables as well as any identified difficulties in attributing changes in indicators to natural or human-related events. Review of these tables led to the identification of data gaps and suggestions of challenges for implementation of this approach within a management context.

3.5. Data gaps identification and implementation challenges

Data gaps impeding full elaboration of the SEEA EEA were identified within the study region. Challenges in implementing the SEEA EEA on a broader scale for marine and coastal habitats were also identified based on the review of identified gaps and considering specific characteristics of the type of data required in the marine and coastal environment. Suggestions for future research and application avenues were then noted.

4. Results

4.1. Study area

The targeted bays and their selected geographic and population characteristics are summarized in Table 3. The Great South Bay is the

Measures of ecosystem condition and extent at end of accounting period for an EAU

	Ecosystem extent	Characteristics of ecosystem condition				
		Vegetation	Biodiversity	Soil	Water	Carbon
		Examples of indicators				
Type of LCEU	Area	Leaf area index, biomass, mean annual increment	Species richness, relative abundance	Soil organic matter content, soil carbon, groundwater table	River flow, water quality, fish species	Net carbon balance, primary productivity
Forest tree cover						
Agricultural land[a]						
Urban and associated developed areas						
Open wetlands						

[a] Medium to large fields of rain-fed herbaceous cropland.

Changes in ecosystem condition for an LCEU

	Characteristics of ecosystem condition				
	Vegetation	Biodiversity	Soil	Water	Carbon
	Examples of indicators				
	Leaf area index, biomass, mean annual increment	Species richness, relative abundance	Soil organic matter content, soil carbon, groundwater table	River flow, water quality, fish species	Net carbon balance, primary productivity
Opening condition					
Improvements in condition					
Improvements due to natural regeneration (net of normal natural losses)					
Improvements due to human activity					
Reductions in condition					
Reductions due to extraction and harvest of resources					
Reductions due to ongoing human activity					
Catastrophic losses due to human activity					
Catastrophic losses due to natural events					
Closing condition					

Table 4.5
Expected ecosystem service flows at end of accounting period for an EAU

	Expected ecosystem service flows per year				
Type of ecosystem services	Forest tree cover	Agricultural land[a]	Urban and associated developed areas	Open wetlands	…
Provisioning services					
Regulating services					
Cultural services					

a Medium to large fields of rain-fed herbaceous cropland.

Fig. 2. Example EEA tables from SEEA EEA 2012, tables 4.3–4.5 [11].

Table 2
Datasets identified, owner, years of coverage, and expected application to the SEEA-EEA system.

Dataset	Owner	Year(s)	EEA Application
Land cover	USGS	2006, 2011	LCEU Wetlands Extent, Barren Land (Beach) Extent
Seagrass cover	NOAA/NYDOS	2002	LCEU Seagrass Extent
DO, T, S, pH, TN	SCDOH	1976-present	Physical and chemical characteristics
BT	SCDOH	1976-present	Biological characteristics
E	NYSDEC	2002-present	Biological characteristics
Shellfish Landings	NYSDEC	1946–2016	Ecosystem Services Proxy
Beach visitation	NYSOPRHP	2003–2016	Ecosystem Services Proxy

DO = dissolved oxygen, T = water temperature, SD = secchi disk depth, DN = dissolved nitrogen, BT = aureococcus concentration, E = E coli concentration.

Table 3
Bays evaluated in SEEA-EEA application.

Bay	Watershed Area (km^2)	Water Area (km^2)	Watershed Population (2010 Census[a])
Great South	539	243	316,743
Mecox	60	5	3008
Moriches	206	33	76,782
Shinnecock	135	32	23,231
Region Total	**940**	**313**	**419,764**

[a] Sum of census blocks whose centroid falls within the designated 12-digit HUCs.

largest of the four bays, in terms of watershed area, water area, and watershed population. Mecox Bay is the smallest. The total population within the defined 12-digit HUCs for this assessment is 419,764, compared with a total Suffolk County population of approximately 1.5 million (2010 Census).

