US Army Corps of Engineers®
New York District

NEW YORK AND NEW JERSEY HARBOR AND TRIBUTARIES STUDY

COASTAL STORM RISK MANAGEMENT STUDY

DRAFT INTEGRATED FEASIBILITY REPORT & TIER 1 ENVIRONMENTAL IMPACT STATEMENT

APPENDIX A11:

Tier 1 New York Bight Ecological Model (NYBEM)

This appendix was prepared by:

S. Kyle McKay, PhD, PE, Environmental Laboratory, US Army Engineer Research and Development Center

Michael P. Dougherty, Rock Island District, US Army Corps of Engineers

Cheryl Alkemeyer, New York District, US Army Corps of Engineers

Table of Contents

1.0 Overview

The New York Bight Ecological Model (NYBEM) is being applied in the context of two large-scale coastal storm risk management feasibility studies in the New York Bight ecosystem, specifically: the New York/New Jersey Harbor and Tributaries (NYNJHATS) and the New Jersey Back Bays (NJBB). In these studies, the United States Army Corps of Engineers (USACE) is considering a diversity of measures for mitigating flood risks, including structural actions (e.g., levees, floodwalls, storm surge barriers), non-structural measures (e.g., buy-outs, elevation of structures, flood-proofing), and natural and nature-based features (e.g., wetland creation, reefs for breakwaters). The NYBEM was developed to partially inform the impact assessment process and is being used in conjunction with other information (e.g., contaminant mapping, cultural and historical resources, flood risk reduction benefits, monetary costs, etc.) to inform these decisions. The models intend to provide a broad general view of the effects of proposed actions on coastal ecosystems, and this document summarizes preliminary model applications in the context of NYNJHATS.

The wide variety of ecosystems in the NYNJHATS Study Area provide habitat for imperiled species, support ecological functions, and generate numerous ecosystem services. These ecosystems span from "ridge to reef", including everything from terrestrial areas to marine deepwater zones; however, the primary focus of this assessment relates to aquatic areas. Comprehensive assessment of these aquatic systems is challenging due to the large spatial scale of the study, variable data availability, potential effects of management actions on hydrodynamic processes, and the need to forecast effects of management actions over long time scales. The NYBEM (sounds like "nigh-bem") is a suite of numerical models developed for this study to better understand potential effects on regional aquatic ecosystems and inform decision making. This appendix provides an overview of the NYBEM approach and tools, discusses how the models were applied to the study area, summarizes the existing condition of regional ecosystems, presents an alternatives analysis of direct and indirect effects based on model results, and summarizes potential effects of the Tentatively Selected Plan by planning region.

2.0 New York Bight Ecological Model

2.1. Model Background

The NYBEM assesses changes in ecosystem extent and condition associated with changing hydrodynamic conditions in six major ecosystem types: freshwater tidal (fresh.tid), estuarine intertidal (est.int), estuarine subtidal (est.sub), marine intertidal (mar.int), marine subtidal (mar.sub), and marine deepwater (mar.deep). Detailed model descriptions are available via online documentation (https://mvr-gis.github.io/NYBEM-Report/), and all model code is contained within a "package" for the R Statistical Software language (https://github.com/MVR-GIS/nybem/). This section briefly highlights key components of development related to model scoping, the process by which tools were assembled, conceptualization of ecosystems, quantification of ecological processes, and evaluation of models relative to observed ecosystem mapping.

The NYBEM was developed to articulate and quantify mechanisms of environmental effects of proposed coastal storm risk management alternatives in the region. Specifically, the model was designed around the NYNJHAT and New Jersey Back Bays studies with a few key goals guiding development. First, the models sought to provide a general description of the ***relative*** environmental effects of large-scale alternatives to inform the feasibility process and NEPA assessments. Second, the models needed to be able to forecast environmental effects over the project planning horizon (50-100 years) based on physical changes to ecosystems resulting from both background processes (e.g., sea level rise) and project alternatives (e.g., change in tidal regime from storm surge barriers). Third, environmental effects on regional ecosystems required differentiation by ecosystem type (e.g., marine deepwater vs. estuarine intertidal) to inform mitigation actions. Fourth, the NYBEM needed to be able to quantify the direct effects of actions at infrastructure locations (e.g., the footprint of a surge barrier) as well as indirect effects induced off-site from infrastructure (e.g., change in bay hydrodynamics associated with a storm surge barrier). Finally, the model framework needed to be adaptable to new information and data as project planning proceeds. Given these goals, the NYBEM is being developed in phases (currently 1.0.0), and tools and techniques will evolve alongside project planning.

2.2. Model Development Process

When used in the context of complex management decisions with many partners, environmental and ecological modeling often benefit from approaches that emphasize transparency, increase user input during development, and clearly communicate model assumptions and limitations (Van den Belt 2004; Voinov and Bousquet 2010; Herman et al. 2019). For NYBEM, a general five-step modeling process is followed that applies best practices in ecological model development (Grant and Swannack 2008). First, general relationships among essential ecosystem components are formally *conceptualized* to tell the story of "how the system works" (Fischenich 2008). Second, the model is *quantified* using a formal structure of functional relationships, algorithms, parameters, and numerical code. Third, models are *evaluated* relative to underlying scientific theory, numerical accuracy, and usability, which often entails techniques such as code checking, testing, verification, and sensitivity analyses. Fourth, a model is *applied* to a given management question, scenario, or assessment. Fifth, a strategy is developed and executed to *communicate* model development and application to technical and non-technical audiences. This process has been applied numerous times to select, adapt, or develop ecological models for USACE and non-USACE studies (Herman et al. 2019), and the mediated modeling development framework is intended to draw heavily from existing knowledge, data, tools, and regional expertise.

The NYBEM was developed with a variety of methods intended to increase the transparency and understandability of the tools. "Mediated modeling" generally describes a family of techniques for building consensus among multiple partners to produce credible and defensible ecological models in a transparent way (van den Belt et al. 2006). For NYBEM, workshop-based model development methods were adapted from Herman et al. (2019), where technical stakeholders were led through the theory of a particular aspect of modeling (e.g., conceptual modeling) and then apply said theory to a focal ecosystem (i.e., the New York Bight).

Four workshops structured the iterative development of NYBEM in 2019 with subsequent research and synthesis between meetings. The dates the workshops were held and the list of participants at each workshop are located at: https://mvr-gis.github.io/NYBEM-Report/model-development-workshops.html. Additionally, all models were developed with a growing family of methods for "reproducible research," which embrace code and data sharing, enable review processes, and facilitate use of methods and results. Specifically, R Markdown is applied to development and document models, which are coded in the R Statistical Software and shared within a transportable "package" of code described below.

2.3. Model Conceptualization

The foundation of ecological modeling is a clear conceptualization of the ecosystem and an approach for translating the conceptual model into a numerical representation. The overarching conceptual model for the NYBEM (Figure A11.1) identifies three principal systems to frame model development: (1) nearshore / marine ecosystems, (2) estuarine ecosystems, and (3) system connectivity between multiple ecosystem types. System connectivity is not included in this initial phase of development and will be addressed in future models. Patch-scale assessment methods were developed for both the marine and estuarine ecosystems. Sub-models were developed for each of six major ecosystem types: freshwater tidal, estuarine intertidal, estuarine subtidal (with modules for hard and soft bottom habitats), marine intertidal, marine subtidal, and marine deepwater. These ecosystems are defined from a combined classification based on historical mapping techniques (Cowardin et al. 1979, FGDC 2013), the Coastal and Marine Ecological Classification Standard (CMECS), habitat definitions specific to the New York Bight (USFWS 1997), and the NY/NJ Port Habitat Functional Assessment Model (USACE 2000, USACE 2020). In addition to this overarching conceptualization, mechanistic conceptual models were developed for each ecosystem type to guide quantitative model development, which are intended for technical audiences focused on the scientific details of ecological assessments.

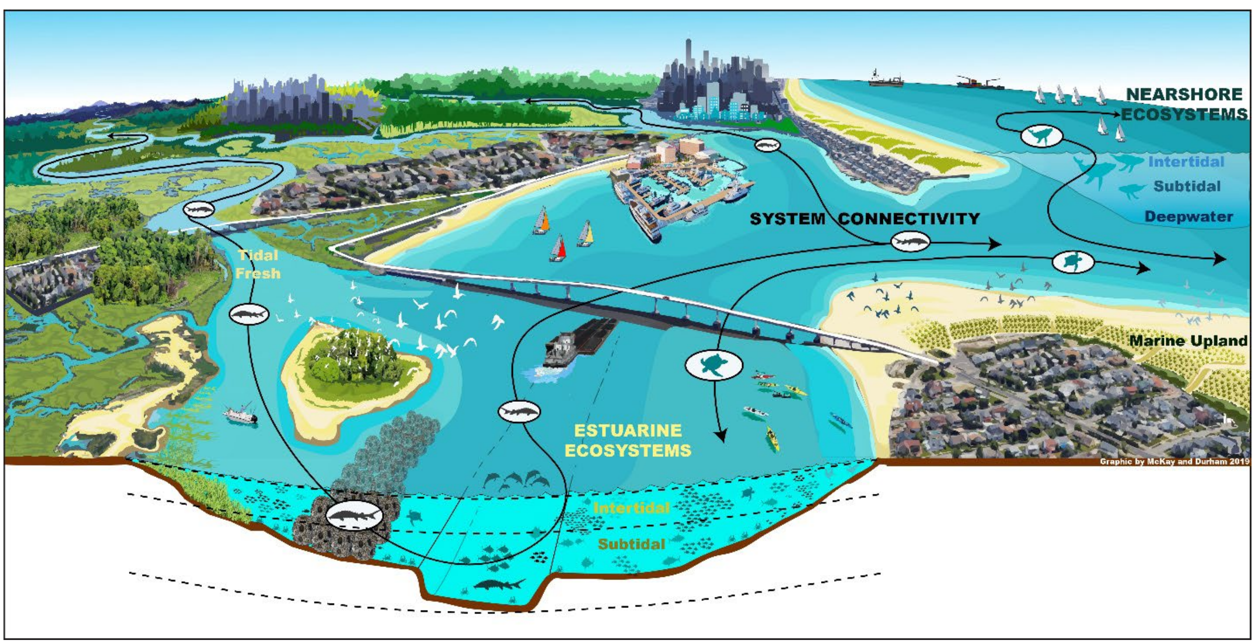

Figure A11.1. Overarching conceptual model of the New York Bight Ecological Model.

Table A11.1. Definition of NYBEM ecosystem types. Cowardin et al. (1979) define the marine-estuarine salinity transition based on a period of average annual low flow, which we define here as a 90% exceedence probability (or 10th percentile salinity).

Tidal Limits	**Marine (Salinity >= 28psu)**	**Estuarine (Salinity = 0.5 to 28psu)**	**Freshwater (Salinity <= 0.5psu)**
Deepwater (-2m to -20m)	Marine, Deep	Estuarine, Subtidal	Freshwater, tidal
Subtidal (MLLW to -2m)	Marine, Subtitdal	Estuarine, Subtidal	Freshwater, tidal
Intertidal (MHHW to MLLW)	Marine, Intertidal	Estuarine, Intertidal	Freshwater, tidal

The quantification phase of ecological model development formalizes a conceptual model in terms of mathematical relationships, model parameters, and a numerical algorithm (Grant and Swannack 2008). The NYBEM takes a common approach to quantifying ecological models based on quantity and quality of habitat. "Index" models (Swannack et al. 2012) were originally developed for species-specific habitat applications (e.g., slider turtles), but the general approach has also been adapted to guilds (e.g., salmonids), communities (e.g., floodplain vegetation), and ecosystem processes (e.g., the Hydrogeomorphic Method). The quantity and quality of each ecosystem type are assessed separately. For instance, ecosystem extent and habitat quantity is delineated from hydrodynamic conditions following the thresholds in Table A11.1. Ecosystem quality is then assessed based on patch-specific data and known thresholds in ecological response (e.g., on a normalized 0 to 1 scale indicating ecological condition or quality). The product of habitat quality and quantity provides a consistent metric across ecosystem types (i.e., "habitat units"). Here, the terms "habitat" and "ecosystem" are used synonymously to indicate a given location or patch on the landscape, and suitability and condition are used interchangeably to indicate the quality of a given patch normalized on a 0 to 1 scale, where 0 is unacceptable or providing little/no ecological value and 1 is a pristine condition or high ecological value.

The overarching quantitative architecture of the NYBEM can generally be summarized in three major elements (Figure A11.2). First, model inputs are assembled in a geospatial database, which includes aspects of the model domain and study area, hydrodynamic inputs, and environmental data compiled from regional and national sources. Second, the model code is prepared as a "package" in the R Statistical Software (https://github.com/MVR-GIS/nybem/). The 'nybem' package contains the model itself, meaning all code, functions, data, and testing. Finally, the model outputs habitat quantity, habitat quality, and habitat units for each patch in the model domain for each of the ecosystem types.

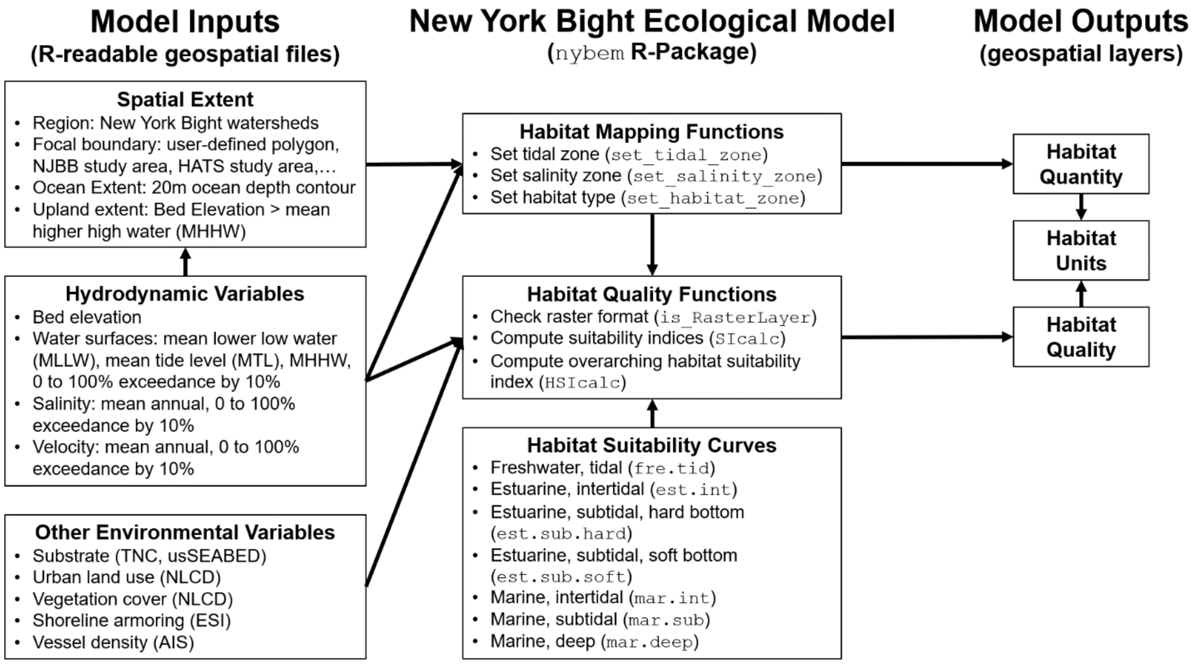

Figure A11.2. Quantitative architecture of the NYBEM.

