Application of SLAMM to Coastal Connecticut

Final Report

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NOTICE

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Acronyms and Abbreviations List

CT	Connecticut
DEM	Digital Elevation Map
FEMA	US Federal Emergency Management Agency
GCM	General Climate Model
GIS	Geographic Information Systems
GT	Great Diurnal Tide Range
HTU	Half-Tide Units (highest tide each day minus the mean tide level)
IFM	Irregularly-Flooded Marsh
LiDAR	Light Detection and Ranging– method to produce elevation data
LRR	Linear Regression Rate
m	Meters
MEM	Marsh Equilibrium Model
MHHW	Mean Higher High Water (average highest tide each day)
MLLW	Mean Lower Low Water (average lowest tide each day)
MTL	Mean Tide Level
NAVD88	North American Vertical Datum of 1988
NED	USGS National Elevation Dataset
NLD	National Levee Database from the U.S. Army Corps of Engineers
NEIWPCC	New England Interstate Water Pollution Control Commission
NOAA	United States National Oceanic and Atmospheric Administration
NWI	National Wetlands Inventory
NYSERDA	New York State Energy Research and Development Authority
RFM	Regularly-Flooded Marsh
RIM	Rapid Ice Melt
RMSE	Root Mean Standard Error
SD	Standard Deviation
SLAMM	Sea-level Affecting Marshes Model
SLR	Sea-Level Rise
STORET	EPA Data Warehouse
TSS	Total Suspended Solids
UConn	University of Connecticut
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
UTM	Universal Transverse Mercator (UTM) conformal projection
VDATUM	NOAA Product for converting vertical datums
WBE	Wetland Boundary Elevation (coastal-wetland to dry land boundary)
WPC	Warren Pinnacle Consulting, Inc.

1 Background

In 2013 and 2014, the New England Interstate Water Pollution Control Commission (NEIWPCC) and the state of Connecticut funded a marsh-habitat migration study for the entirety of coastal Connecticut. The goal of the project is to identify potential responses of Connecticut's coastal marshes and adjacent upland areas to anticipated increases in mean-tide water level elevations in Long Island Sound (LIS) and Connecticut's estuarine embayments. Results of the study will help to identify the most appropriate adaptation strategies for specific areas including land acquisition, marsh restoration, infrastructure development, and other land and facility management actions.

Tidal marshes are dynamic ecosystems that provide significant ecological and economic value. Given that tidal marshes are located at the interface between land and water, they can be among the most susceptible ecosystems to climate change, especially accelerated sea-level rise (SLR). Numerous factors can affect marsh fate including the elevation of marshes relative to the tides, marshes' frequency of inundation, the salinity of flooding waters, the biomass of marsh platforms, land subsidence, marsh substrate, and the settling of suspended sediment into the marshes. Because of these factors, a simple calculation of current marsh elevations as compared to future projections of sea level does not provide an adequate estimation of wetland vulnerability.

Changes in tidal marsh area and habitat type in response to sea-level rise were modeled using the Sea Level Affecting Marshes Model (SLAMM 6). SLAMM is widely recognized as an effective model to study and predict wetland response to long-term sea-level rise (Park et al. 1991) and has been applied in every coastal US state (Craft et al. 2009; Galbraith et al. 2002; Glick et al. 2007, 2011; National Wildlife Federation and Florida Wildlife Federation 2006; Park et al. 1993; Titus et al. 1991).

1.1 Model Summary

SLAMM predicts when marshes are likely to be vulnerable to SLR and locations where marshes may migrate upland in response to changes in water levels. The model attempts to simulate the dominant processes that affect shoreline modifications during long-term sea-level rise and uses a complex decision tree incorporating geometric and qualitative relationships to predict changes in coastal land cover classes. SLAMM is not a hydrodynamic model. Rather, SLAMM predicts long term shoreline and habitat class changes based upon a succession of equilibrium states with sea level. Model outputs include mapped distributions of wetlands at different time steps in response to sea level rise changes as well as tabular and graphical data. The model's relative simplicity and modest data requirements allow its application at a reasonable cost.

Mcleod and coworkers wrote in their review of sea-level rise impact models that "... the SLAMM model provides useful, high-resolution, insights regarding how sea-level rise may impact coastal habitats" (Mcleod et al. 2010).

SLAMM assumes that wetlands inhabit a range of vertical elevations that is a function of the tide range. The model computes relative sea level rise for each cell at each time step. It is calculated by the sum of the historic SLR eustatic trend, the site specific or cell specific rate of change of elevation due to subsidence and isostatic adjustment, and the accelerated sea level rise depending on the scenario considered. Sea level rise is offset by marsh accretion and other factors affecting marsh surface elevation.

When the model is applied, each study site is divided into cells of equal area (5x5 m^2 for these simulations) that are treated individually. The conversion from one land cover class to another is computed by considering the new cell elevation at a given time step with respect to the class in that cell and its inundation frequency. Assumed wetland elevation ranges may be estimated as a function of tidal ranges or may be entered by the user if site-specific data are available. The connectivity module determines salt water paths under normal tidal conditions. In general, when a cell's elevation falls below the minimum elevation of the current land cover class and is connected to open water, then the land cover is converted to a new class according to a decision tree.

In addition to the effects of inundation represented by the simple geometric model described above, the model can account for second order effects that may occur due to changes in the spatial relationships among the coastal elements. In particular, SLAMM can account for exposure to wave action and its *erosion* effects, *overwash* of barrier islands where beach migration and transport of sediments are estimated, *saturation* allowing coastal swamps and fresh marshes to migrate onto adjacent uplands as a response of the fresh water table to rising sea level close to the coast, and *marsh accretion*.

Marsh accretion is the process of wetland elevations changing due to the accumulation of organic and inorganic matter. Accretion is one of the most important processes affecting marsh capability to respond to SLR. The SLAMM model was one of the first landscape-scale models to incorporate the effects of vertical marsh accretion rates on predictions of marsh fates, including this process since the mid-1980s (Park et al. 1989). Since 2010, SLAMM has incorporated dynamic relationships between marsh types, marsh elevations, tide ranges, and predicted accretion rates. The SLAMM application presented here utilizes a mechanistic marsh accretion model to define relationships between tide ranges, water levels, and accretion rates (Morris 2013; Morris et al. 2002).

As with any numerical model, SLAMM has important limitations. As mentioned above, SLAMM is not a hydrodynamic model. Therefore, cell-by-cell water flows are not predicted as a function of topography, diffusion and advection. Furthermore, there are no feedback mechanisms between hydrodynamic and ecological systems. Solids in water are not accounted for via mass balance which may affect accretion (e.g. local bank sloughing does not affect nearby sedimentation rates). The erosion model is also very simple and does not capture more complicated processes such as "nick-point" channel development. SLAMM has the capability to apply a salt-wedge model in an estuary and an overwash model for barrier islands. However, each of these model processes is rather simple and has not been applied in these simulations.

To provide valuable information to decision makers, the confidence of model results should be evaluated and quantified. To address these issues, an uncertainty-analysis module has been included in more recent versions of SLAMM. Using Monte-Carlo simulations, the SLAMM model is run iteratively, with model inputs that are randomly drawn from distributions representing input uncertainty. Each model realization represents one possible "future" for the studied area. All model realizations are then assembled into probability distributions of wetland coverage reflecting the effect of input data/model uncertainties on prediction results. When uncertainty-analysis is incorporated, the relative simplicity of the SLAMM model becomes a useful compromise that allows for an efficient characterization of uncertainties without excessive computational time. In addition, all model uncertainties can be summarized in a single map such as the "percent likelihood of a coastal marsh" for each modeled cell at a given date. In this manner, the uncertainty analysis can actually simplify the presentation of model results.

A more detailed description of model processes, underlying assumptions, and equations can be found in the SLAMM 6.2 Technical Documentation (available at http://warrenpinnacle.com/prof/SLAMM).

2 Methods

2.1 Study Area

The project study area was divided into 3 individual SLAMM projects (Figure 1) that are loosely identified by county:

- Area 1: Fairfield County
- Area 2: New Haven and Middlesex counties
- Area 3: New London County

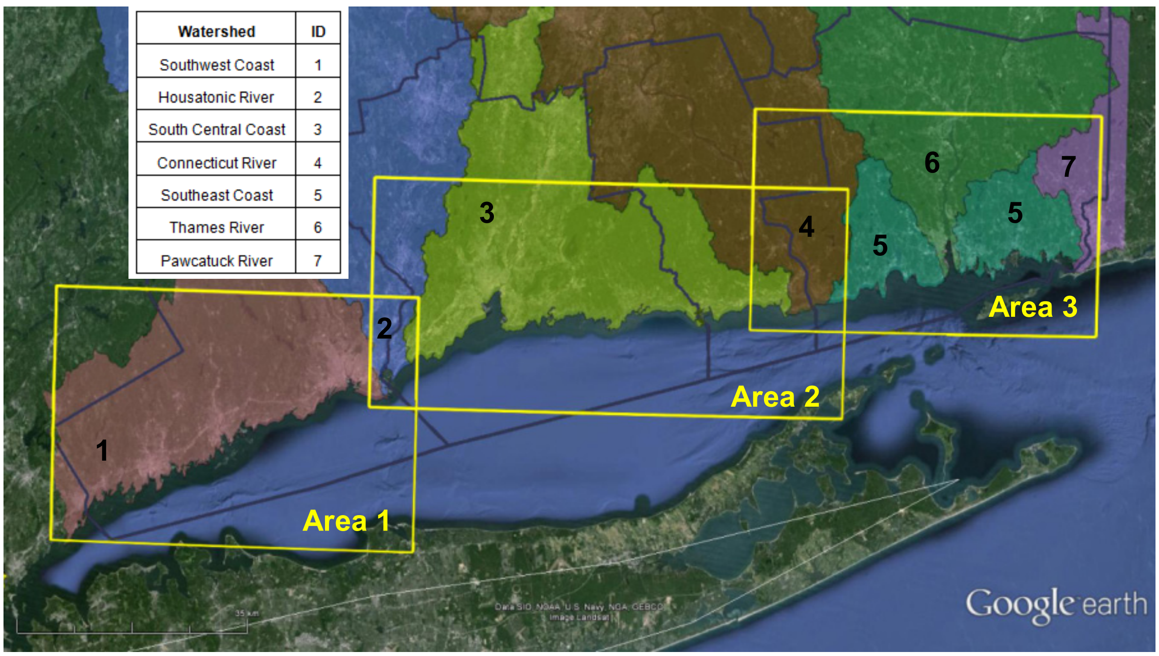

Figure 1. Project study area broken into the three individual SLAMM projects. Blue lines represent county boundaries. Colored areas are major watershed basins.

SLAMM projections results are summarized for the coastal areas subject to analysis according to the major watersheds in Connecticut shown in Figure 1. Appendix D also presents results summarized by county.

2.2 Input Raster Preparation

SLAMM is a raster-based model meaning that input cells are equally-sized squares arranged in a grid, like graph paper or a computer-based image. This section describes these critical data sources and the steps used to process the data for use in SLAMM. Data types reviewed here include elevation, wetland land cover, impervious land cover, dikes and impoundments.

2.2.1 Elevation Data

High vertical-resolution elevation data may be the most important SLAMM data requirement. Elevation data when combined with tidal data are used to determine the extent and frequency of saltwater inundation.

For the purposes of this project, the coastal study areas are limited to those regions along Connecticut's shoreline at elevations less than 5 m above mean tide level (MTL). This boundary elevation was selected in order to limit the study to SLR influenced areas[1].

In order to derive the elevation layers within the study areas, several LiDAR sources were combined as shown in Figure 2:

- 2004 FEMA Bare Earth Topographic LiDAR: Connecticut River;
- 2006 FEMA Topographic LiDAR: Connecticut Coastline Survey;
- 2011 USGS LiDAR for the Northeast;
- 10 m resolution National Elevation Data;
- 2012 Post Sandy LiDAR data; and,
- 2000 DEM (10 foot) from the University of Connecticut derived from Connecticut LiDAR 2000.

[1] In fact, maximum SLR modeled scenarios is 1.72 m SLR by 2100 (see Section 2.4), maximum Mean Higher High Water (MHHW) is 1.25 m (see Section 2.6). Therefore with an extra buffer elevation of approximately 2 m all the areas affected by SLR are included in this analysis under all SLR conditions.

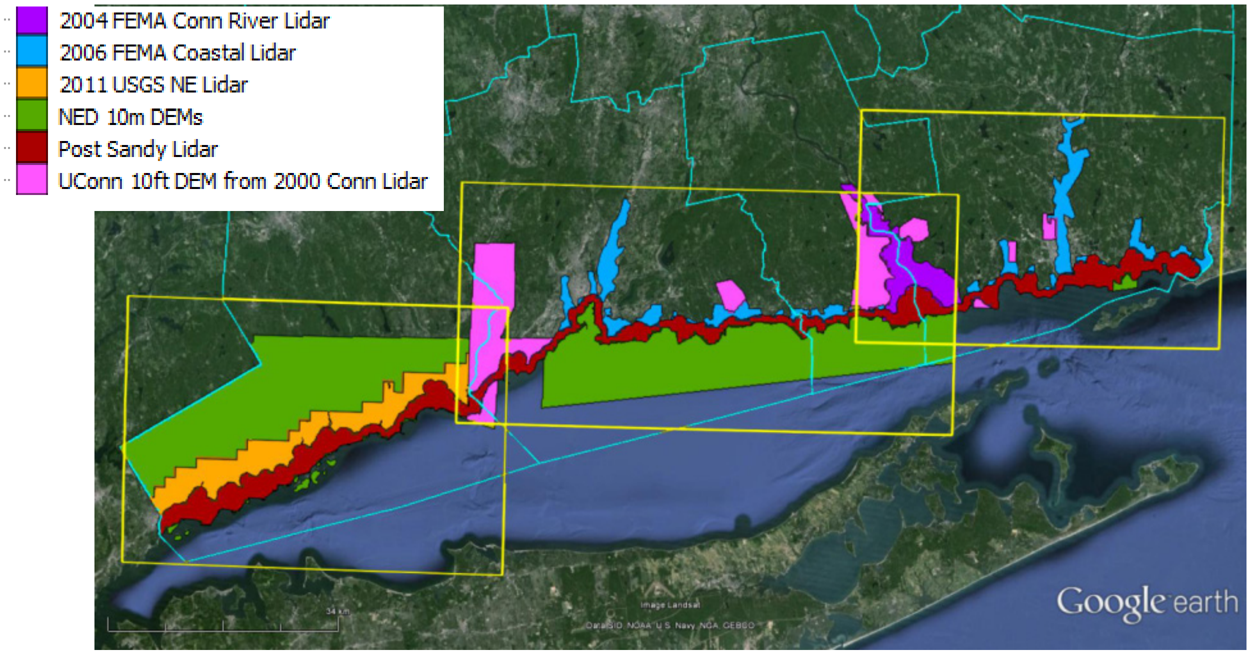

Figure 2. Elevation sources for Connecticut

Starting from these LiDAR data, hydro-enforced Digital Elevation Model (DEM) maps were created for each study area. Hydrologic enforcement refers to the process of correcting LiDAR-detected land surface elevations by modifying the elevations of artificial impediments, such as road fills or railroad grades, to simulate how man-made drainage structures, such as culverts or bridges, allow continuous downslope water flow. Without hydro-enforcement, downslope flow would be functionally dammed by the raised topography, creating false pooling on the upstream side (Poppenga et al. 2014).

Multiple steps were used to produce a hydro-enforced DEM for the Connecticut coastal project area[2].

- **Project Boundary Derivation**: LiDAR data were reprocessed for locations at or below 5 meters above NAVD88 (approximate mean-tide level) to limit the scope of data processed.
- **Data Preparation**: Data were re-projected to project specifications and re-sampled to the 5 meter cell size used in all model runs.
- **Creation of Breaklines for hydrologic enforcement:** Water-flow pathways were defined to determine where the DEM may detect artificial barriers to hydrologic flow, such as at bridges and culverts, Connecticut ortho-imagery was used to examine areas where road centerlines containing such barriers intesect with water flow lines to determine possible locations for DEM hydro-enforcent or 'hydro-modification.'..

[2] More technical details regarding GIS processing can be found in Appendix A.

- **DEM hydrologic enforcement**: Water-flow pathways identified in the steps described above and by examining SLAMM initial inundation conditions were 'enforced' or corrected to allow water flow in the DEM where such artificial barriers were detected..

Further DEM hydrologic enforcement from initial SLAMM simulations. As discussed in more detail in Section 2.10, once initial model set up was completed with all layers and input parameters, the model was calibrated by comparing the consistency of model initial conditions with the input data. Some examples of inconsistencies would be if an area classified as a dry land in the wetland coverage maps is actually not inundated in the model, or if a low marsh classification does get inundated frequently enough. One primary line of investigation is SLAMM's capacity to accurately predict the current frequency of tidal inundation for coastal habitats. This analysis, along with correspondence with CTDEEP technical leads, allowed us to identify areas that were either inundated too frequently or not enough. If water flow pathways did not accurately replicate current hydraulic conditions on the ground, the combined DEMs were further edited by Warren Pinnacle Consulting. Additional water-flow pathways were manually added if water flows had been improperly impeded based on DEM elevations (e.g. adding missing culverts and/or removing bridges from the DEM) .

Slope Layer. Slope rasters were derived from the hydro-enforced DEMs described above using ESRI's spatial analyst tool. The "slope tool" was used to create slope with output values in degrees. Accurate slopes of the marsh surface are an important SLAMM consideration as they are used in the calculation of the fraction of a wetland that is lost (transferred to the next class).

2.2.2 Elevation transformation

VDATUM version 3.2 (NOS 2013) was utilized to convert elevation data from the NAVD88 vertical datum to Mean Tide Level (MTL), which is the vertical datum used in SLAMM. This is required as coastal wetlands inhabit elevation ranges in terms of tide ranges as opposed to geodetic datums (McKee and Patrick 1988). VDATUM does not provide vertical corrections over dry land; dry-land elevations were corrected using the VDATUM correction from the nearest open water. Corrections in the study areas do not vary significantly, ranging from approximately -0.12 m to 0.05 m. A spatial map of corrections is shown in Figure 3.

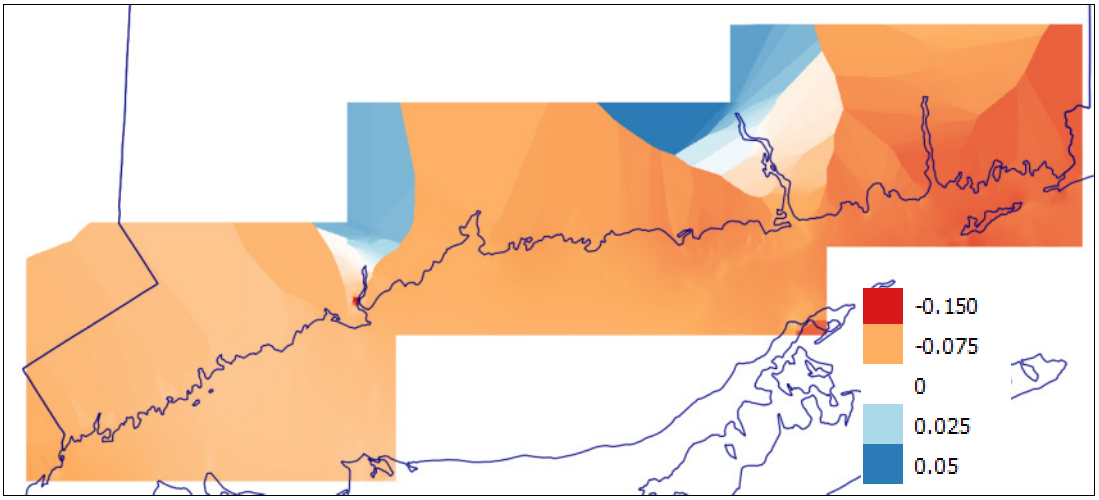

Figure 3. VDATUM-derived correction values (meters)

2.2.3 Wetland Layers and translation to SLAMM

Wetland rasters were created from a National Wetlands Inventory (NWI) survey dated 2010 for the entire study area. NWI land coverage codes were translated to SLAMM codes using Table 4 of the SLAMM Technical Documentation as produced with assistance from Bill Wilen of the National Wetlands Inventory (Clough et al. 2012) and included in Appendix E.

Since dry land (developed or undeveloped) is not classified by NWI, SLAMM classified cells as dry land if they were initially blank but had an elevation assigned. The resulting raster was checked visually to make sure the projection information is correct, has a consistent number of rows and columns as the other rasters in the project area, and to ensure that the data looked complete based on the source data.

Table 1 shows the current land coverage for the entire study area. Of the nearly 436,000 acres that represent the study area, more than 65% is occupied by dry land (developed and undeveloped), and 27.5% by estuarine open water. The remaining 12.5% includes over 23,000 acres of wetland, over 2,500 acres of beaches and tidal flats, and approximately 4,500 acres of inland-fresh open water.

Table 1. Land cover categories for entire Connecticut study area

Land cover type*		Area (acres)	%
	Undeveloped Dry Land	196,599	45.1
	Estuarine Open Water	119,683	27.5
	Developed Dry Land	88,504	20.3
	Irreg.-Flooded Marsh	11,211	2.6
	Swamp	8,591	2.0
	Inland Open Water	4,561	1.0
	Estuarine Beach	2,457	0.6
	Regularly-Flooded Marsh	1,182	0.3
	Inland-Fresh Marsh	850	0.2
	Tidal-Fresh Marsh	743	0.2
	Tidal Swamp	667	0.2
	Riverine Tidal	452	0.1
	Transitional Salt Marsh	158	<0.1
	Inland Shore	120	<0.1
	Tidal Flat	98	<0.1
	Rocky Intertidal	62	<0.1
	Total (incl. water)	**435,938**	**100**

*A table to identify SLAMM categories from the raster map codes is provided in Appendix F

2.2.4 Dikes and Impoundments

Dike rasters were created using different data sources:

- NWI data. All NWI wetland polygons with the "diked or impounded" attribute "h" were selected from the original NWI data layer and these lands were assumed to be permanently protected from flooding. This procedure has the potential to miss dry lands that are protected by dikes and seawalls as contemporary NWI data contains wetlands data only.
- 2013 FEMA Flood Hazard Layers using the attribute of dams. These data were inspected to make sure each feature consisted of a single line drawn on top of the dam structure.
- Connecticut Dams database which consists of point data representing the general location of a dam. A new line feature class was created for each dam feature that could be found within a 500' area surrounding each point.
- National Levee Database (NLD). The U.S. Army Corps of Engineers National Levee Database (2014) (http://nld.usace.army.mil/) was accessed and any additional levees in the study area not included in the NWI, FEMA, and Connecticut Dams database but represented in the NLD were

added manually, based on dimensions shown in the on-line mapping interface. Dikes in locations above five meters in elevation were not digitized.

Line and polygon data from the first three datasets listed above were mosaicked together into a final dikes and dams raster with a 5 meter cell size. Raster data were checked visually to make sure the projection information was correct, layers had a consistent number of rows and columns, and that the data captured all features within the source data. NLD data were then manually added through the SLAMM interface using SLAMM wetland layers laid over satellite imagery to ensure locations were digitized as precisely as possible[3].

In Stamford CT, the dike system has a flood gate that may be closed when necessary. Therefore the open water behind this gate was classified as diked. Because of this, SLAMM projections assume that SLR will not occur behind this gate (the gate will be maintained and improved in the event of SLR).

A significant amount of the Connecticut coastline is protected by seawalls. However, if these structures were uniformly designated as "diked" by SLAMM it would be equivalent to having them continually armored against sea-level rise. There will likely be some changes to the structures over time, but there is no reliable way to assess which structures may be altered. In these simulations, current seawalls were generally accounted for only by their current elevation (provided by the LiDAR data) and were allowed to be overtopped when sea levels become high enough. In a few cases where seawalls were visible on satellite imagery and time-zero flooding was predicted, a few cells were designated as "diked" to protect against immediate flooding[4].

2.2.5 Percent Impervious

Percent Impervious rasters were extracted from the 2006 National Land Cover Dataset (Fry et al. 2011). The cell size was resampled from the original 30 m resolution to 5 m resolution in order to match the cell resolution of the other rasters in the project.

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[3] Dikes were manually added in the following locations: Stonington CT, 41.371465°, -71.833078°; New London CT, 41.349526° -72.101089°;

[4] Some seawalls cells were manually set to "diked" in the following locations: Spruce Swamp Pond 41.087893° -73.394471° ; Rocky Point Club 41.016840° -73.558618°; In front of a pond shown as "impounded" in the NWI Layer 41.021223° -73.577665° .

2.3 Model Timesteps

SLAMM simulations were run from the date of the initial wetland cover layer to 2100 with model-solution time steps of 2025, 2040, 2055, 2070, 2085 and 2100. Maps and numerical data were output for the years 2025, 2055, 2085, and 2100.

2.4 Sea Level Rise Scenarios

The accelerated sea-level rise (SLR) scenarios used in this analysis were developed for a similar project undertaken in New York by the New York State Energy Research and Development Authority (NYSERDA) in conjunction with the project's advisory committee. These SLR scenarios span the range that is currently expected in the region in the coming century (for further discussion, see section 2.12.1 on page 46). Scenarios correspond to the maximum of the General Climate Model (GCM) and the minimum and maximum of the and Rapid Ice Melt (RIM) estimates as described in the New York State ClimAID report (Rozenzweig et al. 2011) as well as the intermediate scenario of 1 meter of SLR by 2100 (39.4 inches). The base year for these scenarios is 2002. The "rapid ice-melt scenarios" are based on the potential acceleration of ice-melt rates in the Greenland and West Antarctic ice sheets as well as paleoclimatological studies. Table 2 and Figure 4 show details of SLR relative to the base year of 2002 used in the four scenarios applied to the Connecticut SLAMM projections.

Table 2. SLR under each scenario for each timestep (mm) relative to the base year of 2002

Scenario	2025	2055	2085	2100
General Climate Model Maximum	127	305	584	718
1 m by 2100	129	431	807	1000
Rapid Ice Melt Minimum	127	483	1041	1327
Rapid Ice Melt Maximum	254	737	1397	1721

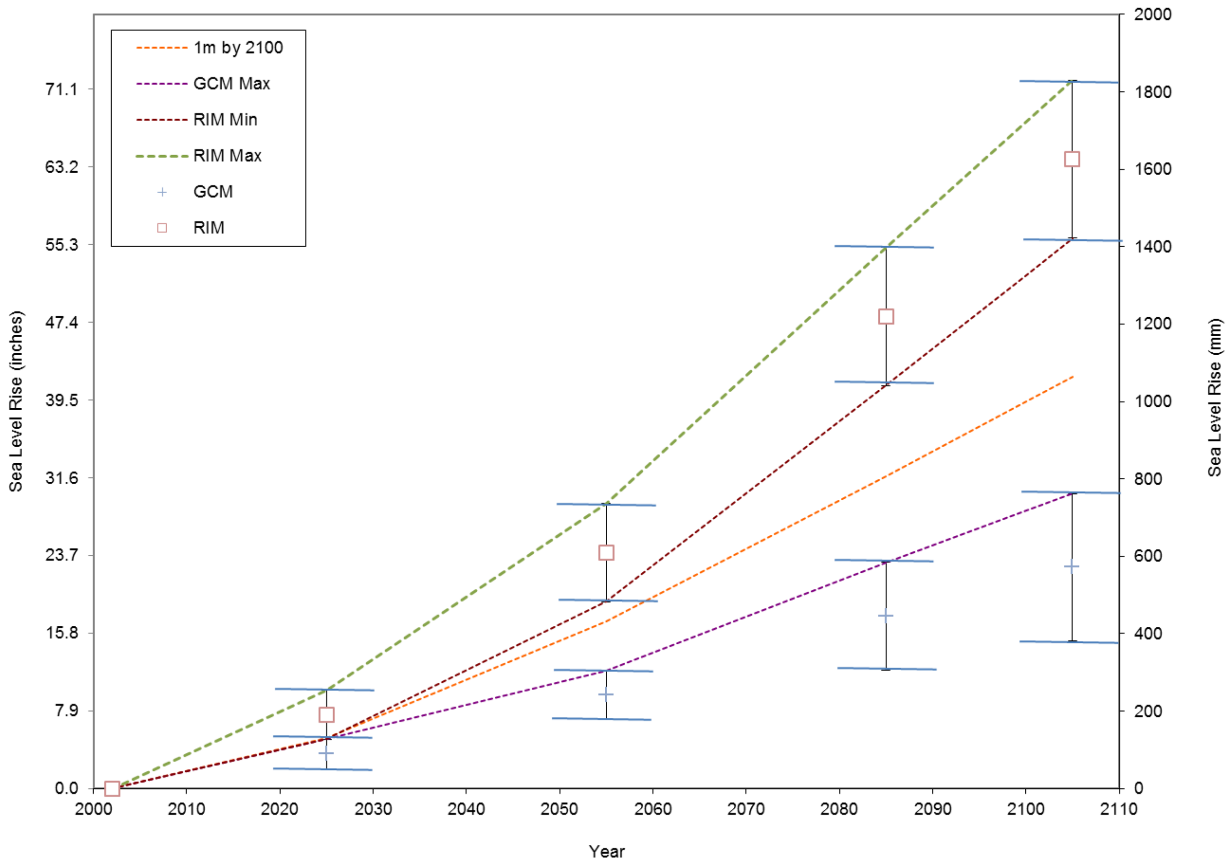

Figure 4. Sea level rise scenarios simulated using SLAMM compared to the General Climate Model and Rapid Ice Melt model predictions.
(Horizontal lines on error bars represent the decadal timescale over which predicted SLR may occur.)

2.5 Historic sea level rise rates

The SLR scenarios shown in the table and figure above are "relative" sea-level rise estimates. Therefore, SLAMM scenarios do not need to be corrected for differentials between local (or relative) SLR and global (or eustatic) SLR trends. For this reason, within the model, the historic SLR was set to zero (to model relative sea level rise rather than eustatic SLR).

According to NOAA, historic sea level rise trends along the Connecticut coast range from 2.25 mm/yr at New London to 2.56 mm/yr in Bridgeport. Each of the four scenarios simulated represents a significant acceleration of SLR from the local historical trend observed.

2.6 Tide Ranges

Tide range data were collected from NOAA tidal data and tide prediction tables for 2011. SLAMM requires the great diurnal tide range (GT)[5] as an input. The GT, along with several other tidal data, are provided directly by the NOAA Tides & Currents website (www.tidesandcurrents.noaa.gov). However, these data provide the mean tide range (MN)[6] of the area in question. Therefore, GT was extrapolated from MN by considering the average ratio between GT/MN measured at the NOAA tidal datum stations.

Overall, GT values in the project area varied from a maximum of 2.5 m at Cos Cobb Harbor to 0.88 m in New London. As discussed in the results section below, a smaller GT tends to make marshes more vulnerable to SLR in the eastern portion of the study area. A map of GT data throughout the study area is provided in Appendix B.

2.6.1 Elevations expressed in half tide units (HTU)

In general, wetlands inhabit a range of vertical elevations that is a function of the tide range (Titus and Wang 2008) - one conceptual example of this is shown in Figure 5. Because of this, rather than expressing marsh elevation in absolute values (e.g. meters, feet, cm, etc.), SLAMM uses units relative to the local tide range or "half-tide units." A "half-tide unit" is defined as half of the great diurnal tide range (GT/2). A numerical example follows:

- If a marsh elevation is "X" meters above MTL, its elevation in half tide units (HTU) is given by X/(GT/2).
- For example, consider a marsh with an elevation 1 m above MTL, with a tide range (GT) of 1.5 m. The height of the marsh in HTU is equal to 1/(1.5/2)=1.33 HTU.
- This set of units is straightforward to understand if you consider that, mean tide level is defined as 0.0 HTU, high tide (MHHW) is defined as 1.0 HTU, and low tide (MLLW) is defined as -1.0 HTU. A marsh with an elevation above 1.0 HTU falls above the high tide line regardless the absolute value of the tide.

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[5] GT - Difference between the mean higher high (MHHW) and mean lower low water (MLLW) levels.
[6] MN - Difference in height between mean high (MHW) and mean low water (MLW) levels.

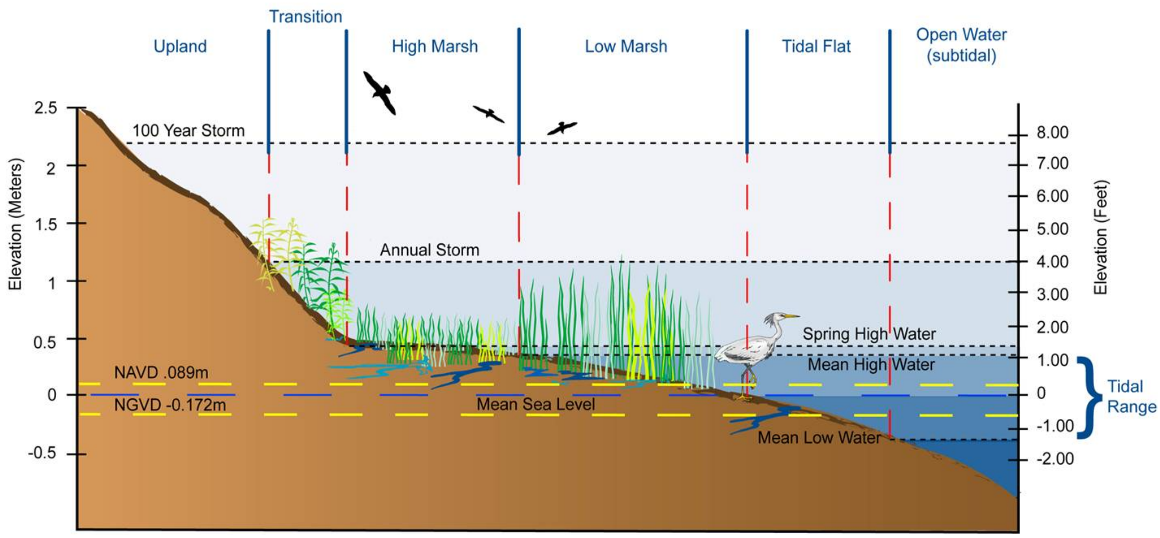

Figure 5. Relationship between tides, wetlands, and reference elevations for an example estuarine shore profile. Source (Titus and Wang 2008)

2.7 Wetland Boundary Elevation

The wetland boundary elevation (WBE) parameter in SLAMM defines the boundary between coastal wetlands and dry lands (including non-tidal wetlands). This elevation, relative to mean-tide level, is determined through analysis of "higher high" water levels in NOAA tide records. In practice, we have found that the elevation that differentiates coastal wetlands and dry lands is approximately the height inundated once every 30 days.

Therefore, the 30-day inundation level was determined for the three locations in Connecticut with NOAA verified water-level data available: Bridgeport, New Haven and New London. Five years of data were analyzed in order to characterize this relationship in each location. Although relatively few data points were available spatially, a linear relationship was determined between the calculated WBEs versus the great diurnal tide ranges for the entire study area ($WBE = 0.6015 \cdot GT + 0.3205$; see Figure 6). This relationship was used to derive site-specific WBEs based on the available local measured GT applied.

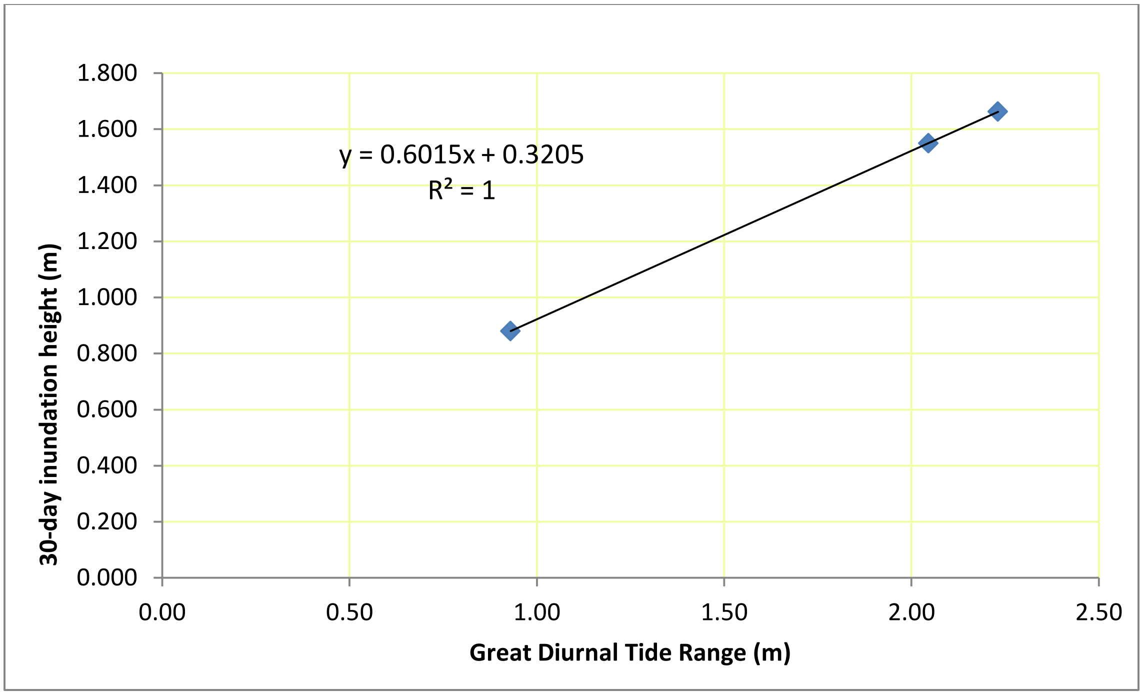

Figure 6. Great Diurnal Tide Range to 30-Day Inundation Height/Wetland Boundary Elevation relationship derived from NOAA

2.8 Accretion Rates

A full literature search was conducted to collect relevant accretion rates. In addition, unpublished data from members of the project advisory committee were used to determine the accretion rates for the study area.

2.8.1 Tidal Salt Marsh

The current SLAMM application attempts to account for what are potentially critical feedbacks between tidal-marsh accretion rates and SLR (Kirwan et al. 2010). In tidal marshes, increasing inundation can lead to additional deposition of inorganic sediment that can help tidal wetlands keep pace with rising sea levels (Reed 1995) . In addition, salt marshes will often grow more rapidly at lower elevations allowing for further inorganic sediment trapping (Morris et al. 2002).

In this project, such feedback relationships were investigated using observed accretion rates as compared to DEM-derived marsh platform elevations. Elevations relative to accretion rates were derived by comparing the location provided in the citations to the corresponding project area DEM. There is significant uncertainty in terms of assigning elevations to these marsh platforms, especially when data from wetland cores were used to derive accretion rates[7].

When sources did not define the type of marsh being studied, data for regularly-flooded marsh (RFM) vs. irregularly-flooded marsh (IFM) were discerned using the NWI wetland layer. Qualitatively, RFM includes low to mid marshes, while IFM includes high marshes. The persistence of these marshes and the decision tree that SLAMM uses when converting them to another land-cover class in the event of inundation are as follows:

- RFM may occupy a region if its platform is between [-0.4, 1.2] HTU (McKee and Patrick 1988). This interval of existence can be adjusted to address local observations. When the marsh platform falls below the minimum elevation, then the land cover is assumed converted to tidal flat.
- IFM may occupy areas that are higher, typically between 0.5 HTU and the wetland boundary elevation. As above, this interval can be adjusted to address local observations. When the marsh platform falls below the minimum elevation, then the land cover is converted to RFM.

All available accretion data are summarized in Table 3. Data with known sampling locations are shown with colored backgrounds in Table 3, and these locations are illustrated in Figure 7.

Figure 7. Locations of Available Accretion Data in Coastal CT. (yellow dots)

[7] With core data, assuming that the marsh has maintained a constant equilibrium elevation relative to sea levels, accretion rate best estimate is the average value over the historical period of the core (in the order of hundred years) while the marsh platform elevation (relative to sea level) best estimate is the current elevation. These accretion rate and marsh platform elevation uncertainties should be accounted for in an accretion rate uncertainty analysis.

Table 3. Accretion database for Connecticut. Shading indicates regions – Red = Fairfield, Green = New Haven, Orange = Barn Island, White = precise locations unknown.

Location	Marsh Type	Accretion (red) or Elevation change (mm/yr)	Accretion (red) or Elevation change Std. Dev. (mm/yr)	elev (m, from LiDAR) NAVD88	GT (m)	Source
Sherwood	RFM	*3.5*		1.55	2.3	Anisfeld 2014
Hoadley	RFM	*3.9*		0.8065	1.9	Anisfeld 2014
Jarvis	RFM	*10.3*		0.337	1.9	Anisfeld 2014
Guilford CT	IFM	*2.5*	*1.4*	1.3692	1.9	Anisfeld et al. (1999)
BP1	IFM	3.2	0.1	0.505	0.85	Barrett and Warren (2014)
BP2	IFM	2.7	0.1	0.4189	0.85	Barrett and Warren (2014)
WC1	IFM	2.3	0.2	0.5	0.85	Barrett and Warren (2014)
HQ1	IFM	1.62	0.07	0.36	0.85	Barrett and Warren (2014)
HQ3	IFM	3.07	0.09	0.68	0.85	Barrett and Warren (2014)
HQ2	IFM	2.4	0.1	0.36	0.85	Barrett and Warren (2014)
IP1	IFM	1.4	0.2	0.4	0.85	Barrett and Warren (2014)
IP2	IFM	1.3	0.4	0.4	0.85	Barrett and Warren (2014)
IP3	IFM	2.8	0.3	0.4	0.85	Barrett and Warren (2014)
CT	IFM	*3.3*		0.39	0.85	Orson, Warren and Niering (1998)
CT	IFM	*2*		0.5	0.85	Orson, Warren and Niering (1998)
CT	IFM	*1.8*		0.455	0.85	Orson, Warren and Niering (1998)
Barn Island		2				Harrison and Bloom, 1977
Great Island		3.8				Harrison and Bloom, 1977
Hammock River marsh, CT		3.6				Harrison and Bloom, 1977
Stony Creek marsh, CT		6.6				Harrison and Bloom, 1977
Nells Island, CT		6				Harrison and Bloom, 1977
Pataguanset		1.1				Orson et al., 1987
Headquarter, CT		1.125				Warren et al., 1993
Wequetequock Cove, CT		2.25				Warren et al., 1993

2.8.1.1 Irregularly-flooded marsh

The accretion data sampled from locations identified as irregularly-flooded marsh were analyzed to determine if they exhibit spatial trends or underlying feedback relationships with elevations. However, the distribution of the available accretion data as a function of the elevation suggests that there is not a strong relationship between elevation and accretion for this type of marsh, as shown in Figure 8. This may be expected since irregularly-flooded marshes are subject to less frequent flooding and therefore less sedimentation. These high marshes can therefore be assumed to be less sensitive to their vertical elevations. The average of the available measured accretion data is 2.42 mm/year. Because observed irregularly-flooded marsh accretion data suggest no strong relationship between marsh surface elevation and accretion rates, the average accretion rate was uniformly applied for all irregularly-flooded marshes across the entire study area. However, the forthcoming uncertainty analysis will explore the effects of other possible accretion-rate relationships by varying maximum and minimum accretion rates based on regional minimum and maximum observed data.

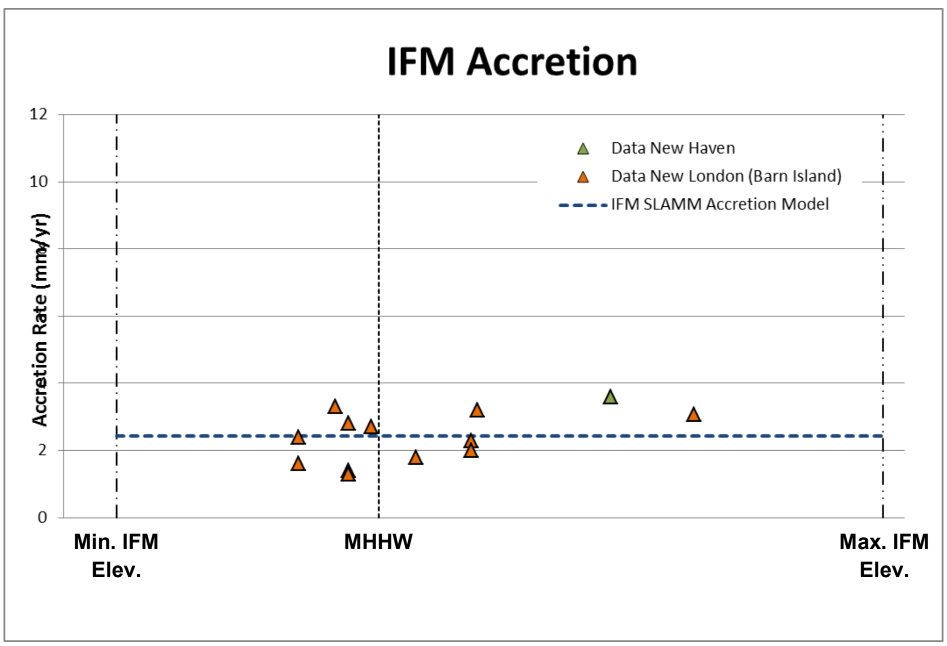

Figure 8. Irregularly-flooded marsh data and models for CT

2.8.1.2 Regularly-flooded Marsh

For Connecticut low marshes, accretion rates and their relationship with elevation were derived by calibrating the Marsh Equilibrium Model (MEM) (Morris 2013; Morris et al. 2002, 2012) to site-specific data. The MEM model was chosen for several reasons. MEM describes feedbacks in marsh accretion rates, it is backed up by existing data, and it accounts for physical and biological processes that cause these feedbacks. An alternative approach could be to fit available accretion data with a simple mathematical function. However, as described below, available accretion data often do not span a wide enough set of elevations to be able to derive the required curve. Furthermore, using a mechanistic model such as MEM helps explain the causes for feedbacks between accretion rates and elevation and therefore can tell a more compelling story. Another important reason to use MEM is that results from this model can be extrapolated to other geographic areas where there are no accretion data available, but when other physical/biological parameters *are* available (e.g. suspended sediment concentrations or tidal regimes). The model can also be extrapolated to vertical positions in the tidal frame where data do not exist. This is often required in areas where there is little marsh low in the tidal frame due to historically low rates of SLR.

The key physical input parameters of the MEM model are tide ranges, suspended sediment concentrations, initial sea-level and marsh platform elevations, and the elevation defining the domain of marsh existence within the tidal frame. Biological input parameters are the peak concentration density of standing biomass at the optimum elevation, organic matter decay rates, and parameters determining the contribution to accretion from belowground biomass. However, several input parameters are not always known (e.g. partition between organic and inorganic components to accretion, peak biomass, settling velocities, trapping coefficients, organic matter decay rate, below ground turnover rate and others). The approach taken was to estimate MEM input parameters based on observations when available and fit the unknown model parameters using observed accretion rates measured in Connecticut (listed in the first four rows of Table 3).

The sections below discuss the regional physical and biological input parameters for developing MEM within Connecticut.

Suspended Sediment. Suspended sediment data (in the form of total suspended solids or TSS) were collected from the US EPA STORET Data Warehouse (U.S. Environmental Protection Agency 2013). Table 4 presents the averages obtained when the TSS data were analyzed by region.

Table 4. Average TSS by Study area

	Fairfield	**New Haven and Middlesex**	**New London**
Average (mg/L)	10	17	8
St.Dev. (mg/L)	13	17	7
N – Sample size	56	45	15

Statistical analyses of the TSS data (Kolmogorov Smirnoff tests) show that the New Haven/Middlesex data set is distinct from the other two data sets, but the Fairfield and New London data sets are not statistically different. Despite this, we have produced three different MEM curves applied to each study region since New London and Fairfield counties are not spatially adjacent and have different tidal range.

Marsh biomass. Relatively few studies on marsh biomass are available within the study area. Anisfeld and Hill (2012) measured a maximum "net aboveground primary production" in a *Spartina alterniflora* marsh in Guilford, CT (Area 2) of 250 g of Carbon/m^2/year. This can be converted into a biomass basis given that aboveground organic carbon content of *Spartina alterniflora* is generally between 39 to 44%. Assuming that this ratio is 39.2% (Middelburg et al. 1997), the peak biomass for the Guilford Marsh can be estimated to be around 625 g/m^2. Hartig et al. (2002) measured biomass of *Spartina alterniflora* ranging 700-1450 g/m^2 in Jamaica Bay.

More recently, values between 700-1000 g/m^2 have been measured at Hoadley and Jarvis marshes in New Haven County, CT (Area 2) and Sherwood marsh in Fairfield County, CT (Area 1) by Shimon Anisfeld (2014). These values, that are more recent and consistent with other regional observations, were used as input parameters for the MEM models developed for the different study areas (Table 5). A peak biomass of 700 g/m^2 was chosen across the study area except for in New Haven and Middlesex counties where available data suggested a higher value.

Table 5. Peak biomass applied to the MEM models in CT

	Fairfield (Area 1)	New Haven and Middlesex (Area 2)	New London (Area 3)
Peak biomass (g/m^2)	700	995	700

MEM Calibration Results. When building MEM for the study areas, model input parameters such as tide ranges, peak biomasses, and total suspended solids were set to the local specific values discussed above while input parameters determining the partition between inorganic and organic contribution to accretion were calibrated to fit the available Connecticut accretion data. The final set of RFM marsh accretion models plotted against data is shown in Figure 9.

Although MEM was used to generate accretion rates for regularly-flooded marshes, Figure 9 also reports irregularly-flooded marsh data (depicted as triangles). This was done because accretion rates for regularly-flooded marshes located high in the tidal frame (near MHHW), are believed to be similar to those for irregularly-flooded marshes. While there is some uncertainty in the National Wetland Inventory between the spatial domains of regularly and irregularly-flooded marshes, overall model uncertainty is reduced as both marshes have very similar accretion rates at their boundaries.

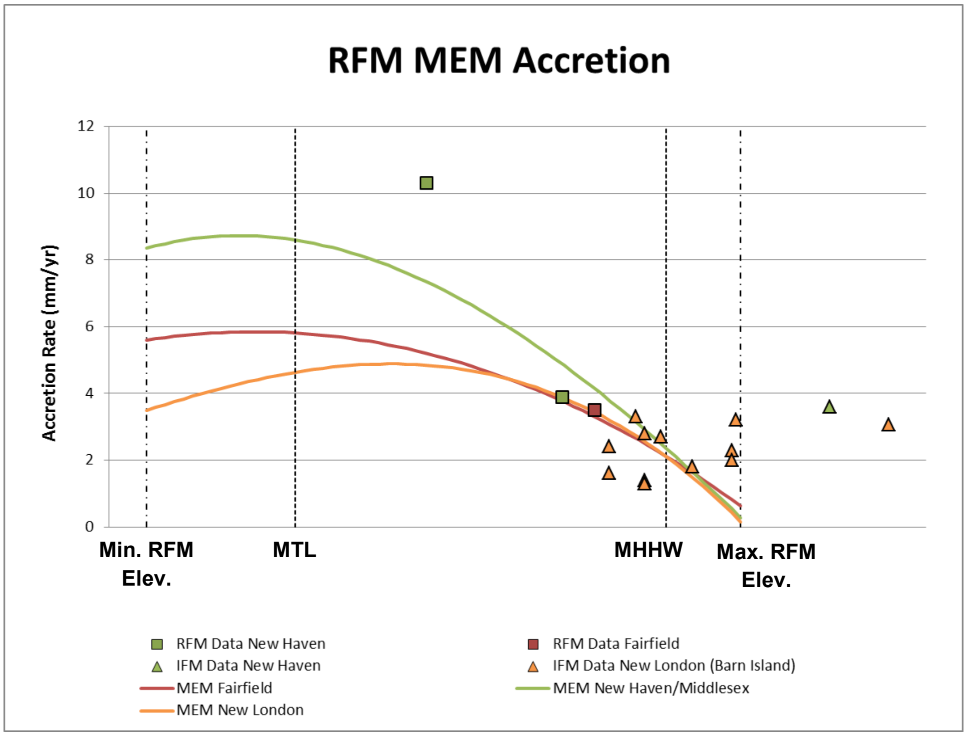

Figure 9. Regularly-flooded marsh accretion models plotted against available data

There is no doubt that the RFM accretion models shown above are somewhat conjectural as there are few site-specific RFM accretion data available to compare our model against, especially when estimating accretion response at low elevations. However, this is one of the main benefit of using MEM – to extrapolate models based on physical relationships into spatial regions (both moving horizontally or vertically) where data are limited or nonexistent.

Overall, at higher elevations, these RFM accretion curves not only reasonably fit the Anisfeld data (Table 3), but they also fit available Barn Island high-marsh data (IFM in Table 3) for marshes at the high-marsh/low marsh boundary. The general curve is also describing a feedback that increases with increasing inundation which is reasonable when considering the qualitative marsh response to sea level rise. As expected, the maximum accretion rate is predicted in New Haven/Middlesex counties due to the high TSS in the area. However, accretion rates predicted in Fairfield county are not too different because, although TSS are lower, the MEM model suggests that the increased average tidal range (GT=2.4 m vs. GT=1.7 m) results in a higher sedimentation rate. On the other hand, for New London, due to the low TSS (half of New Haven) and lower tide range the predicted accretion rate model does not exceed 4.9 mm/yr. However, maximum accretion rates in Fairfield and New London are not so different from measured accretion rates in the north shore of Long Island which make sense when considering the regional area.

2.8.2 Accretion Rates of Other Wetlands

The Inland-fresh Marsh accretion rate was set to 1 mm/yr. Studies of fens and freshwater marshes in Michigan and Georgia (Craft and Casey 2000; Graham et al. 2005) suggest this to be an appropriate value based on ^{210}Pb measurements. Tidal Fresh Marsh accretion was set to 5 mm/yr based on data presented by Neubauer (Neubauer 2008; Neubauer et al. 2002). Tidal-fresh marsh accounts for only one half of one percent of coastal wetlands in the study area. Accretion feedbacks were not used for tidal-fresh marshes due to a lack of site-specific data. Lacking site-specific data, values of 1.6 mm/yr and 1.1 mm/yr were assigned for swamp and tidal swamp accretion, respectively which were measured in Georgia by Dr. Christopher Craft (Craft 2008, 2012a).

Beach sedimentation was set to 0.5 mm/yr, a commonly used value in SLAMM applications. Average beach sedimentation rates are assumed to be lower than marsh-accretion rates due to the lack of vegetation to trap suspended sediment, though it is known to be highly spatially variable. In addition, it is worth noting that future beach nourishment, should it occur within the study area, is not accounted for in these SLAMM simulations.

2.9 Erosion Rates

In SLAMM average erosion rates are entered for marshes, swamps and beaches. SLAMM models erosion as additive to inundation and this is considered the effects of wave action. Horizontal erosion is only applied when the wetland type in question is exposed to open water and where a 9 km fetch[8] is possible. In general, SLAMM has been shown to be less sensitive to the marsh erosion parameters than accretion parameters (Chu-Agor et al. 2010).

In order to parameterize the erosion rates required by SLAMM, we relied on recent shoreline change statistics derived for the CT coast by Barrett and Coworkers (2014). This work characterized transects along the entire coast of CT to determine both long (1880 - 2006) and short-term (1983-2006) shoreline change rates. Long term rates were used to calculate the Linear Regression Rate (LRR) by fitting a least-squares regression line to all shoreline points for a particular transect (Barrett et al. 2014). In several cases the LRR showed positive shoreline movement, indicating aggradation. In these areas erosion rates were set to zero. In areas where shorelines had negative LRRs, the rate derived was applied equally to marsh,

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[8] "Fetch" is the distance traveled by waves over open water, calculated by the model based on current land-cover predictions.

swamp, and beach categories, though erosion only applies in open-water to wetland boundaries. Specific rates applied, ranging from 0.02 to 0.12 meters per year, are described in the individual model calibration sections below. These rates are lower than the 1 m/year observed by Fagherazzi (2013) and applied to the NYSERDA-funded SLAMM modeling of the entire Long Island and New York City coastlines.

2.10 Model Calibration

In order to test the consistency of key SLAMM modeling inputs, such as current land cover, elevations, modeled tidal ranges and hydraulic connectivity, SLAMM is run at “time zero” in which tides are applied to the study area but no sea-level rise, accretion or erosion are considered. Because of DEM and NWI uncertainty, local factors such as variability in the water table, and simplifications within the SLAMM conceptual model, some cells may initially be below their lowest allowable elevation land cover category and are immediately converted by the model to a different land cover category. For example, an area classified in the wetland layer as fresh-water swamp subject to regular saline tides, according to its elevation and tidal information, would be converted by SLAMM to a tidal swamp at time zero.

Where model calibration results in significant land-cover changes, additional investigation is required to confirm that the current land cover of a particular area is correctly represented by time-zero conversion results. If not, it may be necessary to better calibrate data layers and model inputs to the actual observed conditions. The general rule of thumb is that if 95% of a major land cover category (one covering ≥ 5% of the study area) is not converted at time zero, then the model set-up is considered acceptable. However, land coverage conversion maps at time zero are always reviewed to identify any initial problems, and to make necessary adjustments to correct them.

When considering the Connecticut study area in particular, time zero analysis indicated that initial model description of most areas was substantially correct, with a consistent picture between the current land coverage map and modeled inundation zones. However, few areas required adjustments. Below are some specific issues encountered and the steps taken to solve them are discussed.

In some cases the initial land cover re-categorization by SLAMM better describes the current coverage of a given area. In fact, the high horizontal resolution of the elevation data allows for a more refined wetland map than the original NWI-generated shapefiles used in this project. The standard mapping protocol for the NWI maps is to include wetlands with an area of 0.5 acres (2023 m^2). In addition, “long, narrow rectangles …, such as those following drainage-ways and stream corridors…may or may not be mapped, depending on project objectives” (Federal Geographic Data Committee, 2009). With a 5m cell-size, SLAMM is able to discern wetlands of 25 m^2. Therefore, time zero maps sometimes provide a refinement to the initial wetland layers, as shown in Figure 10 and these type of initial land cover conversion are then accepted without any further investigation.

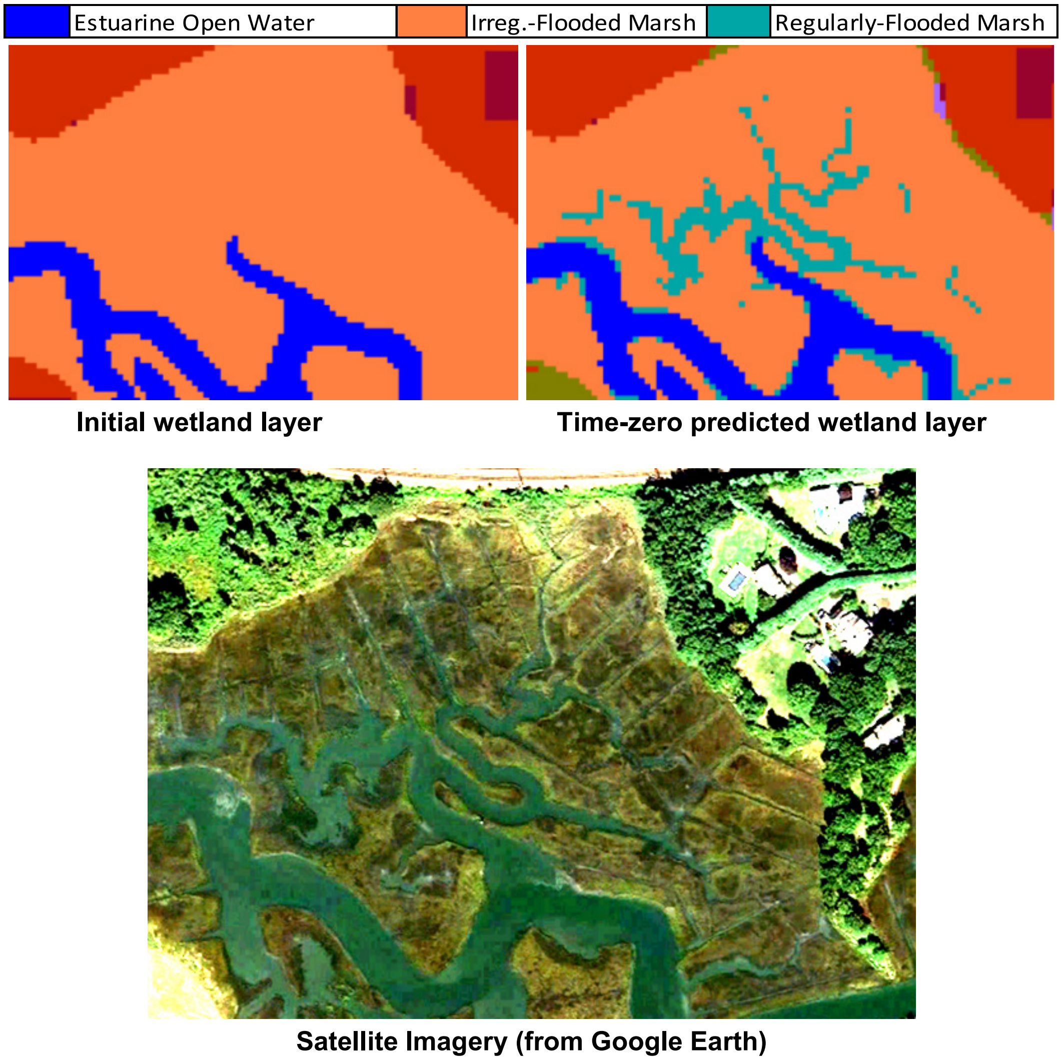

Figure 10. Marsh in Sherwood Island State Park

In addition, as discussed in section 2.2.1, time zero analysis was used to identify areas requiring further hydro-enforcement because initially they were not getting enough inundation although land cover survey classified them for example as tidal marsh areas. Once the problem was confirmed by satellite images that indeed there was a marsh getting flooded for example by water passing under a bridge or through a culvert, the DEM was modified, by removing the bridge or adding the culvert. In practice this was done by adding a line of low elevation cells that would cut the bridge or road initially impeding the water flow. This type of inundation analysis was also used to modify the wetland coverage layer where areas initially identified as covered by tidal water were clearly not tidal, e.g. inland open water bodies.

At the low elevations, another issue encountered during model calibration was the immediate flooding of some cell areas covered by developed land, also referred here as impervious cover. Most often these areas were bridges and piers – areas that are represented as development in the wetland layer but whose elevations are not included in the bare-earth elevation layer. Obviously, these land cover conversions were deemed acceptable. However, occasionally SLAMM predicts some low-lying residential areas to be flooded at least once every 30 days based on tide data. These occurrences were investigated on a case-by-case basis by examining satellite imagery from Google Earth and Bing Maps and performing web searches for any public records of flooding issues. However, in most cases the main reason for these initial land cover conversions is the native resolution of the impervious cover layer determining developed areas, which is 30x30 m^2, compared to the higher resolution of the elevation layer, resampled at 5x5 m^2 for this project. Normally this does not create any problem, but at the interface between dry and wet land 30x30 m^2 areas identified as dry land (36 cells of 5x5 m^2 areas in this project) in reality the land cover may be in part open water and land inundated by tides. Similar to calibration results shown in Figure 10, the higher resolution elevation data allow the model to better define this wet to dry land interface at time zero.

Initial inundation of dry land could not always be explained by the low resolution of the impervious layer. Sometimes, initial inundation of dry land was due to an assigned wetland-boundary elevation ("WBE" parameter) that was too high for the area in question. Because of the lack of fine-scale spatial data and the inherent uncertainty of the wetland-boundary elevation estimates, adjustments were sometimes required on a site by site basis to correct initial dry land conversion.

The occurrence of tidal-freshwater wetlands in riverine environments, such as tidal swamps and tidal-fresh marshes, is generally found to be more closely correlated with the salinity content in the water than the marsh platform elevation. However, the SLAMM salinity submodel was not used in these simulations because of the model's data requirements (often the required data, such as up-river bathymetry and salinity, were not available) and the significant time required for model calibration. The simplified model concept used here is that water salinity is correlated with marsh elevation on an estuary-specific basis. To implement this assumption, the minimum allowable elevations for these tidal-freshwater habitats were set to heights based on the measured marsh elevations using site-specific LiDAR data. These land-cover types are also relatively rare within the Connecticut study area.

The minimum elevation of regularly flooded marsh was set to -0.4 HTU based on observations for Long Island by McKee and Patrick (1988). Table 6 presents the minimum elevations applied for the study area.

Table 6. Default minimum wetland elevations in SLAMM conceptual model.

SLAMM Category	Min Elev.	Min Unit
Undeveloped Dry Land	1	WBE
Developed Dry Land	1	WBE
Swamp	1	WBE
Ocean Beach	-1	HTU
Inland-Fresh Marsh	1	WBE
Tidal Flat	-1	HTU
Regularly-Flooded Marsh	-0.4	HTU
Riverine Tidal	1	WBE
Irreg.-Flooded Marsh	0.5	HTU
Inland Open Water	1	WBE
Trans. Salt Marsh	1	HTU
Tidal Swamp*	N/A	
Tidal-Fresh Marsh*	N/A	
Estuarine Beach	-1	HTU
Rocky Intertidal	-1	HTU
Inland Shore	-1	HTU
Ocean Flat	-1	HTU

*For these marsh habitats lower-boundary elevations are assumed to be highly dependent on freshwater flow and therefore are generally set based on site-specific data (see text for more detailed discussion).

As inundated developed land is unlikely to immediately convert to a coastal wetland, a new landcover category was included in SLAMM: “Flooded Development.” This category occurs when developed dry land is inundated by salt water at least once every 30 days. Flooded developed land is not subject to additional land-cover conversions. There is some uncertainty as to whether a marsh could inhabit this land cover, so the model is likely somewhat conservative with respect to marsh transgression in these locations.

Several iterations of layer refinement were necessary in order to get an acceptable calibrated model to the initial conditions. After each step, time zero maps were compared to the initial condition maps using GIS software and annotating where large conversions of wetlands were observed. These issues were consequently explained or fixed by additional calibration or layer refinement. Any calibrations or “allowable” time zero changes were quality assured by an independent team member. Model projections are reported from time-zero forward so that the projected land cover changes are only due to SLR and not due to initial model calibration.

2.11 Model Setup

As noted above, the study area was divided into 3 individual SLAMM projects: Area 1: Fairfield County, Area 2: New Haven and Middlesex Counties, and Area 3: New London County. Within each of these areas the projects were subdivided into seven watersheds, as shown in Figure 11 and summarized in Table 7.

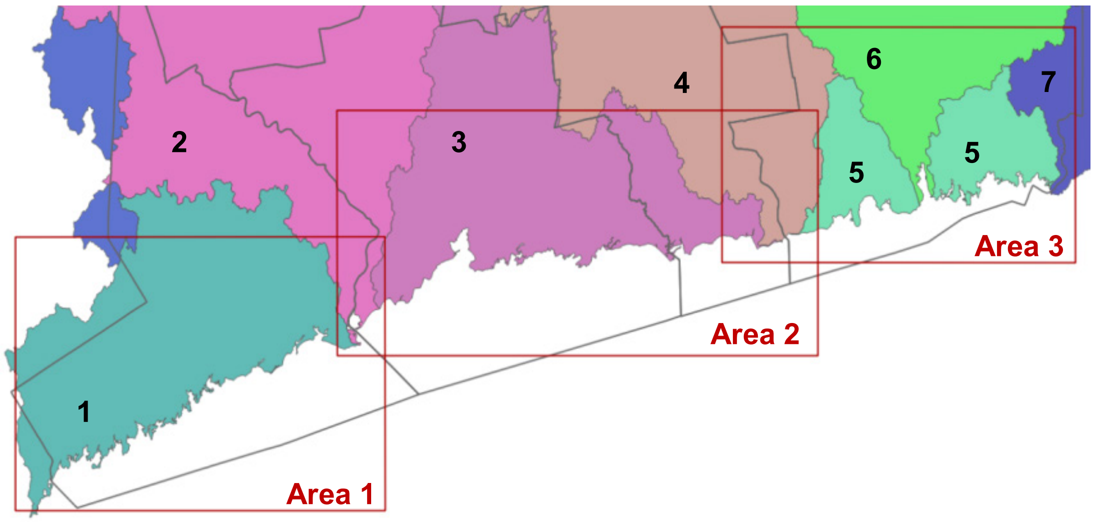

Figure 11. CT SLAMM project areas.

Table 7. Watersheds of coastal CT and the SLAMM project areas where represented

Watershed	Study Area
1 - Southwest Coast	1
2 – Housatonic River	1
3 - South Central Coast	2
4 - Connecticut River	3
5 - Southeast Coast	3
6 - Thames River	3
7 – Pawcatuck River	3

Project areas were also divided into subsites based on tide range and erosion parameters, as described in the following sections.

2.11.1 Area 1 - Fairfield County

Fairfield County Site Description

Study Area 1 was referred to as Fairfield County, although it contains areas beyond the county boundary in order to encompass the Southwestern and Housatonic River Watersheds. The coastal area of Southwest Coast watershed with elevations below 5 m above MTL is composed of 237,676 acres, of which 71% covered by dry land and 25% by estuarine open water. Swamp accounts for nearly 2% (4,423 acres) while the next most prevalent wetland category is irregularly-flooded marsh which makes up only 0.5 % of the study area (1,112 acres). In the Housatonic watershed irregularly-flooded marsh is the most prevalent wetland type, making up 3.5% (710 acres) of the study area (Table 8).

Table 8. Initial Wetland Coverage for the Southwest Coast and Housatonic River watersheds.

Land cover type		Southwest Coast		Housatonic River	
		Area (acres)	%	Area (acres)	%
	Undeveloped Dry Land	120,479	50.7	6,269	30.7
	Estuarine Open Water	58,761	24.7	5,765	28.2
	Developed Dry Land	47,707	20.1	6,584	32.2
	Swamp	4,423	1.9	315	1.5
	Inland Open Water	3,484	1.5	115	0.6
	Irreg.-Flooded Marsh	1,112	0.5	710	3.5
	Estuarine Beach	814	0.3	308	1.5
	Regularly-Flooded Marsh	302	0.1	248	1.2
	Inland-Fresh Marsh	342	0.1	38	0.2
	Inland Shore	119	0.1	-	-
	Trans. Salt Marsh	13	<0.1	44	0.2
	Tidal-Fresh Marsh	15	<0.1	31	0.2
	Tidal Flat	38	<0.1	-	-
	Riverine Tidal	27	<0.1	4	<0.1
	Rocky Intertidal	20	<0.1	-	-
	Tidal Swamp	18	<0.1	9	<0.1
	Total (incl. water)	**237,676**	**100**	**20,441**	**100**

Fairfield County Site Parameters

In order to account for spatially varying tide ranges and erosion rates, the Fairfield County project area was divided into four different input parametric subsites. Details for these study areas are shown in Table 9, while the boundaries of each subsite are shown in Figure 12. The tidal fresh marsh lower bound was set to 0.74 HTU and the Tidal Swamp boundary reduced to 0.77 HTU to reflect site-specific LiDAR data.

Table 9. Input subsites applied to Area 1

Subsite	Description	Great Diurnal Tide Range - GT (m)	WBE (m above MTL)	Horizontal Erosion Rate (m/yr)
General Area 1	Area 1 not included in the subsites below	2.3	1.66	0
1	Pine Creek	1.5	1.22	0
2	Sikorsky Airport	1.2	1.02	0
3	Stratford	2.3	1.66	0.06

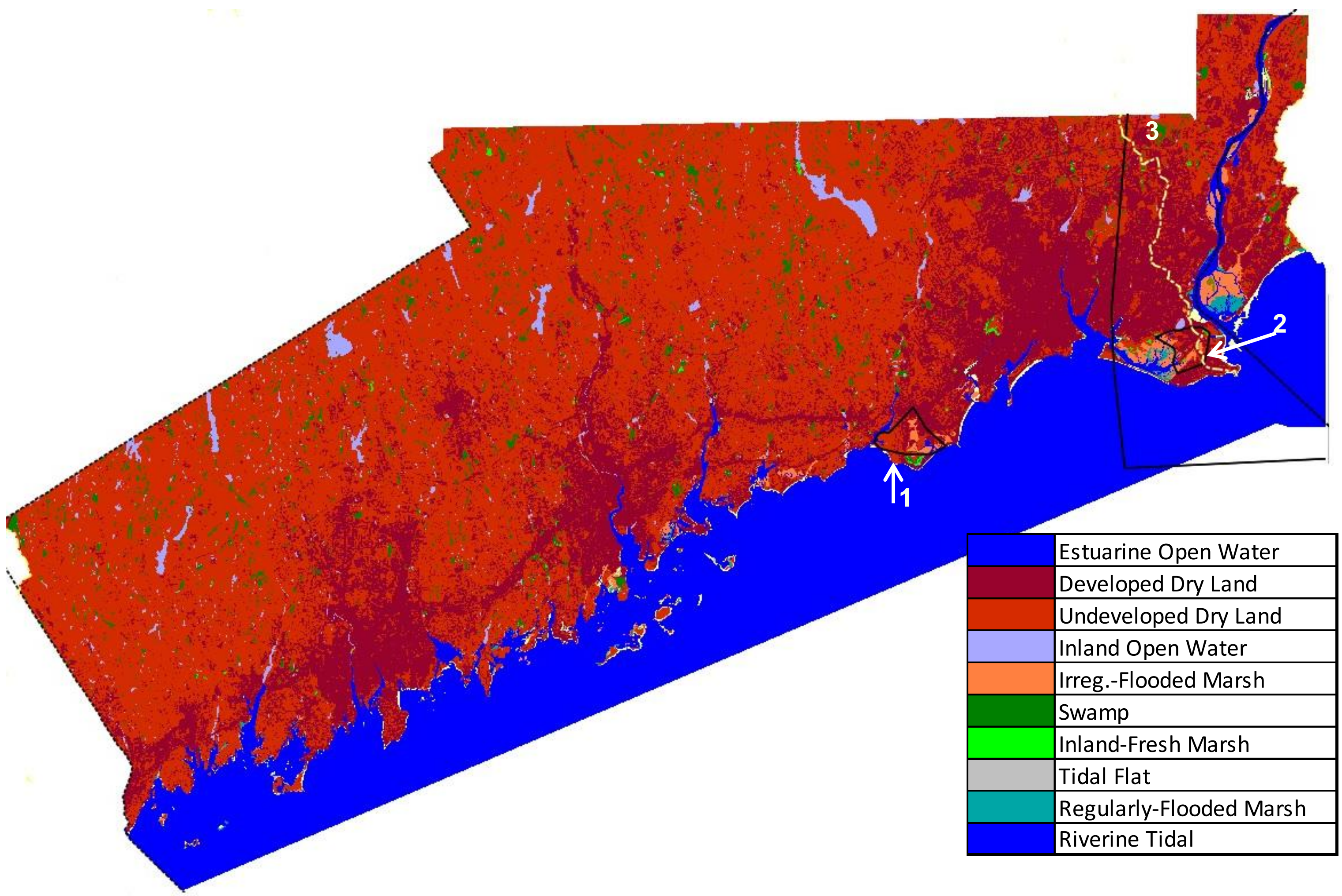

Figure 12. Current land coverage distribution for the Fairfield County Study Area. Numbers correspond to subsites described in Table 9; the yellow dashed line indicates a watershed boundary. The study area is limited to coastal zones with elevations below 5 m above MTL

Fairfield County Site Calibration and Parameters

Several rounds of calibration were run for the Fairfield County study area. These iterations focused mostly on refining the time zero results for the Pine Creek marsh and around Sikorsky Airport where the initial site parameters led to excessive flooding not consistent with the current land cover survey of the areas. As discussed in Section 2.10, this initial model calibration effort suggested that the tide ranges in these areas are lower when compared to the rest of the study area. A study of wetland delineation around the Sikorsky Airport confirmed that the tides are restricted by man-made structures and provided the information of the area affected by this reduced tidal regime (Fitzgerald & Halliday, Inc. 2013). Pine Creek Marsh was investigated by Roman and coworkers and that study, as well as data available from the town of Fairfield, provided insight for the probable extent and tide range of the subsite there (Roman et al. 1984; Town of Fairfield CT, 2014). For the rest of the study area, NOAA gauge stations measure GTs varying between 2.2 m at the mouth of the Housatonic River to 2.4 m at Cos Cob Harbor, CT and Rye Beach, NY. Therefore, an average GT=2.3 m was set.

Results of model calibration are presented in Table 10 and Table 11. Both of these tables indicate there are conversions of greater than 5% of the initial wetland coverage in several categories. However, as discussed in section 2.10, these changes were accepted because these land cover categories had a small coverage, less than 2% of the study area and are explained by wetland layer corrections due to the high resolution of the elevation data.

Table 10. Southwest Coast Watershed Time-Zero Results (acres)

Land cover type		Initial Coverage (acres)	Time Zero - 2010 (acres)	Change (acres)	% Change (- is loss)
	Undeveloped Dry Land	120,479	120,224	-255	-0.2
	Estuarine Open Water	58,761	58,788	27	<0.1
	Developed Dry Land	47,707	47,566	-141	-0.3
	Swamp	4,423	4,412	-11	-0.3
	Inland Open Water	3,484	3,476	-9	-0.2
	Irreg.-Flooded Marsh	1,112	980	-132	-11.8
	Estuarine Beach	814	801	-13	-1.6
	Inland-Fresh Marsh	342	336	-6	-1.9
	Regularly-Flooded Marsh	302	426	123	40.8
	Inland Shore	119	119	0	0.0
	Tidal Flat	38	49	11	29.2
	Riverine Tidal	27	24	-4	-12.9
	Rocky Intertidal	20	20	-1	-3.9
	Tidal Swamp	18	18	0	-1.4
	Tidal-Fresh Marsh	15	14	-1	-3.7
	Transitional Salt Marsh	13	284	270	2002
	Flooded Developed Dry Land	-	141	141	NA
	Total (incl. water)	**237,676**	**237,676**		

Table 11. Housatonic River Watershed Time-Zero Results (acres)

	Land cover type	Initial Coverage (acres)	Time Zero - 2010 (acres)	Change (acres)	% Change (- is loss)
	Developed Dry Land	6,584	6,552	-32	-0.5
	Undeveloped Dry Land	6,269	6,210	-60	-1.0
	Estuarine Open Water	5,765	5,790	25	0.4
	Irreg.-Flooded Marsh	710	653	-57	-8.0
	Swamp	315	315	0	0.0
	Estuarine Beach	308	308	<1	-0.1
	Regularly-Flooded Marsh	248	323	74	29.9
	Inland Open Water	115	93	-22	-19.5
	Transitional Salt Marsh	44	80	37	84.2
	Inland-Fresh Marsh	38	36	-2	-5.8
	Tidal-Fresh Marsh	31	29	-2	-6.3
	Tidal Swamp	9	8	-1	-11.3
	Riverine Tidal	4	2	-2	-56.3
	Tidal Flat	-	11	11	NA
	Flooded Developed Dry Land	-	32	32	NA
	Total (incl. water)	**20,441**	**20,441**		

2.11.2 Area 2 - New Haven and Middlesex Counties

New Haven and Middlesex Counties Site Description

The Area 2 project encompasses both New Haven and Middlesex counties which in turn make up the South Central Coast Watershed. Within this watershed, over eighty thousand acres were within 5 meters of MTL and therefore included in this analysis. The area is predominantly dry land, with irregularly-flooded marsh and swamp comprising the most dominant wetland types, covering 6.8% (5,480 acres) and 2.8% (2,223 acres) of the study area, respectively. Table 12 presents the wetland coverage of the South Central Coast watershed.

Table 12. Current land coverage distribution in South Central Coast watershed.

		South Central Coast	
Land cover type		Area (acres)	%
	Undeveloped Dry Land	26,585	33.2
	Estuarine Open Water	22,210	27.7
	Developed Dry Land	21,087	26.3
	Irreg.-Flooded Marsh	5,480	6.8
	Swamp	2,223	2.8
	Estuarine Beach	1,021	1.3
	Regularly-Flooded Marsh	507	0.6
	Inland Open Water	474	0.6
	Inland-Fresh Marsh	294	0.4
	Tidal-Fresh Marsh	96	0.1
	Tidal Swamp	82	0.1
	Tidal Flat	50	0.1
	Riverine Tidal	37	<0.1
	Rocky Intertidal	32	<0.1
	Transitional Salt Marsh	12	<0.1
	Inland Shore	1	<0.1
	Total (incl. water)	**80,193**	**100**

New Haven and Middlesex Counties Site Parameters

In order to account for variations in tide ranges, erosion rates, and wetland impoundments along the coast, eight input subsites were utilized when setting up this project area. Table 13 presents the subsite areas with the GT, WBE, and horizontal erosion rates applied. Subsite areas are shown in Figure 13. The Housatonic subsite (subsite 3) is the furthest west in Area 2. General Area 2, CT River, and Guilford subsites are the largest input subsites and were used to represent the variation in GT (and WBE) that occurs moving from east to west in the Long Island Sound. The subsites representing the Hammock River, HVN Airport, Sybil Creek, and a smaller area of muted tide were added during the calibration process. Two adjustments to the SLAMM elevation conceptual model were made: a reduction of the minimum boundary of Tidal Fresh Marsh to -0.18 HTU and Tidal Swamp to 0.4 HTU to reflect site-specific fresh-water flows and LiDAR data.

Table 13. SLAMM input subsites applied to Area 2

Subsite	**Description**	**Great Diurnal Tide Range - GT (m)**	**WBE (m above MTL)**	**Horizontal Erosion Rate (m/yr)**
General Area 2	Area 2 not included in the subsites below	2.1	1.1	0
1	CT river	1.1	0.94	0.12
2	Guilford	1.67	1	0.08
3	Housatonic	2.2	1.6	0.06
4	Hammock River	1	0.5	0.08
5	HVN airport	1	0.5	0
6	Sybil Creek	0.5	0.35	0
7	Muted Tide	0.88	0.7	0.12

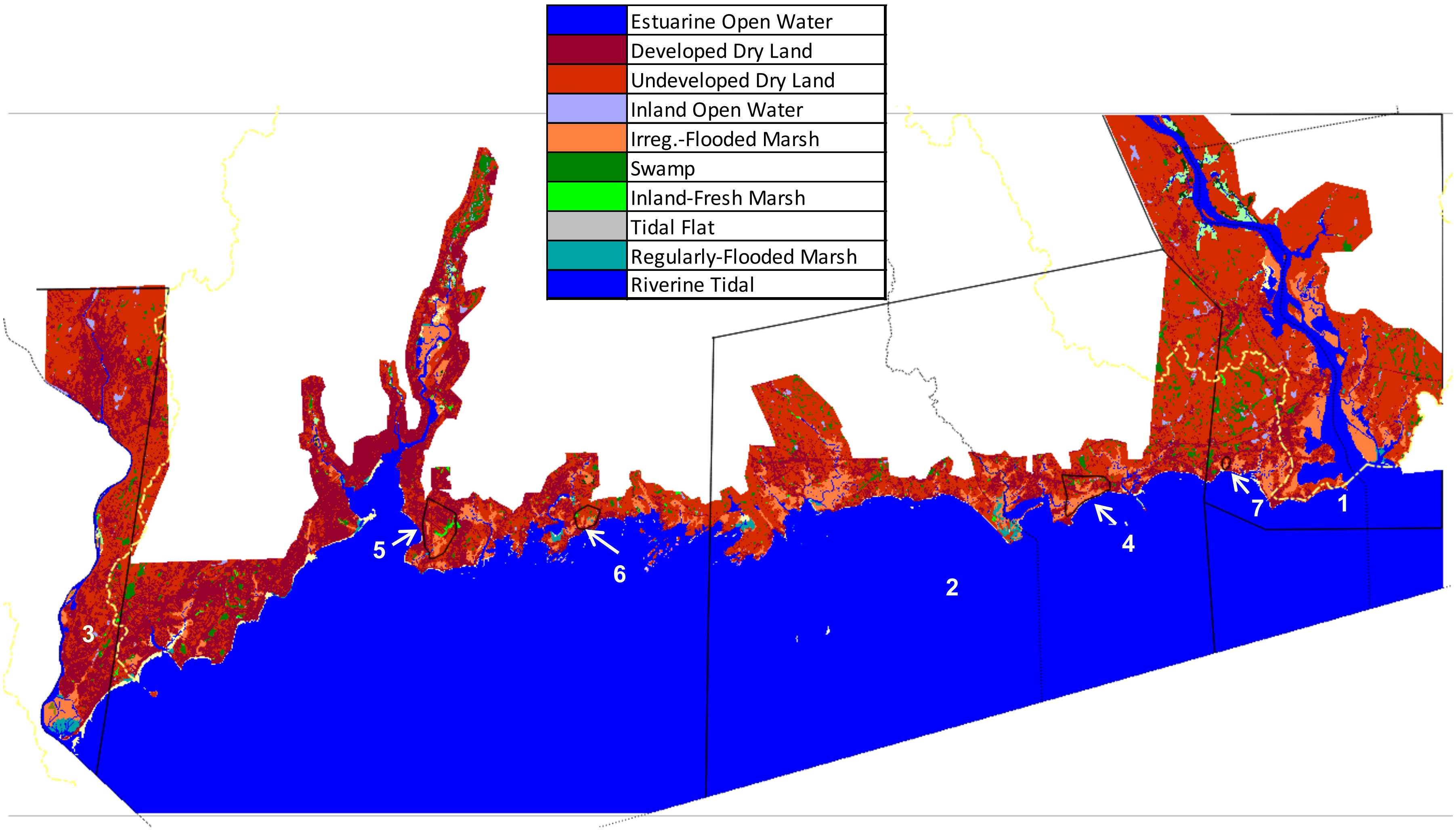

Figure 13. Current land coverage distribution for the New Haven and Middlesex Counties Study Area. Numbers correspond to subsites described in Table 13.

New Haven and Middlesex Counties Site Calibration

Several calibration iterations were carried out in order to adjust tide ranges and wetland boundary elevations within the New Haven and Middlesex study area. Adjustments were made to the WBE in all the large input subsites (General Area 2, CT River, and Guilford), revising them to match the current wetland conditions. Smaller subsites (Hammock River, HVN Airport, Sybil Creek, and Muted Tide) were added during calibration to reflect muted tidal ranges due to tide gates and culverts and to minimize flooding in residential areas. Muted tide ranges were determined based on literature review (Bjerklie et al. 2013; Roman et al. 1984; Rozsa 1995) and examination of marsh elevation profiles using SLAMM. Calibration of this site also included additional hydroenforcement of marshes based on feedback from the CT Department of Energy & Environmental Protection.

Table 14 presents a comparison between the initial observed and time-zero wetland layers for New Haven and Middlesex Counties. Losses in undeveloped dry lands lead to gains in transitional marsh while losses in irregularly-flooded marshes resulted in increases in regularly flooded marsh. Within the 80,193 acre study area, approximately 488 acres of irregularly-flooded marsh converted (to regularly-flooded marsh) in the time-zero analysis. This represents 9% of the initial coverage of irregularly-flooded marsh. As discussed in the Model Calibration section, these changes were accepted based on the approach used by NWI to exclude channels that are included in the LiDAR-derived DEM.

Table 14. South Central Coast Watershed Time-Zero Results (acres)

Land cover type		Initial Coverage (acres)	Time Zero - 2010 (acres)	Change (acres)	% Change (- is loss)
	Undeveloped Dry Land	26,585	26,245	-340	-1.3
	Estuarine Open Water	22,210	22,237	27	0.1
	Developed Dry Land	21,087	20,987	-100	-0.5
	Irreg.-Flooded Marsh	5,480	4,992	-488	-8.9
	Swamp	2,223	2,186	-37	-1.7
	Estuarine Beach	1,021	1,014	-7	-0.7
	Regularly-Flooded Marsh	507	979	472	93.2
	Inland Open Water	474	468	-6	-1.3
	Inland-Fresh Marsh	294	276	-18	-6.2
	Tidal-Fresh Marsh	96	96	<1	-0.5
	Tidal Swamp	82	74	-8	-9.6
	Tidal Flat	50	71	21	42.9
	Riverine Tidal	37	30	-8	-20.9
	Rocky Intertidal	32	30	-3	-8.4
	Transitional Salt Marsh	12	406	394	3326
	Inland Shore	1	1	0	0.0
	Flooded Developed Dry Land	-	100	100	NA
	Total (incl. water)	**80,193**	**80,193**		

2.11.3 Area 3 - New London County

New London County Site Description

This study area includes New London County in its entirety and covers the coastal areas of the Connecticut River, South East Coast, Thames River and Pawcatuck watersheds. Most of the marshes in this portion of the study area are located along of the Connecticut River basin and the coastal area that includes Barn Island (a preferred location for marsh ecology studies). However, significant patches of marsh areas also exist along the coast in between.

Table 15 reports the current wetland coverage for each major watershed in New London County. Overall, nearly 58% of the study area (elevations below 5 m) is occupied by dry land, mostly undeveloped, while open water covers almost 34% of the area. The remaining 8% of this area is characterized as follows: 50% is occupied by coastal saline marshes, (equivalent to 4.2% of study Area 3), 46% is occupied by swamps, fresh marshes and fresh open water, and the remaining acreage is occupied by low-tidal non-vegetated land cover such as beaches and tidal flats.

Table 15. Current wetland coverage for Area 3.