4.2. Indicator elaboration

The LCEUs described in the Data and Methods section provide the ecosystems for association with indicators of ecosystem condition and for association with a flow of ecosystem services. No data were consistently available related to designation of benthic habitat areas; therefore, the analysis focuses on the other 4 LCEU types (water column, wetlands, seagrass areas, and barren/beach). The available datasets compiled from federal, state, and local sources (as summarized in Table 2) for the study area led to selection of a set of indicators of ecosystem condition and ecosystem services relevant to application to commercial fishing and recreational beach visitation. Indicators selected include dissolved oxygen (DO), water temperature (T), Secchi disk depth (SD), dissolved nitrogen (DN), *Aureococcus anophagefferens* concentrations (BT), and *Escherichia coli* (E) concentrations. These condition indicators and their proposed connections to both the LCEUs and the eventual ecosystem services are shown in Fig. 3.

As shown in Fig. 3, changes in the direction of certain indicators for an accounting period would be expected to eventually impact the ecosystem service proxies of beach visitation and fishing activity. For example, increases in brown tides as measured by exceeding *Aureococcus* thresholds would be expected to have a negative impact on fishing activity through impacts on habitats and species [22–25], and increases in *E coli* concentrations in the water column or decreases in water clarity (decreasing Secchi disk depth) would be expected to decrease the value of a given beach and potential beach visits [26,27–31]. Dissolved nitrogen levels, which can be associated with a variety of algal blooms depending on the nitrogen composition [32,33], would be expected to indirectly impact fishing activity through potential eutrophication effects on fish and shellfish communities [34]. Temperature is more uncertain as different coastal and marine species will move to fill niches as species distributions shift, leading to an uncertain effect on fishing activity and the benefits associated with a fishing trip [35,36].

4.3. Population of SEEA-EEA Tables

The example SEEA EEA tables shown in Fig. 2 populated for the study area bays and their selected LCEUs are shown in Tables 4–6. Mecox Bay was not included in the remainder of the piloting exercise because of an absence of monitoring data related to ecosystem condition characteristics and aquatic habitat extent. The aggregated scaled up information for three remaining bays (Great South, Shinnecock, and Moriches) is shown in Table 4 for 2006 (a) and 2011 (b), with supporting individual tables for each bay provided in the Appendix. The years of 2006 and 2011 were selected as time periods for the accounting analysis because these were the years with available land cover extent data through USGS (used for wetlands and barren/beach areas).

The matching of the LCEUs to condition indicators was limited by the level of spatial detail available in the existing coastal water quality monitoring data. Water quality data are collected at stations in the bays and are therefore not specifically associated with a given aquatic