2.4. Model Evaluation and Certification

Model evaluation is the overarching process for ensuring that numerical tools are scientifically defensible and transparently developed. Evaluation is often referred to as verification or validation, but it in fact includes a family of methods ranging from peer review to model testing to error checking (Schmolke et al. 2010). In this more general sense, the USACE has established an ecological model certification process to ensure that planning models are sound and functional relative to three categories: system quality, technical quality, and usability (EC 1105-2-412). Within the USACE, the Ecosystem Restoration Planning Center of Expertise oversees the model certification process. The NYBEM has been formally reviewed by three subject matter experts, comments have been incorporated into the model and documentation, and final certification is anticipated by November 2022. Preliminary verification analyses were also undertaken to compare model outcomes (habitat zones and quality) with existing habitat maps for the region with a specific focus on the freshwater tidal, estuarine intertidal, and estuarine subtidal systems. Broader evaluations of NYBEM against empirical data and including the marine models are currently being prepared for peer-reviewed journal articles.

3.0 Application of NYBEM

NYBEM was applied to assess ecosystem condition in the NYNJHAT Study Area based on three main activities: (1) collection of hydrodynamic model outcomes, (2) compilation of other environmental input data sets, and (3) execution of the NYBEM. The following sections describe these input data sets along with any associated pre-processing for both the existing condition and alternatives analysis. The NYBEM execution and data post-processing are then described.

3.1 Adaptive Hydraulics (AdH) Models

NYBEM is capable of reading in hydrodynamic conditions from empirical or modeled data sources. However, hydrodynamic models provide the primary basis for USACE planning because of their capacity to span large spatial domains and forecast outcomes over long time horizons with and without project actions. A three-dimensional Adaptive Hydraulics (AdH) model was developed for simulating hydrodynamics and salinity (Details provided in McAlpin and Emiren, Appendix B7), based on a prior AdH model applied in the NY/NJ Harbor (McAlpin et al. 2017). The model domain includes a large area extending east beyond Long Island, south to central New Jersey, and upstream to Troy along the Hudson River to provide sufficient boundary conditions and hydrodynamic initialization. The mesh contains over 220,000 nodes and 750,000 elements. Resolution varies across the domain as needed to capture changes in terrain and features. For instance, fine resolution may be used in channels to accurately capture conveyance and salinity dynamics, whereas node have high spacing in off-shore areas. The models were executed for inflow and tidal forcing matching 1995 conditions as detailed in McAlpin et al. (2017) and McAlpin and Emiren (Appendix B7). This year contained no large storm events and only minor storms, so the model can be interpreted as simulating normal or typical hydrologic and tidal conditions. This AdH model was applied to estimate hydrodynamic outcomes for each of the HATS alternatives.

Five AdH simulations were executed for the existing condition and Alternatives 2, 3A, 3B, and 4. Notably, the AdH models were executed to only include storm surge barriers (i.e., no structural, non-structural, or natural or nature-based shore-based measures were included), and hydrodynamic models required significant run times, so structural configurations represent designs from late 2018. Given the focus on only shore-based measures, Alternative-5 was assumed to be the same as the existing condition scenario (i.e., Alternative 1). An elevation shift was added to the water surface elevation at the 1995 tide boundary to adjust base elevations to reflect sea level at the beginning of the project planning horizon (i.e., year 2030). The mesh domain was not expanded to account for potential wetted area with rising sea level. Sea level rise analyses were conducted for increases of 1, 2, 4, and 6 feet above the 2030 base level, which are not presented here.

All analyses are computed for a one-year simulation period with 1995 boundary conditions. Importantly, all assessments represent “open gate” conditions for the barriers, and closure scenarios are not examined in this analysis due to complexities surrounding differences between storms, sea levels, operational timing, and operational duration. Future analyses will examine closure scenarios for the Tentatively Selected Plan (TSP) as these operational conditions will be more locally specific and more feasible for executing AdH simulations. The “open gate” analyses presented here may be thought of as the “typical” condition of the ecosystems with respect to time (i.e., gates would be closed a fraction of the time) and provide a general benchmark of the effects of storm surge barriers on estuarine circulation. Although simulated in three dimensions, the following variables were output as depth-averaged values (i.e., two dimensions) for the existing condition and all alternatives:

- Bed elevation, which was merged with HATS upland topography to provide a seamless surface
- Water surface elevations: mean lower low water (MLLW), mean tide level (MTL), mean higher high water (MHHW), and 0 to 100% exceedence by 10% (calculated over the 1995 period)
- Salinity levels: mean annual and 0 to 100% exceedence by 10% (calculated over the 1995 period)
- Velocity: mean annual and 0 to 100% exceedence by 10% (calculated over the 1995 period)

AdH outputs were interpolated from point data using a spline technique with barriers separating the marine and estuarine environments (i.e., salinity data were not interpolated over barrier islands) using ESRI Spatial Analyst Tools. The interpolated surfaces were rasterized throughout the model domain. A 10m grid cell size was used as a balance between data resolution from the model outcomes, over- vs. under-parameterization, and application resolution (i.e., the relevant size of wetlands in the region).

3.2 Environmental Data Compilation

Four additional environmental data sets are required inputs for NYBEM beyond hydrodynamic inputs. Specifically, model inputs are needed for substrate composition, land use / cover, shoreline armoring, and vessel traffic. All data sets were rasterized at the 10m resolution and aligned with hydrodynamic data. Data compilation is briefly described here with additional detail in the NYBEM model report.

- *Substrate composition*: Substrate is a major driving factor in multiple aspects of the estuarine and marine models. Although many nuanced methods exist for assessing substrate (e.g., grain size, distributional metrics, compaction, etc.), simple composition metrics are used in NYBEM as a balance between information and data availability. Specifically, usSEABED sampling point data were aggregated and interpolated across the region. These data were used to distinguish hard bottom habitats from soft bottom ecosystems (i.e., oysters vs. seagrass, respectively) with a threshold of greater than 90% gravel substrate. Fine substrate composition is used in the estuarine and marine subtidal models and was defined as the silt / clay fraction.
- *Land use and cover*: Vegetation cover and urban land use metrics were derived from the National Land Cover Database (NLCD). A neighborhood analysis was used to translate binary vegetation cover data into a continuous variable by averaging across a 50m buffer distance from each cell in the NYBEM domain. Urban land uses with the NLCD (codes 21, 22, 23, and 24) were reclassified as urban, and all other types were classified as non-urban. A moving window averaging scheme was applied with a 100m buffer distance from each cell in the NYBEM domain to estimate an urban land cover metric.
- *Shoreline armoring*: Shoreline armoring metrics were derived from a linear dataset developed by the NOAA Office of Response and Restoration, the Environmental Sensitivity Index (ESI).

- *Vessel density*: Boat usage is applied as a proxy for human use intensity in NYBEM's subtidal and deepwater models. An Automatic Identification Systems (AIS) vessel traffic density raster dataset was generated by the U.S. Coast Guard Navigation Center, Bureau of Ocean Energy Management, and NOAA Office for Coastal Management from AIS Marine Cadastral data. This layer represents 2019 annual vessel transit counts of all vessels (i.e., commercial, recreational) summarized at a 100 m by 100 m pixel cell resolution.

Table A11.2 table summarizes all data sources used in NYBEM. These data sets each represent trade-offs deemed acceptable for the goals of this application (i.e., relative comparison of large-scale coastal storm risk management alternatives). However, different applications could compel use of other data sources. For instance, the current spatial scale of the HAT study required heavy reliance on regional and national data sets. However, more local applications (e.g., a single bay) could have access to higher resolution data (e.g., locally mapped substrate or shoreline armoring). Data quality and resolution are a common challenge in large scale modeling, and future applications could consider alternative approaches. Each data set is presented along with any notable post-processing required prior to use in NYBEM and assumptions used in forecasting effects of alternatives.

3.3 Model Execution

Hydrodynamic and environmental data were compiled from each resource as described above into a single geospatial database containing all model inputs in raster format. Tidal, salinity, and habitat zones were delineated using the zoning functions in NYBEM based on the criteria in Table A11.1. Data were then used to execute the habitat suitability calculations for each sub-model (e.g., est.int, mar.sub) independently. Habitat zone layers were then used to crop suitability indices to the appropriate locations. All suitability indices and the overarching habitat suitability index for each ecosystem type were stored in *.tif format for transportability and reuse in subsequent analyses. All analyses were conducted using a separate github directory (i.e., repo) for each alternative to record analytical steps and share outcomes among modeling team members. Each model run extended over the entire NYNJHAT Study Area (Figure A11.3), and outputs were broken down by the nine Planning Regions (i.e., Capital District, Mid-Hudson, Lower Hudson / East River, Upper Bay / Arthur Kill, Lower Bay, Hackensack-Passaic, Raritan, Long Island Sound, and Jamaica Bay).

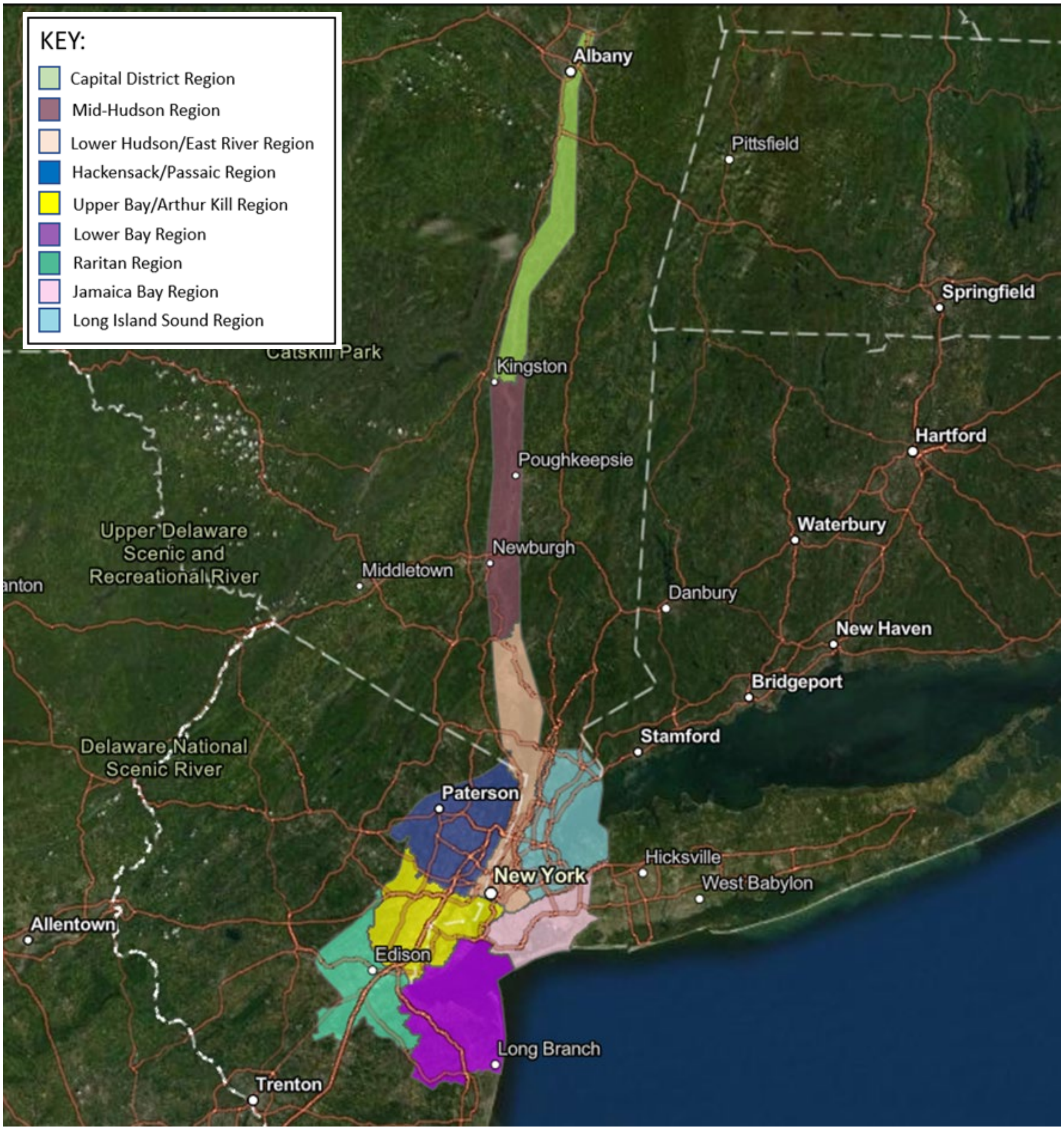

Figure A11.3. Overview of USACE New York-New Jersey Harbor and Tributaries Study Area and Planning Regions.

Table A11.2. Summary of data compilation, pre-processing, and forecasting assumptions. Use in NYBEM indicates the module or function as follows: zone mapping (zone), freshwater tidal (fre.tid), estuarine intertidal (est.int), estuarine subtidal (est.sub), marine intertidal (mar.int), marine subtidal (mar.sub), and marine deepwater (mar.deep).

Data Layer	Use in NYBEM	Source Data	Post-Processing	Forecasting Assumption
Bed elevation (m)	Zone	AdH + topo-bathy	Merged data sets	Manually adjusted mesh for designs
Mean lower low water (m)	Zone	AdH	n/a	AdH simulations
Mean higher high water (m)	zone	AdH	n/a	AdH simulations
10th Percentile Salinity (psu)	zone, est.sub	AdH	n/a	AdH simulations
Hard Bottom Substrate (> 90% gravel)	est.sub	usSEABED	Point data merging and interpolation	Not changed
Intertidal slope	mar.int	AdH	Derived from elevation	AdH simulations
Relative exposure time	mar.int	AdH	Calculated from AdH water surface elevations	AdH simulations
Percent of Light Available	est.sub, mar.sub, mar.deep	AdH	Calculated from AdH depth	AdH simulations
Change in High Velocity (%)	est.int	AdH	Percent change from existing condition	AdH simulations
Mean annual salinity (psu)	est.sub	AdH	n/a	AdH simulations
Duration of salinity greater than 0.5 psu	fre.tid	AdH	Interpolated from salinity exceedance distribution	AdH simulations
Relative depth	fre.tid, est.int	AdH	Calculated from AdH water surface elevations	AdH simulations
Median velocity (cm/s)	mar.sub	AdH	Unit conversion	AdH simulations
Duration of salinity less than 28 psu	mar.deep	AdH	Interpolated from salinity exceedance distribution	AdH simulations
Neighborhood vegetation cover (%)	fre.tid, est.int	NLCD	Percent of cells within 50m with vegetated class	Not changed
Neighborhood urban land use (%)	est.int, mar.int	NLCD	Percent of cells within 100m with urban classes	Not changed
Distance to armored shoreline feature (m)	est.in, mar.int	NOAA ESI	Compute distance from cell to nearest feature	Not changed
Substrate fines composition (%)	est.sub, mar.sub	usSEABED	Point data merging and interpolation	Not changed
Vessel Density (tracks per year)	est.sub, mar.sub, mar.deep	AIS	2019 tracks intersected with raster	Not changed

4.0 Existing Conditions

The existing condition for regional ecosystems in the NYNJHAT Study Area may then be summarized based on NYBEM outputs. Specifically, two outcomes are presented as general summary metrics. First, the extent of a given ecosystem type (in acres) is presented based on NYBEM's tidal, salinity, and habitat zones. This metric provides a general overview of the types of habitats expected within a region (e.g., marine deepwater habitats in the Lower Bay vs. freshwater tidal habitats upstream on the Hudson River) and the order-of-magnitude of their spatial coverage. Second, NYBEM was used to assess the quality of these habitats, and the data are summarized as "habitat units," which represent the product of habitat quantity and quality for each grid cell in the landscape. These units can be thought of as the extent of an ecosystem (in acres) scaled down by the quality of each patch. Notably, the terms habitat suitability and ecosystem condition are used synonymously here to reflect a general notion of the ecological quality of a system scaled from 0 to 1.