Land cover type	Connecticut River Area (acres)	Connecticut River %	South East Coast Area (acres)	South East Coast %	Thames River Area (acres)	Thames River %	Pawcatuck River (CT only) Area (acres)	Pawcatuck River (CT only) %
Undeveloped Dry Land	20,587	60.4	15,805	33.5	6,316	42.4	558	38.8
Estuarine Open Water	5,951	17.5	22,087	46.8	4,615	31.0	294	20.4
Developed Dry Land	2,459	7.2	6,456	13.7	3,730	25.1	481	33.4
Irreg.-Flooded Marsh	2,529	7.4	1,308	2.8	30	0.2	40	2.8
Swamp	748	2.2	742	1.6	85	0.6	54	3.8
Tidal-Fresh Marsh	579	1.7	21	0.0	1	<0.1	-	-
Tidal Swamp	370	1.1	181	0.4	7	<0.1	0.4	<0.1
Inland Open Water	263	0.8	174	0.4	47	0.3	3	0.2
Riverine Tidal	377	1.1	-	-	-	-	6	0.4
Estuarine Beach	107	0.3	189	0.4	18	0.1	-	-
Inland-Fresh Marsh	55	0.2	95	0.2	24	0.2	1	<0.1
Regularly-Flooded Marsh	57	0.2	62	0.1	5	<0.1	-	-
Trans. Salt Marsh	6	<0.1	81	0.2	1	<0.1	1.5	0.1
Tidal Flat	2	<0.1	8	<0.1	-	-	-	-
Rocky Intertidal	-	-	8	<0.1	2	<0.1	-	-
Total (incl. water)	**34,090**	**100**	**47,219**	**100**	**14,881**	**100**	**1,439**	**100**

New London County Site Parameters

Area 3 was divided into three subsites in order to accommodate spatial variations in tide ranges and erosion rates. The tidal information used was from the NOAA data as discussed in Section 2.6 and 2.7. The input parameters assigned to corresponding subsite boundaries are shown in Table 16 and Figure 14.

Table 16. Tidal ranges and erosion rates for different SLAMM subsites in Area 3

Subsite	Description	Great Diurnal Tide Range - GT (m)	WBE (m above MTL)	Horizontal Erosion Rate (horz. m /yr)
General Area 3	Area 3 not in the subsites below	0.92	0.84	0
SubSite 1	Connecticut River	1.1	0.94	0.12
SubSite 2	Erosion zone - Stonington	0.92	0.84	0.02

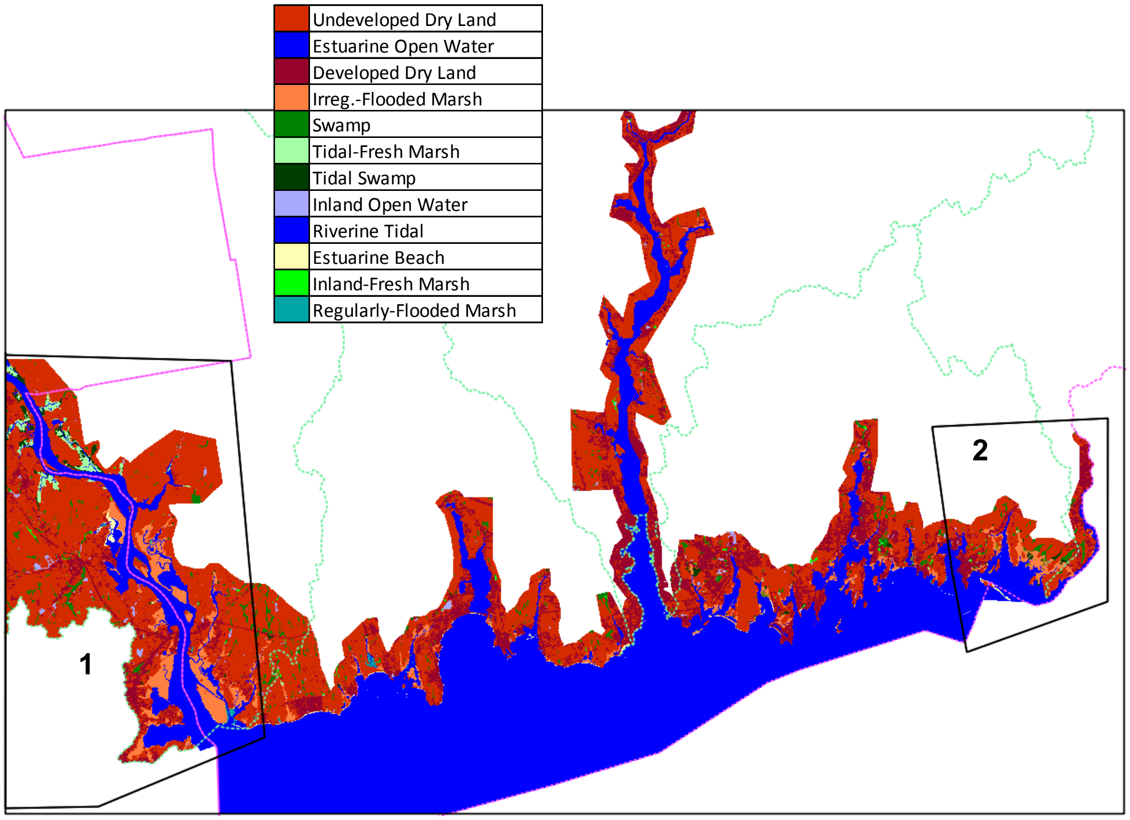

Figure 14. Current land coverage distribution for Area3 and SLAMM analysis subsites in black. Pink lines represent county boundaries while the green lines are watershed boundaries.

New London County Site Calibration

Two rounds of calibration were run on study Area 3. These iterations focused on refining the time zero results until the interplay between tide ranges, elevations, and coastal habitat maps in the initial conditions was deemed satisfactory. Results of the calibration of the initial condition are reported in the tables below and broken down by watershed. Overall, initial land cover changes are minimal indicating a strong agreement between spatial data and tidal information. Two main land cover conversions are observed: some dry lands are found by the model to be inundated at least once every 30 days and thus are converted to either wetlands or flooded developed categories. These areas are usually small fringes of dry land bordering open water. This conversion is mostly due to the wetland-layer horizontal resolution accuracy issues and uncertainty in the elevations assigned to these cells. The elevation assigned to each cell is an average of the LiDAR returns in that cell and may include open water and dry land. Another uncertainty stems from the definition of developed vs. undeveloped dry lands. Developed dry lands were derived from data with 30-m resolution data and rescaled to the 5-m cell size of the project.

The second common initial conversion is from irregularly-flooded marsh to regularly-flooded marsh. This result is somewhat expected as the boundary between low and high marsh is a spatially variable buffer area more than a precise line; thus, wetland classification in this interface is affected by significant uncertainty.

Connecticut River watershed. Time-zero calibration results for this area are reported in Table 17. Overall, there are not significant reclassifications of the major land cover types in the area (those occupying more than 5% of the area) except for irregularly-flooded marsh that is converted by 6.6% likely due to the uncertainty between the elevation boundary between high and low marsh discussed above.

Table 17. Connecticut River watershed Time-Zero Results (acres)

Connecticut River					
Land Cover		**Initial Coverage (acres)**	**Time Zero 2010 (acres)**	**Change (acres)**	**% Change (- is loss)**
	Undeveloped Dry Land	20,587	20,304	-283	-1.4
	Estuarine Open Water	5,951	6,028	77	1.3
	Irreg.-Flooded Marsh	2,529	2,362	-167	-6.6
	Developed Dry Land	2,459	2,450	-9	-0.4
	Swamp	748	743	-5	-0.7
	Tidal-Fresh Marsh	579	549	-30	-5.1
	Riverine Tidal	377	328	-50	-13.1
	Tidal Swamp	370	342	-28	-7.5
	Inland Open Water	263	263	0	0.0
	Estuarine Beach	107	79	-27	-25.5
	Regularly-Flooded Marsh	57	260	203	357.5
	Inland-Fresh Marsh	55	55	<1	-0.4
	Trans. Salt Marsh	6	294	288	5121.1
	Tidal Flat	2	24	21	901.8
	Flooded Developed Dry Land	-	9	9	NA
	Total (incl. water)	**34,090**	**34,090**		

South East Coast watershed. Time-zero calibration results for this area are reported in Table 18 below. For this area, initial land cover changes are minimal indicating a very good agreement between spatial data, parameters and tidal information.

Table 18. South East Coast watershed Time-Zero Results (acres)

Southeast Coast						
Land Cover		Initial Coverage (acres)	Time Zero 2010 (acres)	Change (acres)	% Change (- is loss)
	Estuarine Open Water	22,087	22,107	20	0.1
	Undeveloped Dry Land	15,805	15,586	-219	-1.4
	Developed Dry Land	6,456	6,412	-44	-0.7
	Irreg.-Flooded Marsh	1,308	1,253	-55	-4.2
	Swamp	742	737	-6	-0.8
	Estuarine Beach	189	181	-8	-4.1
	Tidal Swamp	181	180	-1	-0.3
	Inland Open Water	174	174	0	0.0
	Inland-Fresh Marsh	95	94	-1	-0.9
	Trans. Salt Marsh	81	300	219	269.4
	Regularly-Flooded Marsh	62	115	52	84.1
	Tidal-Fresh Marsh	21	21	0	0.0
	Tidal Flat	8	5	-3	-38.7
	Rocky Intertidal	8	8	<1	-0.2
	Flooded Developed Dry Land	-	44	44	NA
	Total (incl. water)	**47,219**	**47,219**		

Thames River watershed. Time-zero calibration results for this area are reported in Table 19 below. There is a good agreement between the data and the model for this area.

Table 19. Thames River watershed Time-Zero Results (acres)

Thames River					
Land Cover		**Initial Coverage (acres)**	**Time Zero 2010 (acres)**	**Change (acres)**	**% Change (- is loss)**
	Undeveloped Dry Land	6,316	6,220	-96	-1.5
	Estuarine Open Water	4,615	4,616	2	<0.1
	Developed Dry Land	3,730	3,708	-22	-0.6
	Swamp	85	84	-1	-1.6
	Inland Open Water	47	46	-1	-2.2
	Irreg.-Flooded Marsh	30	25	-5	-18.1
	Inland-Fresh Marsh	24	22	-3	-10.6
	Estuarine Beach	18	18	<1	0.3
	Tidal Swamp	7	7	<1	-0.3
	Regularly-Flooded Marsh	5	11	6	110.1
	Rocky Intertidal	2	1	<1	-29.1
	Trans. Salt Marsh	1	100	99	9911.1
	Tidal-Fresh Marsh	1	1	0	0.0
	Flooded Developed Dry Land	-	22	22	NA
	Total (incl. water)	**14,881**	**14,881**		

Pawcatuck River watershed. Time-zero calibration results for this area are reported in Table 20 below. Also for this area there is a strong agreement between the data and the model.

Table 20. Pawcatuck River watershed Time-Zero Results (acres)

Pawcatuck River (CT only)					
Land Cover		Initial Coverage (acres)	Time Zero 2010 (acres)	Change (acres)	% Change (- is loss)
	Undeveloped Dry Land	558	548	-11	-1.9
	Developed Dry Land	481	478	-3	-0.6
	Estuarine Open Water	294	295	1	0.4
	Swamp	54	54	<1	-0.1
	Irreg.-Flooded Marsh	40	39	-1	-2.7
	Riverine Tidal	6	4	-1	-22.8
	Inland Open Water	3	3	0	0.0
	Trans. Salt Marsh	1	12	11	737.9
	Inland-Fresh Marsh	1	1	0	0.0
	Tidal Swamp	0	0	0	0.0
	Regularly-Flooded Marsh	-	1	1	NA
	Flooded Developed Dry Land	-	3	3	NA
	Total (incl. water)	**1,439**	**1,439**		

2.12 Uncertainty Analysis Setup

The base analyses (non-uncertainty-analysis runs, also called the "deterministic" model) consider a range of different possible SLR scenarios, but other model uncertainties such as variability in measured input parameters and spatial-data errors were not accounted for. For example, uncertainties arise when literature parameters are used rather than site-specific data. In addition, the strength of feedbacks between marsh vertical accretion rates and SLR can vary significantly from one site to another. SLAMM includes an uncertainty-analysis module that employs Monte-Carlo simulations to study the effects of uncertainties and to produce predictions of wetland coverages as distributions. This module enhances the value of the results by providing confidence intervals, worst and best case scenarios, likelihoods of wetland conversion, and other statistical indicators useful to better characterize possible future outcomes and assist decision making. In addition, simplified maps showing the likelihood of wetland coverage in each location were produced for this project.

All of the site-specific data required by SLAMM, such as the spatial distribution of elevations, wetland coverages, tidal ranges, accretion and erosion rates, local sea-level rise and subsidence rates, may be affected by uncertainties that can propagate into the predicted outputs. The propagation of input-parameter uncertainty into model predictions cannot be derived analytically due to the non-linear spatiotemporal relationships that govern wetland conversion. The Monte Carlo uncertainty analysis module within SLAMM uses efficient Latin-Hypercube sampling of the input parameters (McKay et al. 1979). This module generates hundreds of prediction results that are then assembled into probability distributions of estimated wetland coverages.

For each of the model input parameters, an uncertainty distribution was derived based on available site-specific data. Moreover, mechanistic considerations regarding the proper distributional family and the feasible bounds of the variable were considered. Distributions were derived reflecting the potential for measurement errors, uncertainty within measured central tendencies, and professional judgment (Firestone et al. 1997).

Because SLAMM calculates equilibrium effects of SLR based on relatively large time-steps, long-term erosion rates, accretion rates, and SLR rates were used to drive model predictions. Therefore, the uncertainty distributions described in the following section are based on long-term measurements rather than incorporating short-term variability within measurements. Cell-by-cell spatial variability has been considered for elevation data, but the majority of the input parameters have uncertainty distributions that vary on a subsite basis.

One important limitation that should be considered when interpreting these results is that the uncertainties of the general conceptual model in describing system behaviors are not taken into account (model framework uncertainty; Gaber et al. 2008). For example, within this uncertainty analysis, the flow chart of marsh succession is fixed. Low marshes must initially pass through a tidal flat category before becoming open water rather than directly converting to open water under any circumstance.

The next sections discuss each of the model's input parameters that are affected by uncertainties, and how they were handled within the uncertainty analysis for this project.

2.12.1 SLR by 2100

The extent of future sea-level rise by 2100 is a key model input parameter and possibly the most uncertain. The drivers of climate change used by scientists to derive potential SLR rates include future levels of economic activity, dominant fuel type (e.g., fossil or renewable, etc.), fuel consumption, and resulting greenhouse gas emissions. Because future values of these driving variables are uncertain, the exact extent of future sea-level rise is also therefore uncertain. Therefore, it is necessary to use a range of potential sea-level-rise scenarios in SLAMM analysis, to present a range of possibilities.

As described in Section 2.4, the deterministic SLR scenarios used in this SLAMM application correspond to the maximum of the General Climate Model (GCM), the Minimum and Maximum of the Rapid Ice Melt (RIM) estimates as described in the ClimAID report (Rozenzweig et al. 2011), and the intermediate scenario of 1 meter (39.4 inches) of SLR by 2100. The base year for these scenarios is 2002. In the uncertainty analysis, sea-level rise scenarios were drawn from the triangular probability distribution shown in Figure 15. The deterministic SLR scenarios are also presented in order to illustrate their relationship to the possible simulated SLR scenarios. Figure 15 shows that, under the probability distribution of SLR applied, 1m by 2100 is the "most likely" scenario of those simulated by the deterministic model runs.

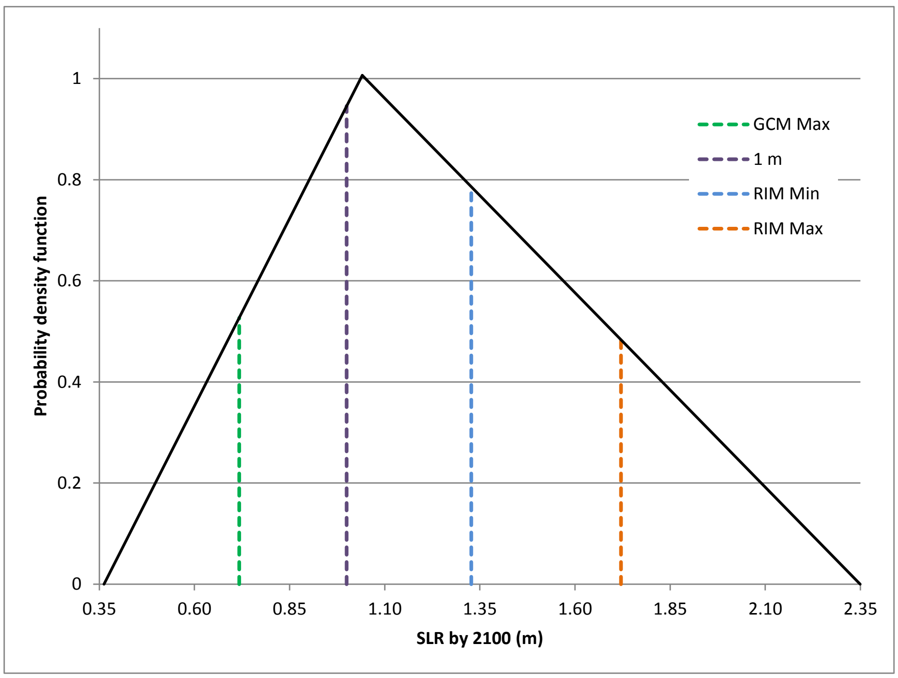

Figure 15. SLR probability distribution

In order to derive the probability distribution in Figure 15, information from the recent NYC Panel on Climate Change (NPCC2) report (C. Rosenzweig and W. Solecki (Editors), NPCC2 2013) was used in addition to the ClimAID report. The NPCC2 study estimates that by the 2020s the sea-level rise (with respect to 2000-2004 baseline level) at the Battery in NYC has a 10% probability to be between 0 and 5.08 cm (10th percentile) and a 90% probability to be less than or equal to 27.94 cm (90th percentile). By the 2050s, these estimated percentiles become 17.78 cm and 78.74 cm respectively, as presented in Table 21.

Table 21. Baseline and SLR Projections (Source NPCC2)

Sea-level rise baseline (2000-2004) 0 inches	**Low-estimate (10th percentile)**	**Middle range (25th to 75th percentile)**	**High-estimate (90th percentile)**
2020s	5.1 cm (2 in)	10.2 to 20.3 cm (4 to 8 in)	27.9 cm (11 in)
2050s	17.8 cm (7 in)	27.9 to 61.0 cm (11 to 24 in)	78.7 cm (31 in)

The sea-level rise estimates shown in Table 21 closely correspond to the GCM Min and RIM Max SLR scenarios. To incorporate these estimates and percentages the SLR predictions were extrapolated to 2100: the 10th percentile SLR projection was set to 36.2 cm (14.3 in), while the 90th percentile set to 1.84 m (72.4 in) by 2100. Assuming a symmetrical, triangular probability distribution, the most likely SLR scenario was estimated equal to 1.04 m (41 in) SLR by 2100. However, the historic SLR rate at the Battery (2.77 mm/yr) is already higher than the estimated current SLR rate of the 10th percentile SLR projection (2.2 mm/yr). It was deemed unlikely that future SLR rates will be lower than the historic recorded data during the past century. For this reason, the more conservative estimate was set to as the minimum possible SLR scenario rather than the 10th percentile, while 1.04-m and 1.84-m SLR by 2100 were kept as the most likely and the 90th percentile SLR scenarios, respectively. The highest possible SLR rate scenario was set to 2.35 m (92.5 in) by 2100.

2.12.2 Digital Elevation Map Uncertainty

LiDAR elevation data is subject to measurement errors due to equipment limitations. In addition, in marsh areas, the laser pulse used to measure elevations does not always reach the bare earth causing additional errors and uncertainty (Schmid et al. 2011). In this SLAMM application, elevation-data uncertainty was evaluated by randomly applying elevation-data error statistics and creating a series of equally likely elevation maps. Maps were created adding a spatially autocorrelated error field to the existing digital elevation map (Heuvelink 1998). Heuvelink's method has been widely recommended as an approach for assessing the effects of elevation data uncertainty (Darnell et al. 2008; Hunter and Goodchild 1997). This approach uses the normal distribution as specified by the Root Mean Squared Error (RMSE) for the LiDAR-derived dataset and applies it randomly over the entire study area, with spatial autocorrelation included, as shown in Figure 16. A stochastic analysis is then executed (implementing the model with one of these elevation maps) to assess the overall effects of elevation uncertainty. In this analysis, it was assumed that elevation errors were strongly spatially autocorrelated, using a p-value of 0.2495. The RMSE applied for the entire Connecticut study areas was set to 0.1 m, derived as a conservative estimate of RMSE of the different elevation sources used to cover the study area. In the past, running an elevation uncertainty analyses alone on elevation data sets with RMSE of 0.1 or even greater has shown very little effect on overall model predictions.[9]

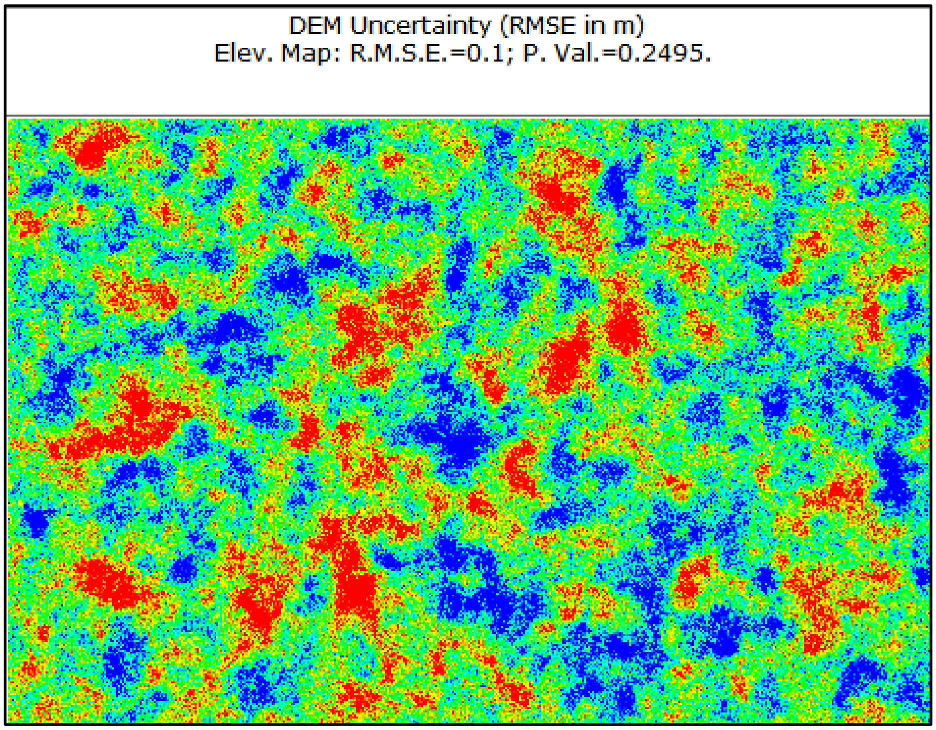

Figure 16. Example of a DEM uncertainty map. Min (blue) = -0.135m, Max (red) = 0.135m.

A different error field such as this one, based on 0.1 RMSE, is derived for each uncertainty iteration and added to the baseline digital elevation map.

2.12.3 Vertical Datum Correction

Correction of elevation data to a tidal basis using the NOAA VDATUM product is also subject to uncertainty due to measurement errors and VDATUM model errors. NOAA characterizes the “maximum cumulative uncertainty” for each location in the documentation of the model (National Oceanic and Atmospheric Association 2010). Like the DEM uncertainty, the vertical-datum-correction uncertainty was also applied via spatially variable autocorrelated maps. The RMSE for the datum correction was set to 10 cm for the entire study area with the assumption of strong spatial autocorrelation with p-value of 0.2495 applied.

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[9] See, for example, the elevation uncertainty analysis performed for Saint Andrew and Choctawhatchee Bays starting on page 59 of this document: http://warrenpinnacle.com/prof/SLAMM/TNC/SLAMM_SAC_Florida_Final.pdf.

2.12.4 Great Diurnal Tide Range

Tide ranges are not measured at each cell and therefore there is spatial uncertainty associated with the tide range assigned. The error associated with the tide ranges applied was considered on an input subsite basis. The GT of each input subsite was represented by a unique probability distribution whose variability reflects the variability the tide data used to the point estimates. These distributions represent multipliers on point estimates, rather than the distribution of the tide range itself. (This approach allows SLAMM to remain flexible when using one probability distribution for many input subsites with varying tide range). An example of the SLAMM interface showing the uncertainty of the Pine Creek subsite in Fairfield County is shown in Figure 17.

In order to calculate the standard-deviation multiplier applied to each subsite, the standard deviation of the tide measurements used for each subsite was calculated. When less than four tide-range measurements were used to determine the GT for an input subsite, the difference between the GT applied and the maximum GT observed was calculated, as was the difference between the GT applied and the minimum GT observed; the greater of these two values was applied as the standard deviation. When subsites were added to represent muted tide ranges (behind a tide gate or upriver where tide data were not available), the standard deviation of nearby subsites were applied.

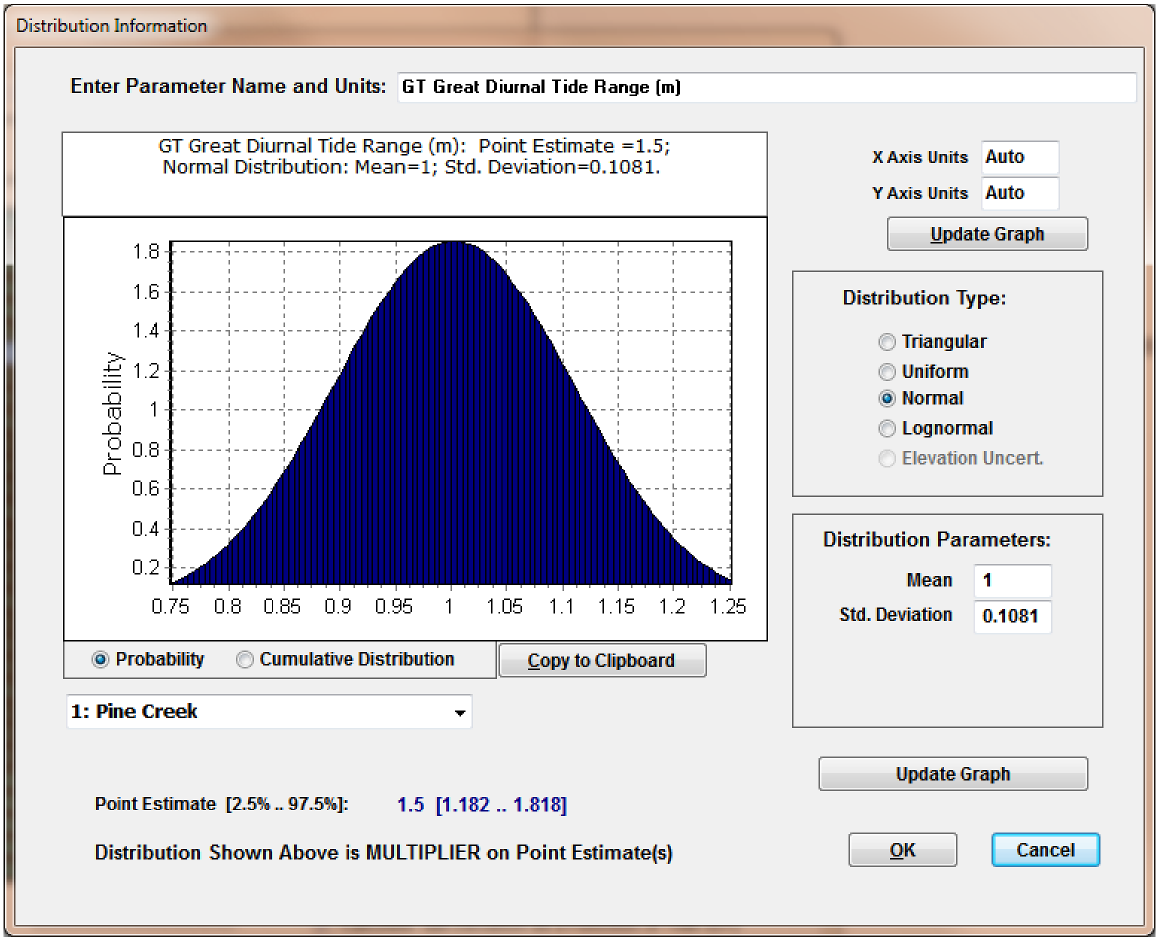


Figure 17. Example Input Distribution for Great Diurnal Tide Range Uncertainty

2.12.5 Wetland Boundary Elevation

As discussed in Section 2.7, the elevation of the coastal-wet-to-dry-land boundary WBE) was estimated as a 30-day inundation elevation and a linear relationship was used to derive site-specific WBE based on the local GT applied. However, this boundary is also subject to uncertainty due to tide-range uncertainty and spatial interpolation. The potential variability of the WBE was estimated by considering the range between the 20-day and 40-day inundation elevations at the three tide stations that have this information. The maximum difference between 20/40-day and the 30-day inundation elevation was 5 cm. Uncertainty distributions for all WBEs were modeled as Gaussian distributions with a standard deviation equal to 5 cm.

Since the tide ranges (GTs) are also part of the uncertainty analysis, the sampling of the WBE for each model realization was carried out by first sampling the GT from its uncertainty distribution, and then calculating the corresponding WBE using the linear relationship presented in Figure 6. Finally, a multiplier to apply to the WBE was derived from the Gaussian uncertainty distribution described above and applied to the parameter for the current model iteration.

2.12.6 Erosion

Historical erosion rates can be quite variable in both space and time and the projection of future erosion rates involves a combination of data and professional judgment. Uncertainty parameters associated with marsh, swamp, and tidal flat erosion parameters were applied uniformly across the study area. The long-term linear regression rates (LRR) determined by Barrett and Coworkers that were applied in the deterministic analysis had associated standard deviations reported (2014). However, these were standard deviations not used in the uncertainty analysis since the ranges were quite narrow and represented uncertainties in past erosion rates as opposed to potential future erosion rates. To reflect overall uncertainty, marsh was modeled using a uniform distribution ranging from 0 m/yr to 2.0 m/yr of erosion across the entire study area (Fagherazzi 2013). Swamp and Tidal Flat erosion uncertainty were assigned to triangular distributions ranging between 0 m/yr and 2.0 m/yr with most likely rates varying spatially and equal to the values used in the base analysis.

This approach was determined based on professional judgment and also maximum erosion rates measured in marshes at other locations in the US (Fagherazzi 2013). While a maximum erosion rate of 2.0 m/yr may be high for the CT coast, it also includes uncertainty due to the potential for future large storms.

2.12.7 Accretion

2.12.7.1 Accretion Point Estimate Uncertainty

Due to a lack of spatially variable site-specific data, uncertainty distributions for the following categories were applied uniformly throughout the entire study area:

- Accretion rates for freshwater marshes (inland and tidal).
- Swamp and tidal swamp accretion rates.
- Beach sedimentation rates.

Tidal fresh marsh accretion was applied as a triangular distribution with a minimum of 2 mm/yr and a maximum of 18 mm/yr, with a most likely value of 5 mm/yr (corresponding to multipliers of 0.4, 3.6, and 1, respectively). The minimum for this distribution was derived from work by Neubauer (2008) in the Hudson River while the maximum was derived from studies of tidal-fresh marshes along the mid-Atlantic coast (Neubauer et al. 2002). The distribution applied is presented in Figure 18.

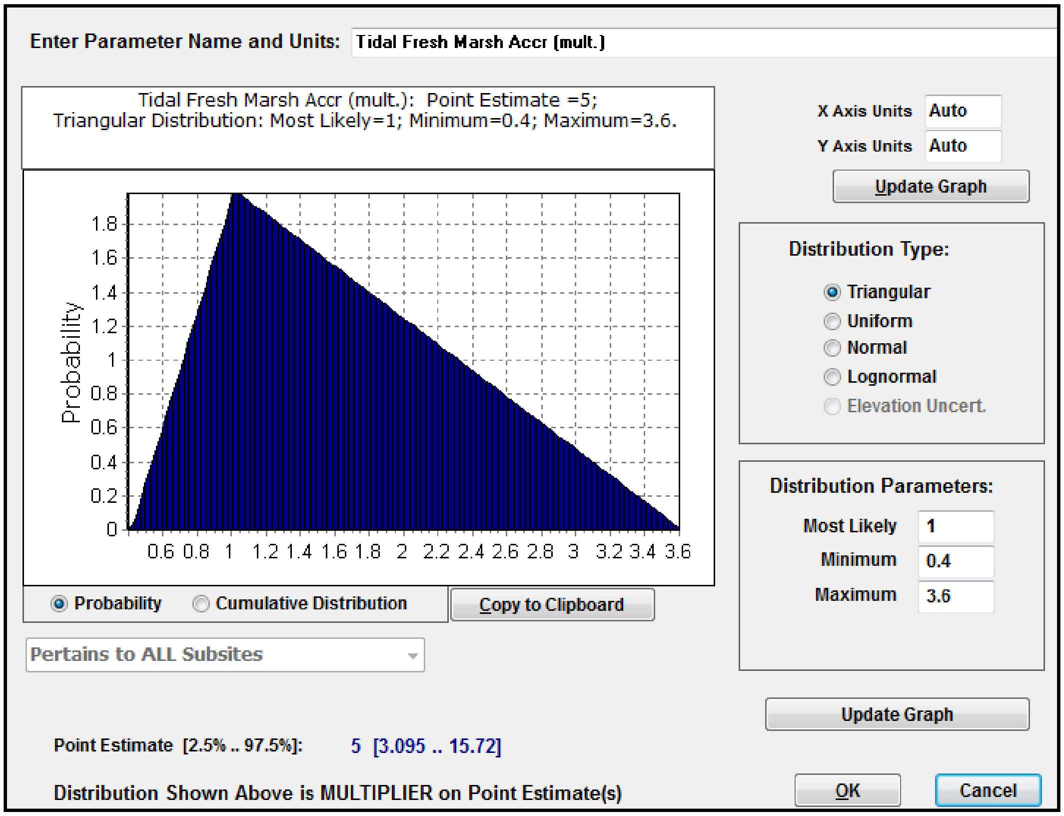


Figure 18. Tidal fresh marsh accretion distribution assigned for uncertainty analysis

Inland fresh marsh accretion uncertainty was modeled using a normal distribution (multiplier) with a standard deviation of 0.153, determined from data presented by Craft and coworkers (Craft and Casey 2000; Craft and Richardson 1998). This assignment resulted in a relatively narrow range of possible values with 2.5th and 97.5th percentile values of 0.7 and 1.3 mm/yr, respectively.

Tidal-swamp accretion was applied a uniform probability distribution. Based on data from Craft (Craft 2012b) collected in Georgia tidal swamps, a maximum of 2.8 mm/yr and a minimum of 0.6 mm/yr were applied.

Accretion observations by Craft were also used to inform the probability distribution for swamps. Based on unpublished data from the Altamaha River in Georgia, a uniform distribution with a minimum on 0.2 mm/yr and maximum 3.4 mm/yr was applied (Craft 2014).

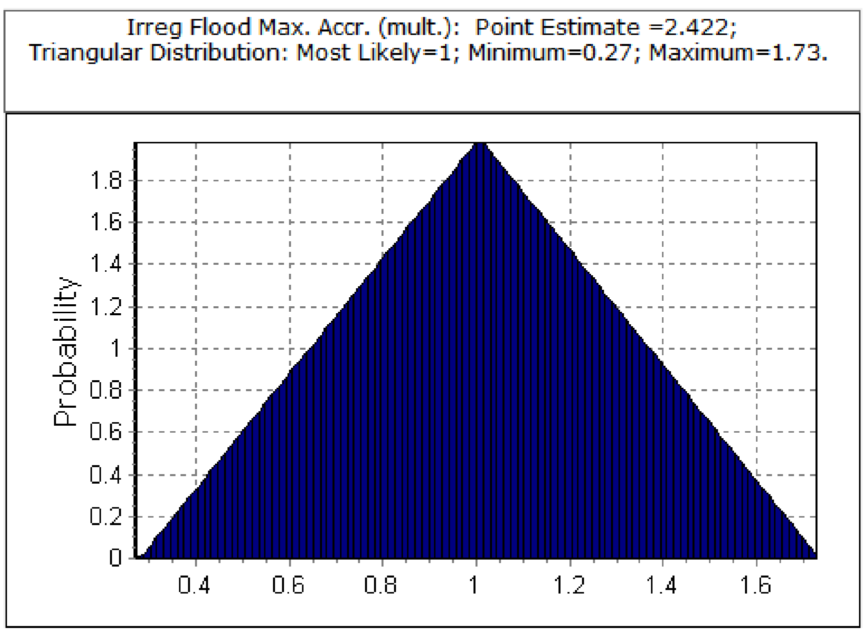
Beach-sedimentation-rate uncertainty was applied as a uniform distribution from 0.1 to 2 mm/yr. Beach sedimentation rates tend to be spatially variable, and are often lower than marsh accretion rates due to the lack of vegetation to trap sediments. The chosen range was fairly wide since there is a considerable amount of uncertainty in beach sedimentation due to the effects of storms and nourishment activities, which are not explicitly included in this study.

2.12.7.2 Mechanistic Accretion Model Uncertainty

The measured accretion-data variability described in Section 2.8.1 was used to estimate the uncertainty distributions attributed to tidal marsh accretion rates, as described below.

Irregularly flooded marsh. The linear accretion-to-elevation relationship used in the deterministic model was also used in the uncertainty analysis (see Section 2.8.1.1). However, the maximum and minimum accretion rates assigned at the upper and lower boundaries of the marsh elevation range (0.5 HTU to 1 WBE) were allowed to vary. These accretion rates were drawn separately from the same probability distribution. This probability distribution was derived using the variability of the available measured accretion rates with respect to the best-fit linear model (see Figure 8). The goal of the uncertainty analysis was to determine the ensemble of linear accretion models that would fit the available data within their confidence intervals. To do this, a triangular distribution was produced for accretion rates both at the maximum (1 WBE) and at the minimum (0.5 HTU) elevations as shown in Figure 19.

Figure 19. Uncertainty distributions for maximum and minimum accretion rates for irregularly flooded marsh



The "most likely" point on the distribution was assigned to 1.0, which would result in the accretion rate used for the deterministic runs— 2.42 mm/yr. The range for the triangular distribution was estimated by adding or subtracting two standard deviations of the observed accretion rate data. This produced a range from 0.65 to 4.19 mm/yr for accretion rates at the boundaries. For high marshes with elevations between these two points, the accretion rate was chosen through linear interpolation. The resulting model could have a positive or negative slope. Often accretion rates are higher at lower elevations due to tides and sediment capture. However, higher accretion rates at higher elevations are also possible due to increased organic production under conditions of lower salinity. Observed data for high marshes do not show a strong relationship with elevation (Figure 8).

Regularly-flooded marsh. For low tidal marsh, uncertainty in accretion-feedback curves was estimated by considering the uncertainty associated with the accretion curves shown in Figure 9. For these marshes, the available accretion data are very limited and do not provide enough information for a meaningful assessment of uncertainty. Therefore, accretion-rate variability was estimated using an analysis from nearby Long Island, NY where more data were available. As MEM contains several parameters that can be varied to calibrate the model, for simplicity it was assumed that the general accretion curves remain the same as in Figure 9. Given this assumption, the calibrated MEM model can be varied by modifying just the maximum and minimum accretion rates.

In the north shore of Long Island, data show that minimum accretion rates could vary in the range from 0 to 4.0 mm/yr while maximum accretion rates could be approximately plus or minus 3 mm/yr around the point estimates used in the deterministic runs. These values were applied also in Connecticut although some uncertainty ranges were conservatively widened to better reflect lack of knowledge. The identified uncertainty distributions are summarized in Table 22. The last two columns provide the range of 95% of the accretion sample values drawn from these distributions.

Table 22. Summary of uncertainty accretion rate distributions. All values mm/yr.

MAX Reg. Flood Accretion	Most Likely	Triangular Distribution Min-Max	2.5th percentile	97.5th percentile
Area 1	5.8	3.4 - 9.5	4.0	8.8
Area 2	8.7	4.0 - 12.5	5.0	11.6
Area 3	4.9	2.4 - 8.5	3.0	7.8

MIN Reg. Flood Accretion	Most Likely	Triangular Distribution Min-Max	2.5th percentile	97.5th percentile
Area 1	0.64	0.0 - 4.0	0.25	3.4
Area 2	0.28	0.0 - 4.0	0.17	3.4
Area 3	0.16	0.0 - 4.0	0.13	3.4

Sampling from these distributions separately, an accretion-feedback curve with the same general parabolic shape as the deterministic runs (Figure 9) will be produced by one of the uncertainty model's iterations. A low minimum accretion rate might be paired with a high maximum accretion rate for example, providing a very strong feedback. Given uncertainty about future suspended-sediment concentrations, spatial variability within marsh accretion rates, and relatively high uncertainty in our data sets, the intent was to be as conservative as possible and to sample from a wide range of feasible relationships between accretion rates and marsh elevations.

3 Results and Discussion

In the following subsections, deterministic model results (non-uncertainty-analysis results) are presented individually for each of the seven modeled watershed areas, as well as the entire study area. Tables of land-cover acreage at each time step for each SLR scenario simulated are included, as well as summary tables showing the percentage loss and acreage gain for selected land-cover types. It is important to note that changes presented in the summary tables are calculated starting from to the 2010 time-zero result and represent projected land-cover changes as a result of sea-level rise excluding any predicted changes that occur when the model is applied to initial-condition data, as discussed in Section 2.10: Model Calibration.

3.1 Entire Study Area

Within the coastal-Connecticut study area, irregularly-flooded marshes are the most vulnerable category to sea-level rise, with predicted losses ranging from 50% to 97% by 2100 (Table 23). This Connecticut high marsh is also, by far, the most prevalent coastal wetland type in the study area. Other vulnerable habitats include tidal-swamps, tidal-fresh marshes, and estuarine beaches. In addition to these wetland losses, between 2.4 and 8.8 percent of developed dry land within the study area is predicted to be flooded regularly due to SLR (under the RIM max. scenario by 2100).

Table 23. Predicted percentage change in land covers from 2010 to 2100 for the entire study area

Land cover category	Acres in 2010	Percentage Land cover change from 2010 to 2100 for different SLR scenarios			
		GCM Max	1m	RIM Min	RIM Max
Undeveloped Dry Land	195,337	-1.5	-2.3	-3.3	-4.2
Estuarine Open Water	119,861	1.2	1.7	3.3	6.9
Developed Dry Land	88,153	-2.6	-4.6	-7.0	-9.5
Irreg.-Flooded Marsh	10,306	-50.0	-87.7	-95.1	-97.4
Swamp	8,531	-2.6	-4.3	-6.1	-8.4
Inland Open Water	4,523	-2.3	-3.1	-3.9	-4.5
Estuarine Beach	2,406	-23.8	-34.4	-47.2	-57.0
Regularly-Flooded Marsh	2,114	363.3	592.7	533.3	462.5
Trans. Salt Marsh	1,472	40.7	57.0	66.0	57.3
Inland-Fresh Marsh	819	-14.0	-21.4	-26.2	-28.8
Tidal-Fresh Marsh	710	-8.8	-27.6	-62.8	-85.6
Tidal Swamp	629	-43.8	-61.0	-72.7	-80.6
Riverine Tidal	387	-83.3	-85.6	-87.7	-89.5
Flooded Developed Dry Land	351	642.7	1148.8	1749.3	2390.2
Tidal Flat	159	40.7	395.8	2037.9	2114.8
Inland Shore	120	0.0	0.0	0.0	0.0
Rocky Intertidal	58	-19.6	-27.2	-39.5	-51.1

Figure 20 shows the interplay between marsh types as SLR increases. Currently in the CT study area irregularly-flooded (high) marsh dominates the intertidal landscape. However, as SLR increases, more frequent inundation will increase the salinity in these marshes and lower their elevation relative to the tides, converting them to the regularly-flooded or low marsh category. When SLR by 2100 exceeds 40 inches, even total area of low marsh begins to decline as it is largely replaced with non-vegetated tidal flats.

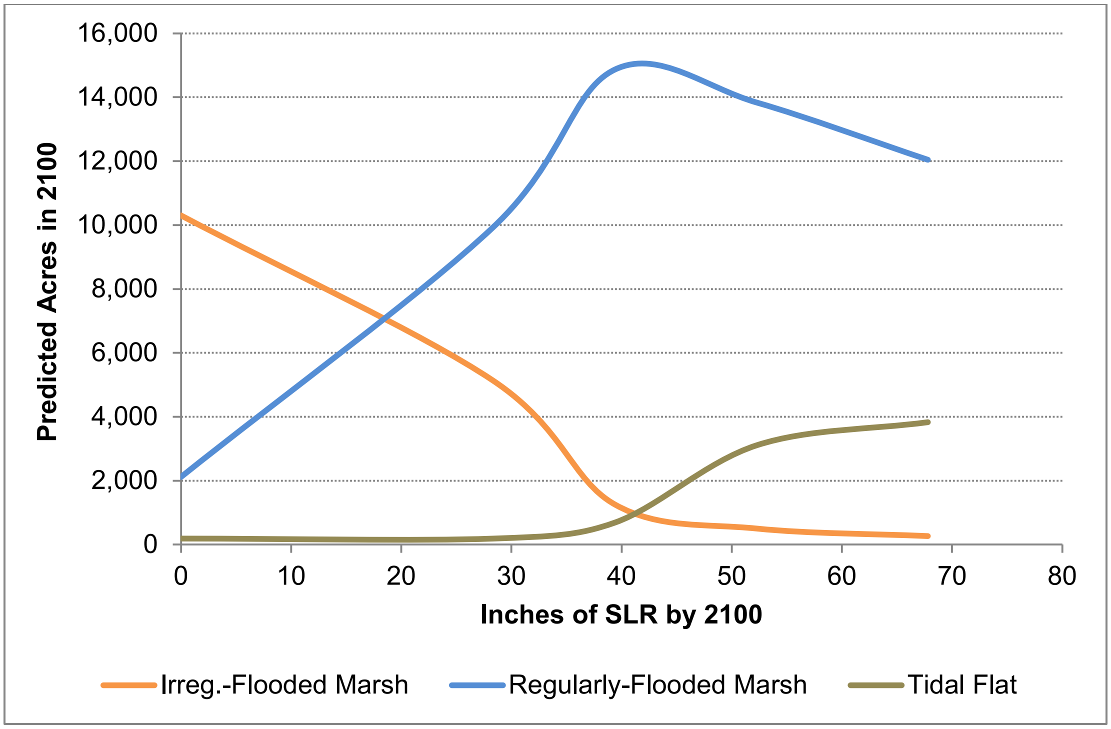


Figure 20. Marsh and Tidal-Flat fate as a function of SLR by 2100

One trend noted throughout the study area is that as tide ranges get smaller, moving from west to east along the CT coast, marshes are predicted to be less resilient. This result has been shown in other studies and is documented in the literature (Kirwan et al. 2010). It can be explained by considering that the persistence of an intertidal marsh is defined by the elevation ranges with respect to the tidal amplitude. For simplicity, assume no marsh accretion or subsidence. If a regularly-flooded marsh is in an area with a GT of 2 m, the viable elevation range goes from -0.4 m to1.2 m above MTL. However, if a regularly-flooded marsh in an area with a GT of 1 m, the range of elevations is narrower, from -0.2 m to 0.6 m. Now suppose that initially both marshes platforms are at 0.5 m above MTL. If sea level rises 0.7 m then both marsh platforms will go down to -0.2 m. However, the first one is still above the minimum elevation while the second is drowned. A similar and even more evident conclusion is achieved if one assumes that the long-term sustainability of a marsh is related to the platform elevation within the tidal frame. If they both start at MHHW (1 m and 0.5 m respectively) then after a SLR of 0.7 m, the first marsh, having more ‘elevation capital’ can still withstand an additional 0.5 m SLR while the second marsh is gone.

Table 24 through Table 27 present the acreages predicted by SLAMM at each timestep for each SLR scenario examined. These tables are followed by results analyzed by watershed. As this report summarizes results from watersheds from west to east, more conversion to open water is evident later in the report.

Table 24. Entire Study Area, GCM Max (Acres)

		Initial	2010	2025	2055	2085	2100
	Undeveloped Dry Land	196,599	195,337	195,114	194,511	193,104	192,425
	Estuarine Open Water	119,683	119,861	120,237	120,521	121,021	121,267
	Developed Dry Land	88,504	88,153	88,078	87,826	86,632	85,894
	Irreg.-Flooded Marsh	11,211	10,306	10,146	9,715	7,245	5,155
	Swamp	8,591	8,531	8,511	8,472	8,366	8,308
	Inland Open Water	4,561	4,523	4,494	4,489	4,446	4,419
	Estuarine Beach	2,457	2,406	2,354	2,225	1,970	1,834
	Regularly-Flooded Marsh	1,182	2,114	2,938	3,602	6,977	9,793
	Trans. Salt Marsh	158	1,472	928	1,278	2,037	2,072
	Inland-Fresh Marsh	850	819	811	791	716	705
	Tidal-Fresh Marsh	743	710	708	702	666	648
	Tidal Swamp	667	629	614	571	416	354
	Riverine Tidal	452	387	115	88	71	65
	Flooded Developed Dry Land	0	351	427	678	1,872	2,610
	Tidal Flat	98	159	286	295	229	223
	Inland Shore	120	120	120	120	120	120
	Rocky Intertidal	62	58	57	53	49	47
	Total (incl. water)	**435,938**	**435,938**	**435,938**	**435,938**	**435,938**	**435,938**

Table 25. Entire Study Area, 1m by 2100 (Acres)

		Initial	2010	2025	2055	2085	2100
	Undeveloped Dry Land	196,599	195,337	195,110	193,914	191,930	190,814
	Estuarine Open Water	119,683	119,861	120,237	120,737	121,480	121,853
	Developed Dry Land	88,504	88,153	88,076	87,383	85,398	84,115
	Irreg.-Flooded Marsh	11,211	10,306	10,142	8,581	2,677	1,273
	Swamp	8,591	8,531	8,511	8,423	8,264	8,166
	Inland Open Water	4,561	4,523	4,494	4,479	4,409	4,384
	Estuarine Beach	2,457	2,402	2,350	2,113	1,744	1,575
	Regularly-Flooded Marsh	1,182	2,114	2,949	5,061	12,604	14,643
	Trans. Salt Marsh	158	1,476	930	1,622	2,108	2,317
	Inland-Fresh Marsh	850	819	811	759	689	644
	Tidal-Fresh Marsh	743	710	708	667	577	514
	Tidal Swamp	667	629	614	499	309	245
	Riverine Tidal	452	387	115	82	63	56
	Flooded Developed Dry Land	0	351	428	1,122	3,106	4,389
	Tidal Flat	98	159	287	324	414	787
	Inland Shore	120	120	120	120	120	120
	Rocky Intertidal	62	58	57	51	45	42
	Total (incl. water)	**435,938**	**435,938**	**435,938**	**435,938**	**435,938**	**435,938**

Table 26. Entire Study Area, RIM Min (Acres)

		Initial	2010	2025	2055	2085	2100
	Undeveloped Dry Land	196,599	195,337	195,114	193,669	190,584	188,982
	Estuarine Open Water	119,683	119,861	120,237	120,835	122,071	123,855
	Developed Dry Land	88,504	88,153	88,078	87,220	83,824	82,005
	Irreg.-Flooded Marsh	11,211	10,306	10,146	7,791	1,001	503
	Swamp	8,591	8,531	8,511	8,405	8,143	8,011
	Inland Open Water	4,561	4,523	4,494	4,476	4,385	4,346
	Estuarine Beach	2,457	2,406	2,354	2,065	1,536	1,270
	Regularly-Flooded Marsh	1,182	2,114	2,938	5,993	13,904	13,386
	Trans. Salt Marsh	158	1,472	928	1,734	2,430	2,445
	Inland-Fresh Marsh	850	819	811	750	633	605
	Tidal-Fresh Marsh	743	710	708	651	450	264
	Tidal Swamp	667	629	614	463	227	172
	Riverine Tidal	452	387	115	80	57	48
	Flooded Developed Dry Land	0	351	427	1,284	4,681	6,500
	Tidal Flat	98	159	286	353	1,853	3,392
	Inland Shore	120	120	120	120	120	120
	Rocky Intertidal	62	58	57	50	42	35
	Total (incl. water)	**435,938**	**435,938**	**435,938**	**435,938**	**435,938**	**435,938**

Table 27. Entire Study Area, RIM Max (Acres)

		Initial	2010	2025	2055	2085	2100
	Undeveloped Dry Land	196,599	195,337	194,848	192,570	188,844	187,181
	Estuarine Open Water	119,683	119,861	120,307	121,302	124,354	128,094
	Developed Dry Land	88,504	88,153	87,983	86,050	81,843	79,752
	Irreg.-Flooded Marsh	11,211	10,306	9,847	3,416	454	267
	Swamp	8,591	8,531	8,486	8,294	7,980	7,817
	Inland Open Water	4,561	4,523	4,493	4,434	4,345	4,318
	Estuarine Beach	2,457	2,402	2,299	1,856	1,252	1,033
	Regularly-Flooded Marsh	1,182	2,114	3,350	11,050	12,526	11,890
	Trans. Salt Marsh	158	1,476	1,098	2,067	2,536	2,322
	Inland-Fresh Marsh	850	819	802	704	603	583
	Tidal-Fresh Marsh	743	710	688	559	195	102
	Tidal Swamp	667	629	592	343	164	122
	Riverine Tidal	452	387	112	72	48	41
	Flooded Developed Dry Land	0	351	522	2,455	6,661	8,752
	Tidal Flat	98	159	336	599	3,978	3,514
	Inland Shore	120	120	120	120	120	120
	Rocky Intertidal	62	58	55	47	35	28
	Total (incl. water)	**435,938**	**435,938**	**435,938**	**435,938**	**435,938**	**435,938**

Dry-land loss rates are somewhat more linear with respect to sea-level rise effects. Up to 9% of developed lands and up to 4% of undeveloped lands have been found to be vulnerable under the SLR scenarios examined (Figure 21).

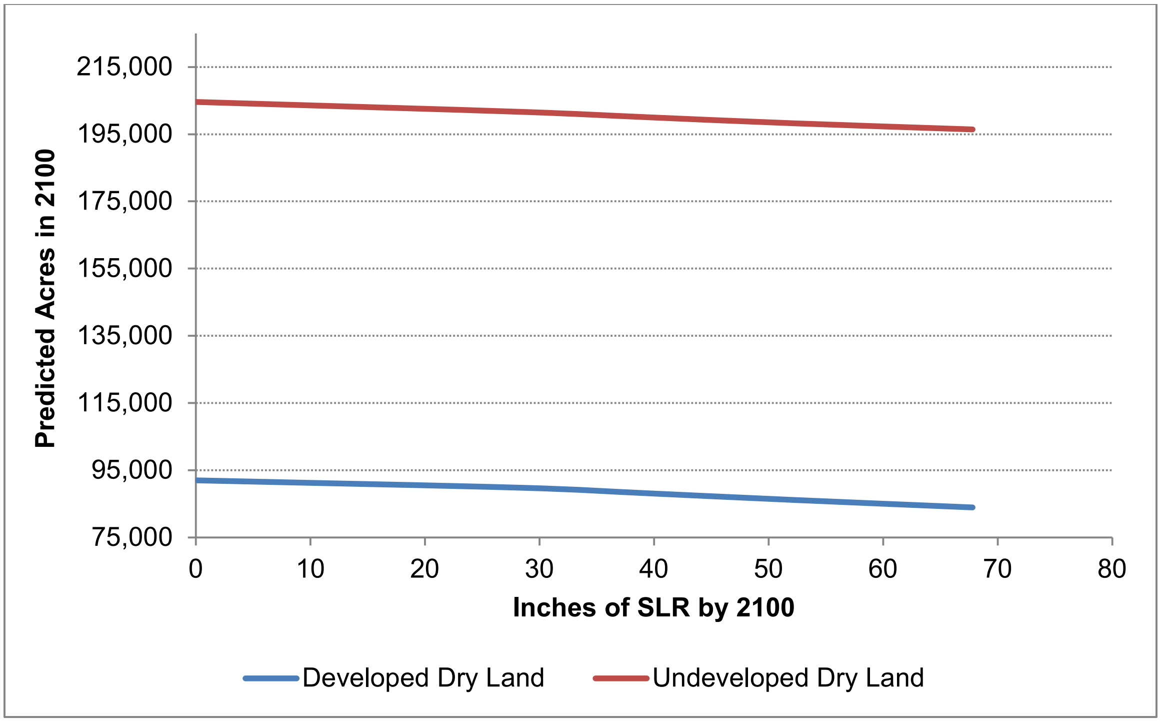


Figure 21. Dry-land fate as a function of SLR by 2100

Presenting results maps for the entire study area, which was mapped at 5 meters cell size, is not practical for this type of report. However, the sections below will discuss results for each of the seven relevant watersheds in the study area and will present maps of some areas of particular interest. Maps presented herein are only a tiny portion of available mapped output,. As part of this project, GIS maps of the entire study area are being made publicly available for every scenario and time-step simulated along with numerous maps derived from uncertainty analyses (http://warrenpinnacle.com/prof/SLAMM/LISS/). Watershed results are presented below moving from west to east. Tables of results broken down by county are available in Appendix D of this document.

3.2 Southwest Coast Watershed

The Southwest Coast watershed is the largest portion of the study area, and results are similar to the results for the entire study area. Table 28 shows that irregularly-flooded marshes are expected to decline by at least 25% by 2100 and up to 97%. Low marshes, on the other hand, are predicted to increase by a factor of 2 to 5 by 2100 depending on the SLR scenario examined.

Table 28. Southwest Coast Watershed Landcover Change Summary
(positive indicates a gain, negative is a loss)

Land cover category	Acres in 2010	Percentage Land cover change from 2010 to 2100 for different SLR scenarios			
		GCM Max	1m	RIM Min	RIM Max
Undeveloped Dry Land	120,224	-0.7	-1.0	-1.4	-1.8
Estuarine Open Water	58,788	0.3	0.5	0.7	1.1
Developed Dry Land	47,566	-2.9	-5.0	-7.2	-9.0
Swamp	4,412	-1.3	-1.8	-2.2	-2.4
Inland Open Water	3,476	-1.4	-1.6	-1.8	-2.1
Irreg.-Flooded Marsh	980	-26.1	-78.9	-93.0	-96.6
Estuarine Beach	801	-7.7	-17.0	-27.6	-37.1
Regularly-Flooded Marsh	426	167.3	360.6	482.8	521.1
Inland-Fresh Marsh	336	-10.1	-11.1	-12.8	-12.9
Trans. Salt Marsh	284	137.3	186.2	168.0	114.4
Flooded Developed Dry Land	141	972.9	1693.4	2414.2	3045.7
Inland Shore	119	0.0	0.0	0.0	0.0
Tidal Flat	49	1.1	57.6	294.6	937.5
Riverine Tidal	24	-84.0	-85.0	-90.5	-90.6
Rocky Intertidal	20	-7.2	-11.9	-18.7	-35.7
Tidal Swamp	18	-9.4	-18.9	-33.0	-40.5
Tidal-Fresh Marsh	14	-10.2	-33.8	-59.9	-75.5

Figure 22 shows predictions for marshes and dry lands in a portion of Bridgeport, CT under one meter of SLR by 2100. In this location, the majority of high marsh has become more-regularly flooded and extensive flooded developed lands are predicted.

Figure 23 shows this same location under rapid ice melt scenarios which results in additional flooded developed lands, but the salt marshes in this region have the potential to remain fairly resilient against this sea-level rise due to their initial-condition elevations and rates of vertical accretion. Some tidal-flats and open-water regions are predicted, however, suggesting that the remaining marshes are on the brink of extensive habitat loss under these higher scenarios.

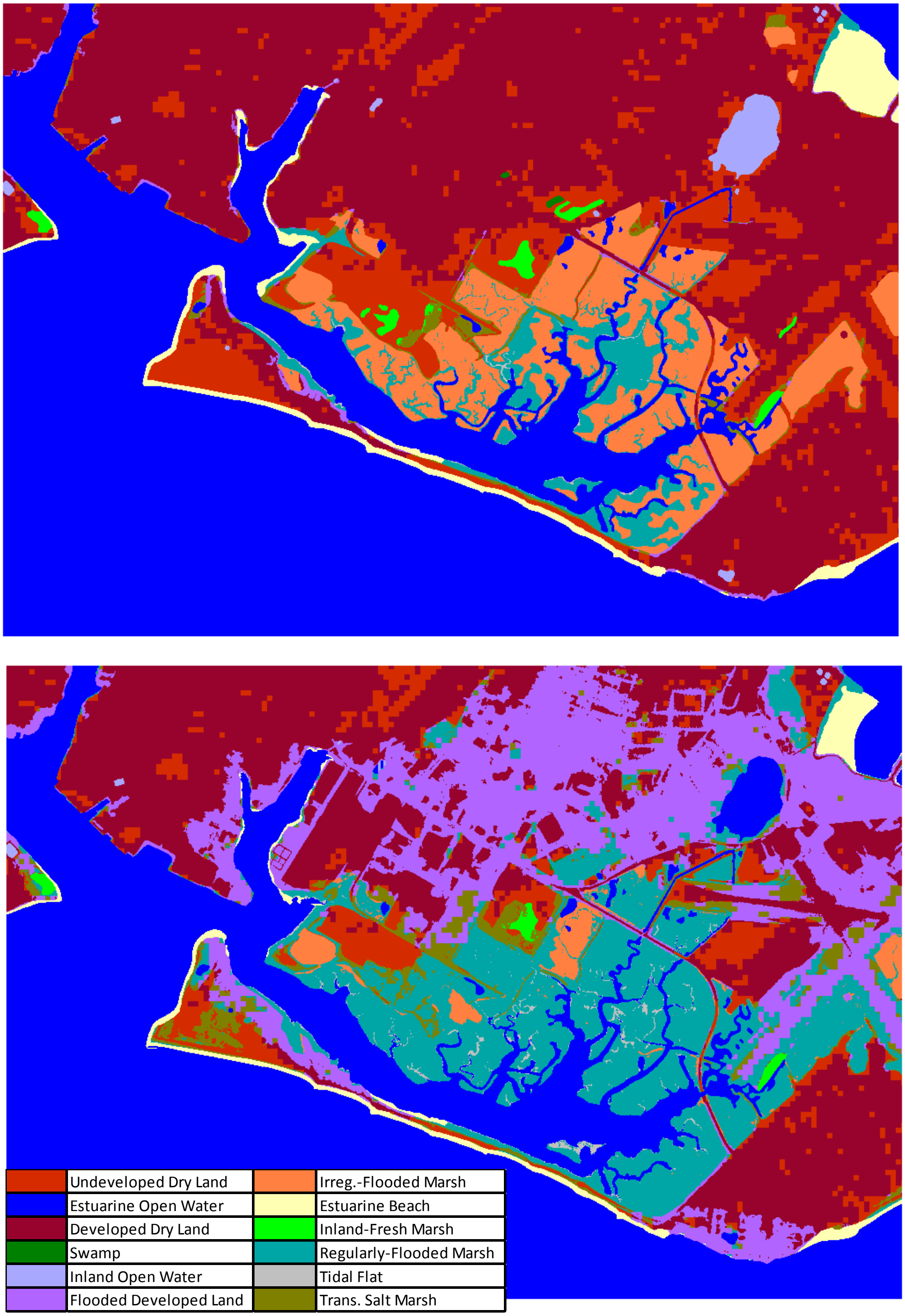


Figure 22. SLAMM predictions for Marshes in Bridgeport Connecticut by Pleasure Beach
Top map shows current conditions and bottom maps in 2100 given 1 meter of SLR

Note, SLAMM output maps show current or predicted land-cover <u>conditions at low tide (MLLW)</u>

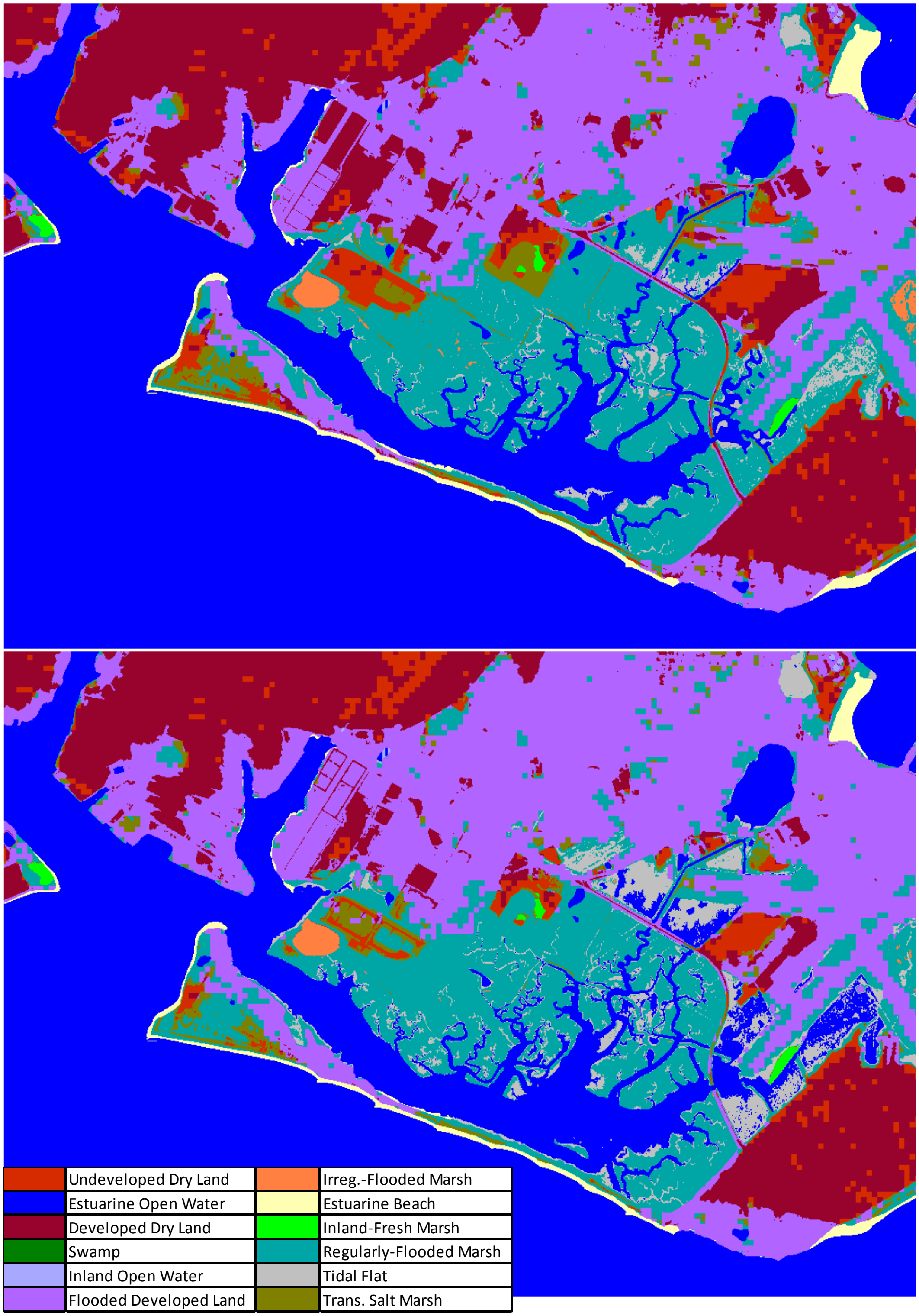


Figure 23. SLAMM predictions for Marshes in Bridgeport Connecticut under Rapid Ice Melt Scenarios
Top map shows RIM Minimum in 2100 (1.4 meters) and the bottom RIM Maximum in 2100 (1.7 meters)

Note, SLAMM output maps show current or predicted land-cover conditions at low tide (MLLW)

Table 29. Southwest Coast Watershed, GCM Max (Acres)

		Initial	2010	2025	2055	2085	2100
	Undeveloped Dry Land	120,479	120,224	120,179	120,050	119,615	119,431
	Estuarine Open Water	58,761	58,788	58,812	58,835	58,907	58,959
	Developed Dry Land	47,707	47,566	47,538	47,431	46,663	46,194
	Swamp	4,423	4,412	4,411	4,408	4,380	4,357
	Inland Open Water	3,484	3,476	3,470	3,467	3,443	3,428
	Irreg.-Flooded Marsh	1,112	980	968	937	823	724
	Estuarine Beach	814	801	798	790	763	739
	Inland-Fresh Marsh	342	336	335	331	302	302
	Regularly-Flooded Marsh	302	426	568	618	872	1,138
	Inland Shore	119	119	119	119	119	119
	Tidal Flat	38	49	54	59	54	49
	Riverine Tidal	27	24	12	8	5	4
	Rocky Intertidal	20	20	19	19	18	18
	Tidal Swamp	18	18	18	17	17	16
	Tidal-Fresh Marsh	15	14	14	14	13	13
	Trans. Salt Marsh	13	284	193	298	638	673
	Flooded Developed Dry Land	0	141	169	276	1,044	1,512
	Total (incl. water)	**237,676**	**237,676**	**237,676**	**237,676**	**237,676**	**237,676**

Table 30. Southwest Coast Watershed 1m (Acres)

		Initial	2010	2025	2055	2085	2100
	Undeveloped Dry Land	120,479	120,224	120,178	119,859	119,303	118,963
	Estuarine Open Water	58,761	58,788	58,812	58,854	58,994	59,070
	Developed Dry Land	47,707	47,566	47,538	47,135	45,921	45,179
	Swamp	4,423	4,412	4,411	4,404	4,347	4,333
	Inland Open Water	3,484	3,476	3,470	3,466	3,427	3,421
	Irreg.-Flooded Marsh	1,112	980	967	869	479	207
	Estuarine Beach	814	801	798	781	716	665
	Inland-Fresh Marsh	342	336	334	327	301	299
	Regularly-Flooded Marsh	302	426	569	720	1,470	1,961
	Inland Shore	119	119	119	119	119	119
	Tidal Flat	38	49	54	67	70	77
	Riverine Tidal	27	24	12	7	4	4
	Rocky Intertidal	20	20	19	19	18	17
	Tidal Swamp	18	18	18	17	15	14
	Tidal-Fresh Marsh	15	14	14	13	11	9
	Trans. Salt Marsh	13	284	194	448	695	812
	Flooded Developed Dry Land	0	141	169	572	1,786	2,528
	Total (incl. water)	**237,676**	**237,676**	**237,676**	**237,676**	**237,676**	**237,676**

Table 31. Southwest Coast Watershed RIM MIN (Acres)

		Initial	2010	2025	2055	2085	2100
	Undeveloped Dry Land	120,479	120,224	120,179	119,797	118,898	118,508
	Estuarine Open Water	58,761	58,788	58,812	58,865	59,089	59,202
	Developed Dry Land	47,707	47,566	47,538	47,044	45,016	44,163
	Swamp	4,423	4,412	4,411	4,404	4,330	4,317
	Inland Open Water	3,484	3,476	3,470	3,464	3,421	3,414
	Irreg.-Flooded Marsh	1,112	980	968	842	148	68
	Estuarine Beach	814	801	798	775	651	580
	Inland-Fresh Marsh	342	336	335	326	298	293
	Regularly-Flooded Marsh	302	426	568	768	2,073	2,481
	Inland Shore	119	119	119	119	119	119
	Tidal Flat	38	49	54	70	105	192
	Riverine Tidal	27	24	12	7	4	2
	Rocky Intertidal	20	20	19	19	17	16
	Tidal Swamp	18	18	18	17	14	12
	Tidal-Fresh Marsh	15	14	14	13	8	6
	Trans. Salt Marsh	13	284	193	484	795	760
	Flooded Developed Dry Land	0	141	169	663	2,691	3,544
	Total (incl. water)	**237,676**	**237,676**	**237,676**	**237,676**	**237,676**	**237,676**

Table 32. Southwest Coast Watershed RIM MAX (Acres)

		Initial	2010	2025	2055	2085	2100
	Undeveloped Dry Land	120,479	120,224	120,130	119,477	118,480	118,114
	Estuarine Open Water	58,761	58,788	58,818	58,942	59,228	59,411
	Developed Dry Land	47,707	47,566	47,501	46,285	44,097	43,273
	Swamp	4,423	4,412	4,409	4,352	4,315	4,307
	Inland Open Water	3,484	3,476	3,470	3,443	3,414	3,404
	Irreg.-Flooded Marsh	1,112	980	944	569	60	33
	Estuarine Beach	814	801	795	741	573	504
	Inland-Fresh Marsh	342	336	334	302	293	293
	Regularly-Flooded Marsh	302	426	605	1,195	2,453	2,644
	Inland Shore	119	119	119	119	119	119
	Tidal Flat	38	49	60	92	258	504
	Riverine Tidal	27	24	11	5	2	2
	Rocky Intertidal	20	20	19	18	16	13
	Tidal Swamp	18	18	17	16	12	10
	Tidal-Fresh Marsh	15	14	14	10	5	3
	Trans. Salt Marsh	13	284	225	689	742	608
	Flooded Developed Dry Land	0	141	206	1,422	3,609	4,434
	Total (incl. water)	**237,676**	**237,676**	**237,676**	**237,676**	**237,676**	**237,676**

3.3 Housatonic River Watershed

The narrow Housatonic River watershed has nearly 1000 acres of intertidal marshes towards its mouth. As usual, the high marshes are most plentiful initially but most vulnerable, with up to 96% loss predicted by 2100. Open water in this portion of the study area can increase by as much as 6%, with up to 145 acres of wetlands converting to open waters. Up to 136 acres of coastal developed land is also predicted to become regularly flooded.

Table 33. Housatonic River Watershed land cover change summary
(positive indicates a gain, negative is a loss)

Land cover category	Acres in 2010	Percentage Land cover change from 2010 to 2100 for different SLR scenarios			
		GCM Max	1m	RIM Min	RIM Max
Developed Dry Land	6,552	-2.0	-3.2	-4.9	-6.7
Undeveloped Dry Land	6,210	-1.9	-2.9	-4.2	-5.2
Estuarine Open Water	5,790	2.0	2.9	4.2	6.5
Irreg.-Flooded Marsh	653	-25.8	-62.6	-88.5	-96.1
Regularly-Flooded Marsh	323	78.1	152.1	204.4	222.7
Swamp	315	-0.1	-0.2	-0.4	-0.4
Estuarine Beach	308	-32.9	-45.1	-58.7	-69.0
Inland Open Water	93	-4.7	-7.8	-10.9	-11.6
Trans. Salt Marsh	80	37.2	43.9	49.1	13.4
Inland-Fresh Marsh	36	-25.9	-33.2	-46.8	-48.6
Flooded Developed Dry Land	32	421.8	661.1	1019.0	1374.7
Tidal-Fresh Marsh	29	-10.1	-31.4	-60.9	-85.1
Tidal Flat	11	92.2	642.4	1212.1	1134.1
Tidal Swamp	8	-21.8	-44.1	-59.9	-68.4
Riverine Tidal	2	-90.6	-93.9	-97.0	-97.3

Figure 24 shows model outputs for the mouth of the Housatonic River as it empties into Long Island Sound. Given 1 meter of SLR by 2100, regularly-flooded marsh starts to dominate, but given 1.7 meters of SLR by 2100, much of the initial low marshes have converted to open water. Additionally, more frequent inundation is predicted to move up the river converting much of the irregularly-flooded marshes and tidal-fresh marshes into low marshes. However, how far salinity will move up the river is uncertain and is governed as much by changes in fresh water flows as it is by sea-level rise.

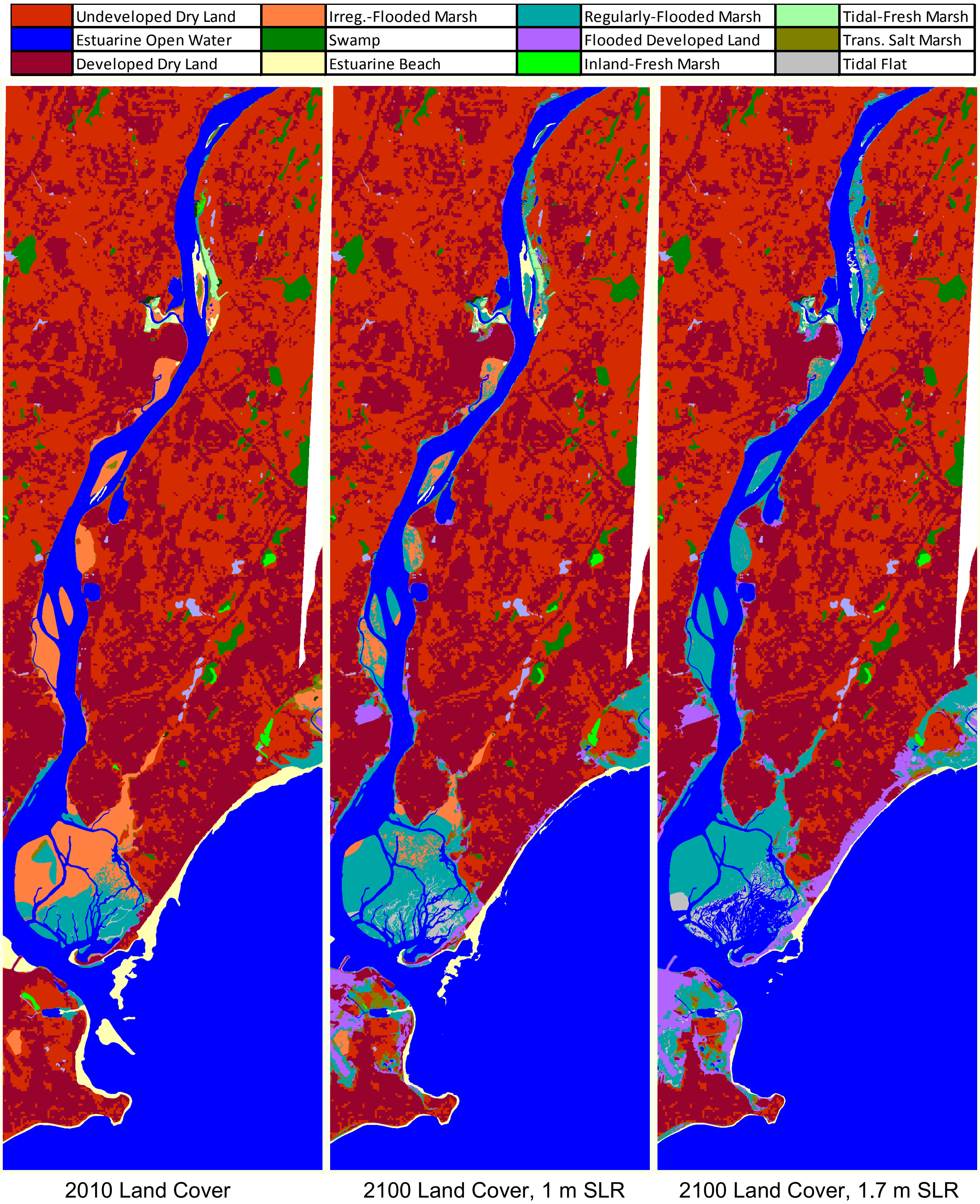


Figure 24. SLAMM predictions for the mouth of the Housatonic River in 2100 compared to initial conditions

Table 34. Housatonic River Watershed GCM Max

		Initial	2010	2025	2055	2085	2100
	Developed Dry Land	6,584	6,552	6,547	6,533	6,451	6,418
	Undeveloped Dry Land	6,269	6,210	6,206	6,183	6,117	6,091
	Estuarine Open Water	5,765	5,790	5,792	5,810	5,875	5,908
	Irreg.-Flooded Marsh	710	653	646	632	567	485
	Regularly-Flooded Marsh	248	323	368	393	471	574
	Swamp	315	315	315	315	314	314
	Estuarine Beach	308	308	307	292	234	206
	Inland Open Water	115	93	93	91	89	88
	Trans. Salt Marsh	44	80	44	58	109	110
	Inland-Fresh Marsh	38	36	36	34	28	27
	Flooded Developed Dry Land	0	32	37	51	133	166
	Tidal-Fresh Marsh	31	29	29	28	27	27
	Tidal Flat	0	11	12	13	19	20
	Tidal Swamp	9	8	8	8	7	6
	Riverine Tidal	4	2	1	0	0	0
	Total (incl. water)	**20,441**	**20,441**	**20,441**	**20,441**	**20,441**	**20,441**

Table 29. Housatonic River Watershed 1 m SLR by 2100

		Initial	2010	2025	2055	2085	2100
	Developed Dry Land	6,584	6,552	6,547	6,519	6,396	6,342
	Undeveloped Dry Land	6,269	6,210	6,206	6,171	6,065	6,027
	Estuarine Open Water	5,765	5,790	5,792	5,837	5,930	5,960
	Irreg.-Flooded Marsh	710	653	646	605	392	244
	Regularly-Flooded Marsh	248	323	369	418	654	813
	Swamp	315	315	315	315	314	314
	Estuarine Beach	308	308	307	266	191	169
	Inland Open Water	115	93	93	91	87	86
	Trans. Salt Marsh	44	80	44	63	119	115
	Inland-Fresh Marsh	38	36	36	33	25	24
	Flooded Developed Dry Land	0	32	37	64	188	242
	Tidal-Fresh Marsh	31	29	29	27	21	20
	Tidal Flat	0	11	12	24	54	79
	Tidal Swamp	9	8	8	7	5	5
	Riverine Tidal	4	2	1	0	0	0
	Total (incl. water)	**20,441**	**20,441**	**20,441**	**20,441**	**20,441**	**20,441**

Table 35. Housatonic River Watershed RIM Min

		Initial	2010	2025	2055	2085	2100
	Developed Dry Land	6,584	6,552	6,547	6,511	6,331	6,228
	Undeveloped Dry Land	6,269	6,210	6,206	6,157	6,019	5,949
	Estuarine Open Water	5,765	5,790	5,792	5,850	5,969	6,035
	Irreg.-Flooded Marsh	710	653	646	582	181	75
	Regularly-Flooded Marsh	248	323	368	439	852	982
	Swamp	315	315	315	315	314	313
	Estuarine Beach	308	308	307	254	163	127
	Inland Open Water	115	93	93	91	86	83
	Trans. Salt Marsh	44	80	44	74	117	120
	Inland-Fresh Marsh	38	36	36	30	20	19
	Flooded Developed Dry Land	0	32	37	73	253	356
	Tidal-Fresh Marsh	31	29	29	27	18	12
	Tidal Flat	0	11	12	31	114	139
	Tidal Swamp	9	8	8	7	4	3
	Riverine Tidal	4	2	1	0	0	0
	Total (incl. water)	**20,441**	**20,441**	**20,441**	**20,441**	**20,441**	**20,441**

Table 36. Housatonic River Watershed RIM Max

		Initial	2010	2025	2055	2085	2100
	Developed Dry Land	6,584	6,552	6,540	6,428	6,217	6,115
	Undeveloped Dry Land	6,269	6,210	6,193	6,100	5,944	5,888
	Estuarine Open Water	5,765	5,790	5,798	5,907	6,063	6,164
	Irreg.-Flooded Marsh	710	653	637	426	63	25
	Regularly-Flooded Marsh	248	323	381	575	984	1,041
	Swamp	315	315	315	314	313	313
	Estuarine Beach	308	308	302	207	125	96
	Inland Open Water	115	93	93	88	83	82
	Trans. Salt Marsh	44	80	50	110	115	91
	Inland-Fresh Marsh	38	36	34	26	19	18
	Flooded Developed Dry Land	0	32	44	156	366	469
	Tidal-Fresh Marsh	31	29	27	21	9	4
	Tidal Flat	0	11	19	76	136	131
	Tidal Swamp	9	8	8	6	3	3
	Riverine Tidal	4	2	1	0	0	0
	Total (incl. water)	**20,441**	**20,441**	**20,441**	**20,441**	**20,441**	**20,441**

3.4 South Central Coast Watershed

Within the south central coast watershed tide ranges are starting to decrease compared to the watersheds to the west. Therefore, while low marshes are predicted to thrive under many SLR scenarios, more tidal flats and open waters start to be predicted, especially under rapid-ice-melt scenarios.

Table 37. South Central Coast Watershed Landcover Change Summary
(positive indicates a gain, negative is a loss)

Land cover category	Acres in 2010	Percentage Land cover change from 2010 to 2100 for different SLR scenarios			
		GCM Max	1m	RIM Min	RIM Max
Undeveloped Dry Land	26,245	-3.5	-5.4	-7.8	-10.4
Estuarine Open Water	22,237	2.2	3.2	4.7	7.9
Developed Dry Land	20,987	-2.0	-4.0	-6.7	-10.7
Irreg.-Flooded Marsh	4,992	-48.1	-89.5	-95.4	-97.3
Swamp	2,186	-4.5	-7.4	-11.2	-17.3
Estuarine Beach	1,018	-31.5	-44.0	-59.1	-68.7
Regularly-Flooded Marsh	979	353.8	605.6	637.6	544.3
Inland Open Water	468	-7.6	-10.6	-12.5	-15.2
Trans. Salt Marsh	402	-16.6	10.9	59.0	98.6
Inland-Fresh Marsh	276	-17.2	-32.9	-40.5	-46.9
Flooded Developed Dry Land	100	428.3	836.0	1409.0	2248.2
Tidal-Fresh Marsh	96	-1.7	-5.0	-19.7	-55.0
Tidal Swamp	74	-23.2	-49.4	-64.4	-77.2
Tidal Flat	71	-44.5	52.4	567.1	2167.4
Rocky Intertidal	30	-29.4	-38.5	-54.4	-62.8
Riverine Tidal	30	-85.3	-86.0	-86.0	-86.4
Inland Shore	1	0.0	0.0	0.0	0.0

Figure 25 illustrates the effects of SLR on the Hammock River marshes behind the town beaches of Clinton CT, towards the eastern portion of this watershed. High marshes are universally converted to low marshes under the 1-meter scenario and under the higher scenarios, considerable unvegetated tidal flats and open water are predicted.