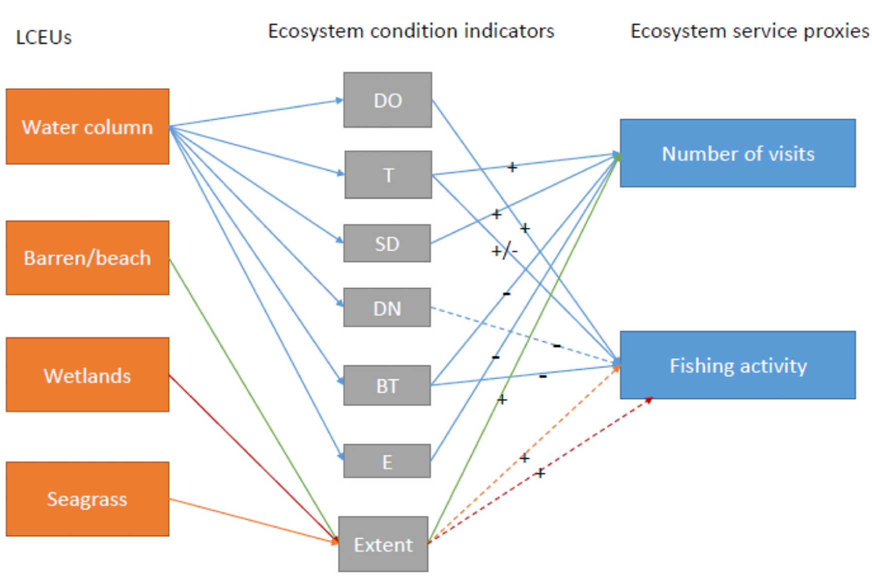

Fig. 3. Proposed connections between LCEUs, ecosystem condition, and selected ecosystem services within the study area. Arrow colors show connection flows from LCEUs through indicators to ecosystem service proxies. Solid lines indicate anticipated direct effects while dashed lines indicate indirect effects. A (+) sign indicates expected proportional relationship between condition indicator change direction and ecosystem service proxy change direction, (-) indicates an expected inverse relationship and (+/-) indicates uncertainty in the relationship between the condition direction change and the ecosystem service proxy change. DO = dissolved oxygen, T = water temperature, SD = secchi disk depth, DN = dissolved nitrogen, BT = aureococcus concentration, E = E coli concentration.

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Table 4
Regional Aggregation of Ecosystem Condition Characteristics for accounting periods of (a) 2006 and (b) 2011. These correspond to SEEA EEA Table 4.3 [11]. U indicates data are unavailable for association with a specific habitat type while N/A indicates that data are not applicable to a certain habitat type.

(a)

LCEU	Extent (km^2)	Characteristics of ecosystem condition					
Year: 2006		Physical/Chemical				Biological	
		DO (mg/l)	T (°C)	S (ft)	DN (mg/l)	BT (cells/ml)	E[a] (MPN/100 ml)
Water column	310	9.8	9.4	5.2	0.33	1945	29
Barren land (Beach)	23.8	N/A	N/A	N/A	N/A	N/A	N/A
Wetlands	49	U	U	U	U	U	U
Seagrass[b]	67.4	U	U	U	U	U	U

(b)

LCEU	Total Extent (km^2)	Characteristics of ecosystem condition					
Year: 2011		Physical/Chemical				Biological	
		DO (mg/l)	T (°C)	S (ft)	DN (mg/l)	BT (cells/ml)	E[a] (MPN/100 ml)
Water column	315	8.5	14	5.7	0.23	84,274	21
Barren land (Beach)	18.3	N/A	N/A	N/A	N/A	N/A	N/A
Wetlands	51	U	U	U	U	U	U
Seagrass[b]	67.4	U	U	U	U	U	U

[a] Represents a single state park within Great South Bay.
[b] Region-wide data collected in 2002 only.

habitat type. For example, the data are not specifically collected above and around seagrass habitats. Moreover, data are not consistently collected in a way that would allow evaluation of water quality impacting wetlands during periods of submersion. As such, the water column LCEU was determined to be the most appropriate asset for initial association with the ecosystem condition characteristics derived from the water quality data. This resulted in an unavailable (U) coding for data across the majority of marine and coastal LCEU categories. An alternative future approach could be to assume that the water column values (which are averages across the individual bays) also are representative of the average values overlaying an underwater or submerged habitat type.

Extent was the only variable available across all LCEUs. Total extent of the regional study area did not vary from year to year as the HUCs were used as constant boundaries. It is important to note that the extent data for the seagrass LCEU was based on only one year of data (2002) as it is not included as a separate land cover type in the USGS land cover data set, which mainly focuses on terrestrial habitats. The tables therefore apply this single value from the NOAA/NYDOS seagrass dataset to both 2006 and 2011 accounting periods and notes it as a footnote to the accounting tables. The *E. coli* data were also only available for water adjacent to a single beach state park within the study region as most of the barren land (beach) LCEUs are in private locations without requirements for public health-related data collection. No physical/chemical or biological data specifically relevant to barren land (beach) LCEU were available, such as litter density and cover by macroalgae, both of which may impact beach visitation. For some portion of the beachgoing public engaged in water recreation,

Table 6
Connection to Potential Regional Ecosystem Service Flows. This corresponds to SEEA EEA example Table 4.5 [11].

Type of service	End of 2006 Accounting Period	End of 2011 Accounting Period
Provisioning services		
Shellfishing (bushels landed)[a]	12,169	21,501
Cultural Services		
Beach visitation (number of visits)[b]	772,803	1,125,800

[a] Totals across all study bays.
[b] Represents data from a single park.