Acreage and habitat units were summarized for each ecosystem type across the Study Area as a whole. Based on the salinity criteria used in NYBEM, the Study Area contains small amounts of marine ecosystems with no observed marine intertidal or marine subtidal habitats. This finding emphasizes the important role of freshwater inputs from the Hudson River and other major waterways and generally reflects the focus of the location of the study areas within this major estuary complex. Estuarine subtidal areas provide the greatest coverage in across the region (over 150,000 ac) with notably large patches in the Lower Bay, Upper Bay, Jamaica Bay, and Long Island Sound regions. Freshwater tidal areas are the second largest ecosystem type with large expanses extending up the Hudson River and other freshwater sources. Estuarine intertidal zones represent a smaller fraction of the total area, but a key ecological transition zone and location of potential effect.

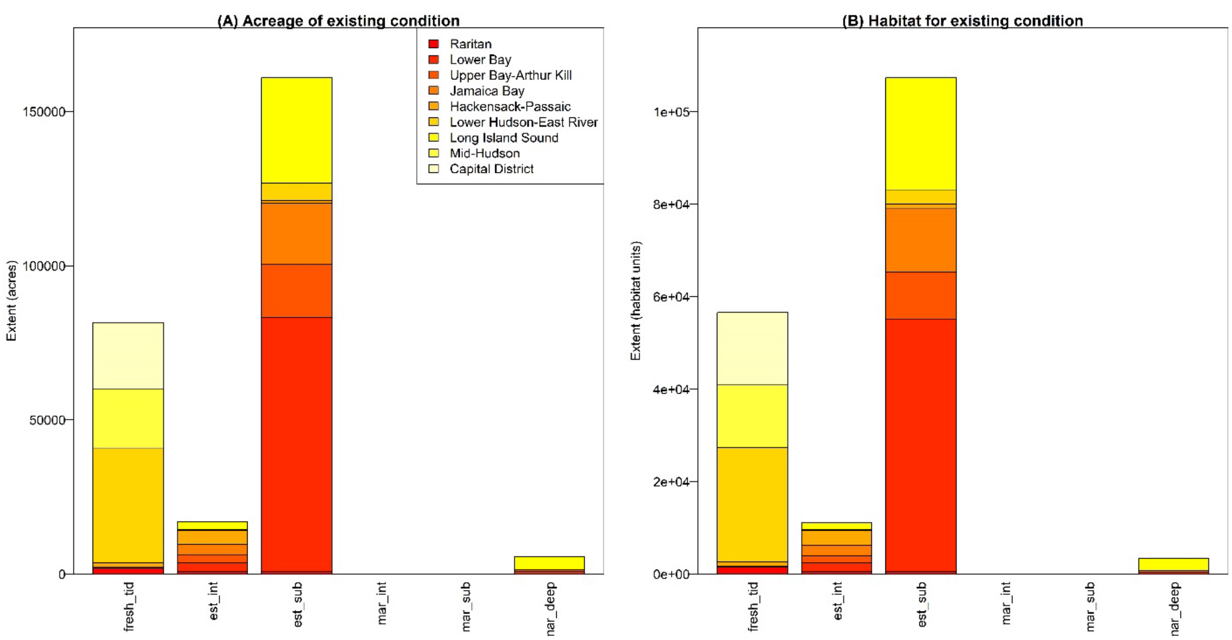

Figure A11.4. NYBEM outputs summarizing the existing condition by ecosystem type.

NYBEM estimates were also output by planning region to show the distribution of ecosystem types within a region and provide a point of comparison among regions. The largest extents of habitat are in the areas with the largest open water zones (i.e., Lower Bay, Long Island Sound, and the Lower Hudson – East River). Habitat quantity and quality, however, show different trends in the system. The overall magnitude of habitat is reduced from the extent of an ecosystem, and in some cases (e.g., Lower Hudson – East River), the distribution of habitat within the region is quite different in light of habitat quality. Some regions contain relatively homogeneous habitats (e.g., along the Hudson River and Lower Bay), whereas others are quite diverse (e.g., Hackensack-Passaic, Jamaica Bay). The following sections describe ecosystem condition at more local scale of the regions.

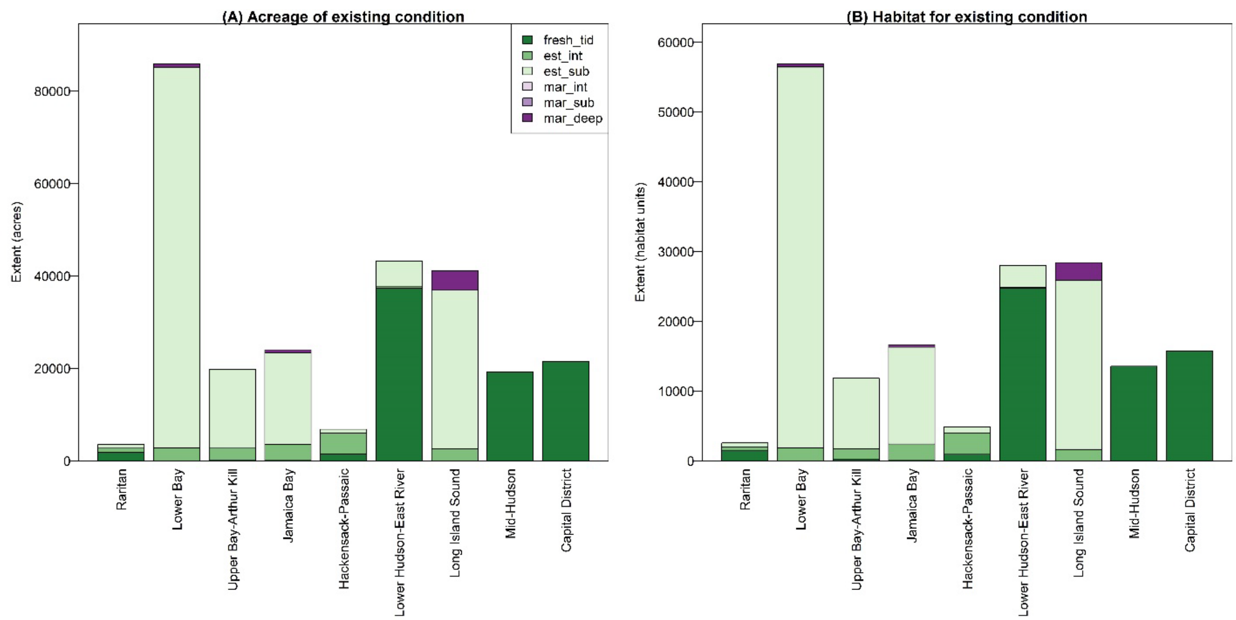

Figure A11.5. NYBEM outputs summarizing the existing condition by planning regions.

Capital District, Mid-Hudson, and Lower Hudson/East River Regions

Unsurprisingly, the Hudson River corridor is the primary location for tidal freshwater systems in the study area. In particular, the fringing marshes of the Hudson River cover large areas of more than 16,000 habitat units. As the river enters the city, the salinity regime shifts into estuarine conditions, and the deeper subtidal waters of the harbor are the major ecosystem type. The extent of estuarine intertidal habitat is relatively limited due to urban land use pressures around the metropolitan area.

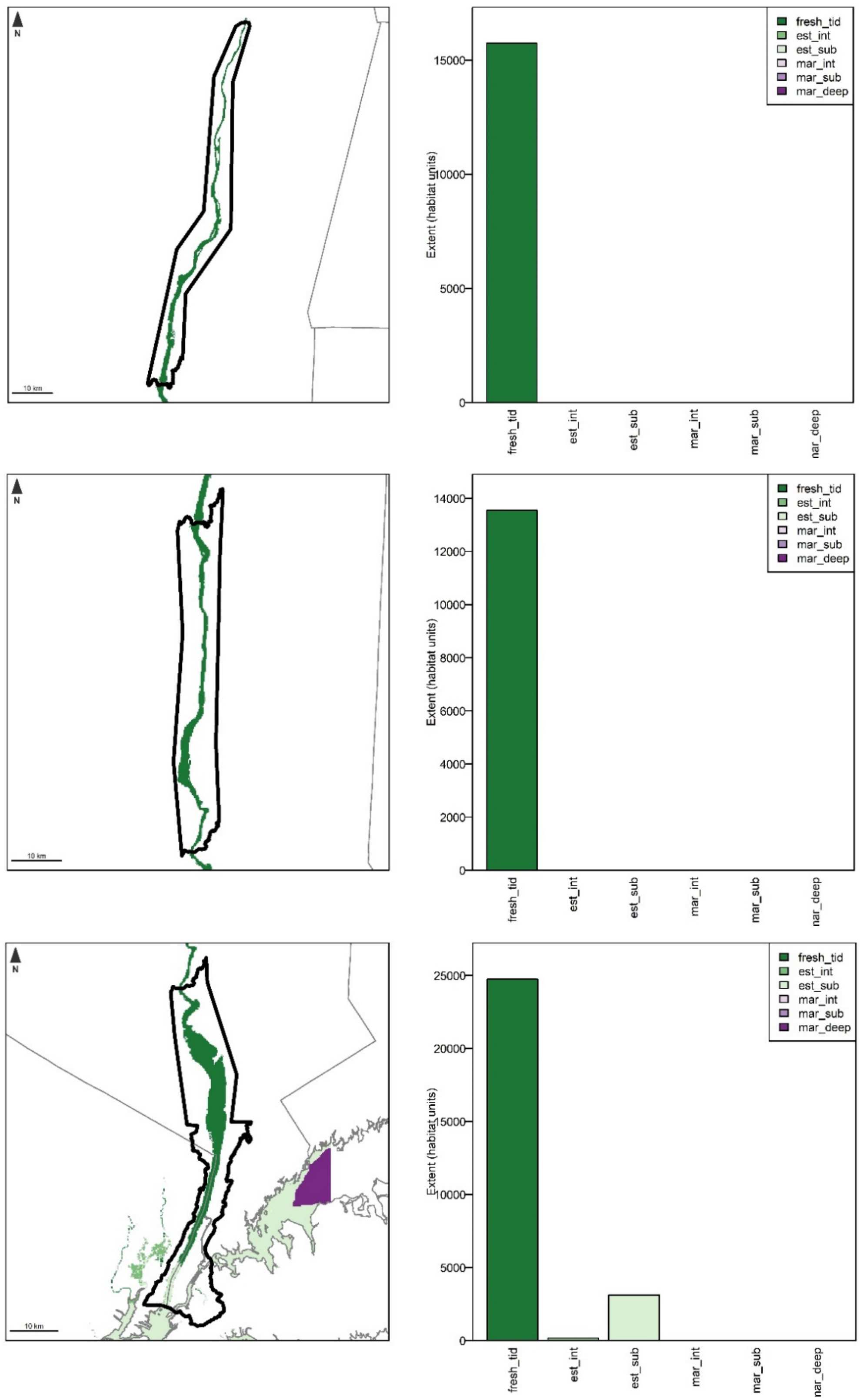

Figure A11.6. Existing condition summary for the Capital District (top), Mid-Hudson (middle), and Lower Hudson-East River (bottom) Regions.

Hackensack-Passaic Region

The Hackensack-Passaic region provides the largest extent of estuarine intertidal habitat in the study area (over 3,000 habitat units). The upstream portions of the system are tidal freshwaters, while the downstream areas are estuarine subtidal zones.

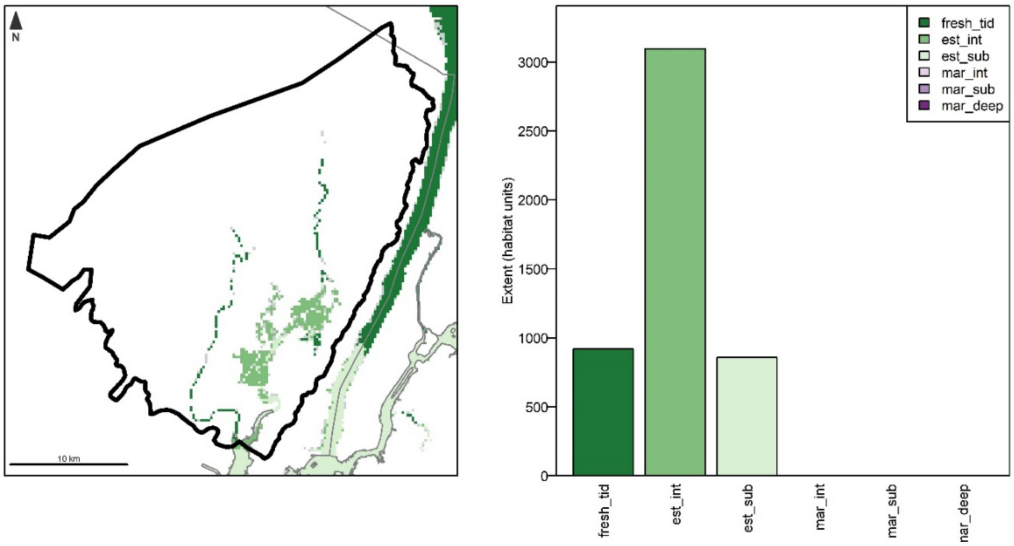

Figure A11.7. Existing condition summary for the Hackensack-Passaic Region.

Jamaica Bay Region

This region provides large expanses of estuarine subtidal areas, primarily in the more sheltered bayside system. The estuarine intertidal areas are fringing marshes and marsh island systems. The marshes areas are relatively narrow, given adjacent urban land use pressures. A small amount of marine deepwater is included in this region, although that is largely an artifact of the region boundaries extending south into the Atlantic Ocean.