Undeveloped Dry Land	Irreg.-Flooded Marsh	Regularly-Flooded Marsh	Tidal-Fresh Marsh
Estuarine Open Water	Swamp	Flooded Developed Land	Trans. Salt Marsh
Developed Dry Land	Estuarine Beach	Inland-Fresh Marsh	Tidal Flat

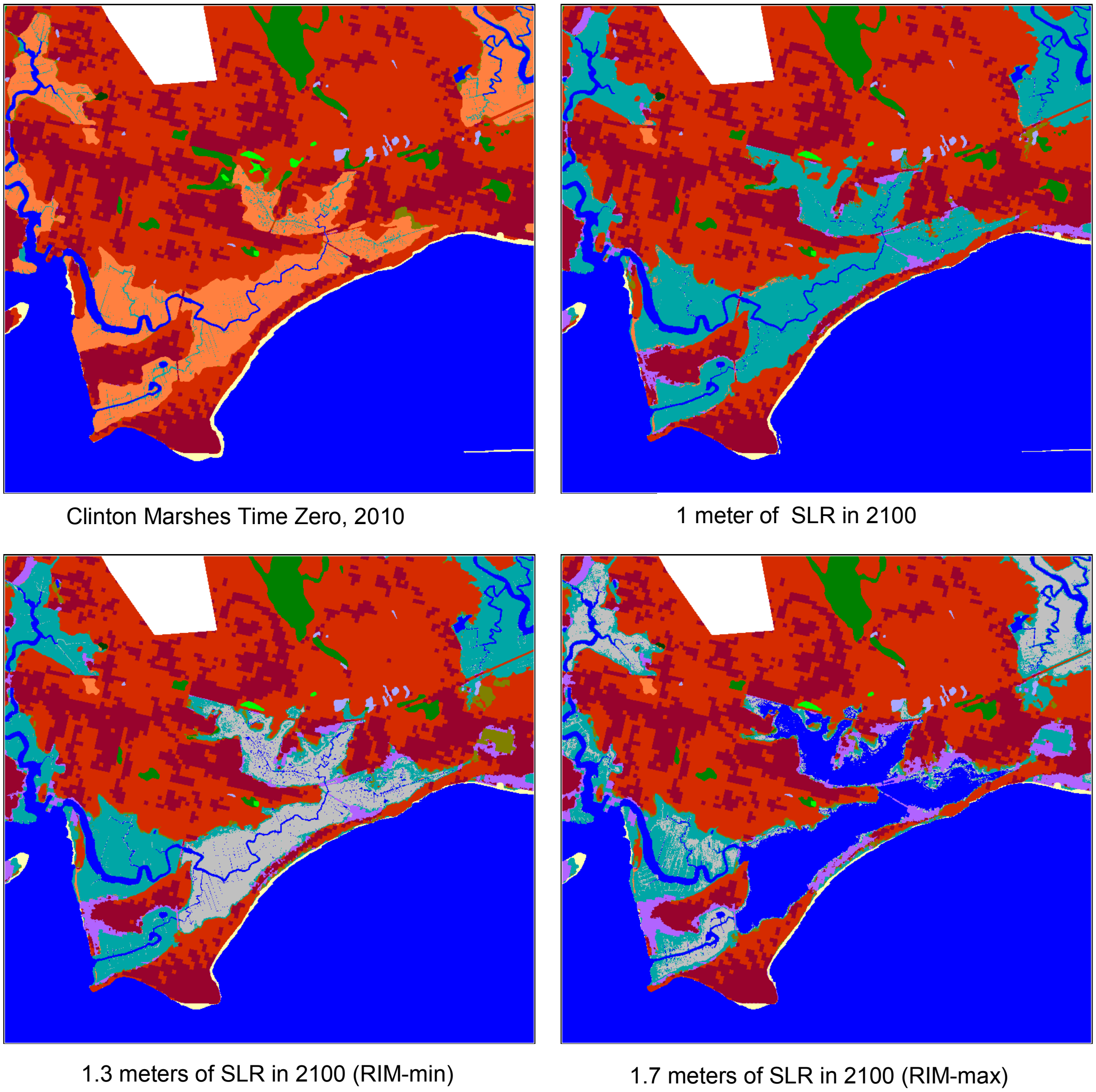


Figure 25. SLAMM predictions for Hammock River Marshes, Clinton CT in 2100 compared to initial conditions

Note, SLAMM output maps show current or predicted land-cover conditions at low tide (MLLW)

Table 38. South Central Coast GCM Max (Acres)

		Initial	2010	2025	2055	2085	2100
	Undeveloped Dry Land	26,585	26,245	26,171	25,980	25,564	25,337
	Estuarine Open Water	22,210	22,237	22,315	22,421	22,631	22,737
	Developed Dry Land	21,087	20,987	20,962	20,887	20,700	20,558
	Irreg.-Flooded Marsh	5,480	4,992	4,899	4,641	3,541	2,591
	Swamp	2,223	2,186	2,177	2,156	2,111	2,089
	Estuarine Beach	1,021	1,018	995	923	772	697
	Regularly-Flooded Marsh	507	979	1,376	1,776	3,243	4,441
	Inland Open Water	474	468	448	447	441	433
	Trans. Salt Marsh	12	402	144	199	327	335
	Inland-Fresh Marsh	294	276	270	261	235	229
	Flooded Developed Dry Land	0	100	126	200	387	529
	Tidal-Fresh Marsh	96	96	96	96	95	94
	Tidal Swamp	82	74	73	70	60	57
	Tidal Flat	50	71	107	104	58	39
	Rocky Intertidal	32	30	29	26	22	21
	Riverine Tidal	37	30	5	5	4	4
	Inland Shore	1	1	1	1	1	1
	Total (incl. water)	**80,193**	**80,193**	**80,193**	**80,193**	**80,193**	**80,193**

Figure 26. High Marsh Habitat in Clinton CT looking east from Town Beach, (photo credit J.Clough)

Table 39. South Central Coast 1m (Acres)

		Initial	2010	2025	2055	2085	2100
	Undeveloped Dry Land	26,585	26,245	26,169	25,810	25,165	24,820
	Estuarine Open Water	22,210	22,237	22,315	22,510	22,814	22,947
	Developed Dry Land	21,087	20,987	20,961	20,814	20,428	20,150
	Irreg.-Flooded Marsh	5,480	4,992	4,896	4,087	1,162	527
	Swamp	2,223	2,186	2,176	2,133	2,064	2,024
	Estuarine Beach	1,021	1,014	991	858	651	567
	Regularly-Flooded Marsh	507	979	1,383	2,448	5,931	6,905
	Inland Open Water	474	468	448	444	429	419
	Trans. Salt Marsh	12	406	145	285	429	451
	Inland-Fresh Marsh	294	276	270	243	217	185
	Flooded Developed Dry Land	0	100	126	273	659	938
	Tidal-Fresh Marsh	96	96	96	95	93	91
	Tidal Swamp	82	74	73	64	50	38
	Tidal Flat	50	71	107	101	75	108
	Rocky Intertidal	32	30	29	24	20	18
	Riverine Tidal	37	30	5	5	4	4
	Inland Shore	1	1	1	1	1	1
	Total (incl. water)	**80,193**	**80,193**	**80,193**	**80,192**	**80,193**	**80,193**

Table 40. South Central Coast RIM Min (Acres)

		Initial	2010	2025	2055	2085	2100
	Undeveloped Dry Land	26,585	26,245	26,171	25,733	24,747	24,210
	Estuarine Open Water	22,210	22,237	22,315	22,554	23,023	23,279
	Developed Dry Land	21,087	20,987	20,962	20,781	20,078	19,576
	Irreg.-Flooded Marsh	5,480	4,992	4,899	3,755	421	232
	Swamp	2,223	2,186	2,177	2,120	2,012	1,941
	Estuarine Beach	1,021	1,018	995	830	552	417
	Regularly-Flooded Marsh	507	979	1,376	2,813	6,824	7,218
	Inland Open Water	474	468	448	443	419	410
	Trans. Salt Marsh	12	402	144	329	619	639
	Inland-Fresh Marsh	294	276	270	239	180	164
	Flooded Developed Dry Land	0	100	126	306	1,010	1,512
	Tidal-Fresh Marsh	96	96	96	94	88	77
	Tidal Swamp	82	74	73	62	35	26
	Tidal Flat	50	71	107	104	162	473
	Rocky Intertidal	32	30	29	23	18	14
	Riverine Tidal	37	30	5	5	4	4
	Inland Shore	1	1	1	1	1	1
	Total (incl. water)	**80,193**	**80,193**	**80,193**	**80,193**	**80,193**	**80,193**

Table 41. South Central Coast RIM Max (Acres)

		Initial	2010	2025	2055	2085	2100
	Undeveloped Dry Land	26,585	26,245	26,082	25,380	24,160	23,504
	Estuarine Open Water	22,210	22,237	22,346	22,732	23,405	24,004
	Developed Dry Land	21,087	20,987	20,930	20,594	19,529	18,735
	Irreg.-Flooded Marsh	5,480	4,992	4,706	1,552	209	133
	Swamp	2,223	2,186	2,163	2,081	1,929	1,807
	Estuarine Beach	1,021	1,014	969	716	410	317
	Regularly-Flooded Marsh	507	979	1,584	5,165	6,851	6,305
	Inland Open Water	474	468	447	433	410	397
	Trans. Salt Marsh	12	406	227	470	731	807
	Inland-Fresh Marsh	294	276	265	228	163	147
	Flooded Developed Dry Land	0	100	157	494	1,558	2,352
	Tidal-Fresh Marsh	96	96	95	92	70	43
	Tidal Swamp	82	74	72	56	25	17
	Tidal Flat	50	71	116	175	724	1,608
	Rocky Intertidal	32	30	28	21	13	11
	Riverine Tidal	37	30	5	4	4	4
	Inland Shore	1	1	1	1	1	1
	Total (incl. water)	**80,193**	**80,193**	**80,193**	**80,193**	**80,193**	**80,193**

3.5 Connecticut River Watershed

The narrow Connecticut River watershed continues the trend of increasing vulnerability (from west to east) with 94% to 99% of high marsh habitat predicted to be lost in SLR scenarios of over 1 meter (Table 42). As many as 3,600 acres of additional open water is predicted if SLR reaches 1.7 meters. Tidal fresh habitats are predicted to be flooded more frequently and likely converted on the basis of increased salinity.

Table 42 Connecticut River Watershed Landcover Change Summary
(positive indicates a gain, negative is a loss)

Land cover category	Acres in 2010	Percentage Land cover change from 2010 to 2100 for different SLR scenarios			
		GCM Max	1m	RIM Min	RIM Max
Undeveloped Dry Land	20,304	-2.2	-3.1	-4.1	-5.0
Estuarine Open Water	6,028	8.1	10.4	19.1	58.6
Developed Dry Land	2,450	-1.7	-2.8	-4.3	-5.9
Irreg.-Flooded Marsh	2,362	-57.6	-93.9	-98.1	-98.9
Swamp	743	-0.9	-1.7	-2.1	-2.5
Tidal-Fresh Marsh	549	-10.2	-32.1	-72.4	-93.4
Tidal Swamp	342	-63.6	-77.1	-85.1	-90.1
Riverine Tidal	328	-83.6	-86.0	-88.0	-89.9
Transitional Salt Marsh	294	17.9	1.2	-11.3	-18.5
Inland Open Water	263	-2.0	-2.7	-4.1	-5.4
Regularly-Flooded Marsh	260	702.7	1055.6	460.6	163.8
Estuarine Beach	79	-82.8	-86.5	-89.8	-92.3
Inland-Fresh Marsh	55	-6.1	-7.4	-10.5	-12.5
Tidal Flat	24	251.0	1195.1	8091.8	2882.4
Flooded Developed Dry Land	9	469.3	772.0	1196.3	1637.0

Figure 27 illustrates predictions at the mouth of the Connecticut River. Open water and tidal flats are predicted to become prevalent under 1.3 meters of SLR and nearly all marshes are lost and converted to open water by 2100. The relatively steep shorelines of the CT River mean that there are few locations for marsh transgression. Much of the dry lands that could offer new marsh habitat are developed and thus unlikely to offer a smooth marsh-migration process.

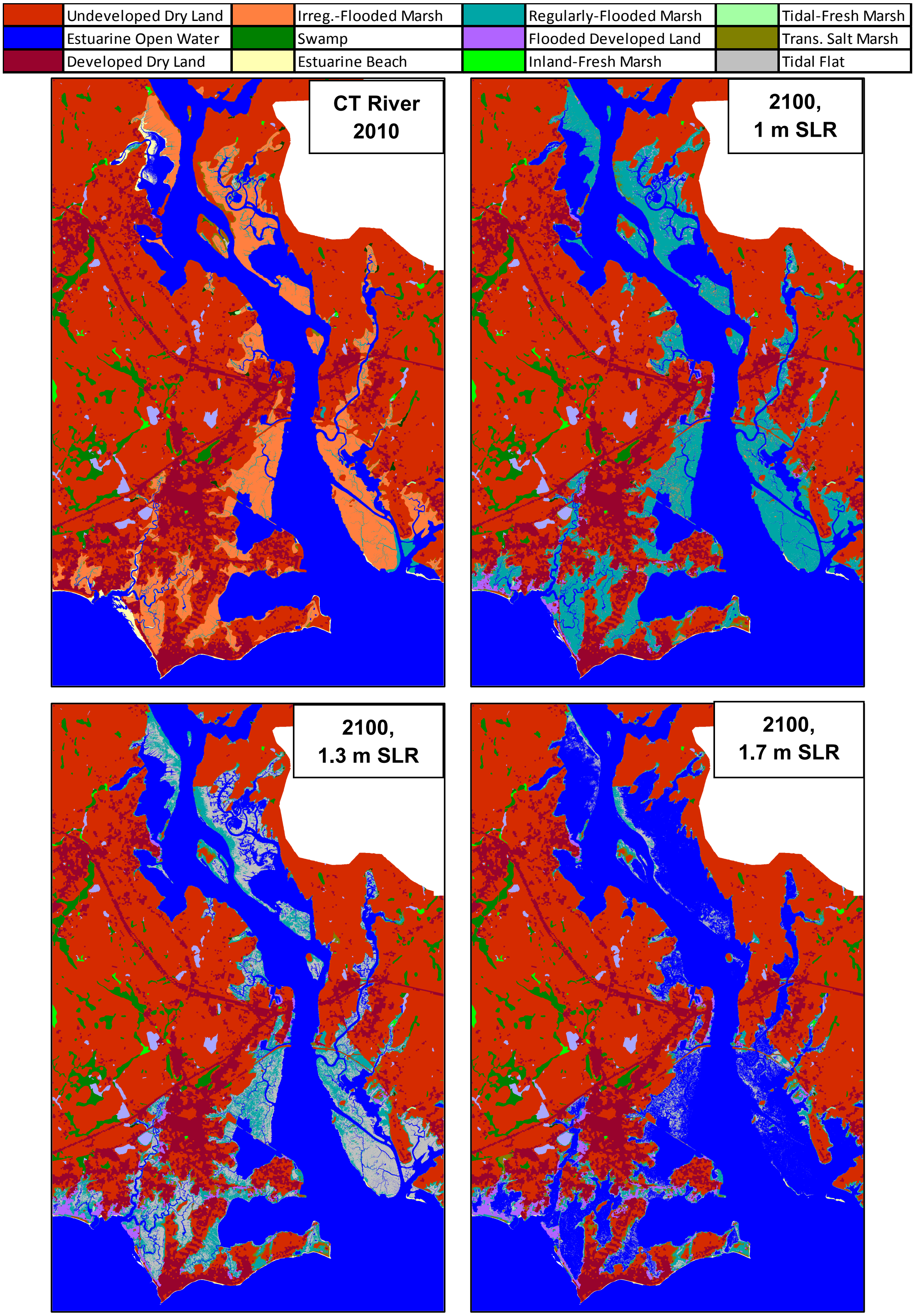


Figure 27. SLAMM Predictions for the Mouth of the CT River, Initial Condition vs. 2100

Table 43. Connecticut River Watershed GCM Max (Acres)

		Initial	2010	2025	2055	2085	2100
	Undeveloped Dry Land	20,587	20,304	20,260	20,143	19,950	19,862
	Estuarine Open Water	5,951	6,028	6,293	6,394	6,487	6,518
	Irreg.-Flooded Marsh	2,529	2,362	2,324	2,237	1,682	1,002
	Developed Dry Land	2,459	2,450	2,448	2,440	2,420	2,409
	Swamp	748	743	742	741	737	736
	Tidal-Fresh Marsh	579	549	547	542	510	493
	Riverine Tidal	377	328	94	73	59	54
	Tidal Swamp	370	342	329	290	165	125
	Inland Open Water	263	263	261	261	260	257
	Estuarine Beach	107	79	56	26	16	14
	Regularly-Flooded Marsh	57	260	363	504	1,281	2,090
	Inland-Fresh Marsh	55	55	55	54	52	52
	Trans. Salt Marsh	6	294	222	291	365	346
	Tidal Flat	2	24	87	75	67	83
	Flooded Developed Dry Land	0	9	11	19	39	51
	Total (incl. water)	**34,090**	**34,090**	**34,090**	**34,090**	**34,090**	**34,090**

Table 44. Connecticut River Watershed 1m by 2100 (Acres)

		Initial	2010	2025	2055	2085	2100
	Undeveloped Dry Land	20,587	20,304	20,259	20,052	19,800	19,676
	Estuarine Open Water	5,951	6,028	6,293	6,444	6,569	6,655
	Irreg.-Flooded Marsh	2,529	2,362	2,323	2,048	415	143
	Developed Dry Land	2,459	2,450	2,448	2,433	2,400	2,382
	Swamp	748	743	742	738	735	730
	Tidal-Fresh Marsh	579	549	547	511	430	373
	Riverine Tidal	377	328	94	68	53	46
	Tidal Swamp	370	342	329	228	104	78
	Inland Open Water	263	263	261	260	257	255
	Estuarine Beach	107	79	56	19	12	11
	Regularly-Flooded Marsh	57	260	364	805	2,750	3,009
	Inland-Fresh Marsh	55	55	55	52	52	51
	Trans. Salt Marsh	6	294	222	317	300	297
	Tidal Flat	2	24	87	87	154	305
	Flooded Developed Dry Land	0	9	11	26	59	77
	Total (incl. water)	**34,090**	**34,090**	**34,090**	**34,090**	**34,090**	**34,090**

Table 45. Connecticut River Watershed RIM Min (Acres)

		Initial	2010	2025	2055	2085	2100
	Undeveloped Dry Land	20,587	20,304	20,260	20,018	19,651	19,478
	Estuarine Open Water	5,951	6,028	6,293	6,462	6,722	7,178
	Irreg.-Flooded Marsh	2,529	2,362	2,324	1,870	112	45
	Developed Dry Land	2,459	2,450	2,448	2,429	2,377	2,344
	Swamp	748	743	742	738	730	727
	Tidal-Fresh Marsh	579	549	547	496	316	151
	Riverine Tidal	377	328	94	66	47	39
	Tidal Swamp	370	342	329	199	71	51
	Inland Open Water	263	263	261	260	255	252
	Estuarine Beach	107	79	56	18	10	8
	Regularly-Flooded Marsh	57	260	363	1,031	2,771	1,460
	Inland-Fresh Marsh	55	55	55	52	51	49
	Trans. Salt Marsh	6	294	222	322	278	260
	Tidal Flat	2	24	87	100	617	1,932
	Flooded Developed Dry Land	0	9	11	30	82	115
	Total (incl. water)	**34,090**	**34,090**	**34,090**	**34,090**	**34,090**	**34,090**

Table 46. Connecticut River Watershed RIM Max (Acres)

		Initial	2010	2025	2055	2085	2100
	Undeveloped Dry Land	20,587	20,304	20,206	19,878	19,465	19,286
	Estuarine Open Water	5,951	6,028	6,316	6,556	7,418	9,559
	Irreg.-Flooded Marsh	2,529	2,362	2,276	602	45	25
	Developed Dry Land	2,459	2,450	2,444	2,410	2,342	2,305
	Swamp	748	743	741	736	727	725
	Tidal-Fresh Marsh	579	549	530	415	94	36
	Riverine Tidal	377	328	93	59	40	33
	Tidal Swamp	370	342	308	119	48	34
	Inland Open Water	263	263	261	258	252	248
	Estuarine Beach	107	79	37	14	8	6
	Regularly-Flooded Marsh	57	260	459	2,467	1,054	687
	Inland-Fresh Marsh	55	55	54	52	49	48
	Trans. Salt Marsh	6	294	240	287	259	239
	Tidal Flat	2	24	109	190	2,172	703
	Flooded Developed Dry Land	0	9	15	49	118	154
	Total (incl. water)	**34,090**	**34,090**	**34,090**	**34,090**	**34,090**	**34,090**

3.6 Southeast Coast Watershed

The coastal Southeast Coast watershed is split into two pieces with the narrow Thames watershed cutting in the middle. This watershed has the most vulnerable developed dry land in the study area with up to 16% of these lands vulnerable to regular flooding by 2100. Up to 27% of coastal fresh-water swamps and up to 69% of tidal swamps are also predicted to be vulnerable.

Table 47 Southeast Coast Watershed Landcover Change Summary
(positive indicates a gain, negative is a loss)

Land cover category	Acres in 2010	Percentage Land cover change from 2010 to 2100 for different SLR scenarios			
		GCM Max	1m	RIM Min	RIM Max
Estuarine Open Water	22,107	0.4	0.7	4.6	7.8
Undeveloped Dry Land	15,586	-3.6	-5.6	-8.1	-10.5
Developed Dry Land	6,412	-3.7	-6.9	-11.3	-15.7
Irreg.-Flooded Marsh	1,253	-73.9	-88.7	-93.8	-96.1
Swamp	737	-8.2	-14.1	-21.0	-27.0
Trans. Salt Marsh	300	77.5	84.8	83.8	55.9
Estuarine Beach	181	-9.6	-17.4	-29.4	-43.8
Tidal Swamp	180	-20.0	-41.4	-58.2	-69.0
Inland Open Water	174	-4.5	-9.1	-18.6	-18.8
Regularly-Flooded Marsh	115	1122.7	1444.7	850.9	802.8
Inland-Fresh Marsh	94	-20.0	-31.1	-37.0	-39.0
Flooded Developed Dry Land	44	536.2	996.9	1630.7	2263.6
Tidal-Fresh Marsh	21	-0.4	-2.5	-13.1	-31.4
Rocky Intertidal	8	-10.6	-18.5	-29.8	-38.4
Tidal Flat	5	287.8	3827.6	11827.3	10259.8

Figure 27 and Figure 28 show maps of SLAMM predictions from the mouth of the Thames River east into the Southeast Coast watershed. Loss of high-marsh habitat is predicted in this region as well as some conversion of marshes to open water under rapid ice melt scenarios. Parts of the Groton-New London airport are also predicted to be regularly flooded under all sea-level scenarios examined.

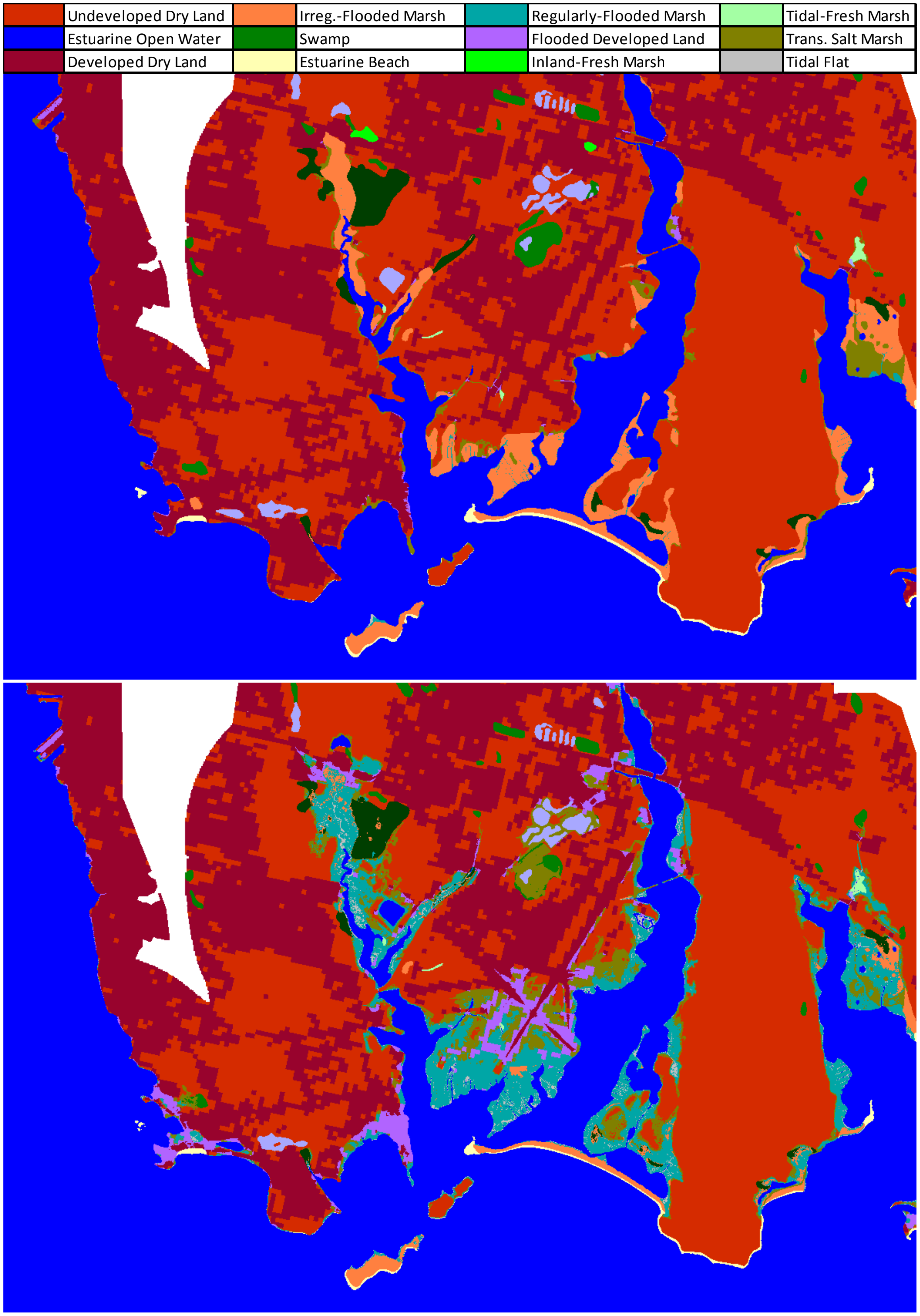


Figure 28. Predictions from the Eastern Mouth of the Thames River to Bluff Point State Park

Top figure shows 2010 conditions and bottom 2100 under 1 meter of SLR

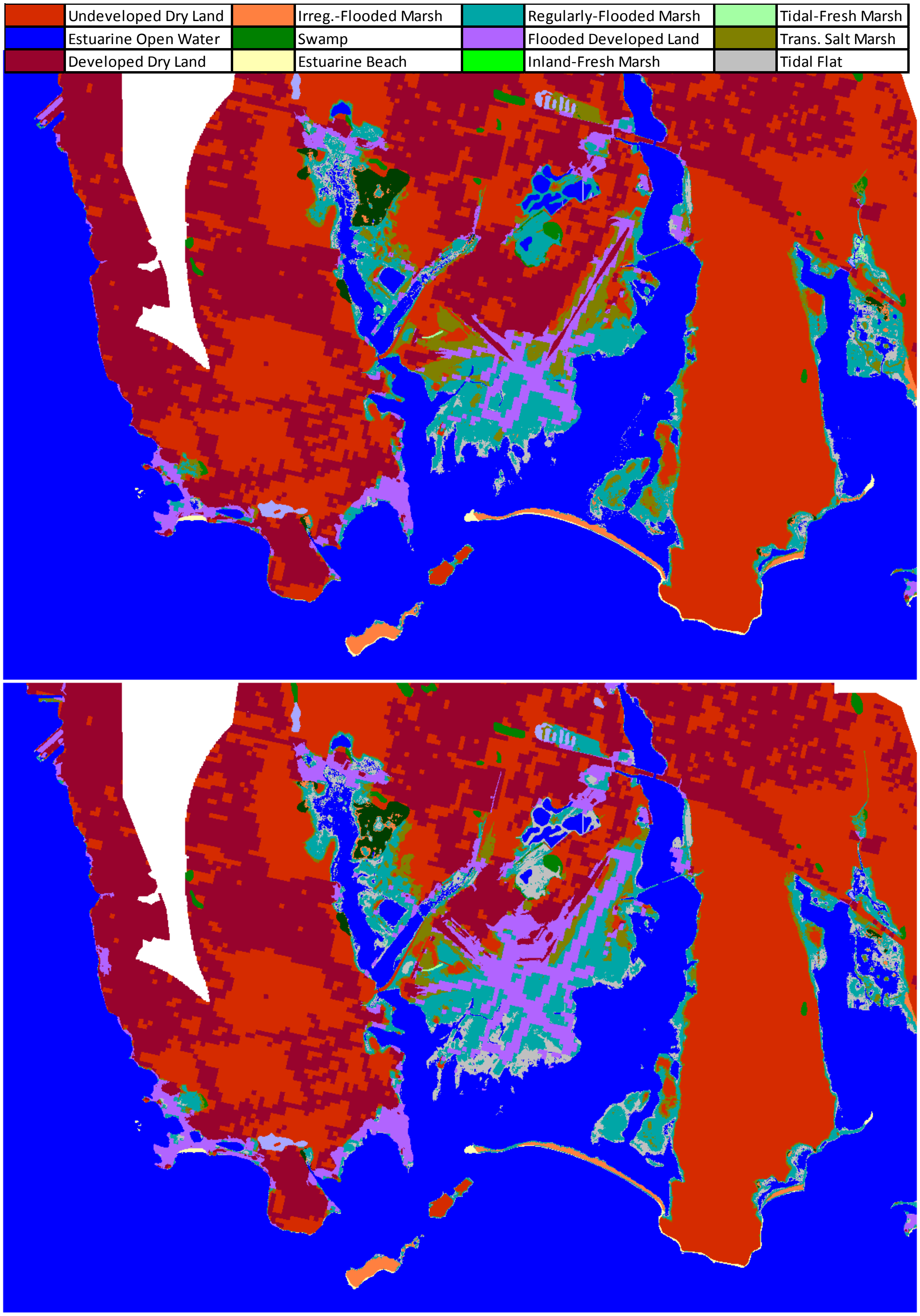


Figure 29. Rapid Ice Melt Predictions from the Eastern Mouth of the Thames River to Bluff Point State Park

Top figure shows 2100 conditions under 1.3 meters of SLR and the bottom 2100 under 1.7 meters of SLR

Table 48. Southeast Coast Watershed GCM Max (Acres)

		Initial	2010	2025	2055	2085	2100
	Estuarine Open Water	22,087	22,107	22,113	22,144	22,181	22,197
	Undeveloped Dry Land	15,805	15,586	15,541	15,420	15,162	15,029
	Developed Dry Land	6,456	6,412	6,401	6,360	6,244	6,174
	Irreg.-Flooded Marsh	1,308	1,253	1,246	1,207	587	328
	Swamp	742	737	729	716	687	676
	Estuarine Beach	189	181	180	176	170	164
	Tidal Swamp	181	180	180	179	162	144
	Inland Open Water	174	174	174	174	167	166
	Inland-Fresh Marsh	95	94	93	91	77	76
	Trans. Salt Marsh	81	300	271	368	522	533
	Regularly-Flooded Marsh	62	115	183	236	1,000	1,403
	Tidal-Fresh Marsh	21	21	21	21	21	21
	Tidal Flat	8	5	24	24	18	19
	Rocky Intertidal	8	8	7	7	7	7
	Flooded Developed Dry Land	0	44	56	96	213	283
	Total (incl. water)	**47,219**	**47,219**	**47,219**	**47,219**	**47,219**	**47,219**

Table 49. Southeast Coast Watershed 1m by 2100 (Acres)

		Initial	2010	2025	2055	2085	2100
	Estuarine Open Water	22,087	22,107	22,113	22,164	22,215	22,251
	Undeveloped Dry Land	15,805	15,586	15,540	15,304	14,938	14,711
	Developed Dry Land	6,456	6,412	6,400	6,315	6,122	5,969
	Irreg.-Flooded Marsh	1,308	1,253	1,246	917	215	142
	Swamp	742	737	729	696	669	633
	Estuarine Beach	189	181	180	174	160	150
	Tidal Swamp	181	180	180	175	128	106
	Inland Open Water	174	174	174	172	164	158
	Inland-Fresh Marsh	95	94	93	83	75	65
	Trans. Salt Marsh	81	300	272	444	492	555
	Regularly-Flooded Marsh	62	115	184	583	1,636	1,772
	Tidal-Fresh Marsh	21	21	21	21	21	20
	Tidal Flat	8	5	24	24	44	193
	Rocky Intertidal	8	8	7	7	7	6
	Flooded Developed Dry Land	0	44	56	141	334	487
	Total (incl. water)	**47,219**	**47,219**	**47,219**	**47,219**	**47,219**	**47,219**

Table 50. Southeast Coast Watershed RIM Min (Acres)

		Initial	2010	2025	2055	2085	2100
	Estuarine Open Water	22,087	22,107	22,113	22,169	22,289	23,129
	Undeveloped Dry Land	15,805	15,586	15,541	15,253	14,665	14,316
	Developed Dry Land	6,456	6,412	6,401	6,291	5,941	5,688
	Irreg.-Flooded Marsh	1,308	1,253	1,246	692	132	78
	Swamp	742	737	729	692	626	582
	Estuarine Beach	189	181	180	173	147	128
	Tidal Swamp	181	180	180	171	99	75
	Inland Open Water	174	174	174	172	159	142
	Inland-Fresh Marsh	95	94	93	82	64	60
	Trans. Salt Marsh	81	300	271	460	530	552
	Regularly-Flooded Marsh	62	115	183	845	1,223	1,091
	Tidal-Fresh Marsh	21	21	21	21	20	18
	Tidal Flat	8	5	24	26	803	585
	Rocky Intertidal	8	8	7	7	6	5
	Flooded Developed Dry Land	0	44	56	165	516	769
	Total (incl. water)	**47,219**	**47,219**	**47,219**	**47,219**	**47,219**	**47,219**

Table 51. Southeast Coast Watershed RIM Max (Acres)

		Initial	2010	2025	2055	2085	2100
	Estuarine Open Water	22,087	22,107	22,115	22,209	23,199	23,834
	Undeveloped Dry Land	15,805	15,586	15,489	15,055	14,283	13,954
	Developed Dry Land	6,456	6,412	6,387	6,187	5,659	5,407
	Irreg.-Flooded Marsh	1,308	1,253	1,222	250	75	48
	Swamp	742	737	720	676	565	538
	Estuarine Beach	189	181	178	165	126	102
	Tidal Swamp	181	180	179	140	73	56
	Inland Open Water	174	174	174	167	142	141
	Inland-Fresh Marsh	95	94	93	75	59	58
	Trans. Salt Marsh	81	300	302	450	571	468
	Regularly-Flooded Marsh	62	115	230	1,501	1,037	1,036
	Tidal-Fresh Marsh	21	21	21	20	17	14
	Tidal Flat	8	5	30	47	610	508
	Rocky Intertidal	8	8	7	7	5	5
	Flooded Developed Dry Land	0	44	69	269	798	1,050
	Total (incl. water)	**47,219**	**47,219**	**47,219**	**47,219**	**47,219**	**47,219**

3.7 Thames Watershed

The area of the Thames Watershed that is below 5 meters elevation is somewhat limited. Within this study area, from 1% to 6% of developed lands are predicted to be flooded by 2100 depending on the SLR scenario evaluated. This watershed has few intertidal wetlands, with under 250 total acres of habitat. Within these habitats a similar pattern of high marsh loss and low marsh increases are predicted as found throughout the entire study area.

Table 52 Thames Watershed Landcover Change Summary
(positive indicates a gain, negative is a loss)

Land cover category	Acres in 2010	Percentage Land cover change from 2010 to 2100 for different SLR scenarios			
		GCM Max	1m	RIM Min	RIM Max
Undeveloped Dry Land	6,220	-1.0	-1.6	-2.6	-3.7
Estuarine Open Water	4,616	0.7	1.1	2.2	3.4
Developed Dry Land	3,708	-1.0	-2.0	-4.1	-6.1
Trans. Salt Marsh	100	-50.5	-45.5	-23.3	-16.3
Swamp	84	-3.4	-5.8	-7.8	-9.3
Inland Open Water	46	-6.4	-6.8	-7.4	-8.2
Irreg.-Flooded Marsh	25	-55.3	-82.7	-91.8	-92.1
Flooded Developed Dry Land	22	162.6	339.8	676.6	1019.9
Inland-Fresh Marsh	22	-7.1	-7.7	-7.7	-7.8
Estuarine Beach	18	-25.2	-32.5	-45.1	-57.9
Regularly-Flooded Marsh	11	881.4	1009.4	850.6	972.5
Tidal Swamp	7	-14.5	-26.5	-42.5	-62.6
Rocky Intertidal	1	-36.3	-54.2	-71.1	-89.5
Tidal-Fresh Marsh	1	-5.8	-23.7	-61.5	-64.7

Table 53. Thames Watershed GCM Max (Acres)

		Initial	2010	2025	2055	2085	2100
	Undeveloped Dry Land	6,316	6,220	6,213	6,198	6,172	6,159
	Estuarine Open Water	4,615	4,616	4,617	4,620	4,642	4,649
	Developed Dry Land	3,730	3,708	3,705	3,699	3,683	3,672
	Swamp	85	84	84	83	82	81
	Inland Open Water	47	46	46	45	43	43
	Irreg.-Flooded Marsh	30	25	24	23	17	11
	Inland-Fresh Marsh	24	22	21	21	20	20
	Estuarine Beach	18	18	18	18	14	14
	Tidal Swamp	7	7	7	7	6	6
	Regularly-Flooded Marsh	5	11	75	69	87	104
	Rocky Intertidal	2	1	1	1	1	1
	Trans. Salt Marsh	1	100	43	48	52	50
	Tidal-Fresh Marsh	1	1	1	1	1	1
	Flooded Developed Dry Land	0	22	25	31	47	59
	Tidal Flat	0	0	1	18	13	12
	Total (incl. water)	**14,881**	**14,881**	**14,881**	**14,881**	**14,881**	**14,881**

Table 54. Thames Watershed 1m by 2100 (Acres)

		Initial	2010	2025	2055	2085	2100
	Undeveloped Dry Land	6,316	6,220	6,213	6,186	6,148	6,123
	Estuarine Open Water	4,615	4,616	4,617	4,631	4,658	4,669
	Developed Dry Land	3,730	3,708	3,705	3,692	3,663	3,632
	Swamp	85	84	83	82	80	79
	Inland Open Water	47	46	46	44	43	43
	Irreg.-Flooded Marsh	30	25	24	20	7	4
	Inland-Fresh Marsh	24	22	21	20	20	20
	Estuarine Beach	18	18	18	15	13	12
	Tidal Swamp	7	7	7	7	6	5
	Regularly-Flooded Marsh	5	11	75	75	110	118
	Rocky Intertidal	2	1	1	1	1	1
	Trans. Salt Marsh	1	100	43	47	47	55
	Tidal-Fresh Marsh	1	1	1	1	1	1
	Flooded Developed Dry Land	0	22	25	38	67	98
	Tidal Flat	0	0	1	21	17	22
	Total (incl. water)	**14,881**	**14,881**	**14,881**	**14,881**	**14,881**	**14,881**

Table 55. Thames Watershed RIM Min (Acres)

		Initial	2010	2025	2055	2085	2100
	Undeveloped Dry Land	6,316	6,220	6,213	6,182	6,115	6,057
	Estuarine Open Water	4,615	4,616	4,617	4,637	4,678	4,716
	Developed Dry Land	3,730	3,708	3,705	3,690	3,621	3,557
	Swamp	85	84	84	82	79	77
	Inland Open Water	47	46	46	44	43	43
	Irreg.-Flooded Marsh	30	25	24	18	4	2
	Inland-Fresh Marsh	24	22	21	20	20	20
	Estuarine Beach	18	18	18	15	12	10
	Tidal Swamp	7	7	7	6	5	4
	Regularly-Flooded Marsh	5	11	75	79	104	101
	Rocky Intertidal	2	1	1	1	1	0
	Trans. Salt Marsh	1	100	43	47	55	77
	Tidal-Fresh Marsh	1	1	1	1	1	0
	Flooded Developed Dry Land	0	22	25	41	110	173
	Tidal Flat	0	0	1	20	36	43
	Total (incl. water)	**14,881**	**14,881**	**14,881**	**14,881**	**14,881**	**14,881**

Table 56. Thames Watershed RIM Max (Acres)

		Initial	2010	2025	2055	2085	2100
	Undeveloped Dry Land	6,316	6,220	6,206	6,161	6,050	5,989
	Estuarine Open Water	4,615	4,616	4,617	4,658	4,721	4,773
	Developed Dry Land	3,730	3,708	3,703	3,675	3,551	3,480
	Swamp	85	84	83	81	77	76
	Inland Open Water	47	46	46	43	43	42
	Irreg.-Flooded Marsh	30	25	23	8	2	2
	Inland-Fresh Marsh	24	22	21	20	20	20
	Estuarine Beach	18	18	18	14	10	8
	Tidal Swamp	7	7	7	6	4	3
	Regularly-Flooded Marsh	5	11	83	99	95	114
	Rocky Intertidal	2	1	1	1	0	0
	Trans. Salt Marsh	1	100	42	41	80	84
	Tidal-Fresh Marsh	1	1	1	1	0	0
	Flooded Developed Dry Land	0	22	27	55	179	250
	Tidal Flat	0	0	3	18	49	40
	Total (incl. water)	**14,881**	**14,881**	**14,881**	**14,881**	**14,881**	**14,881**

3.8 Pawcatuck Watershed (CT portion)

The portion of the Pawcatuck watershed within the Connecticut study area is limited to 1,144 total acres. However, within this region, undeveloped dry lands are predicted to be quite vulnerable with 5% to 18% losses predicted by 2100. Developed-dry land losses range from 2% to 8% by 2100.

Table 57 Pawcatuck Watershed (CT) Landcover Change Summary

(positive indicates a gain, negative is a loss)

Land cover category	Acres in 2010	Percentage Land cover change from 2010 to 2100 for different SLR scenarios			
		GCM Max	1m	RIM Min	RIM Max
Undeveloped Dry Land	548	-5.5	-9.7	-15.2	-18.4
Developed Dry Land	478	-1.7	-3.3	-5.9	-8.4
Estuarine Open Water	295	1.4	1.9	7.4	18.4
Swamp	54	-0.2	-0.9	-1.9	-6.1
Irreg.-Flooded Marsh	39	-62.1	-87.9	-95.8	-98.1
Trans. Salt Marsh	12	99.2	169.9	198.0	101.5
Riverine Tidal	4	-40.4	-53.4	-59.0	-70.4
Flooded Developed Dry Land	3	273.3	535.3	954.1	1364.1
Inland Open Water	3	-18.5	-20.0	-20.0	-20.7
Regularly-Flooded Marsh	1	3665.6	5647.8	4688.9	5573.3
Inland-Fresh Marsh	1	0.0	-100.0	-100.0	-100.0
Tidal Swamp	<1	-44.9	-100.0	-100.0	-100.0

Table 58. Pawcatuck Watershed GCM Max (Acres)

		Initial	2010	2025	2055	2085	2100
	Undeveloped Dry Land	558	548	545	537	525	517
	Developed Dry Land	481	478	477	476	472	470
	Estuarine Open Water	294	295	296	297	298	299
	Swamp	54	54	54	54	54	54
	Irreg.-Flooded Marsh	40	39	39	38	28	15
	Riverine Tidal	6	4	3	3	3	3
	Inland Open Water	3	3	3	3	3	2
	Trans. Salt Marsh	1	12	11	17	23	24
	Inland-Fresh Marsh	1	1	1	1	1	1
	Tidal Swamp	0	0	0	0	0	0
	Regularly-Flooded Marsh	0	1	5	6	23	42
	Flooded Developed Dry Land	0	3	3	5	9	11
	Tidal Flat	0	0	0	1	1	1
	Total (incl. water)	**1,439**	**1,439**	**1,439**	**1,439**	**1,439**	**1,439**

Table 59. Pawcatuck Watershed in Connecticut; 1m by 2100 (Acres)

		Initial	2010	2025	2055	2085	2100
	Undeveloped Dry Land	558	548	545	533	511	494
	Developed Dry Land	481	478	477	474	468	462
	Estuarine Open Water	294	295	296	298	299	301
	Swamp	54	54	54	54	54	54
	Irreg.-Flooded Marsh	40	39	39	36	8	5
	Riverine Tidal	6	4	3	3	3	2
	Inland Open Water	3	3	3	3	2	2
	Trans. Salt Marsh	1	12	11	18	25	33
	Inland-Fresh Marsh	1	1	1	1	0	0
	Tidal Swamp	0	0	0	0	0	0
	Regularly-Flooded Marsh	0	1	5	12	53	64
	Flooded Developed Dry Land	0	3	3	7	13	19
	Tidal Flat	0	0	0	1	1	3
	Total (incl. water)	**1,439**	**1,439**	**1,439**	**1,439**	**1,439**	**1,439**

Table 60. Pawcatuck Watershed in Connecticut; RIM Min (Acres)

		Initial	2010	2025	2055	2085	2100
	Undeveloped Dry Land	558	548	545	530	488	465
	Developed Dry Land	481	478	477	474	461	450
	Estuarine Open Water	294	295	296	298	301	317
	Swamp	54	54	54	54	54	53
	Irreg.-Flooded Marsh	40	39	39	32	4	2
	Riverine Tidal	6	4	3	3	2	2
	Inland Open Water	3	3	3	3	2	2
	Trans. Salt Marsh	1	12	11	19	35	36
	Inland-Fresh Marsh	1	1	1	1	0	0
	Tidal Swamp	0	0	0	0	0	0
	Regularly-Flooded Marsh	0	1	5	18	56	53
	Flooded Developed Dry Land	0	3	3	7	20	31
	Tidal Flat	0	0	0	1	15	28
	Total (incl. water)	**1,439**	**1,439**	**1,439**	**1,439**	**1,439**	**1,439**

Table 61. Pawcatuck Watershed in Connecticut; RIM Max (Acres)

		Initial	2010	2025	2055	2085	2100
	Undeveloped Dry Land	558	548	543	519	462	447
	Developed Dry Land	481	478	477	470	449	438
	Estuarine Open Water	294	295	296	299	320	349
	Swamp	54	54	54	54	52	51
	Irreg.-Flooded Marsh	40	39	39	10	1	1
	Riverine Tidal	6	4	3	3	2	1
	Inland Open Water	3	3	3	2	2	2
	Trans. Salt Marsh	1	12	12	20	37	25
	Inland-Fresh Marsh	1	1	1	1	0	0
	Tidal Swamp	0	0	0	0	0	0
	Regularly-Flooded Marsh	0	1	7	48	52	63
	Flooded Developed Dry Land	0	3	4	11	32	43
	Tidal Flat	0	0	0	1	29	19
	Total (incl. water)	**1,439**	**1,439**	**1,439**	**1,439**	**1,439**	**1,439**

3.9 Uncertainty Results

For uncertainty simulations, 200 unique model realizations were run for each of the three study areas. The number of uncertainty iterations performed in this analysis was relatively small due to model complexity and CPU-time restrictions. However, the calculation of land-cover confidence intervals takes into account the number of iterations run and widens these confidence intervals appropriately. Using non-parametric statistical methods, without requiring assumptions regarding the underlying statistical distribution, the confidence interval of each percentile can be calculated using the properties of binomial distributions (Walsh 1962). To be conservative, in the graphs presented herein the 5th percentile curve is reported by its lowest 5% confidence boundary (5% low), while the 95th percentile curve by its highest 95% confidence boundary (95% high) to fully account for any additional uncertainty caused by the low number of model iterations. In summary, the number of uncertainty iterations performed in this analysis was relatively small due to CPU-time restrictions. However, this limitation was accounted for by conservatively widening confidence intervals in year-to-year maps and tables of output.

Uncertainty results are presented in four ways: tabular summaries, time-series graphs, histograms, and maps. Tables of results are broken down by watershed in Table 62 to Table 75, with results presented for 2055 and 2100. These results present minimum and maximum values and, more importantly, confidence intervals based on the 5th to 95th percentile. The standard deviation presented in these tables, with units of acres, gives a sense of the relative uncertainty for each model category. For example, Table 62 of the Southwest Coast watershed suggests that, by 2055, developed dry land has the highest uncertainty range, with a confidence interval ranging from 45,885 acres to 47,473 acres. This table also shows that regularly-flooded marsh is the wetland category with the highest uncertainty.

Time-series graphs are useful to visualize the results for individual wetland types. Figure 30 and Figure 31 present the results for irregularly-flooded marsh and swamp. The 5th and 95th percentile estimates are shown in black lines, presenting a confidence interval for predictions in each category. These results illustrate the increasing uncertainty in model results the further into the future projections run.

It is also worth noting that the results presented in this section represent uncertainty in all model parameters and driving variables including sea-level rise. While the model is sensitive to many parameters, particularly accretion rates (Chu-Agor et al. 2010), sea-level rise is often the most important driver of model uncertainty. When presenting time series of confidence intervals in this report, we also plot results from each of the four deterministic SLR scenarios. These four deterministic results help to add context of how much the overall uncertainty interval is driven by future SLR as opposed to other parameter choices. For example, in Figure 31, the vast majority of uncertainty in high-marsh predictions can be explained by the uncertainty in SLR with the lowest scenario (GCM Max) resulting in a prediction very close to the top of the confidence interval and the highest SLR scenario (RIM Max) resulting in a value nearly identical to the bottom of the confidence interval.

Table 62. Uncertainty Results for Southwest Coast Watershed by Landcover (acres, 2055)

Landcover Type	Min	5th Percentile	Mean	95th Percentile	Max	Std. Dev.
Undeveloped Dry Land	119,110	119,255	119,722	120,110	120,140	220
Estuarine Open Water	58,841	58,849	58,933	59,053	59,089	53
Developed Dry Land	45,581	45,885	46,808	47,473	47,512	429
Swamp	4,334	4,342	4,384	4,411	4,413	21
Inland Open Water	3,424	3,428	3,452	3,470	3,471	13
Estuarine Beach	656	682	740	781	784	26
Regularly-Flooded Marsh	562	602	929	1,557	1,703	252
Irreg.-Flooded Marsh	300	359	750	939	976	154
Inland-Fresh Marsh	299	300	313	334	336	12
Trans. Salt Marsh	215	247	508	775	825	137
Flooded Dev. Dry Land	195	234	899	1,822	2,126	429
Inland Shore	119	119	119	119	119	0
Tidal Flat	41	44	63	93	102	13
Rocky Intertidal	17	18	19	19	20	0
Tidal Swamp	15	15	17	17	18	1

Table 63. Uncertainty Results for Southwest Coast Watershed by Landcover (acres, 2100)

Landcover Type	Min	5th Percentile	Mean	95th Percentile	Max	Std. Dev.
Undeveloped Dry Land	117,697	117,868	118,750	119,654	119,981	494
Estuarine Open Water	58,925	58,949	59,230	59,806	59,904	208
Developed Dry Land	42,357	42,681	44,692	46,760	47,260	1,100
Swamp	4,300	4,304	4,332	4,382	4,407	23
Inland Open Water	3,401	3,403	3,419	3,448	3,470	11
Regularly-Flooded Marsh	632	879	2,060	2,756	2,859	531
Flooded Dev. Dry Land	447	947	3,015	5,026	5,350	1,100
Estuarine Beach	363	387	591	736	745	90
Trans. Salt Marsh	345	496	710	939	989	112
Inland-Fresh Marsh	291	292	297	306	332	5
Inland Shore	119	119	119	119	119	0
Tidal Flat	30	34	179	720	812	178
Irreg.-Flooded Marsh	20	25	242	833	940	238
Tidal Swamp	10	10	13	17	17	2
Rocky Intertidal	6	8	16	19	19	3

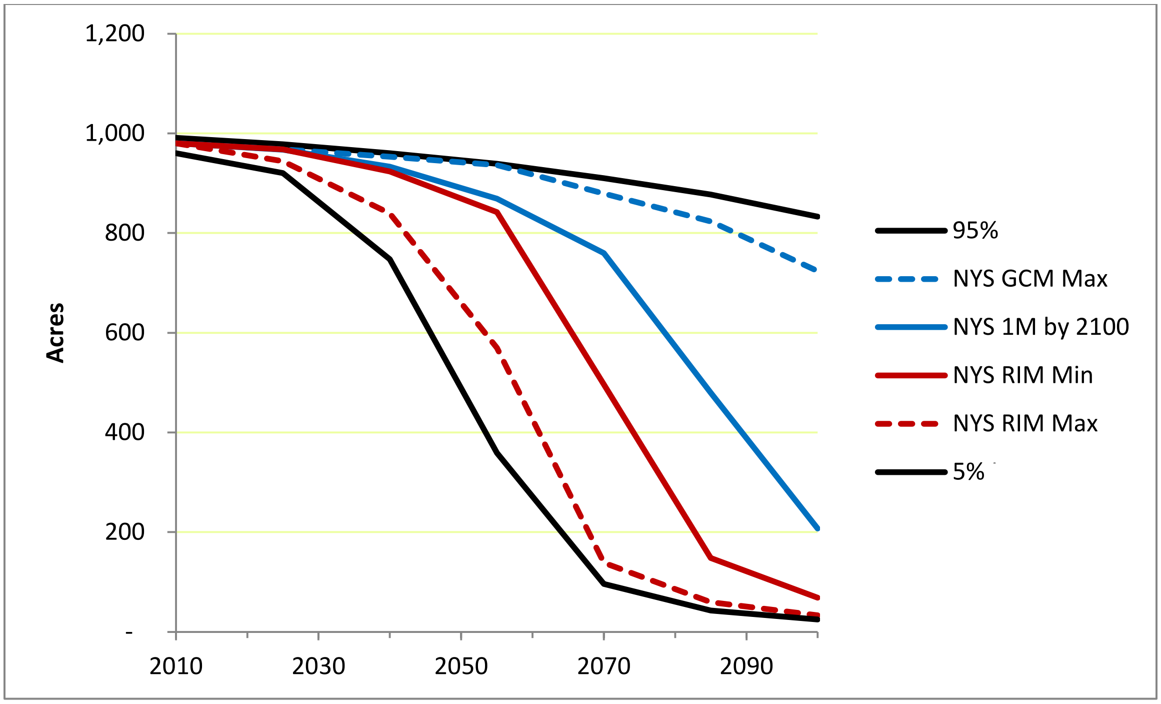


Figure 30. Time series for Irregularly-flooded marsh area coverage in the Southwest Coast Watershed, CT

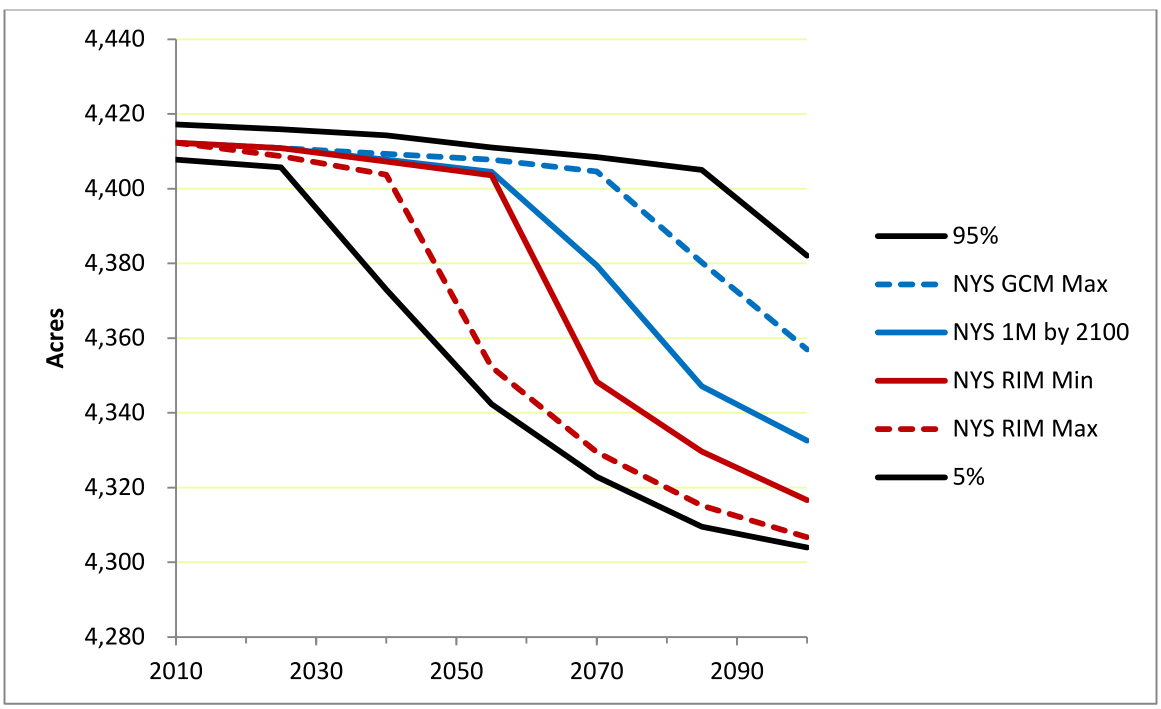
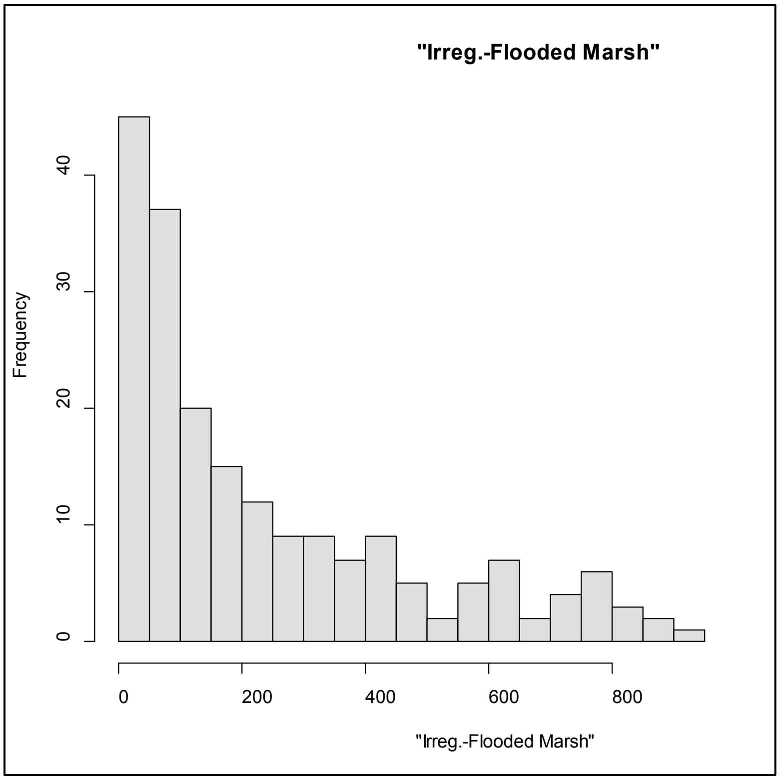


Figure 31. Time series for Swamp area coverage in the Southwest Coast Watershed, CT



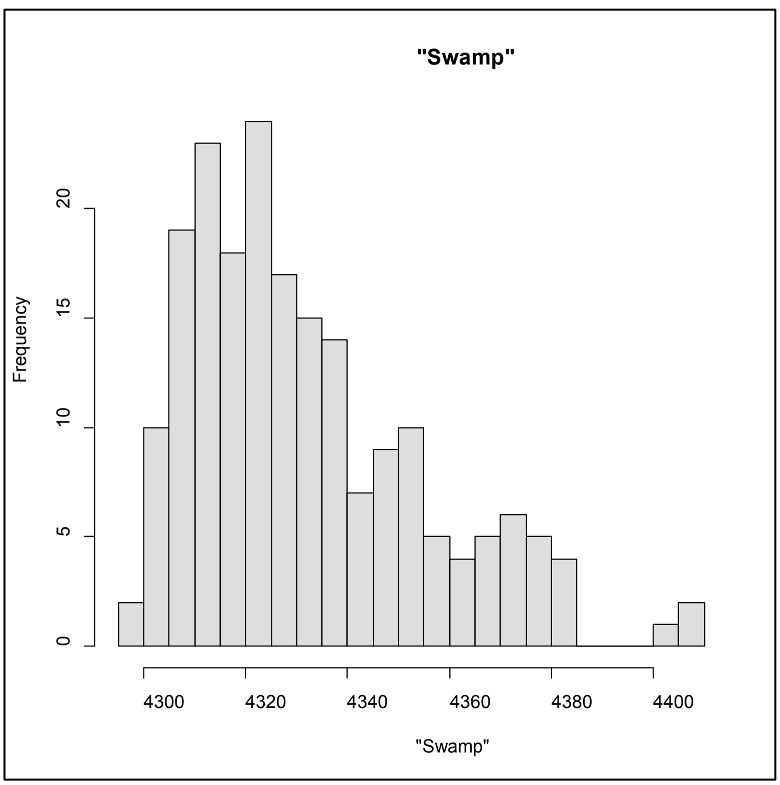


Figure 32. Histograms for Irregularly-flooded marsh and Swamp for the Southwest Coast Watershed in 2100 (acres)

Figure 32 presents two histograms of model predictions for Southwest Coast for the year 2100. This type of graphic shows the likelihood of different acreage predictions within the year-2100 confidence intervals in the tables and graphs discussed above. For example, the result for irregularly-flooded marsh shown at the top of Figure 32 suggests that predictions of lower acreages are much more likely than higher acreages, with the most likely outcome being below 100 acres. For swamps, a value of approximately 4,325 acres is most likely. Histograms show that distributions within the reported confidence intervals can be skewed, potentially resulting in a more likely result towards the top or the bottom of a confidence interval. Appendix H presents histograms for all modeled land-cover and open-water categories broken down by watershed in the year 2100.

Uncertainty results for the Housatonic River watershed indicate that the high and low marsh coverages have the widest confidence intervals (Table 64 and Table 65). For high marsh, this uncertainty is again primarily driven by uncertainty over SLR scenarios (Figure 33); however, low predictions for high marsh by 2100 are more likely than higher predictions within the confidence interval (Figure 34, top).

Table 64. Uncertainty Results for Housatonic Watershed by Landcover (acres, 2055)

Landcover Type	Min	5th Percentile	Mean	95th Percentile	Max	Std. Dev.
Developed Dry Land	6,358	6,378	6,482	6,540	6,559	45
Undeveloped Dry Land	6,036	6,053	6,141	6,199	6,219	37
Estuarine Open Water	5,801	5,806	5,858	5,927	5,963	36
Regularly-Flooded Marsh	325	379	483	701	758	83
Swamp	314	314	315	315	315	0
Irreg.-Flooded Marsh	276	321	528	636	655	88
Estuarine Beach	175	196	252	297	301	30
Inland Open Water	86	87	90	93	93	1
Trans. Salt Marsh	46	49	82	129	139	21
Flooded Dev. Dry Land	25	44	102	206	226	45
Inland-Fresh Marsh	24	25	31	35	36	3
Tidal-Fresh Marsh	14	19	27	30	30	3
Tidal Flat	11	13	43	101	118	24
Tidal Swamp	5	5	7	8	8	1

Table 65. Uncertainty Results for Housatonic Watershed by Landcover (acres, 2100)

Landcover Type	Min	5th Percentile	Mean	95th Percentile	Max	Std. Dev.
Developed Dry Land	6,000	6,044	6,277	6,481	6,543	119
Estuarine Open Water	5,831	5,852	6,017	6,242	6,296	103
Undeveloped Dry Land	5,828	5,849	5,986	6,136	6,200	78
Regularly-Flooded Marsh	352	476	838	1,044	1,072	166
Swamp	313	313	314	315	315	0
Inland Open Water	82	82	84	91	93	3
Estuarine Beach	66	82	158	257	271	46
Trans. Salt Marsh	60	74	112	144	161	19
Flooded Dev. Dry Land	41	103	307	539	584	119
Inland-Fresh Marsh	17	18	22	31	35	4
Tidal Flat	9	12	98	329	452	65
Irreg.-Flooded Marsh	8	14	204	572	642	168
Tidal Swamp	2	2	4	7	8	1
Tidal-Fresh Marsh	1	3	21	30	30	8

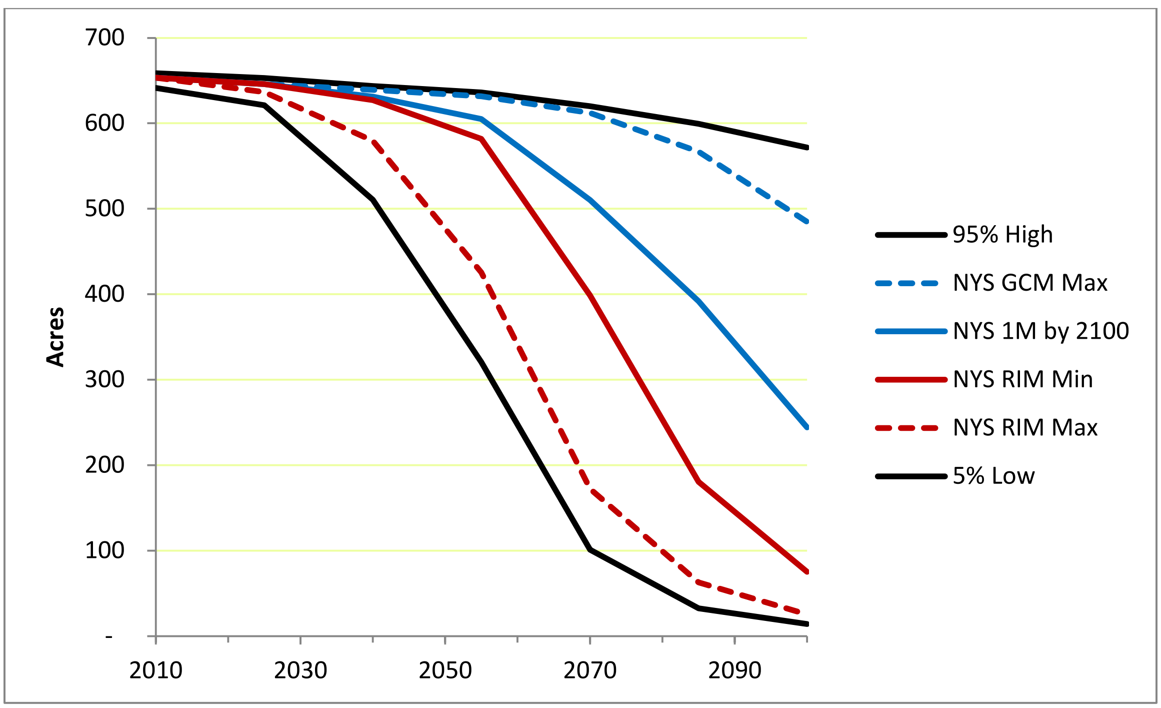


Figure 33. Time series for Irregularly-flooded marsh area coverage in the Housatonic Watershed, CT

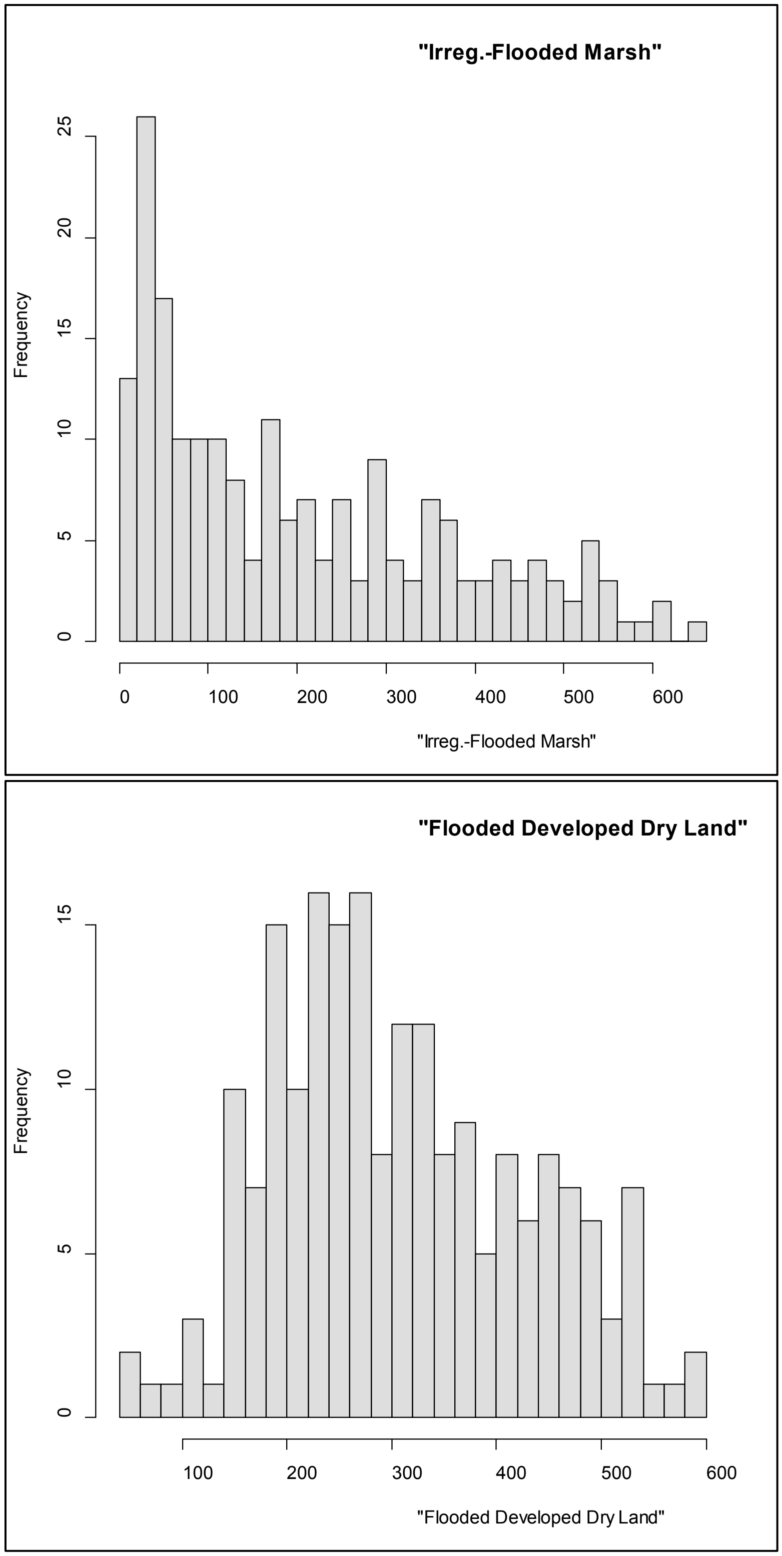


Figure 34. Histograms for Irregularly-flooded marsh and Flooded Developed Dry Land for the Housatonic Watershed in 2100 (acres)

Uncertainty-analysis results can also be visualized as GIS maps in which results are broken down on a cell-by-cell basis. The four maps that were specifically derived for this project are:

- **Percent Likelihood of Habitat Change:** For each cell in the study area, the percent likelihood that this cell has changed category since the start of the simulation.
- **Probability that the cell is a coastal marsh:** This map can assist in identifying potential locations for "marsh migration." A coastal marsh is defined as a cell that is flooded by tidal waters including low marsh (regularly flooded marsh), high marsh (irregularly flooded marsh), dry land recently converted to marsh (transitional marsh), and tidal-fresh marshes.
- **Probability that the cell contains flooded-developed land:** Likelihood a developed cell in initial layers will be regularly flooded at the map date.
- **Probability that a land category has converted to open water:** Likelihood a cell that is not water at low tide (MLLW) will become open water at that tide at the map date.

Figure 35 suggests that there is a moderate-to-low percent likelihood of habitat change in the Southwest Coast and Housatonic Watershed study area by 2055. Figure 36 suggests a higher percent likelihood of habitat change by 2100. As shown in Figure 37 there is a high likelihood that marshes will be present along the coast of these watersheds in 2100. However, it is important to bear in mind that this result does not take into account restrictions in marsh migration due to current land uses. Uncertainty maps are all available as GIS layers with a 5-m resolution allowing for close inspection of model results for individual locations.

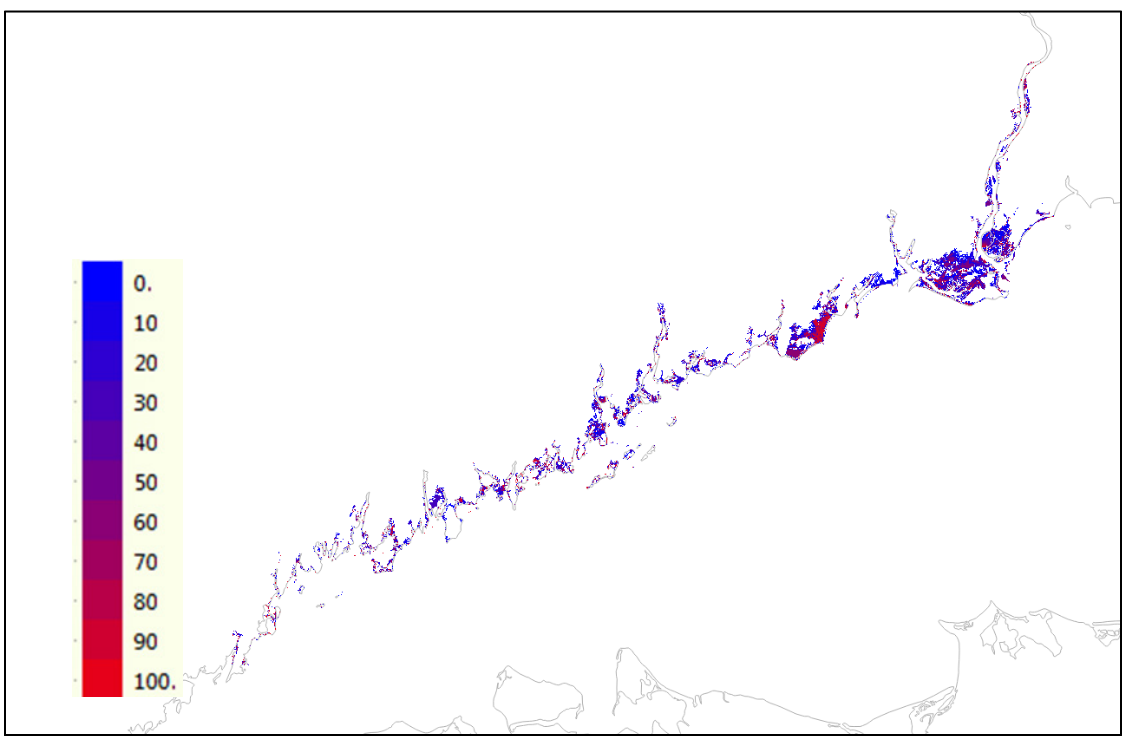


Figure 35. Area 1 -Southwest Coast and Housatonic Percent Likelihood of habitat change by 2055

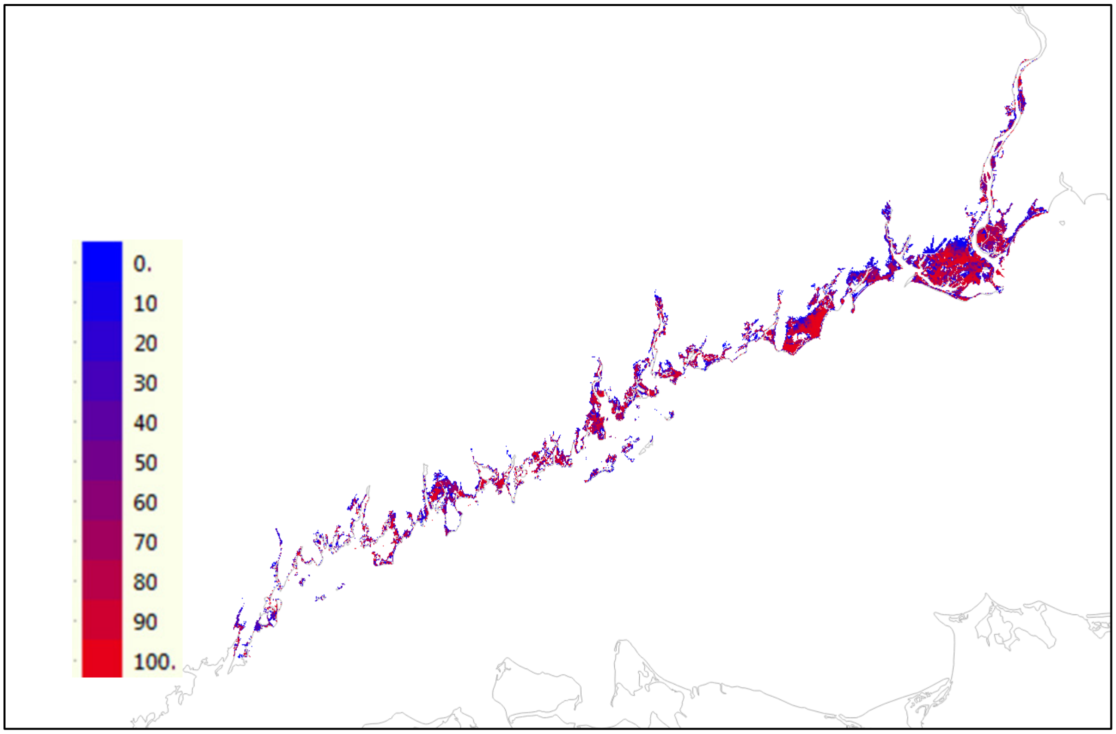


Figure 36. Area 1 -Southwest Coast and Housatonic Percent Likelihood of habitat change by 2100

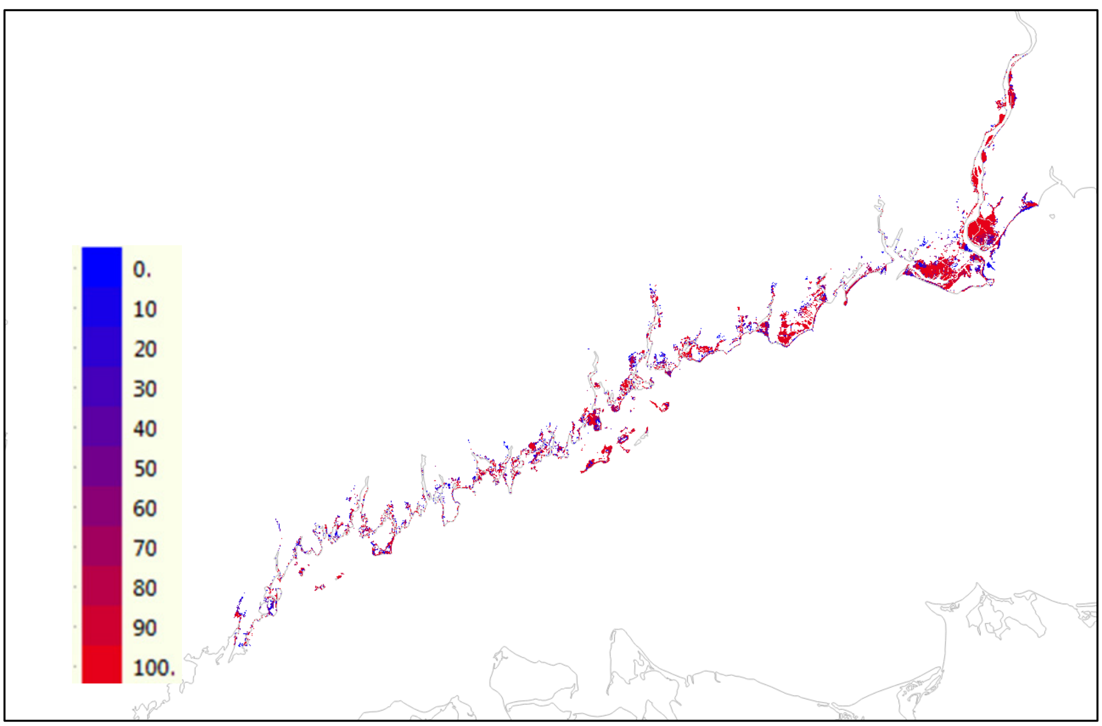


Figure 37. Area 1 -Southwest Coast and Housatonic Percent Likelihood of coastal wetland by 2100

Uncertainty Analysis results for the Southcentral Coast watershed follow in tables, graphs, histograms, and maps.

Table 66. Uncertainty Results for Southcentral Coast Watershed by Landcover (acres, 2055)

Landcover Type	Min	5th Percentile	Mean	95th Percentile	Max	Std. Dev.
Undeveloped Dry Land	24,947	25,083	25,687	26,060	26,231	244
Estuarine Open Water	22,468	22,510	22,690	22,961	23,059	123
Developed Dry Land	20,271	20,395	20,740	20,918	20,972	131
Swamp	2,034	2,054	2,122	2,177	2,187	31
Regularly-Flooded Marsh	1,285	1,682	3,225	5,652	6,016	1,117
Irreg.-Flooded Marsh	864	1,090	3,296	4,661	4,908	1,018
Estuarine Beach	526	572	732	852	878	76
Inland Open Water	432	434	452	472	483	9
Inland-Fresh Marsh	200	204	242	270	275	15
Flooded Dev. Dry Land	116	169	347	693	816	131
Trans. Salt Marsh	107	179	355	651	705	121
Tidal-Fresh Marsh	87	91	95	96	96	1
Tidal Flat	71	76	116	229	328	40
Tidal Swamp	45	48	63	72	73	6
Rocky Intertidal	19	20	24	27	28	2

Table 67. Uncertainty Results for Southcentral Coast Watershed by Landcover (acres, 2100)

Landcover Type	Min	5th Percentile	Mean	95th Percentile	Max	Std. Dev.
Undeveloped Dry Land	22,677	22,886	24,498	25,650	26,033	707
Estuarine Open Water	22,630	22,736	23,454	25,131	26,441	663
Developed Dry Land	17,772	17,963	19,775	20,726	20,884	700
Regularly-Flooded Marsh	1,730	3,010	5,989	7,252	7,335	1,247
Swamp	1,696	1,717	1,974	2,141	2,180	112
Inland Open Water	385	390	425	464	476	19
Flooded Dev. Dry Land	203	362	1,313	3,125	3,315	700
Estuarine Beach	150	181	419	682	768	141
Trans. Salt Marsh	146	274	545	913	970	175
Inland-Fresh Marsh	129	132	181	242	264	31
Irreg.-Flooded Marsh	69	89	919	3,760	4,628	1,051
Tidal Flat	30	31	557	3,047	3,767	785
Tidal-Fresh Marsh	13	40	86	96	96	15
Tidal Swamp	11	13	37	66	69	15
Rocky Intertidal	9	10	16	23	25	4

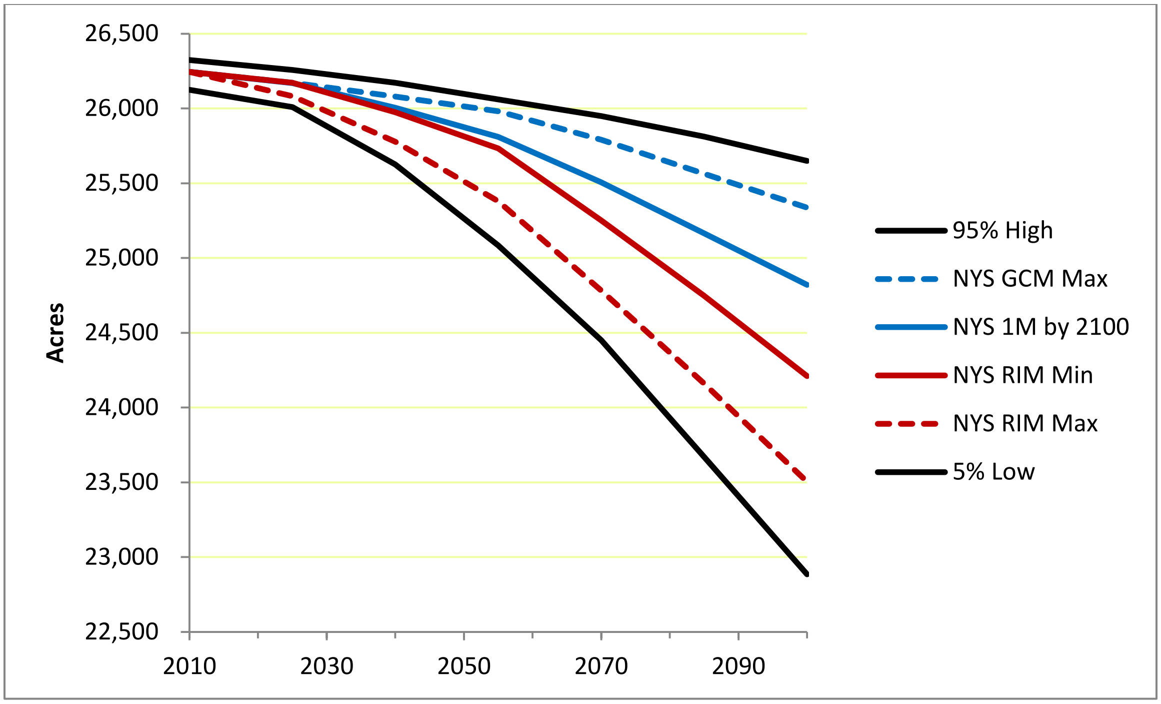


Figure 38. Time series for Undeveloped Dry Land area coverage in the Southcentral Coast Watershed, CT

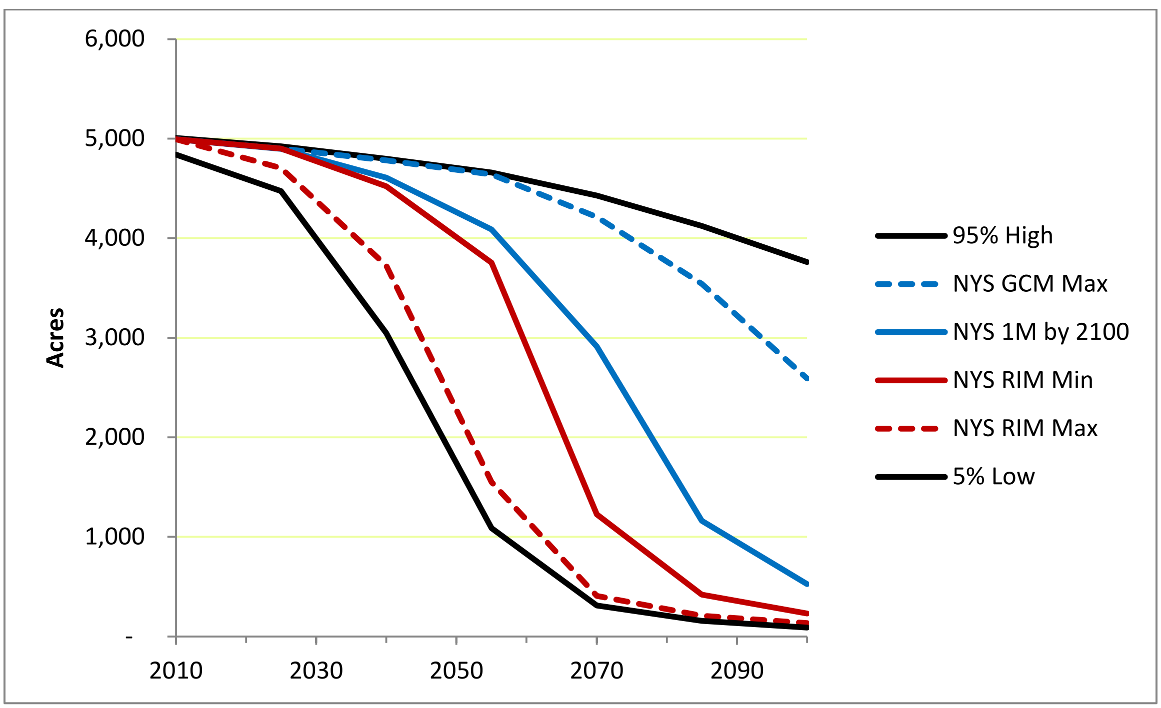


Figure 39. Time series for Irregularly-flooded Marsh area coverage in the Southcentral Coast Watershed, CT

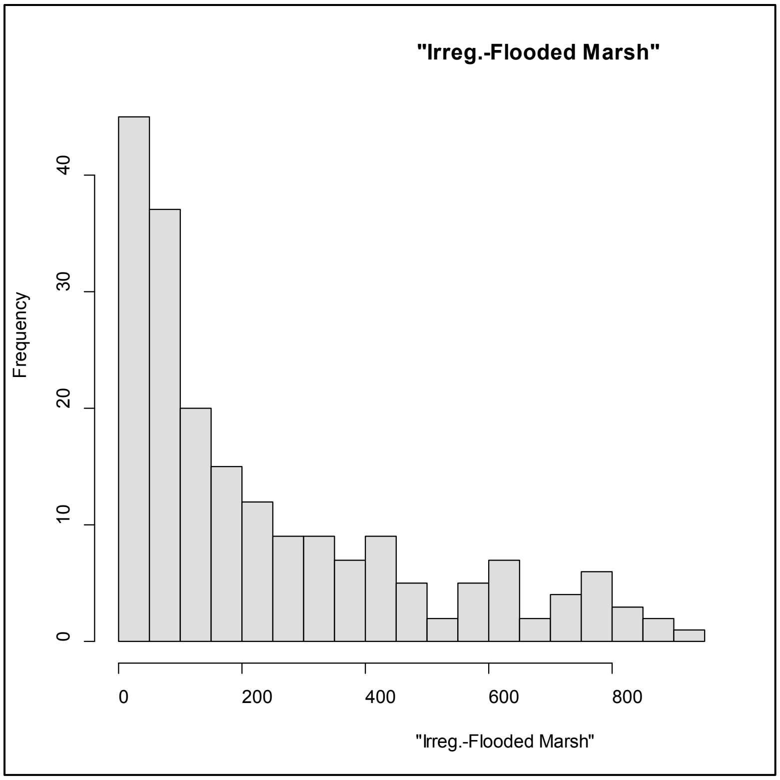


Figure 40. Histograms for Irregularly Flooded Marsh Land for the Southcentral Coast Watershed in 2100 (acres)

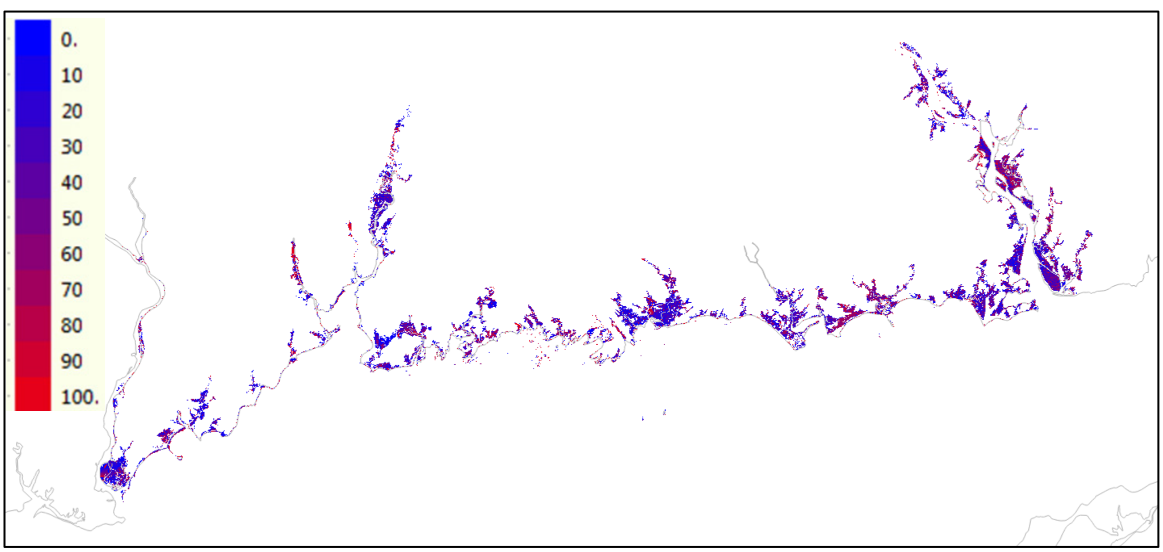


Figure 41. Area 2 –Southcentral Coast Percent Likelihood of habitat change by 2055

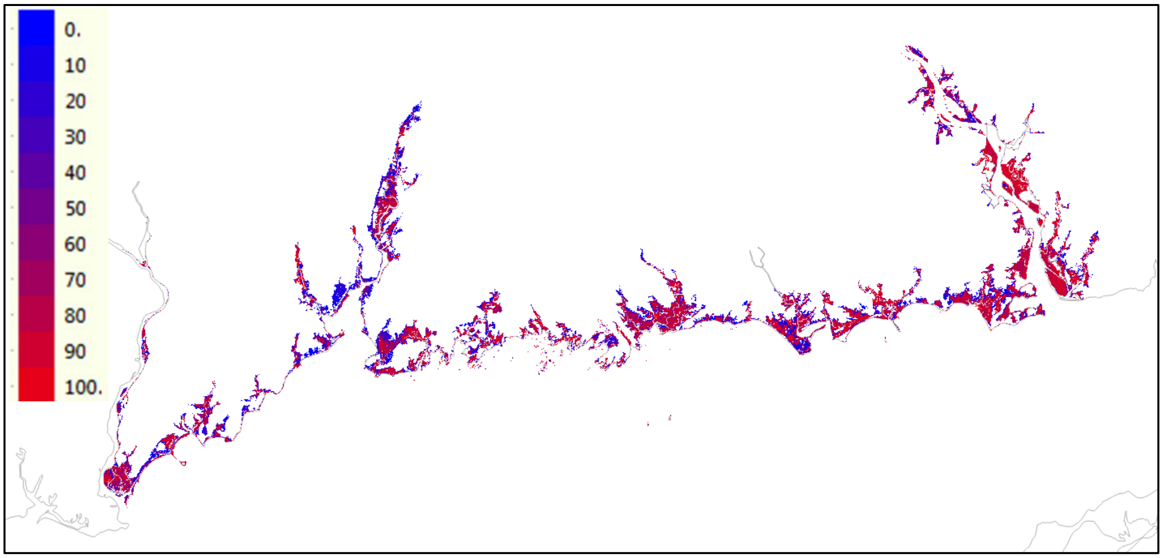


Figure 42. Area 2 –Southcentral Coast Percent Likelihood of habitat change by 2100

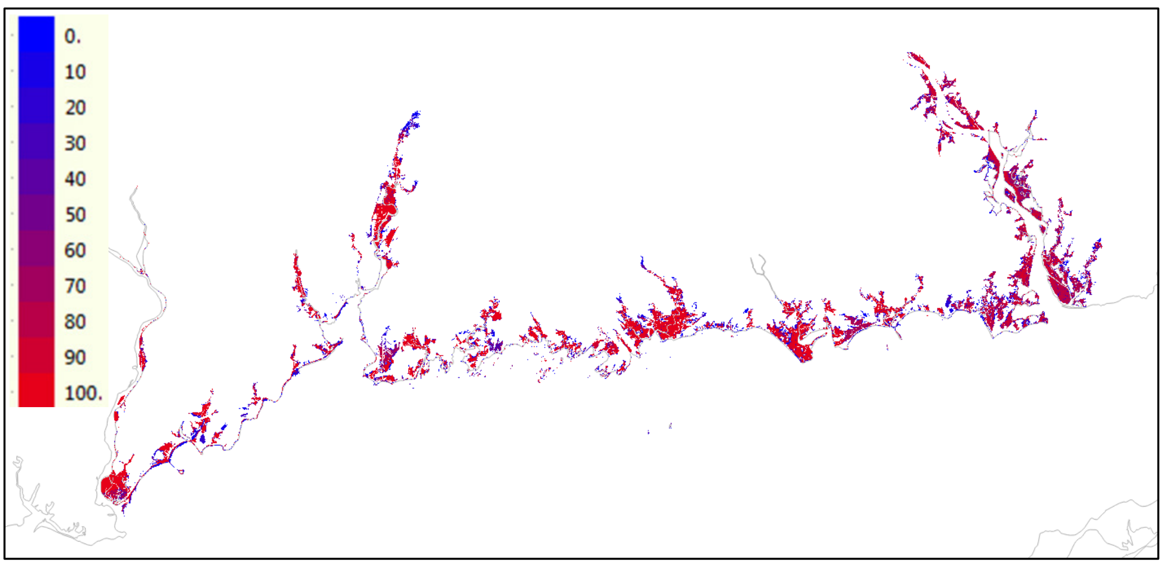


Figure 43. Area 2 –Southcentral Coast Percent Likelihood of coastal wetland by 2100

Uncertainty Analysis results for the Connecticut River watershed follow.