Table 5
Changes in ecosystem condition for water column LCEU. This corresponds to EEA Table 4.4 [11].

	Characteristics of Ecosystem Condition				
	DO (mg/l)	T (°C)	S (ft)	BT (cells/ml)	E (MPN/100 ml)
Opening condition	9.8	9.4	5.2	1945	29
Improvements in condition			0.5		8
Improvements due to natural activity			?		?
Improvements due to human activity			?		?
Reductions in condition	1.3			82,329	
Reductions due to extraction and harvest	?			?	
Reductions due to ongoing human activity	?			?	
Catastrophic losses due to human activity	?			?	
Catastrophic losses due to natural activity	?			?	
Closing condition	8.5	14[a]	5.7	84,274	21

[a] Context is important for determining whether such a change represents a reduction or improvement in condition. For certain species a temperature increase may be a benefit, while for others it may be a detriment.

however, the *E coli* levels in adjacent waters would likely also be relevant.

Table 5 combines information from the 2005 and 2011 accounting reporting year from Table 4 to evaluate how characteristics of ecosystem condition are changing over time. This corresponds to Table 4.4 in the SEEA EEA 2012 [11]. As the SEEA EEA suggests compiling these tables by LCEU, our table uses the water column LCEU, which we used for assignment of available condition measures. Extent data could be calculated in a similar manner using the Land Accounts of the SEEA Central Framework [10]. The question marks indicate areas where further research would be needed to evaluate the accounting rows specifying causes of the observed changes in condition. Readily available information does not indicate what might have led to the changes in ecosystem condition. Classification of a change as an "improvement" or a "reduction" was based on our assumption of the preferred direction for change of an indicator from Fig. 3(e.g., higher DO is preferred to lower DO meaning that the observed decrease in DO between 2005 and 2011 is a "reduction" in condition). In the case of temperature, it was unclear whether the observed change should be flagged as an improvement or a reduction in condition.

The final component of this pilot application was determining what existing data for ecosystem services could be used to populate the table corresponding to SEEA EEA Table 4.5 [11]. Since the focus of this analysis was on specific ecosystem service flows associated with coastal beach recreation and commercial fishing, available spatially referenced data within those categories were compiled. Two activities that could serve as proxies for these potential ecosystem service flows were identified—shellfishing and beach visitation. These are grouped, respectively, as provisioning and cultural according to the original Millennium Ecosystem Assessment designations [14] and would also align with codes 1.1.4.1 and 3.1.1.1, respectively, in version 5 of the CICES (https://cices.eu/resources/). The appropriate accounting classification system to use in these tables is currently under discussion and may include CICES, the FEGS-CS, or some combination of these classifications. As noted in the table footnotes, data for these ecosystem service proxies are spatially limited.

5. Discussion

The results of this first pilot demonstration of the SEEA-EEA within a United States coastal and marine context suggest that development of a coastal EEA is feasible but would require significant investments in environmental and economic monitoring, at least within the targeted region. Clearly, data limitations represent a significant challenge to full implementation of the SEEA EEA in this geography, as many of the proposed habitats and characteristics of ecosystem condition that link to fishing and recreational use are either not collected at all or not collected at the most appropriate level of spatial or temporal disaggregation. Despite the difficulty posed by the data gaps in populating the EEA tables, lessons can be learned from this pilot exercise.

5.1. Value of conceptual model

Developing a conceptual model for the ecosystem of concern (Fig. 3) was found to be an important step in this pilot exercise. The model provides guidance for indicators and also provides a frame of reference for evaluating potential relationships across the accounting tables tracking condition changes and ecosystem services (here, Tables 5 and 6, respectively). For example, changes in brown tides and changes in fishing activity may be viewed as co-varying indicators, with increased presence of brown tides leading to decreases in fish landings.

Verification of the conceptual model and its assumed directionalities would rely upon primary research within the study system. The EEA, as an accounting system, will not be able to verify the appropriateness of the conceptual model but can suggest potential avenues for research into indicators of condition and ecosystem services based on observed trends in consistently monitored indicators. The conceptual model may also form the basis for ensuring that contributions of intermediate ecosystem services (sometimes referred to as ecosystem functions or processes) are acknowledged, even if valuation of information in the accounts focuses on the final ecosystem good or service.