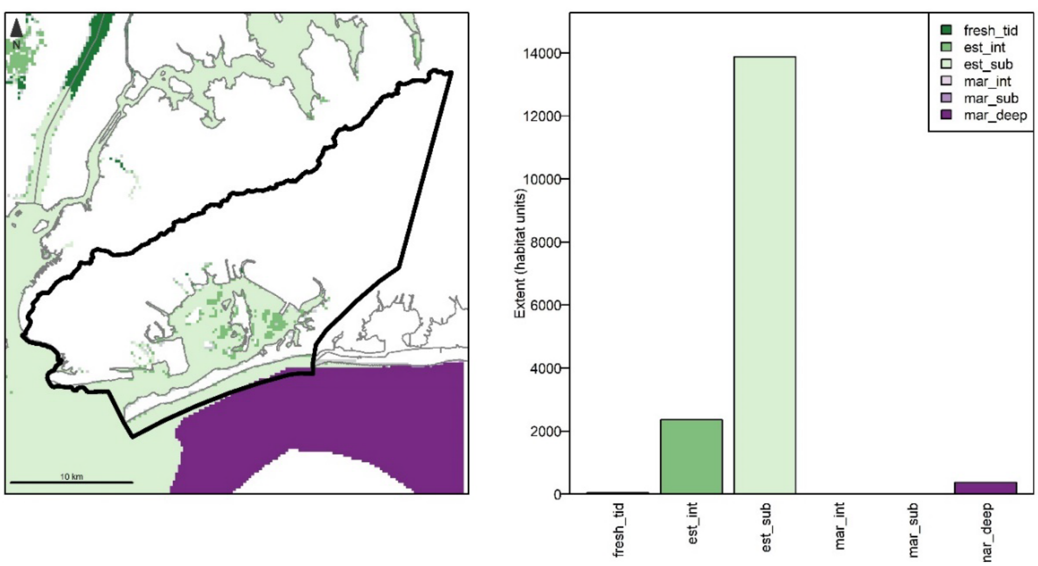

Figure A11.8. Existing condition summary for the Jamaica Bay Region.

Long Island Sound, Lower Bay, and Upper Bay-Arthur Kill Regions

These three regions contain distributions of ecosystem types with large segment of estuarine subtidal systems connecting to marine deepwater and fringed by estuarine intertidal areas. All three regions have large amount of estuarine subtidal habitat (i.e., 20,000, 5,000, and 9,000 habitat units, respectively). These systems are also directly within the harbor environment and experience high use rates from commercial and recreational vessels as well as other forms of development intensity.

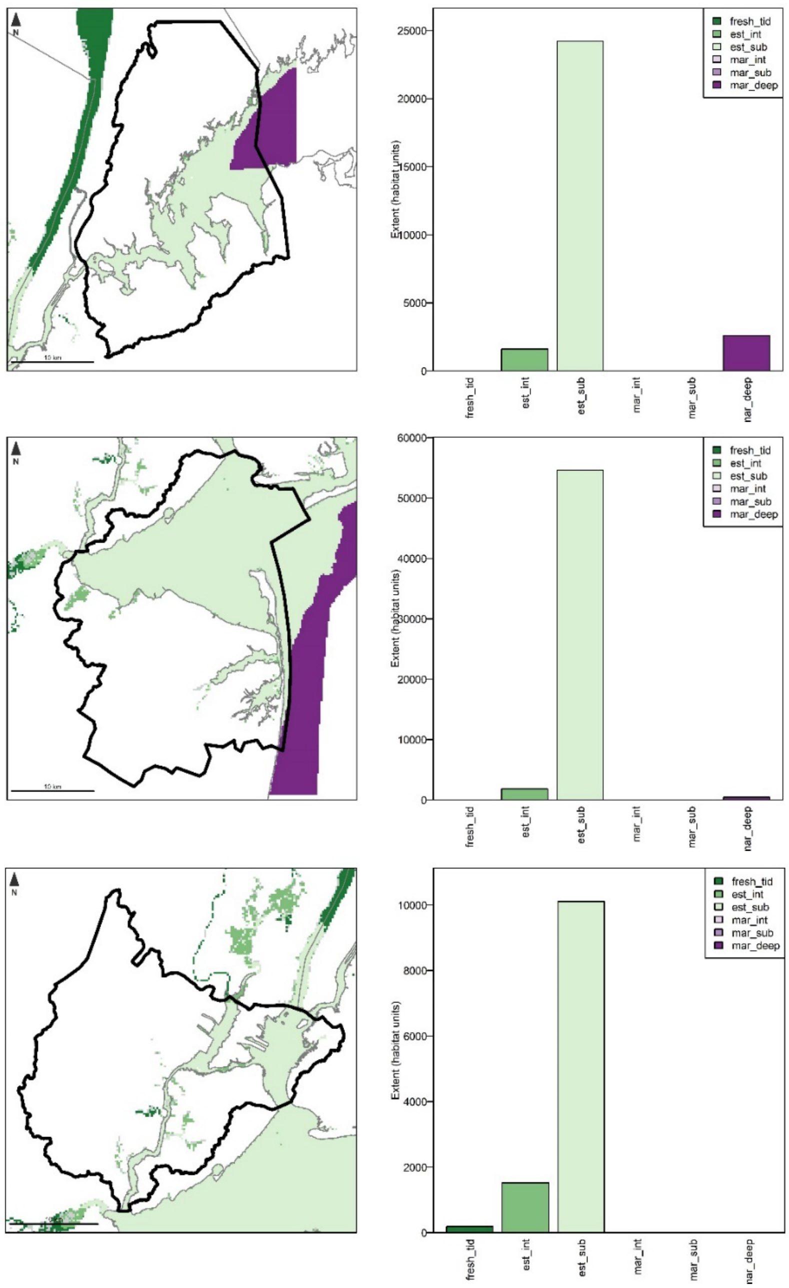

Figure A11.9. Existing condition summary for the Long Island Sound (top), Lower Bay (middle), and Upper Bay-Arthur Kill (bottom) Regions.

Raritan Region

The Raritan region has the most balance composition of estuarine habitats in region showing the transition from relatively freshwaters in upstream areas to brackish waters near the Lower Bay. The overall extent of these ecosystems is, however, significantly small than other portions of the HAT study area (i.e., on the order of hundreds of habitat units rather than thousands or tens of thousands).

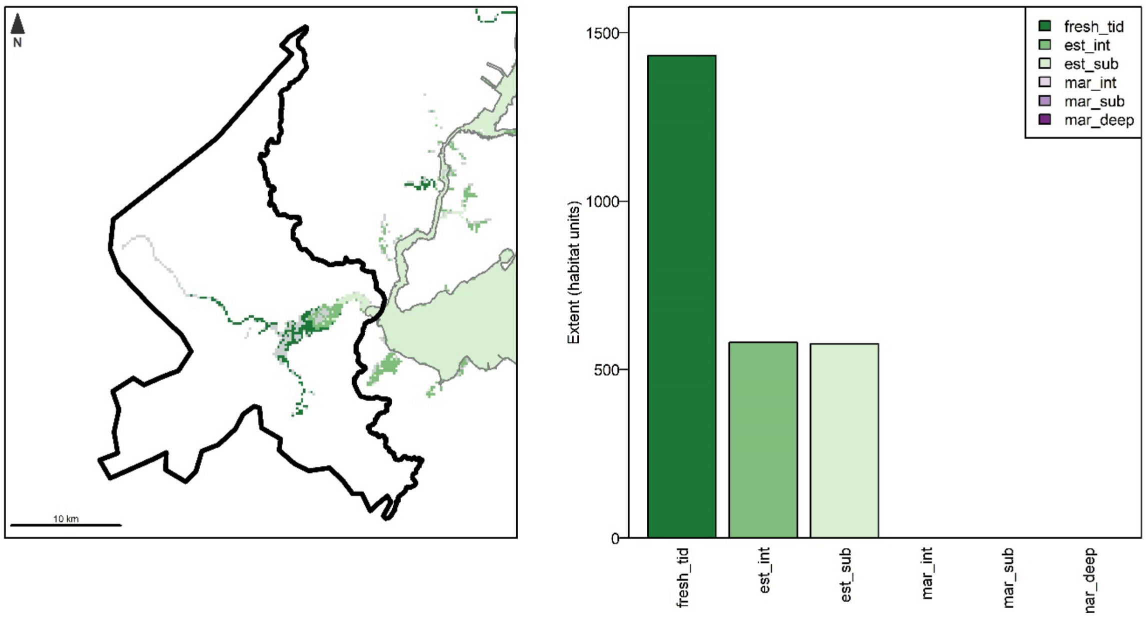

Figure A11.10. Existing condition summary for the Raritan Region.

5.0 Alternatives Analysis

Six generalized conceptual alternatives were developed for the NYNJHAT Study (Main Report Section 4.11, Appendix B1, and Appendix B2). These alternatives bracket an array of actions from a small number of large storm surge barriers to many shore-based actions (Figure A11.11), and the alternatives provide varying levels of flood risk reduction, cost, and benefit. Alternatives with storm surge barriers provide the primary source of potential change in estuarine circulation and were the focus of hydrodynamic simulations (McAlpin and Emiren, Appendix B7). Although all alternatives include multiple shore-based actions, storm surge barriers are the focus of this analysis, and barriers included in each alternative are as follows:

- Alt1: Existing condition and future without project
- Alt2: Outer Harbor and Throgs Neck
- Alt3A: Arthur Kill, Verrazano Narrows, Jamaica Bay, Throgs Neck, Sheepshead Bay, Gerritsen Creek, and Coney Island Creek
- Alt3B: Arthur Kill, Kill Van Kull, Jamaica Bay, Gowanus Canal, Newtown Creek, Flushing Creek, Sheepshead Bay, Gerritsen Creek, and Coney Island Creek
- Alt4: Hackensack, Jamaica Bay, Gowanus Canal, Newtown Creek, Flushing Creek, Sheepshead Bay, Gerritsen Creek, and Coney Island Creek
- Alt5: Shore-based measure only (not pictured)

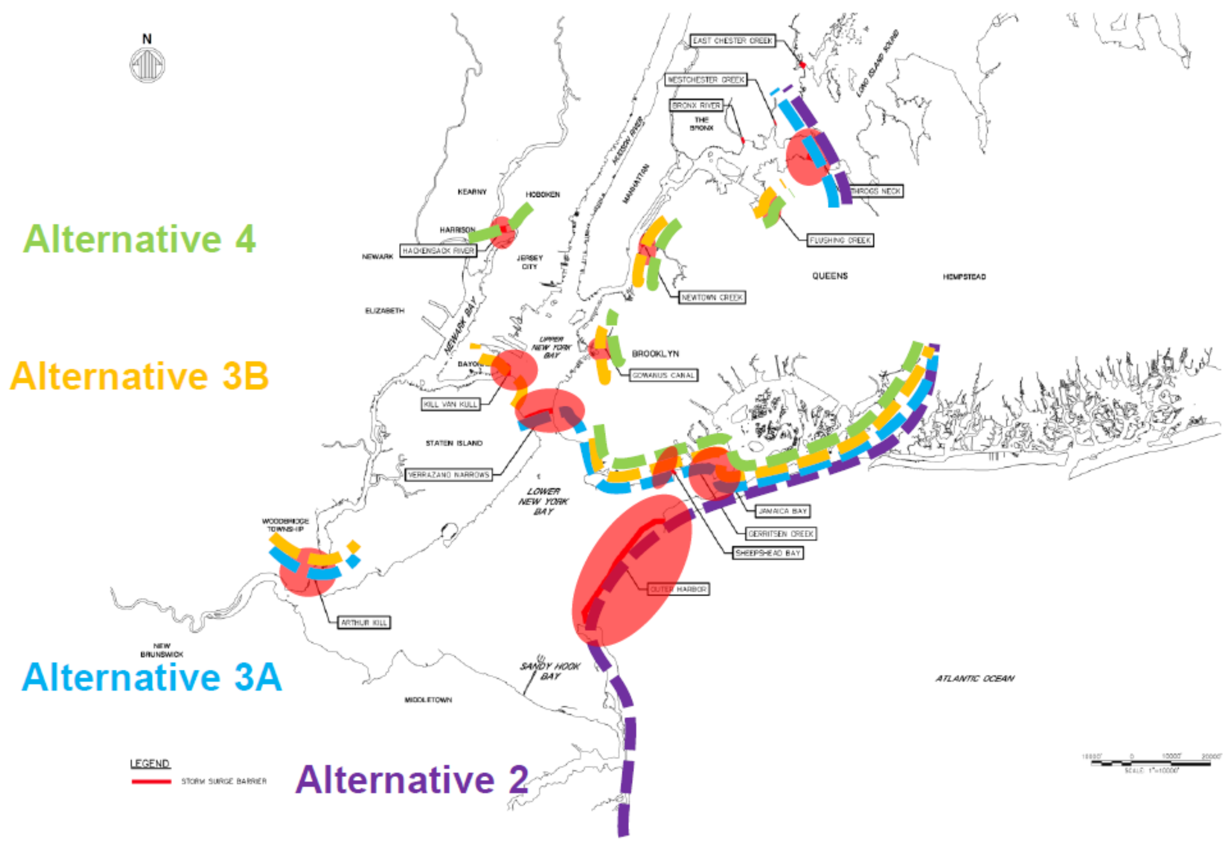

Figure A11.11. Summary of the HAT study alternatives.

Two applications of NYBEM were undertaken to inform feasibility study planning. First, direct effects of management actions were quantified by examining the “footprint” of all structural features (e.g., floodwalls, storm surge barriers, etc.). Second, the indirect effects of actions were quantified by estimating hydrodynamic change associated with storm surge barriers at the system-wide scale. AdH models were executed for each proposed storm surge barrier configuration over an annual simulation window in an open gates, sunny day condition. These hydrodynamic data were then used to parameterize NYBEM and estimate cumulative effects of these features off-site from the infrastructure itself. Finally, the relative amounts of direct and indirect effects are summarized for each alternative to inform feasibility planning.

5.1 Direct Effects Summary

Direct effects of management actions are defined here as the anticipated impacts associated with a given piece of infrastructure (i.e., measure) in terms of construction, operations, and inspection corridors. Appendices B and E present addition detail about each of the measures, alternatives and associated alignments. The direct effects of HATS alternatives on regional ecosystems were estimated for the structural footprint of all features buffered by a 100 foot corridor. The buffered distance was included to account for potential impacts associated with construction staging areas, access to build a feature, and long-term maintenance corridors. Specifically, the existing condition maps of the six ecosystems (from Section 4 of this appendix) were intersected with proposed infrastructure polygons for all storm surge barriers and shore-based actions. Existing condition maps were used for this analysis under the assumption that these represent current habitat and would be the primary focus for considering potential mitigation actions in subsequent phases of the Study (Final Integrated FR/Tier 1 EIS and Tier 2 EIS(s)). Figure A11.12 summarizes the results of this analysis, and notable findings include the following:

- Across all alternatives, the vast majority of effects are in the estuarine intertidal and subtidal zones. This is expected, given the low coverage of marine areas in the HAT study area and minimal presence of structural features in freshwater areas. Within the estuarine zones, the effects are generally even across intertidal and subtidal habitats with shore-based features driving larger effects in intertidal areas.
- Bulkheads, floodwalls, seawalls, and storm surge barriers consistently show the largest sources of project impacts across alternatives driven by the more extensive footprint of these actions.
- Alternative 2 has higher direct footprint impacts than the other alternatives, and Alternative 3A results in a similar level of effect.
- Alternative 5 consistently has the lowest direct effects at both alternative-scale as well as on a feature-by-feature basis.
- Alternative 3B has second lowest direct impacts, although these effects are much larger than Alt-5 (i.e., 350% greater). By comparison, Alternatives 3A and 4 have much greater impacts than Alt-5 (i.e., 530% and 440% greater, respectively).