Table 68. Uncertainty Results for CT River Watershed by Landcover (acres, 2055)

Landcover Type	Min	5th Percentile	Mean	95th Percentile	Max	Std. Dev.
Undeveloped Dry Land	19,731	19,774	20,011	20,217	20,348	113
Estuarine Open Water	6,338	6,354	6,482	6,674	6,783	78
Developed Dry Land	2,390	2,396	2,425	2,444	2,452	13
Swamp	731	732	738	742	745	3
Regularly-Flooded Marsh	348	470	1,330	2,554	2,696	596
Irreg.-Flooded Marsh	322	476	1,539	2,230	2,313	515
Tidal-Fresh Marsh	280	353	506	548	549	52
Inland Open Water	256	256	260	261	262	1
Trans. Salt Marsh	144	211	295	375	405	42
Tidal Swamp	94	104	212	308	332	56
Riverine Tidal	52	54	66	77	92	6
Inland-Fresh Marsh	51	51	53	54	55	1
Tidal Flat	49	59	115	359	558	76
Estuarine Beach	11	12	24	54	58	10
Flooded Dev. Dry Land	8	15	34	63	69	13

Table 69. Uncertainty Results for CT River Watershed by Landcover (acres, 2100)

Landcover Type	Min	5th Percentile	Mean	95th Percentile	Max	Std. Dev.
Undeveloped Dry Land	19,051	19,151	19,589	20,017	20,225	228
Estuarine Open Water	6,443	6,467	7,327	10,044	10,348	1,054
Developed Dry Land	2,248	2,274	2,361	2,427	2,446	41
Swamp	715	721	730	739	744	5
Regularly-Flooded Marsh	488	550	1,849	2,946	3,052	782
Inland Open Water	244	245	254	260	261	4
Trans. Salt Marsh	200	207	283	394	433	48
Inland-Fresh Marsh	46	48	50	53	54	2
Riverine Tidal	27	30	44	63	76	9
Tidal Swamp	25	27	86	221	302	51
Irreg.-Flooded Marsh	18	20	354	1,854	2,200	489
Tidal Flat	15	42	676	1,716	2,006	557
Flooded Dev. Dry Land	13	32	98	185	211	41
Tidal-Fresh Marsh	11	25	378	547	549	173
Estuarine Beach	3	5	11	21	27	4

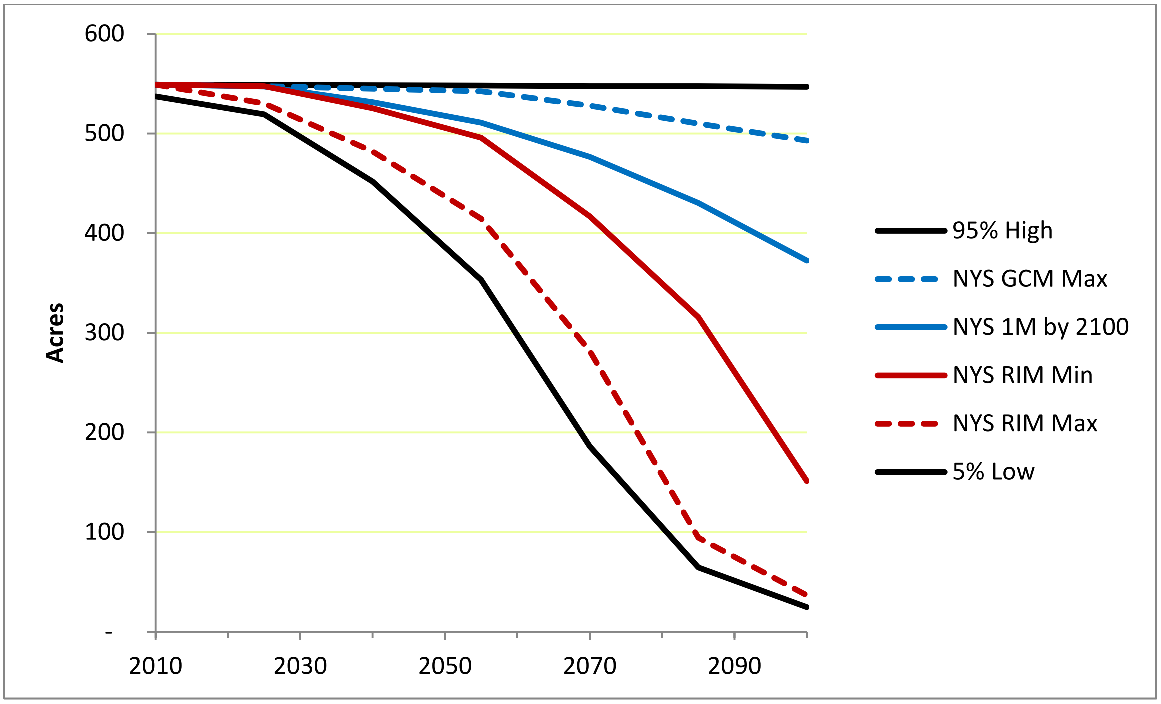
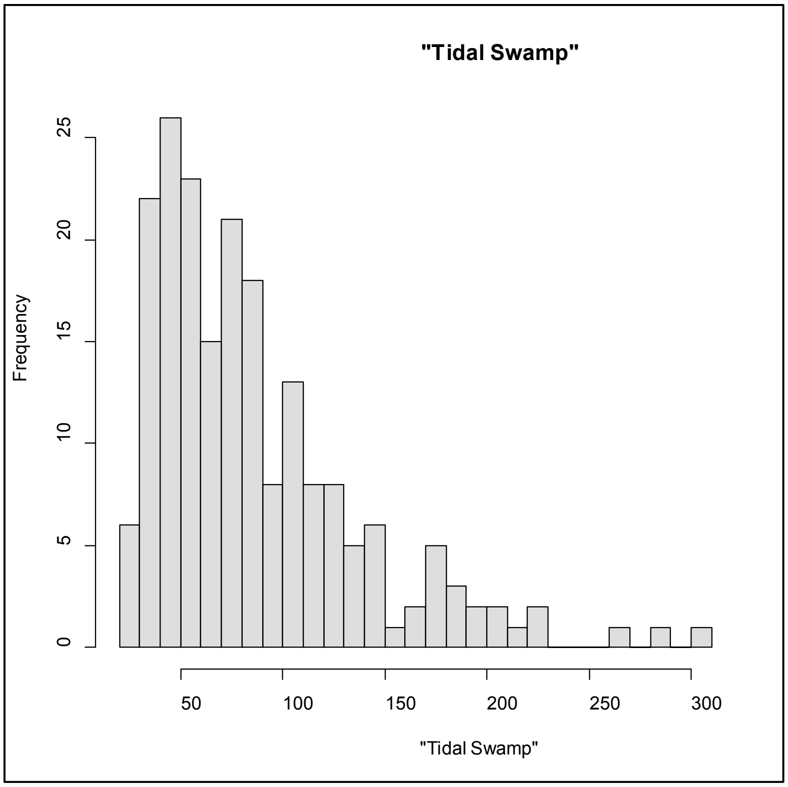


Figure 44. Time series for Tidal-fresh Marsh area coverage in the Connecticut River Watershed, CT



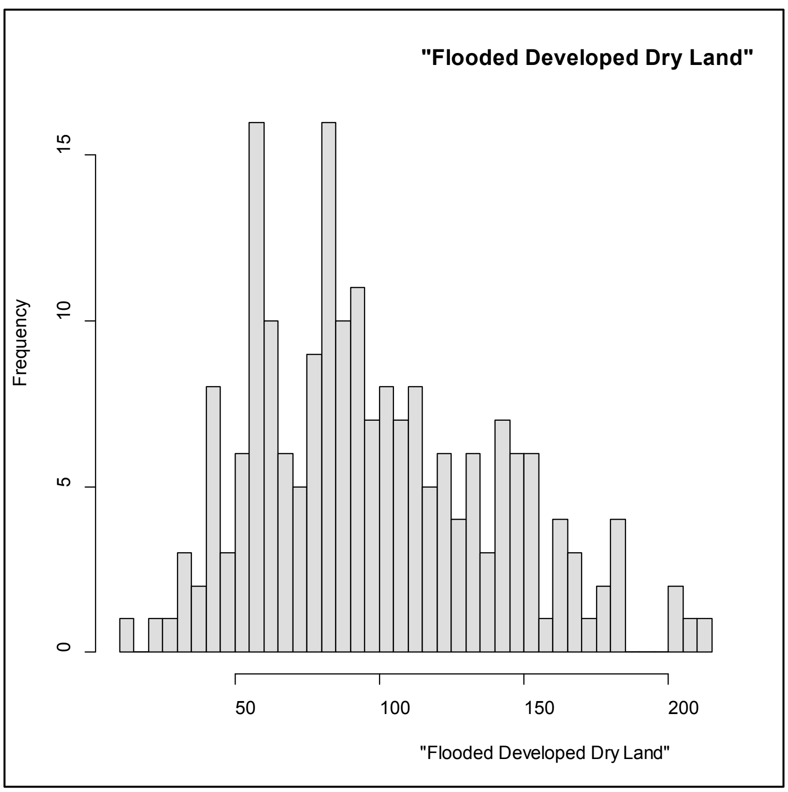


Figure 45. Histograms for Tidal Swamp and Flooded Developed Land for the Connecticut River Watershed in 2100 (acres)

Uncertainty Analysis results for the Southeast Coast watershed follow, with tables, graphs, and histograms.

Table 70. Uncertainty Results for Southeast Coast Watershed by Landcover (acres, 2055)

Landcover Type	Min	5th Percentile	Mean	95th Percentile	Max	Std. Dev.
Estuarine Open Water	22,141	22,154	22,205	22,279	22,360	32
Undeveloped Dry Land	14,801	14,885	15,238	15,491	15,601	153
Developed Dry Land	6,021	6,074	6,275	6,388	6,412	76
Swamp	643	655	697	731	741	18
Trans. Salt Marsh	209	296	419	569	602	70
Irreg.-Flooded Marsh	191	209	700	1,170	1,232	285
Regularly-Flooded Marsh	167	263	853	1,476	1,616	361
Inland Open Water	159	162	173	183	185	5
Tidal Swamp	119	125	163	179	180	14
Estuarine Beach	112	120	147	172	175	14
Inland-Fresh Marsh	68	71	82	93	95	6
Flooded Dev. Dry Land	44	68	181	383	435	76
Tidal-Fresh Marsh	20	20	21	21	21	0
Tidal Flat	16	18	57	312	470	71
Rocky Intertidal	6	6	7	7	7	0

Table 71. Uncertainty Results for Southeast Coast Watershed by Landcover (acres, 2100)

Landcover Type	Min	5th Percentile	Mean	95th Percentile	Max	Std. Dev.
Estuarine Open Water	22,178	22,201	22,804	24,201	24,469	649
Undeveloped Dry Land	13,568	13,659	14,526	15,212	15,472	413
Developed Dry Land	5,151	5,204	5,822	6,262	6,374	289
Swamp	510	524	614	703	735	54
Trans. Salt Marsh	307	388	517	665	674	68
Regularly-Flooded Marsh	274	663	1,245	1,763	1,886	294
Inland Open Water	138	139	156	177	182	12
Flooded Dev. Dry Land	82	194	635	1,252	1,305	289
Inland-Fresh Marsh	55	56	65	83	92	8
Estuarine Beach	45	69	111	157	168	21
Tidal Swamp	41	45	102	171	179	35
Irreg.-Flooded Marsh	33	37	196	865	1,158	210
Tidal-Fresh Marsh	7	11	19	21	21	3
Tidal Flat	7	12	400	807	888	260
Rocky Intertidal	4	4	6	7	7	1

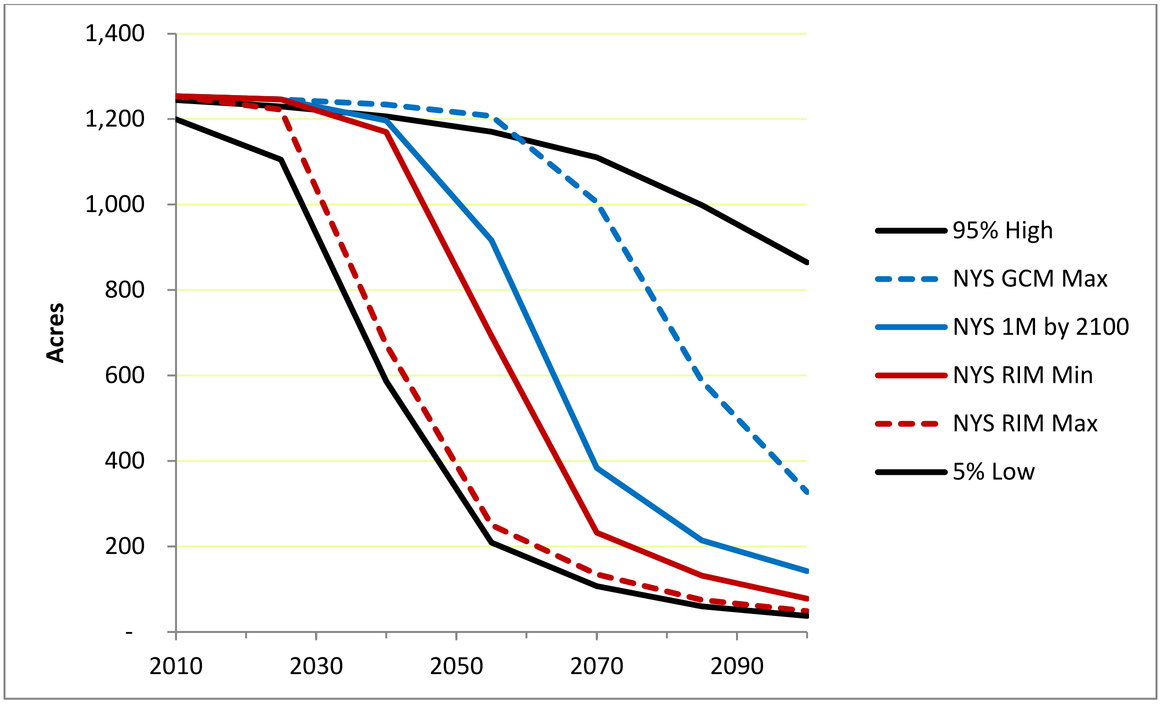
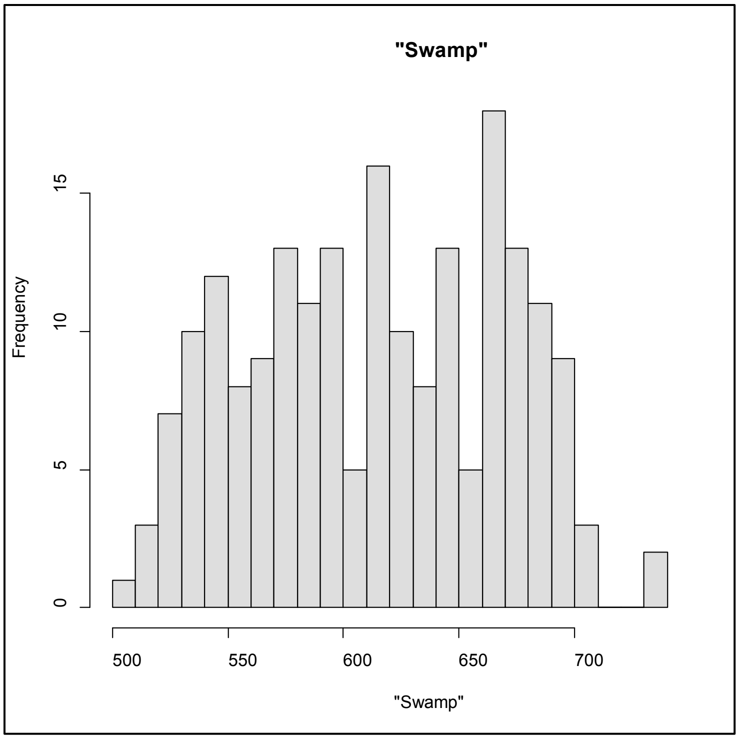


Figure 46. Time series for Irregularly Flooded Marsh area coverage in the Southeast Coast Watershed, CT



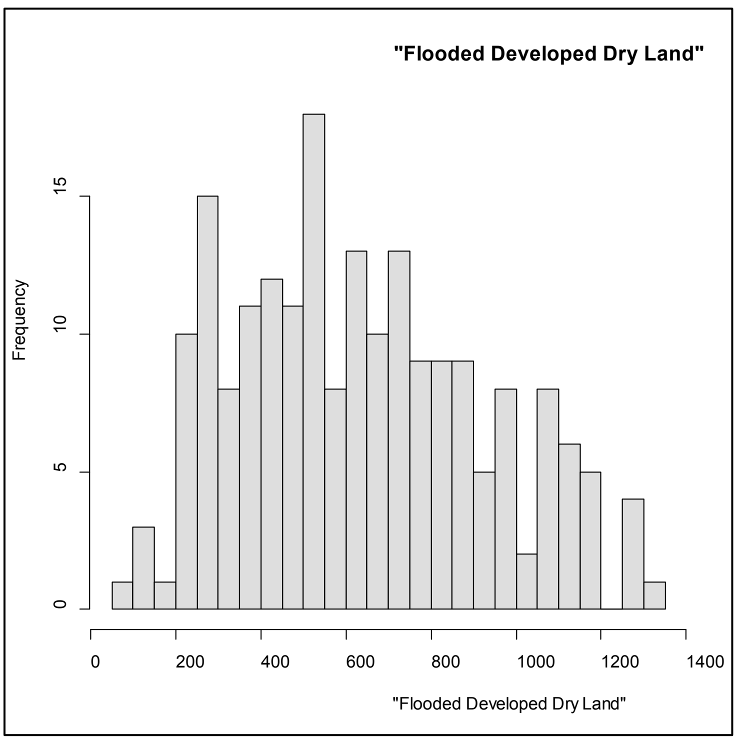


Figure 47. Histograms for Swamp and Flooded Developed Land for Southeast Coast Watershed in 2100 (acres)

Uncertainty Analysis results for the Thames watershed follow, with tables, graphs, and histograms.

Table 72. Uncertainty Results for Thames Watershed by Landcover (acres, 2055)

Landcover Type	Min	5th Percentile	Mean	95th Percentile	Max	Std. Dev.
Undeveloped Dry Land	6,131	6,143	6,179	6,208	6,224	16
Estuarine Open Water	4,620	4,623	4,643	4,669	4,681	13
Developed Dry Land	3,641	3,653	3,686	3,703	3,708	12
Swamp	78	80	82	84	85	1
Regularly-Flooded Marsh	55	61	82	103	110	11
Inland Open Water	43	43	44	46	46	1
Trans. Salt Marsh	28	31	46	58	66	7
Flooded Dev. Dry Land	22	28	44	77	89	12
Inland-Fresh Marsh	20	20	20	21	22	0
Estuarine Beach	11	12	14	17	18	1
Tidal Flat	8	10	16	25	27	4
Irreg.-Flooded Marsh	6	7	16	24	24	5
Tidal Swamp	5	5	6	7	7	0
Tidal-Fresh Marsh	1	1	1	1	1	0
Rocky Intertidal	0	1	1	1	1	0

Table 73. Uncertainty Results for Thames Watershed by Landcover (acres, 2100)

Landcover Type	Min	5th Percentile	Mean	95th Percentile	Max	Std. Dev.
Undeveloped Dry Land	5,919	5,934	6,084	6,176	6,203	66
Estuarine Open Water	4,634	4,637	4,702	4,806	4,832	48
Developed Dry Land	3,400	3,417	3,587	3,684	3,701	73
Swamp	75	75	79	83	84	2
Regularly-Flooded Marsh	66	79	109	139	154	14
Inland Open Water	39	42	43	44	46	1
Trans. Salt Marsh	37	41	66	97	104	15
Flooded Dev. Dry Land	29	46	143	313	330	73
Inland-Fresh Marsh	19	19	20	20	21	0
Tidal Flat	4	6	28	49	50	13
Estuarine Beach	3	6	10	14	16	2
Tidal Swamp	2	2	5	7	7	1
Irreg.-Flooded Marsh	1	1	5	19	22	5
Tidal-Fresh Marsh	0	0	1	1	1	0
Rocky Intertidal	0	0	0	1	1	0

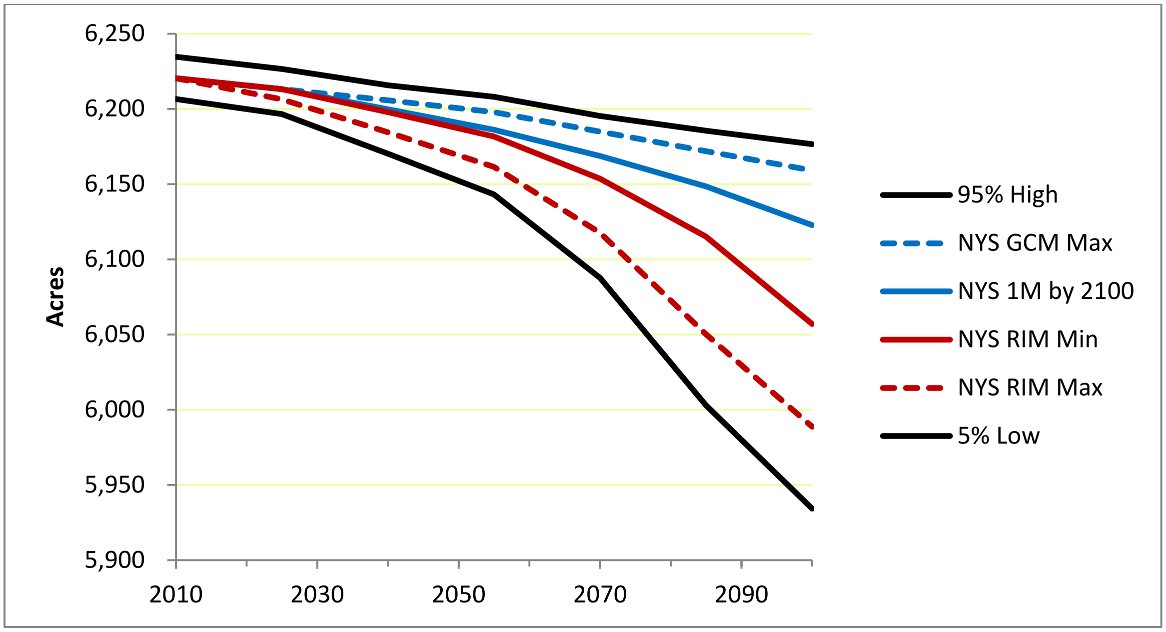


Figure 48. Time series for undeveloped dry land area coverage in the Thames Watershed, CT.

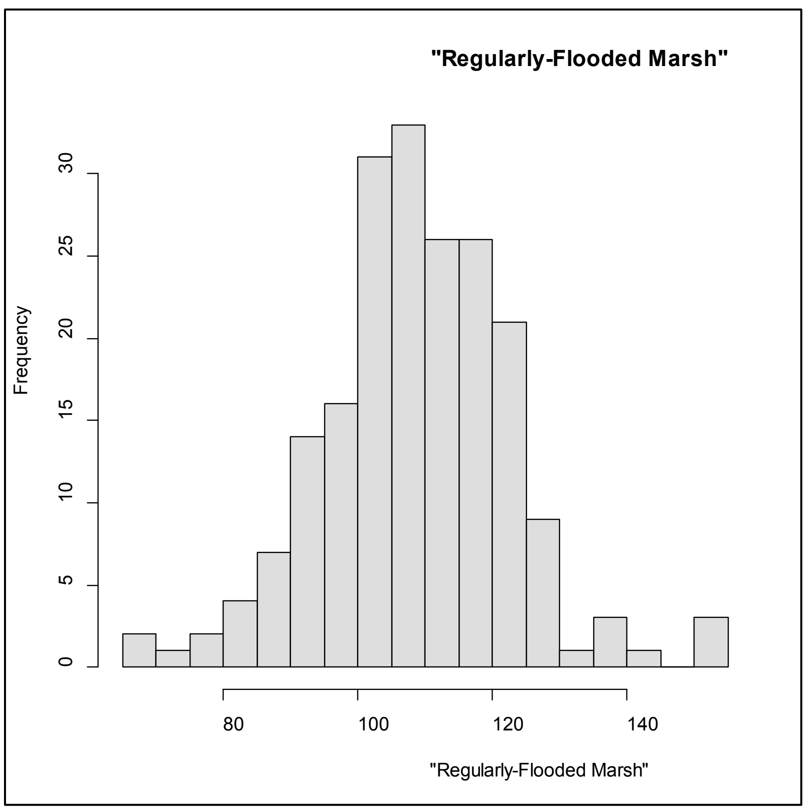


Figure 49. Histogram for Irregularly-Flooded and Regularly flooded marsh for Thames Watershed in 2100 (acres)

Uncertainty Analysis results for the Pawcatuck watershed follow, with tables, graphs, and histograms, followed by uncertainty maps derived for the western portion of the study area.

Table 74. Uncertainty Results for Pawcatuck Watershed by Landcover (acres, 2055)

Landcover Type	Min	5th Percentile	Mean	95th Percentile	Max	Std. Dev.
Undeveloped Dry Land	494	507	528	544	550	9
Developed Dry Land	463	466	473	477	478	3
Estuarine Open Water	297	297	299	301	302	1
Swamp	54	54	54	54	54	0
Trans. Salt Marsh	6	12	19	30	36	4
Irreg.-Flooded Marsh	6	7	26	38	39	9
Regularly-Flooded Marsh	3	6	25	50	56	13
Flooded Dev. Dry Land	3	4	8	15	18	3
Riverine Tidal	2	2	3	3	3	0
Inland Open Water	2	2	3	3	3	0
Tidal Flat	0	0	1	5	11	1

Table 75. Uncertainty Results for Pawcatuck Watershed by Landcover (acres, 2100)

Landcover Type	Min	5th Percentile	Mean	95th Percentile	Max	Std. Dev.
Undeveloped Dry Land	428	436	482	527	543	26
Developed Dry Land	423	429	455	472	477	12
Estuarine Open Water	298	298	316	364	375	21
Swamp	48	51	53	54	54	1
Trans. Salt Marsh	12	17	30	43	46	7
Regularly-Flooded Marsh	7	17	53	69	78	13
Flooded Dev. Dry Land	4	8	26	52	57	12
Inland Open Water	2	2	2	3	3	0
Riverine Tidal	1	1	2	3	3	0
Irreg.-Flooded Marsh	1	1	7	32	38	8
Tidal Flat	0	0	12	27	30	9

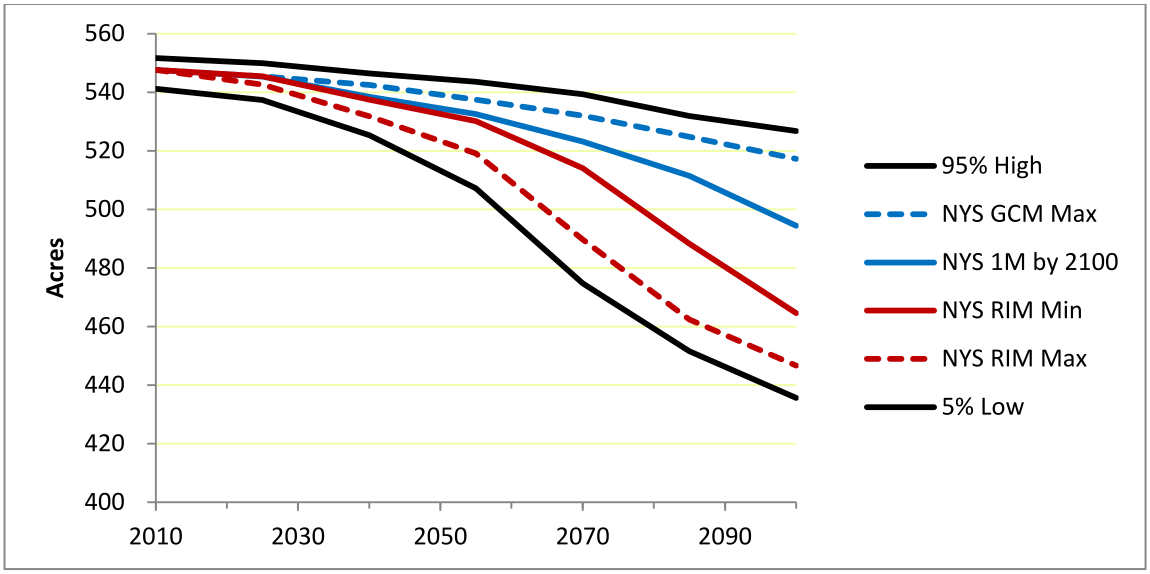


Figure 50. Time series for undeveloped dry land area coverage in the Pawcatuck Watershed, CT.

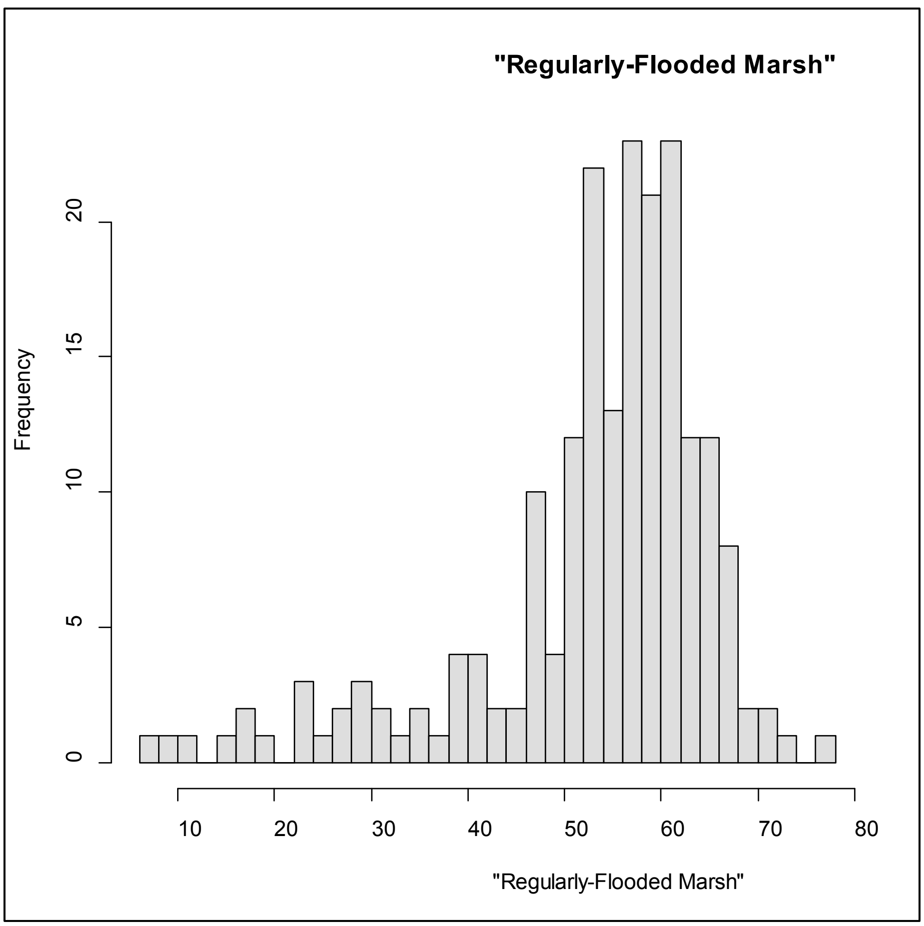


Figure 51. Histogram for Regularly flooded marsh for Pawcatuck Watershed, CT in 2100 (acres)

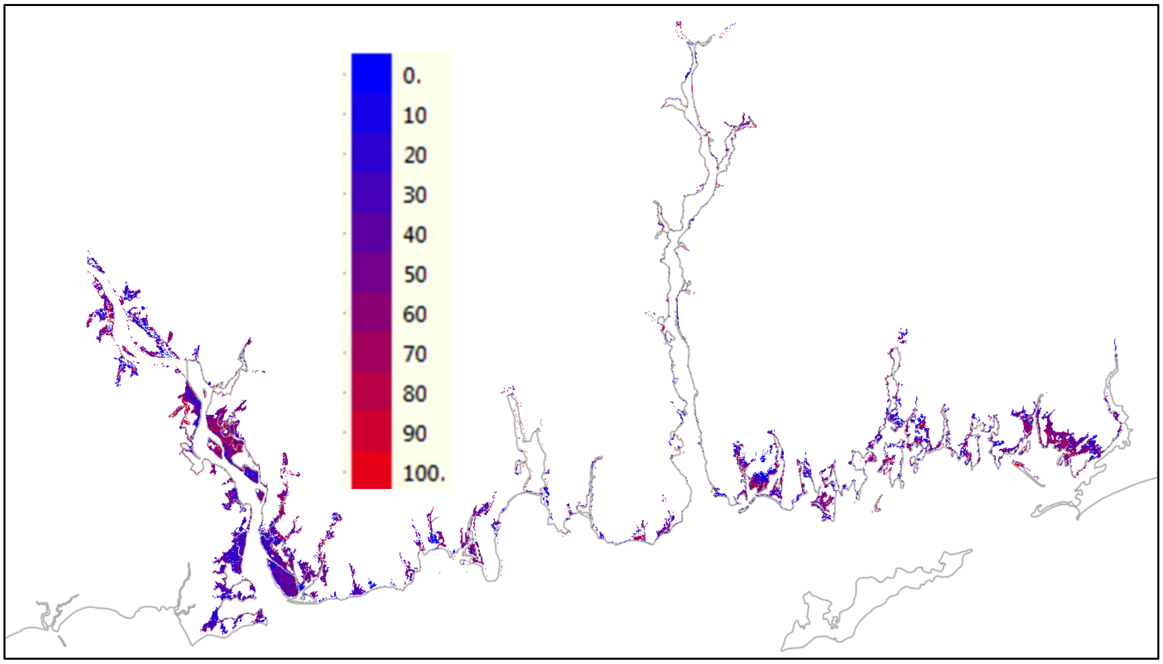


Figure 52. Area 3 Percent Likelihood of habitat change by 2055

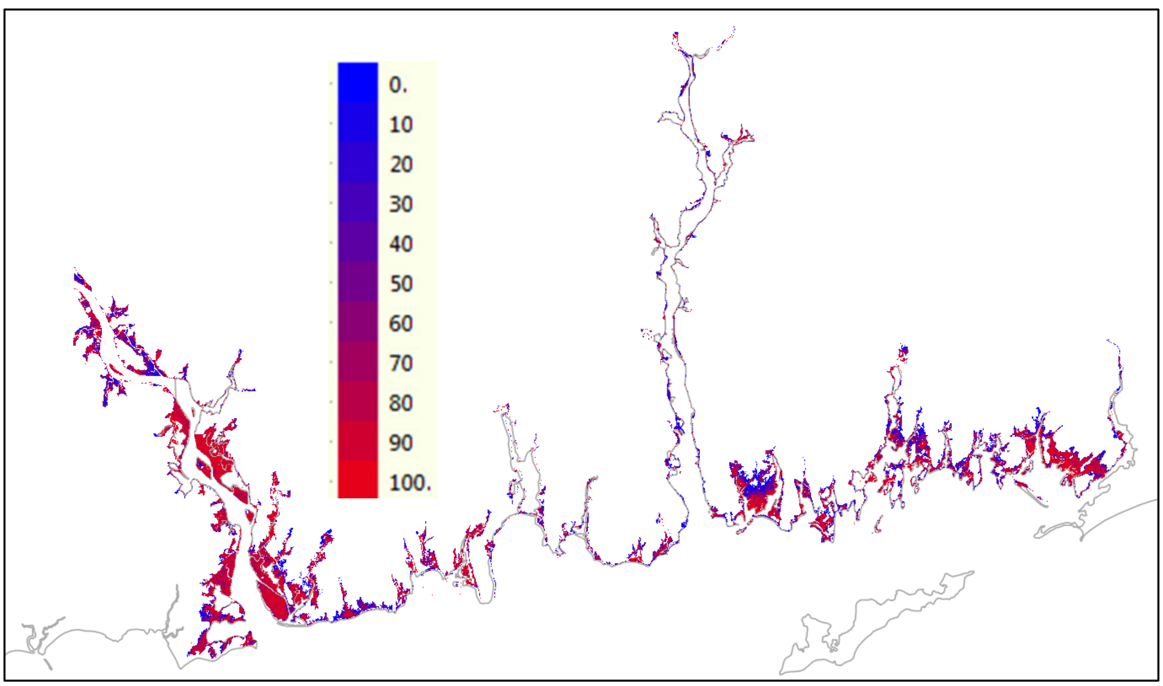


Figure 53. Area 3 Percent Likelihood of habitat change by 2100

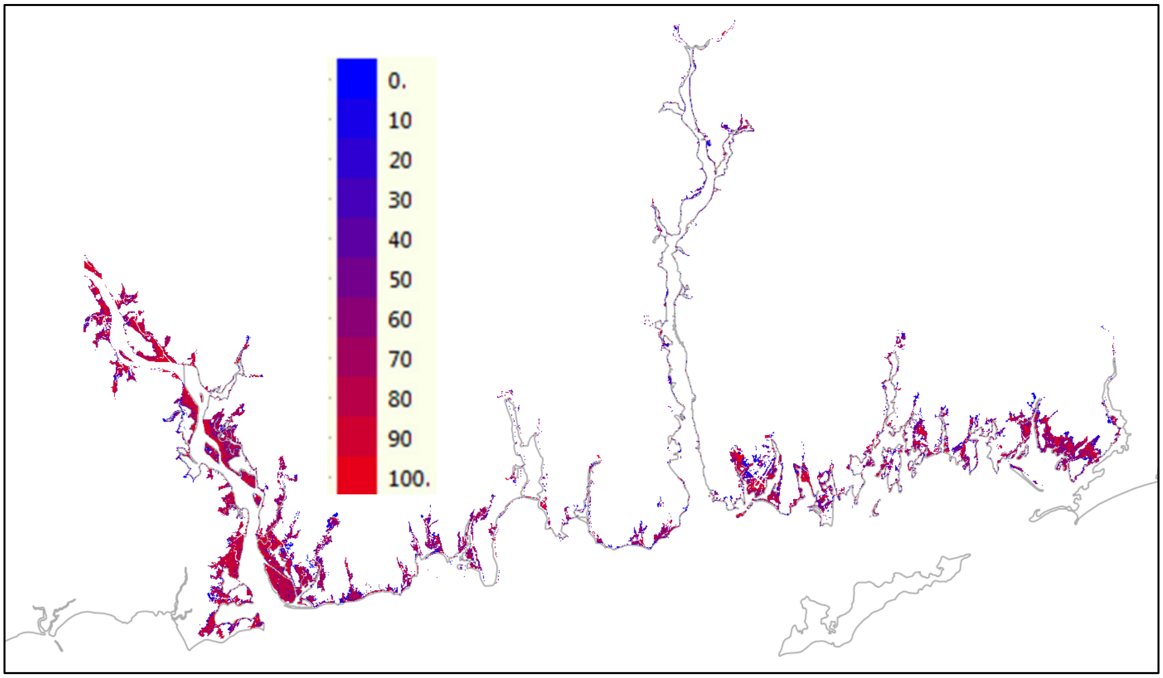


Figure 54. Area 3 Percent Likelihood Percent Likelihood of coastal wetland by 2100

4 Conclusions

This application of the Sea-Level Affecting Marshes Model was funded by the New England Interstate Water Pollution Control Commission (NEIWPCC) and Connecticut Department of Energy and Environmental Protection (CTDEEP) with the goal of identifying potential responses of the coastal marshes and adjacent upland areas in this area to accelerated Sea-Level Rise. The model application and results reported herein can be useful in identifying and prioritizing potential adaptation strategies including land acquisition, marsh restoration, infrastructure development, and other land and facility management actions. This study focused on coastal regions of the entire state of Connecticut with elevations of below five meters (NAVD88) and examines sea-level-rise effects through the year 2100.

Results of this model application find that high marshes (irregularly-flooded marshes) are the most vulnerable category to sea-level rise, with predicted losses ranging from 50% to 97% by 2100. However, as there is uncertainty in model predictions between high marshes and "transitional salt marshes," some irregularly-flooded marsh loss may be offset by increases predicted in the transitional salt marsh category (occupying previous upland areas). Conversely, regularly-flooded marsh is predicted to make substantial gains under all SLR scenarios by occupying areas previously covered by high marsh and by other land types becoming regularly flooded over time. In addition, both high and low marsh are predicted to convert to open water more rapidly in the eastern portion of the study area where lower tide ranges place this resource at greater risk. SLAMM predictions of significant marsh vulnerability to SLR, particularly that of high-marsh habitat, are in line with observations of marsh status in this area over the last 30 to 40 years (Tiner et al. 2006). In addition to wetland losses, up to 9.5% of developed dry land in the study area is also predicted to become regularly flooded.

Details regarding individual marsh systems and the identification of marsh-migration pathways can be produced by spatial analysis of the GIS results derived for this project; the five meter cell size makes it possible to focus closely on areas of interest. The primary product of this project is the suite of GIS layers derived from the deterministic model application as well as the percent-likelihood maps (all available through the project website: www.warrenpinnacle.com/prof/SLAMM/LISS) which provide the basis for further spatial analysis and evaluation.

In considering these results, it is important to bear in mind some limitations of the study. While SLAMM is a useful tool for visualizing potential effects of SLR, the model only predicts changes due to long-term changes in sea levels. Anthropogenic changes such as beach nourishment, shoreline armoring, construction of levees, and changing tide gate configurations are not included in simulations presented here. In addition, the effects of large storms on landcover conversion and marsh loss are not directly considered. Given that many of these changes or events can be injurious to marsh habitats, the results of this model application can be considered optimistic. SLAMM also predicts that high marsh habitat that is regularly flooded will successfully convert into a viable low-marsh habitat. In some cases, it is possible that adding significant salinity to high marsh habitats will result in peat collapse and direct conversion of irregularly-flooded marshes into open water.

There are also data limitations to consider. This study employed a developed-land footprint with a 30 meter resolution which was lower than the resolution of the elevation data layers. The consequence of this coarse resolution may be an over prediction of flooded-developed lands and uncertainty in the available corridors for marsh migration. While SLAMM does not assume that developed dry lands convert to viable marsh habitat when inundated, the model does allow marshes to migrate beyond currently developed areas which may be unlikely.

In addition, SLAMM does not automatically include the “dampening” effect of barriers to tidal flow that have been modified with culverts, tide gates, etc. In other words, the tidal amplitude will be the same in front of and behind a barrier once sea level is high enough to have water flowing beyond the barrier. However, specific input subsites were defined for those areas currently known to have reduced tidal amplitude because of the presence of these barriers, e.g. the Sikorsky Airport area.

Accretion rates are critical input parameters to SLAMM. As discussed in section 2.8, the precise derivation of accretion-feedback curves for regularly-flooded marshes was limited by several factors. Data limitations included a lack of accretion-rate data collected low in the tidal frame, limited marsh-platform elevations at the time of accretion measurement, and incomplete information on marsh biomass within the study area. Accretion-data limitations introduce considerable uncertainty to marsh response patterns predicted by SLAMM.

The vast majority of parameter and data-layer uncertainties have been well addressed by the stochastic uncertainty analysis reported herein. An important uncertainty in the application of SLAMM is the extent of future sea-level rise. Because future values of the driving variables of climate change used by scientists to derive potential SLR rates (i.e., future levels of economic activity, dominant fuel type, fuel consumption, and resulting greenhouse gas emissions) are uncertain, the exact extent of future sea-level rise is also uncertain. Future sea level is not only uncertain now, but the magnitude of this uncertainty increases the further into the future one projects. To incorporate this uncertainty, we’ve used multiple sea-level rise scenarios and their associated uncertainties derived by and vetted through experts in the region. This approach provides a report that presents a range of future SLR scenarios based on the best available data without defaulting to bounding scenarios that may be alarming on one hand or overly optimistic on the other as well as considering other sources of uncertainties that may affect projections.

One of the most useful aspects of the uncertainty analysis may be that it can take a complex model with many SLR scenarios and the uncertainty in all model driving data and parameters and derive a single simplified map to summarize results. For example maps of "the likelihood of a land-type change by a date" or "the likelihood of a coastal marsh by a certain date" have been derived for this project (see Figure 36 and Figure 37, respectively, for examples). These GIS layers can be overlaid on maps of public lands to help inform decisions on how to manage parcels or prioritize land acquisition.

Despite model and data limitations, the model's results can provide useful insight to scientists, managers, and policy makers. For example, federal and state wildlife managers responsible for managing high marsh habitat can use SLAMM's results to help direct habitat and species conservation and restoration resources to marsh systems mostly likely to provide sustained ecological benefits. Similarly, public works managers can use the results of this investigation to prioritize alternative investments in public infrastructure and appropriately site and design new or modifications to existing public infrastructure, such as roads and culverts, consistent with their expected use life and required capacities.

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Appendix A: GIS Methods

DEM Preparation:

Multiple steps were used to produce a hydro-enforced DEM for the Connecticut coastal project area. The 2011 and 2012 LiDAR dataset ground points were converted to DEMs with 5m cell resolution. The earlier NED and UConn DEM data were resampled to a 5m cell resolution. The DEMs were mosaicked together. The Post Sandy DEM elevation data were used wherever cells overlapped with the other datasets. The other datasets were used to fill in gaps in the Post Sandy data, or to extend coverage inland (i.e., 2011 USGS LiDAR data), to islands along the coast (NED), and along the Housatonic River (UConn DEM). The mosaicked DEM was reclassified to create the hydro-enforcement extent, which is limited to elevated areas at or below 5.5 m above mean tide level.

Pre-processing. The LiDAR datasets were downloaded in laz format. The files were extracted and re-projected from geographic to UTM coordinate systems. Post Sandy heights are referenced to ellipsoidal heights using Geoid12a. USGS LiDAR heights are referenced to ellipsoidal heights using Geoid09. The NED data were downloaded and reprojected from geographic to UTM coordinate systems. NED heights are referenced to NAVD88. The 10ft UConn DEM was downloaded and reprojected from State Plane US_ft to UTM meters coordinate systems. There is no height information for the 10ft UConn DEM. The FEMA Structures database was used as the primary source of data to locate all bridges and culverts in the project area. If a bridge or culvert existed, the LiDAR data and publicly available orthoimagery (i.e., ESRI online imagery) was used as reference data to digitize a line through the bridge or culvert. If the stream was greater than 5m wide then a polygon was digitized through the bridge or culvert along with a centerline. All lines were digitized in the downstream direction. Elevation values were then conflated to the end points of the lines using the hybrid elevation dataset. A custom ArcGIS tool was used to verify the start point of each artificial path was higher than or the same elevation of the endpoint. Vertices were edited as needed to ensure a downstream constraint. The vertices of each line and polygon were then densified to 5m spacing. Another custom tool conflated elevation values to the interior vertices of all lines using the start point and end point elevations. If the start point and end point had the same elevation value then all interior vertices will have the same elevation value. If the start point and end point had different elevation values then the value of each interior vertex was calculated using a linear algorithm based on the values of the two endpoints. We used the LP360 Flatten River Polygon tool to conflate the elevation values of each artificial path to each vertex of the polygons that were digitized at each bridge/culvert location, resulting in 3d polygon breaklines that cut through every culvert/bridge location in the study area.

DEM Hydroenforcement: The mosaicked DEM was converted to a multipoint feature class. Points were then erased from the multipoint feature class that fell inside the bridge/culvert polygons. Multipoint feature class and polygon breaklines were then used to create an ESRI terrain dataset. The terrain dataset was converted to a raster DEM with a 5m cell resolution. The breakline polygon areas were inspected to make sure they were represented in the final DEM. For bridges/culverts represented by lines only, the vertices of the lines were converted to points. Points were converted to raster and mosaicked onto the DEM that was converted from the ESRI terrain.

Wetland-Layer Preparation:

The preparation for all wetland layers required the following steps:

- The projection for each data source was checked/converted to NAD83 UTM Zone 18N.
- ESRI's ArcGIS Union tool was used to join each wetland data layer in order of priority.
- The attributes for the priority layer were updated with each subsequent join operation.
- This process was repeated until all the data sources were combined in the order of priority.
- ESRI's Dissolve tool was used to merge adjacent polygons with the same attribute.
- The wetland polygons for individual project areas were merged together into one single dataset representing the full extent of the project using ESRI's Merge tool.
- ESRI's Conversion tool was used to convert the polygon data to raster format with 5 m cell resolution.
- Each project area was then extracted from the full extent raster using the ESRI's Spatial Analyst tool "Extract by Mask".

Appendix B: Great Diurnal Tide Ranges in CT (m)

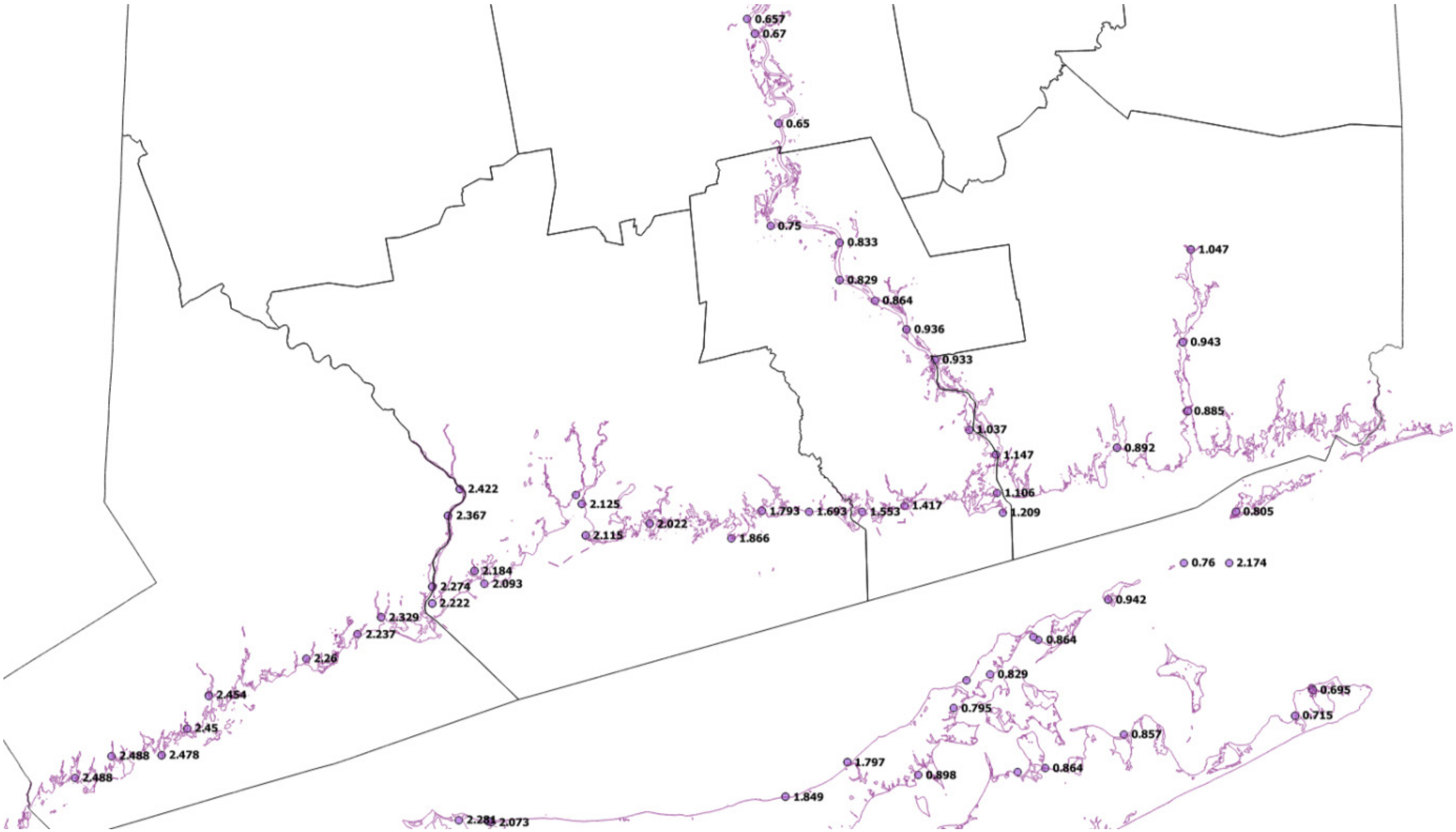


Figure 55. Great diurnal tide ranges in CT (m)

Appendix C: Comprehensive Tables of Input Parameters

Table 76. Area 1 Input Parameters

Subsite	General Area 1	1	2	3
Description		**Pine Creek**	**Erosion Zone - Stratford**	**Sikorsky Airport**
NWI Photo Date (YYYY)	2010	2010	2010	2010
DEM Date (YYYY)	2012	2012	2012	2012
Direction Offshore [n,s,e,w]	South	South	South	South
Historic Trend (mm/yr)	0	0	0	0
Historic Eustatic Trend (mm/yr)	0	0	0	0
MTL-NAVD88 (m)	0	0	0	0
GT Great Diurnal Tide Range (m)	2.3	1.5	2.3	1.2
Wet. Bound. Elev. (m above MTL)	1.66	1.22	1.66	1.02
Marsh Erosion (horz. m /yr)	0	0	0.06	0.06
Swamp Erosion (horz. m /yr)	0	0	0.06	0.06
T.Flat Erosion (horz. m /yr)	0	0	0.06	0.06
Reg.-Flood Marsh Accr (mm/yr)	0	0	0	0
Irreg.-Flood Marsh Accr (mm/yr)	2.422	2.422	2.422	2.422
Tidal-Fresh Marsh Accr (mm/yr)	5	5	5	5
Inland-Fresh Marsh Accr (mm/yr)	1	1	1	1
Mangrove Accr (mm/yr)	0	0	0	0
Tidal Swamp Accr (mm/yr)	1.1	1.1	1.1	1.1
Swamp Accretion (mm/yr)	1.6	1.6	1.6	1.6
Beach Sed. Rate (mm/yr)	0.5	0.5	0.5	0.5
Freq. Overwash (years)	0	0	0	0
Use Elev Pre-processor [True,False]	FALSE	FALSE	FALSE	FALSE
Reg Flood Use Model [True,False]	TRUE	TRUE	TRUE	TRUE
Reg Flood Max. Accr. (mm/year)	5.8474	5.8474	5.8474	5.8474
Reg Flood Min. Accr. (mm/year)	0.6378	0.6378	0.6378	0.6378
Reg Flood Elev a (mm/(year HTU^3))	-0.0304	-0.0304	-0.0304	-0.0304
Reg Flood Elev b (mm/(year HTU^2))	-3.015	-3.015	-3.015	-3.015
Reg Flood Elev c (mm/(year*HTU))	-0.6502	-0.6502	-0.6502	-0.6502
Reg Flood Elev d (mm/year)	5.8123	5.8123	5.8123	5.8123

Table 77. Area 2 Input Parameters (partial)

Subsite	General Area 2	1	2	3	4	5
Description		**CT river**	**Guilford**	**Housatonic**	**Hammock River**	**HVN airport**
NWI Photo Date (YYYY)	2010	2010	2010	2010	2010	2010
DEM Date (YYYY)	2012	2012	2012	2012	2012	2012
Direction Offshore [n,s,e,w]	South	South	South	South	South	South
Historic Trend (mm/yr)	0	0	0	0	0	0
Historic Eustatic Trend (mm/yr)	0	0	0	0	0	0
MTL-NAVD88 (m)	0	0	0	0	0	0
GT Great Diurnal Tide (m)	2.1	1.1	1.67	2.3	1	1
Wet. Bound. Elev. (m above MTL)	1.1	0.94	1	1.66	0.5	0.5
Marsh Erosion (horz. m /yr)	0	0.12	0.08	0.06	0.08	0
Swamp Erosion (horz. m /yr)	0	0.12	0.08	0.06	0.08	0
T.Flat Erosion (horz. m /yr)	0	0.12	0.08	0.06	0.08	0
Reg.-Flood Marsh Accr (mm/yr)	0	0	0	0	0	0
Irreg.-Flood Marsh Accr (mm/yr)	2.422	2.422	2.422	2.422	2.422	2.422
Tidal-Fresh Marsh Accr (mm/yr)	5	5	5	5	5	5
Inland-Fresh Marsh Accr (mm/yr)	1	1	1	1	1	1
Mangrove Accr (mm/yr)	0	0	0	0	0	0
Tidal Swamp Accr (mm/yr)	1.1	1.1	1.1	1.1	1.1	1.1
Swamp Accretion (mm/yr)	1.6	1.6	1.6	1.6	1.6	1.6
Beach Sed. Rate (mm/yr)	0.5	0.5	0.5	0.5	0.5	0.5
Freq. Overwash (years)	0	0	0	0	0	0
Use Elev Pre-processor	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
Reg Flood Use Model	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
Reg Flood Max. Accr. (mm/year)	8.7271	4.8859	8.7271	5.8474	8.7271	8.7271
Reg Flood Min. Accr. (mm/year)	0.2791	0.1571	0.2791	0.6378	0.2791	0.2791
Reg Flood Elev a	0.9191	-1.3211	0.9191	-0.0304	0.9191	0.9191
Reg Flood Elev b	-5.4485	-3.0723	-5.4485	-3.015	-5.4485	-5.4485
Reg Flood Elev c (mm/(year*HTU))	-1.7157	1.8588	-1.7157	-0.6502	-1.7157	-1.7157
Reg Flood Elev d (mm/year)	8.5954	4.6335	8.5954	5.8123	8.5954	8.5954

Table 78. Area 2 Input Parameters, continued, and Area 3 Input Parameters

Subsite	Area 2, Site 6	Area 2, Site 7	Area 3, General	Area 3, Site 1	Area 3, Site 2
Parameter Description	**Sybil Creek**	**Muted Tide**		**CT river**	**Erosion zone - Stonington**
NWI Photo Date (YYYY)	2010	2010	2010	2010	2010
DEM Date (YYYY)	2012	2012	2012	2012	2012
Direction Offshore [n,s,e,w]	South	South	South	South	South
Historic Trend (mm/yr)	0	0	0	0	0
Historic Eustatic Trend (mm/yr)	0	0	0	0	0
MTL-NAVD88 (m)	0	0	0	0	0
GT Great Diurnal Tide Range (m)	0.5	0.88	0.92	1.1	0.92
Wet. Bound. Elev. (m above MTL)	0.35	0.7	0.84	0.94	0.84
Marsh Erosion (horz. m /yr)	0	0.12	0	0.12	0.02
Swamp Erosion (horz. m /yr)	0	0.12	0	0.12	0.02
T.Flat Erosion (horz. m /yr)	0	0.12	0	0.12	0.02
Reg.-Flood Marsh Accr (mm/yr)	0	0	0	0	0
Irreg.-Flood Marsh Accr (mm/yr)	2.422	2.422	2.422	2.422	2.422
Tidal-Fresh Marsh Accr (mm/yr)	5	5	5	5	5
Inland-Fresh Marsh Accr (mm/yr)	1	1	1	1	1
Mangrove Accr (mm/yr)	0	0	0	0	0
Tidal Swamp Accr (mm/yr)	1.1	1.1	1.1	1.1	1.1
Swamp Accretion (mm/yr)	1.6	1.6	1.6	1.6	1.6
Beach Sed. Rate (mm/yr)	0.5	0.5	0.5	0.5	0.5
Freq. Overwash (years)	0	0	0	0	0
Use Elev Pre-processor [True,False]	FALSE	FALSE	FALSE	FALSE	FALSE
Reg Flood Use Model [True,False]	TRUE	TRUE	TRUE	TRUE	TRUE
Reg Flood Max. Accr. (mm/year)	8.7271	8.7271	4.8859	4.8859	4.8859
Reg Flood Min. Accr. (mm/year)	0.2791	0.2791	0.1571	0.1571	0.1571
Reg Flood Elev a (mm/(year HTU^3))	0.9191	0.9191	-1.3211	-1.3211	-1.3211
Reg Flood Elev b (mm/(year HTU^2))	-5.4485	-5.4485	-3.0723	-3.0723	-3.0723
Reg Flood Elev c (mm/(year*HTU))	-1.7157	-1.7157	1.8588	1.8588	1.8588
Reg Flood Elev d (mm/year)	8.5954	8.5954	4.6335	4.6335	4.6335

Appendix D: Tables of Results by County

The following tables present results by county and SLR scenario run. Coastal areas with elevations less than 5 m are included in the SLAMM study area.

Table 79. Fairfield County, GCM Max (Acres)

		Initial	2010	2025	2055	2085	2100
	Undeveloped Dry Land	124,204	123,924	123,877	123,738	123,262	123,060
	Estuarine Open Water	59,675	59,726	59,751	59,783	59,895	59,962
	Developed Dry Land	51,610	51,448	51,417	51,303	50,467	49,973
	Swamp	4,617	4,606	4,605	4,602	4,574	4,551
	Inland Open Water	3,555	3,524	3,519	3,516	3,490	3,475
	Irreg.-Flooded Marsh	1,292	1,160	1,146	1,114	991	882
	Estuarine Beach	940	927	923	907	843	804
	Inland-Fresh Marsh	357	350	349	346	314	313
	Regularly-Flooded Marsh	342	468	627	681	952	1,246
	Inland Shore	119	119	119	119	119	119
	Tidal Flat	38	49	55	60	54	50
	Riverine Tidal	32	26	13	8	5	4
	Tidal-Fresh Marsh	26	24	24	24	22	22
	Tidal Swamp	22	21	21	21	20	19
	Rocky Intertidal	20	20	19	19	18	18
	Trans. Salt Marsh	13	308	205	316	692	730
	Flooded Developed Dry Land	0	162	193	307	1,143	1,637
	Total (incl. water)	**246,864**	**246,864**	**246,864**	**246,864**	**246,864**	**246,864**

Table 80. Fairfield County, 1m by 2100 (Acres)

		Initial	2010	2025	2055	2085	2100
	Undeveloped Dry Land	124,204	123,924	123,876	123,540	122,920	122,556
	Estuarine Open Water	59,675	59,726	59,752	59,820	60,003	60,086
	Developed Dry Land	51,610	51,448	51,417	50,999	49,685	48,908
	Swamp	4,617	4,606	4,605	4,598	4,541	4,526
	Inland Open Water	3,555	3,524	3,519	3,514	3,473	3,466
	Irreg.-Flooded Marsh	1,292	1,160	1,145	1,045	621	309
	Estuarine Beach	940	927	923	880	775	719
	Inland-Fresh Marsh	357	350	349	342	312	309
	Regularly-Flooded Marsh	342	468	628	788	1,605	2,158
	Inland Shore	119	119	119	119	119	119
	Tidal Flat	38	49	55	67	70	78
	Riverine Tidal	32	26	13	7	4	4
	Tidal-Fresh Marsh	26	24	24	22	18	15
	Tidal Swamp	22	21	21	20	18	17
	Rocky Intertidal	20	20	19	19	18	17
	Trans. Salt Marsh	13	308	206	471	755	874
	Flooded Developed Dry Land	0	162	193	611	1,925	2,702
	Total (incl. water)	**246,864**	**246,864**	**246,864**	**246,864**	**246,864**	**246,864**

Table 81. Fairfield County, RIM Min (Acres)

		Initial	2010	2025	2055	2085	2100
	Undeveloped Dry Land	124,204	123,924	123,877	123,470	122,488	122,065
	Estuarine Open Water	59,675	59,726	59,751	59,839	60,107	60,230
	Developed Dry Land	51,610	51,448	51,417	50,903	48,738	47,833
	Swamp	4,617	4,606	4,605	4,597	4,523	4,510
	Inland Open Water	3,555	3,524	3,519	3,512	3,466	3,459
	Irreg.-Flooded Marsh	1,292	1,160	1,146	1,013	228	110
	Estuarine Beach	940	927	923	867	703	623
	Inland-Fresh Marsh	357	350	349	339	308	302
	Regularly-Flooded Marsh	342	468	627	843	2,297	2,778
	Inland Shore	119	119	119	119	119	119
	Tidal Flat	38	49	55	71	107	195
	Riverine Tidal	32	26	13	7	4	2
	Tidal-Fresh Marsh	26	24	24	22	13	10
	Tidal Swamp	22	21	21	20	17	14
	Rocky Intertidal	20	20	19	19	17	16
	Trans. Salt Marsh	13	308	205	514	855	819
	Flooded Developed Dry Land	0	162	193	708	2,872	3,777
	Total (incl. water)	**246,864**	**246,864**	**246,864**	**246,864**	**246,864**	**246,864**

Table 82 Fairfield County; RIM Max (Acres)

		Initial	2010	2025	2055	2085	2100
	Undeveloped Dry Land	124,204	123,924	123,822	123,114	122,034	121,643
	Estuarine Open Water	59,675	59,726	59,761	59,944	60,258	60,451
	Developed Dry Land	51,610	51,448	51,376	50,072	47,761	46,893
	Swamp	4,617	4,606	4,603	4,546	4,509	4,500
	Inland Open Water	3,555	3,524	3,519	3,490	3,459	3,449
	Irreg.-Flooded Marsh	1,292	1,160	1,122	718	95	47
	Estuarine Beach	940	927	917	806	615	538
	Inland-Fresh Marsh	357	350	349	313	302	302
	Regularly-Flooded Marsh	342	468	666	1,303	2,759	2,999
	Inland Shore	119	119	119	119	119	119
	Tidal Flat	38	49	61	94	263	522
	Riverine Tidal	32	26	12	5	2	2
	Tidal-Fresh Marsh	26	24	23	17	8	6
	Tidal Swamp	22	21	21	19	14	13
	Rocky Intertidal	20	20	19	18	16	13
	Trans. Salt Marsh	13	308	241	748	799	651
	Flooded Developed Dry Land	0	162	234	1,538	3,849	4,717
	Total (incl. water)	**246,864**	**246,864**	**246,864**	**246,864**	**246,864**	**246,864**

Table 83. New Haven County, GCM Max (Acres)

		Initial	2010	2025	2055	2085	2100
	Estuarine Open Water	139,226	139,264	139,378	139,482	139,686	139,801
	Undeveloped Dry Land	27,636	27,315	27,258	27,104	26,752	26,564
	Developed Dry Land	24,650	24,550	24,531	24,470	24,327	24,214
	Irreg.-Flooded Marsh	4,554	4,112	4,026	3,808	3,093	2,412
	Swamp	1,720	1,685	1,678	1,663	1,625	1,605
	Estuarine Beach	1,040	1,039	1,020	958	819	747
	Regularly-Flooded Marsh	692	1,131	1,519	1,859	2,870	3,768
	Inland Open Water	537	531	510	510	502	495
	Inland-Fresh Marsh	277	261	256	246	221	215
	Riverine Tidal	207	186	122	111	101	93
	Tidal-Fresh Marsh	115	115	115	115	114	113
	Tidal Swamp	74	66	65	62	53	50
	Tidal Flat	71	100	124	121	79	57
	Rocky Intertidal	49	46	45	41	37	36
	Trans. Salt Marsh	47	393	129	165	293	290
	Inland Shore	1	1	1	1	1	1
	Flooded Developed Dry Land	0	99	119	179	323	436
	Total (incl. water)	**200,896**	**200,896**	**200,896**	**200,896**	**200,896**	**200,896**

Table 84. New Haven County, 1m by 2100 (Acres)

		Initial	2010	2025	2055	2085	2100
	Estuarine Open Water	139,226	139,264	139,378	139,572	139,873	140,009
	Undeveloped Dry Land	27,636	27,315	27,257	26,968	26,424	26,128
	Developed Dry Land	24,650	24,550	24,530	24,416	24,107	23,863
	Irreg.-Flooded Marsh	4,554	4,112	4,024	3,456	1,252	589
	Swamp	1,720	1,685	1,678	1,644	1,583	1,546
	Estuarine Beach	1,040	1,036	1,017	896	700	613
	Regularly-Flooded Marsh	692	1,131	1,526	2,302	4,973	5,916
	Inland Open Water	537	531	510	506	491	480
	Inland-Fresh Marsh	277	261	256	228	203	172
	Riverine Tidal	207	186	122	104	93	91
	Tidal-Fresh Marsh	115	115	115	114	112	110
	Tidal Swamp	74	66	65	57	44	32
	Tidal Flat	71	100	124	117	92	130
	Rocky Intertidal	49	46	45	39	35	33
	Trans. Salt Marsh	47	397	129	243	370	396
	Inland Shore	1	1	1	1	1	1
	Flooded Developed Dry Land	0	99	120	233	543	786
	Total (incl. water)	**200,896**	**200,896**	**200,896**	**200,896**	**200,896**	**200,896**

Table 85. New Haven County, RIM Min (Acres)

		Initial	2010	2025	2055	2085	2100
	Estuarine Open Water	139,226	139,264	139,378	139,610	140,093	140,363
	Undeveloped Dry Land	27,636	27,315	27,258	26,907	26,067	25,627
	Developed Dry Land	24,650	24,550	24,531	24,392	23,799	23,363
	Irreg.-Flooded Marsh	4,554	4,112	4,026	3,244	467	241
	Swamp	1,720	1,685	1,678	1,633	1,534	1,486
	Estuarine Beach	1,040	1,039	1,020	871	584	434
	Regularly-Flooded Marsh	692	1,131	1,519	2,537	5,850	6,442
	Inland Open Water	537	531	510	505	480	469
	Inland-Fresh Marsh	277	261	256	225	166	149
	Riverine Tidal	207	186	122	103	92	86
	Tidal-Fresh Marsh	115	115	115	113	107	97
	Tidal Swamp	74	66	65	55	30	21
	Tidal Flat	71	100	124	122	198	282
	Rocky Intertidal	49	46	45	38	32	25
	Trans. Salt Marsh	47	393	129	282	546	524
	Inland Shore	1	1	1	1	1	1
	Flooded Developed Dry Land	0	99	119	257	851	1,287
	Total (incl. water)	**200,896**	**200,896**	**200,896**	**200,896**	**200,896**	**200,896**

Table 86 New Haven County; RIM Max (Acres)

		Initial	2010	2025	2055	2085	2100
	Estuarine Open Water	139,226	139,264	139,412	139,779	140,442	140,762
	Undeveloped Dry Land	27,636	27,315	27,190	26,599	25,586	25,040
	Developed Dry Land	24,650	24,550	24,507	24,243	23,321	22,595
	Irreg.-Flooded Marsh	4,554	4,112	3,859	1,604	216	132
	Swamp	1,720	1,685	1,669	1,597	1,476	1,390
	Estuarine Beach	1,040	1,036	994	759	425	325
	Regularly-Flooded Marsh	692	1,131	1,703	4,268	6,221	6,154
	Inland Open Water	537	531	510	495	469	457
	Inland-Fresh Marsh	277	261	252	214	147	128
	Riverine Tidal	207	186	122	103	86	79
	Tidal-Fresh Marsh	115	115	114	111	89	62
	Tidal Swamp	74	66	64	49	20	12
	Tidal Flat	71	100	128	214	440	1,019
	Rocky Intertidal	49	46	43	36	24	21
	Trans. Salt Marsh	47	397	186	416	602	665
	Inland Shore	1	1	1	1	1	1
	Flooded Developed Dry Land	0	99	143	407	1,329	2,055
	Total (incl. water)	**200,896**	**200,896**	**200,896**	**200,896**	**200,896**	**200,896**

Table 87. Middlesex County, GCM Max (Acres)

		Initial	2010	2025	2055	2085	2100
	Estuarine Open Water	37,005	37,071	37,325	37,421	37,520	37,547
	Undeveloped Dry Land	21,262	21,075	21,036	20,932	20,752	20,661
	Developed Dry Land	4,990	4,970	4,961	4,931	4,858	4,815
	Irreg.-Flooded Marsh	2,401	2,241	2,218	2,149	1,604	1,059
	Swamp	1,267	1,265	1,262	1,256	1,250	1,248
	Inland Open Water	442	442	441	441	441	440
	Riverine Tidal	321	286	66	47	36	30
	Tidal-Fresh Marsh	292	261	260	256	238	230
	Estuarine Beach	277	247	218	168	124	107
	Tidal Swamp	198	190	186	172	119	93
	Inland-Fresh Marsh	92	88	87	85	82	81
	Regularly-Flooded Marsh	30	205	301	430	1,187	1,855
	Trans. Salt Marsh	9	202	139	194	240	245
	Tidal Flat	3	28	60	49	7	3
	Flooded Developed Dry Land	0	21	30	59	132	176
	Total (incl. water)	**68,590**	**68,590**	**68,590**	**68,590**	**68,590**	**68,590**

Table 88. Middlesex County, 1m by 2100 (Acres)

		Initial	2010	2025	2055	2085	2100
	Estuarine Open Water	37,005	37,071	37,326	37,472	37,580	37,636
	Undeveloped Dry Land	21,262	21,075	21,036	20,852	20,593	20,458
	Developed Dry Land	4,990	4,970	4,960	4,902	4,781	4,712
	Irreg.-Flooded Marsh	2,401	2,241	2,217	1,888	409	161
	Swamp	1,267	1,265	1,262	1,253	1,245	1,242
	Inland Open Water	442	442	441	441	440	439
	Riverine Tidal	321	286	66	43	30	20
	Tidal-Fresh Marsh	292	261	260	239	201	168
	Estuarine Beach	277	246	217	148	98	85
	Tidal Swamp	198	190	186	150	77	59
	Inland-Fresh Marsh	92	88	87	83	80	79
	Regularly-Flooded Marsh	30	205	303	785	2,553	2,954
	Trans. Salt Marsh	9	202	139	211	241	243
	Tidal Flat	3	28	60	35	52	55
	Flooded Developed Dry Land	0	21	30	88	209	279
	Total (incl. water)	**68,590**	**68,590**	**68,590**	**68,590**	**68,590**	**68,590**

Table 89. Middlesex County, RIM Min (Acres)

		Initial	2010	2025	2055	2085	2100
	Estuarine Open Water	37,005	37,071	37,325	37,493	37,668	37,813
	Undeveloped Dry Land	21,262	21,075	21,036	20,817	20,430	20,221
	Developed Dry Land	4,990	4,970	4,961	4,888	4,696	4,570
	Irreg.-Flooded Marsh	2,401	2,241	2,218	1,721	124	52
	Swamp	1,267	1,265	1,262	1,251	1,241	1,219
	Inland Open Water	442	442	441	441	440	438
	Riverine Tidal	321	286	66	42	21	16
	Tidal-Fresh Marsh	292	261	260	232	136	63
	Estuarine Beach	277	247	218	139	85	70
	Tidal Swamp	198	190	186	137	53	38
	Inland-Fresh Marsh	92	88	87	82	79	78
	Regularly-Flooded Marsh	30	205	301	983	2,877	2,639
	Trans. Salt Marsh	9	202	139	219	253	280
	Tidal Flat	3	28	60	43	192	673
	Flooded Developed Dry Land	0	21	30	102	294	421
	Total (incl. water)	**68,590**	**68,590**	**68,590**	**68,590**	**68,590**	**68,590**

Table 90 Middlesex County; RIM Max (Acres)

		Initial	2010	2025	2055	2085	2100
	Estuarine Open Water	37,005	37,071	37,352	37,567	37,970	38,810
	Undeveloped Dry Land	21,262	21,075	20,988	20,679	20,203	19,974
	Developed Dry Land	4,990	4,970	4,948	4,824	4,559	4,405
	Irreg.-Flooded Marsh	2,401	2,241	2,173	575	48	27
	Swamp	1,267	1,265	1,258	1,247	1,217	1,180
	Inland Open Water	442	442	441	440	437	437
	Riverine Tidal	321	286	65	37	16	11
	Tidal-Fresh Marsh	292	261	248	190	45	20
	Estuarine Beach	277	246	194	114	71	57
	Tidal Swamp	198	190	179	89	36	27
	Inland-Fresh Marsh	92	88	86	81	78	76
	Regularly-Flooded Marsh	30	205	375	2,242	2,250	1,319
	Trans. Salt Marsh	9	202	169	229	296	301
	Tidal Flat	3	28	72	109	933	1,361
	Flooded Developed Dry Land	0	21	43	166	431	586
	Total (incl. water)	**68,590**	**68,590**	**68,590**	**68,590**	**68,590**	**68,590**

Table 91. New London County, GCM Max (Acres)

		Initial	2010	2025	2055	2085	2100
	Estuarine Open Water	55,657	55,694	55,860	55,936	56,041	56,082
	Undeveloped Dry Land	32,773	32,276	32,194	31,984	31,580	31,379
	Developed Dry Land	11,108	11,037	11,022	10,973	10,833	10,747
	Irreg.-Flooded Marsh	2,970	2,789	2,755	2,640	1,548	796
	Swamp	1,266	1,254	1,244	1,229	1,196	1,183
	Tidal Swamp	377	361	353	333	248	207
	Tidal-Fresh Marsh	330	326	326	324	310	300
	Inland Open Water	305	304	302	301	291	288
	Riverine Tidal	251	236	80	63	54	51
	Estuarine Beach	217	209	207	203	193	186
	Inland-Fresh Marsh	139	136	135	131	117	115
	Regularly-Flooded Marsh	118	311	513	671	2,050	3,038
	Trans. Salt Marsh	88	595	463	606	807	801
	Tidal Flat	10	12	71	79	68	78
	Rocky Intertidal	9	9	9	8	8	7
	Flooded Developed Dry Land	0	71	86	136	275	361
	Total (incl. water)	**105,619**	**105,619**	**105,619**	**105,619**	**105,619**	**105,619**

Table 92. New London County, 1m by 2100 (Acres)

		Initial	2010	2025	2055	2085	2100
	Estuarine Open Water	55,657	55,694	55,860	55,990	56,137	56,240
	Undeveloped Dry Land	32,773	32,276	32,192	31,798	31,239	30,901
	Developed Dry Land	11,108	11,037	11,022	10,918	10,683	10,489
	Irreg.-Flooded Marsh	2,970	2,789	2,754	2,177	395	203
	Swamp	1,266	1,254	1,244	1,206	1,174	1,132
	Tidal Swamp	377	361	353	298	182	148
	Tidal-Fresh Marsh	330	326	326	310	260	232
	Inland Open Water	305	304	302	297	284	278
	Riverine Tidal	251	236	80	60	50	44
	Estuarine Beach	217	209	207	199	181	169
	Inland-Fresh Marsh	139	136	135	123	114	103
	Regularly-Flooded Marsh	118	311	515	1,258	3,596	3,821
	Trans. Salt Marsh	88	595	464	697	729	807
	Tidal Flat	10	12	71	89	163	426
	Rocky Intertidal	9	9	9	8	7	7
	Flooded Developed Dry Land	0	71	86	190	425	619
	Total (incl. water)	**105,619**	**105,619**	**105,619**	**105,619**	**105,619**	**105,619**

Table 93. New London County, RIM Min (Acres)

		Initial	2010	2025	2055	2085	2100
	Estuarine Open Water	55,657	55,694	55,860	56,010	56,333	57,541
	Undeveloped Dry Land	32,773	32,276	32,194	31,722	30,829	30,300
	Developed Dry Land	11,108	11,037	11,022	10,890	10,447	10,114
	Irreg.-Flooded Marsh	2,970	2,789	2,755	1,800	180	99
	Swamp	1,266	1,254	1,244	1,202	1,124	1,076
	Tidal Swamp	377	361	353	277	138	103
	Tidal-Fresh Marsh	330	326	326	301	204	104
	Inland Open Water	305	304	302	297	278	258
	Riverine Tidal	251	236	80	58	45	38
	Estuarine Beach	217	209	207	197	166	144
	Inland-Fresh Marsh	139	136	135	121	102	96
	Regularly-Flooded Marsh	118	311	513	1,702	3,051	1,976
	Trans. Salt Marsh	88	595	463	714	775	813
	Tidal Flat	10	12	71	101	1,281	1,958
	Rocky Intertidal	9	9	9	8	6	6
	Flooded Developed Dry Land	0	71	86	218	661	995
	Total (incl. water)	**105,619**	**105,619**	**105,619**	**105,619**	**105,619**	**105,619**

Table 94 New London County; RIM Max (Acres)

		Initial	2010	2025	2055	2085	2100
	Estuarine Open Water	55,657	55,694	55,864	56,124	57,786	59,861
	Undeveloped Dry Land	32,773	32,276	32,103	31,416	30,251	29,750
	Developed Dry Land	11,108	11,037	11,005	10,765	10,077	9,735
	Irreg.-Flooded Marsh	2,970	2,789	2,686	523	95	61
	Swamp	1,266	1,254	1,235	1,182	1,058	1,026
	Tidal Swamp	377	361	342	200	99	74
	Tidal-Fresh Marsh	330	326	320	251	64	30
	Inland Open Water	305	304	302	288	258	254
	Riverine Tidal	251	236	79	53	38	32
	Estuarine Beach	217	209	206	186	141	114
	Inland-Fresh Marsh	139	136	134	115	96	94
	Regularly-Flooded Marsh	118	311	643	3,301	1,726	1,584
	Trans. Salt Marsh	88	595	500	674	835	707
	Tidal Flat	10	12	90	190	2,058	919
	Rocky Intertidal	9	9	9	8	6	5
	Flooded Developed Dry Land	0	71	103	344	1,031	1,373
	Total (incl. water)	**105,619**	**105,619**	**105,619**	**105,619**	**105,619**	**105,619**

Appendix E: NWI Classes to SLAMM 6 Categories

		NWI code characters					
SLAMM Code	Name	System	Subsystem	Class	Subclass	Water Regime	Notes
1	Developed Dry Land (upland)	U					SLAMM assumes developed land will be defended against sea-level rise. Categories 1 & 2 need to be distinguished manually.
2	Undeveloped Dry land (upland)	U					
3	Nontidal Swamp	P	NA	FO, SS	1, 3 to 7, None	A,B,C,E,F,G,H,J,K None or U	Palustrine Forested and Scrub-Shrub (living or dead)
4	Cypress Swamp	P	NA	FO, SS	2	A,B,C,E,F,G,H,J,K None or U	Needle-leaved Deciduous forest and Scrub-Shrub (living or dead)
5	Inland Fresh Marsh	P	NA	EM, **f ****	All None	A,B,C,E,F,G,H,J,K None or U	Palustrine Emergents; Lacustrine and Riverine Nonpersistent Emergents
		L	2	EM	2 None	E, F, G, H, K None or U	
		R	2, 3	EM	2 None	E, F, G, H, K None or U	
6	Tidal Fresh Marsh	R	1	EM	2, None	Fresh Tidal N, T	Riverine and Palustrine Freshwater Tidal Emergents
		P	NA	EM	All, None	Fresh Tidal S, R, T	
7	Transitional Marsh / Scrub Shrub	E	2	SS, FO	1, 2, 4 to 7,None	Tidal M, N, P None or U	Estuarine Intertidal, Scrub-shrub and Forested (ALL except 3 subclass)
8	Regularly Flooded Marsh (Saltmarsh)	E	2	EM	1 None	Tidal N None or U	Only regularly flooded tidal marsh No intermittently flooded "P" water Regime
9	Mangrove **Tropical settings only, otherwise 7**	E	2	FO, SS	3	Tidal M, N, P None or U	Estuarine Intertidal Forested and Scrub-shrub, Broad-leaved Evergreen
10	Estuarine Beach old code BB and FL = US	E	2	US	1,2 Important codes	Tidal N, P	Estuarine Intertidal Unconsolidated Shores
		E	**2**	**US**	**None**	**Tidal N, P**	**Only when shores (need images or base map)**
11	Tidal Flat old code BB and FL =US	E	2	US	3,4 None	Tidal M, N None or U	Estuarine Intertidal Unconsolidated Shore (mud or organic) and Aquatic Bed; Marine Intertidal Aquatic Bed
		E	2	AB	All Except 1	Tidal M, N None or U	
		E	**2**	**AB**	**1**	**P**	**Specifically, for wind driven tides on the south coast of TX**
		M	2	AB	1, 3 None	Tidal M, N None or U	
12	Ocean Beach old code BB and FL = US	M	2	US	1,2 Important	Tidal N, P	Marine Intertidal Unconsolidated Shore, cobble-gravel, sand
		M	2	US	None	Tidal P	
13	Ocean Flat old code BB and FL = US	M	2	US	3,4 None	Tidal M, N None or U	Marine Intertidal Unconsolidated Shore, mud or organic, (low energy coastline)

Source, Bill Wilen, National Wetlands Inventory.

		NWI code characters					
SLAMM Code	Name	System	Subsystem	Class	Subclass	Water Regime	Notes
14	Rocky Intertidal	M	2	RS	All None	Tidal M, N, P None or U	Marine and Estuarine Intertidal Rocky Shore and Reef
		E	2	RS	All None	Tidal M ,N, P None or U	
		E	2	RF	2, 3 None	Tidal M, N, P None or U	
		E	2	AB	1	Tidal M, N None or U	
15	Inland Open Water	R	2	UB, AB	All, None	All, None	Riverine, Lacustrine, and Palustrine Unconsolidated Bottom, and Aquatic Beds
		R	3	UB, AB, RB	All, None	All, None	
	old code OW = UB	L	1, 2	UB, AB, RB	All, None	All, None	
		P	NA	UB, AB, RB	All, None	All, None	
		R	5	UB	All	Only U	
16	Riverine Tidal Open Water old code OW = UB	R	1	All **Except EM**	All None **Except 2**	Fresh Tidal S, R, T, V	Riverine Tidal Open water **R1EM2 falls under SLAMM Category 6**
17	Estuarine Open Water (no h* for diked / impounded) old code OW=UB	E	1	All	All None	Tidal L, M, N, P	Estuarine subtidal
18	Tidal Creek	E	2	SB	All, None	Tidal M, N, P Fresh Tidal R, S	Estuarine Intertidal Streambed
19	Open Ocean old code OW = UB	M	1	All	All	Tidal L, M, N, P	Marine Subtidal and Marine Intertidal Aquatic Bed and Reef
		M	2	RF	1,3, None	Tidal M, N, P None or U	
20	Irregularly Flooded Marsh	E	2	EM	1, 5 None	P	Irregularly Flooded Estuarine Intertidal Emergent marsh
		E	**2**	**US**	**2, 3, 4 None**	**P**	**Only when these salt pans are associated with E2EMN or P**
21	Not Used						
22	Inland Shore old code BB and FL = US	L	2	US, RS	All	All Nontidal	Shoreline not pre-processed using Tidal Range Elevations
		P	NA	US	All, None	All Nontidal None or U	
		R	2, 3	US, RS	All, None	All Nontidal None or U	
		R	4	SB	All, None	All Nontidal None or U	
23	Tidal Swamp	P	NA	SS, FO	All, None	Fresh Tidal R, S, T	Tidally influenced swamp

* **h=Diked/Impounded** - When it is desirable to model the protective effects of dikes, an additional raster layer must be specified.