5.2. Identified data gaps and challenges

While data are available on coastal wetlands by assessments undertaken every 5 years by the United States Geological Survey (USGS), no similar assessments are regularly scheduled for habitats that are particularly significant in the marine environment, such as seagrasses. Instead, surveying of seagrasses occurs on an ad hoc basis based on research interests and funding availability. This causes a mismatch in reporting across accounting periods since data collection activities on all LCEUs are not conducted within every accounting period. For example, an ecosystem account updated every 5 years based on the USGS land cover data schedule would be limited if data on seagrass extent were only collected every 10 years. Effective accounting would require strategies to address environmental data that are collected at differing frequencies and to adjust for the uncertainty associated with older data (such as the 2002 seagrass cover data used here) that nonetheless represent the most recent comprehensive data source for a given LCEU. This clearly also presents a challenge for selecting a relevant baseline for tracking of marine and coastal condition measures; hindcasting and forecasting from available extent and condition data points may provide solutions to this challenge.

Accounting period averages of ecosystem condition measures will obscure seasonal variation of those measures—variation that might be relevant for decision making. For example, within our pilot accounts, dissolved oxygen decreased on average for the regional bays between 2006 and 2011. Dissolved oxygen (DO), however, varies with the season based on fluctuations in temperature and water column mixing, among other considerations. As such, instead of using the average as a measure for certain characteristics, it may be appropriate to use the minimum or maximum value observed during the accounting reporting period, such as lowest DO within the EAU during the accounting period or highest SST during the accounting period. Frequency of occurrence or exceedance of thresholds may also be a potential alternative measure for indicators like BT and DN, where pulses into the environment may be important, depending on the ecosystem services concerned (i.e., concentrations might not be as important as the frequency of these events and their water quality impacts for recreational use and fishing). There may also be a desire to link the accounting indicators (and their specification) to seasonally important times of year (e.g., average SST during spawning season of a target species). Since national statistical agencies frequently adjust GDP for known seasonal trends, so as not to obscure underlying structural shifts, similar seasonality adjustments should likewise be compatible with an ecosystem accounting framework. Such decisions about appropriate metrics to use for ecosystem indicators and seasonality adjustments should be made in consultation with relevant ecosystem experts and environmental managers within the target region. The level of detail, timescale, and frequency of reporting of an EEA will dictate the need for seasonality adjustments.

Another specific data challenge raised by this pilot effort is how to accurately populate Table 5, which assigns the changes observed to the drivers of the observed change (e.g., improvements due to natural activity versus improvements due to human activity). Such information may be gleaned from review of governmental policies and strategies as well as records of storm events or other natural meteorological influences within the study area. In this way, an iterative process for completing the tables may be most appropriate; first, note the beginning and end-of-period values without detailing the reason for the change and second, conduct in-depth investigation of potential drivers of documented changes of concern, which can then be used to complete

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population of the table. The need for this attribution, of course, relies on the intended use of the SEEA-EEA tables by the compiling authority (a topic discussed further below).

5.3. Assignment of condition indicators to LCEUs

One challenge that is somewhat unique to the marine habitat is in the process for assigning condition measures to each habitat type. Variables related to water quality, for obvious reasons, are measured at levels in the water column, but not at a level of spatial resolution where their values above and within certain marine LCEUs can be estimated. However, depending upon the use of the habitat area (e.g., seagrass as fish nursery habitat) the specific value of a condition measure (e.g., DO or environmental contaminant) within that habitat type may be quite relevant. Barring additional sampling within the area that permits interpolation, it may be appropriate to use the nearest water quality station data to indicate values for the habitat type. In addition, it is important to develop additional metrics for marine habitat types (e.g., density and height of seagrass, species association with seagrasses) that are consistently collected and may indicate the health of the habitat; this would lessen the need to extrapolate from sparse water column water quality data.