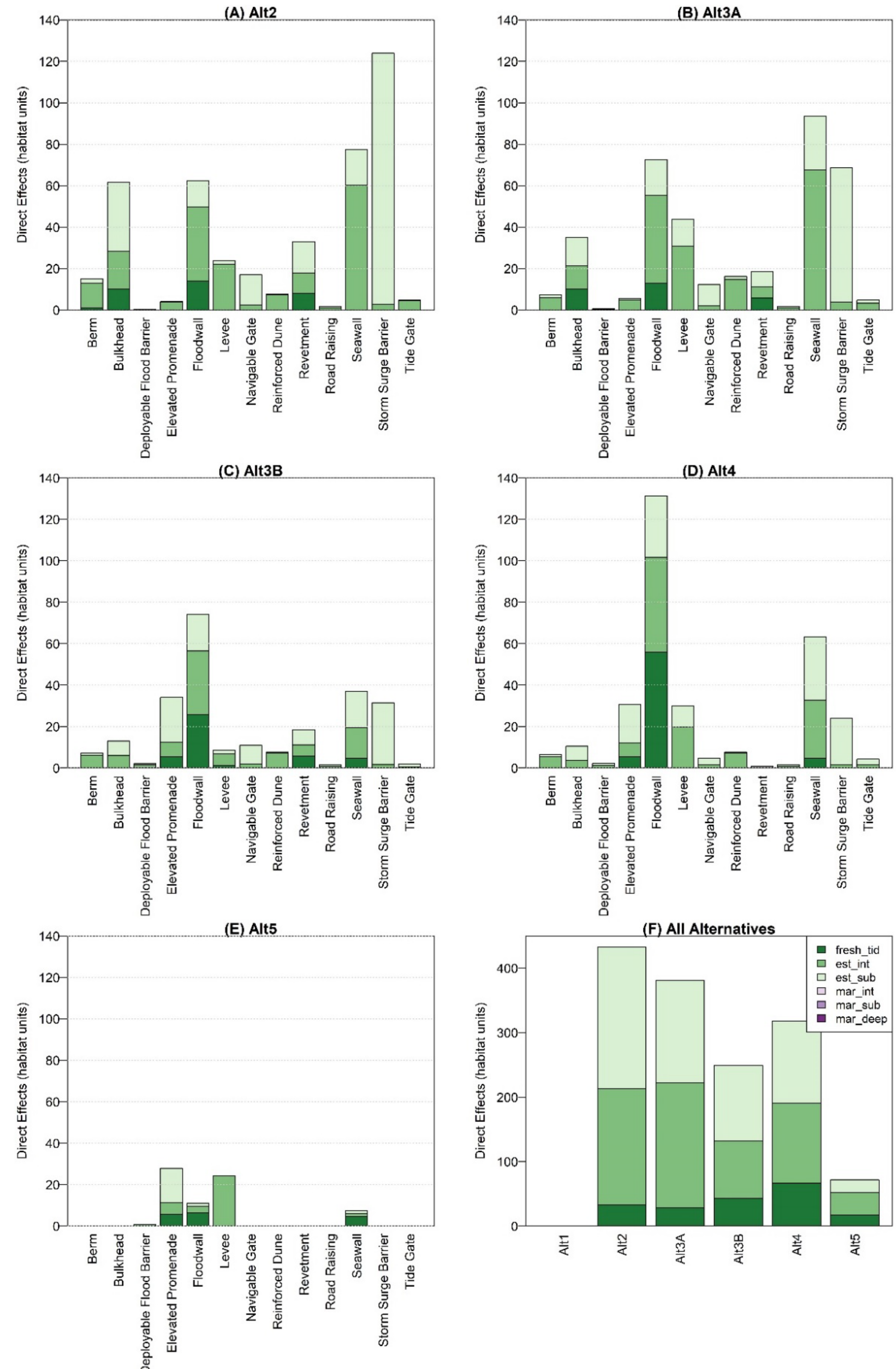

Figure A11.12. Summary of the direct, footprint effects of the NYNJHAT study alternatives.

5.2 Indirect Effects Summary

Indirect effects of management actions are defined here as the changes in regional ecosystems off-site or distant from storm surge barriers resulting from change in hydrodynamics or estuary circulation patterns. In particular, storm surge barriers have the potential to change hydrodynamics and estuarine function beyond the footprint of the structure itself. These "off-site" or indirect effects are addressed here through changes in habitat quantity and quality as summarized for the project area and regions. For instance, tidal ranges or salinity levels could change at a given patch as a result of a barrier, and these effects could indicate a change in habitat type. Similarly, a barrier could induce a change in a hydrodynamic variable within a given habitat suitability model (e.g., velocity) even in this open gate simulation.

Indirect effects of actions were quantified by estimating hydrodynamic change associated with storm surge barriers at the system-wide scale. AdH models were executed for each proposed storm surge barrier configuration over an annual simulation window in an open gates, sunny day condition (McAlpin and Emiren, Appendix B7). These hydrodynamic data were then used to parameterize NYBEM and estimate cumulative effects of these features off-site from the infrastructure itself.

Figure A11.13 summarizes expected changes in habitat quantity and quality at the scale of the entire project area. Four stipulations assist in interpreting these outcomes.

- Outcomes represent aggregated effects, not site-specific effects. For example, an ecosystem could change at multiple locations, but the net effect could be zero change.
- Indirect effects can only be quantified using hydrodynamic data, and thus, are only shown at the alternative scale with multiple barriers, rather than feature-by-feature.
- Indirect effects require a point of comparison, and all results are presented relative to the existing condition. For instance, did the extent of a given ecosystem type go up or down as the result of an alternative?
- Although "impacts" are typically thought of as unidirectional (i.e., negative), change may be more generally considered in this analysis as deviation from current conditions, and large amounts of change (positive or negative) could be considered impactful.
- Multiple metrics are presented to better characterize and contextualize the changes estimated by these models. Metrics for habitat extent (i.e., area) and quality (i.e., habitat units) can provide useful distinctions between the magnitude of change resulting from tidal and salinity zones versus changes in ecosystem condition. Similarly, the net change from the existing condition baseline may provide a very different outlook that the relative change in ecosystem type or condition at a regional scale.

Figure A11.13 can then be interpreted through the lens of alternatives analysis as follows:

- Across alternatives, NYBEM consistently predicts that storm surge barriers would induce habitat switching from estuarine intertidal areas to freshwater tidal ecosystems. This finding could be expected given the NYBEM's use of salinity as a delineating criteria, and the role of barriers in altering salinity influx to the estuary.

- The magnitude of change generally decreases as the alternatives move farther into the estuary (i.e., Alt2 > Alt3A > Alt3B > Alt4 > Alt5).
- Marine intertidal and subtidal ecosystems are minimally affected by all alternatives (12A and 12B), due to their minimal extent in the project area (Section 4 of this appendix). However, these systems show high amounts of relative change (12C and 12D), again because a small change in a small area is a relatively large effect on a percentage basis.
- Conversely, freshwater tidal, estuarine intertidal, and estuarine subtidal ecosystem show small amounts of relative change on a percentage basis because of the large extent of these ecosystems across the region. The systems also show a high amount of net change as a result of the alternatives.
- Alt2 produces the largest amount of total change in ecosystem extent (12A) and condition (12B). Specifically, the alternative shows a large impact on estuarine intertidal areas with a significant amount of habitat switching to freshwater tidal.

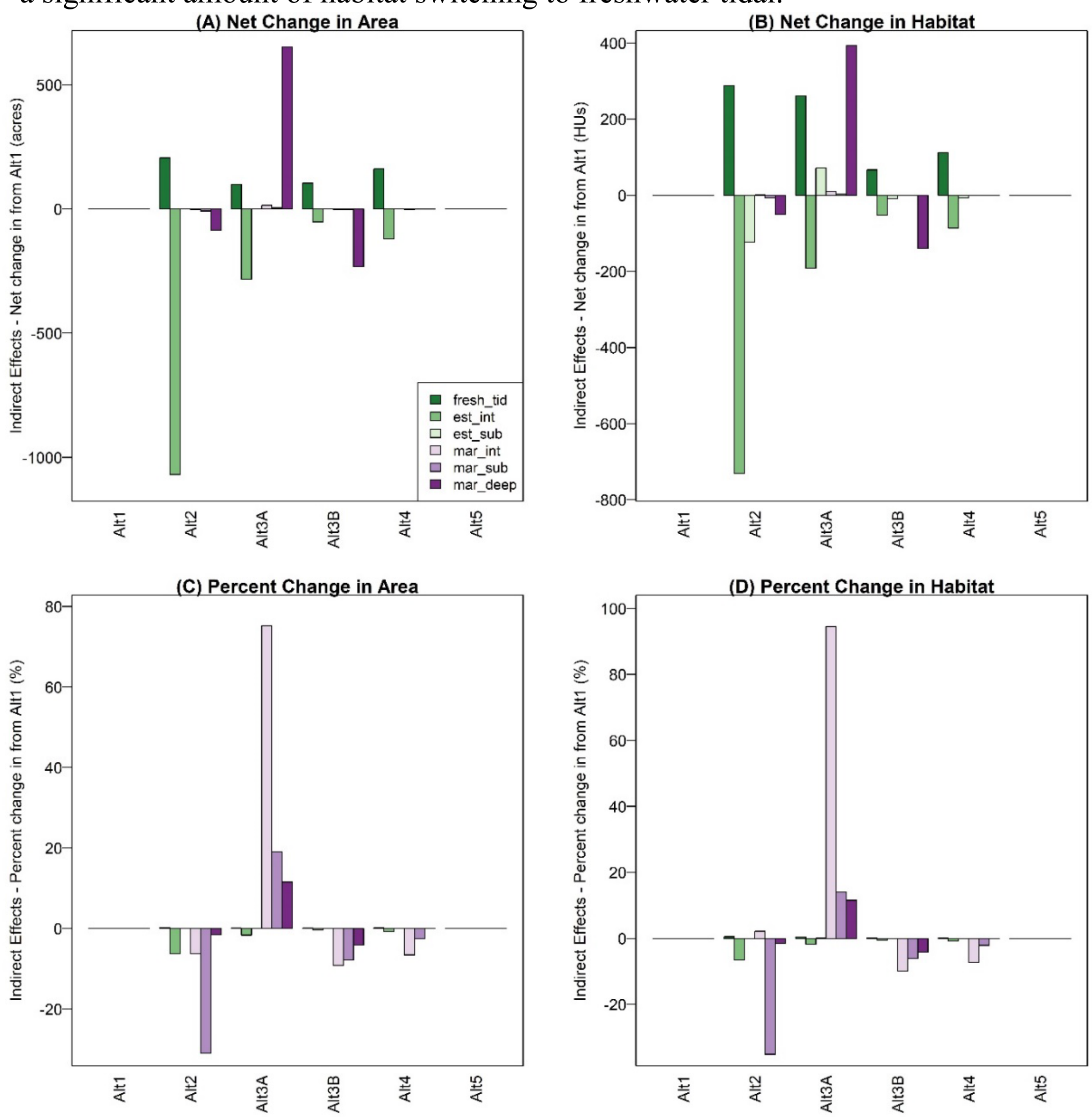

Figure A11.13. Summary of indirect effects analysis for the entire HAT study area.

Negative values imply reductions from existing condition, and positive values indicate increases. Figures C and D show change normalized by the current extent of an ecosystem.

Figures A11.14 and A11.15 break-down habitat quantity and ecosystem condition outcomes, respectively, based on region of effect. The regional results provide additional insight into the effects of individual alternatives and alternative comparison more generally, specifically:

- Habitat quantity and quality effects are consistent across alternatives and regions. Said differently, the two metrics provide the same point of relative comparison. However, observations about the total magnitude of affect are quite different.
- Alt5 was assumed to have no hydrodynamic change and Alt1 (i.e., existing condition) hydrodynamics were used in NYBEM. Resultingly, this alternative shows no indirect effects observed.
- The locations of indirect effects change significantly depending on which storm surge barriers are included in a given alternative. For instance, Alt3B and Alt4 show very different levels of effects in the Hackensack-Passaic region due to the presence of the Hackensack barrier in Alt4 (in two otherwise similar alternatives). This finding increases confidence that models are showing localized responds to hydrodynamic change and are providing a useful framework for assessing relative effects of the alternatives.
- Alt2 shows a large amount of ecological change across regions. This alternative's level of hydrodynamic and ecological change is clearly high relative to even actions much close to a given region. For instance, Alt2 significantly alters habitats in the Hackensack-Passaic region, although the region is rather distant from the structure itself.
- Alt3B shows a significant amount of change in the Lower Hudson-East River and the Long Island Sound regions. In particular, the change in marine deep ecosystems in the Long Island Sound area could be a result of reduced salinity in the East River system.