** Farmed wetlands are coded Pf
All: valid components
None: no Subclass or Water regime listed
U: Unknown water regime
NA: Not applicable

DATE 1/14/12010

Water Regimes	
Nontidal	A, B, C, E, F,G, J, K
Saltwater Tidal	L, M, N, P
Fresh Tidal	R, S,T, V

Note: Illegal codes must be categorize by intent.
Old codes BB, FL = US
Old Code OW = UB

Source, Bill Wilen, National Wetlands Inventory

For more information on the NWI coding system see Appendix A of (Dahl et al. 2009)

Appendix F: SLAMM Codes

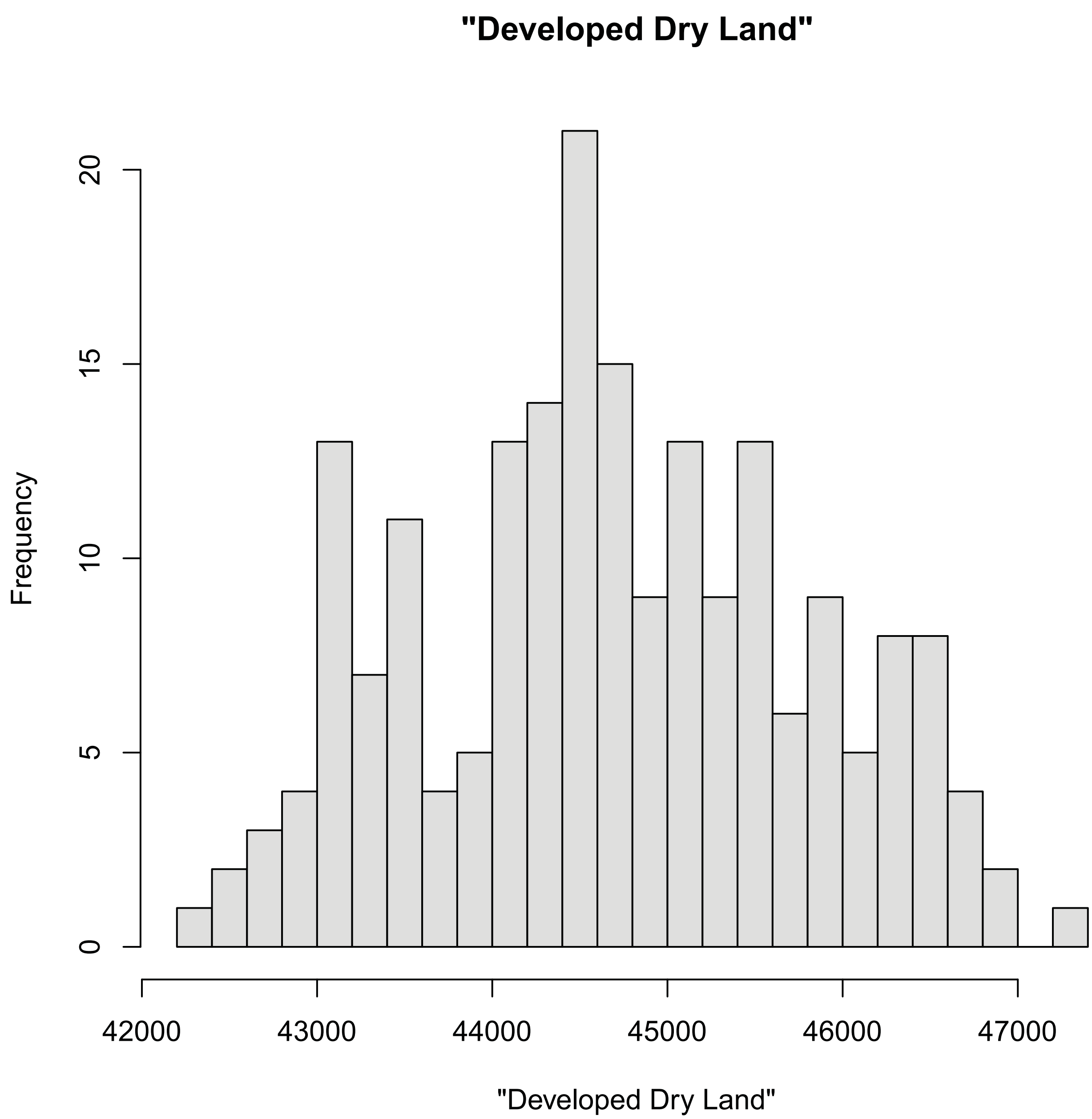
SLAMM Codes	SLAMM Colors	SLAMM Description
1		Developed Dry Land
2		Undeveloped Dry Land
3		Swamp
4		Cypress Swamp
5		Inland Fresh Marsh
6		Tidal Fresh Marsh
7		Transitional Salt Marsh
8		Regularly-flooded Marsh
9		Mangrove
10		Estuarine Beach
11		Tidal Flat
12		Ocean Beach
13		Ocean Flat
14		Rocky Intertidal
15		Inland Open Water
16		Riverine Tidal
17		Estuarine Open Water
18		Tidal Creek
19		Open Ocean
20		Irregularly-flooded Marsh
21		Tall Spartina
22		Inland Shore
23		Tidal Swamp
24		Blank
25		Flooded Developed Dry Land
26		Backshore

Appendix G: SLAMM Land Cover Conversion Rules

	Inundation: *Non-adjacent to open water or Fetch < 9km (non tropical systems)*	**Erosion:** *Adjacent to Open Water and Fetch > 9km (erosion)*
Converting From	**Converts To**	**Converts To**
Dry Land	Transitional salt marsh, ocean beach, tidal swamp, or estuarine beach, depending on context (see below)	Erosion of dry land is ignored.
Swamp	Transitional salt marsh *or Tidal Swamp if designated as "freshwater-flow influenced"*	Erosion to Tidal Flat
Cypress Swamp	Open Water	Erosion to Tidal Flat
Inland Fresh Marsh	Transitional salt marsh *or Tidal-fresh Marsh if designated as "freshwater-flow influenced"*	Erosion to Tidal Flat
Tidal Swamp	Irregularly-flooded Marsh *or Tidal-fresh Marsh if designated as "freshwater-flow influenced"*	Erosion to Tidal Flat
Tidal Fresh Marsh	Irregularly Flooded Marsh	Erosion to Tidal Flat
Transitional or Irregularly-Flooded Marsh	to Regularly Flooded Marsh	Erosion to Tidal Flat
Regularly Flooded Marsh	to Tidal Flat	Erosion to Tidal Flat
Mangrove	to Estuarine Water	Erosion & Inundation to Estuarine Water
Ocean Flat	to Open Ocean	Erosion to Open Ocean
Tidal Flat	Erosion or Inundation to Estuarine Water	Erosion to Estuarine Water
Estuarine Beach, Ocean Beach	open water	Erosion to open water

Appendix H: Uncertainty Analysis Histograms

Appendix H presents histograms for all modeled land-cover and open-water categories broken down by watershed in the year 2100. This type of graphic shows the likelihood of different acreage predictions within year-2100 confidence intervals. Histograms can illustrate if distributions within the reported confidence intervals are skewed, potentially resulting in a more likely result towards the top or the bottom of a confidence interval.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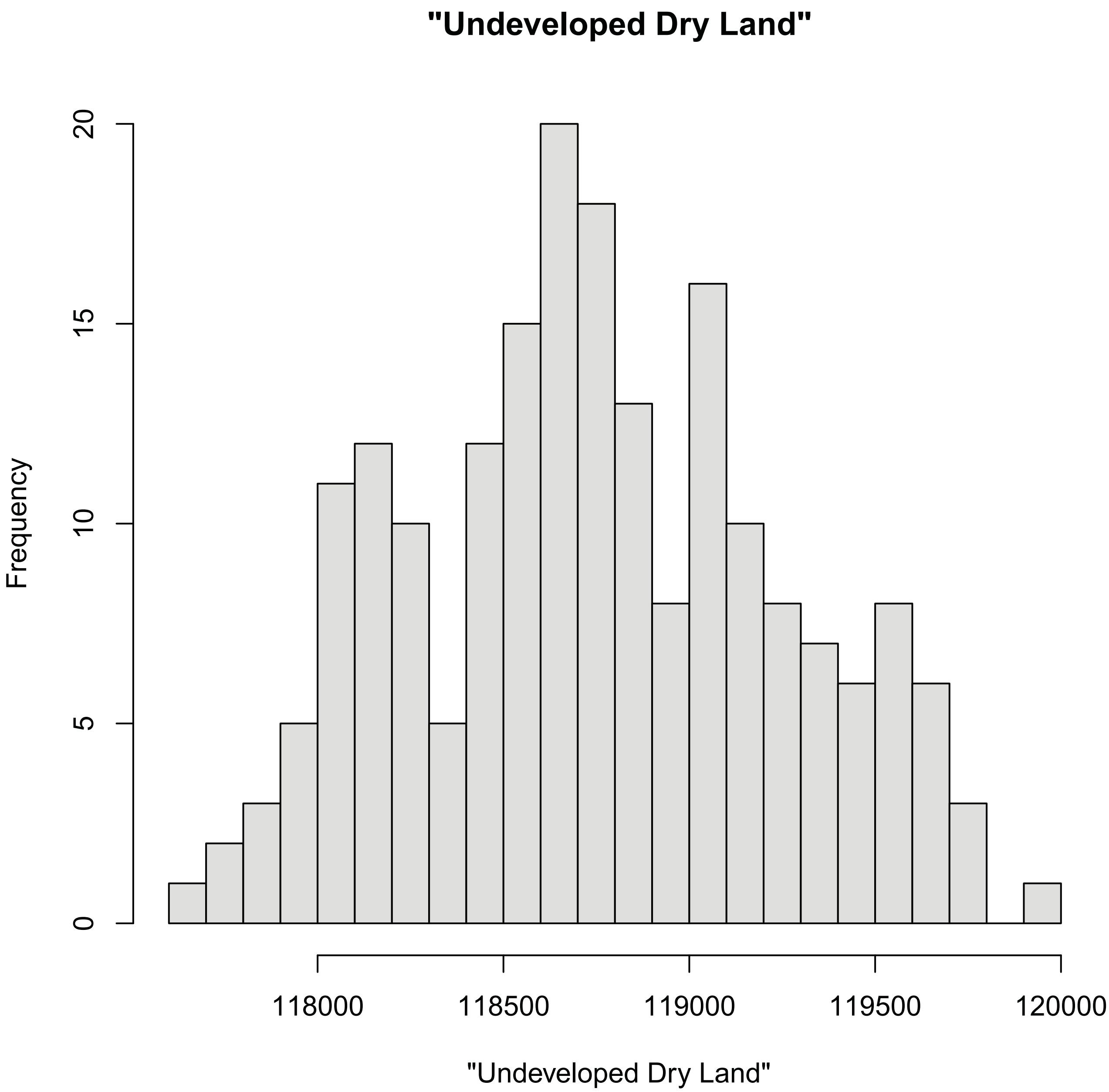
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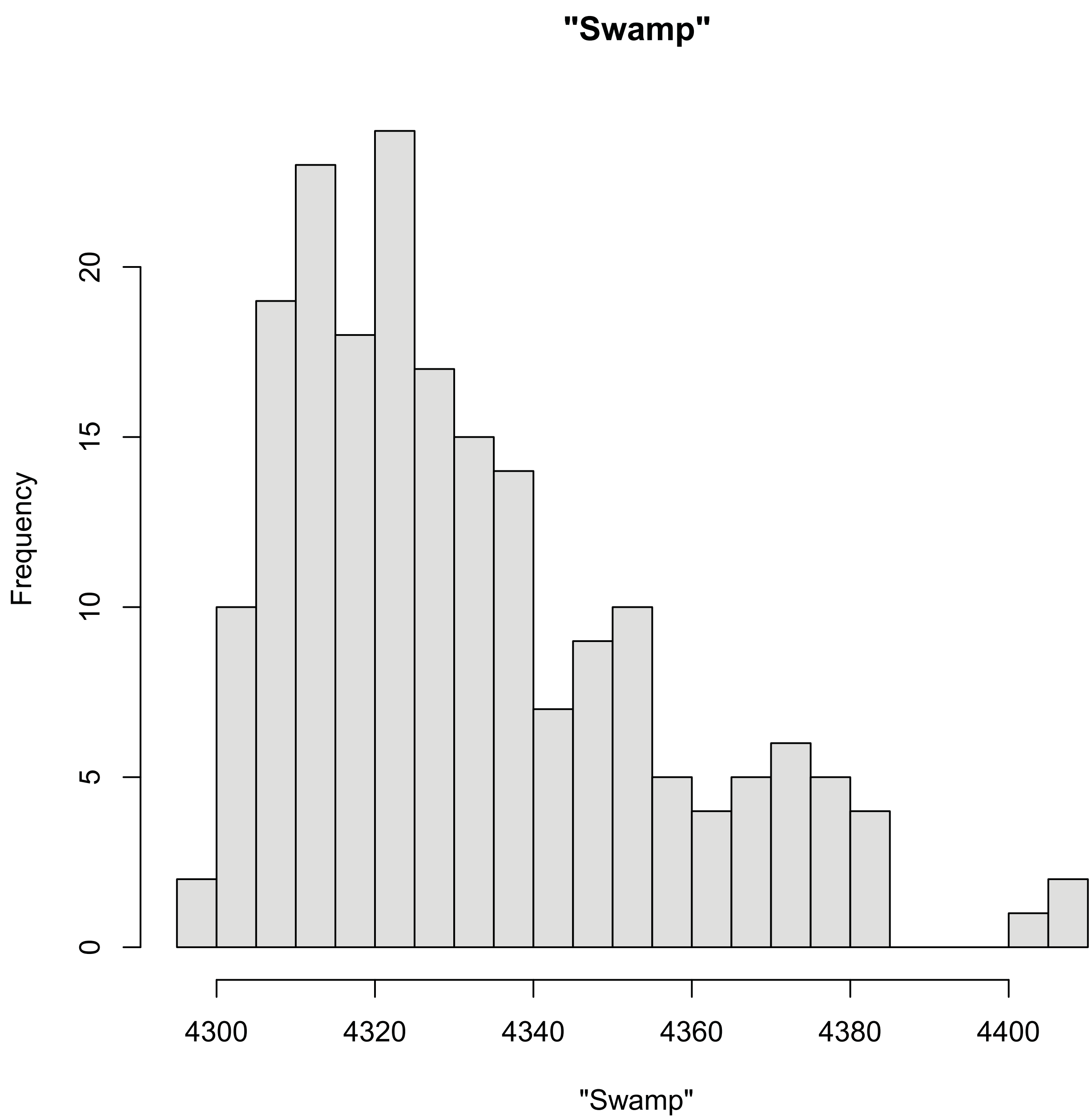
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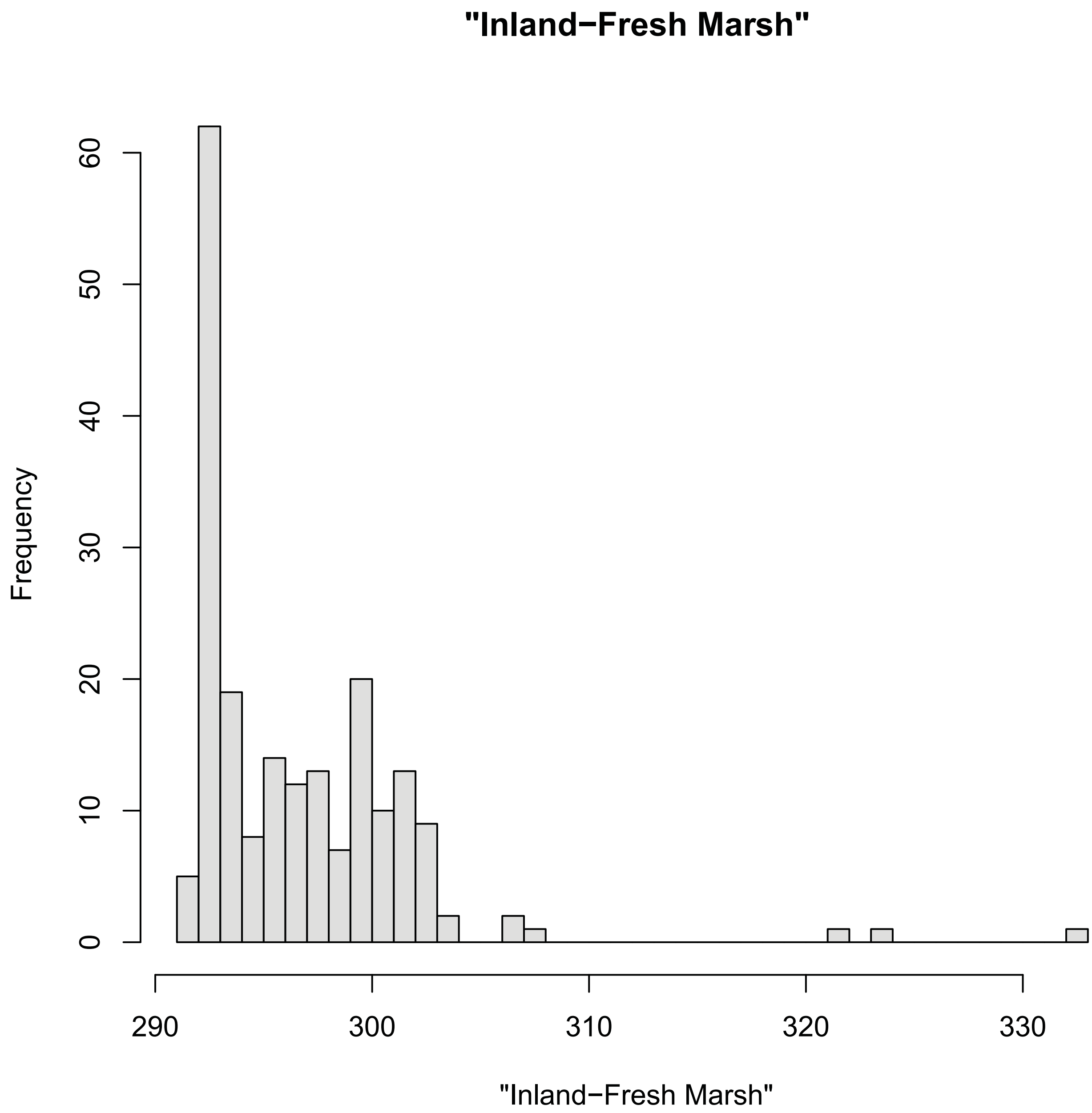
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300
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320
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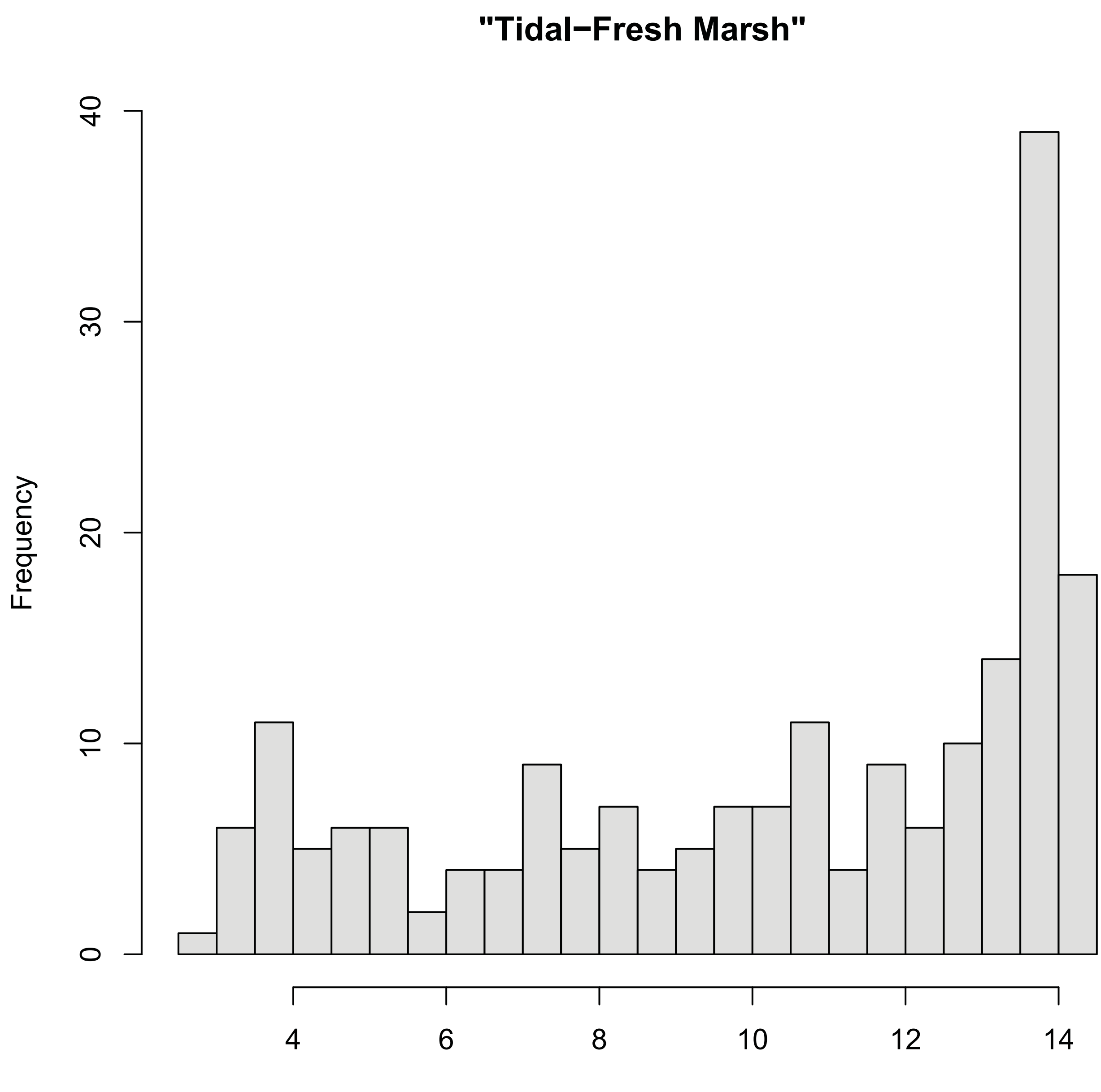
"Inland−Fresh Marsh"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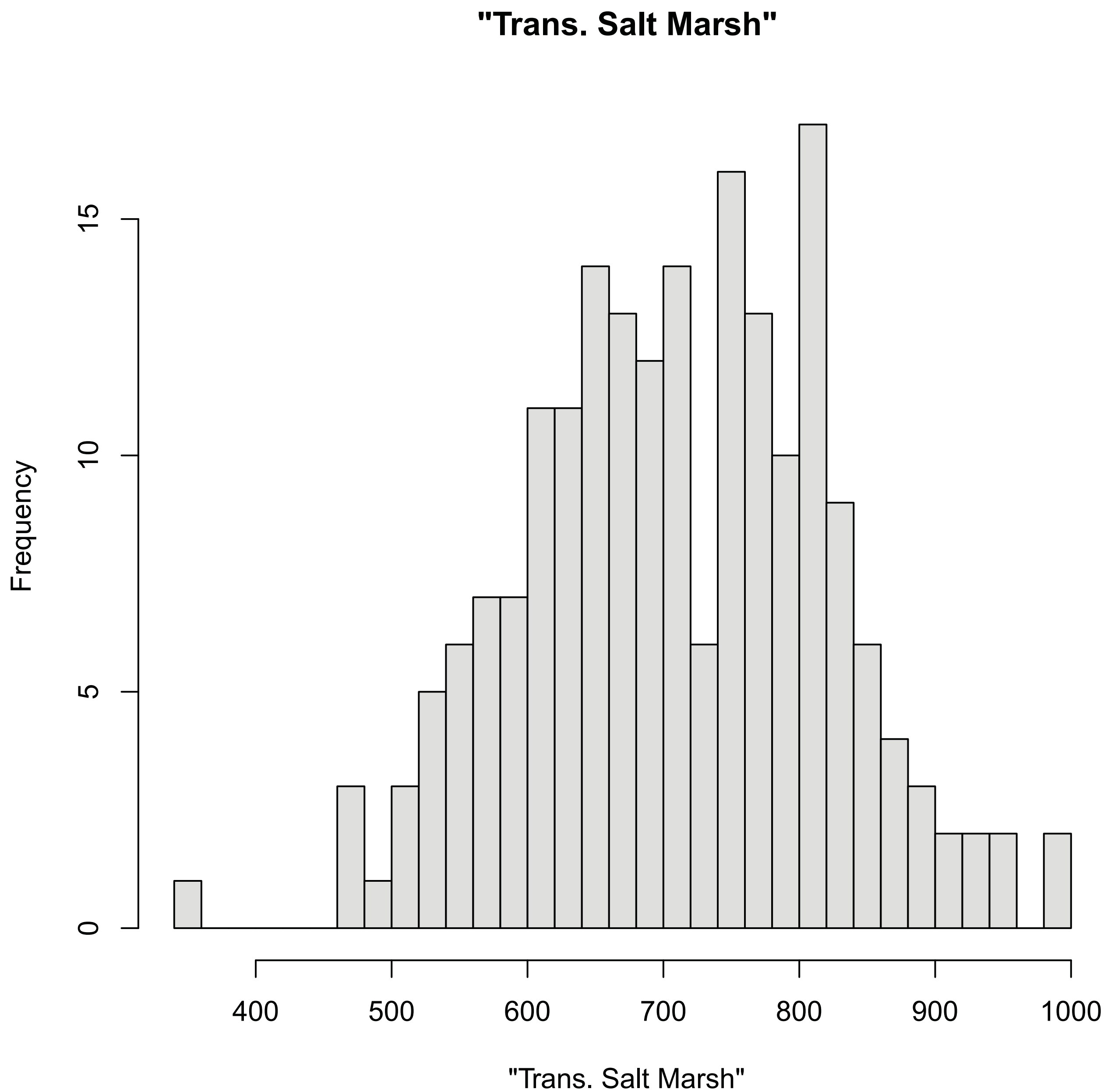
30
40
4
6
8
10
12
14
"Tidal−Fresh Marsh"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600
700
800
900
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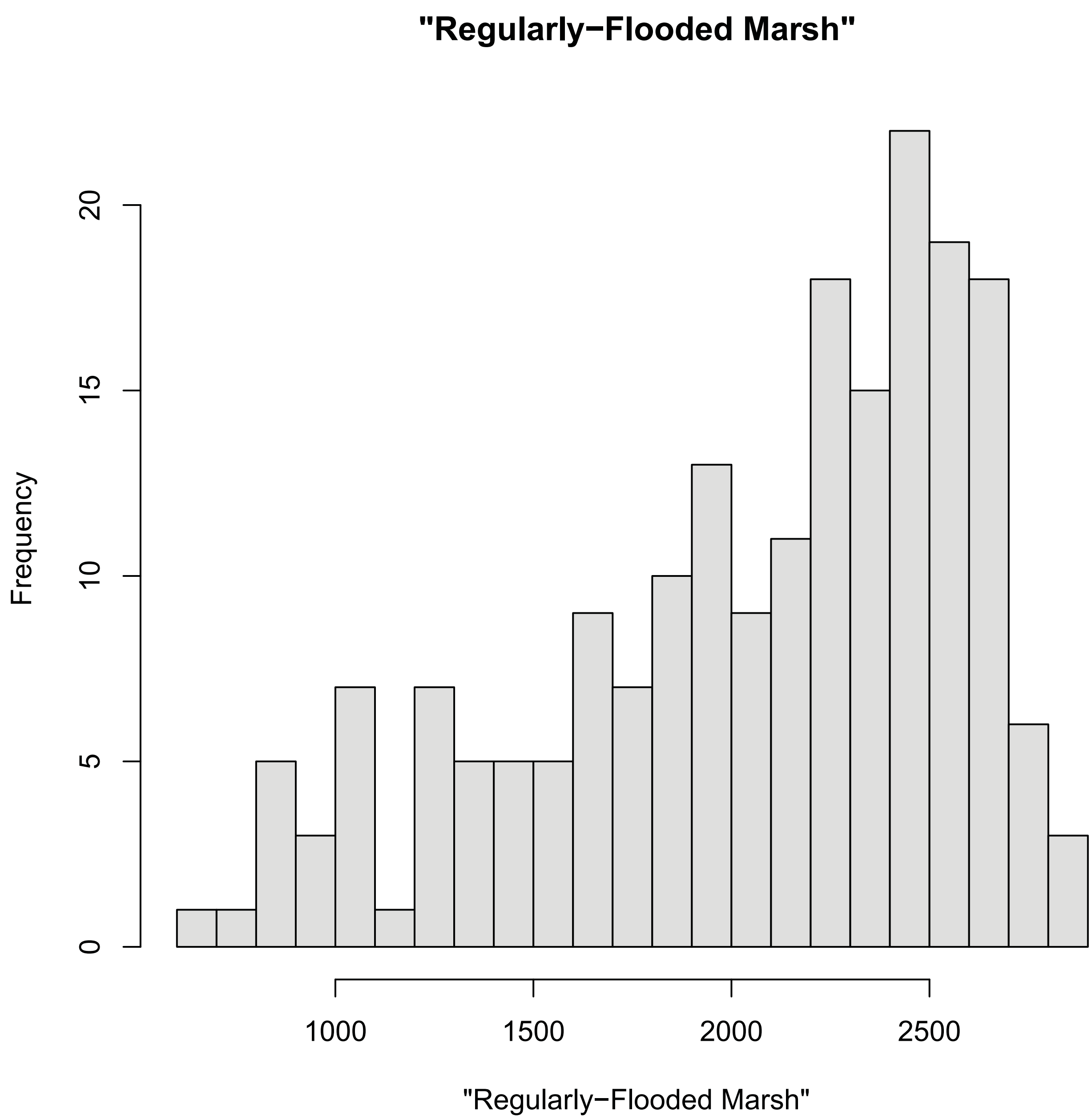
"Trans. Salt Marsh"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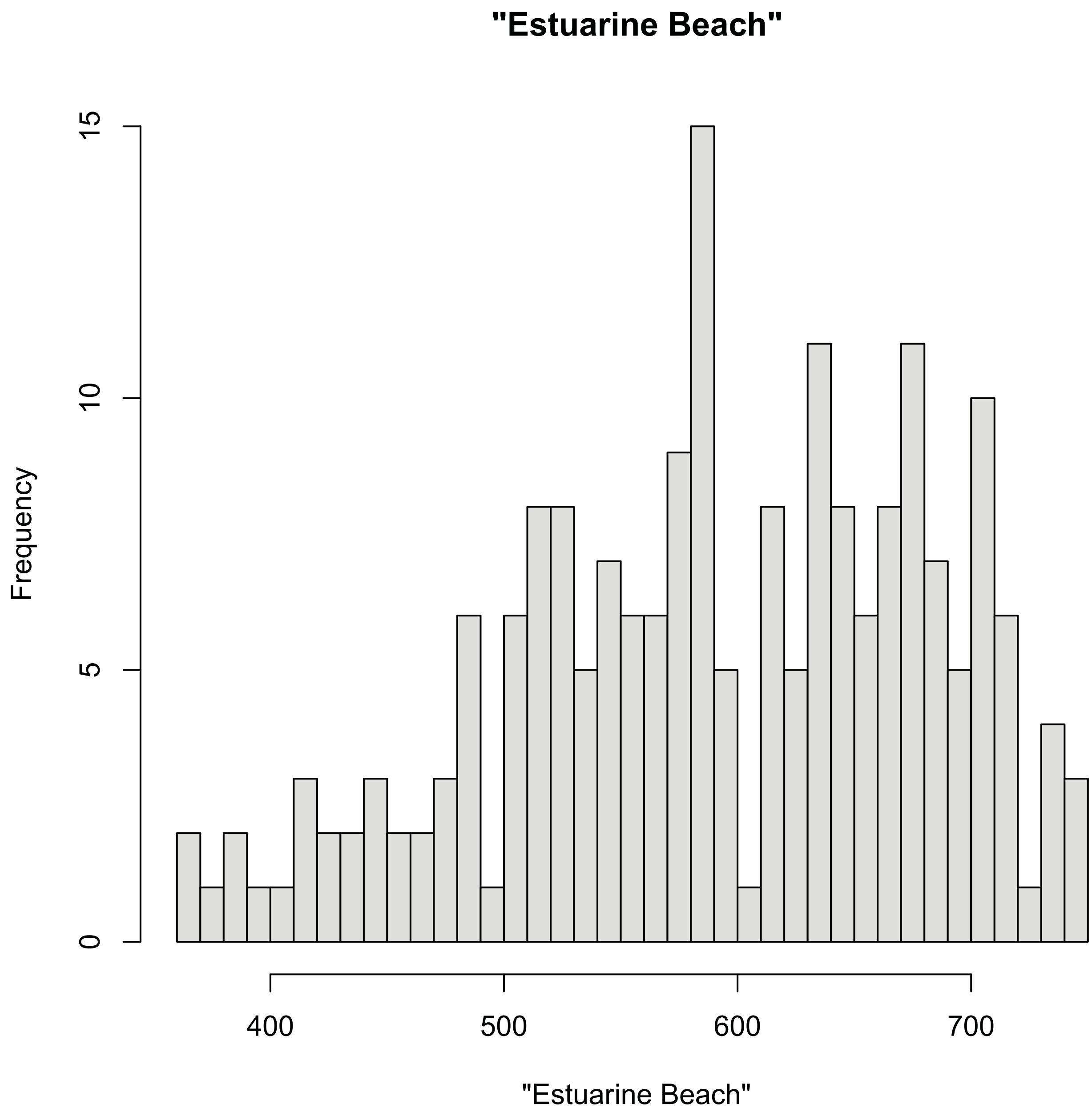
2000
2500
"Regularly−Flooded Marsh"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500
600
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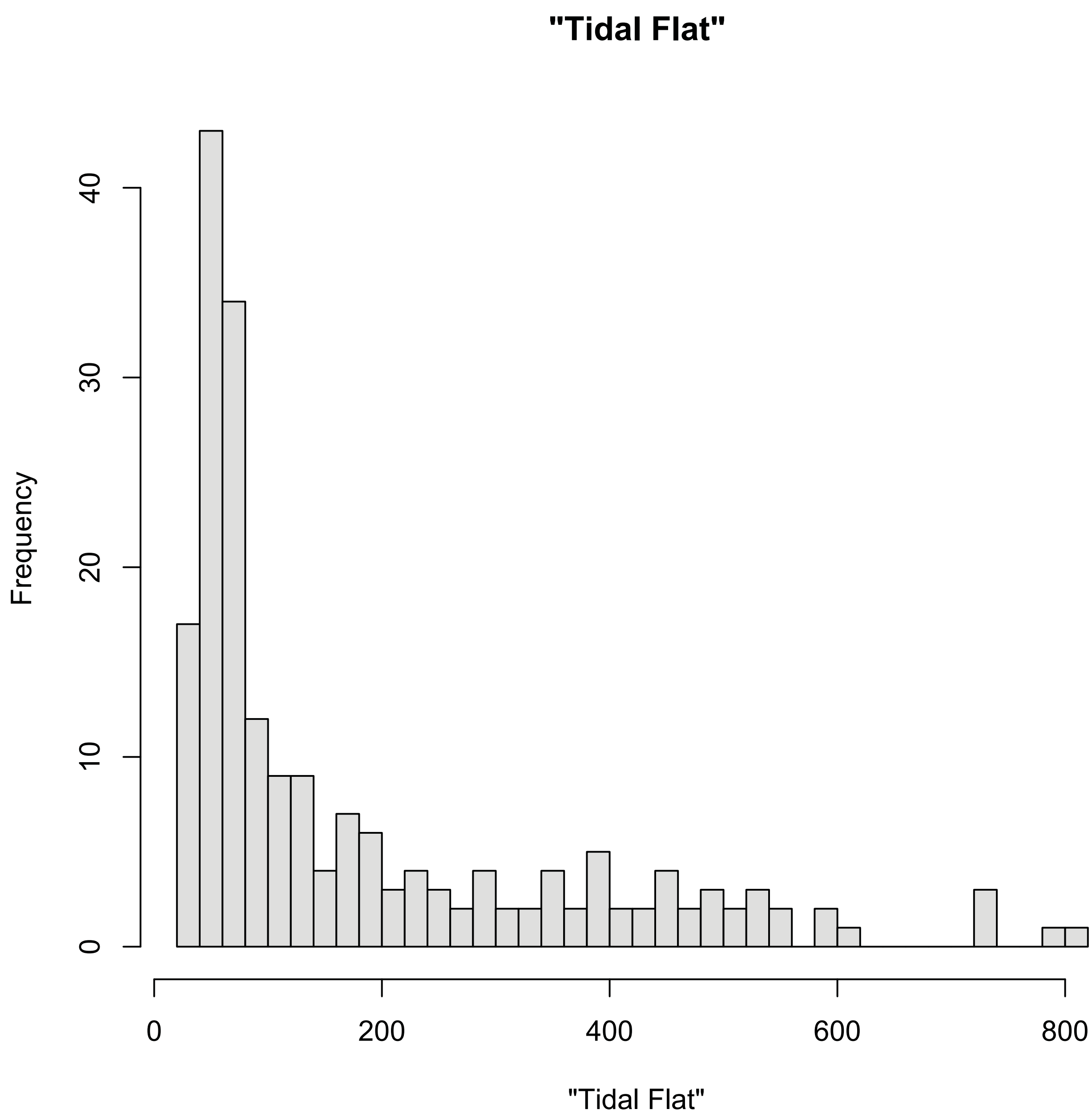
"Estuarine Beach"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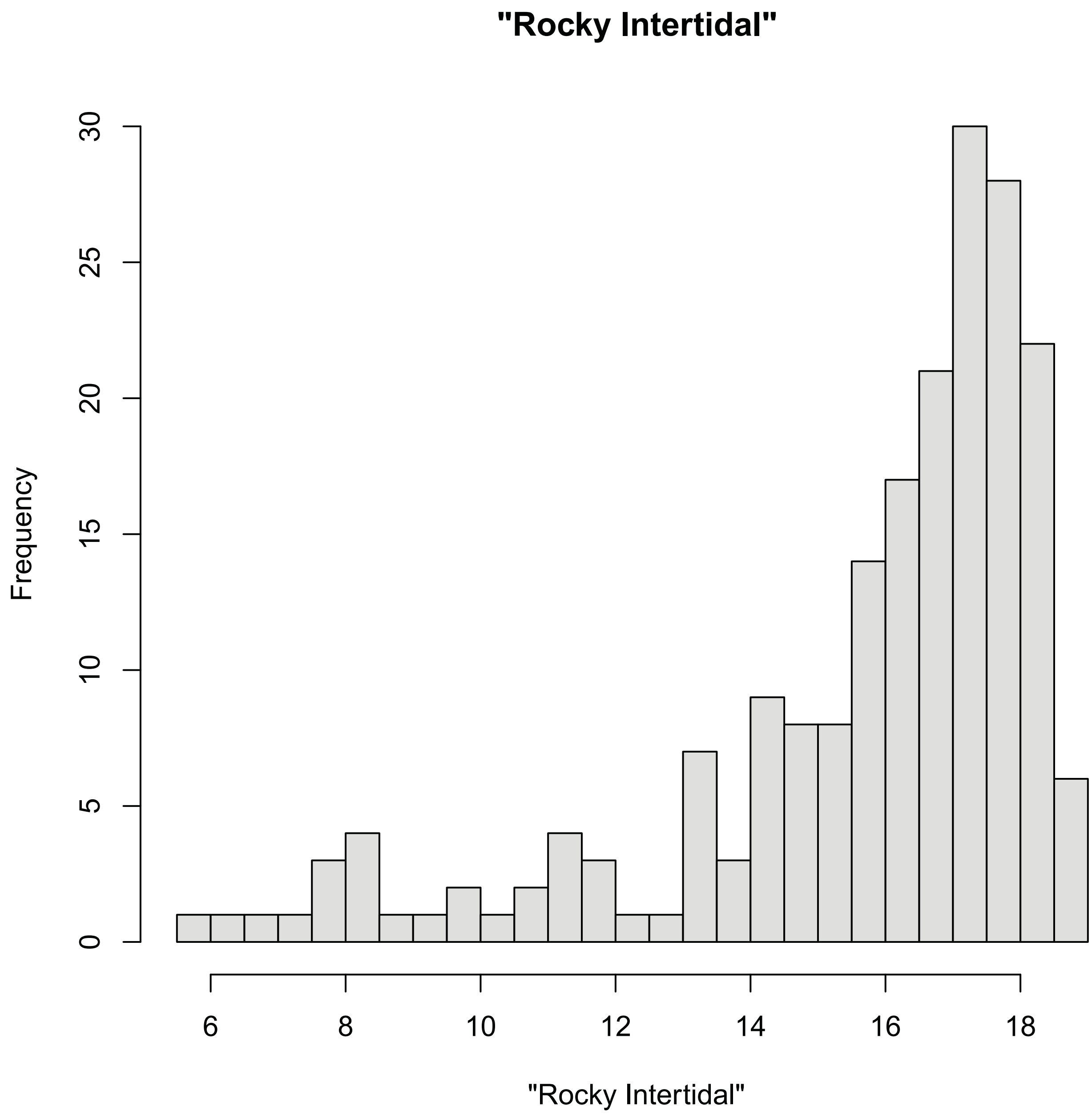
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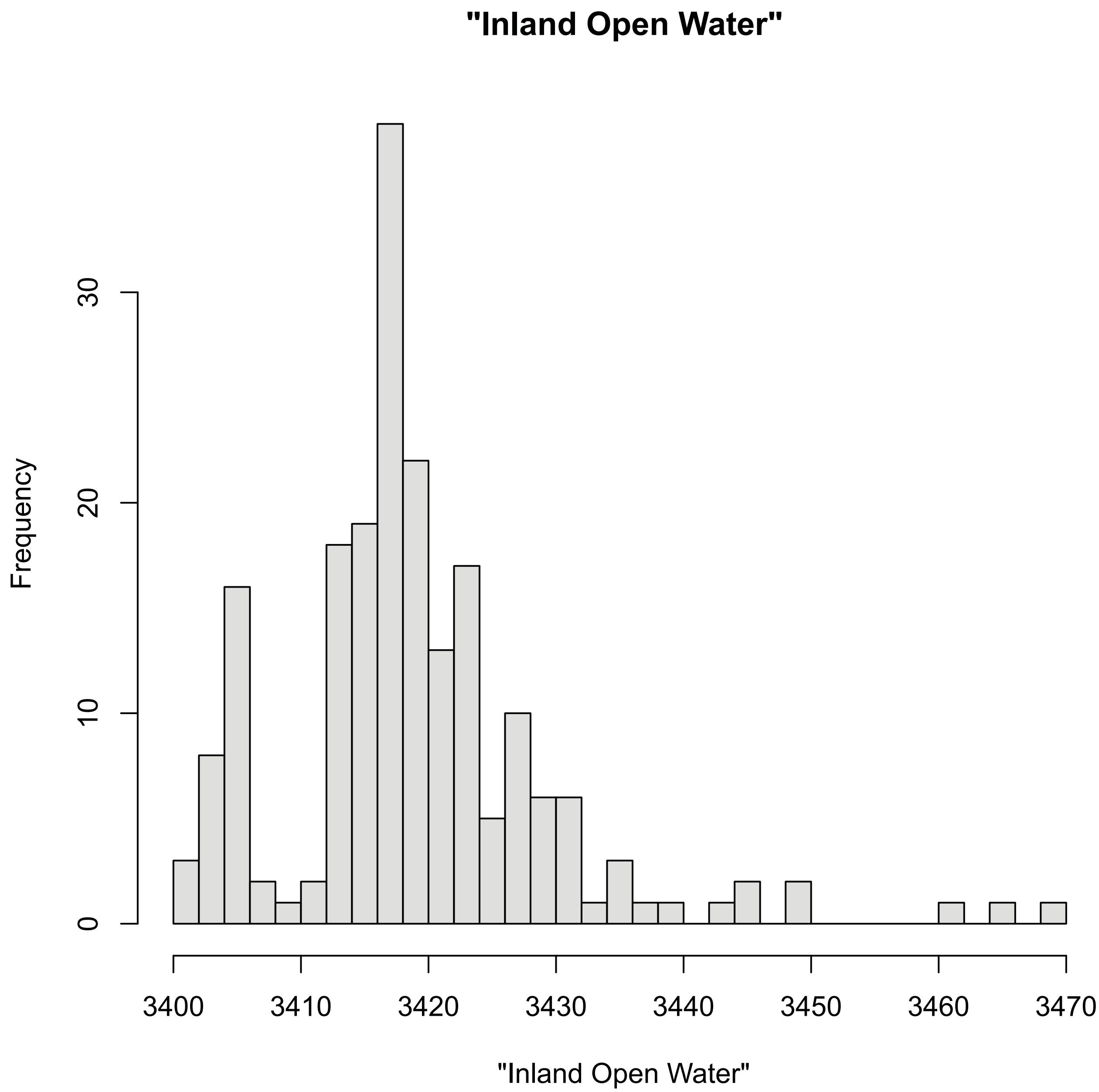
14
16
18
"Rocky Intertidal"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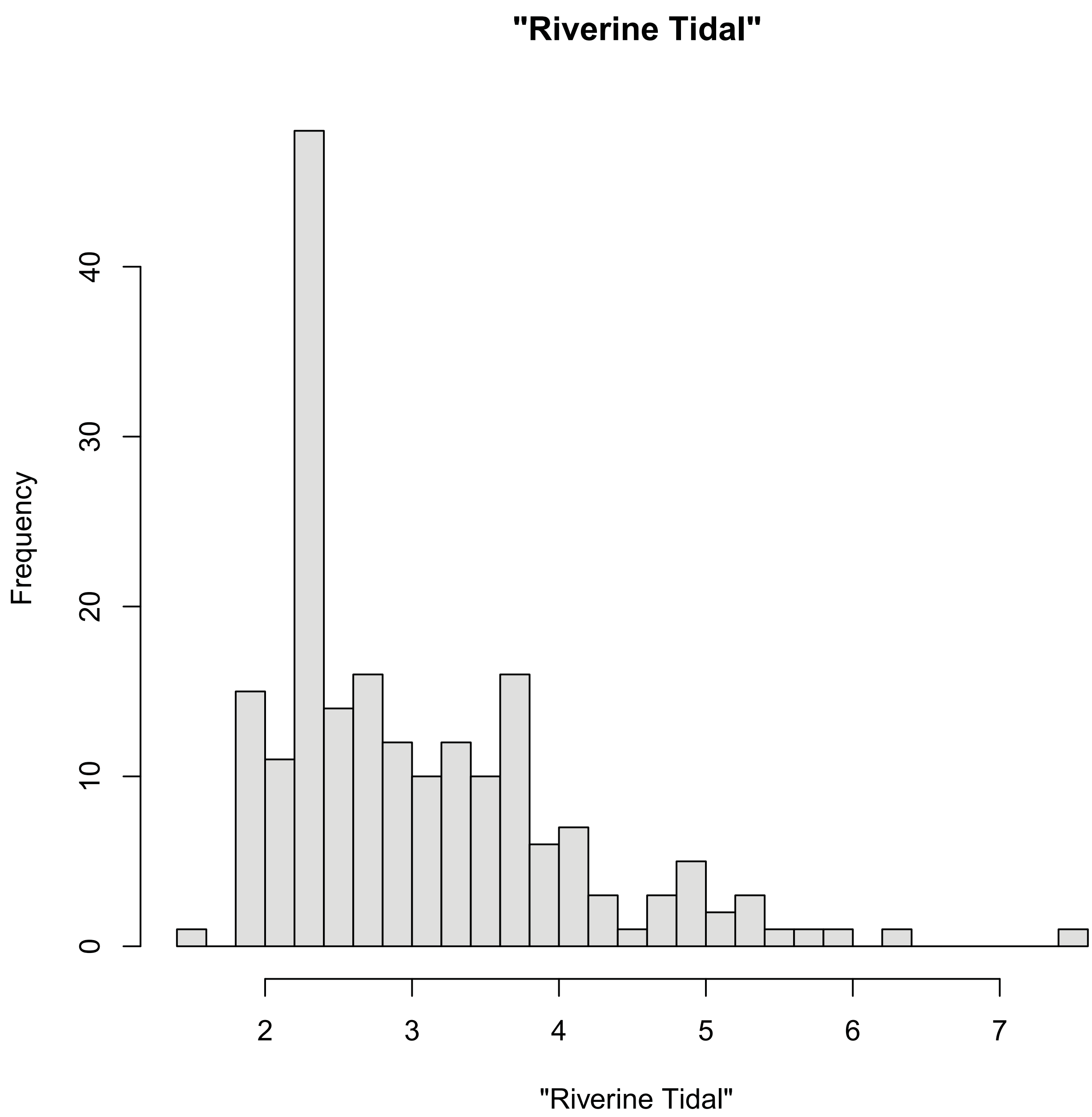
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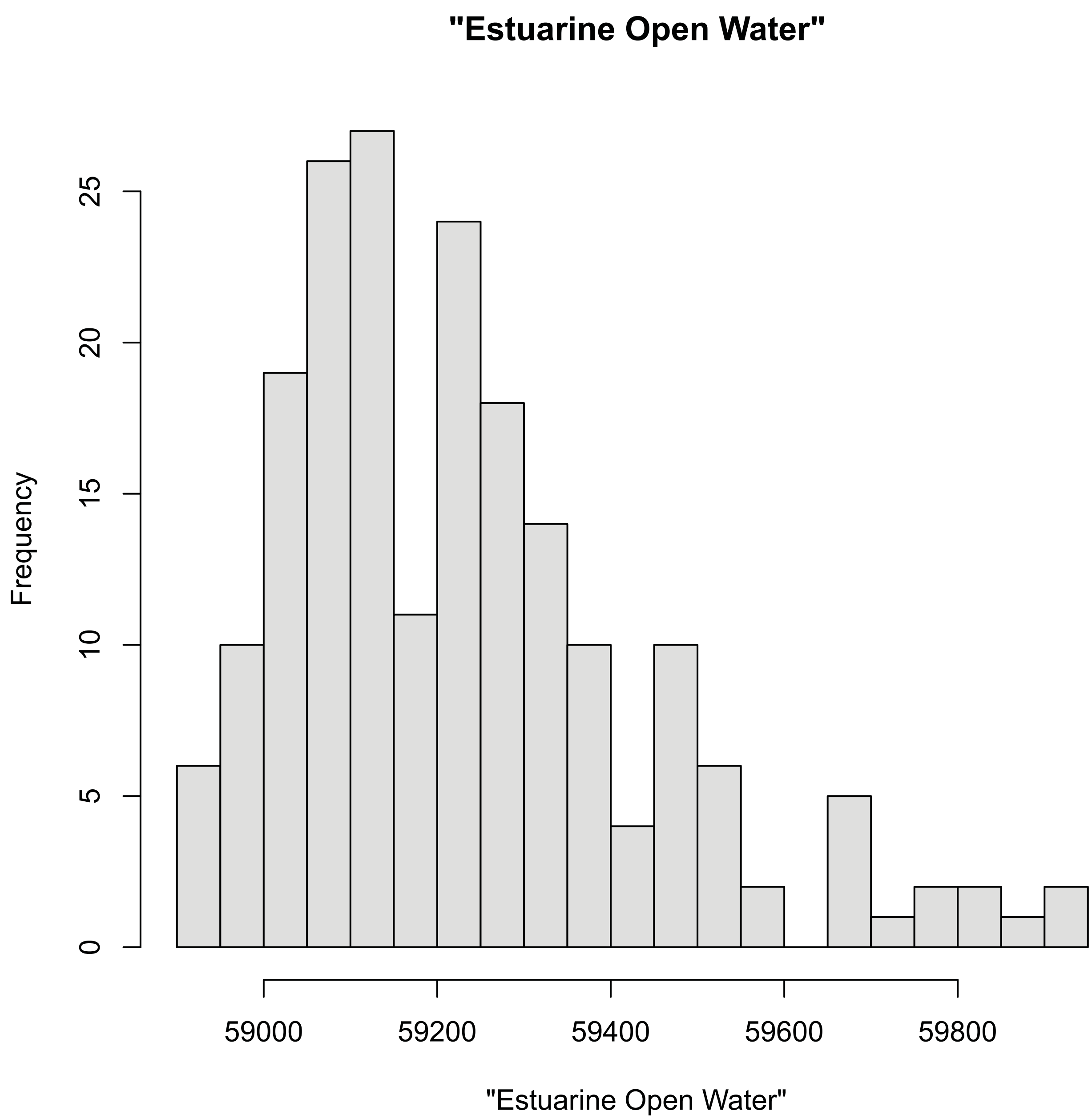
3
4
5
6
7
"Riverine Tidal"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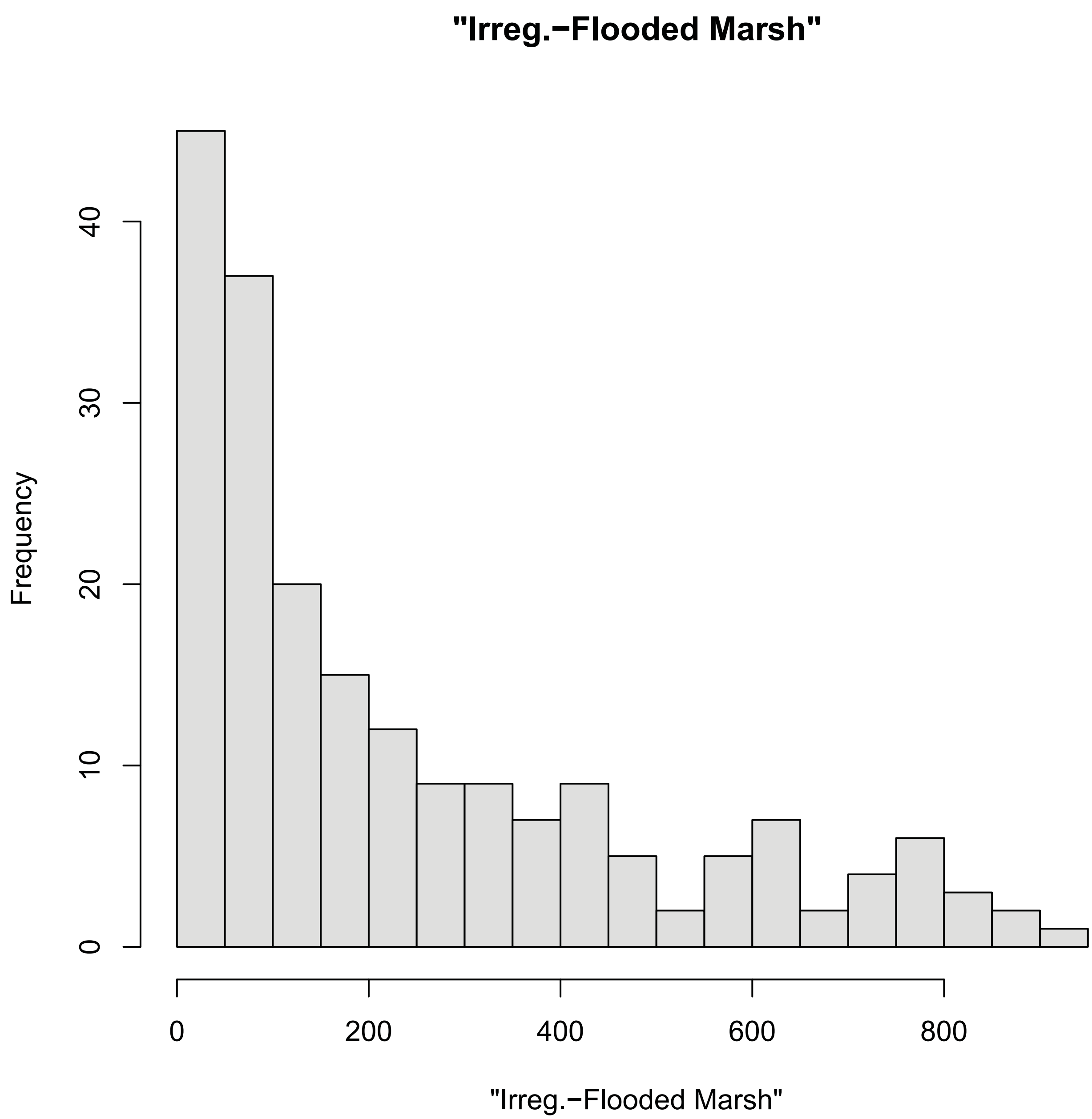
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400
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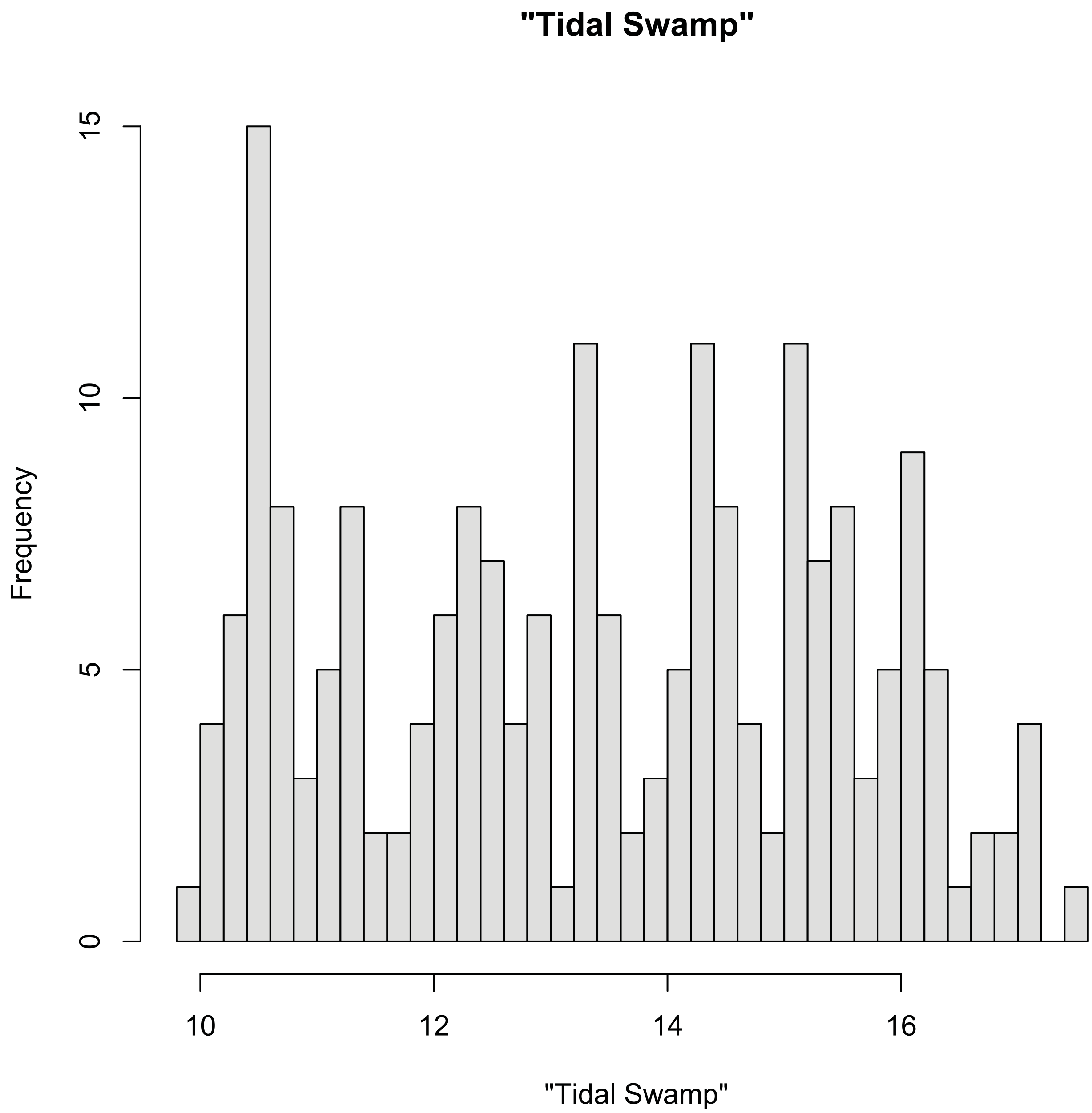
800
"Irreg.−Flooded Marsh"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14
16
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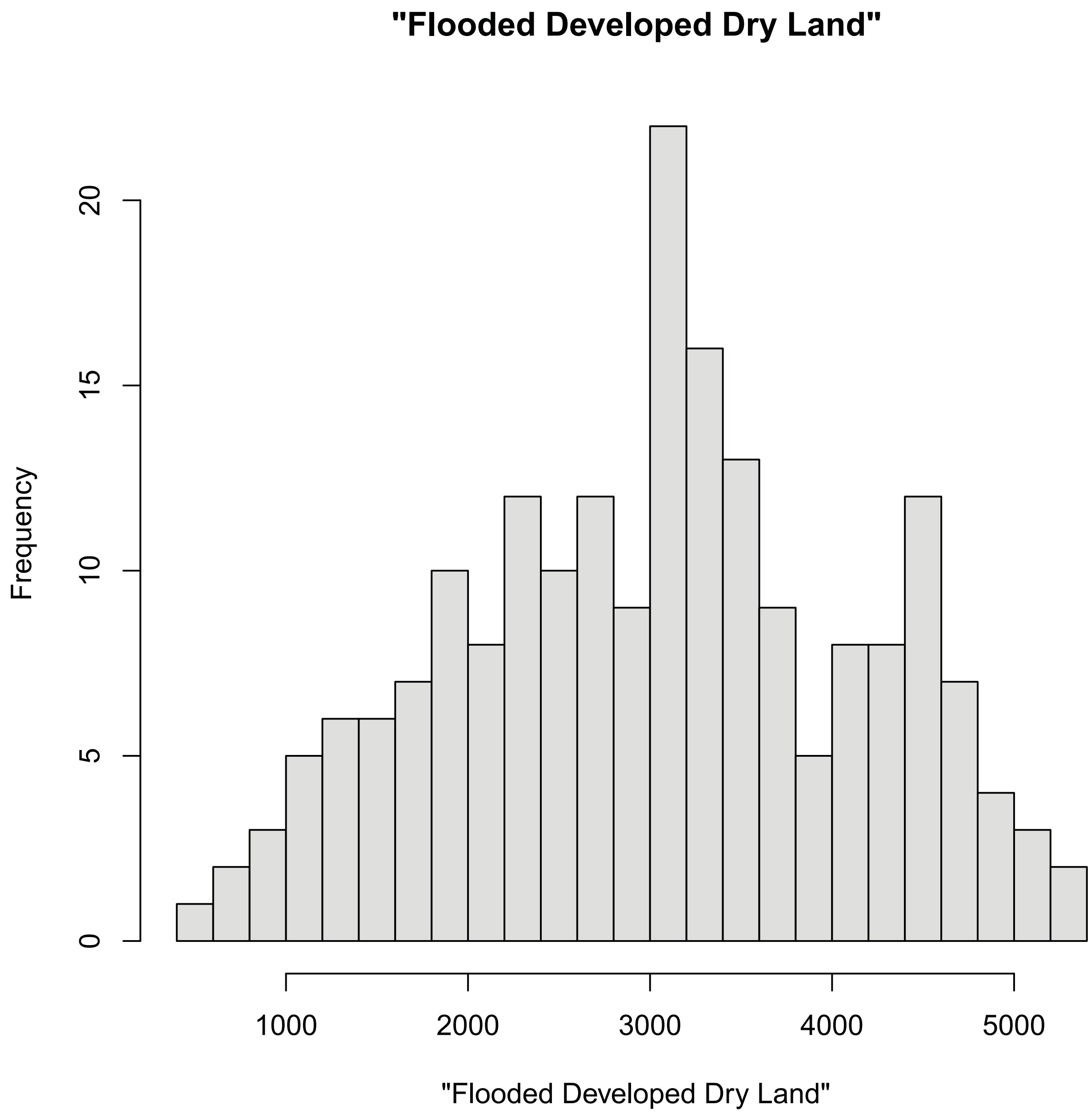
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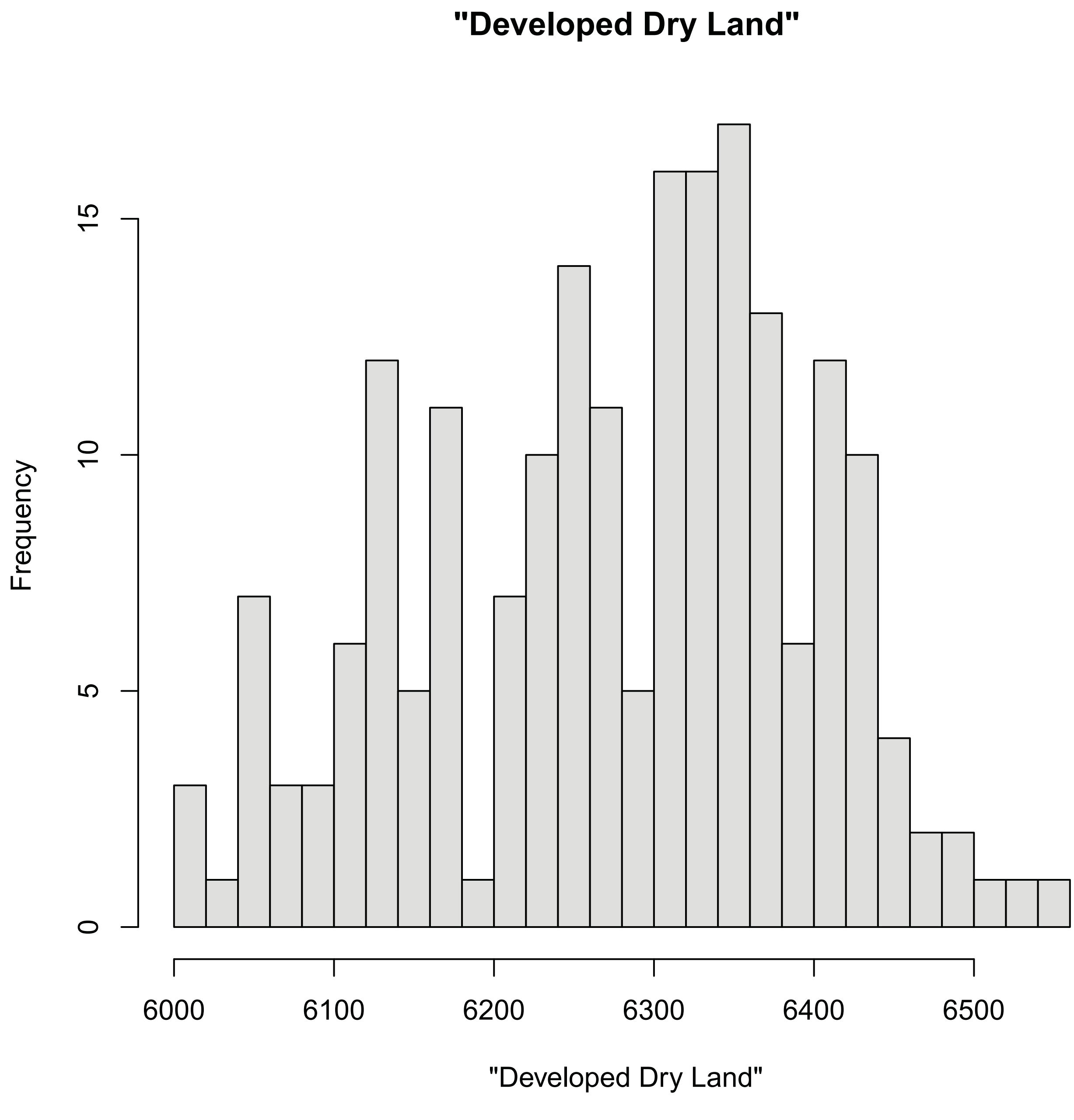
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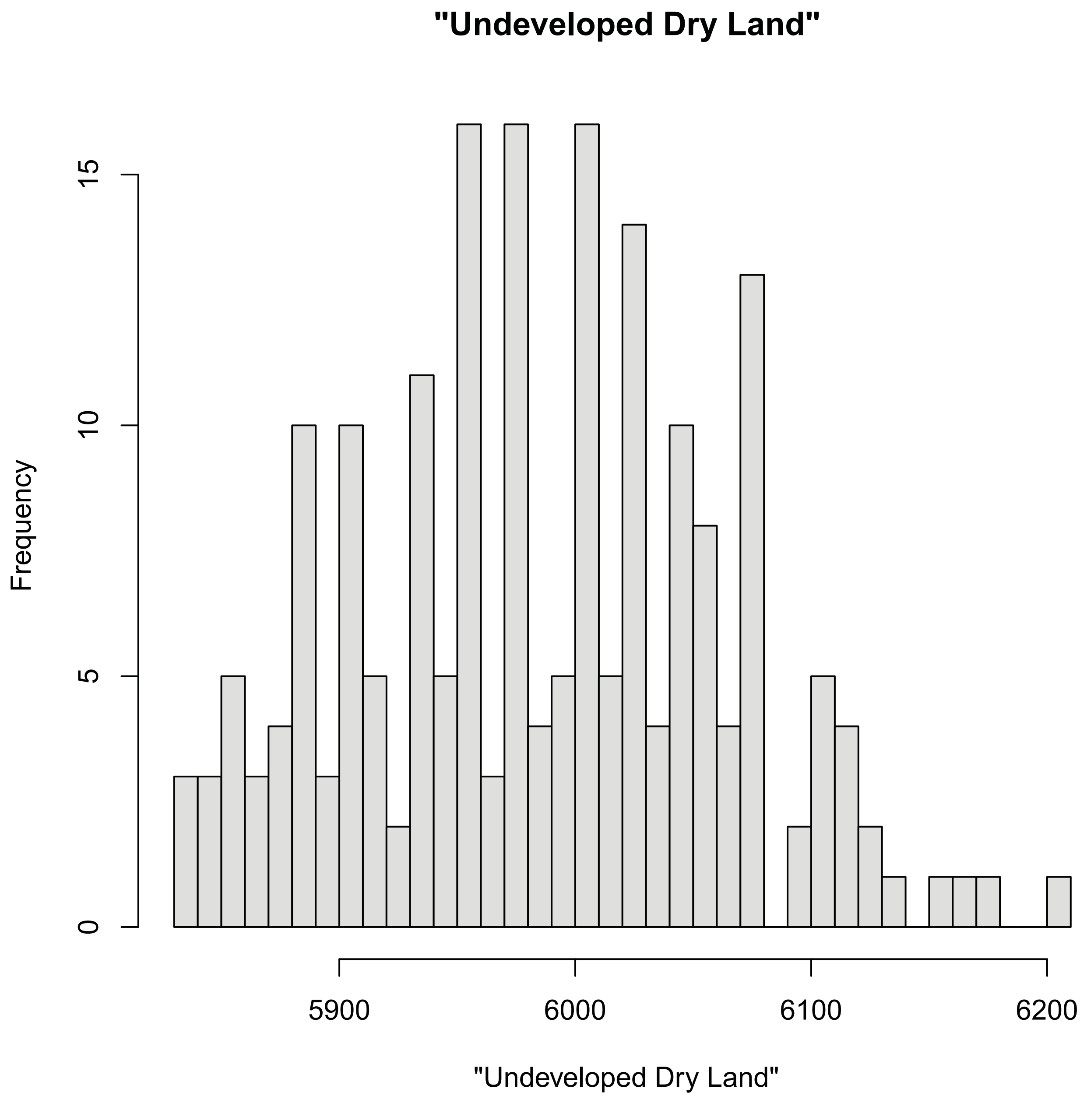
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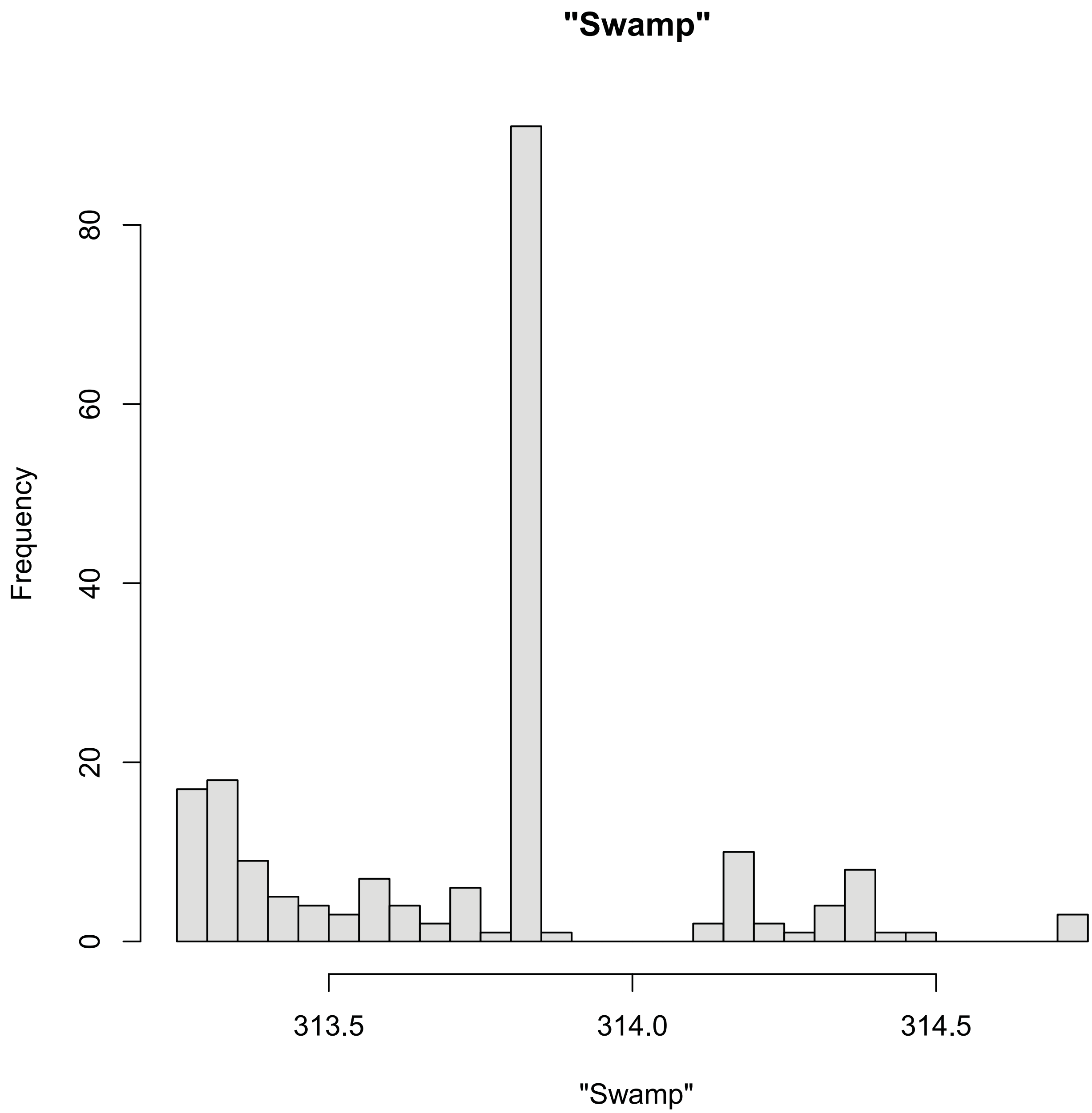
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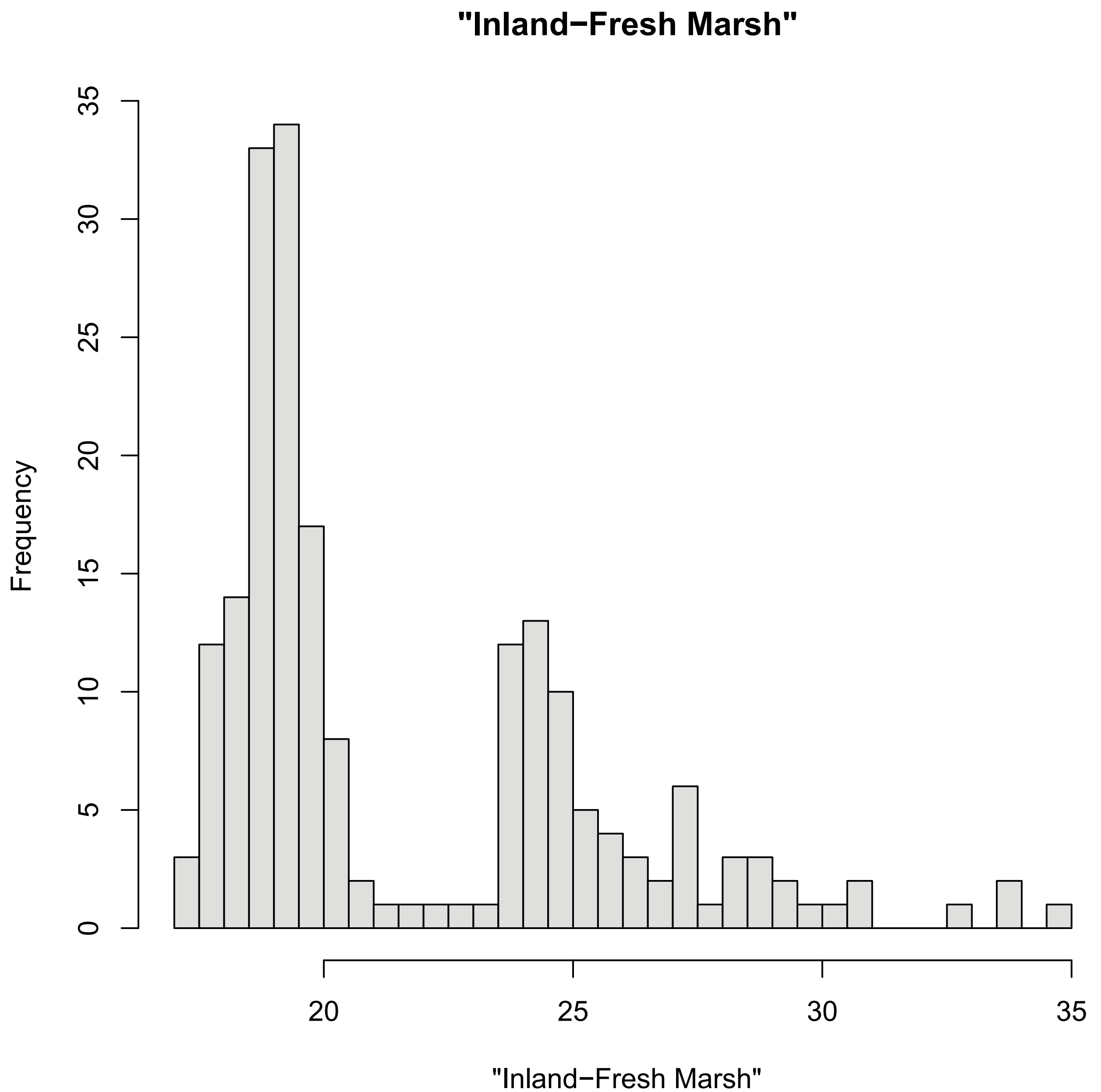
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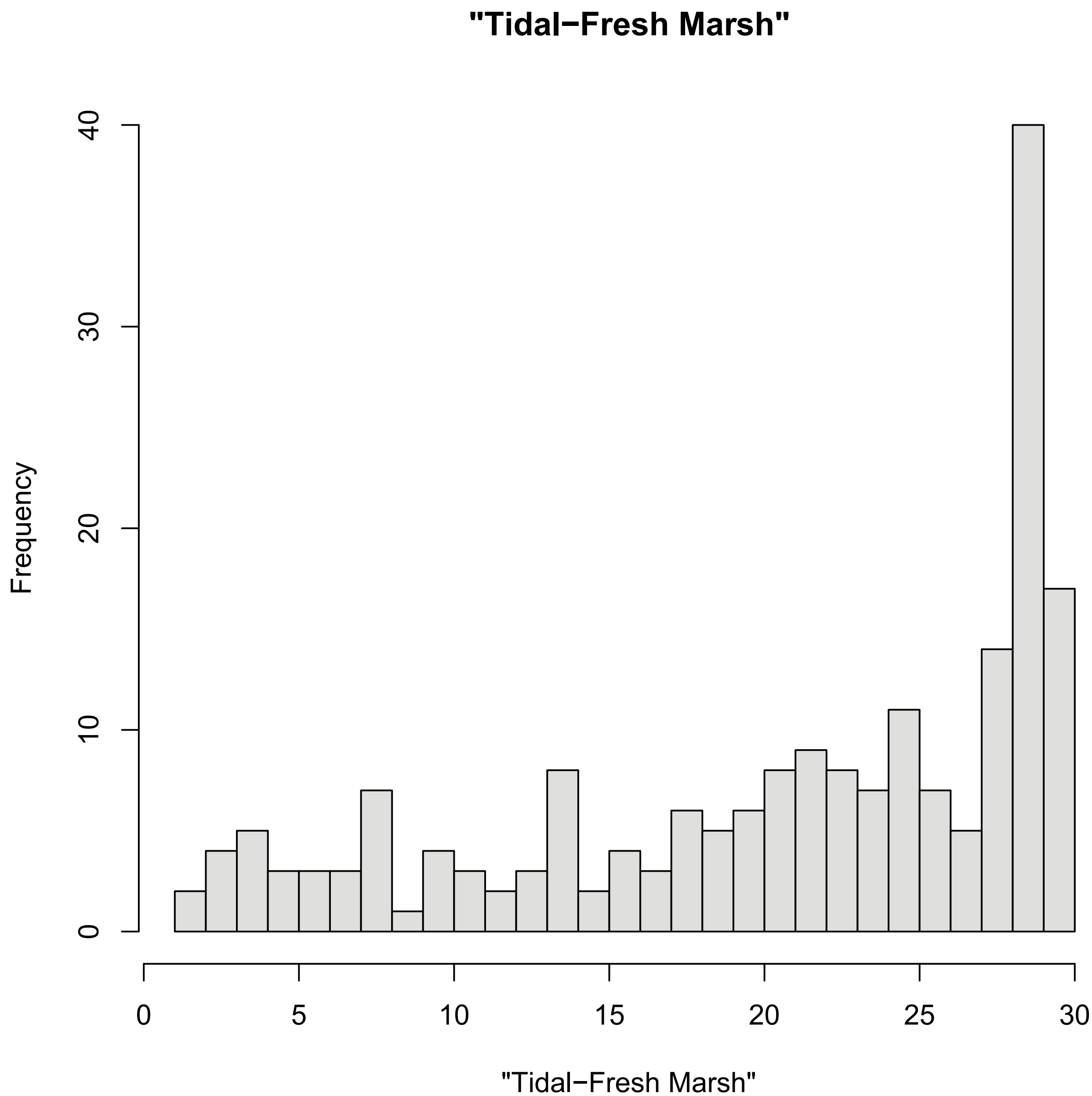
"Inland−Fresh Marsh"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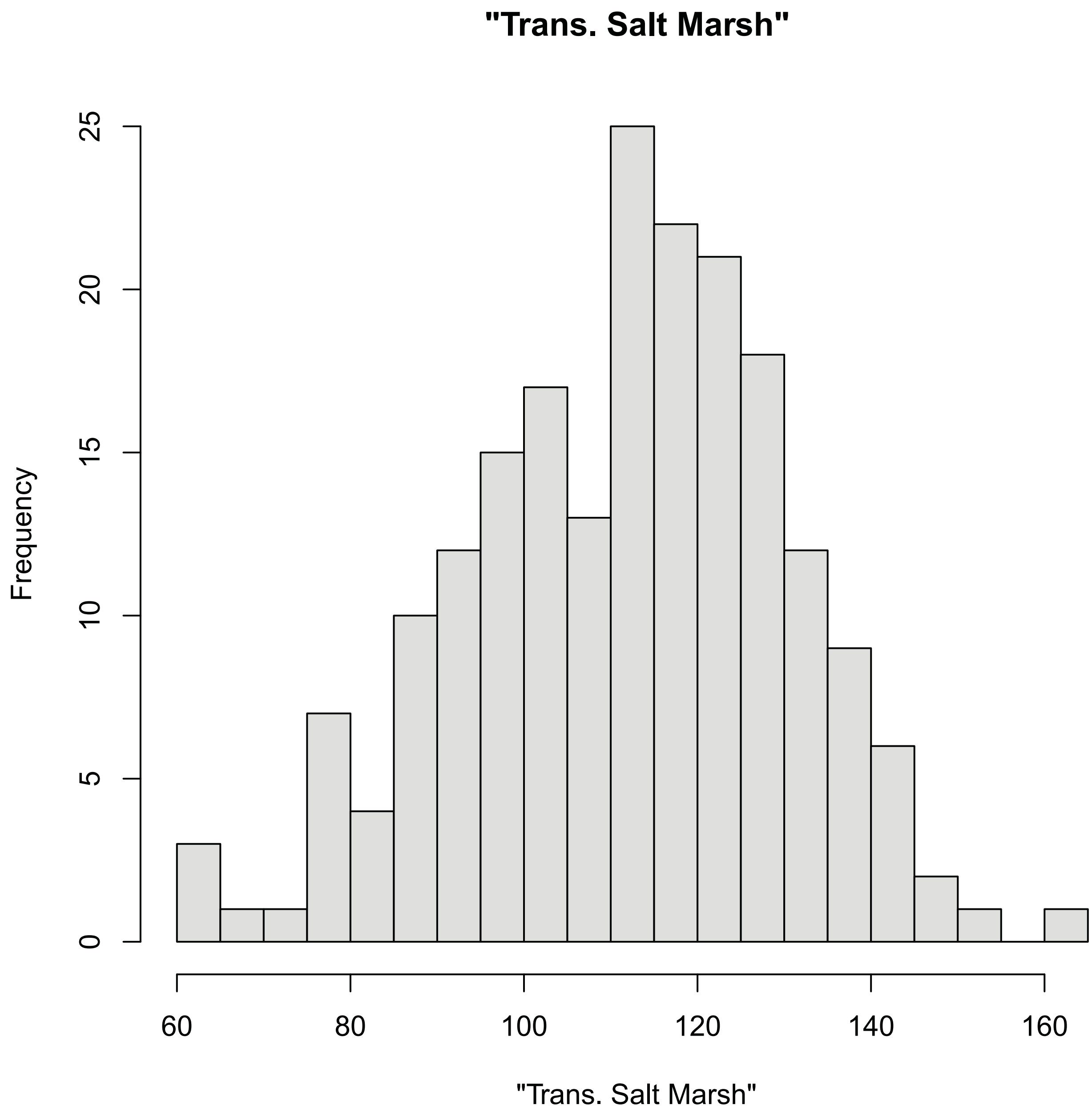
"Tidal−Fresh Marsh"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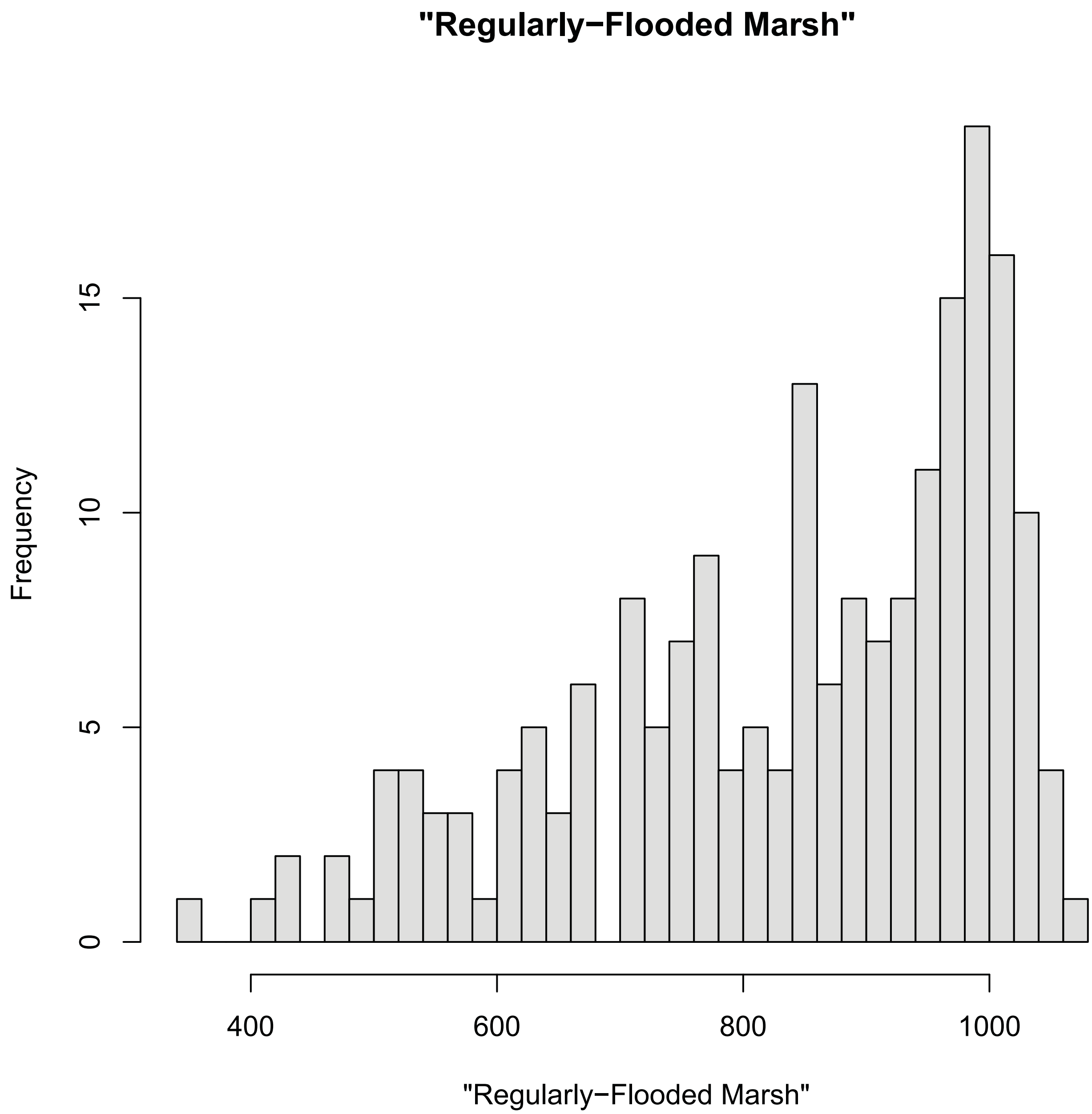
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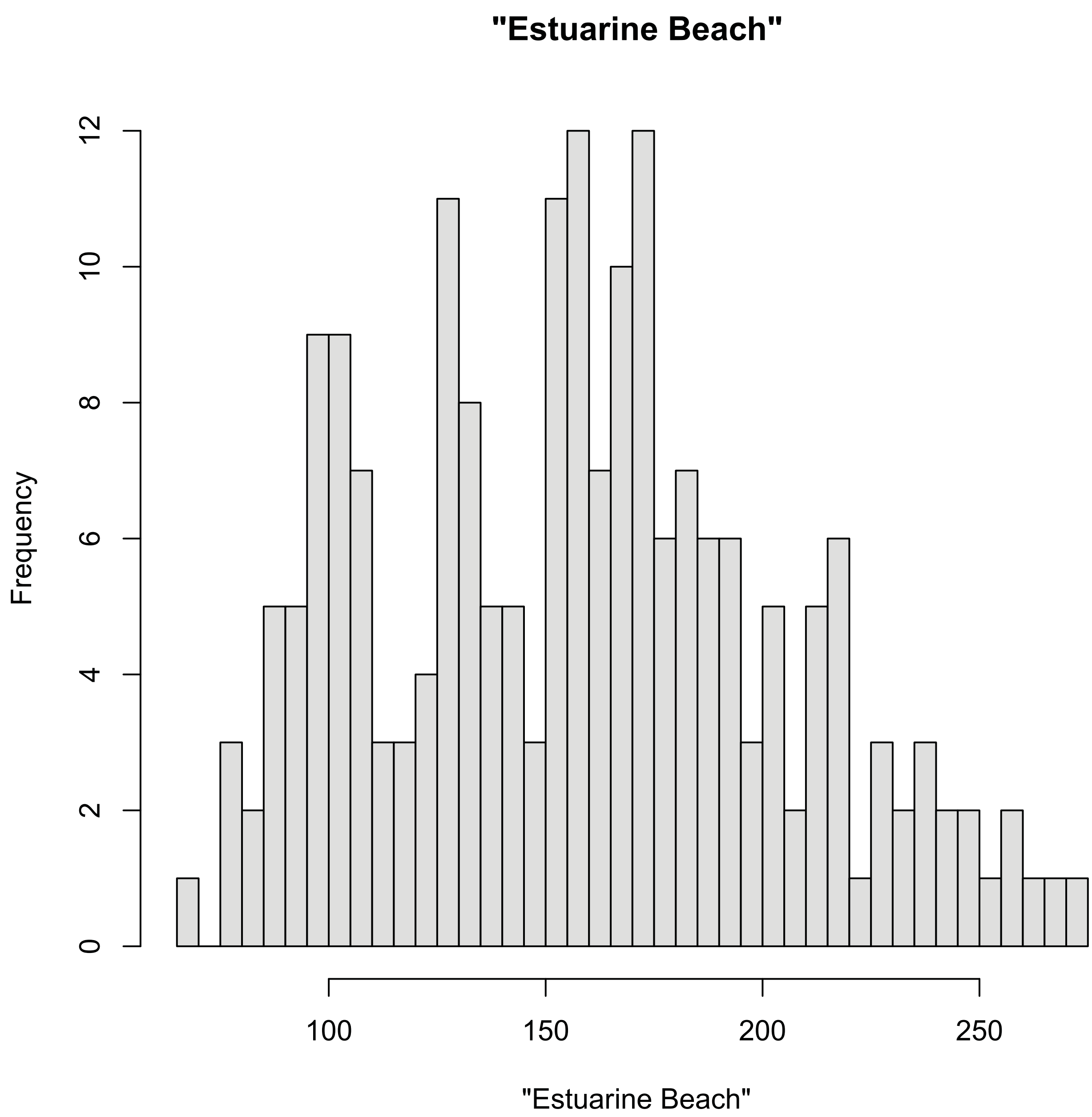
"Regularly−Flooded Marsh"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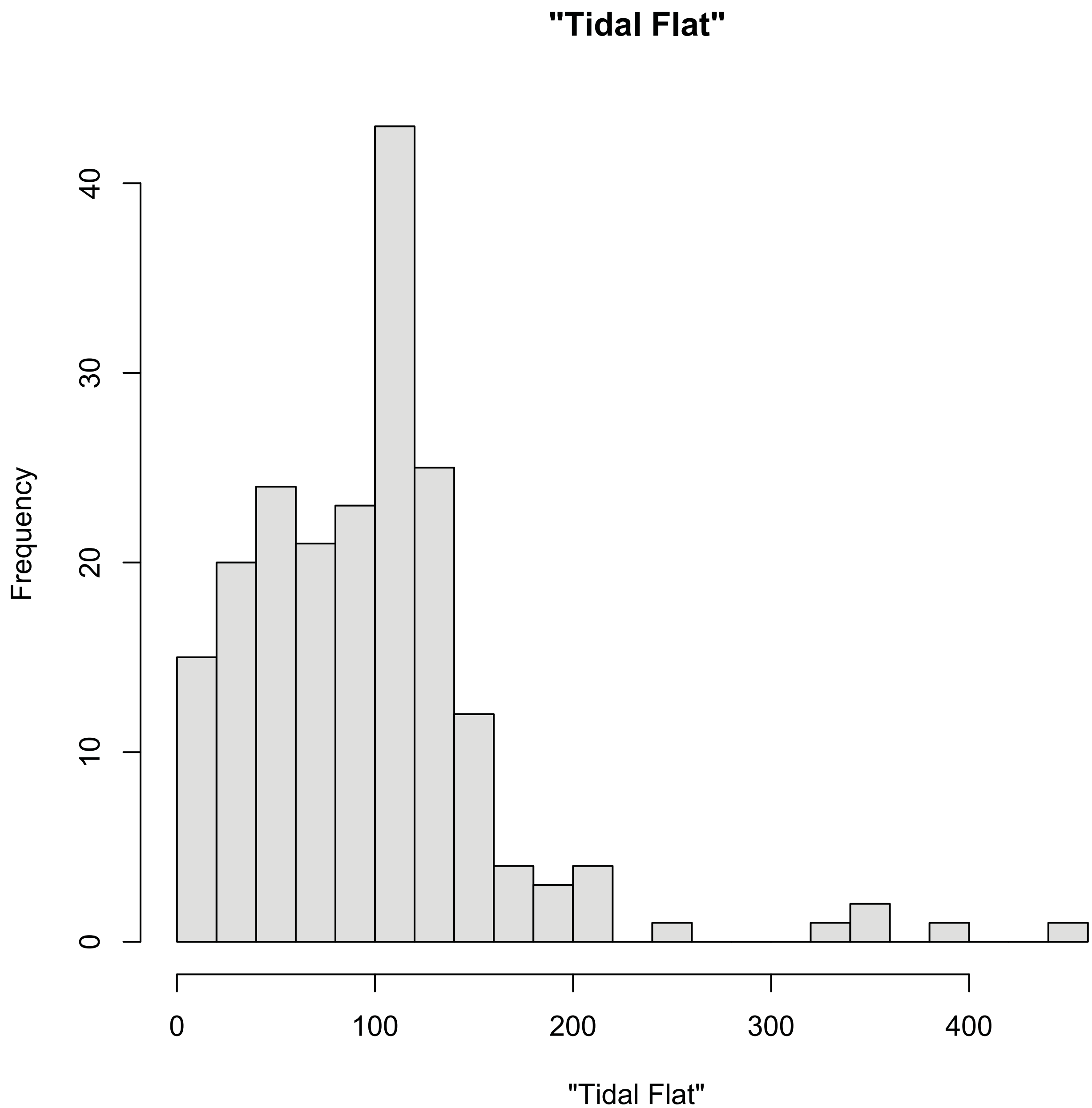
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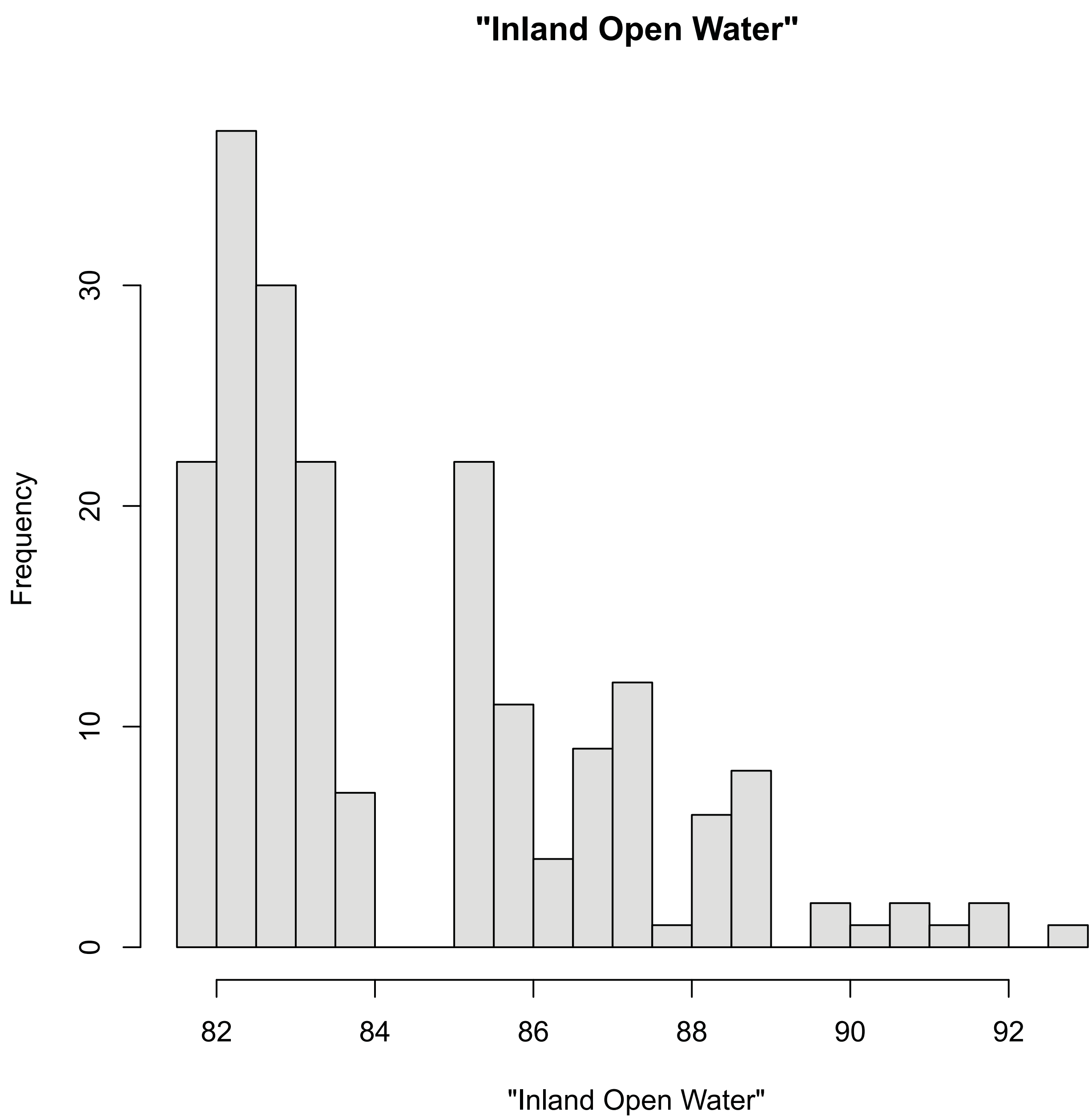
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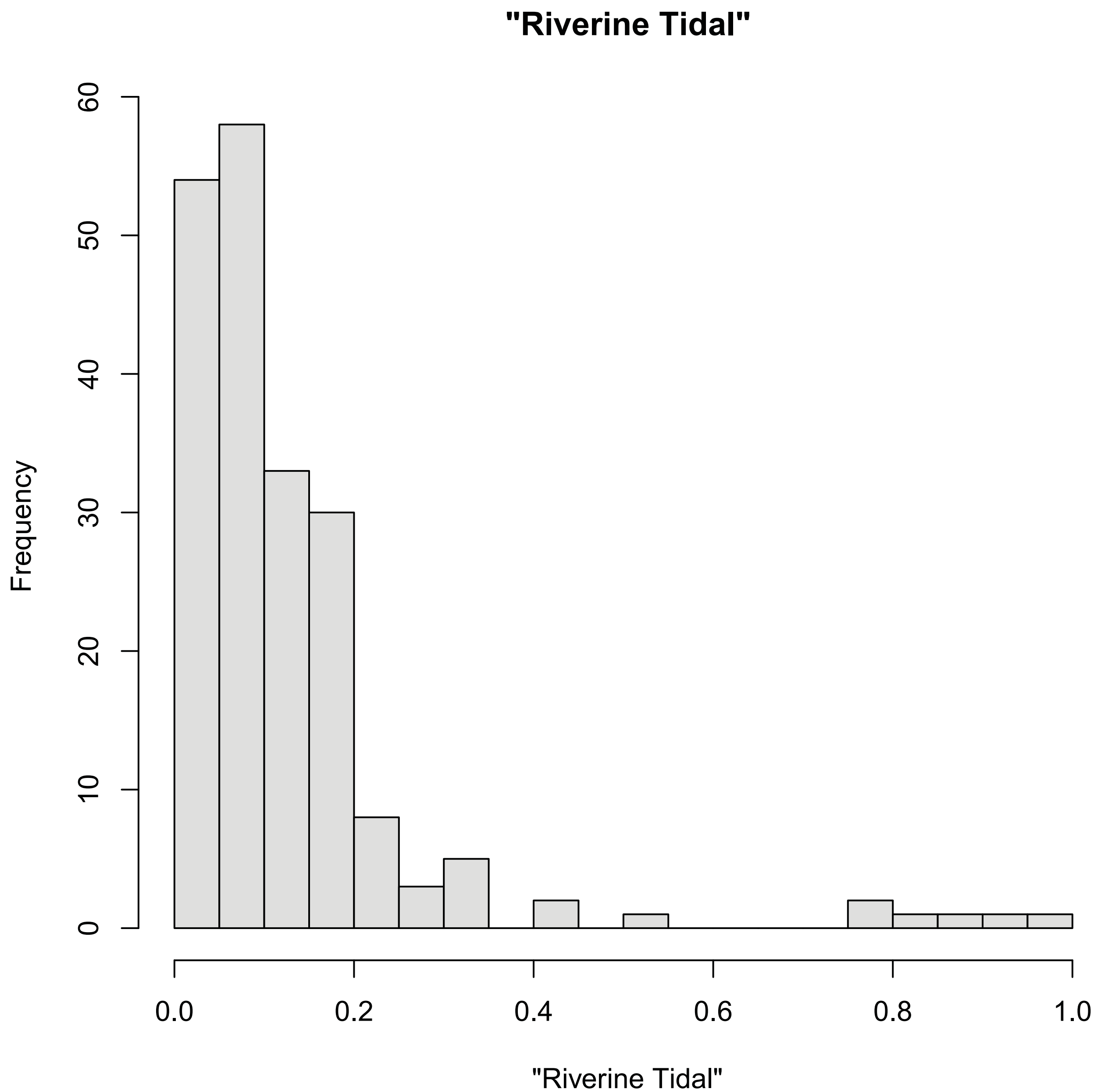
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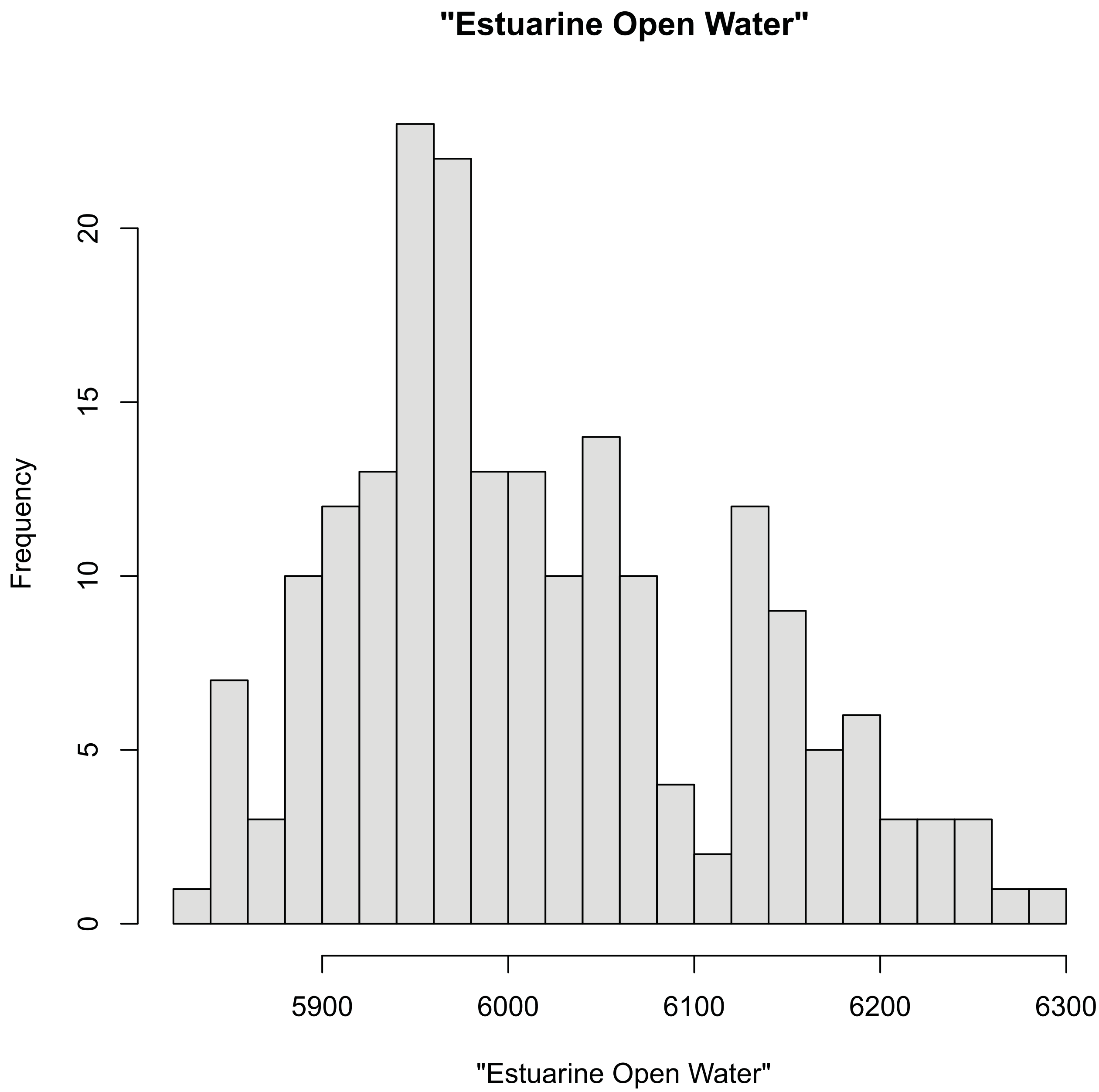
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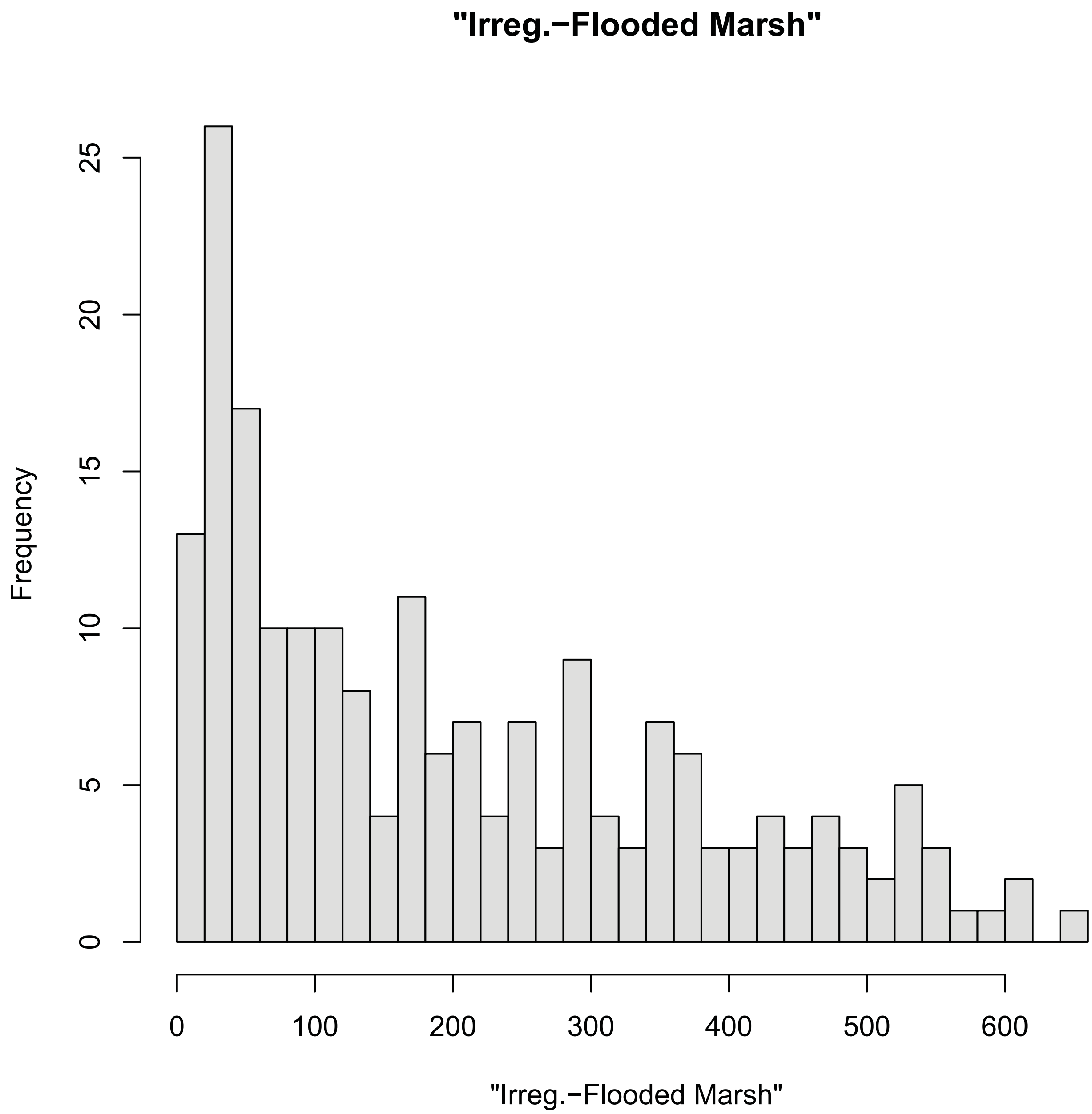
"Estuarine Open Water"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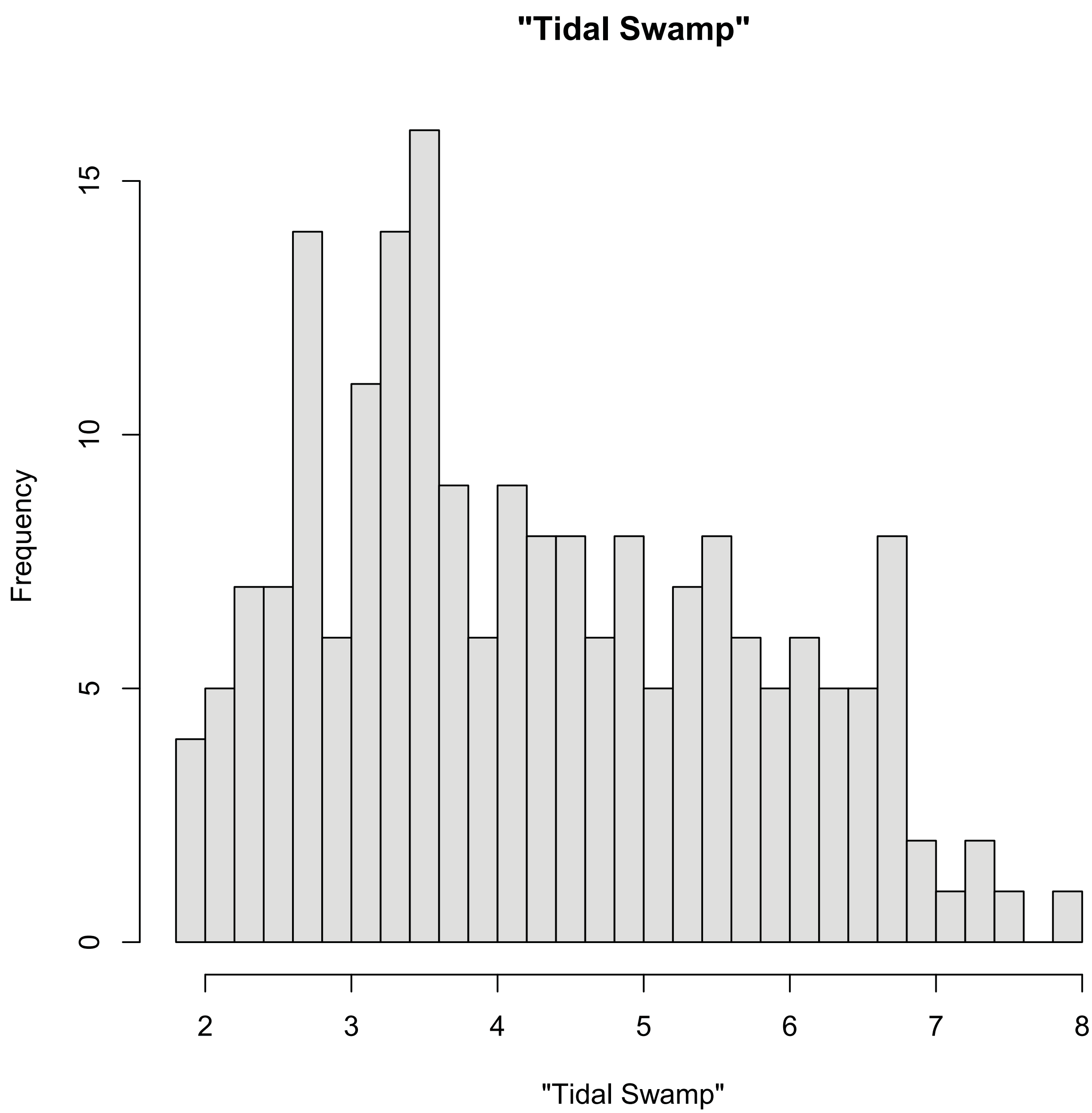
"Irreg.−Flooded Marsh"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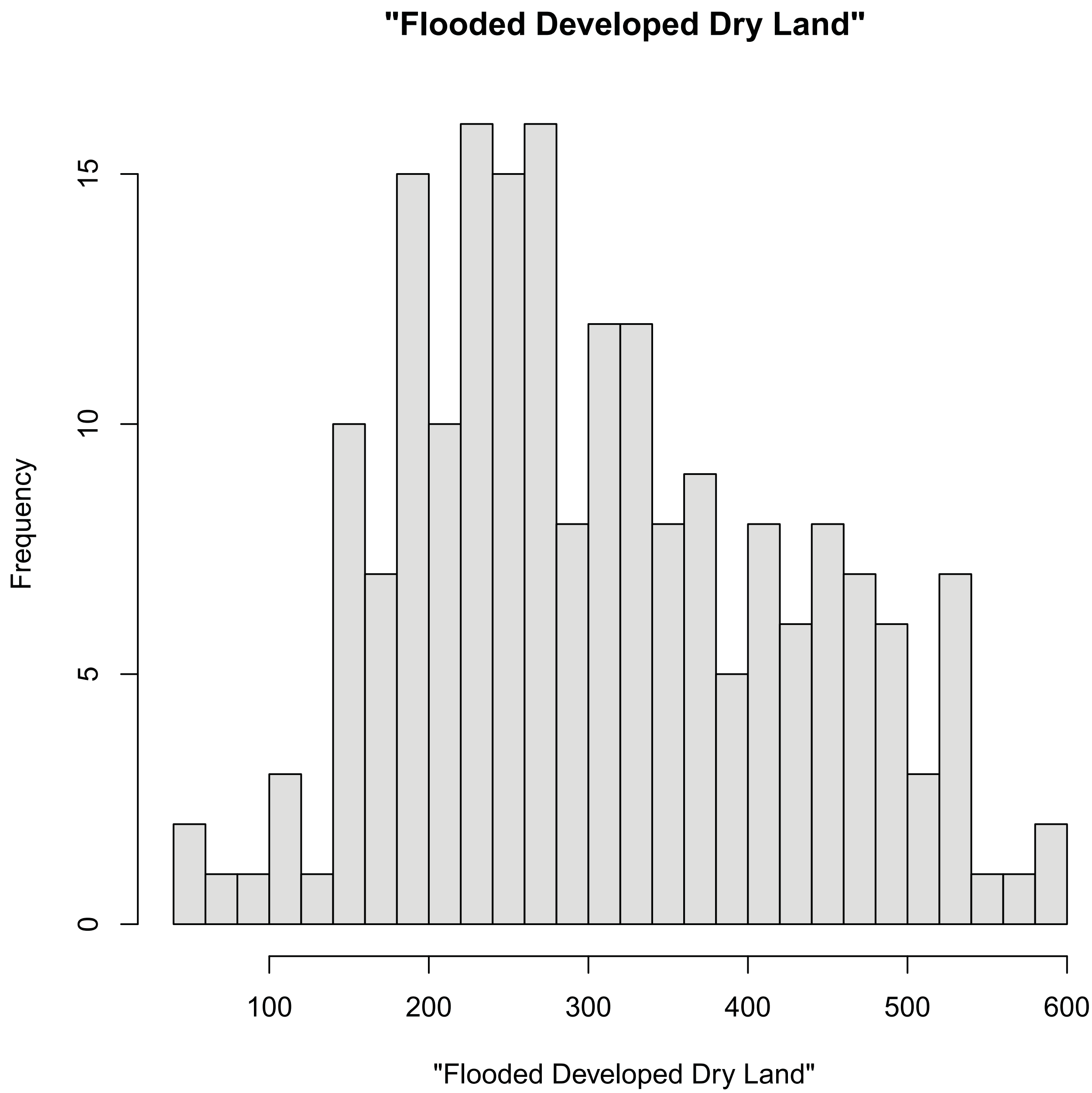
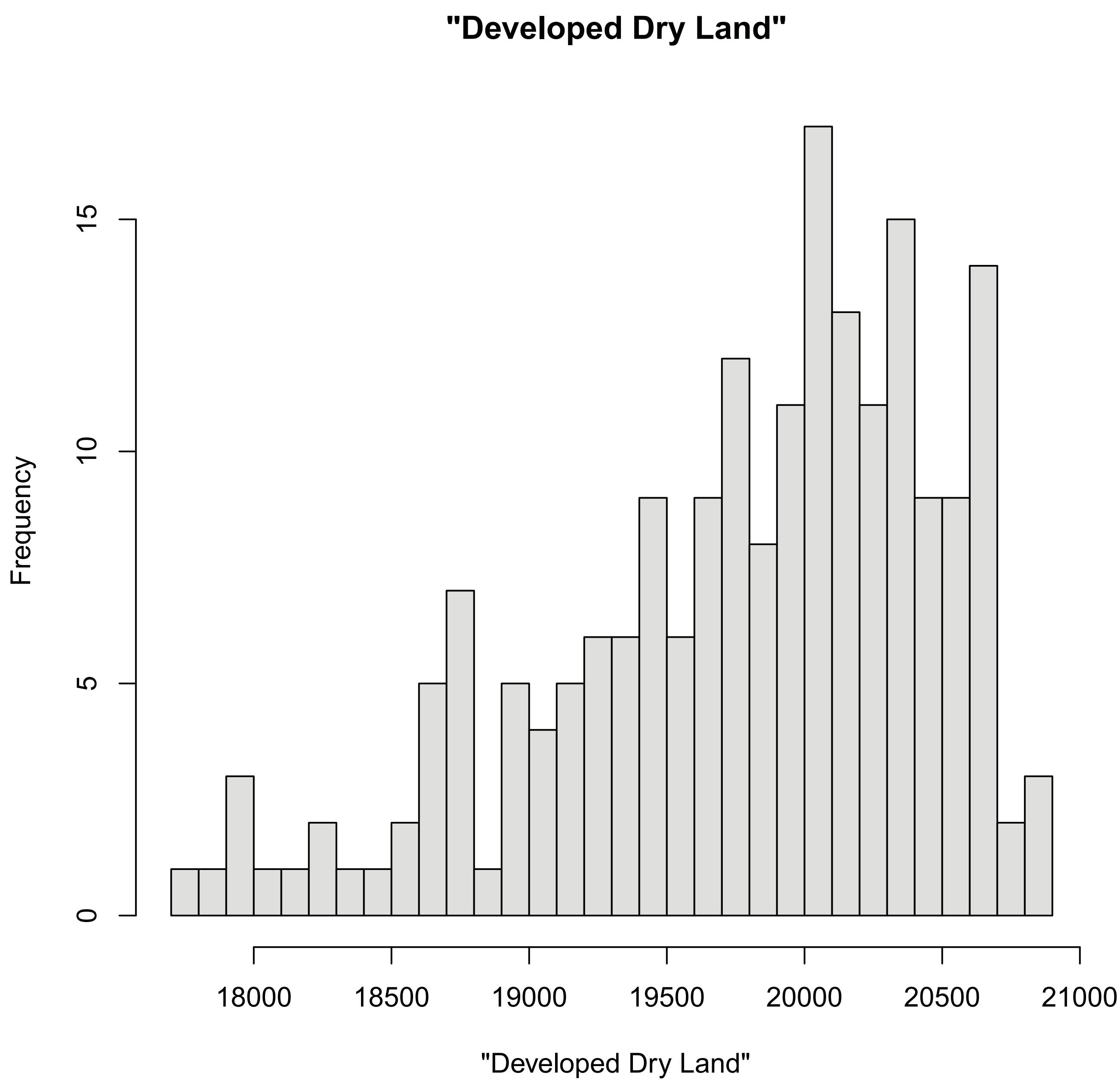
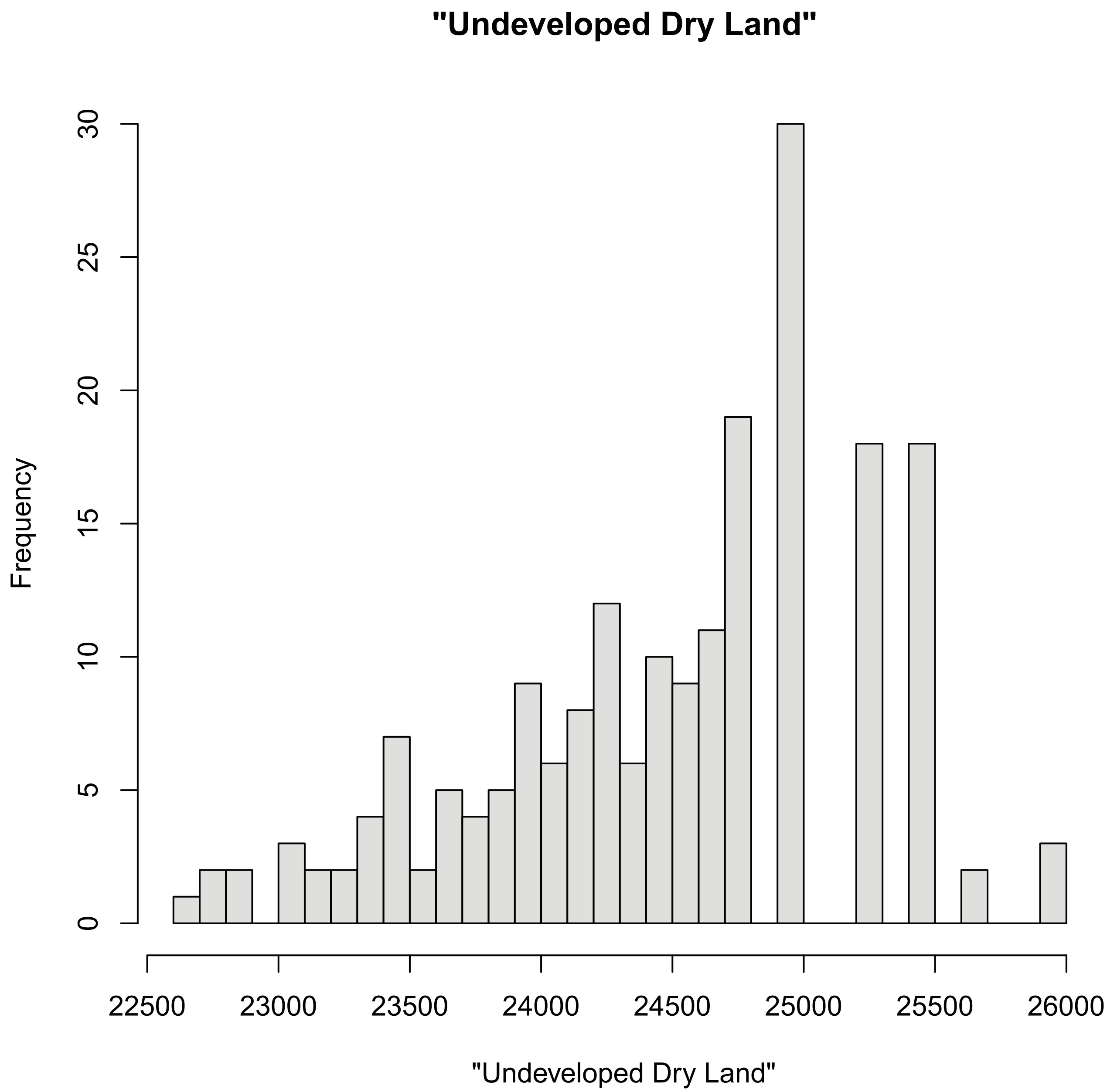
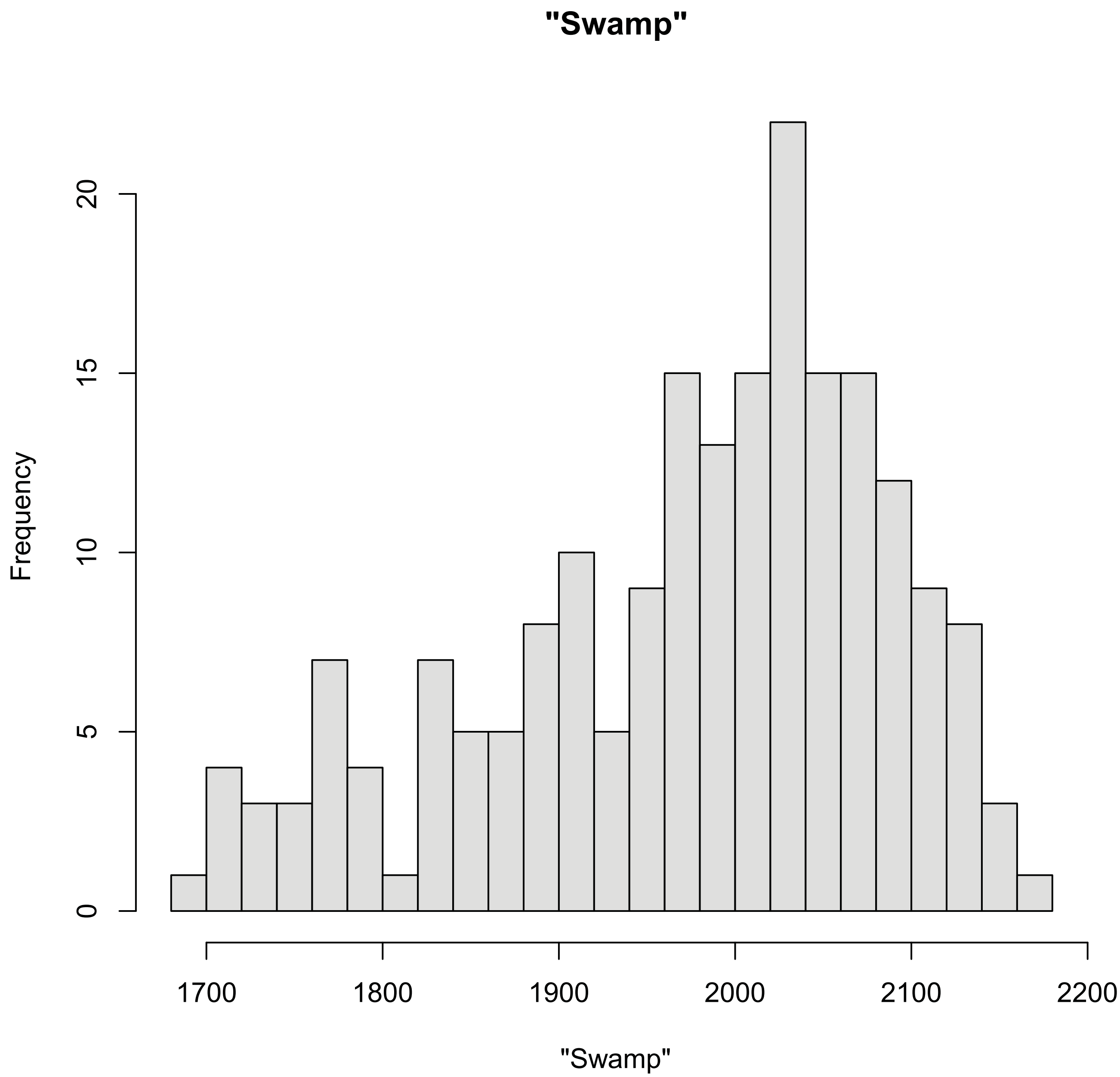
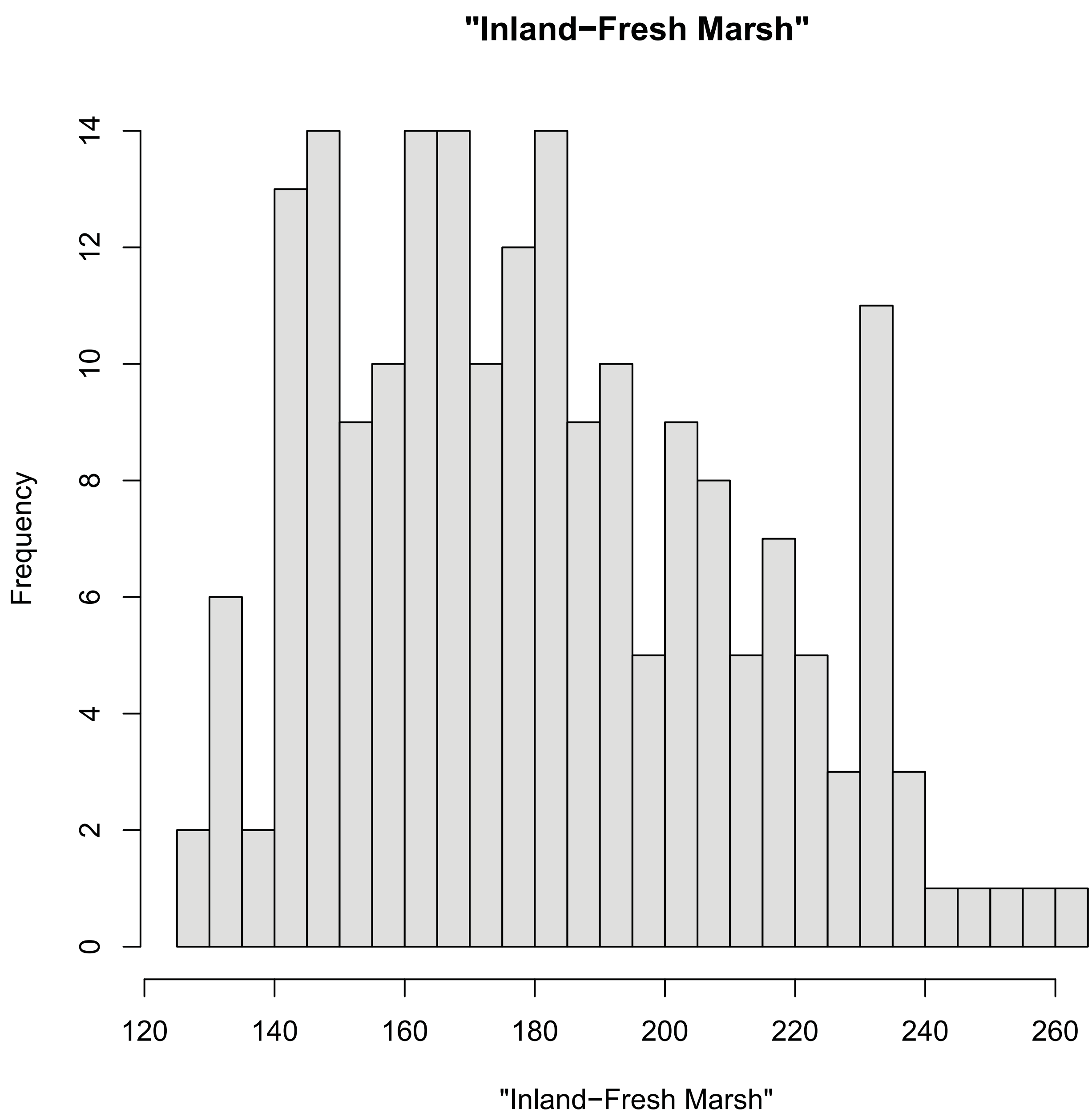
"Tidal Swamp"