The appropriate period of assignment for condition indicators may also be influenced by any lags between changes in condition and changes in ecosystem service indicators. For example, habitat degradation related to fish nurseries may not affect current period supply of fish, but may affect the supply of fish in later accounting periods. While it is likely most appropriate to track condition and services at the time they occur, regions and countries implementing the SEEA EEA should develop sets of rules that require evaluation of trends, not only within the current accounting period, but also in relation to earlier and future accounting periods.

5.4. Integration of EEA with existing ecosystem monitoring frameworks

A broader, higher level question that also drives the level of detail needed for an EEA relates to the intended uses for the developed ecosystem accounts. For example, will they be used for specific decision making at local levels or rather to provide broad indications about ecosystem (and corresponding economic) trends? The SNA has clear end users (government officials, businesses) who make use of broad measures/indicators produced by the accounting system (e.g., GDP). The audiences for the SEEA EEA will need to be more fully defined as additional pilot experiences accumulate and provide examples of ways that the rigorous environment-economy tracking involved in an EEA system translates into decisions by end users. Care will be needed to avoid the expectation that the accounting system alone will be able to meet the broad range of needs of potential end users.

In addition, several coastal and marine ecosystems have been the subject of assessment approaches using report cards or other methodologies that include measures for ecosystem condition as well as proxies for ecosystem services. Examples include the Vital Signs work in Puget Sound (http://www.psp.wa.gov/vitalsigns/), and the report cards developed for Chesapeake Bay (https://ecoreportcard.org/report-cards/chesapeake-bay/). There is a need to determine how an EEA complements (or supplements) existing approaches linked to water bodies within the United States and globally, how lessons learned in the development of existing ecological monitoring programs may be transferred to the EEA, and how accounting principles of the EEA may bolster these existing programs.

The objective of scaling up EEA measures to national, monetized estimates (as comparators/corollaries to GDP) clearly distinguishes EEA approaches from the ecological monitoring approaches and report cards noted above, as the latter rarely assess the economic contributions of ecosystem services associated with changing ecosystem condition. However, apart from questions about the appropriate process for imputing the monetary valuation of services across diverse populations, which are beyond the scope of this article, this objective raises important questions about how to scale up estimates from local ecosystems to regional and national figures. As in this current pilot case, access to both the regional and disaggregated tables is likely an important component of the EEA system. In this pilot case, the ability to separately view the disaggregated, lower scale accounting units verifies that the overall regional trend in condition changes is not masking diverging trends across each of the bays. With only 3 bays across relatively narrow geographic range, it is perhaps not surprising that the trends are consistent; however, the likelihood of divergence in directionality for condition indicators across EAUs would likely increase as scaling moved from a local to regional and national levels. As many environmental resources are managed at a local or regional level (in this case by the New York State Department of Environmental Conservation, Suffolk County, and the relevant towns), the ability to disaggregate national estimates is therefore likely critical.

5.5. Linkage to central framework land accounting tables

Extent data on wetlands (which is collected every 5 years through USGS) in combination with more frequent assessment of other aquatic habitats would provide a clear linkage to the existing land accounts of the SEEA Central Framework. At present, consistent, long-term data on coastal habitats are limited, which limits the ability to evaluate extent trends of habitats of concern. A full population of habitat extent tables, even in the absence of significant data on condition indicators, could be an appropriate initial step for areas considering adopting an ecosystem accounting approach.

5.6. Potential applications of developed accounting tables

While many challenges have been noted above in the development of the accounting tables, these challenges are not specific to accounting but rather can indicate lack of regularly collected data to inform decision makers about environment-economy linkages. The produced tables as well as the process of populating all or a subset of the tables can provide a range of useful outputs. Tables can demonstrate the current state of the ecosystem (similar to report card approaches noted above), and if the accounting is conducted on a regularly scheduled basis, can provide broad trends in ecosystem condition and ecosystem services. Identification of potential trends can motivate research into areas of concern; for example, from this pilot analysis, decision makers may pursue research to further evaluate the apparent temperature increase in regional South Shore bay waters over the observed time period. Grounding the data collection within an accounting system can ensure that stocks and flows associated with ecosystems are tracked in a consistent manner across intra- and international locations. Furthermore, if spatial ecosystem units are connected to beneficiaries of ecosystem services (such as through the National Ecosystem Services Classification Standard (NESCS) approach [37]), these tables can explicitly connect spatial landscape changes to potentially impacted beneficiary groups and economic welfare and output measures. In this way the statistics compiled in the EEA accounts can support a range of analytic and research questions.