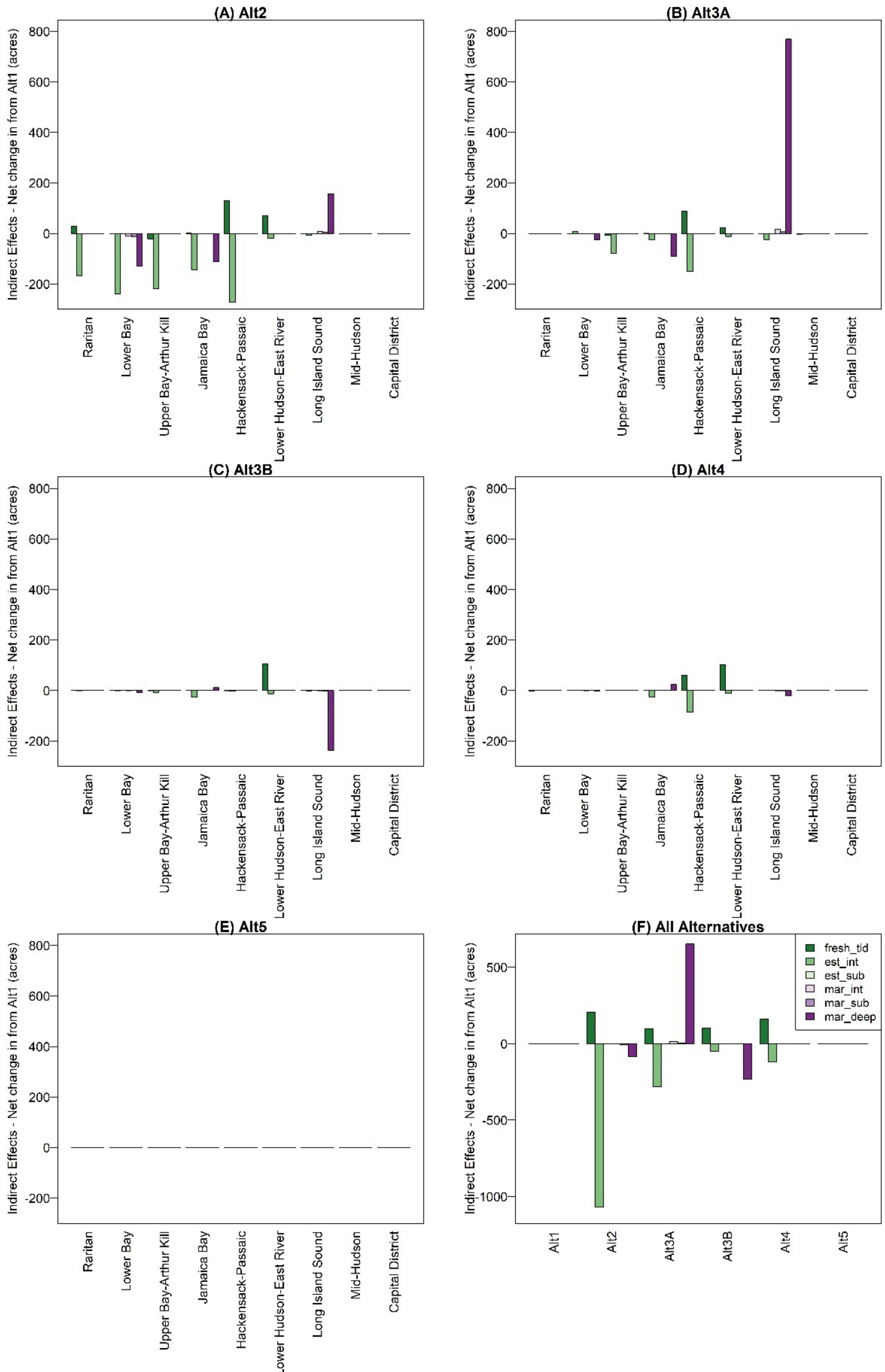

Figure A11.14. Summary of indirect effects. Net change in area (acres) of different ecosystem types by region and alternative.

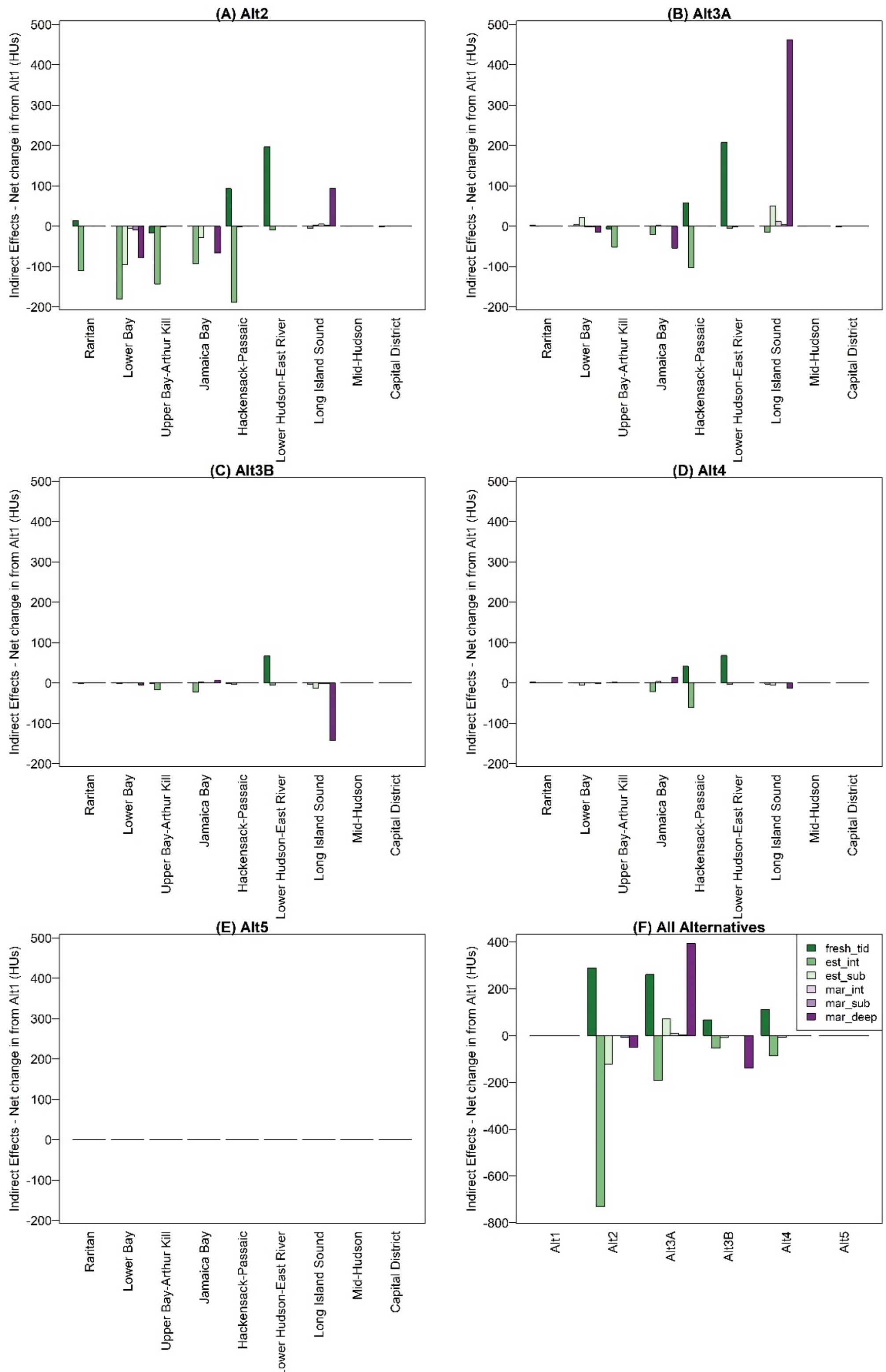

Figure A11.15. Summary of indirect effects. Net change in habitat (habitat units) of different ecosystem types by region and alternative.

5.3 Summary of Direct and Indirect Effects Combined

Although direct and indirect effects may be considered separately, this section considers the relative effect of these two potential sources of impact or change. Figure A11.16 summarizes these two outcomes for comparison of alternatives and with each other.

- The relative proportion of direct and indirect effect changes with alternative. For instance, indirect effects are a larger contribution to change for Alt2, whereas this ratio inverses for alternatives with more shore-based measures (i.e., Alt3B, Alt4, Alt5).
- Alt2 and Alt3A consistently show large magnitudes of change overall, specifically for the indirect effects which are more than triple any other alternative.
- Alt5 is consistently the lowest amount of direct or indirect effect.
- Alt3B presents a lower amount of change on an ecosystem-by-ecosystem basis than Alt4, although when aggregated Alt4 shows a lower net magnitude of change.

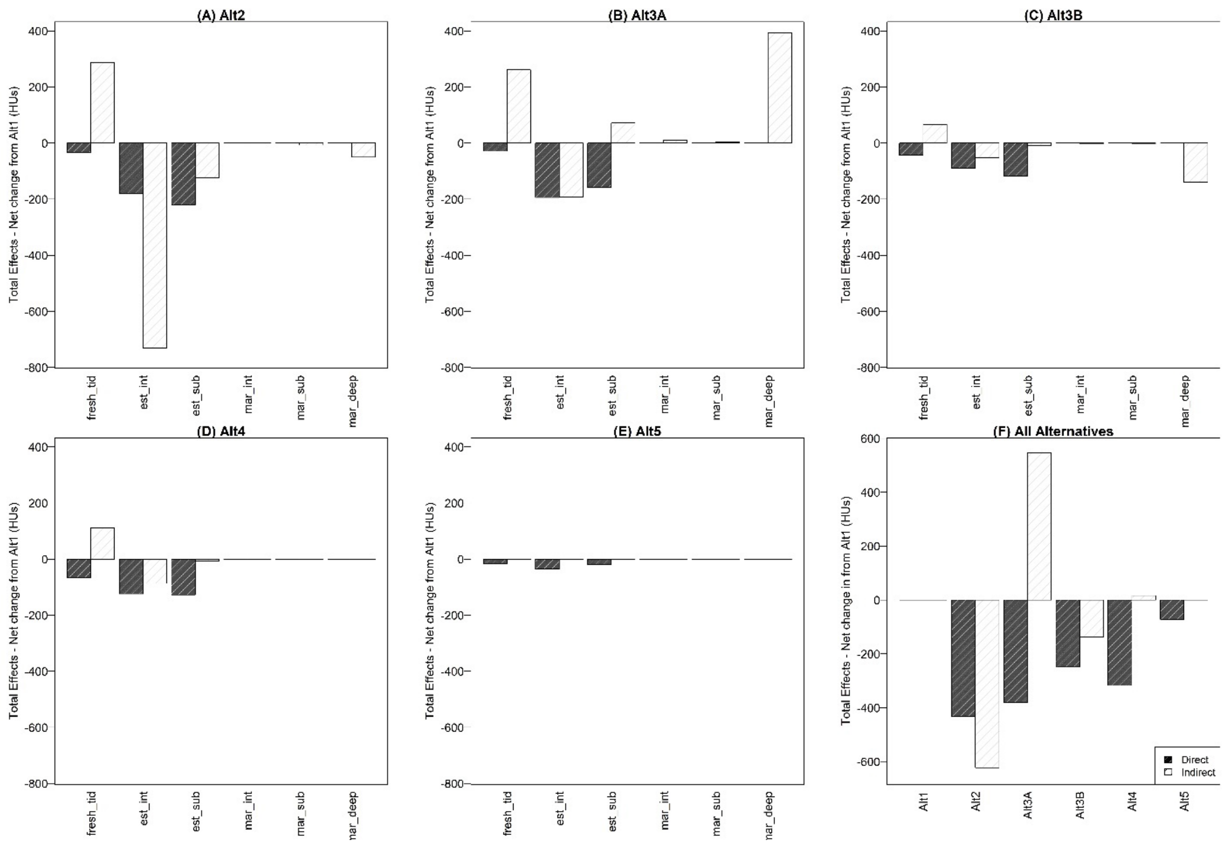

Figure A11.16. Summary of direct and indirect effects of HAT study alternatives. Values represent net change in habitat units from the existing condition (Alt1) summarized by ecosystem type.

6.0 Tentatively Selected Plan (Alt3B)

Based on analyses presented elsewhere in the feasibility report, the Tentatively Selected Plan is alternative 3b (Alt3B). This alternative includes major storm surge barriers in the Arthur Kill, Kill Van Kull, and Jamaica Bay systems, and a number of smaller barriers at Gowanus Canal, Newtown Creek, Flushing Creek, Sheepshead Bay, Gerritsen Creek, and Coney Island Creek. Table A11.3 summarizes features and measures included in Alt3B by Planning Region. Notably, indirect effects are only computed for storm surge barriers, rather than all features. This section provides a deeper examine of direct and indirect effects of this alternative at the scales of the Study Area as well as each Planning Region.

Table A11.3. Summary of measures included in Alt3B by Planning Region.

PLANNING REGION	STORM SURGE BARRIERS	TIDE GATES	FLOODWALL	LEVEES	ELEVATED PROMENADES	BURIED SEAWALL AND SAND DUNES	SEAWALLS	REVETMENTS	BERMS	BULKHEADS	PEDESTRIAN OR VEHICULAR GATES	ROAD RAISING
Capital District	N	N	N	N	N	N	N	N	N	N	N	N
Mid-Hudson	N	N	N	N	N	N	N	N	N	N	N	N
Lower Hudson - East River	Y	N	Y	Y	Y	N	Y	N	N	N	Y	N
Upper Bay - Arthur Kill	Y	Y	Y	Y	N	N	Y	Y	Y	N	Y	N
Lower Bay	N	N	N	N	N	N	N	N	N	N	N	N
Hackensack-Passaic	N	N	Y	N	N	N	N	Y	Y	N	Y	Y
Raritan	N	N	N	N	N	N	N	N	N	N	N	N
Long Island Sound	Y	N	Y	N	Y	N	Y	N	N	N	N	N
Jamaica Bay	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Figure A11.17 summarizes the direct effects of Alt3B with metrics of both habitat quantity (area) and ecosystem condition (habitat units). This alternative only shows footprint effects in freshwater tidal, estuarine intertidal, and estuarine subtidal areas. As shown above in Figure A11.12C, these impacts are dispersed over a large number of features with a majority of the direct effects occurring for actions other than storm surge barriers. Specifically, floodwalls are a significant component of the direct effects of this alternative.

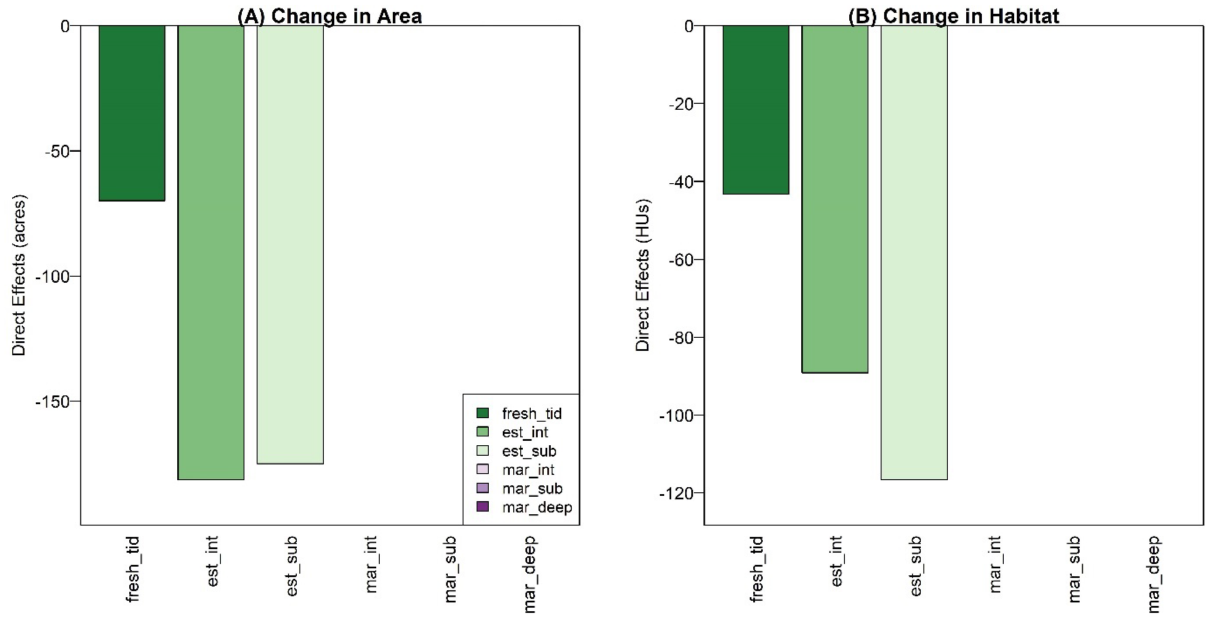

Figure A11.17. Summary of direct effects of Alt3B for the entire HAT study area. Values represent net change in area (acres) and habitat quality (habitat units) from the existing condition (Alt1) summarized by ecosystem type.