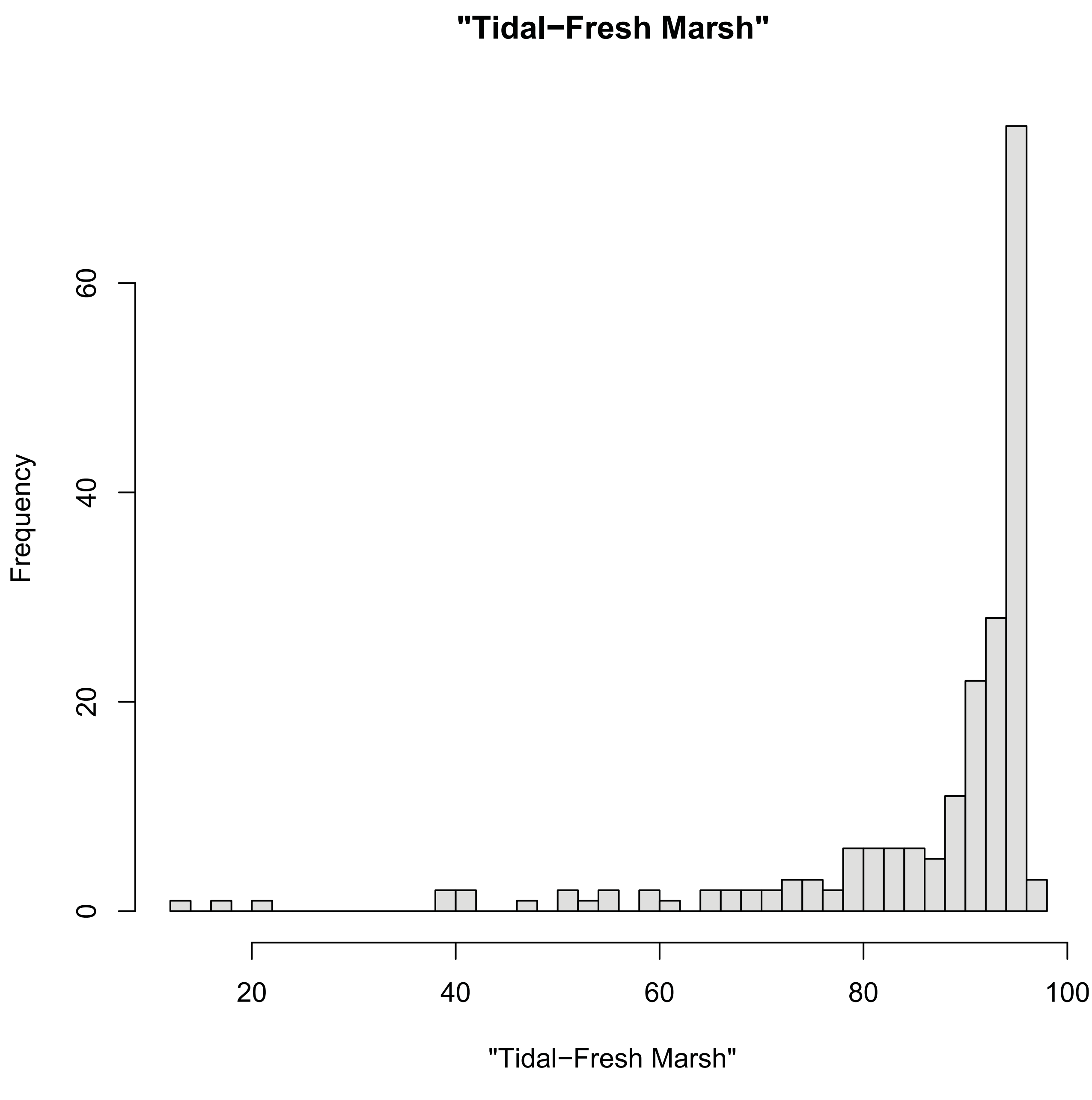

"Flooded Developed Dry Land"
Frequency
0
5
10
15
100
200
300
400
500
600
"Flooded Developed Dry Land"

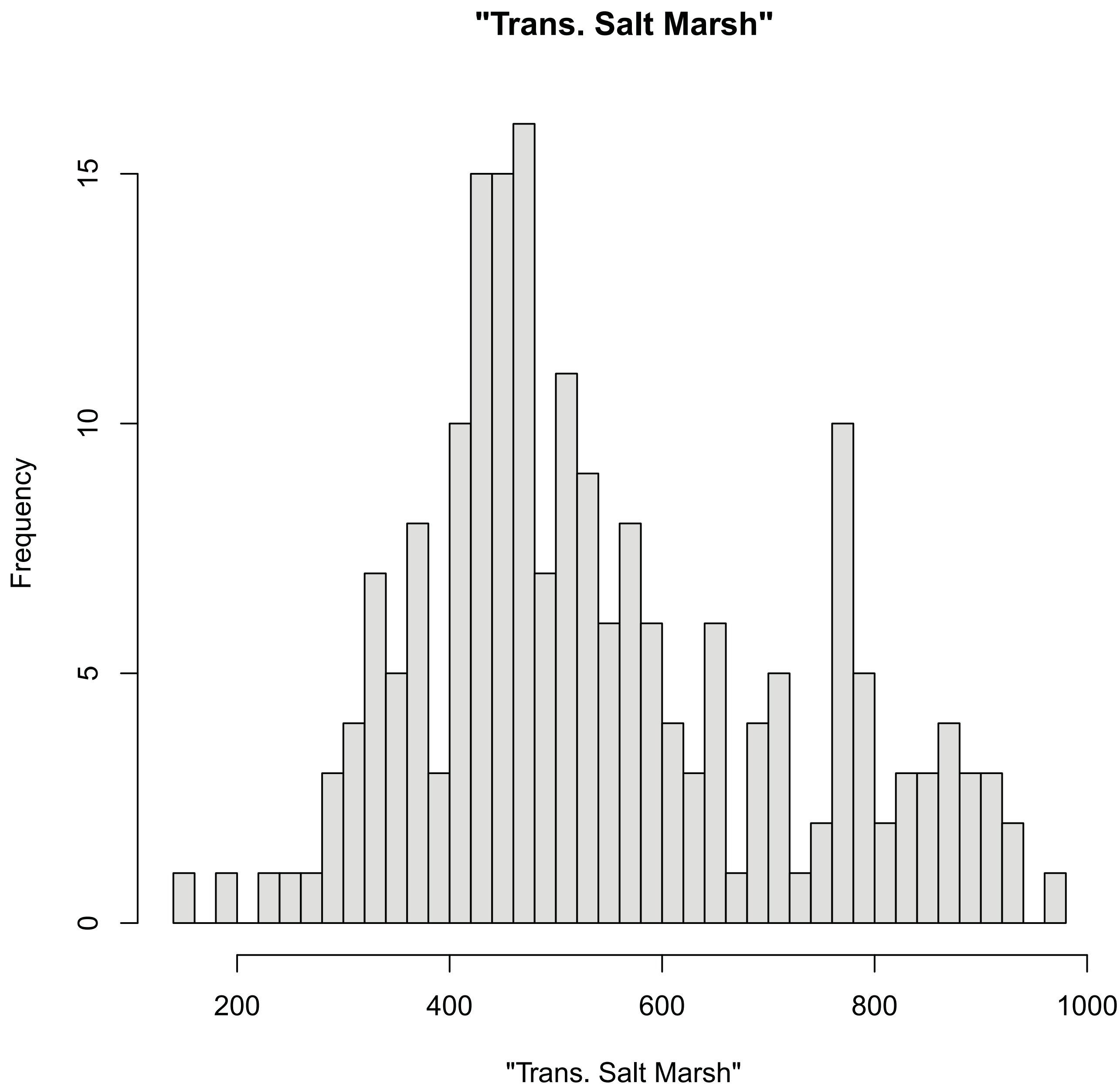

"Developed Dry Land"
Frequency
0
5
10
15
18000
18500
19000
19500
20000
20500
21000
"Developed Dry Land"

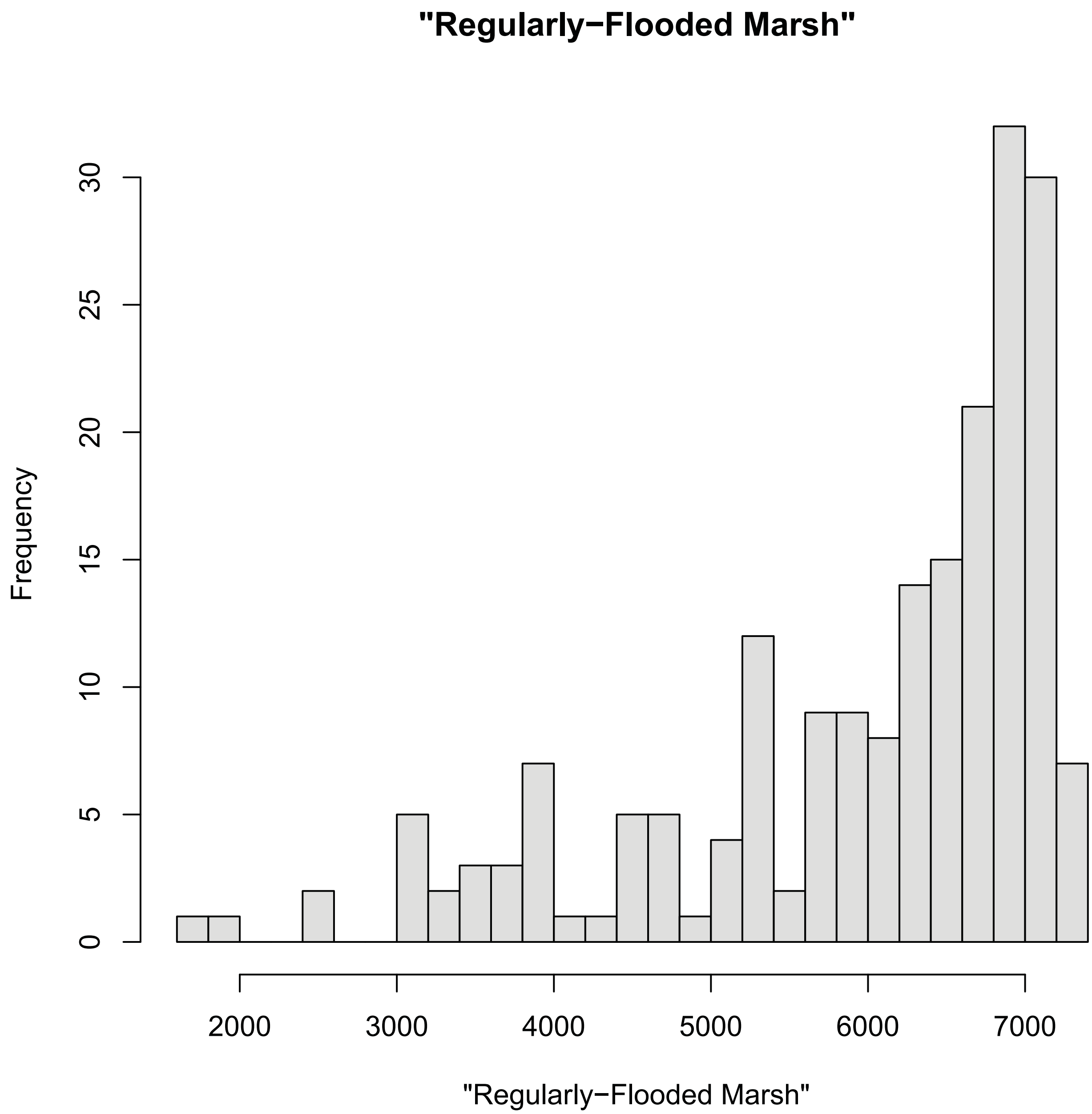

"Undeveloped Dry Land"
Frequency
0
5
10
15
20
25
30
22500
23000
23500
24000
24500
25000
25500
26000
"Undeveloped Dry Land"

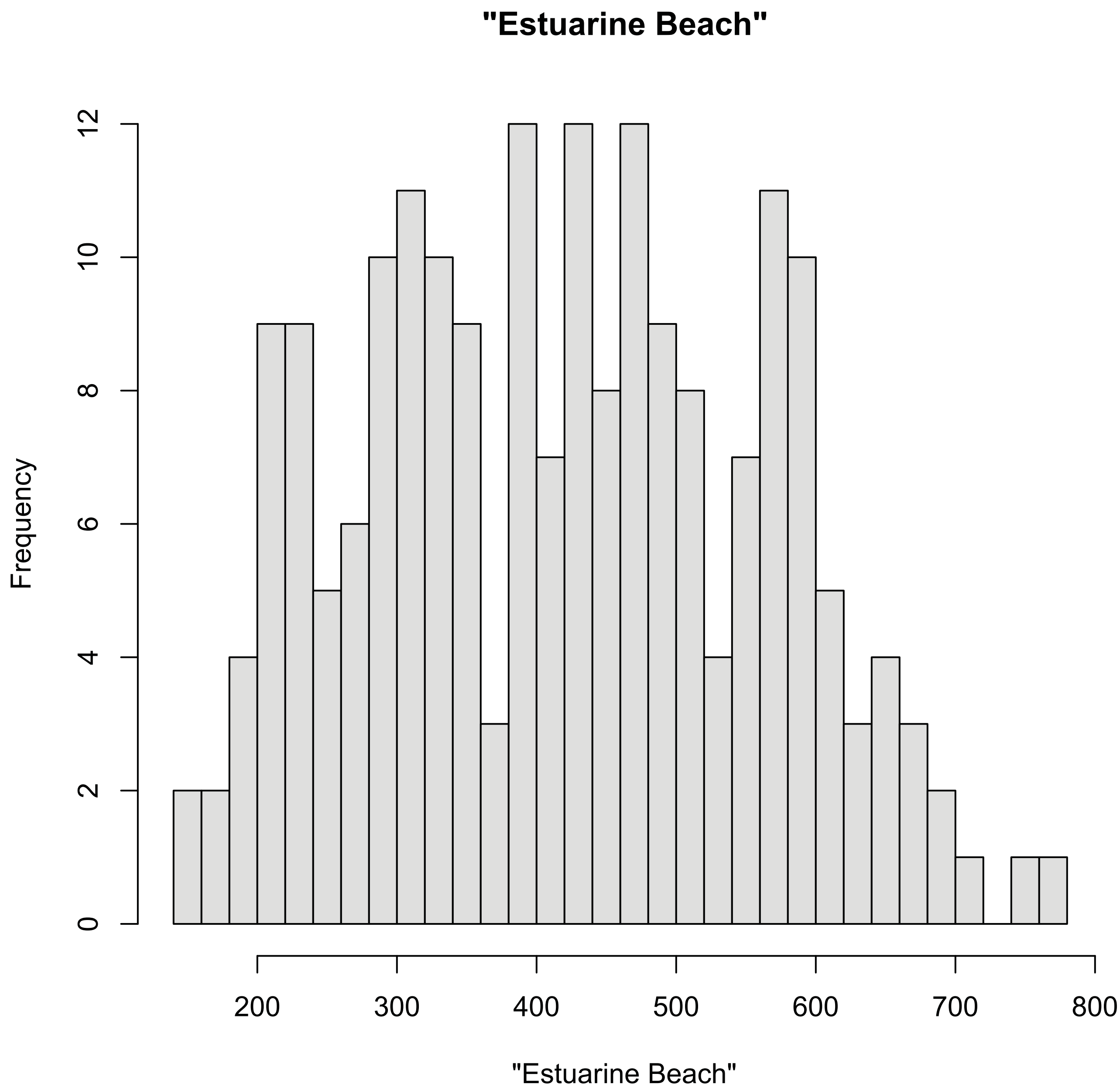

"Swamp"
Frequency
0
5
10
15
20
1700
1800
1900
2000
2100
2200
"Swamp"

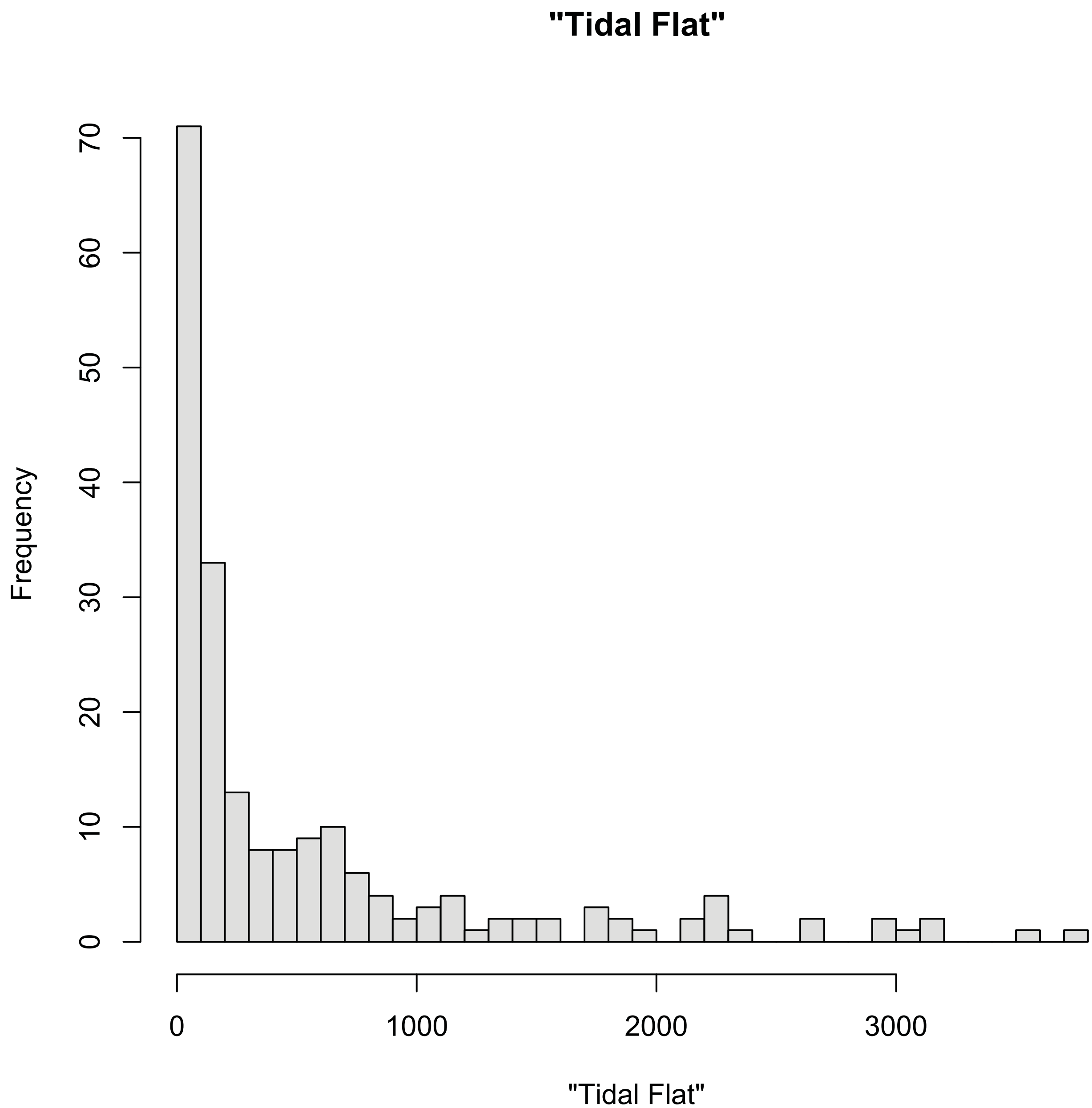

"Inland−Fresh Marsh"
Frequency
0
2
4
6
8
10
12
14
120
140
160
180
200
220
240
260
"Inland−Fresh Marsh"

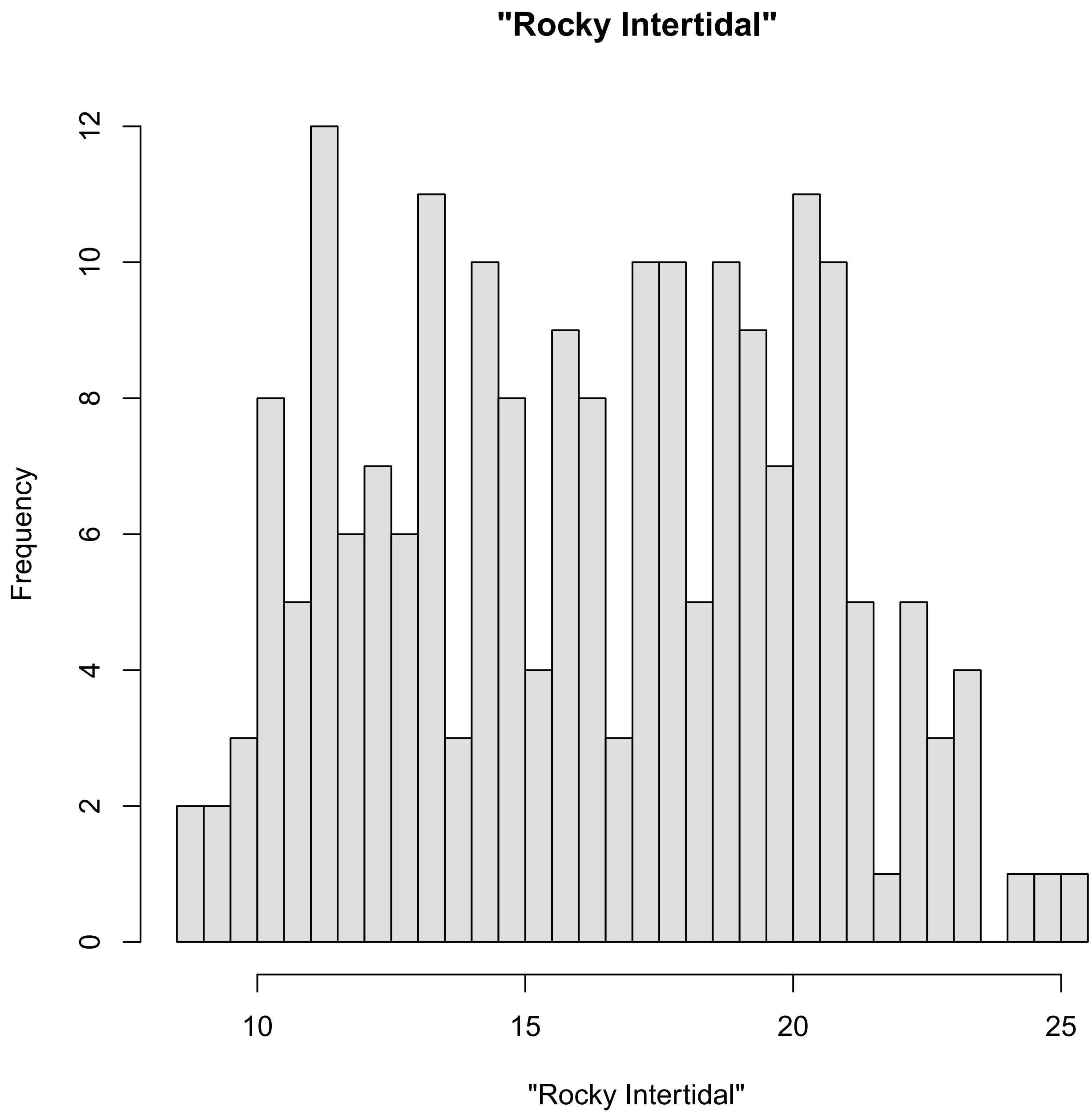

"Tidal−Fresh Marsh"
Frequency
0
20
40
60
20
40
60
80
100
"Tidal−Fresh Marsh"

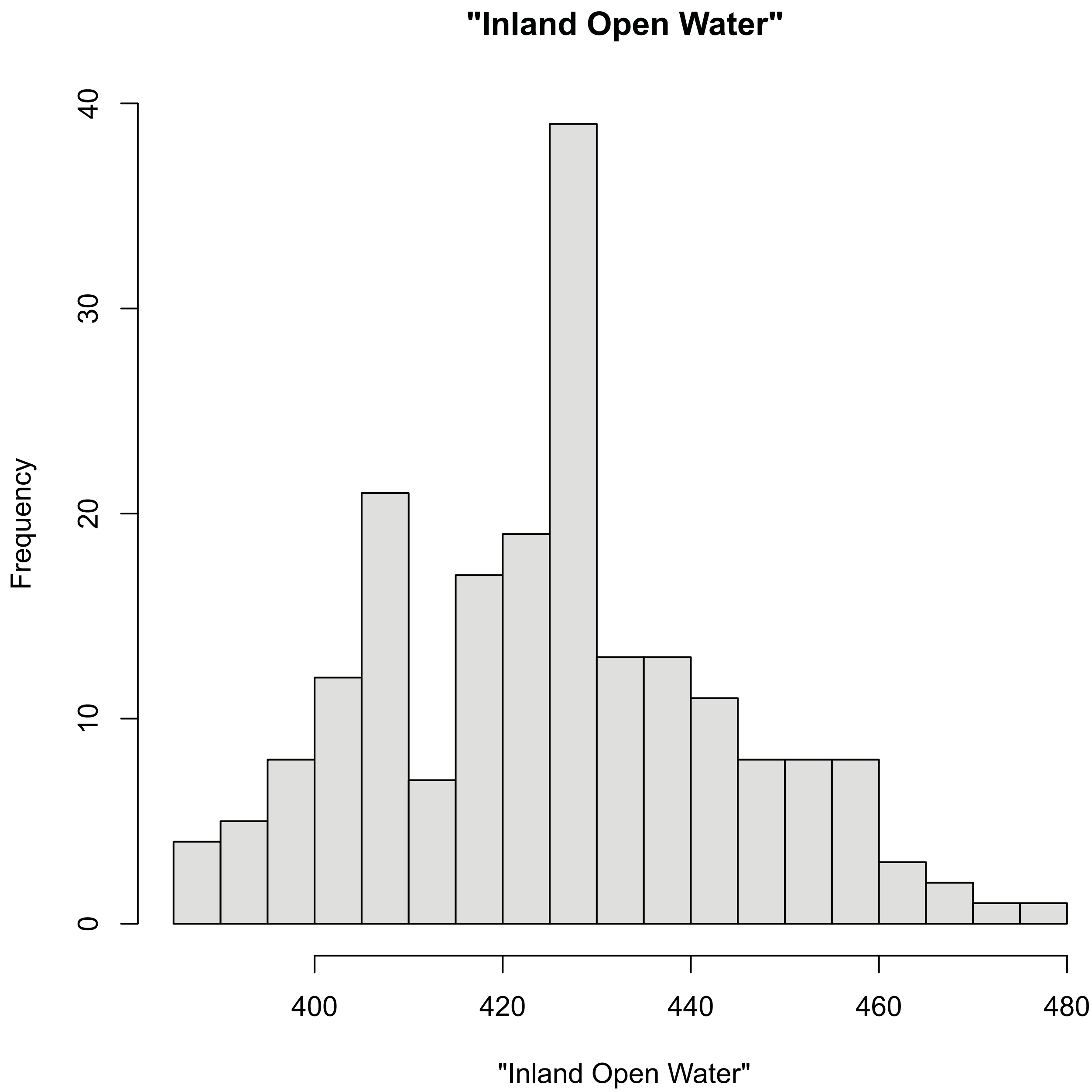

"Trans. Salt Marsh"
Frequency
0
5
10
15
200
400
600
800
1000
"Trans. Salt Marsh"

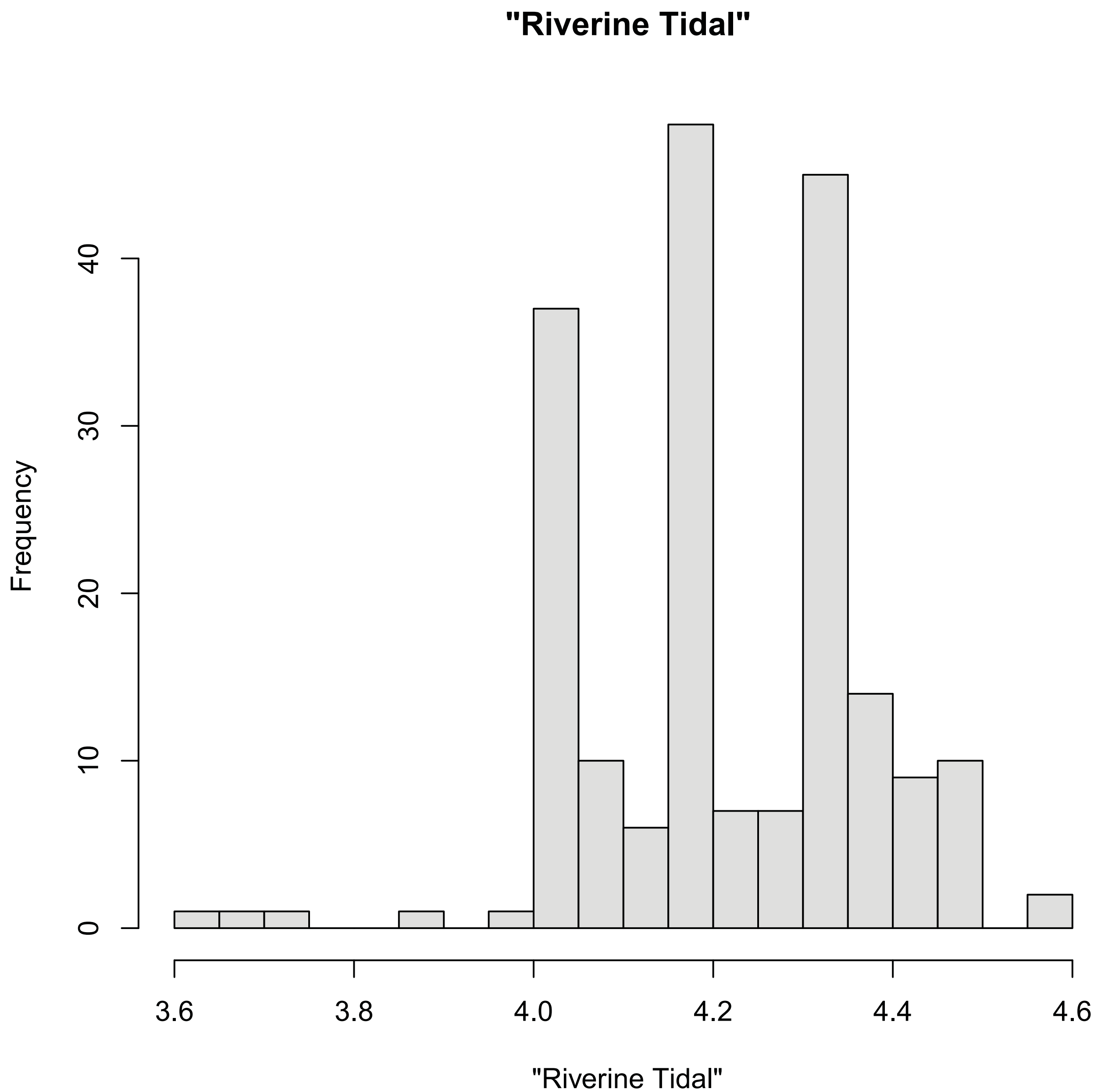

"Regularly−Flooded Marsh"
Frequency
0
5
10
15
20
25
30
2000
3000
4000
5000
6000
7000
"Regularly−Flooded Marsh"

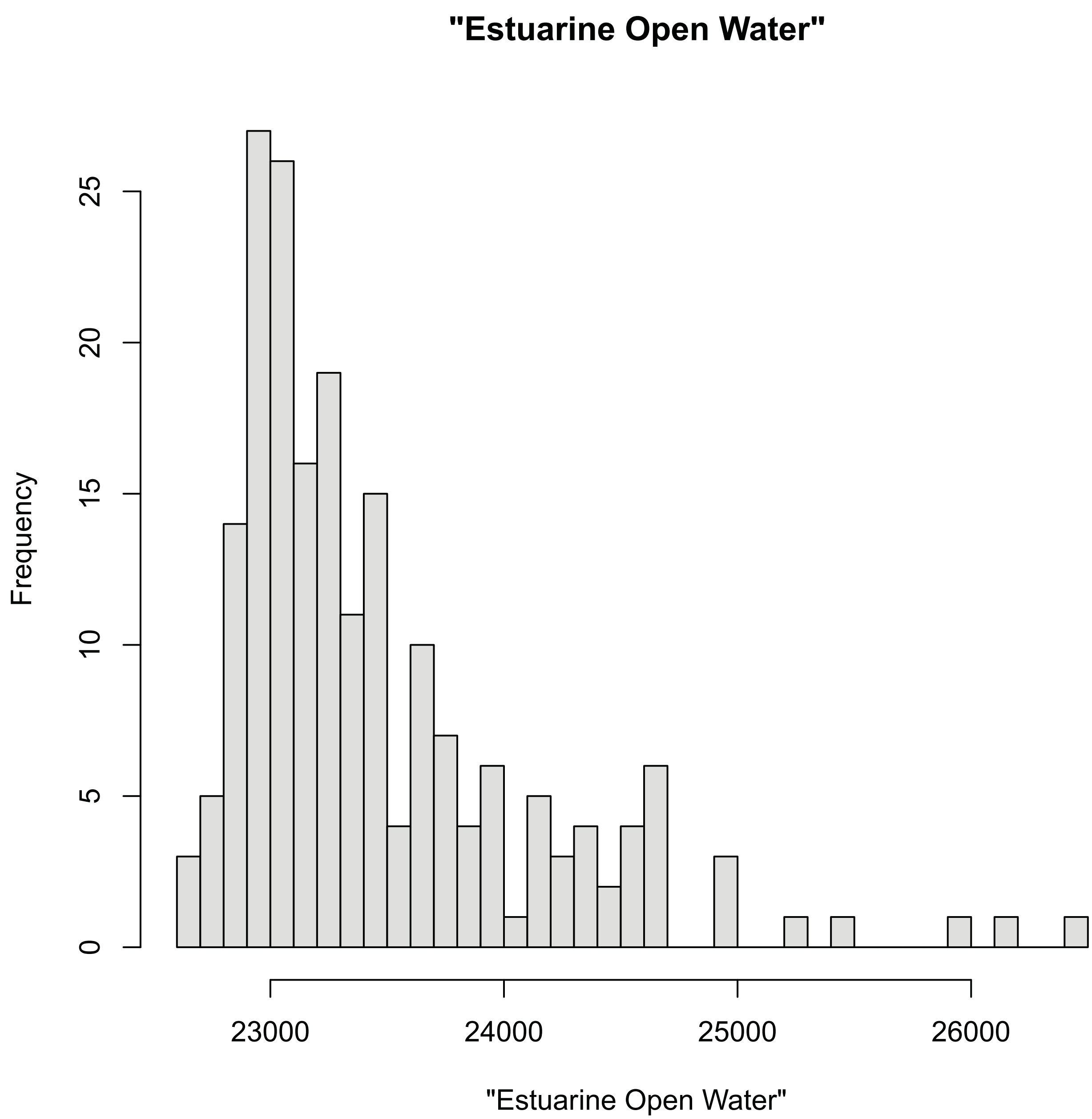

"Estuarine Beach"
Frequency
0
2
4
6
8
10
12
200
300
400
500
600
700
800
"Estuarine Beach"

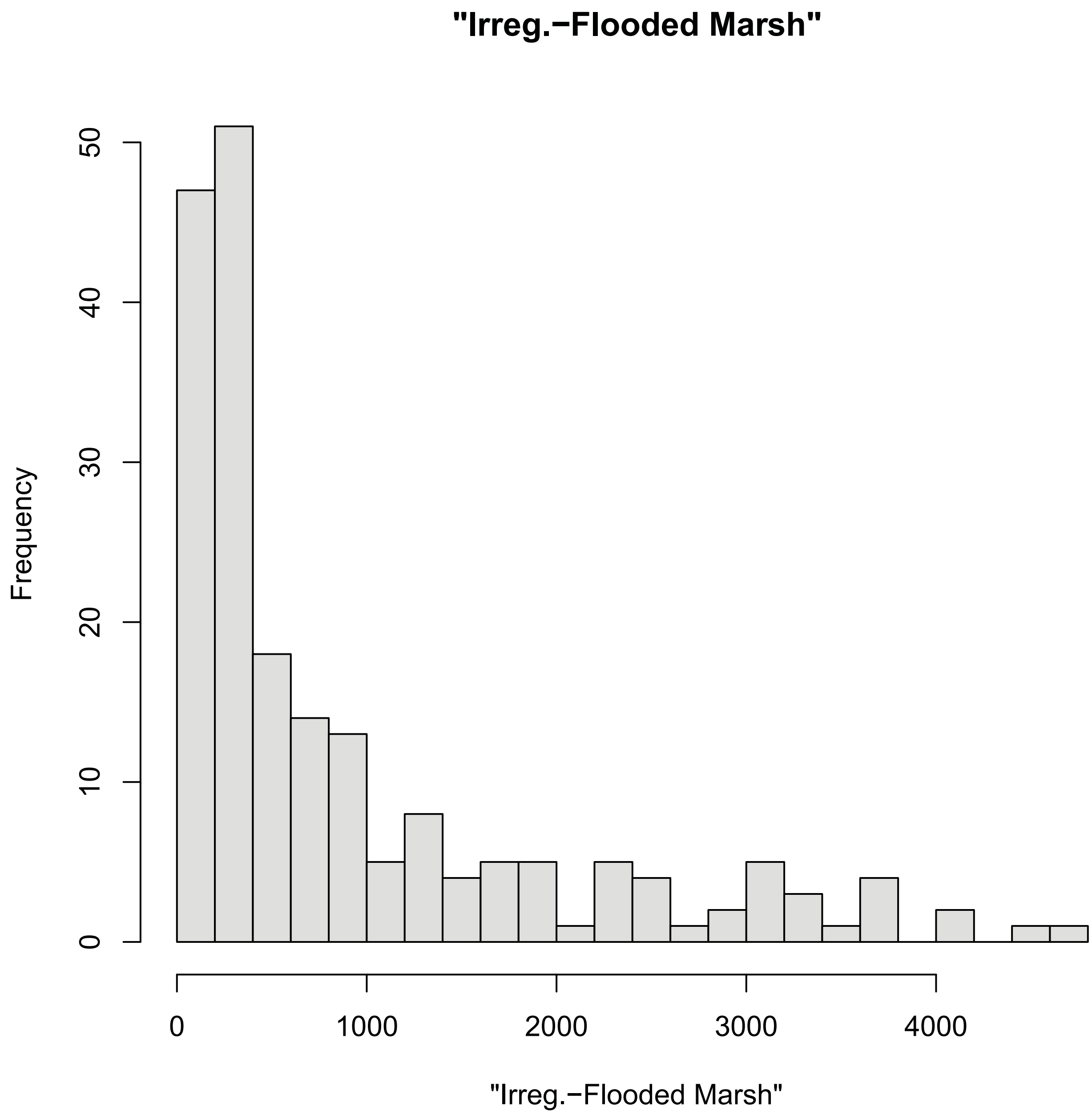

"Tidal Flat"
Frequency
0
10
20
30
40
50
60
70
0
1000
2000
3000
"Tidal Flat"

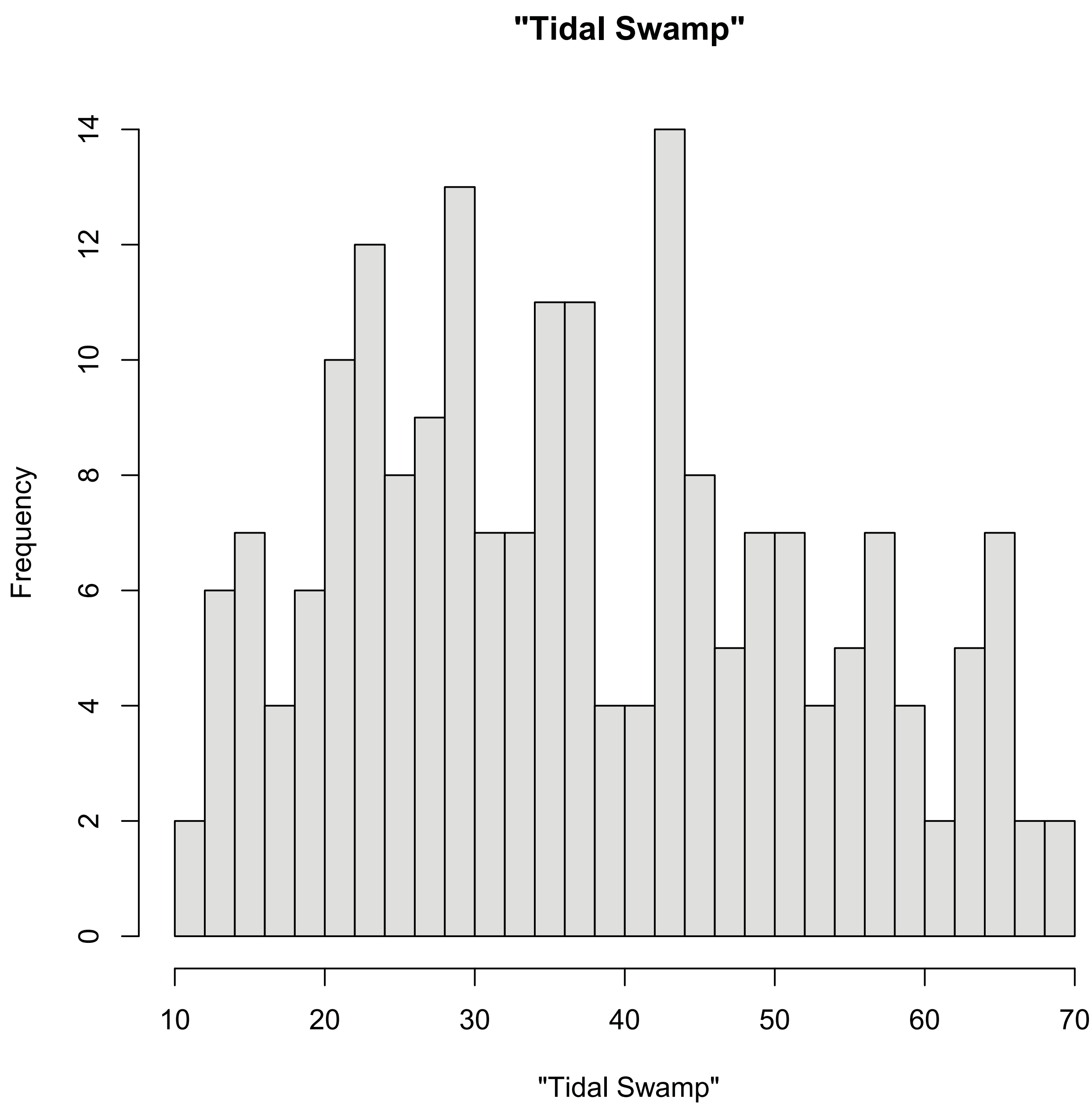

"Rocky Intertidal"
Frequency
0
2
4
6
8
10
12
10
15
20
25
"Rocky Intertidal"