The spatial nature of the SEEA in conjunction with its scaling up from consistent smaller scale spatial units provides an additional strength. Decision makers can move from high-level national or regional indicators of changes in ecosystem extent or condition to a more localized evaluation of indicators, or vice versa. This can ensure that local level trends of concern (e.g., changes in dissolved oxygen) are flagged for state, regional and national resource managers even if those

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trends do not appear at higher levels of aggregation. For example, in this pilot example, use of the 12-digit HUC as an EAU allows for elaboration of stocks and flows within a given geographic region of interest (i.e., the coastal bays), while also allowing for a scaling up to fully cover coastal areas at a state, regional, and, eventually, national level.

Finally, the process of compiling the coastal and ocean ecosystem accounting tables can be useful in supporting coastal management and resource allocation decisions. As in this pilot study, attempts to populate EEA tables can identify data gaps and highlight the need for long-term monitoring to support regularly scheduled accounting (e.g., at 5 or 10 year intervals). Here, for example, consistent, scheduled monitoring of seagrass extent across all bays would improve the extent accounts. The process of compiling the data also can organize data dispersed across a range of governmental, non-governmental, and research entities [38]. As noted above, the data used to compile these tables came from national (NOAA, USGS), state (NYSDEC, NYSOPRHP), and county (SCDOH) entities. In this way, populating ecosystem accounting tables can document holders of data and encourage collaboration across relevant agencies.

5.7. Future extensions

Spatial datasets have been developed through ESRI and USGS using a statistical clustering approach to classify coastal and ocean space as ecological marine units (EMUs) through ESRI (https://www.esri.com/en-us/about/science/ecological-marine-units/overview), using definitions consistent with the Coastal and Marine Ecosystem Classification Standard (CMECS) [20]. These datasets represent a potentially exciting approach to answer questions about broad scale changes in the extent and condition of coastal habitats. They may also be useful in providing a consistent organizational and classification structure to EEA work within coastal and marine habitats.

Future research could also integrate the above work tracing condition to ecosystem services with the NESCS approach to evaluate how linkages to business and product sectors may be influenced by changes in the tracked ecosystem condition and ecosystem service proxies. The SEEA EEA Technical Recommendations (2017) specifically note the importance of including assessment of the reliance of the business sector on ecosystem services and on the potential for collaborations between private and public sector entities in compiling and using ecosystem accounts. The development of an accounting system for marine and coastal ecosystems could in this way connect with research into supply chains for marine and coastal ecosystem goods and services (and their associated businesses) [39].

6. Conclusions

This pilot application of the SEEA EEA, the first in a marine context within the United States, provides important insights and recommendations for future evaluation and application of the SEEA-EEA. While data limited full population of the proposed SEEA EEA tables, the pilot test was valuable in highlighting potential challenges in expanding the EEA approach to encompass broad geographies of marine and coastal ecosystems. Consultation with an interdisciplinary team of ecologists and economists will be needed to successfully complete an EEA. Close coordination with the potential end users for the EEA is also necessary to ensure that the information presented is potentially useful to informing decisions and taking relevant actions. Guiding environmental management questions (e.g., how does hypoxia impact the fishery sector?) may provide important context for initial development of EEA tables and a preliminary focus that avoids attempting to compile statistics on all condition indicators and all ecosystem service flows.

A key question raised by this study and relevant to future research and application of the SEEA EEA is how to best populate the proposed accounting tables in habitat types where data is, at present, limited. Additional studies investigating the pilot application of the EEA system in other coastal and marine areas can assist in informing whether or not common coastal and marine data challenges exist across regions and countries and provide additional strategies for working with the best available data. Even if initial data tables are sparse, as in this paper, attempting to conduct an EEA can be instructive to governmental authorities, marine resource managers and planners as it can assist in identifying needed data to better track environment-economy linkages. Alternatively, instead of working with a bottom-up approach to scaling using local and state datasets, as done here, advances in remote sensing technology may also assist in providing a streamlined set of broad coastal and ocean indicators (e.g., chlorophyll a) that can be compiled at a national level.