Figure A11.18 summarizes the indirect effects of Alt3B with metrics of net change in habitat quantity and ecosystem condition (Panels A&B) as well as relative change in these metrics (Panels C&D). Freshwater tidal areas are predicted to increase as a result of this alternative, which is not unexpected given the potential for storm surge barriers to alter salinity input to the estuary. Estuarine intertidal areas represent a potential location of impacts associated with this alternative, potentially due to reduced tidal amplitudes behind barriers. Marine deepwater zones are predicted to contract under this alternative, potentially due to a freshening effect in Long Island Sound as described above. Percentage-based metrics indicate significant amounts of change in marine ecosystems, although these areas represent small fractions of the overall NYNJHAT Study Area.

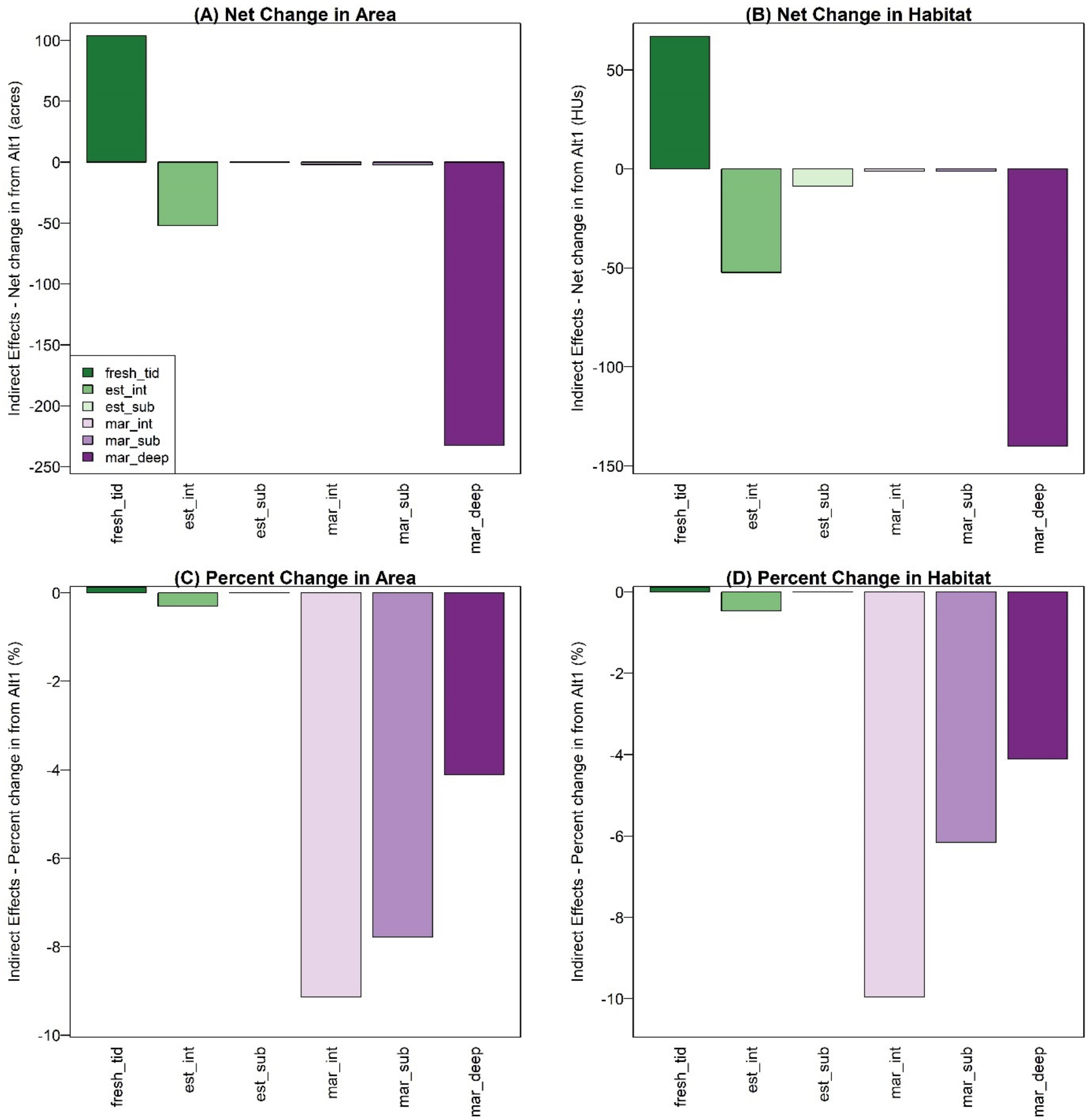

Figure A11.18. Summary of indirect effects of Alt3B for the entire HAT study area. Values represent change from the existing condition (Alt1) summarized by ecosystem type. (A) net change in area in acres, (B) net change in habitat quality in habitat units, (C) percent change in area, and (D) percent change in habitat units.

The following sections summarize key direct and indirect effects on a region-by-region basis. The objective of this analysis is to note major trends and outcomes, not break-down specific locations of impact or attribute those effects to a specific piece of proposed infrastructure.

Capital District, Mid-Hudson, and Raritan Regions

The Capital District, Mid-Hudson, and Raritan regions are unique in the relatively small (or non-existent) effects of the TSP. For instance, there are no features proposed in the two Hudson River regions, and the indirect effects only represent negligible change in ecosystem extent or condition.

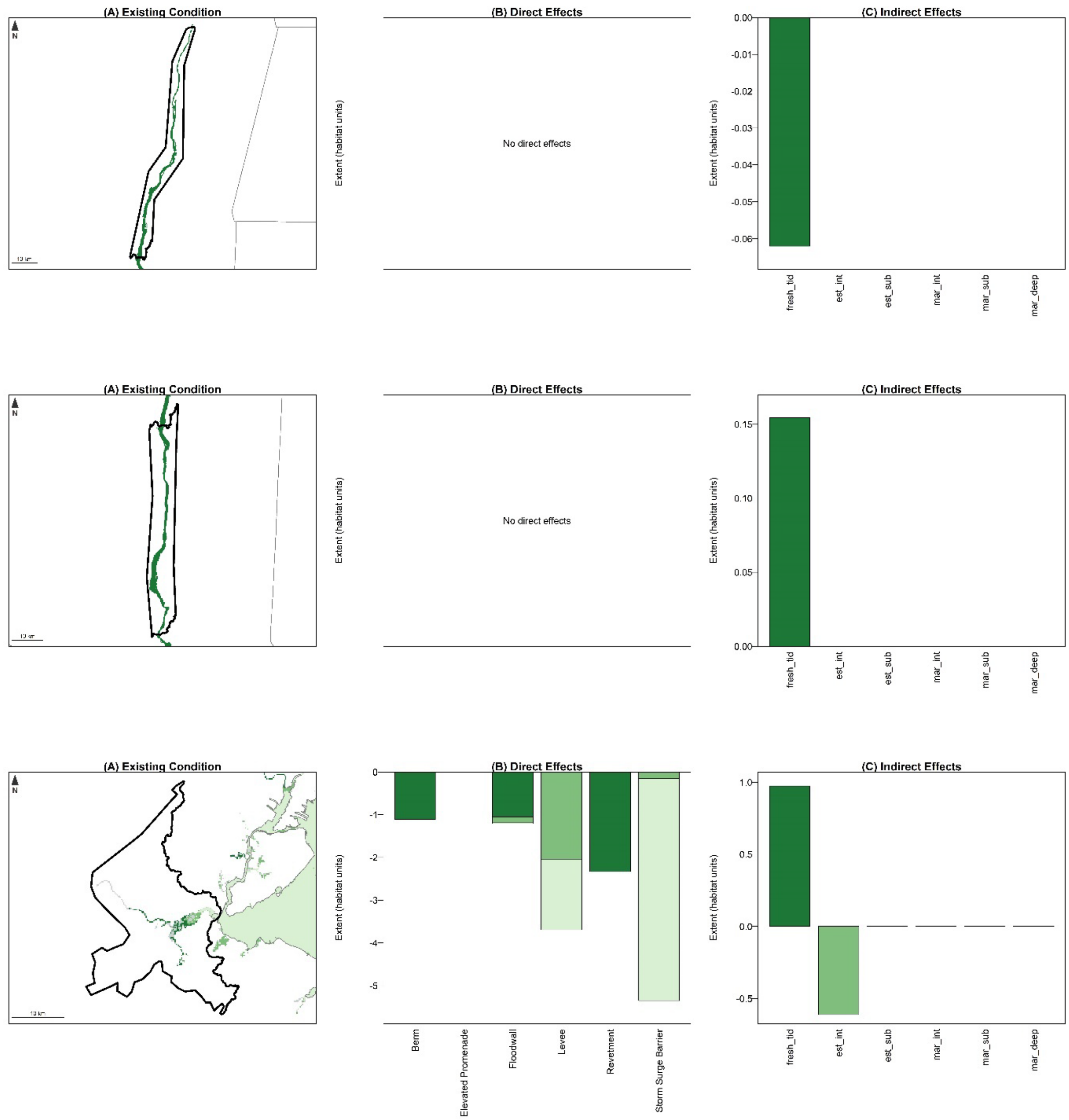

Figure A11.19. Summary of Alt3B effects for the Capital District (top), Mid-Hudson (middle), and Raritan (bottom) Regions.

Lower Hudson/East River Regions

The Lower Hudson-East River region represents a key transitional zone between freshwater and estuarine ecosystems, and both direct and indirect effects reflect this transition. Direct effects include a variety of features, which collectively represent a large footprint of actions with one of the largest impact areas of any region. The indirect effects in this region are reflecting a change in the transitional point between salinity zones, and a general freshening resulting from multiple small storm surge barriers.

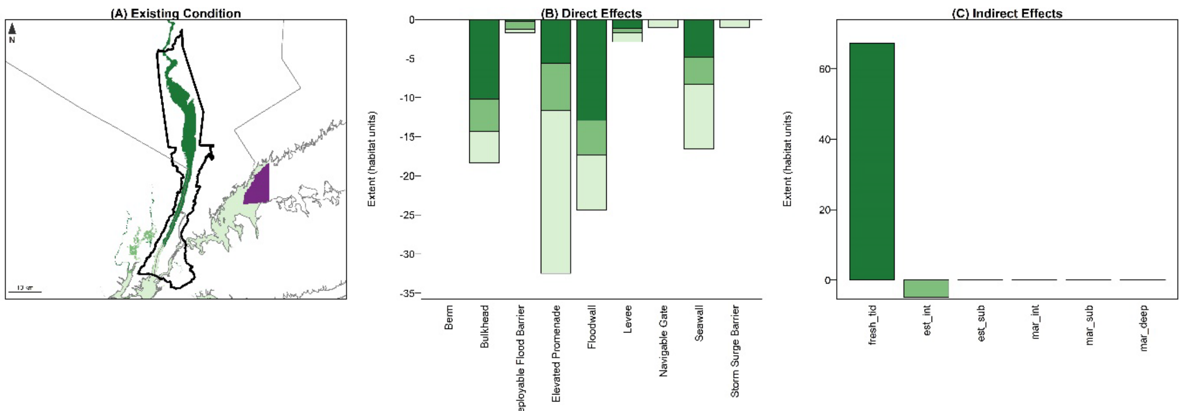

Figure A11.20. Summary of Alt3B effects for the Lower Hudson-East River Region.

Hackensack-Passaic Region

Alt3B provides substantial direct effects in the Hackensack-Passaic region. Specifically, floodwall and levee features are the major source of impact in this region. Indirect effects are very small and likely resulting from the cumulative effects of the Arthur Kill and Kill Van Kull storm surge barriers.

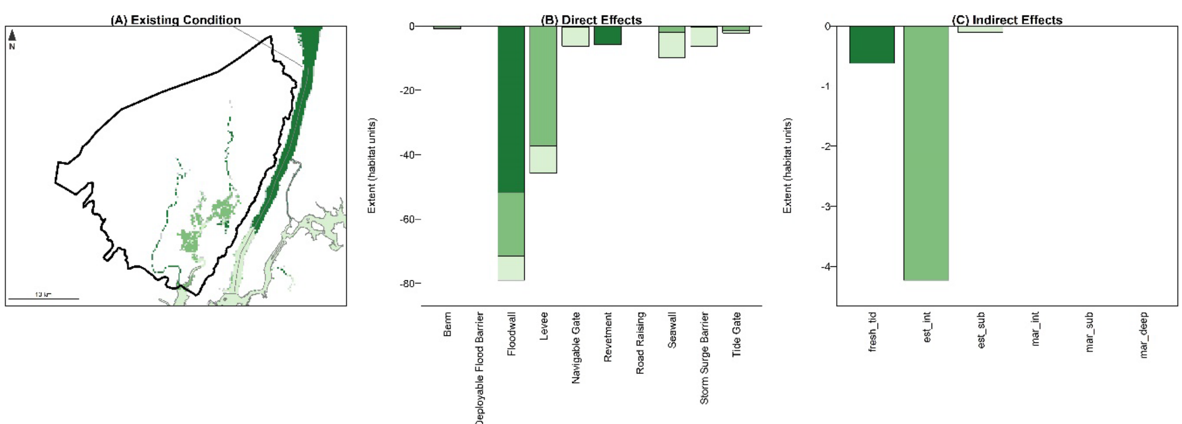

Figure A11.21. Summary of Alt3B effects for the Hackensack-Passaic Region.

Jamaica Bay Region

The Jamaica Bay region is a primary focal point for Alt3B with both shore-based and in-water features. As anticipated, the shore-based measures have predictable direct effects on the estuarine intertidal areas of this region, and the storm surge barrier would also alter these ecosystems due to changes in tidal regime.

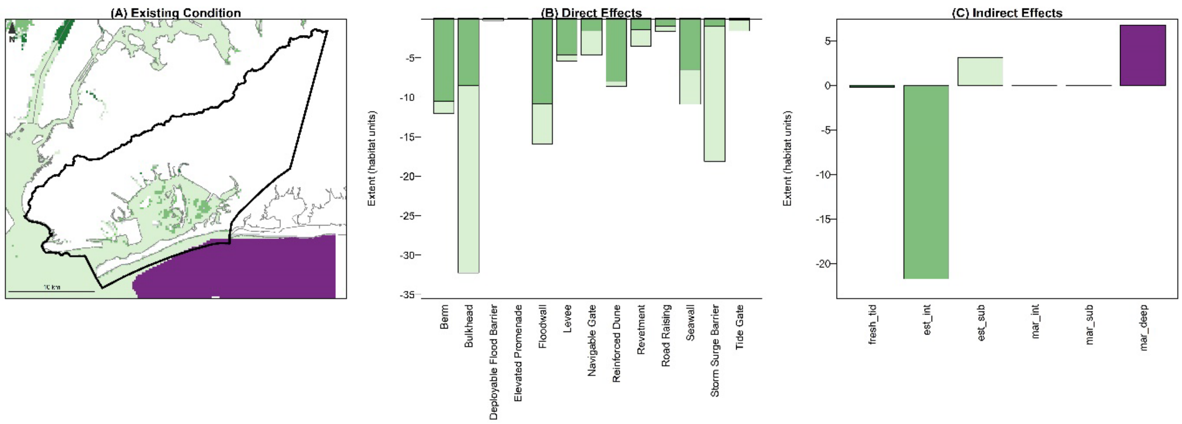

Figure A11.22. Summary of Alt3B effects for the Jamaica Bay Region.