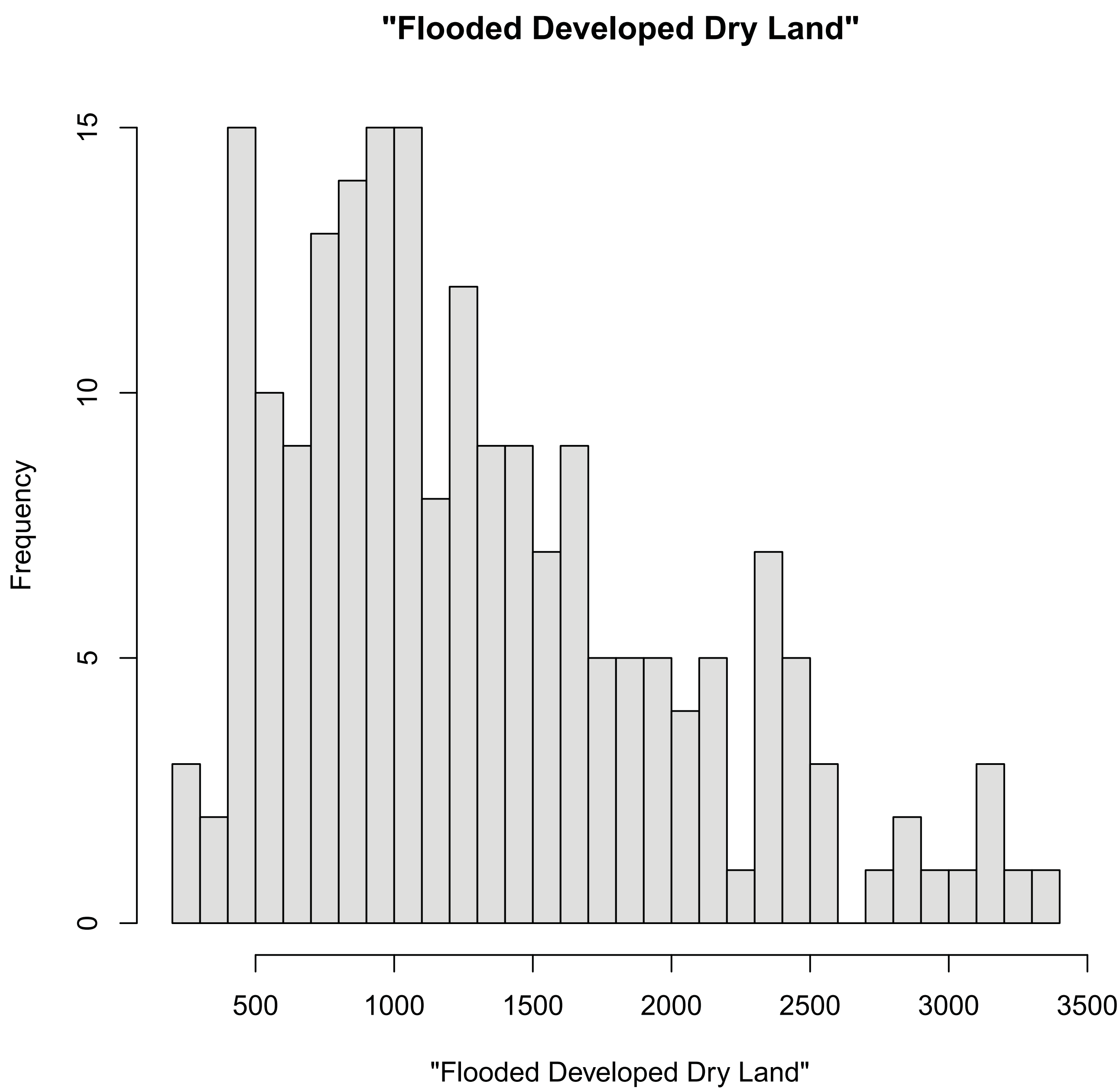

"Inland Open Water"
Frequency
0
10
20
30
40
400
420
440
460
480
"Inland Open Water"

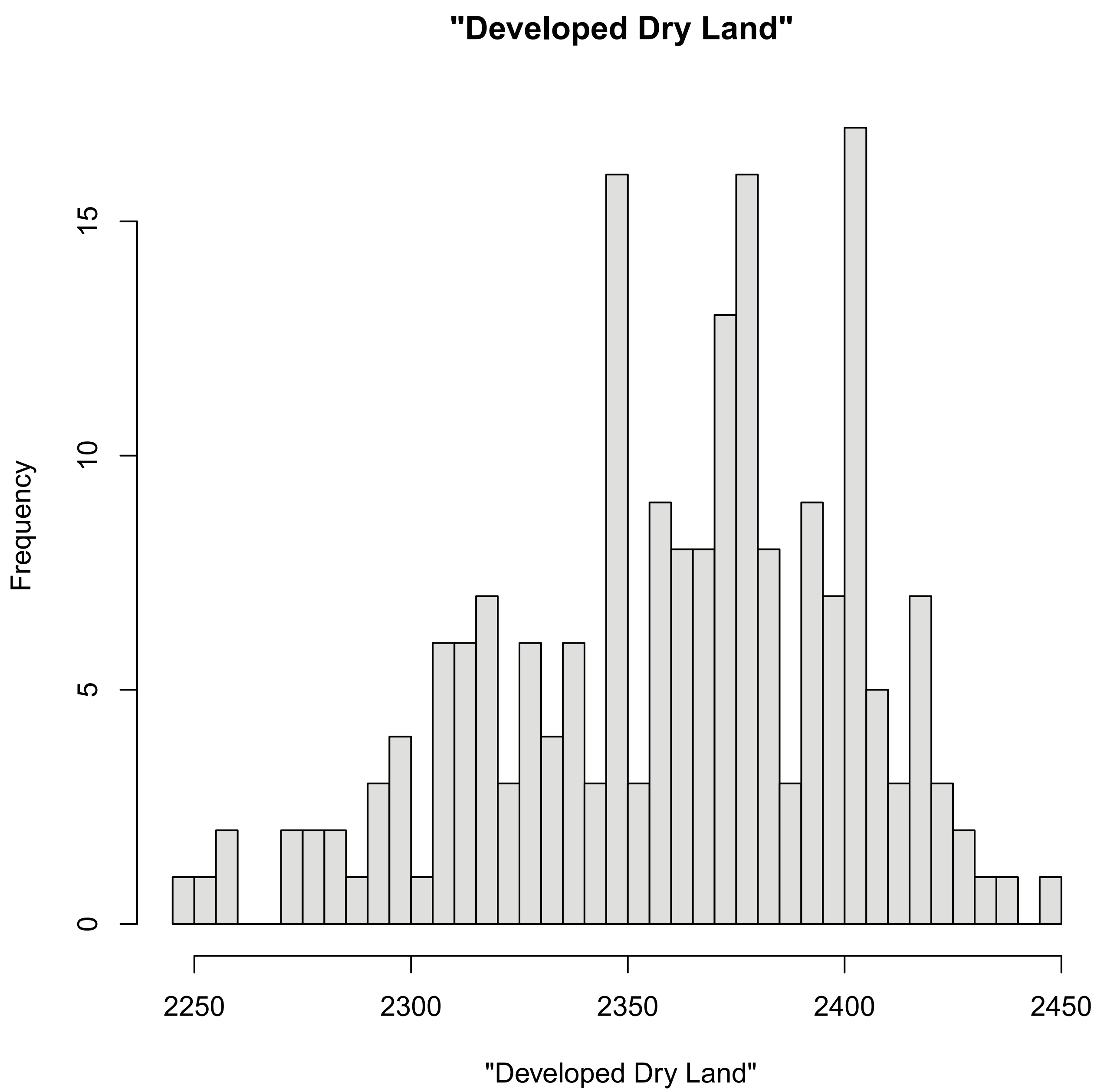

"Riverine Tidal"
Frequency
0
10
20
30
40
3.6
3.8
4.0
4.2
4.4
4.6
"Riverine Tidal"

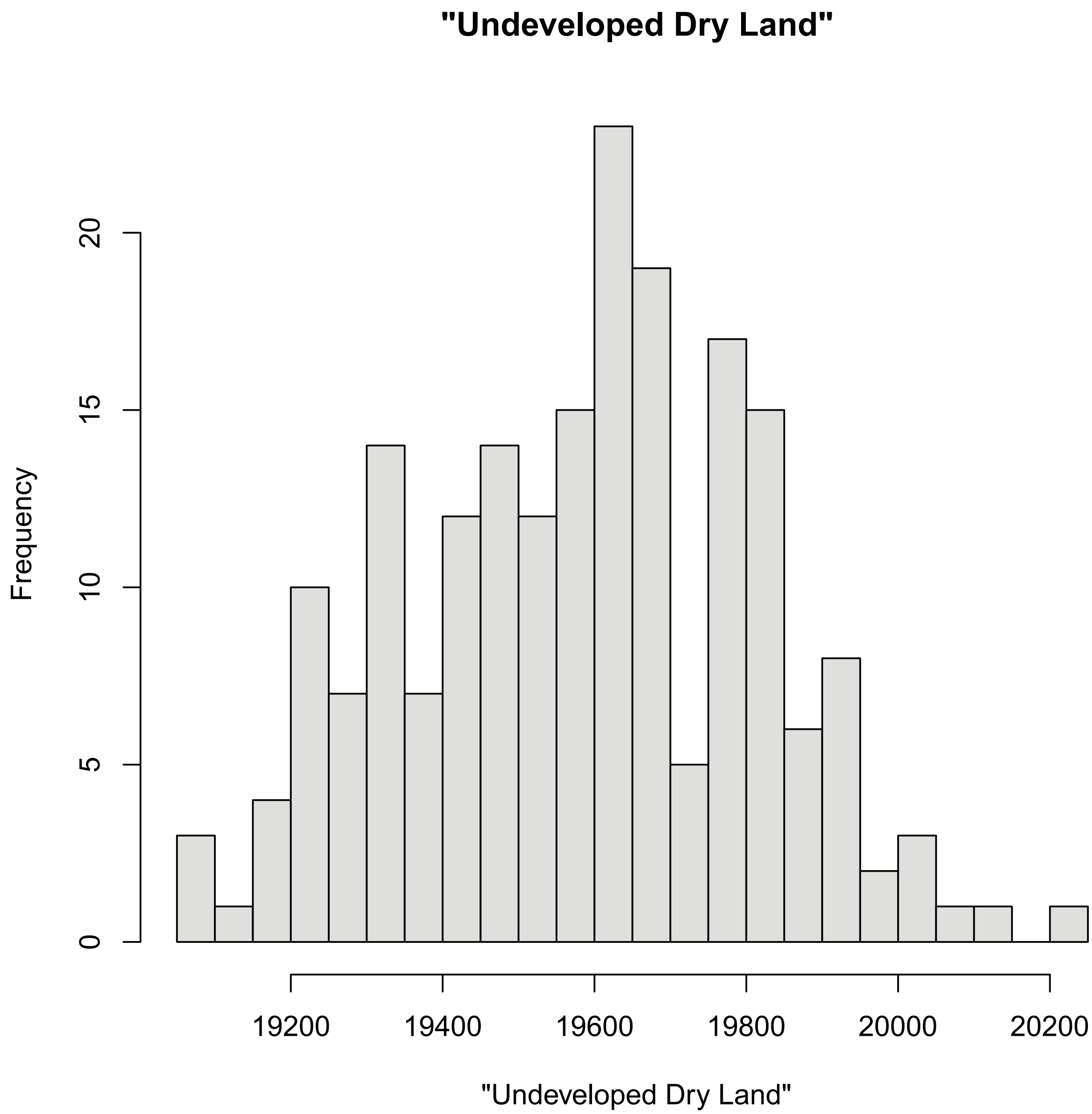

"Estuarine Open Water"
Frequency
0
5
10
15
20
25
23000
24000
25000
26000
"Estuarine Open Water"

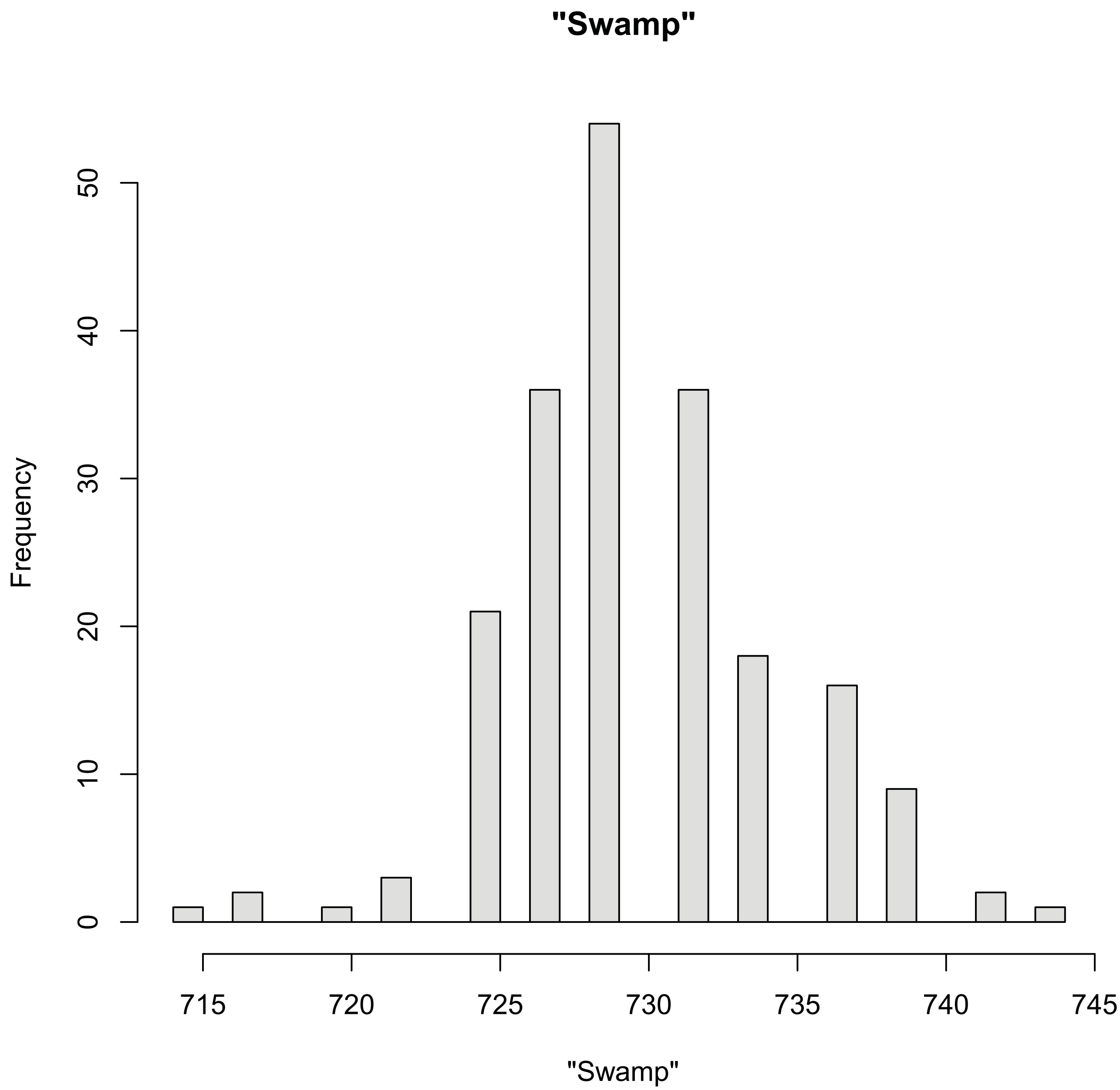

"Irreg.−Flooded Marsh"
Frequency
0
10
20
30
40
50
0
1000
2000
3000
4000
"Irreg.−Flooded Marsh"

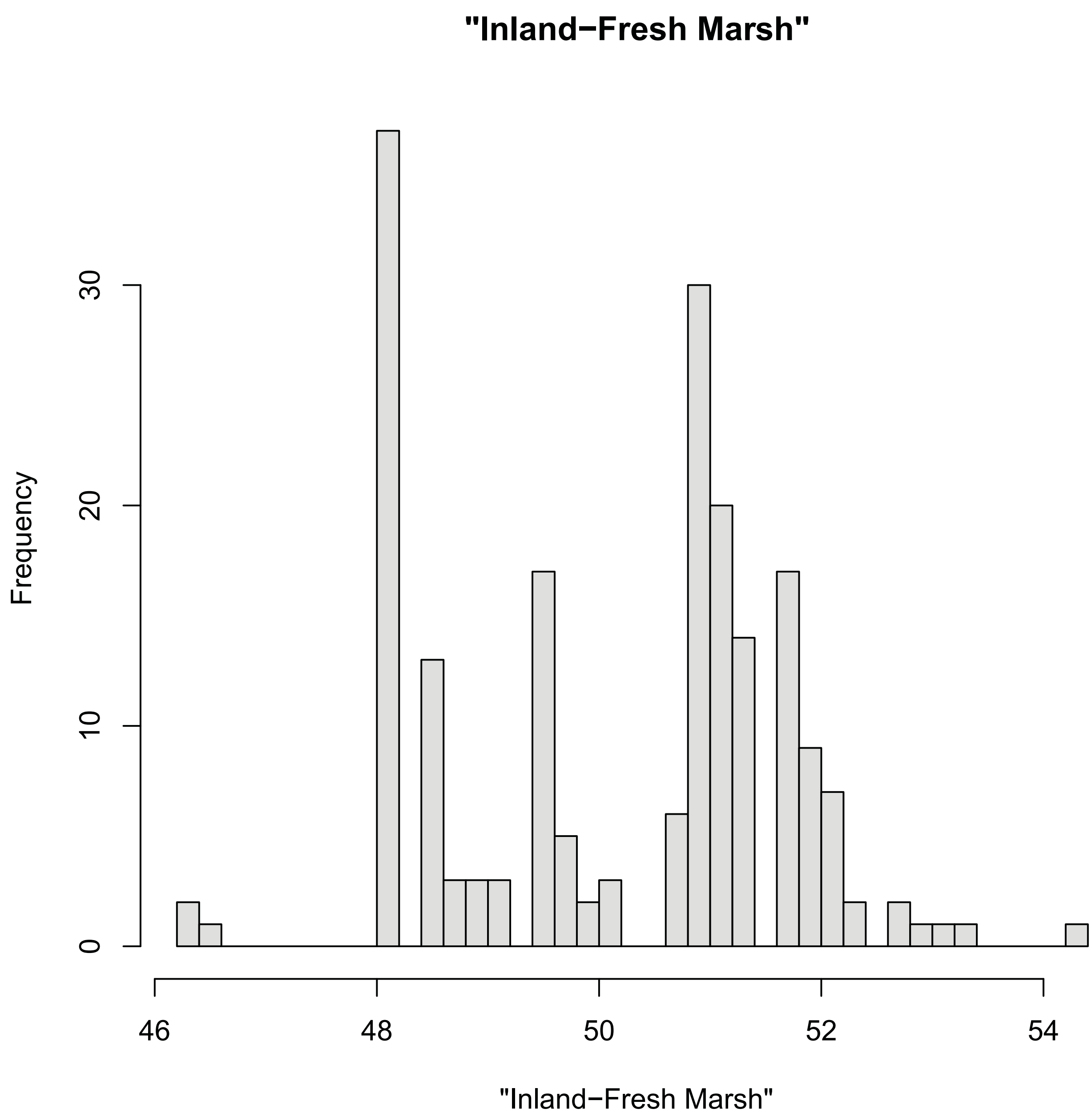

"Tidal Swamp"
Frequency
0
2
4
6
8
10
12
14
10
20
30
40
50
60
70
"Tidal Swamp"

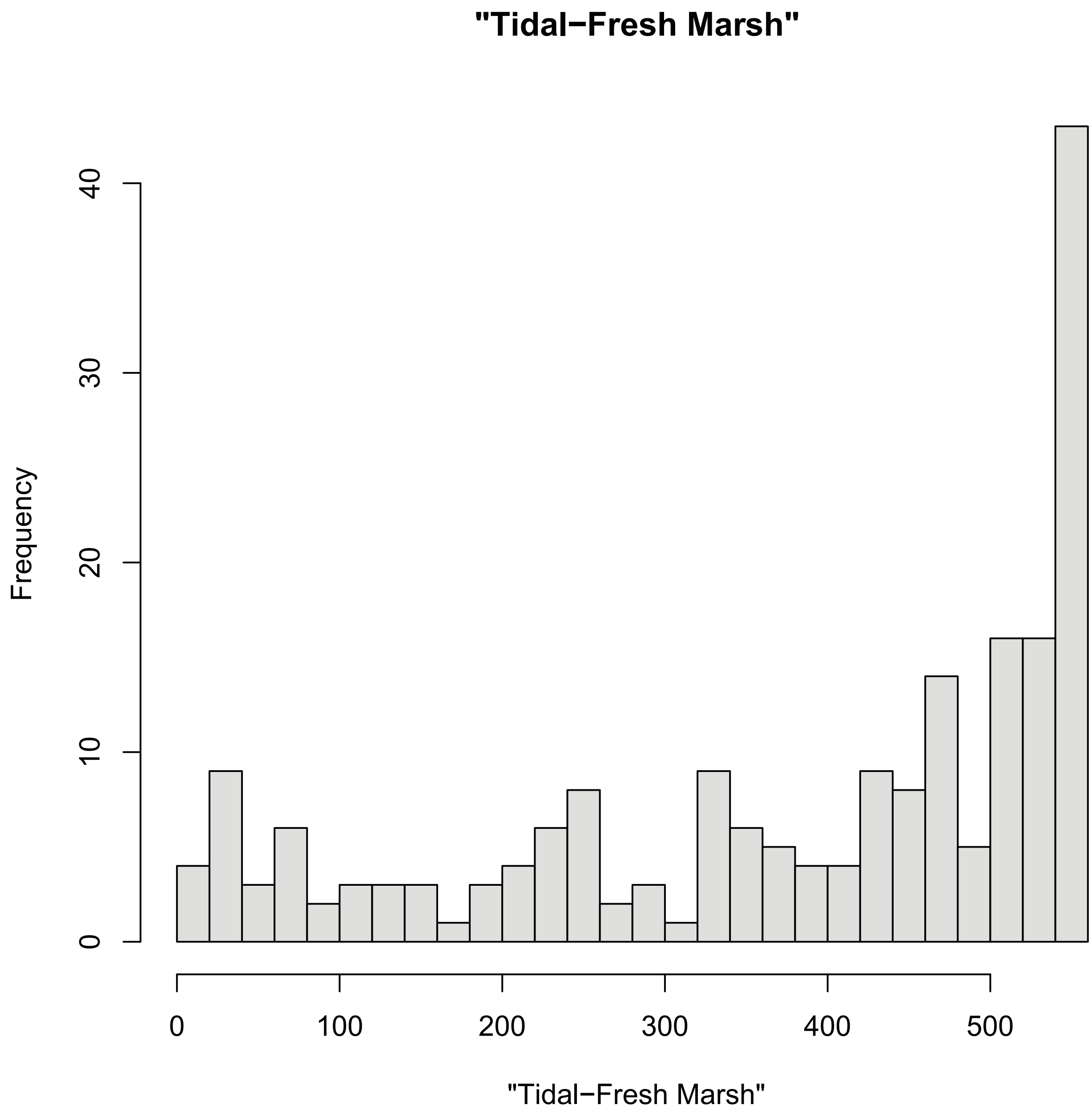

"Flooded Developed Dry Land"
Frequency
0
5
10
15
500
1000
1500
2000
2500
3000
3500
"Flooded Developed Dry Land"

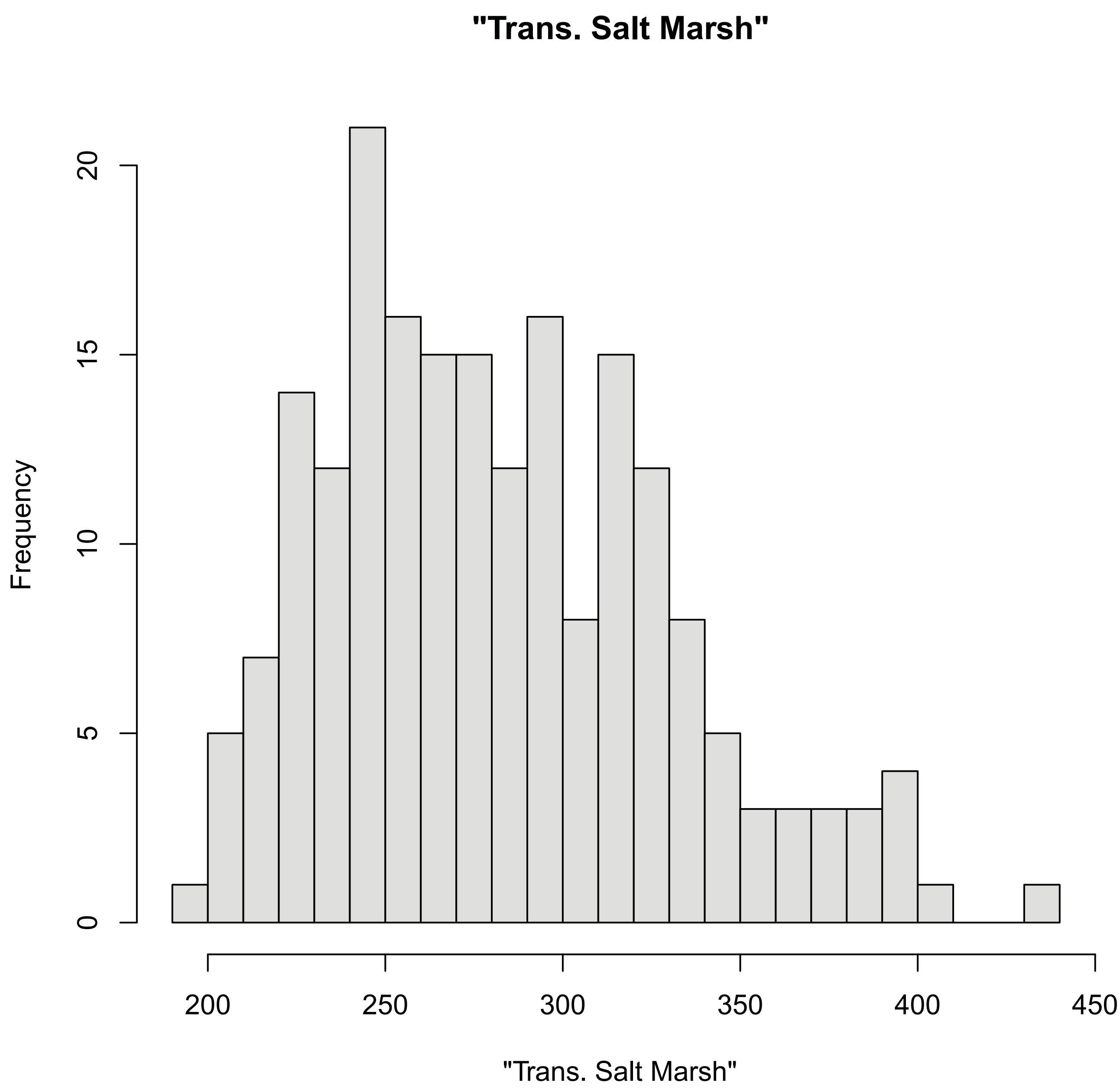

"Developed Dry Land"
Frequency
0
5
10
15
2250
2300
2350
2400
2450
"Developed Dry Land"

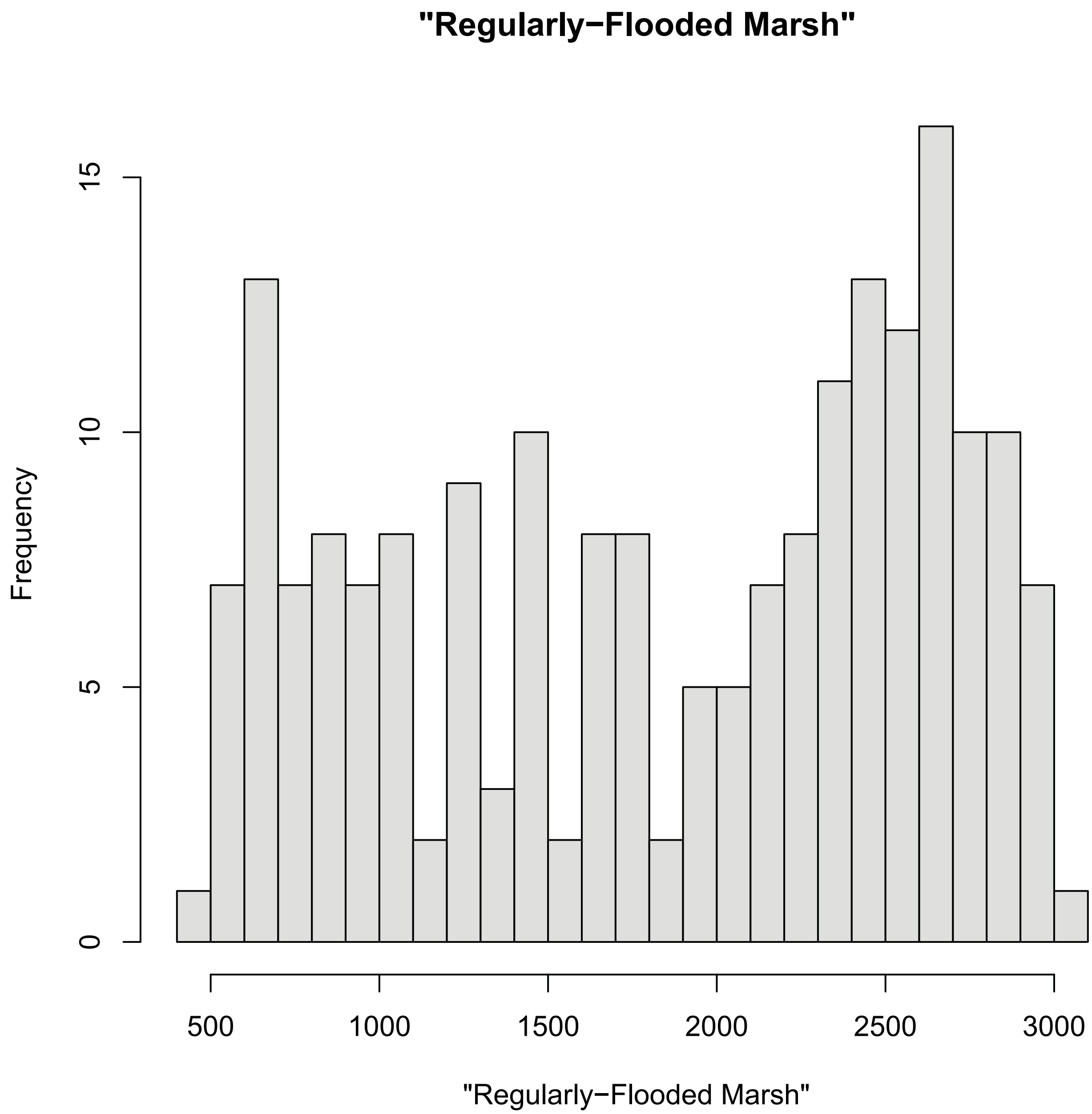

"Undeveloped Dry Land"
Frequency
0
5
10
15
20
19200
19400
19600
19800
20000
20200
"Undeveloped Dry Land"

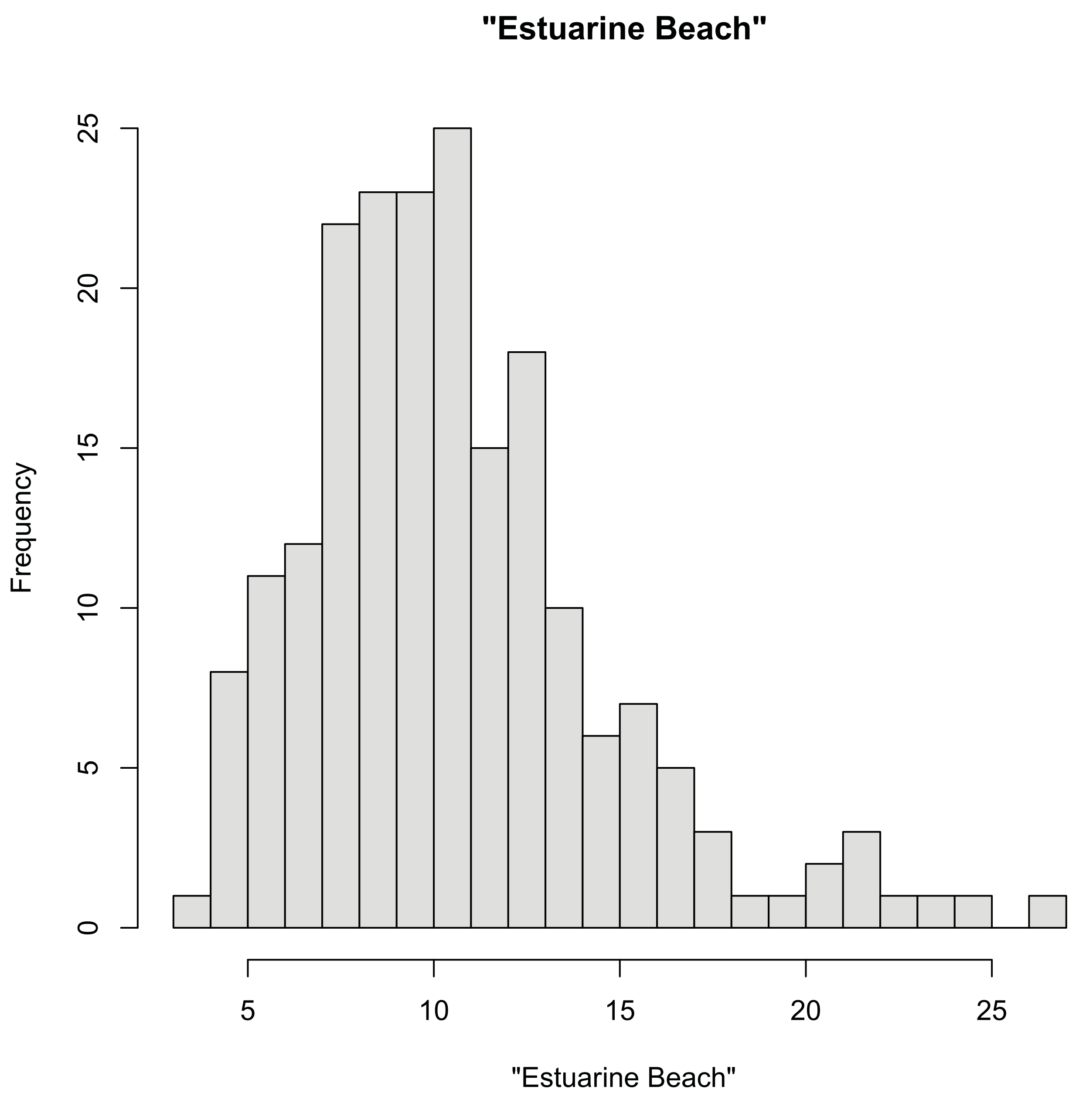

"Swamp"
Frequency
0
10
20
30
40
50
715
720
725
730
735
740
745
"Swamp"


"Inland−Fresh Marsh"
Frequency
0
10
20
30
46
48
50
52
54
"Inland−Fresh Marsh"

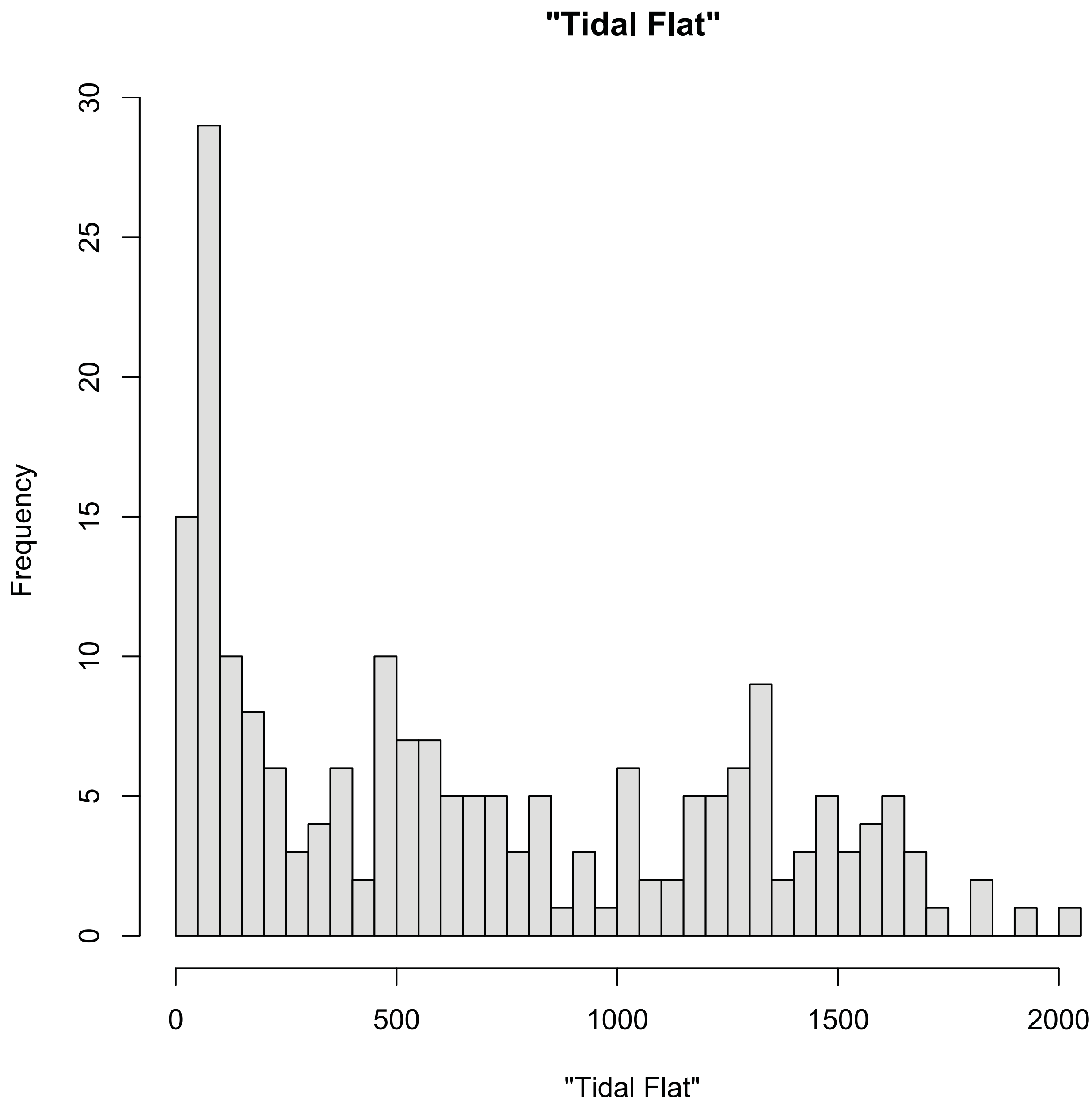

"Tidal−Fresh Marsh"
Frequency
0
10
20
30
40
0
100
200
300
400
500
"Tidal−Fresh Marsh"

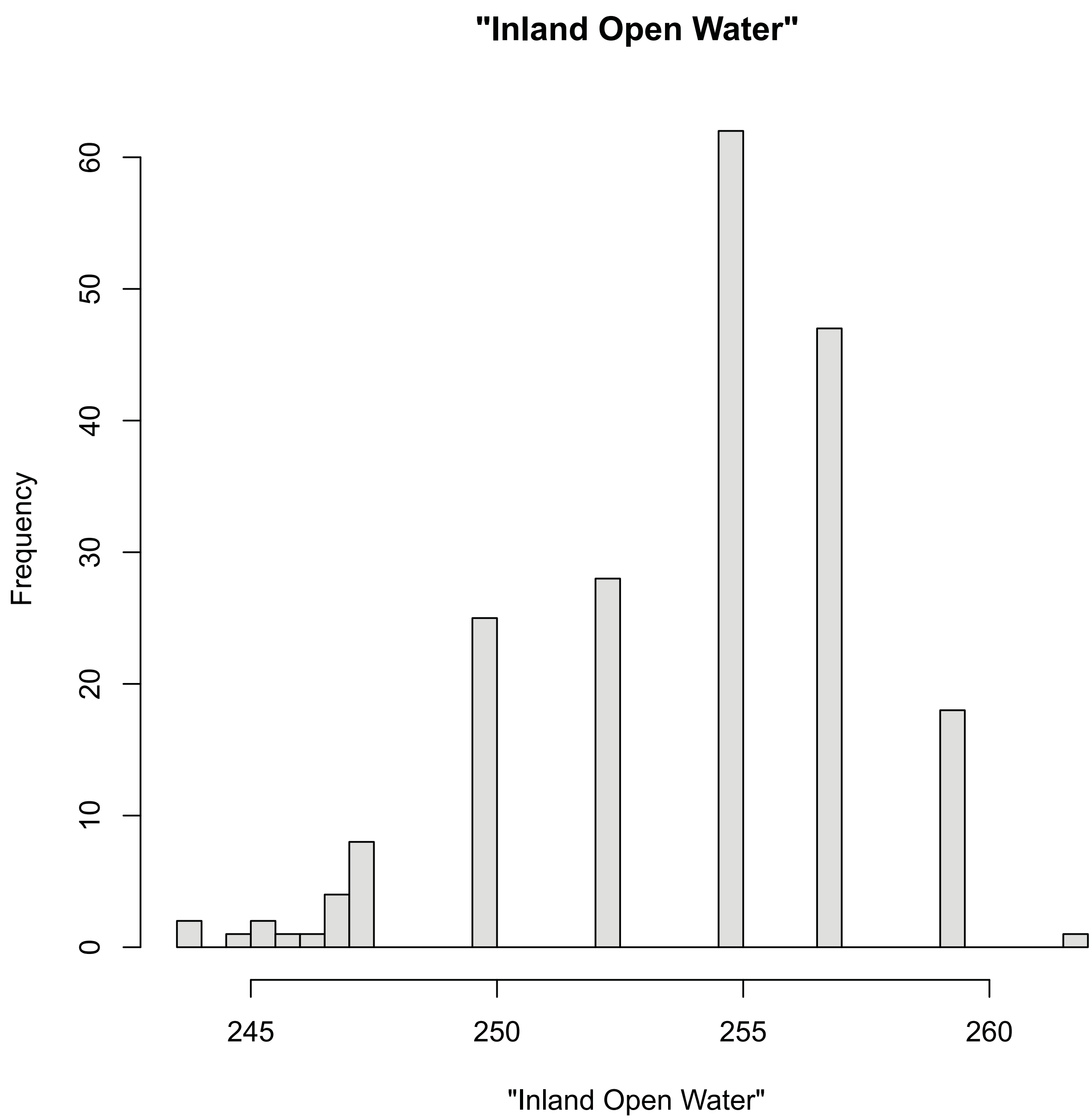

"Trans. Salt Marsh"
Frequency
0
5
10
15
20
200
250
300
350
400
450
"Trans. Salt Marsh"

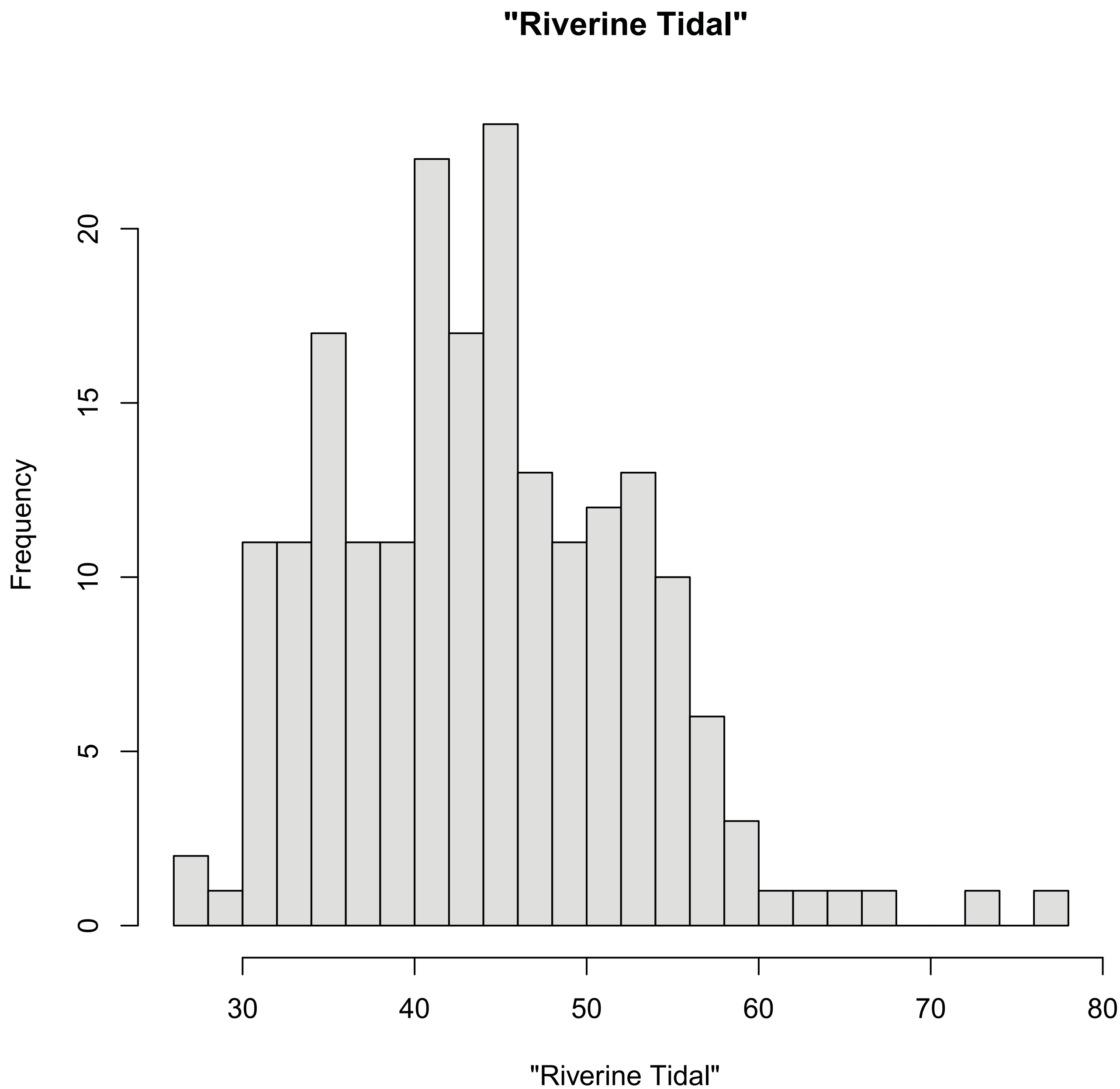

"Regularly−Flooded Marsh"
Frequency
0
5
10
15
500
1000
1500
2000
2500
3000
"Regularly−Flooded Marsh"

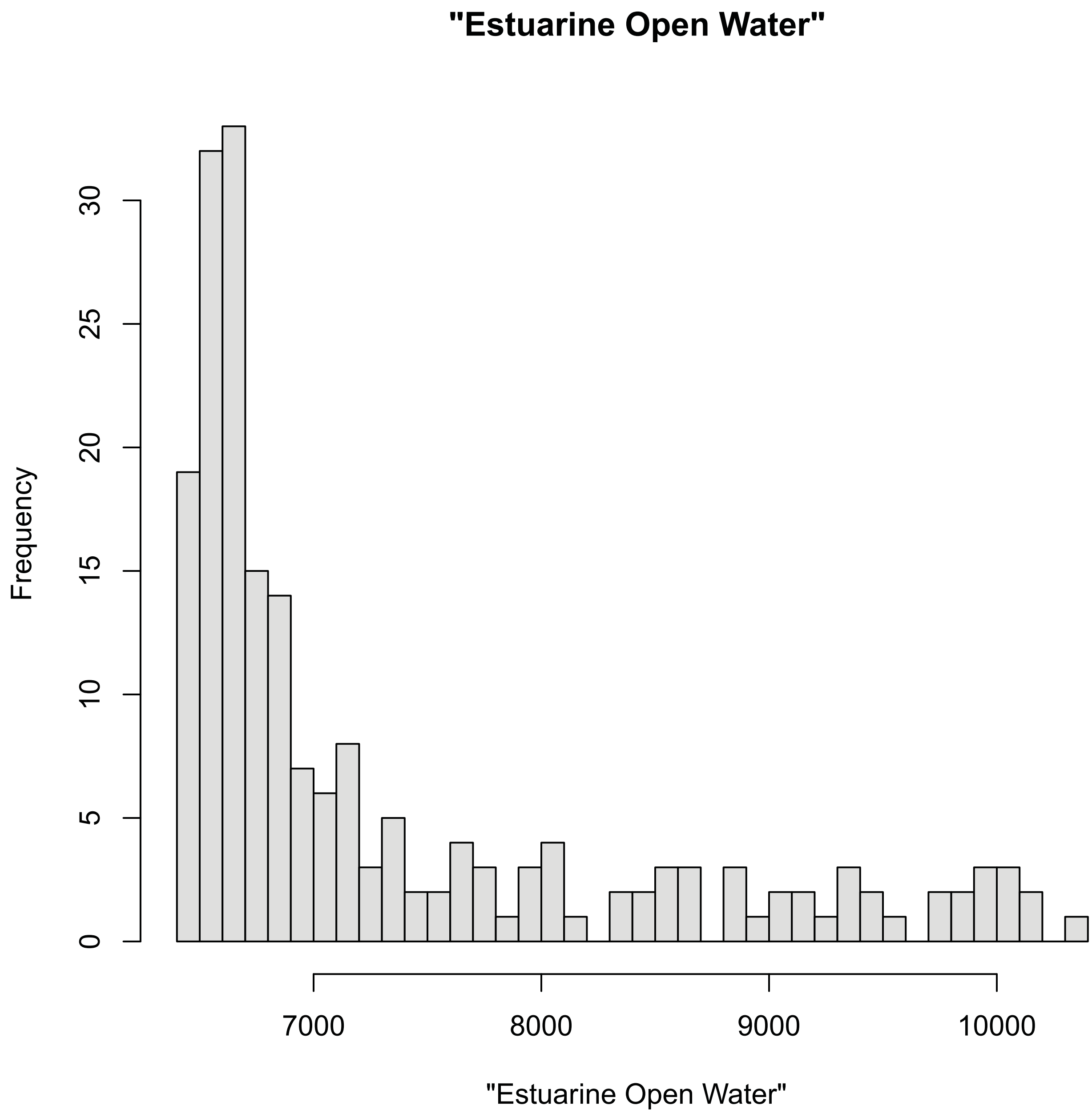


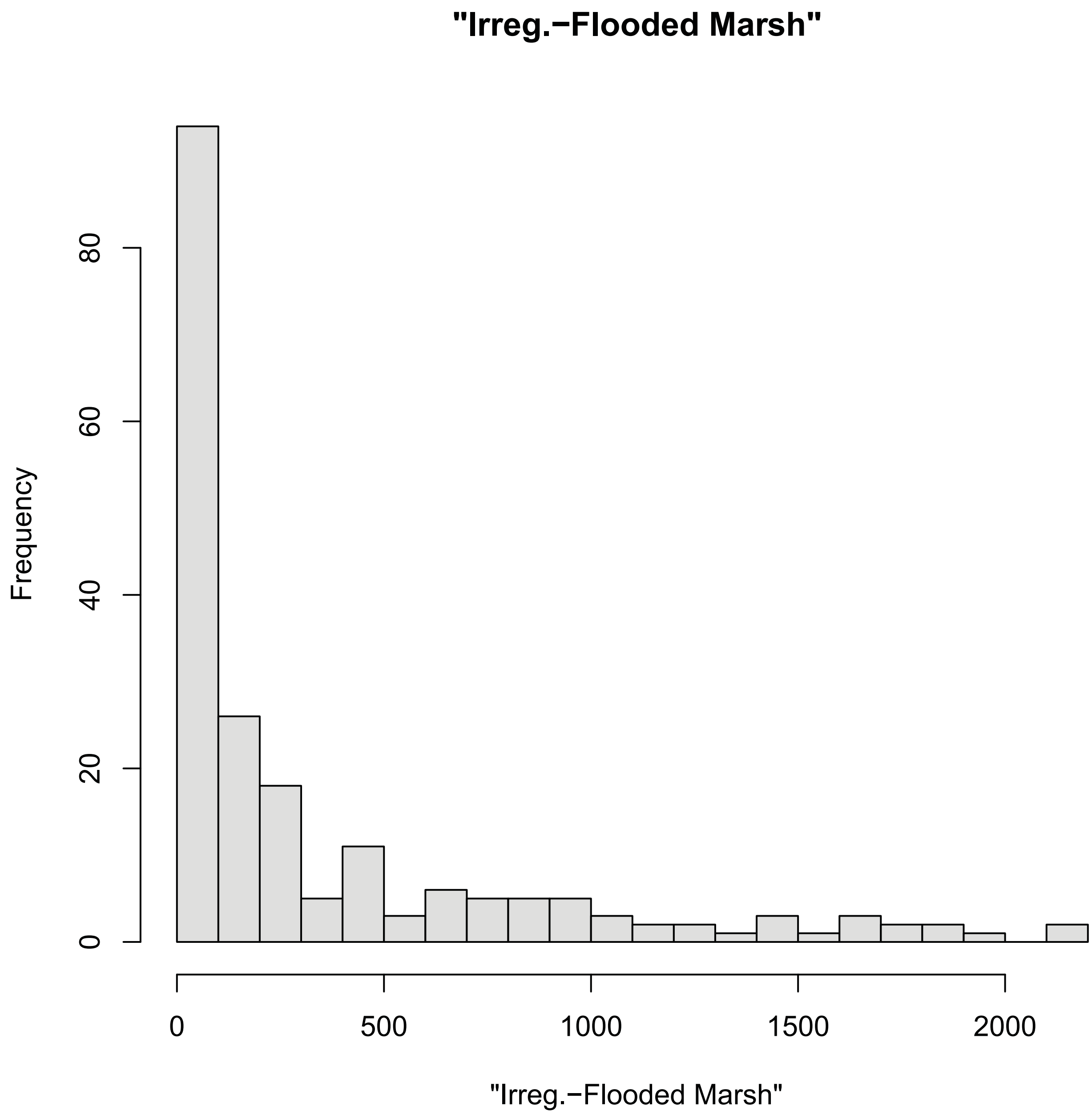
"Estuarine Beach"
Frequency
0
5
10
15
20
25
5
10
15
20
25
"Estuarine Beach"

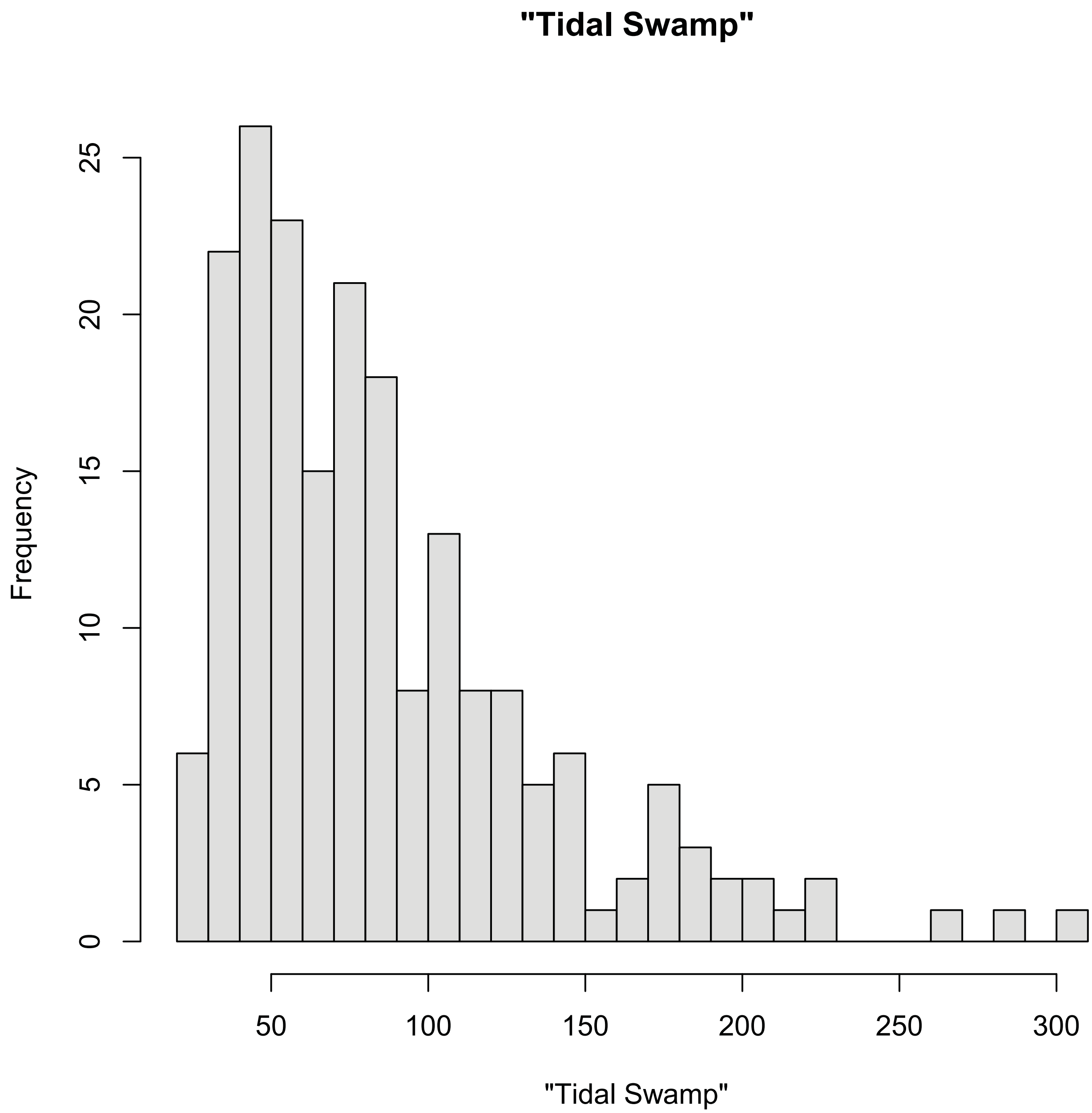

"Tidal Flat"
Frequency
0
5
10
15
20
25
30
0
500
1000
1500
2000
"Tidal Flat"

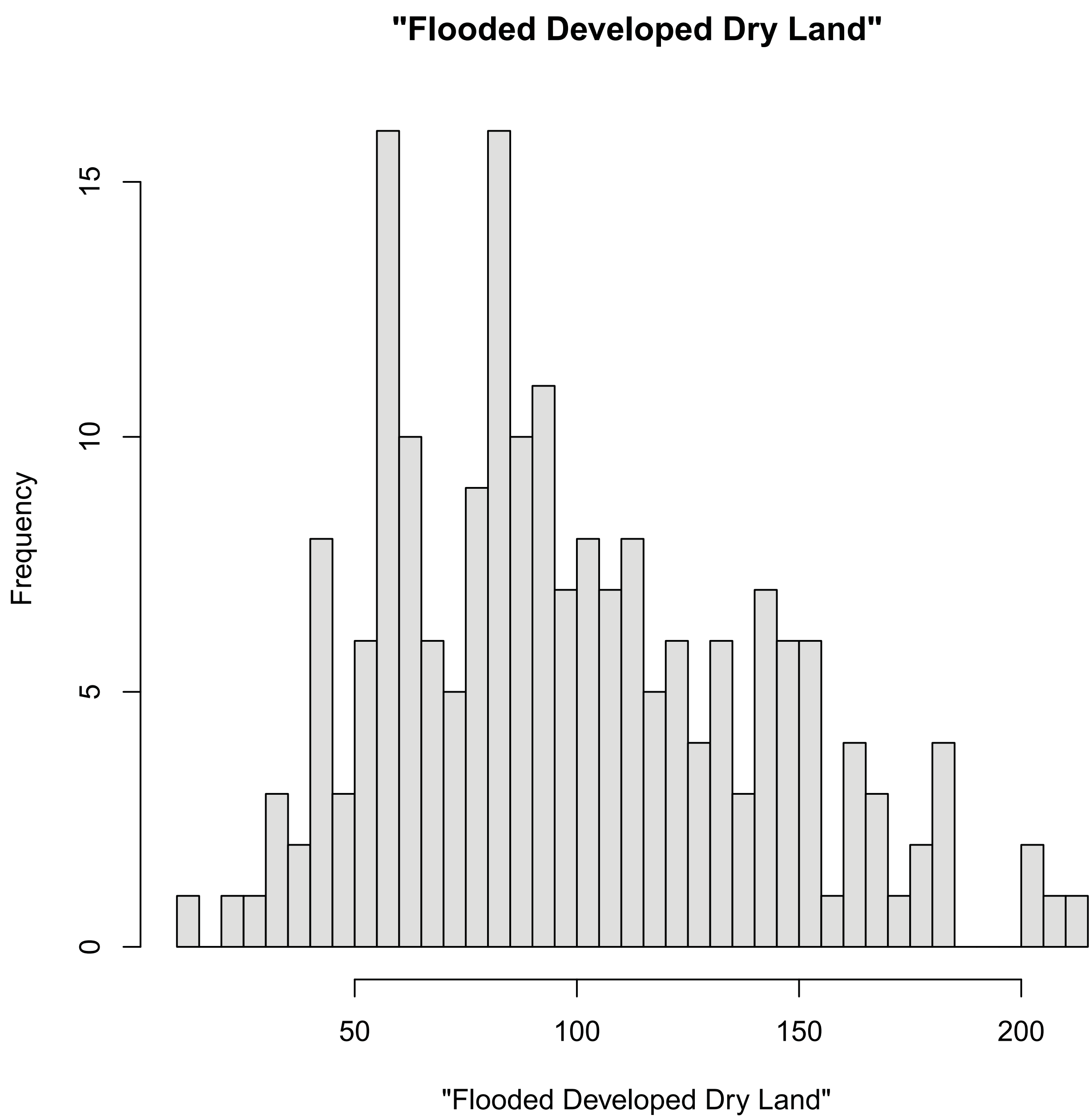

"Inland Open Water"
Frequency
0
10
20
30
40
50
60
245
250
255
260
"Inland Open Water"

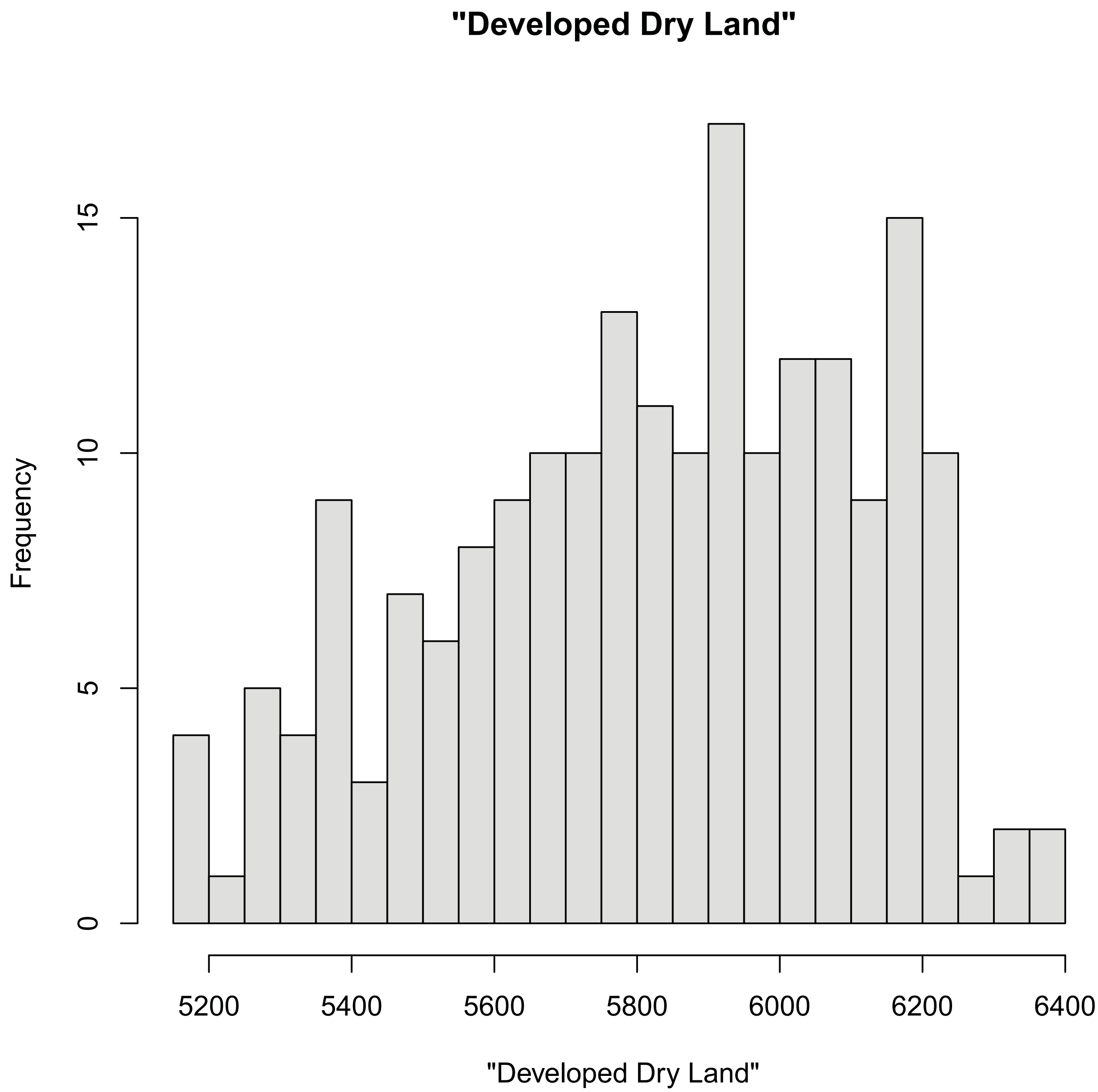

"Riverine Tidal"
Frequency
0
5
10
15
20
30
40
50
60
70
80
"Riverine Tidal"

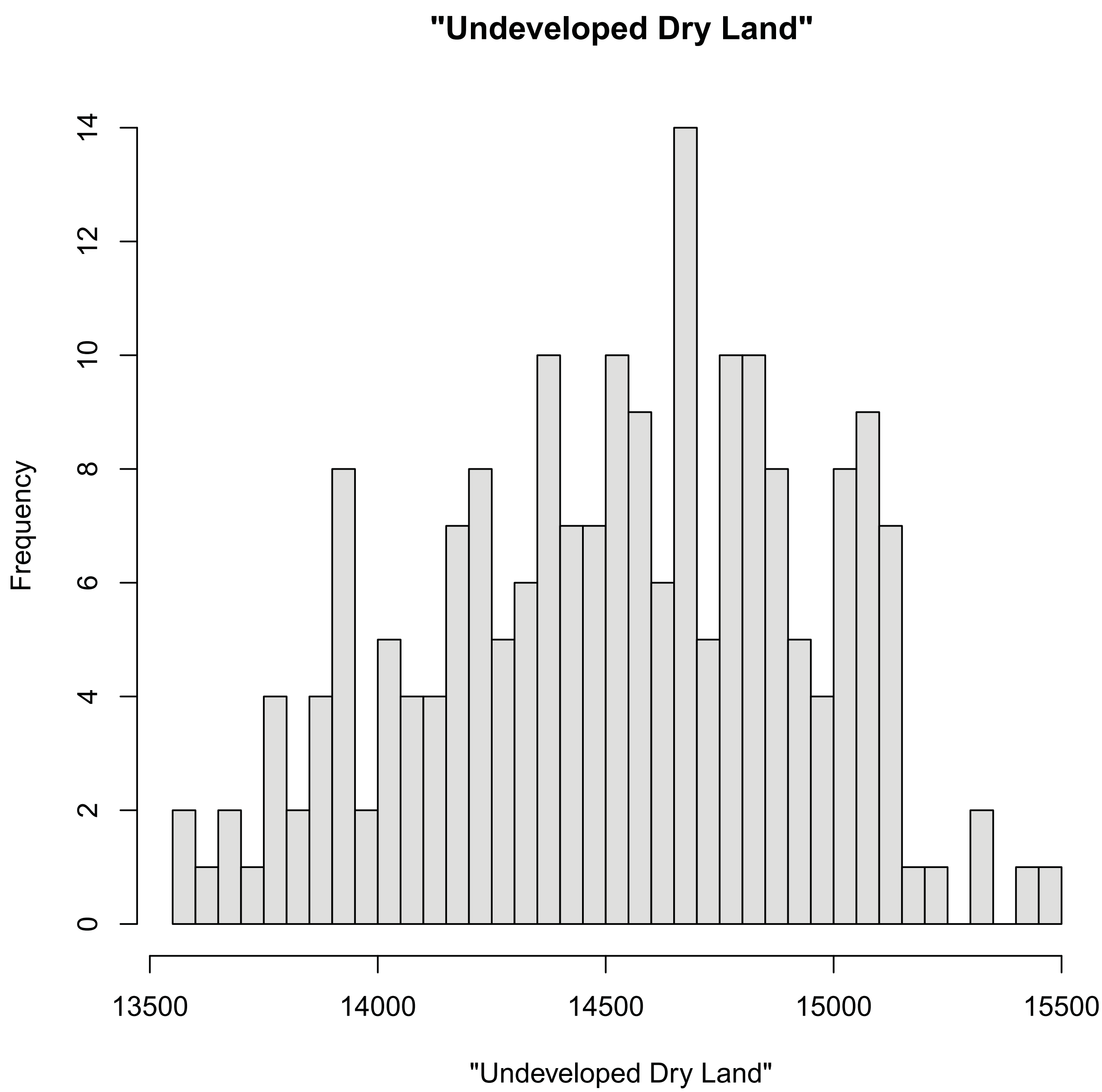

"Estuarine Open Water"
Frequency
0
5
10
15
20
25
30
7000
8000
9000
10000
"Estuarine Open Water"

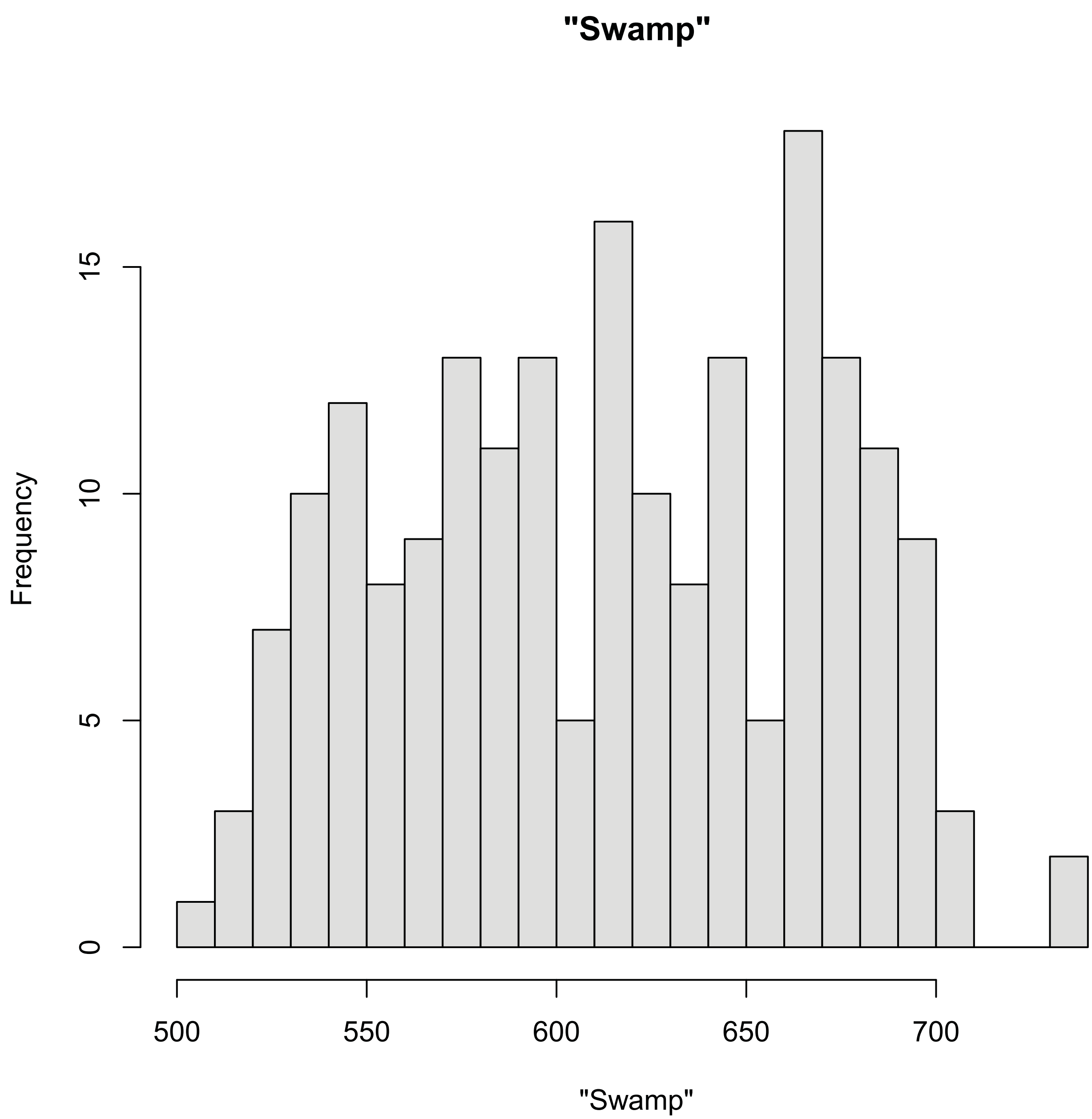

"Irreg.−Flooded Marsh"
Frequency
0
20
40
60
80
0
500
1000
1500
2000
"Irreg.−Flooded Marsh"

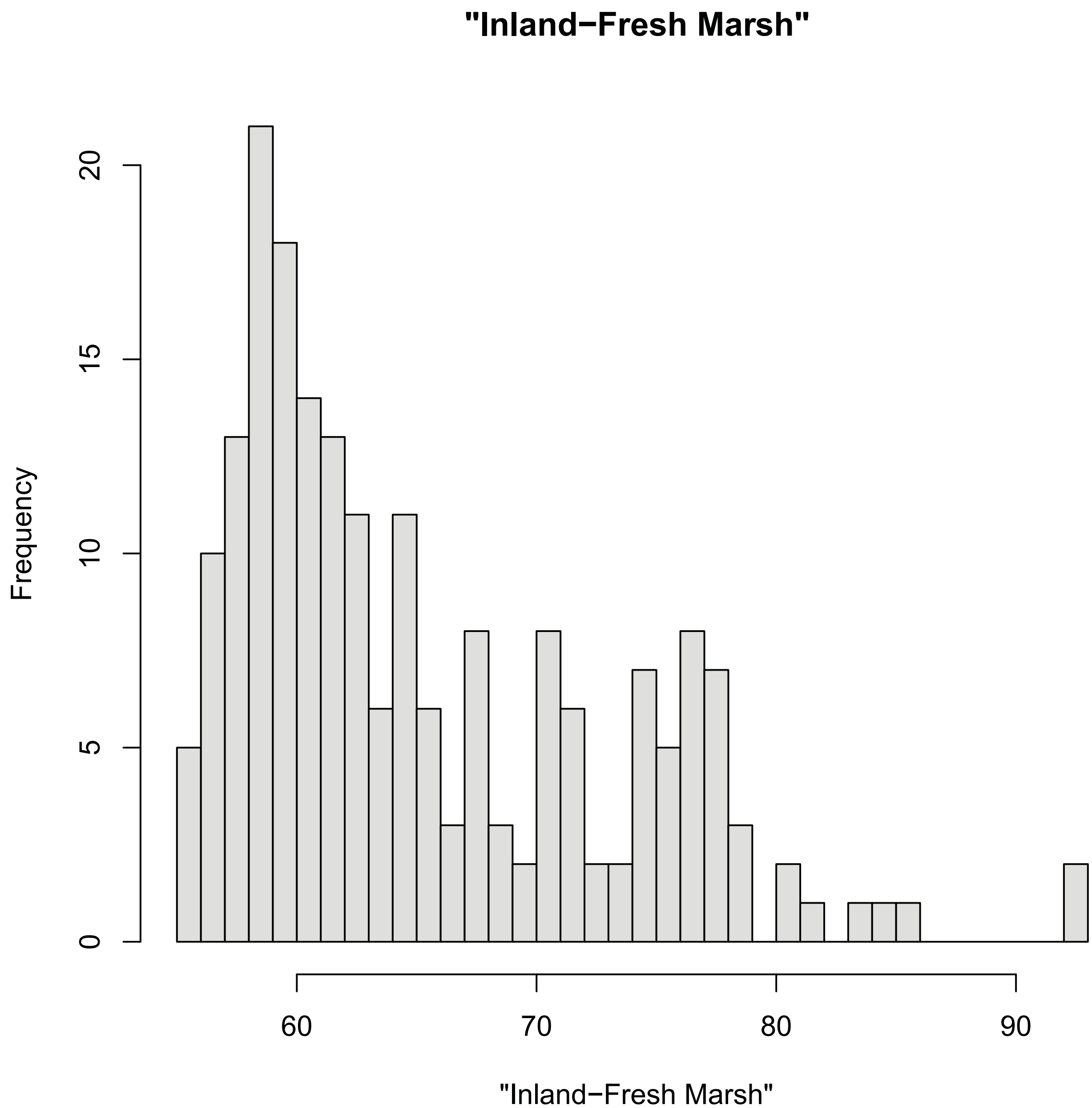

"Tidal Swamp"
Frequency
0
5
10
15
20
25
50
100
150
200
250
300
"Tidal Swamp"

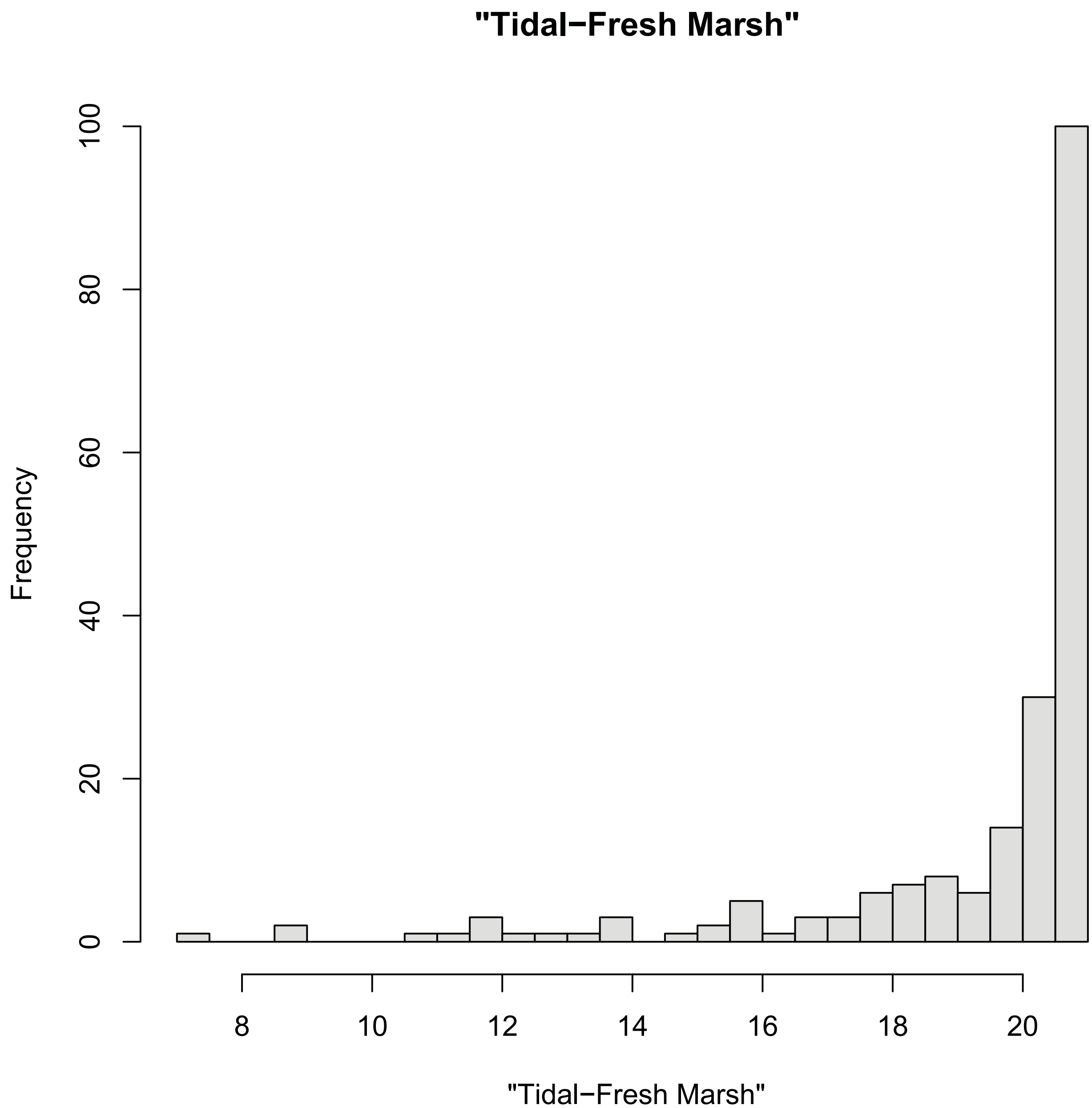

"Flooded Developed Dry Land"
Frequency
0
5
10
15
50
100
150
200
"Flooded Developed Dry Land"

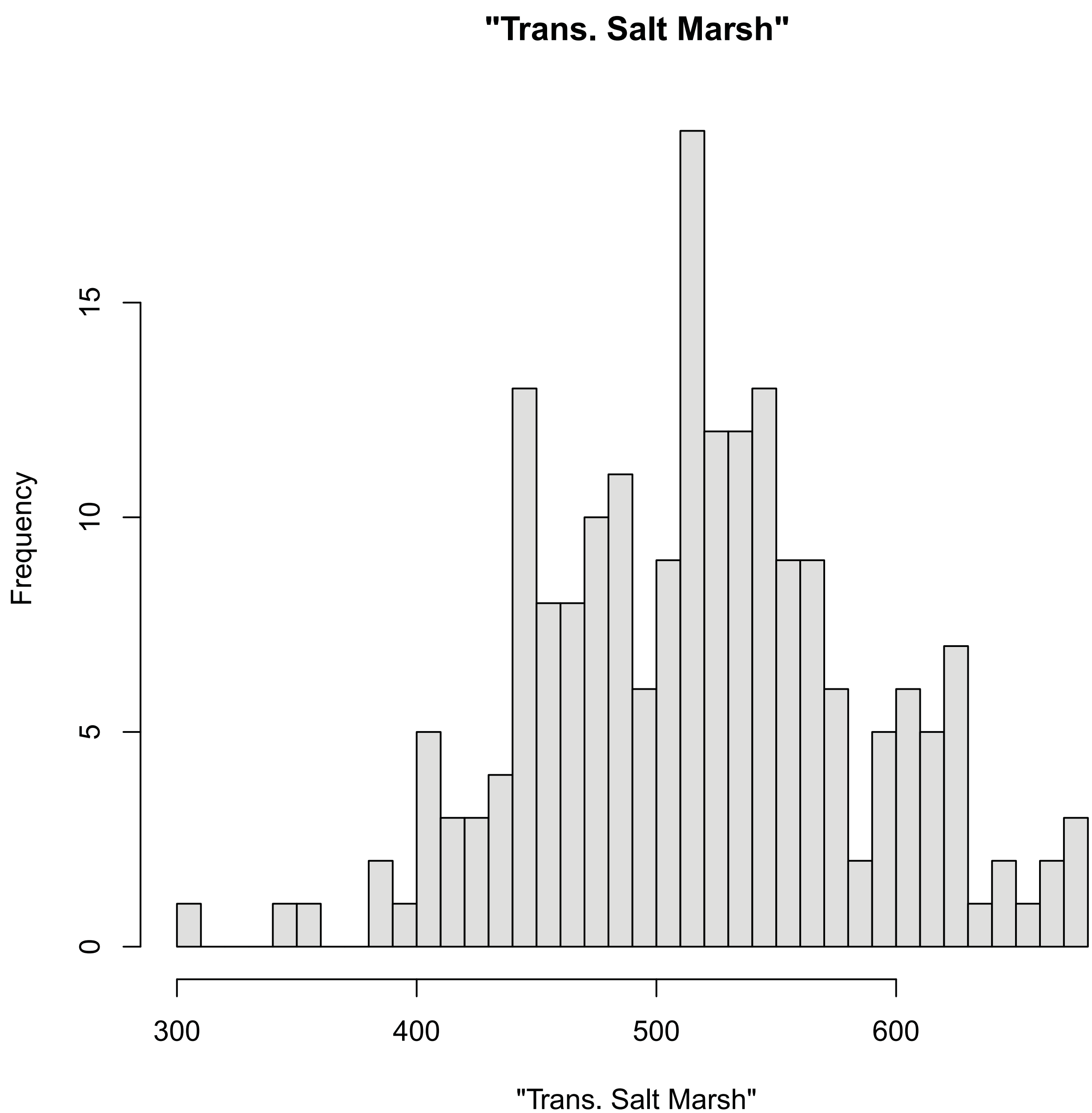

"Developed Dry Land"
Frequency
0
5
10
15
5200
5400
5600
5800
6000
6200
6400
"Developed Dry Land"

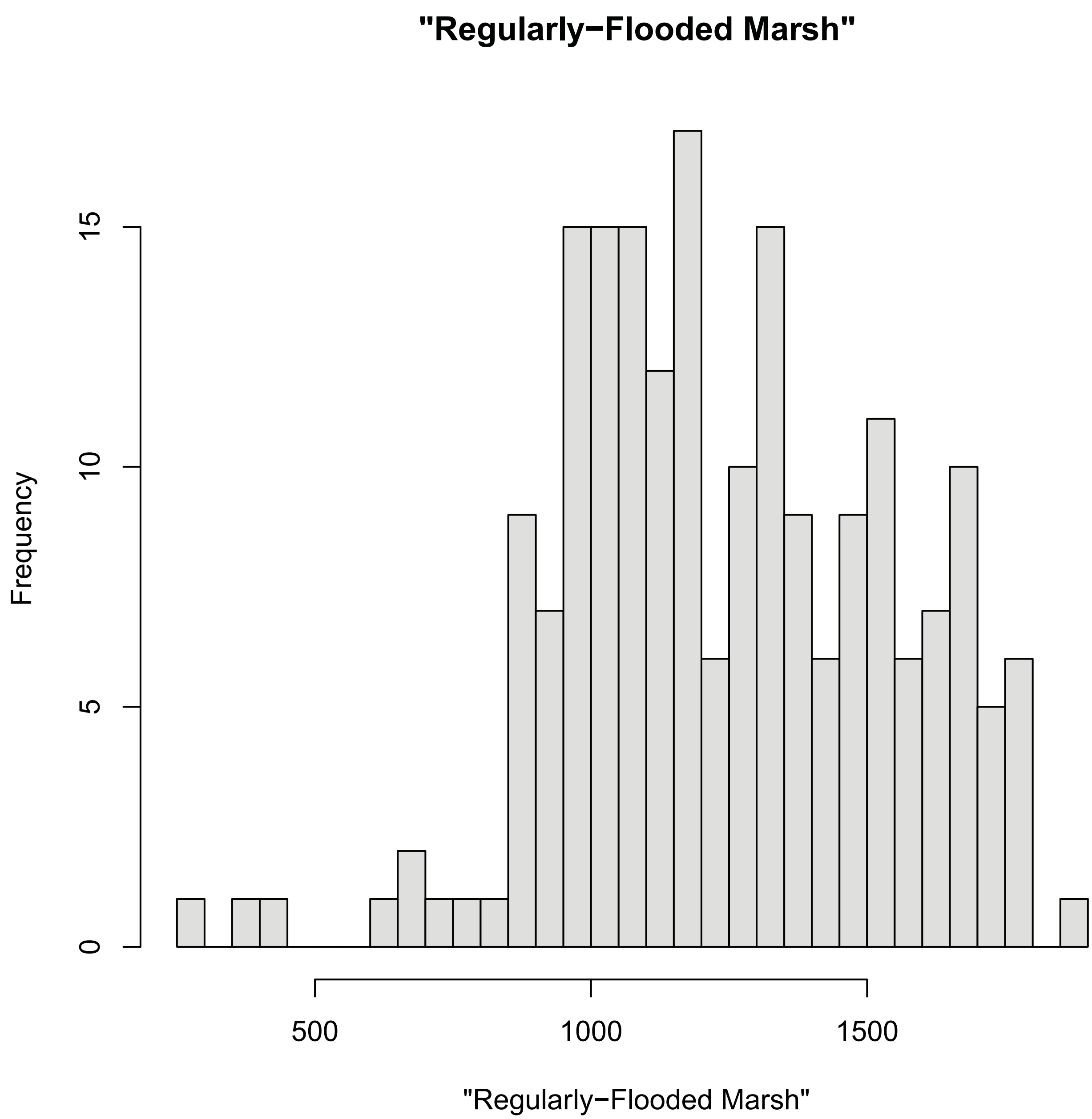

"Undeveloped Dry Land"
Frequency
0
2
4
6
8
10
12
14
13500
14000
14500
15000
15500
"Undeveloped Dry Land"