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Appendix. Supporting individual EEA tables

See Tables A1–A6

Table A1
Great South Bay: 2006.

LCEU	Extent (km^2)	Characteristics of ecosystem condition					
		Physical/Chemical				Biological	
		DO (mg/l)	Temp (°C)	Secchi (ft)	DN (mg/l)	Aureococcus (cells/ml)	Ecoli** (MPN/100 ml)
Water column	243	9.1	13	4.9	0.37	1205	29
Barren land (Beach)	9.5	N/A	N/A	N/A	N/A	N/A	21
Wetlands	30	U	U	U	U	U	U
Seagrass[a]	46	U	U	U	U	U	U

[a] 2002 data only.

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Table A2
Great South Bay 2011.

LCEU	Extent (km²)	Characteristics of ecosystem condition					
		Physical/Chemical				Biological	
		DO (mg/l)	Temp (°C)	Secchi (ft)	DN (mg/l)	*Aureococcus* (cells/ml)	*E coli* (MPN/100 ml)
Water column	245	7.97	17	5.2	0.28	43, 931	29
Barren land (Beach)	8.1	N/A	N/A	N/A	N/A	N/A	21
Wetlands	31	U	U	U	U	U	U
Seagrass[a]	46	U	U	U	U	U	U

[a] 2002 data only.

Table A3
Moriches Bay 2006.

LCEU	Extent (km²)	Characteristics of ecosystem condition					
		Physical/Chemical				Biological	
		DO (mg/l)	Temp (°C)	Secchi (ft)	DN (mg/l)	*Aureococcus* (cells/ml)	*E coli* (MPN/100 ml)
Open water column	33.4	10.2	7.1	5.2	0.32	1593	U
Barren land (Beach)	7.7	N/A	N/A	N/A	N/A	N/A	N/A
Wetlands	11	U	U	U	U	U	U
Seagrass[a]	14	U	U	U	U	U	U

[a] 2002 data only.

Table A4
Moriches Bay 2011.

LCEU	Extent (km²)	Characteristics of ecosystem condition					
		Physical/Chemical				Biological	
		DO (mg/l)	Temp (°C)	Secchi (ft)	DN (mg/l)	*Aureococcus* (cells/ml)	*E coli* (MPN/100 ml)
Open water column	35.7	8.4	13.9	5.6	0.22	126,206	U
Barren land (beach)	5.2	N/A	N/A	N/A	N/A	N/A	N/A
Wetlands	11	U	U	U	U	U	U
Seagrass[a]	14	U	U	U	U	U	U

[a] 2002 data only.

Table A5
Shinnecock Bay 2006.

LCEU	Extent (km²)	Characteristics of ecosystem condition					
		Physical/Chemical				Biological	
		DO (mg/l)	Temp (°C)	Secchi (ft)	DN (mg/l)	*Aureococcus* (cells/ml)	*E coli* (MPN/100 ml)
Open water column	32.4	10	8.1	5.4	0.29	3037	U
Barren land (Beach)	9.5	N/A	N/A	N/A	N/A	N/A	N/A
Wetlands	8.6	U	U	U	U	U	U
Seagrass[a]	7.4	U	U	U	U	U	U

[a] 2002 data only.

Table A6
Shinnecock Bay 2011.

LCEU	Extent (km²)	Characteristics of ecosystem condition					
		Physical/Chemical				Biological	
		DO (mg/l)	Temp (°C)	Secchi (ft)	DN (mg/l)	*Aureococcus* (cells/ml)	*E coli* (MPN/100 ml)
Open water column	34	9.0	12	6.3	0.20	82,686	U
Barren land (beach)	8.1	N/A	N/A	N/A	N/A	N/A	N/A
Wetlands	9.1	U	U	U	U	U	U
Seagrass[a]	7.4	U	U	U	U	U	U

[a] 2002 data only.

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