Long Island Sound Region

The TSP leads to substantial direct effects in this region, partially due to residual risk features addressed flood risks without storm surge barriers. The indirect effects in the region are due to a predicted shift in the estuarine-marine salinity, which would decrease the overall extent of marine ecosystems.

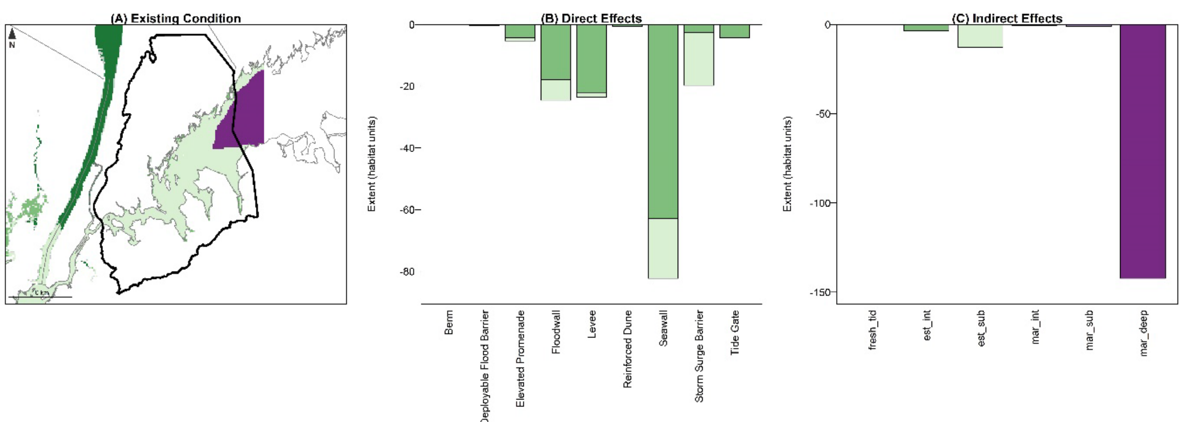

Figure A11.23. Summary of Alt3B effects for the Long Island Sound Region.

Lower Bay Region

The Arthur Kill storm surge barrier is the primary driver of direct and indirect effects in the Lower Bay region. However, the indirect effects are quite small in this region, and direct effects are significantly larger than indirect changes (i.e., 20-40X).

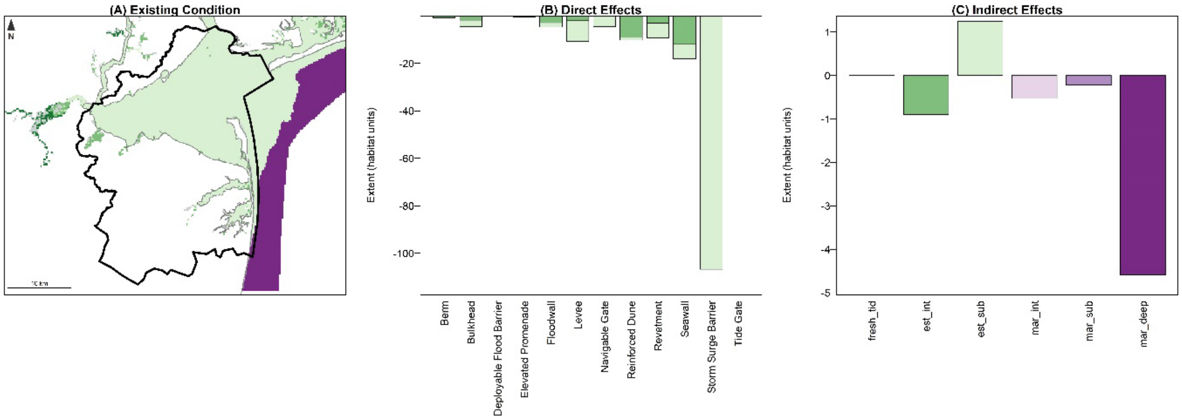

Figure A11.24. Summary of Alt3B effects for the Lower Bay Region.

Upper Bay-Arthur Kill Region

Alt3B has a substantial effect on the Upper Bay-Arthur Kill Region. The direct effects in this region are driven by the Kill Van Kull storm surge barrier and floodwall projects, and the indirect effects are driven by the combined effect of the Kill Van Kull and Arthur Kill barriers.

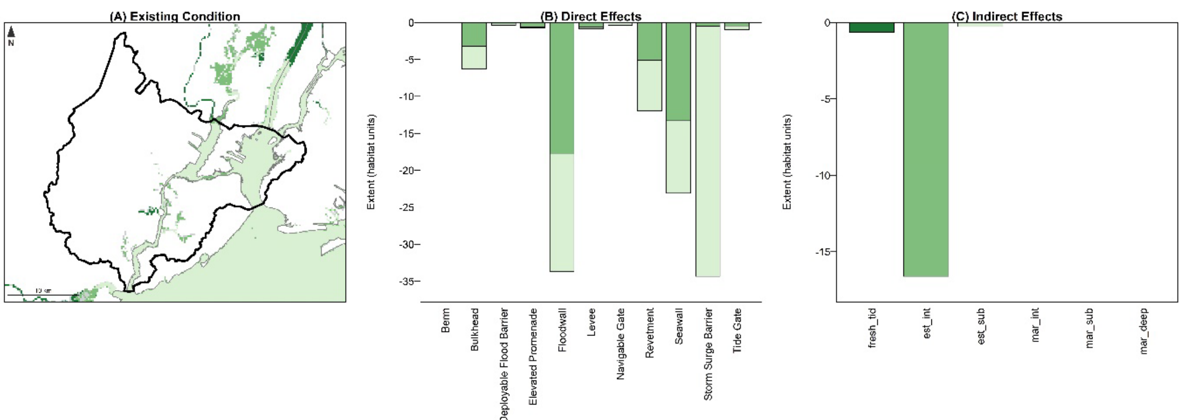

Figure A11.25. Summary of Alt3B effects for the Upper Bay-Arthur Kill Region.

7.0 Future Analyses

This appendix has presented the application of the New York Bight Ecological Model (NYBEM), and the model report provides additional description of the models themselves (https://mvr-gis.github.io/NYBEM-Report/). The models currently apply an index-based modeling framework (i.e., a habitat-suitability-style, quantity-quality approach) to assess patch-scale effects for six ecosystem types (e.g., estuarine intertidal zones). In all applications, models represent incomplete abstractions of reality, and opportunities exist for future development of this toolkit. Specifically, the following items were identified as important topics for potential expansion of the model and its application to the NYNJHAT study:

- Improvements to Sub-Models: Six major habitat types were examined in the NYBEM, and important model extensions and knowledge gaps were noted as part of model development. Habitat types could also be further divided into sub-types such as low marsh, high marsh, and tidal flats, and the model domain could be expanded to other habitat types (e.g., non-tidal freshwaters or riparian systems).

- Model Evaluation: Habitat zones and quality should be more formally validated against existing habitat maps for the region. The model report presented a preliminary set of verification analyses, which are being prepared for peer-review. Furthermore, models could also be compared with field-based approaches such as the Evaluation of Planned Wetlands (Bartoldus 1994), the New England Marsh Models (McKinney et al. 2009ab), or the Marsh Resilience to Sea-level rise model (Raposa et al. 2016).

- System connectivity: As described, NYBEM was originally conceived as a suite of models including habitat-type effects (applied here) as well as connectivity for migratory organisms. To date, connectivity models have not been developed to address impacts of storm surge barriers on migratory organisms. These models could draw from existing approaches in freshwater systems as well as experiences in other estuarine systems with storm surge barriers (NOAA-Sponsored Workshop).

- Taxa-Specific Outcomes: NYBEM was designed as a tool for examining broad-scale effects of proposed coastal infrastructure on regional ecosystems. This model intends to provide a ***relative*** accounting of ecological outcomes at a regional scale with highly divergent management actions (e.g., Are the effects of Barrier-A 5% or 50% different than Barrier-B?). The model has been used to compare management alternatives to inform feasibility scale planning in the USACE and identify key regions where effects are anticipated. From these analyses, additional models may be required to examine specific ecological outcomes at a particular location (e.g., a locally parameterized model of a specific imperiled taxa).

- Effects of Barrier Closures: NYBEM is designed generally to respond to changes in hydrodynamics as a result of storm surge barriers. Clearly, the operational patterns of these features would affect model outcomes (e.g., frequency or duration of gate closure). The HAT strategy for model application is proceeding through a series of increasingly detailed considerations of operations. First, a “gates open” scenario was used to examine the effects of barrier structures on general hydrodynamic conditions, which would occur the majority of time (i.e., this appendix). Second, a worst case scenario could be designed to study the effects of a complete closure or long-term closure on estuarine circulation and habitats. Third, more nuanced closure scenarios could be studied using more representative closure frequencies, duration, and timing.

8.0 Acronyms

AdH	Adaptive Hydraulics
AIS	Automatic Identification Systems for vessel data
EIS	Environmental Impact Statement
ERDC	U.S. Army Engineer Research and Development Center
ESI	Environmental Sensitivity Index for shorelines
est.int	Estuarine intertidal sub-model of NYBEM
est.sub	Estuarine subtidal sub-model of NYBEM
FR	Feasibility Report
fresh.tid	Freshwater tidal sub-model of NYBEM
HATS	New York / New Jersey Harbor and Tributaries feasibility study
HU	Habitat unit
mar.deep	Marine deepwater sub-model of NYBEM
mar.int	Marine intertidal sub-model of NYBEM
mar.sub	Marine subtidal sub-model of NYBEM
MHHW	Mean Higher High Water
MLLW	Mean Lower Low Water
NJ	New Jersey
NJBB	New Jersey Back Bays feasibility study
NJDEP	New Jersey Department of Environmental Protection
NLCD	National Land Cover Dataset
NY	New York
NYBEM	New York Bight Ecological Model
TSP	Tentatively Selected Plan
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service

9.0 References Cited

Bartoldus, C. C. 1994. “EPW: A Procedure for the Functional Assessment of Planned Wetlands.” Water, Air, & Soil Pollution 77 (3-4): 533–41. https://doi.org/10.1007/BF00478437.

Cowardin L.M., Carter V., Golet F.C., and LaRoe E.T. 1979. Classification of Wetlands and Deepwater Habitats of the United States. Washington, D.C.: U.S. Department of the Interior, Fish; Wildlife Service. https://www.fws.gov/wetlands/documents/classwet/index.html.

Federal Geographic Data Committee (FGDC). 2012. Coastal and Marine Ecological Classification Standard (CMECS). FGDC-STD-018-2012. Marine and Coastal Spatial Data Subcommittee. https://iocm.noaa.gov/standards/cmecs-home.html.

Federal Geographic Data Committee (FGDC). 2013. Classification of Wetlands and Deepwater Habitats of the United States. FGDC–STD-004-2013. Wetlands Subcommittee.

Fischenich C. 2008. The Application of Conceptual Models to Ecosystem Restoration. ERDC TN-EBA-TN-08-1. U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi. https://apps.dtic.mil/sti/pdfs/ADA477865.pdf.

Grant W.E. and Swannack T.M. 2008. Ecological Modeling: A Common-Sense Approach to Theory and Practice. Malden (Mass.): Blackwell.

Herman B.D., McKay S.K., Altman S., Richards N.S., Reif M., Piercy C.D., and Swannack T.M. 2019. Unpacking the Black Box: Demystifying Ecological Models Through Interactive Workshops and Hands-On Learning. Frontiers in Environmental Science 7 (October): 122. https://doi.org/10.3389/fenvs.2019.00122.

McAlpin T.O., Letter J.V., Bryant M., Broan G.L., Savant G., Wisemiller B.W., Sulayman J.A., Trahan C.J., and Emiren A.G. 2017. New York/New Jersey Harbor Sedimentation Study: Numerical Modeling of Hydrodynamics and Sediment Transport. ERDC TR-20-15. Coastal and Hydraulics Laboratory, U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi.

McAlpin T.O. and Emiren A.G. *Draft*. Analysis of Potential Storm Surge Barrier Impacts during Normal Tidal Conditions. Draft Technical Report. Coastal and Hydraulics Laboratory, U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi.

McKay S.K., Mahan V., Dougherty M.P., Swannack T.M., Hall C., Saltus C.L., Reif M.K., and Allen S. 2022. New York Bight Ecological Model (NYBEM), Version 1.0. USACE Model Certification Report. https://mvr-gis.github.io/NYBEM-Report/.

McKinney R.A., Charpentier M.A., and Wigand C. 2009a. “Assessing the Wildlife Habitat

Value of New England Salt Marshes: I. Model and Application." Environmental Monitoring and Assessment 154 (1-4): 29–40. https://doi.org/10.1007/s10661-008-0375-6.

McKinney R.A., Charpentier M.A., and Wigand C. 2009b. "Assessing the Wildlife Habitat Value of New England Salt Marshes: II. Model Testing and Validation." Environmental Monitoring and Assessment 154 (1-4): 361–71. https://doi.org/10.1007/s10661-008-0403-6.

Raposa et al. 2016. "Assessing Tidal Marsh Resilience to Sea-Level Rise at Broad Geographic Scales with Multi-Metric Indices." Biological Conservation 204 (December): 263–75. https://doi.org/10.1016/j.biocon.2016.10.015.

Schmolke A., Thorbek P., DeAngelis D.L., and Grimm V. 2010. Ecological Models Supporting Environmental Decision Making: A Strategy for the Future. Trends in Ecology & Evolution 25 (8): 479–86. https://doi.org/10.1016/j.tree.2010.05.001.

Swannack T.M., Fischenich C., and Tazik D.J. 2012. Ecological Modeling Guide for Ecosystem Restoration and Management. ERDC/EL TR-12-18. U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi. https://apps.dtic.mil/sti/citations/ADA572123.

USACE. 2000. New York and New Jersey Harbor Navigation Study. Mitigation vol. 2. USACE New York District.

USACE. 2011. Assuring Quality of Planning Models. EC-1105-2-412. Washington, DC.

U. S. Fish and Wildlife Service (USFWS). 1997. Significant Habitats and Habitat Complexes of the New York Bight Watershed. Charlestown, Rhode Island: Southern New England - New York Bight Coastal Ecosystems Program. https://nctc.fws.gov/pubs5/web_link/text/toc.htm.

Van den Belt, M. 2004. Mediated Modeling: A System Dynamics Approach to Environmental Consensus Building. Washington, D.C: Island.

Voinov A., and Bousquet F. 2010. Modelling with Stakeholders. Environmental Modelling & Software 25 (11): 1268–81. https://doi.org/10.1016/j.envsoft.2010.03.007.