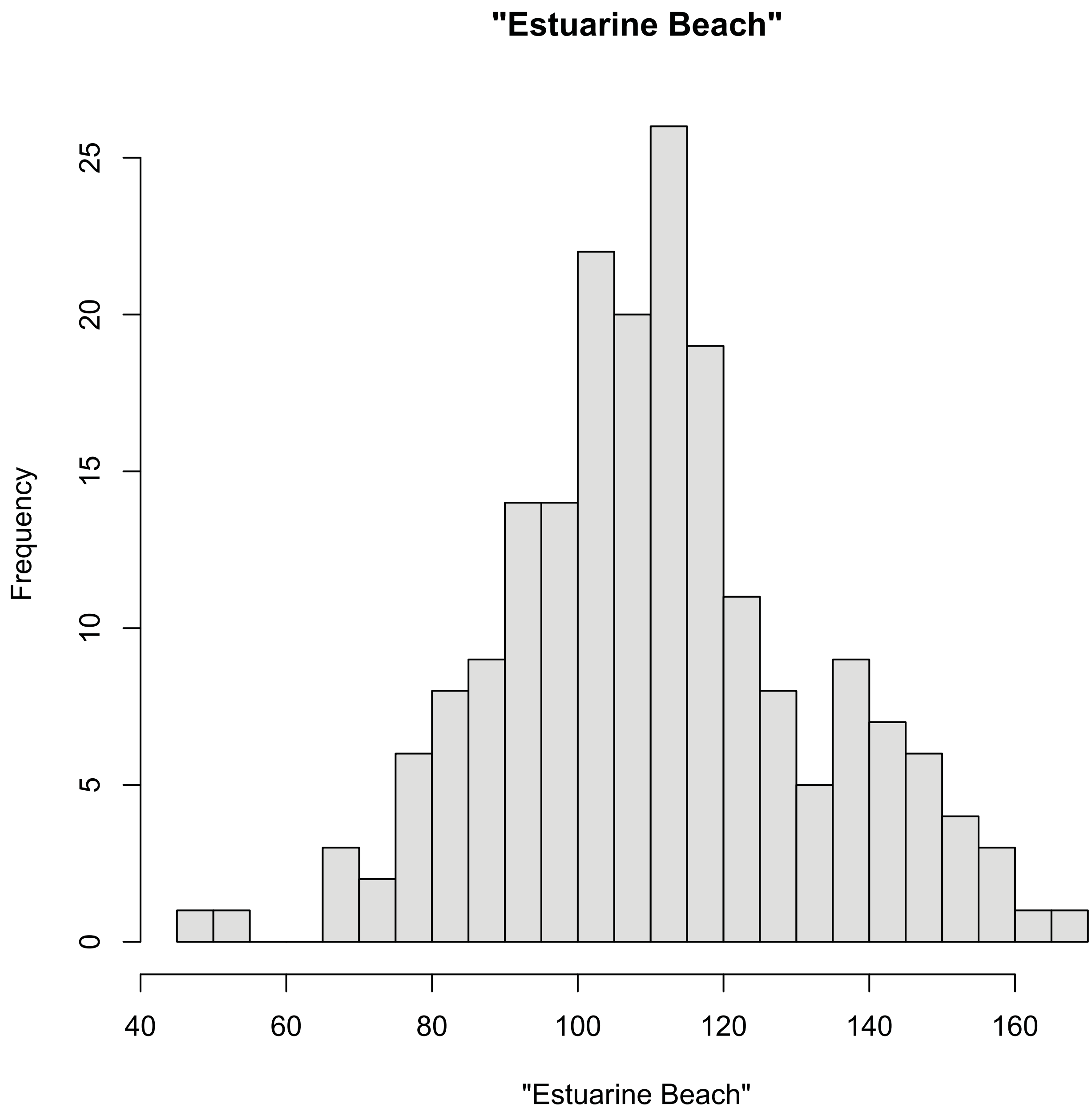

"Swamp"
Frequency
0
5
10
15
500
550
600
650
700
"Swamp"

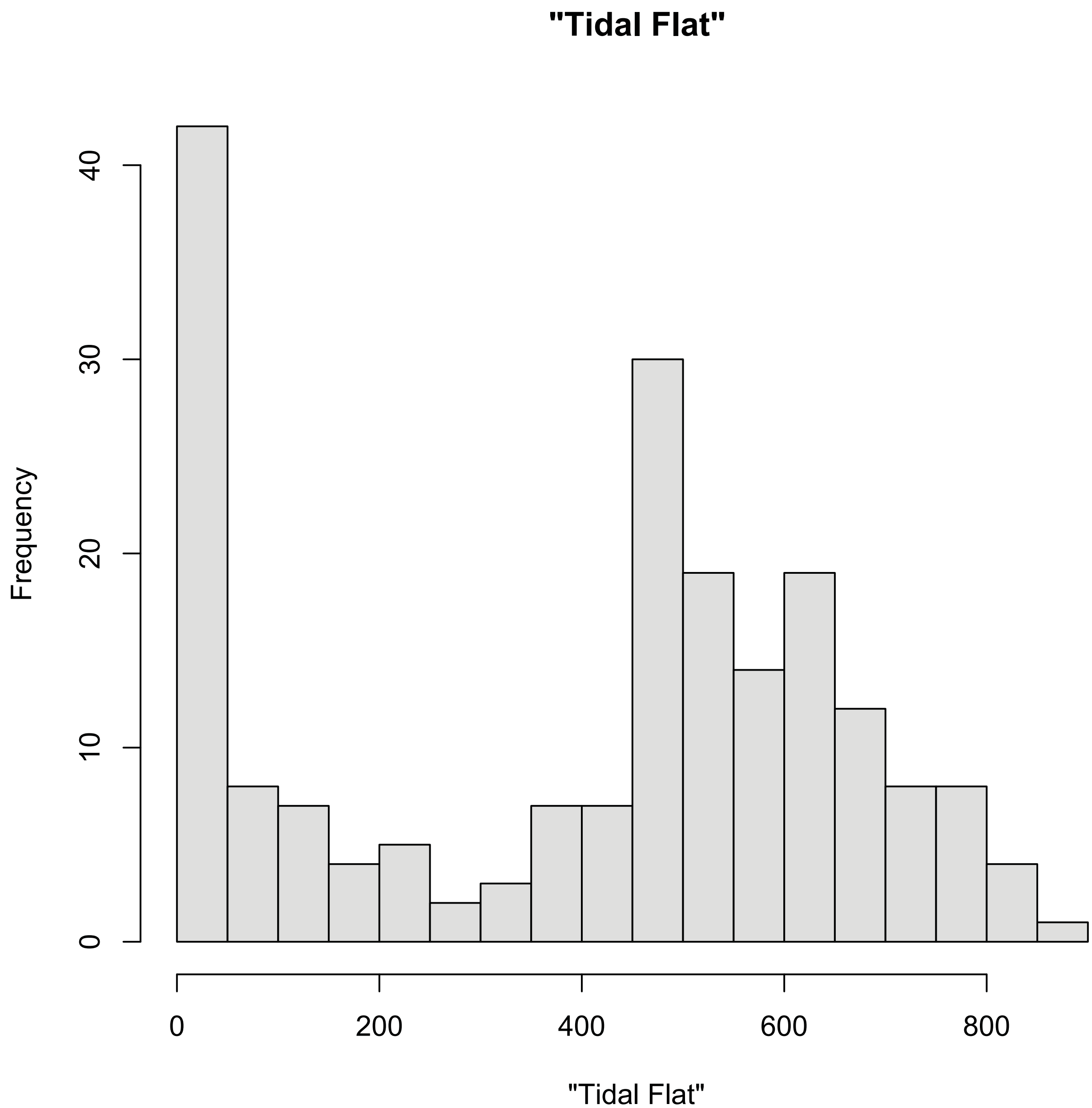

"Inland−Fresh Marsh"
Frequency
0
5
10
15
20
60
70
80
90
"Inland−Fresh Marsh"

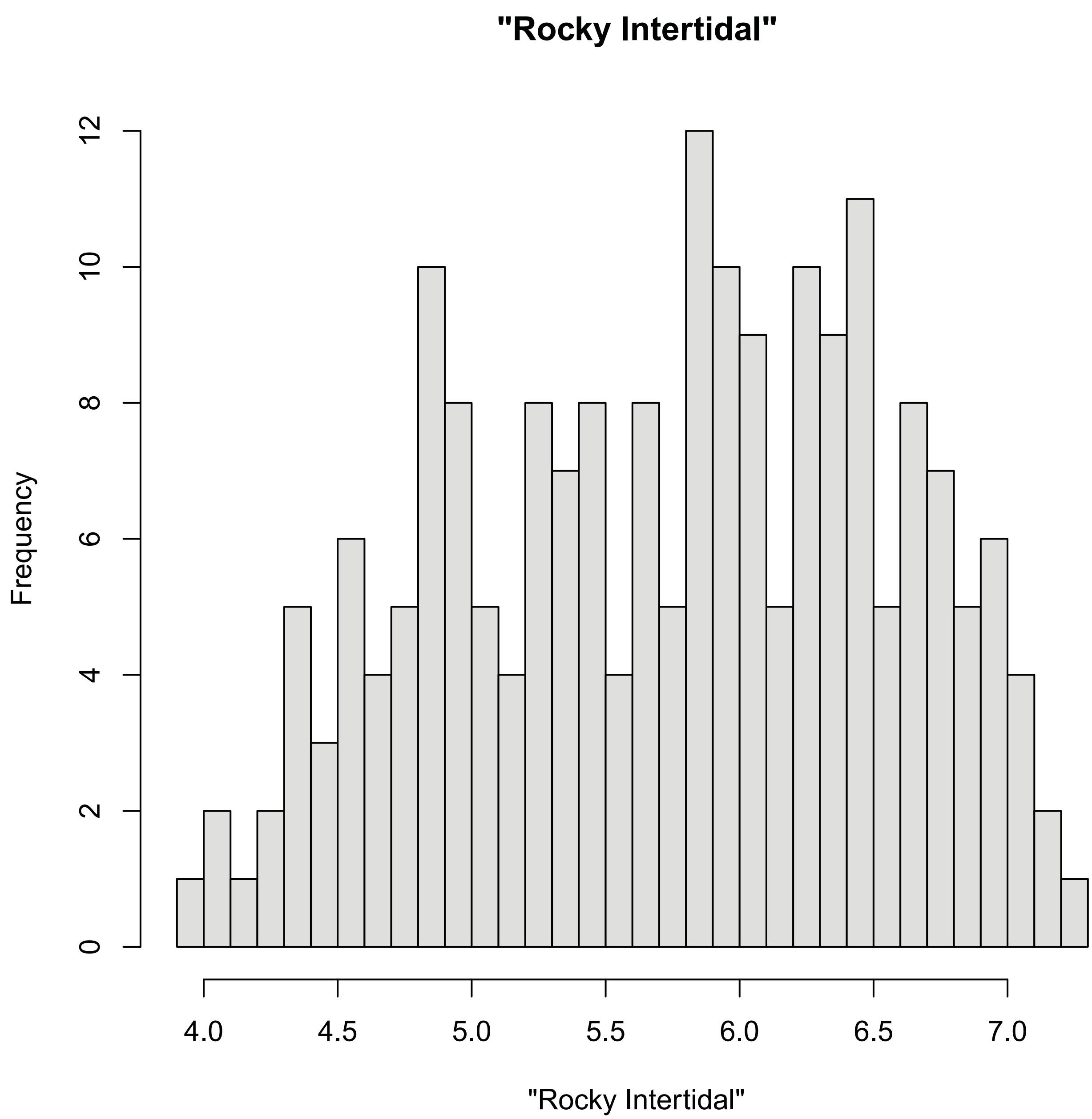

"Tidal−Fresh Marsh"
Frequency
0
20
40
60
80
100
8
10
12
14
16
18
20
"Tidal−Fresh Marsh"

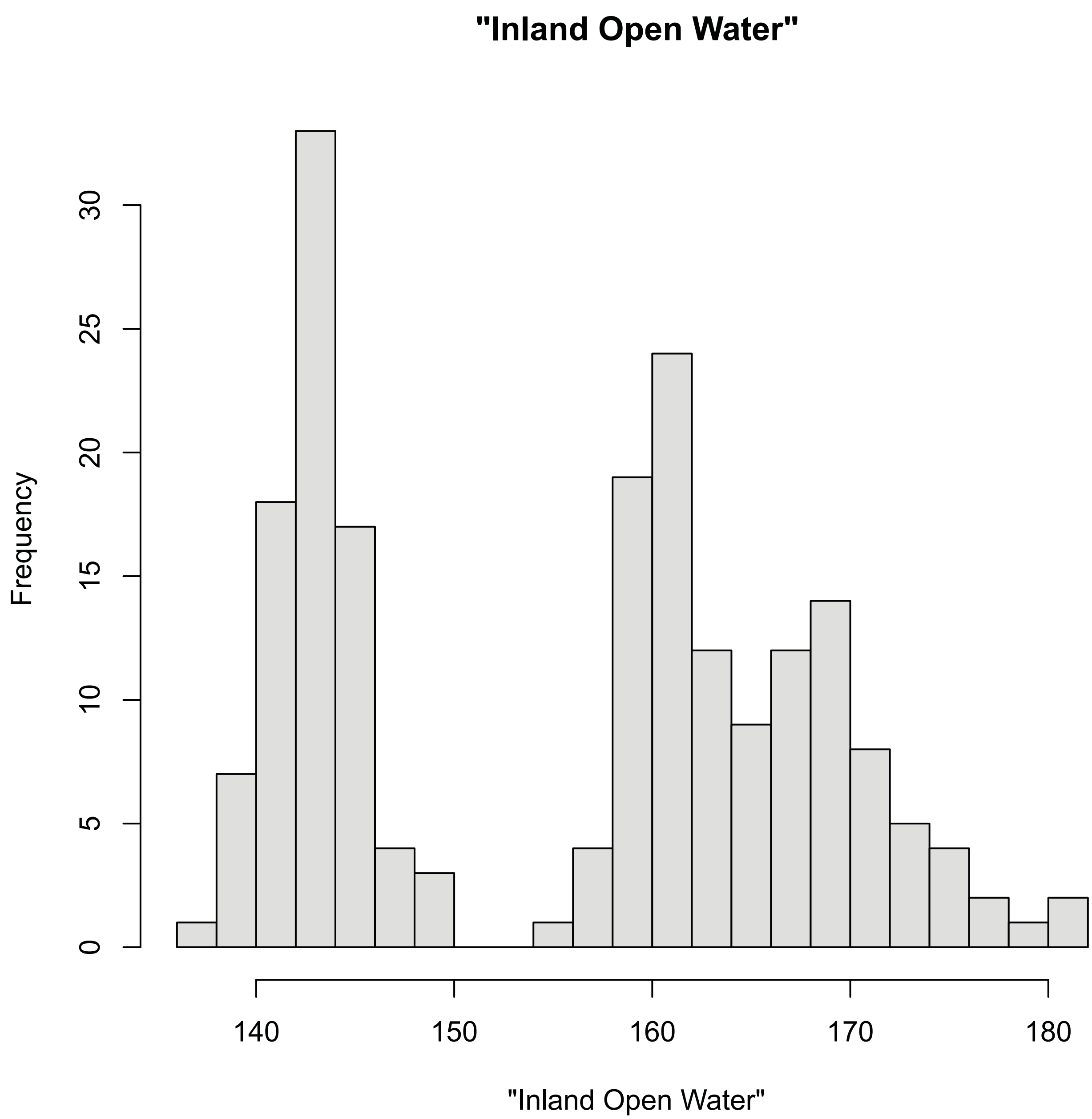

"Trans. Salt Marsh"
Frequency
0
5
10
15
300
400
500
600
"Trans. Salt Marsh"

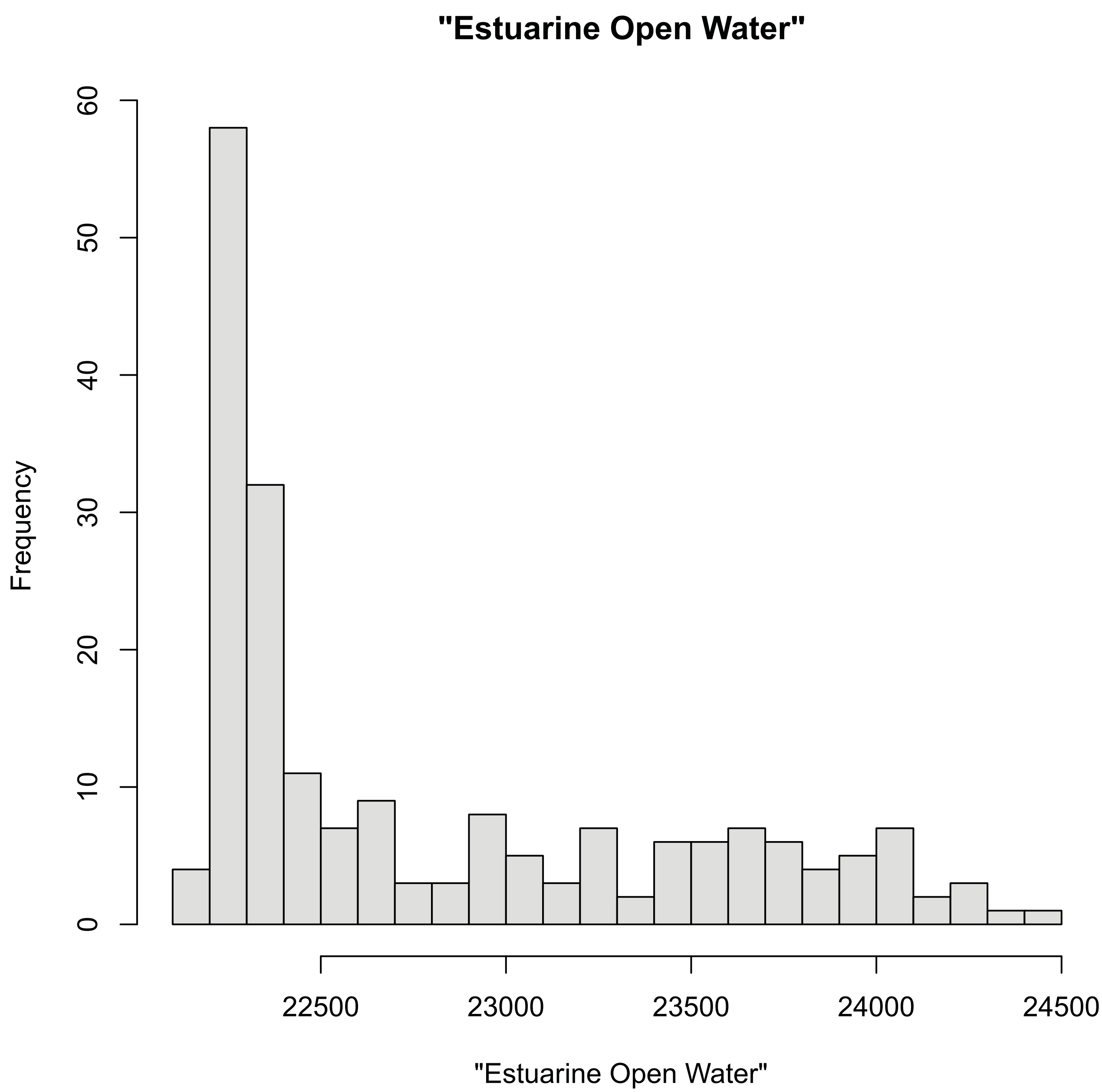

"Regularly−Flooded Marsh"
Frequency
0
5
10
15
500
1000
1500
"Regularly−Flooded Marsh"

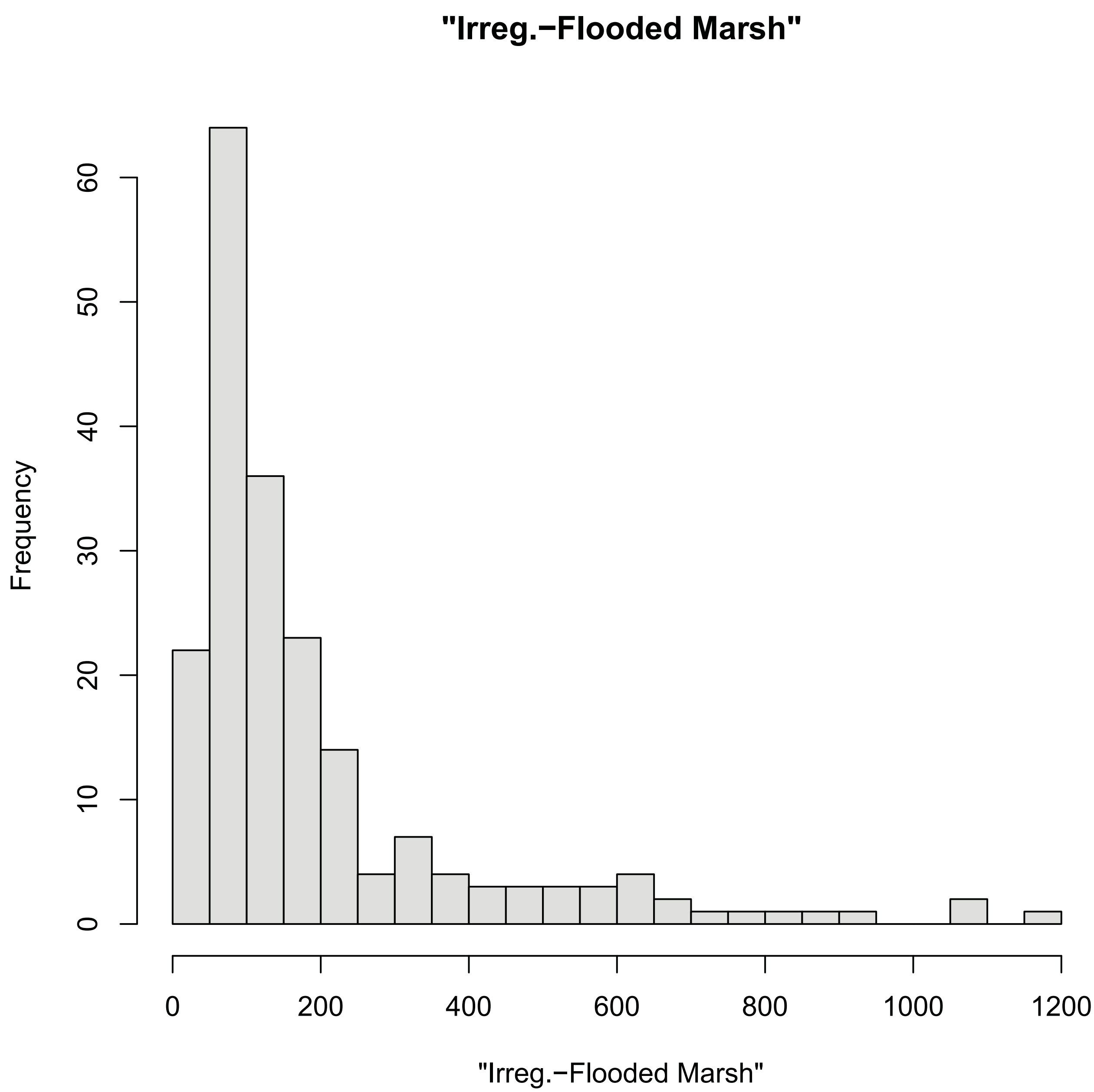

"Estuarine Beach"
Frequency
0
5
10
15
20
25
40
60
80
100
120
140
160
"Estuarine Beach"

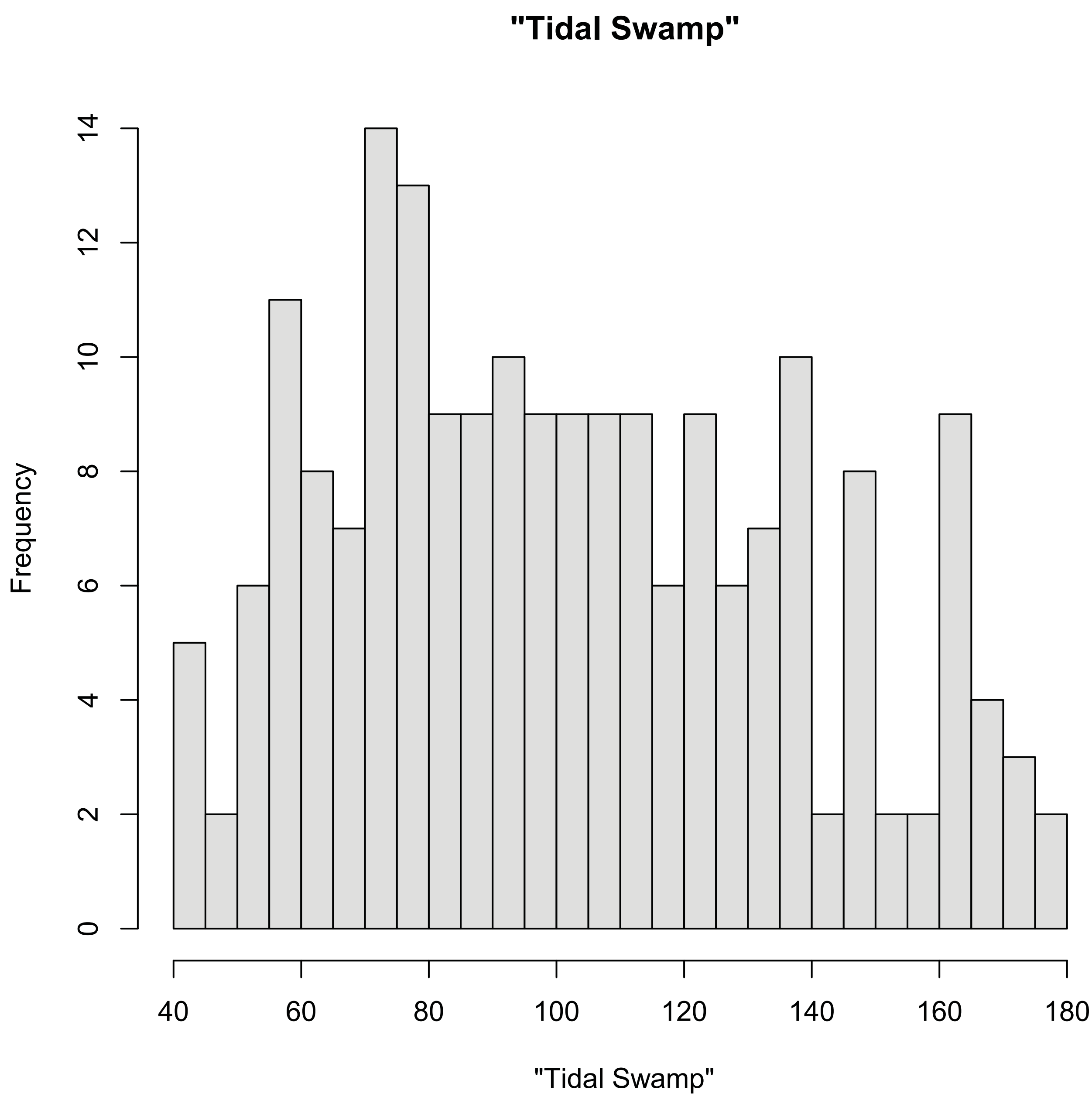

"Tidal Flat"
Frequency
0
10
20
30
40
0
200
400
600
800
"Tidal Flat"

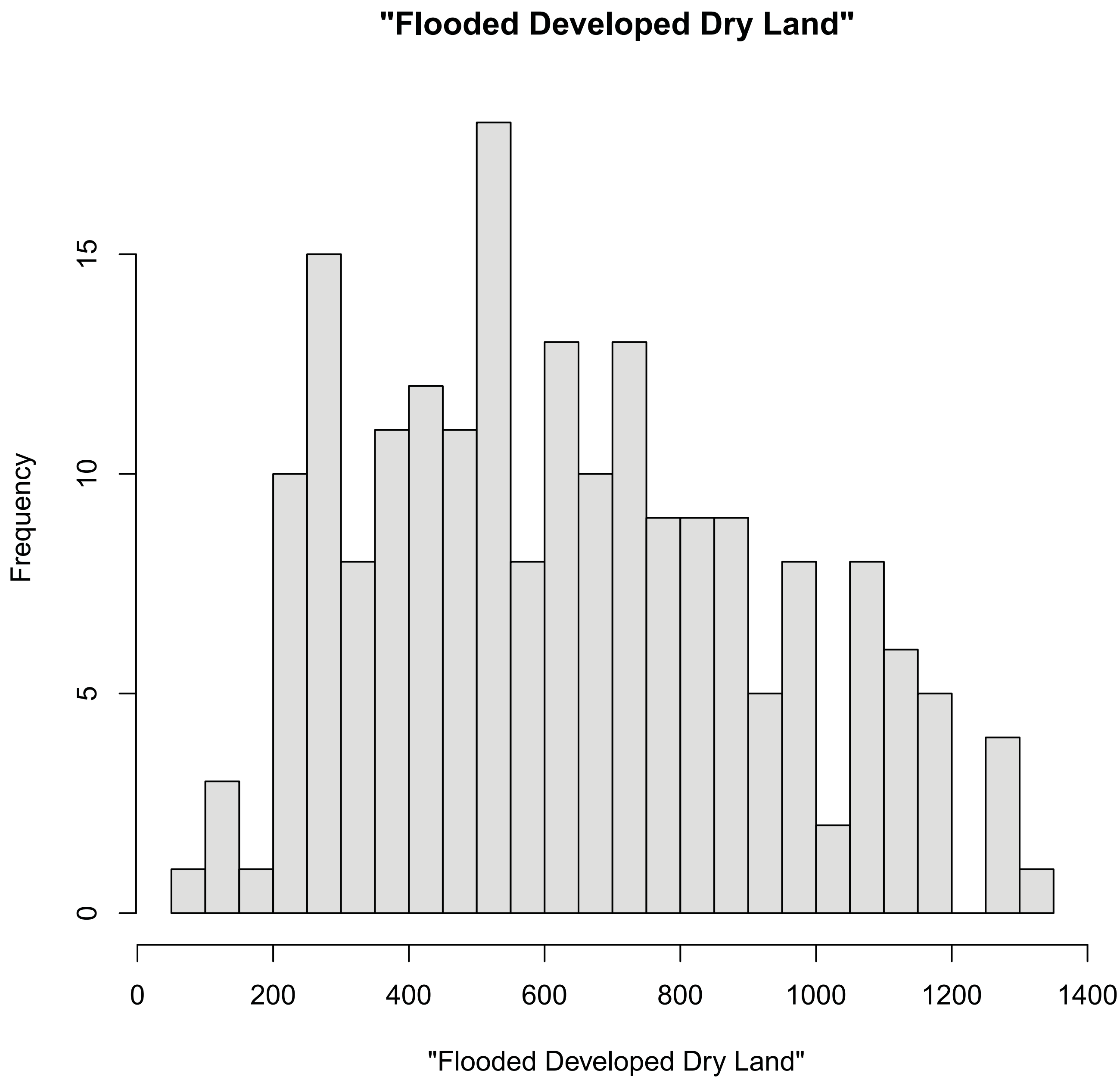

"Rocky Intertidal"
Frequency
0
2
4
6
8
10
12
4.0
4.5
5.0
5.5
6.0
6.5
7.0
"Rocky Intertidal"

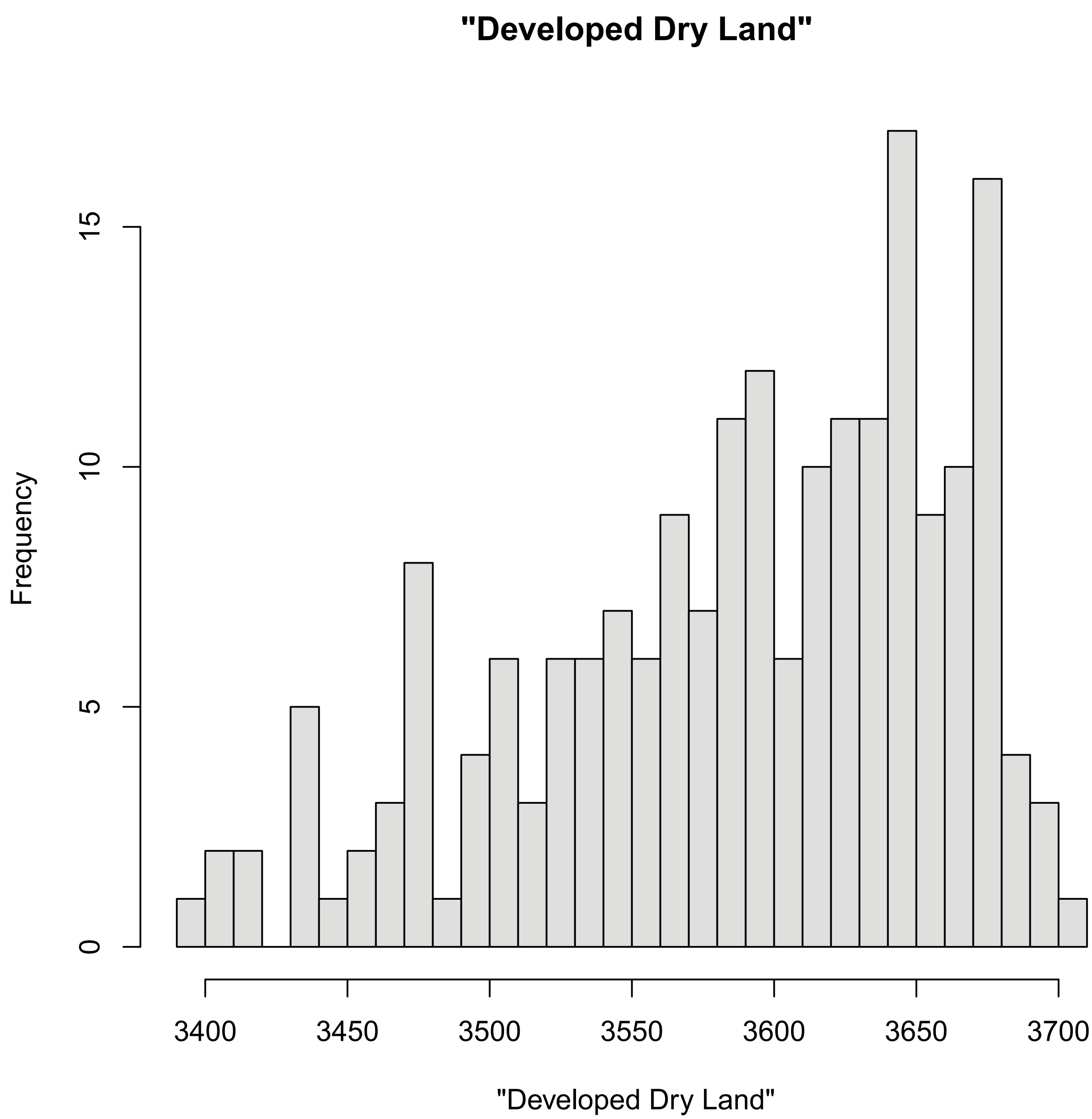

"Inland Open Water"
Frequency
0
5
10
15
20
25
30
140
150
160
170
180
"Inland Open Water"

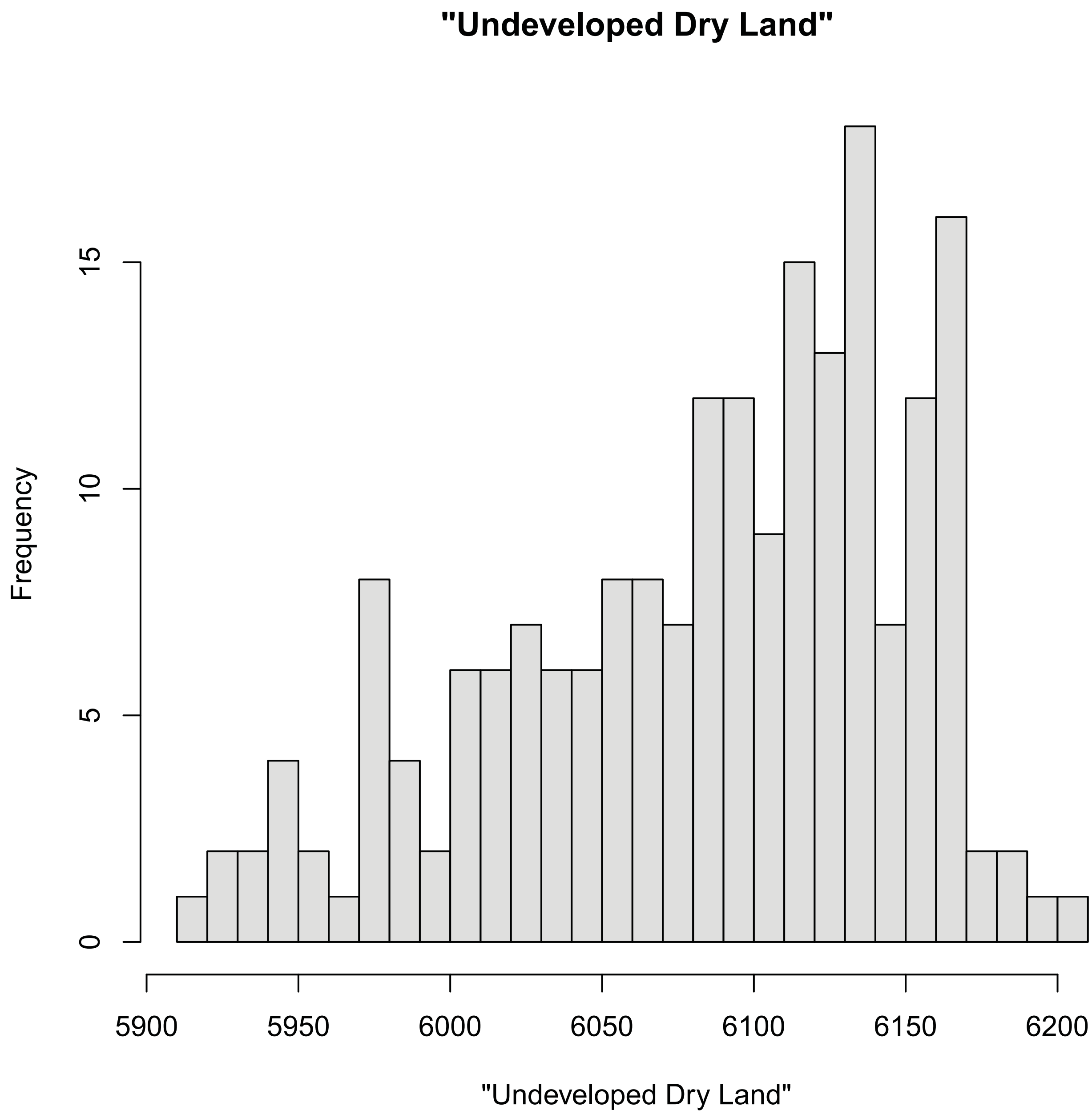

"Estuarine Open Water"
Frequency
0
10
20
30
40
50
60
22500
23000
23500
24000
24500
"Estuarine Open Water"

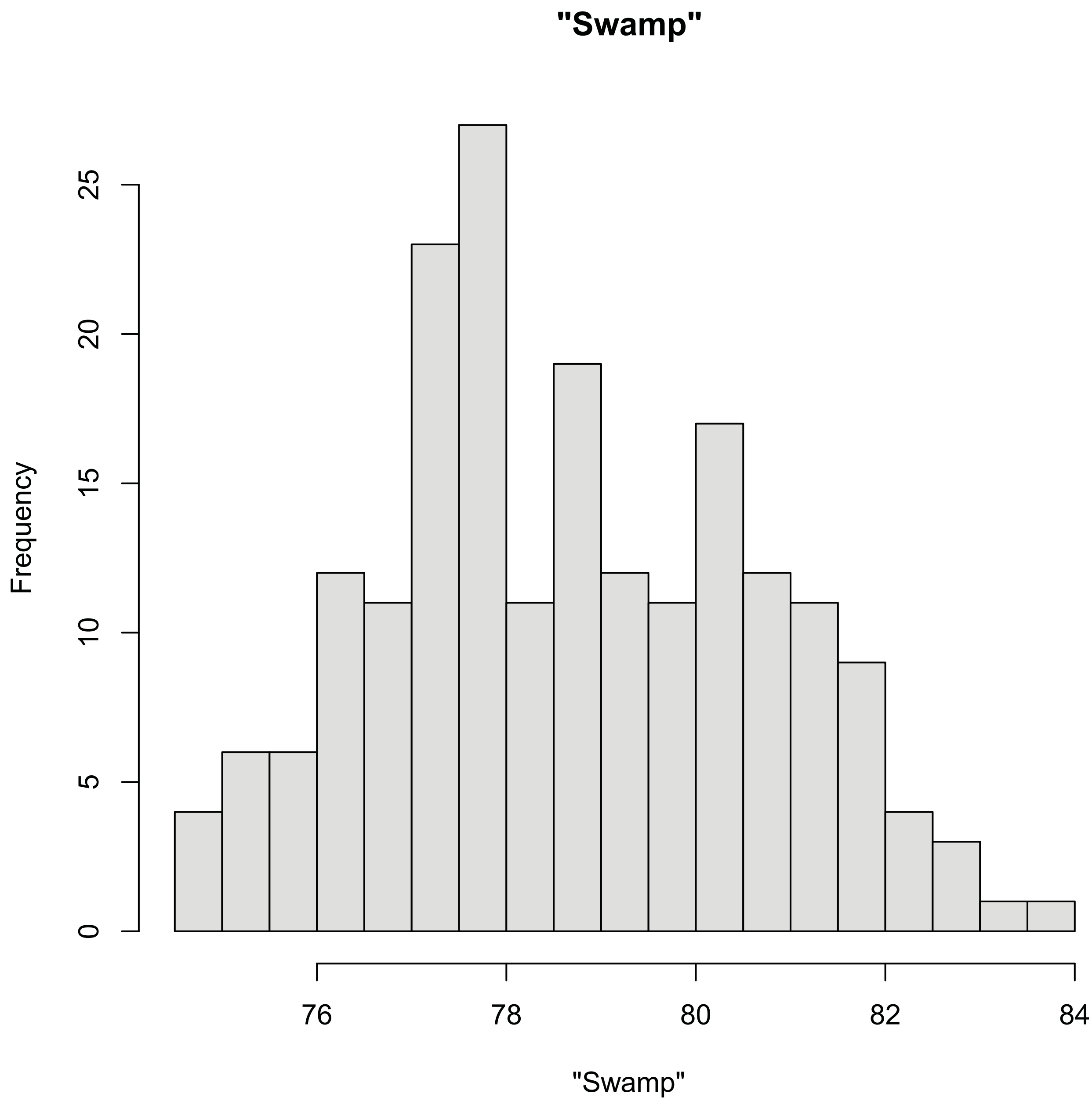

"Irreg.−Flooded Marsh"
Frequency
0
10
20
30
40
50
60
0
200
400
600
800
1000
1200
"Irreg.−Flooded Marsh"

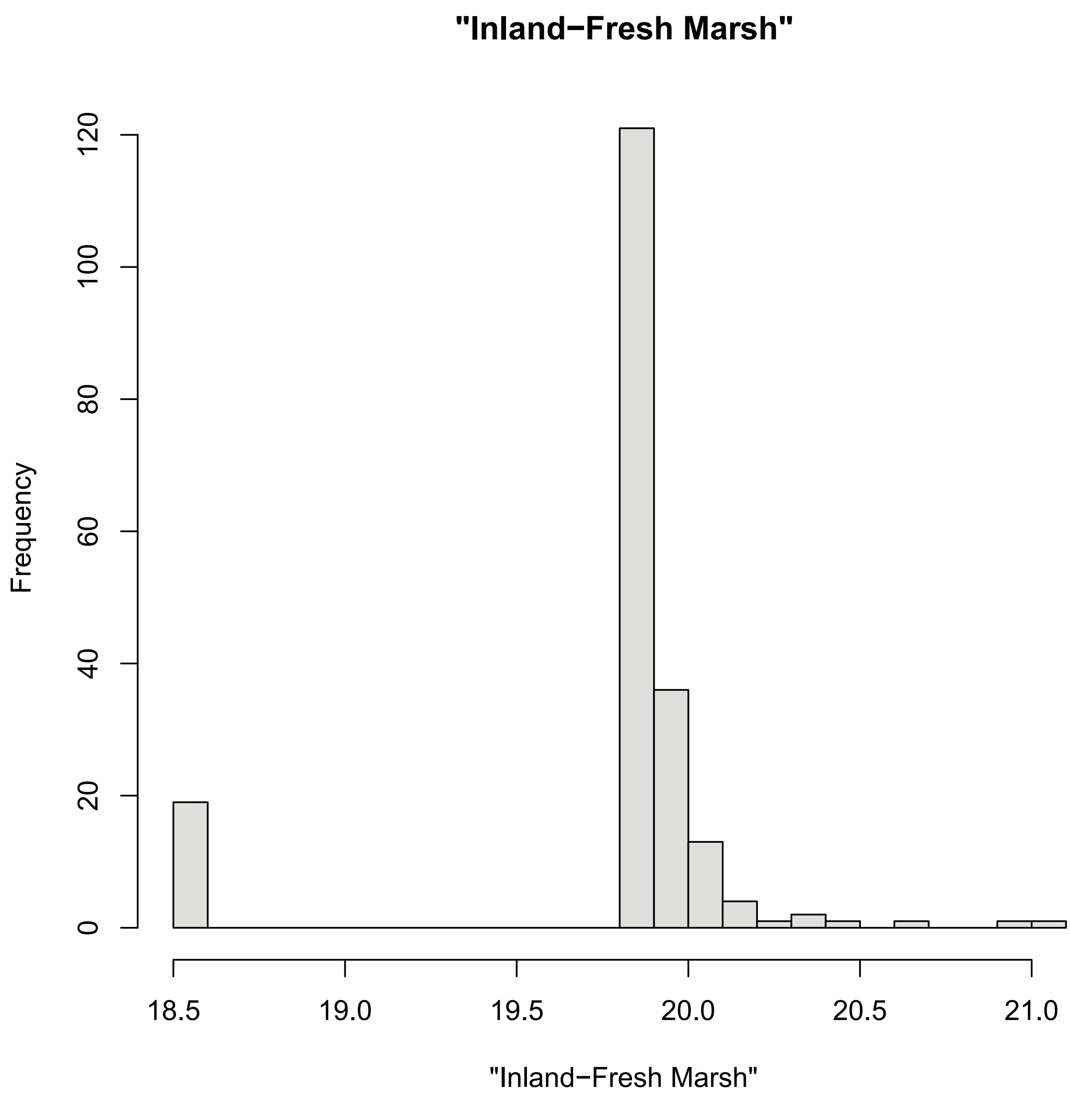

"Tidal Swamp"
Frequency
0
2
4
6
8
10
12
14
40
60
80
100
120
140
160
180
"Tidal Swamp"

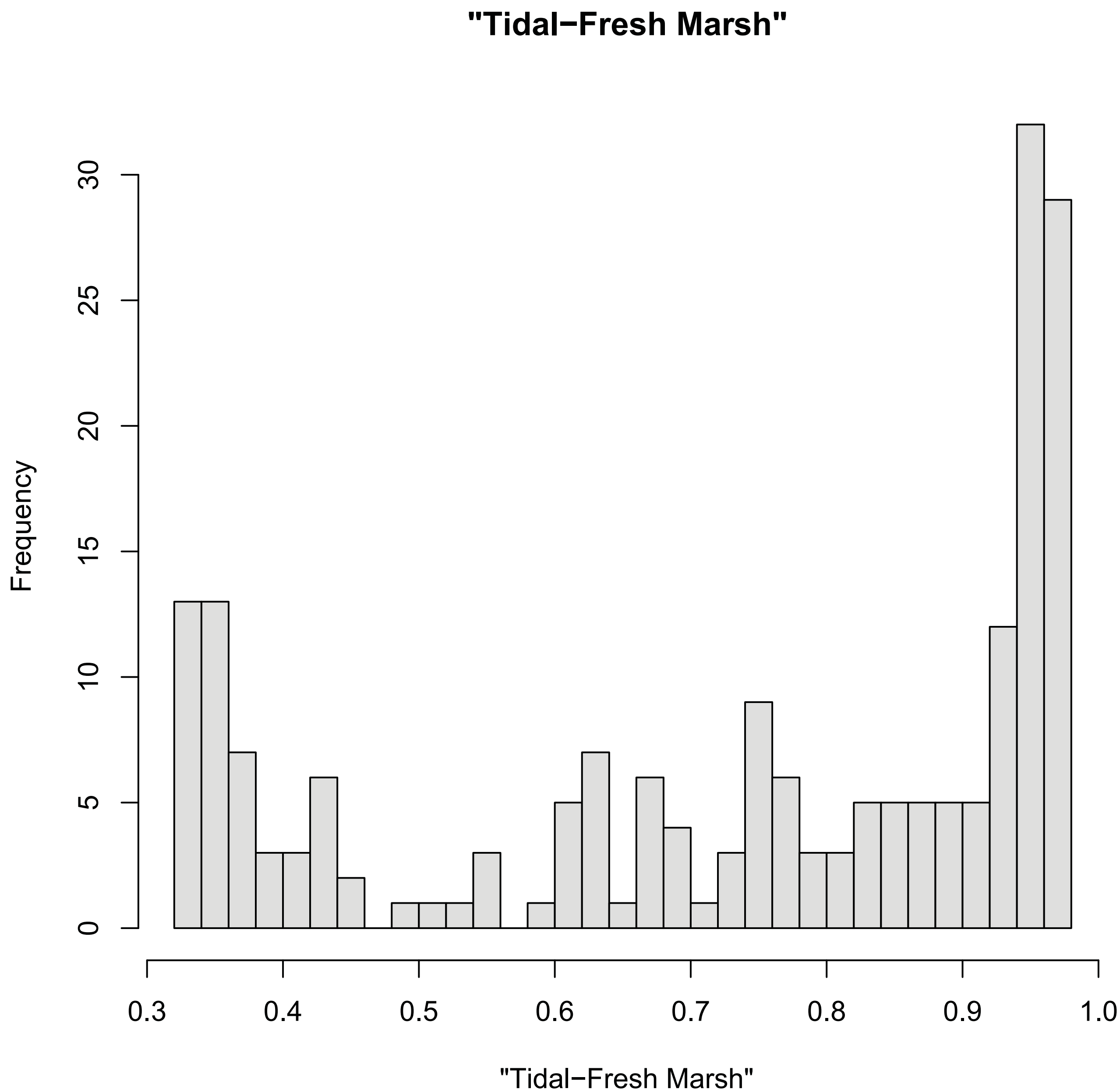

"Flooded Developed Dry Land"
Frequency
0
5
10
15
0
200
400
600
800
1000
1200
1400
"Flooded Developed Dry Land"

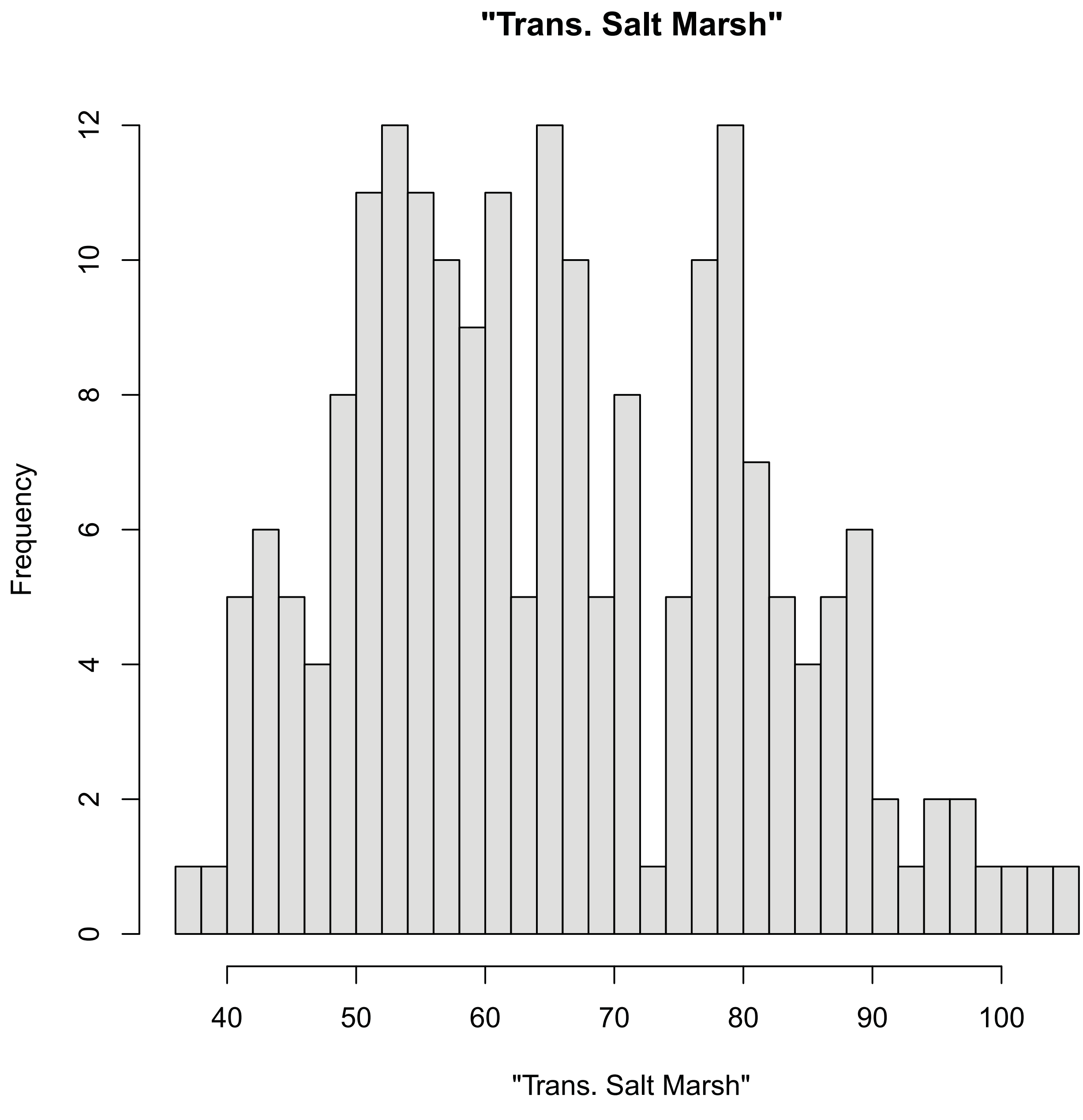

"Developed Dry Land"
Frequency
0
5
10
15
3400
3450
3500
3550
3600
3650
3700
"Developed Dry Land"

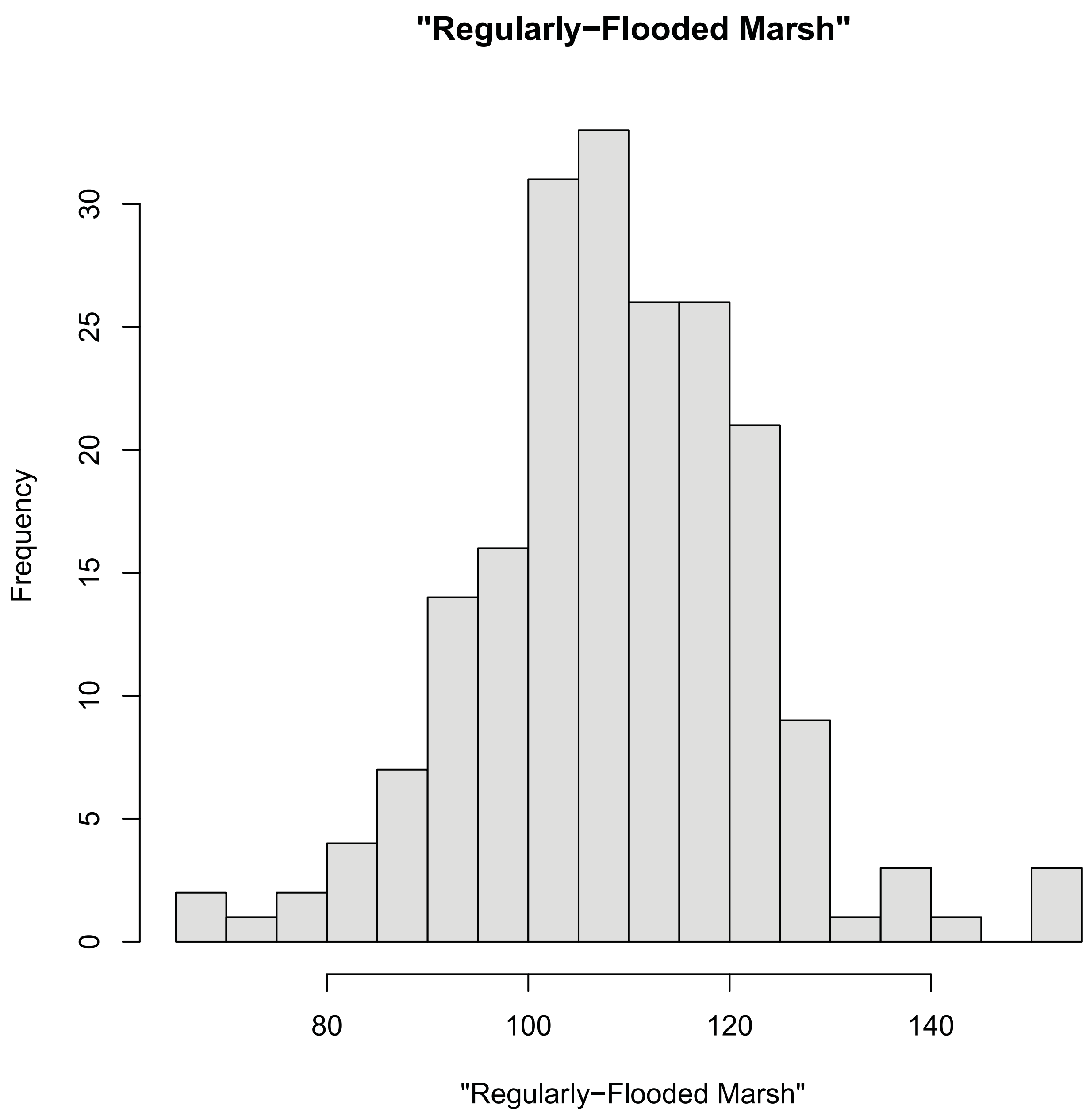

"Undeveloped Dry Land"
Frequency
0
5
10
15
5900
5950
6000
6050
6100
6150
6200
"Undeveloped Dry Land"

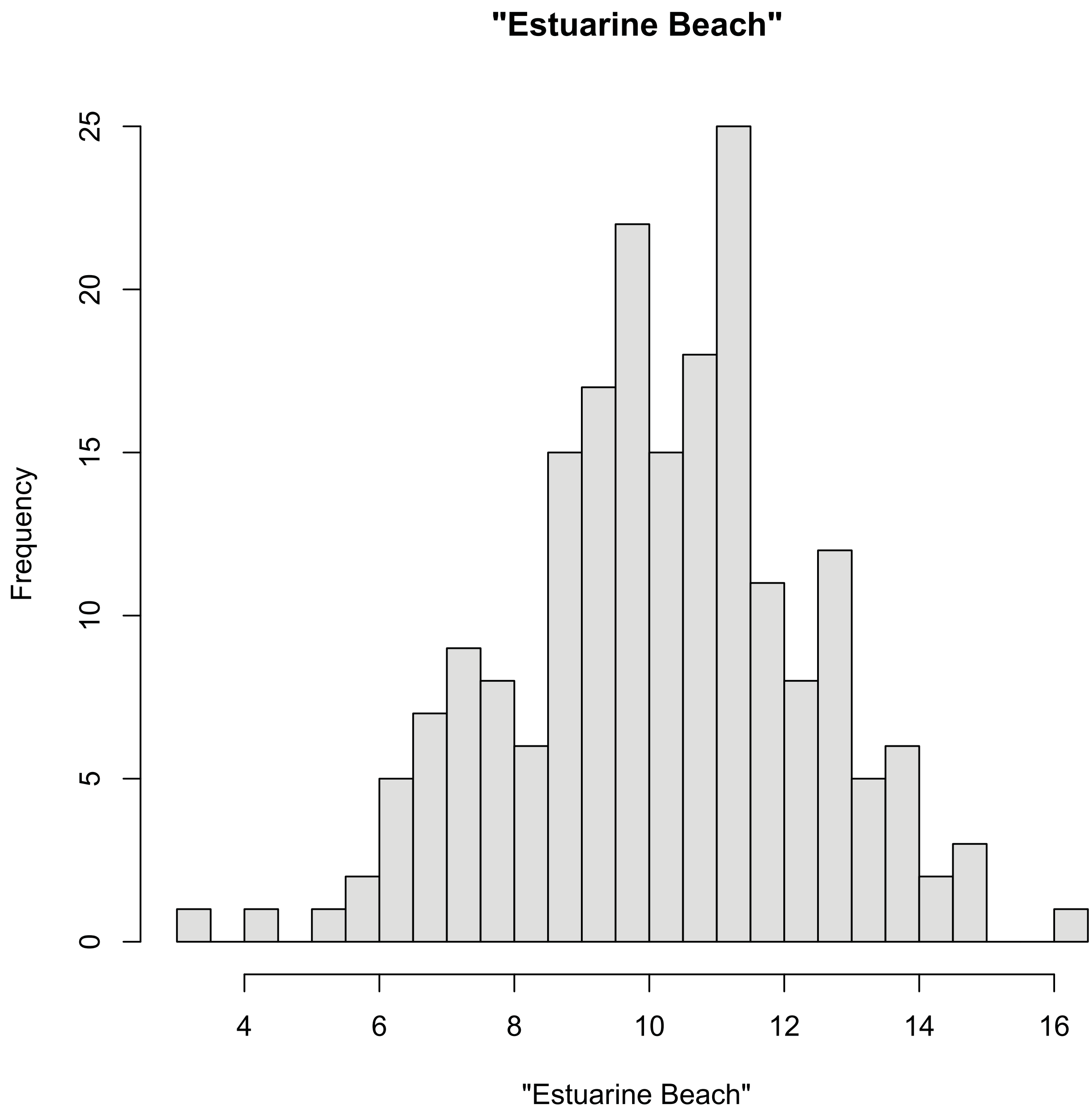

"Swamp"
Frequency
0
5
10
15
20
25
76
78
80
82
84
"Swamp"

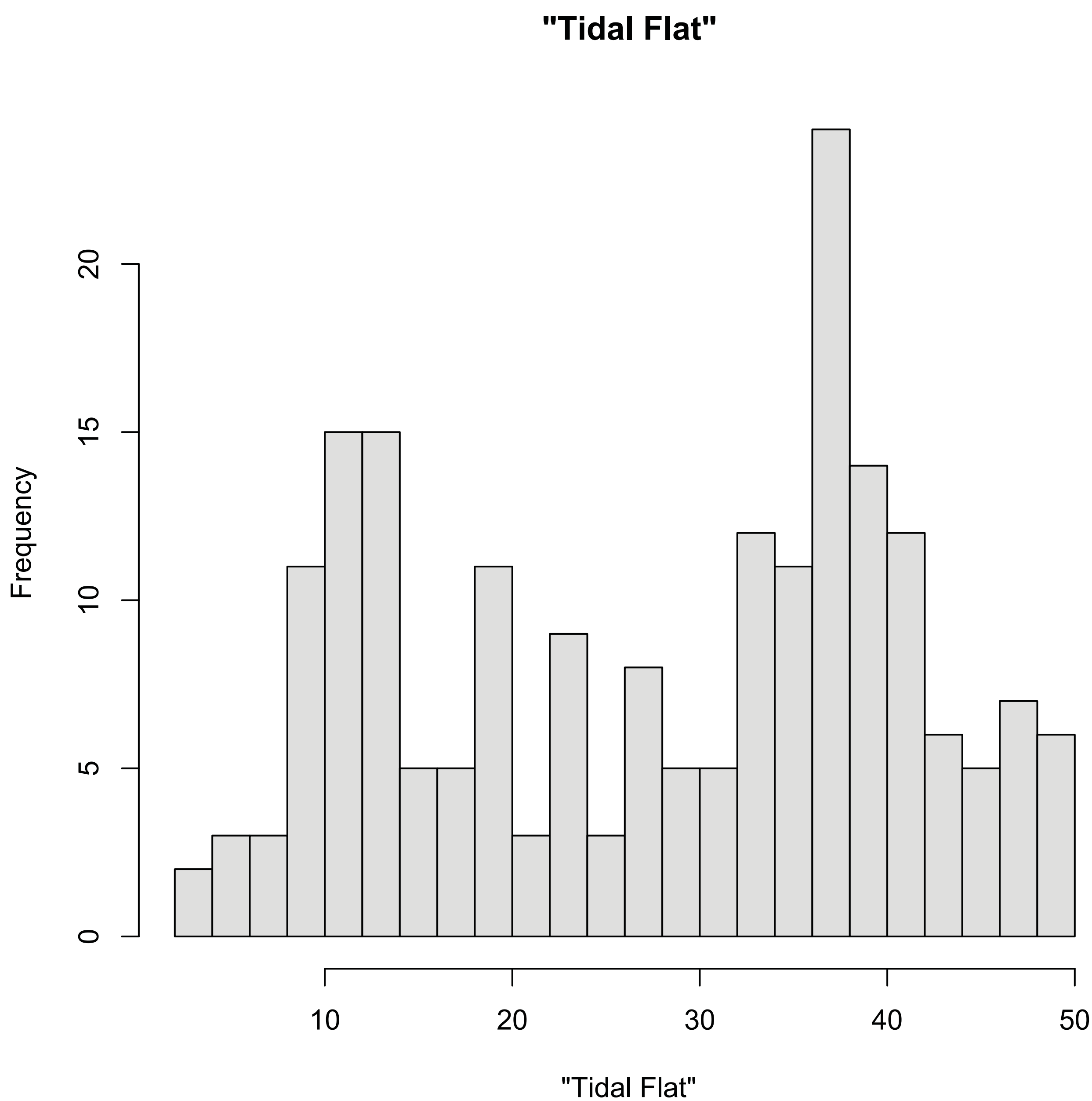

"Inland−Fresh Marsh"
Frequency
0
20
40
60
80
100
120
18.5
19.0
19.5
20.0
20.5
21.0
"Inland−Fresh Marsh"

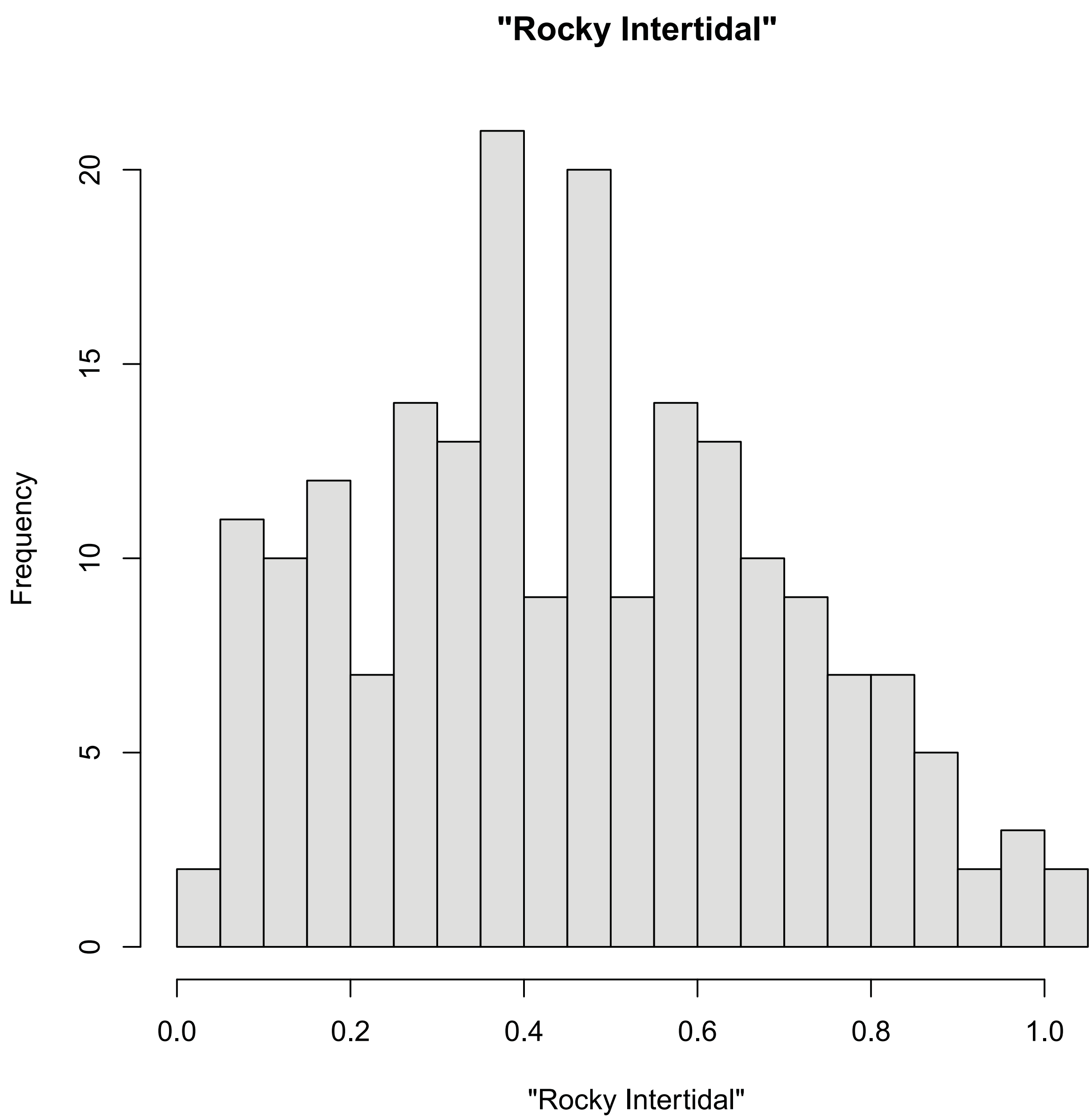

"Tidal−Fresh Marsh"
Frequency
0
5
10
15
20
25
30
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
"Tidal−Fresh Marsh"

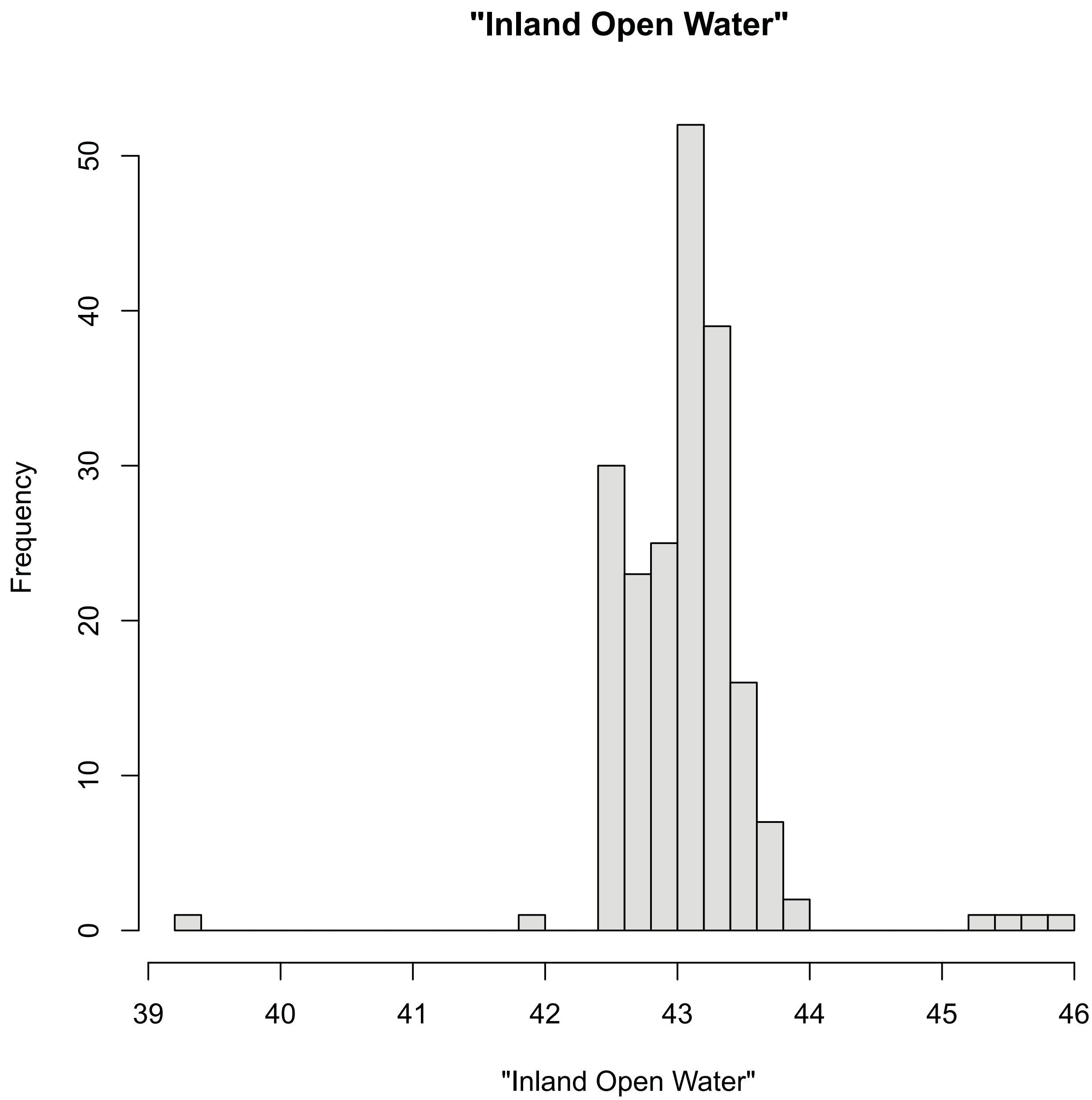

"Trans. Salt Marsh"
Frequency
0
2
4
6
8
10
12
40
50
60
70
80
90
100
"Trans. Salt Marsh"

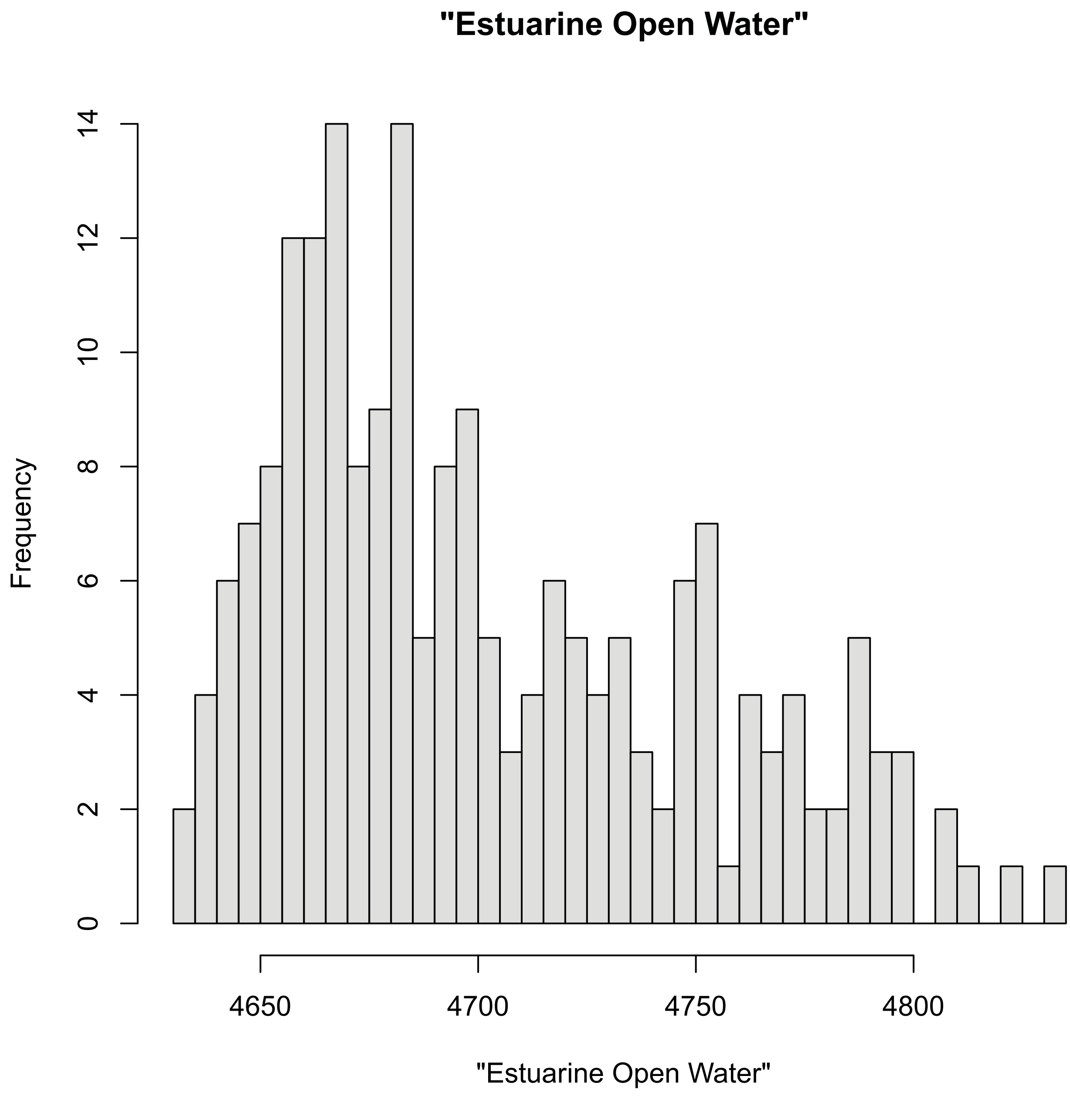

"Regularly−Flooded Marsh"
Frequency
0
5
10
15
20
25
30
80
100
120
140
"Regularly−Flooded Marsh"

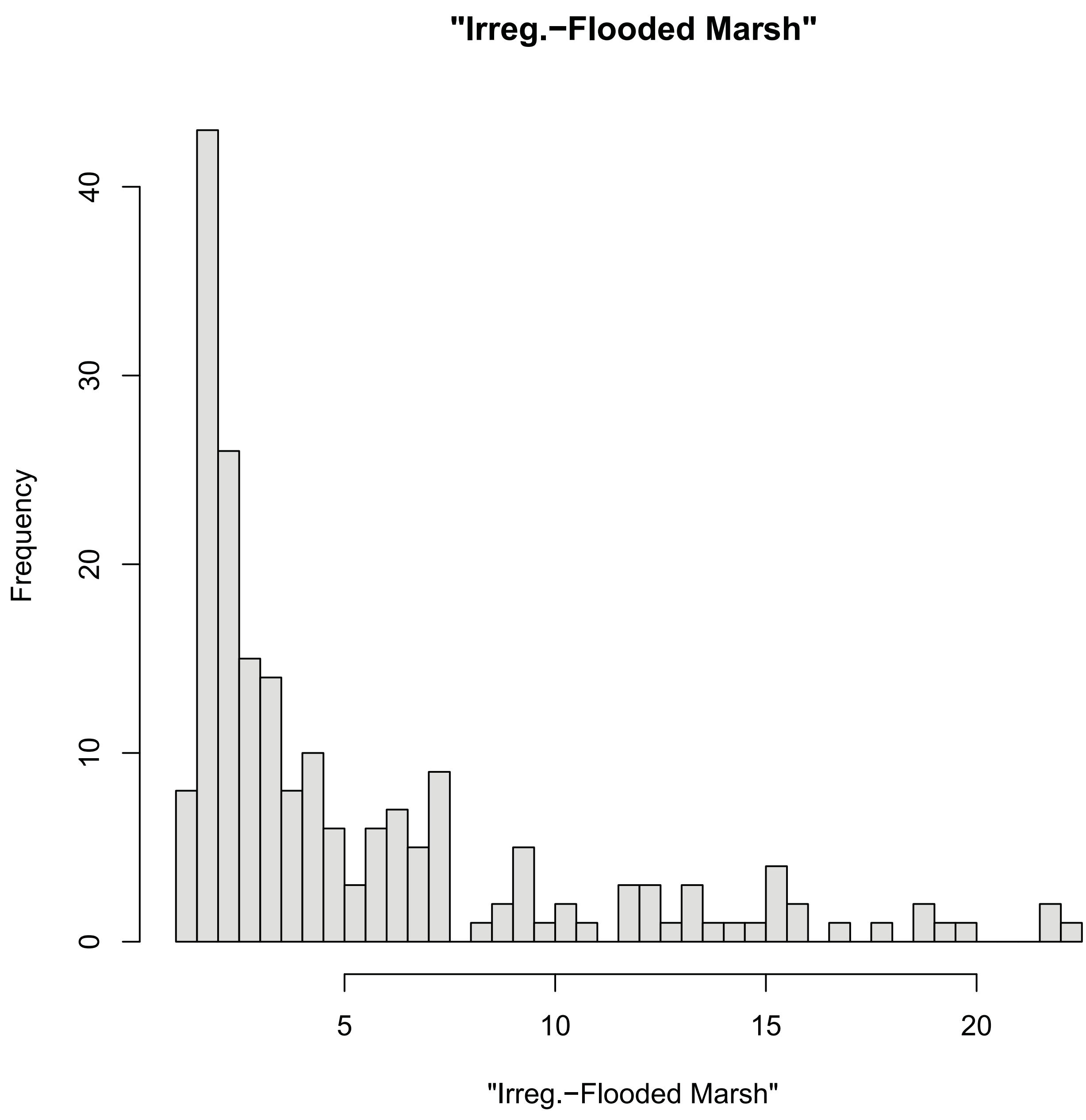

"Estuarine Beach"
Frequency
0
5
10
15
20
25
4
6
8
10
12
14
16
"Estuarine Beach"

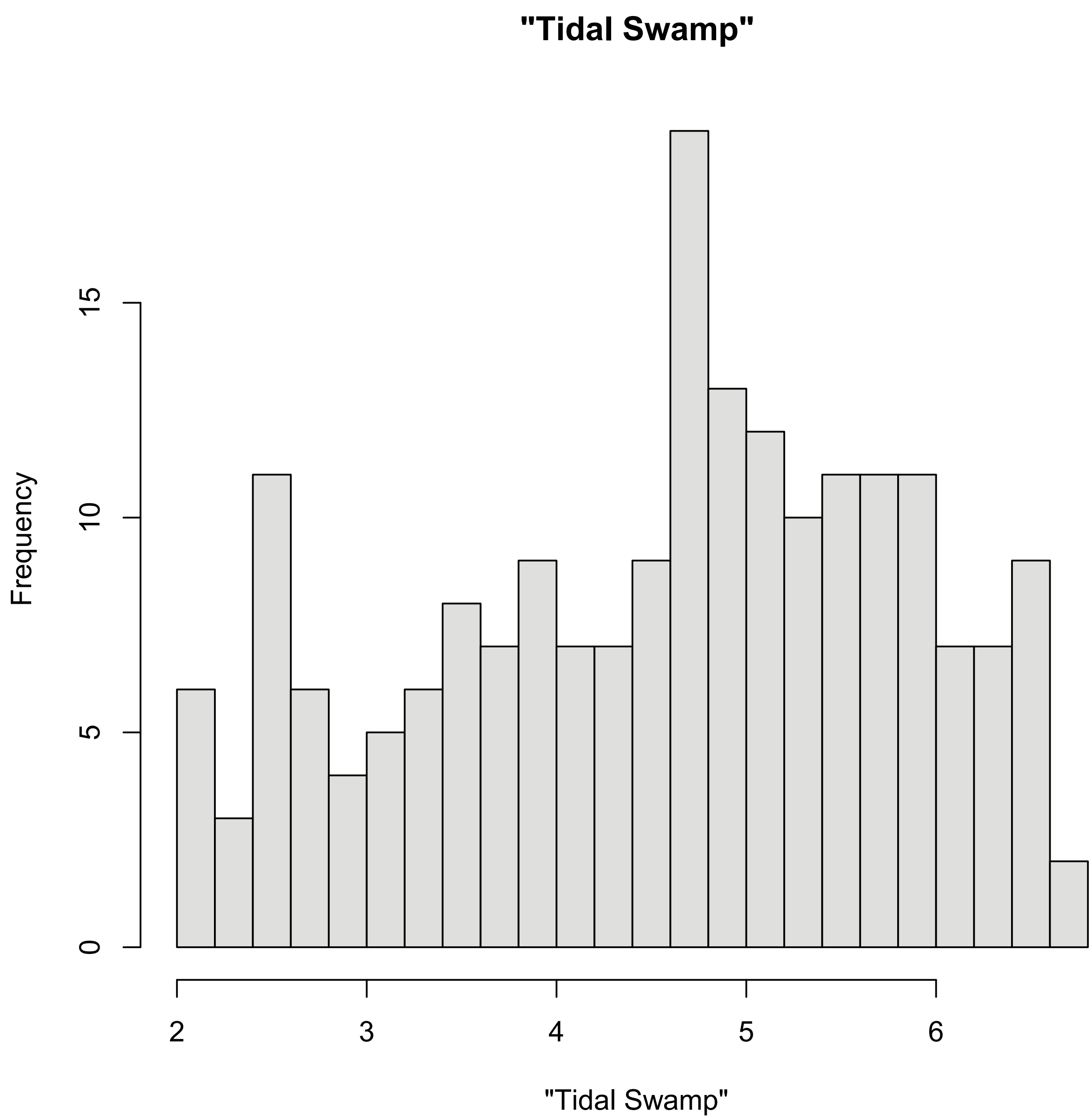

"Tidal Flat"
Frequency
0
5
10
15
20
10
20
30
40
50
"Tidal Flat"

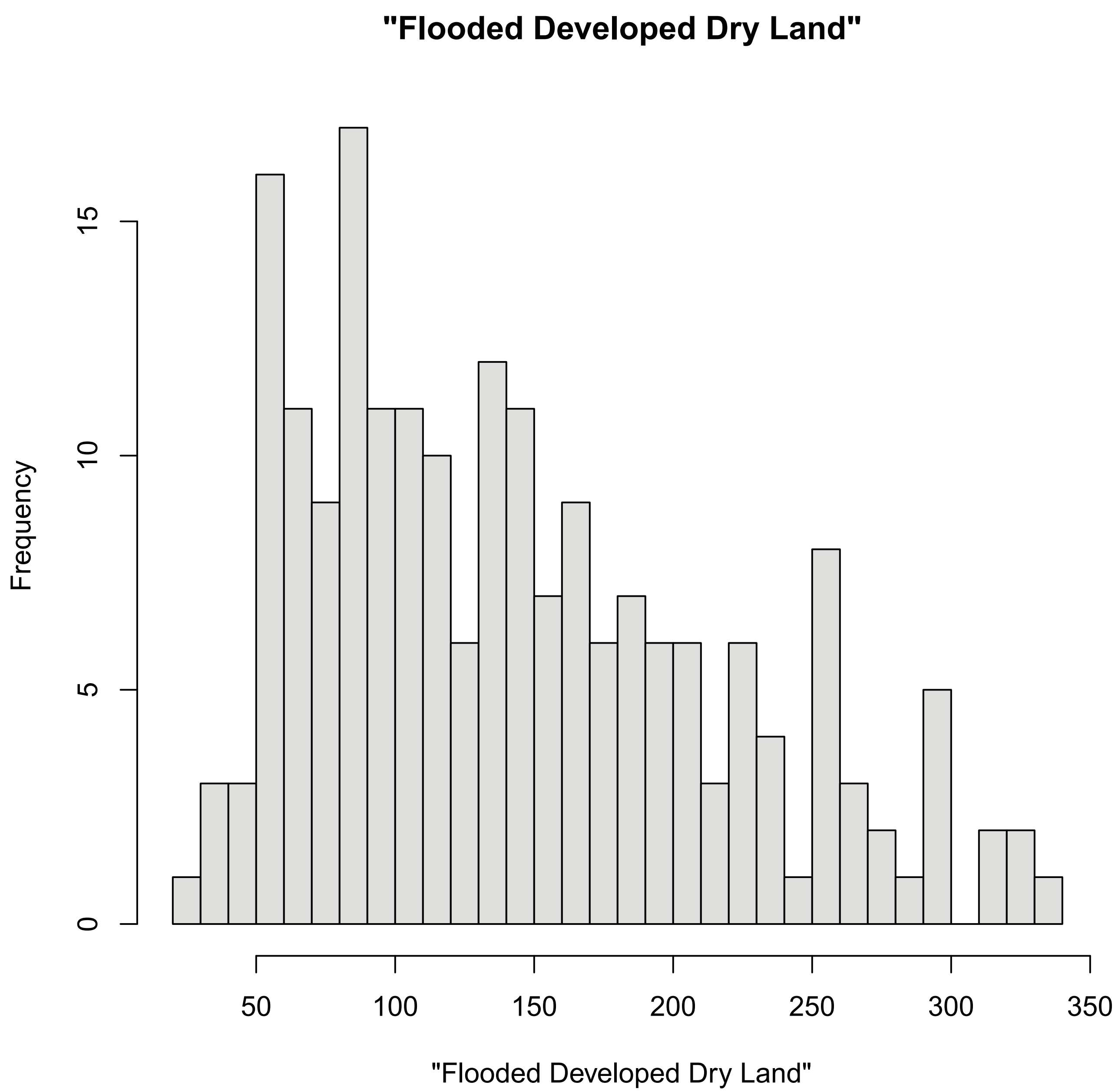

"Rocky Intertidal"
Frequency
0
5
10
15
20
0.0
0.2
0.4
0.6
0.8
1.0
"Rocky Intertidal"

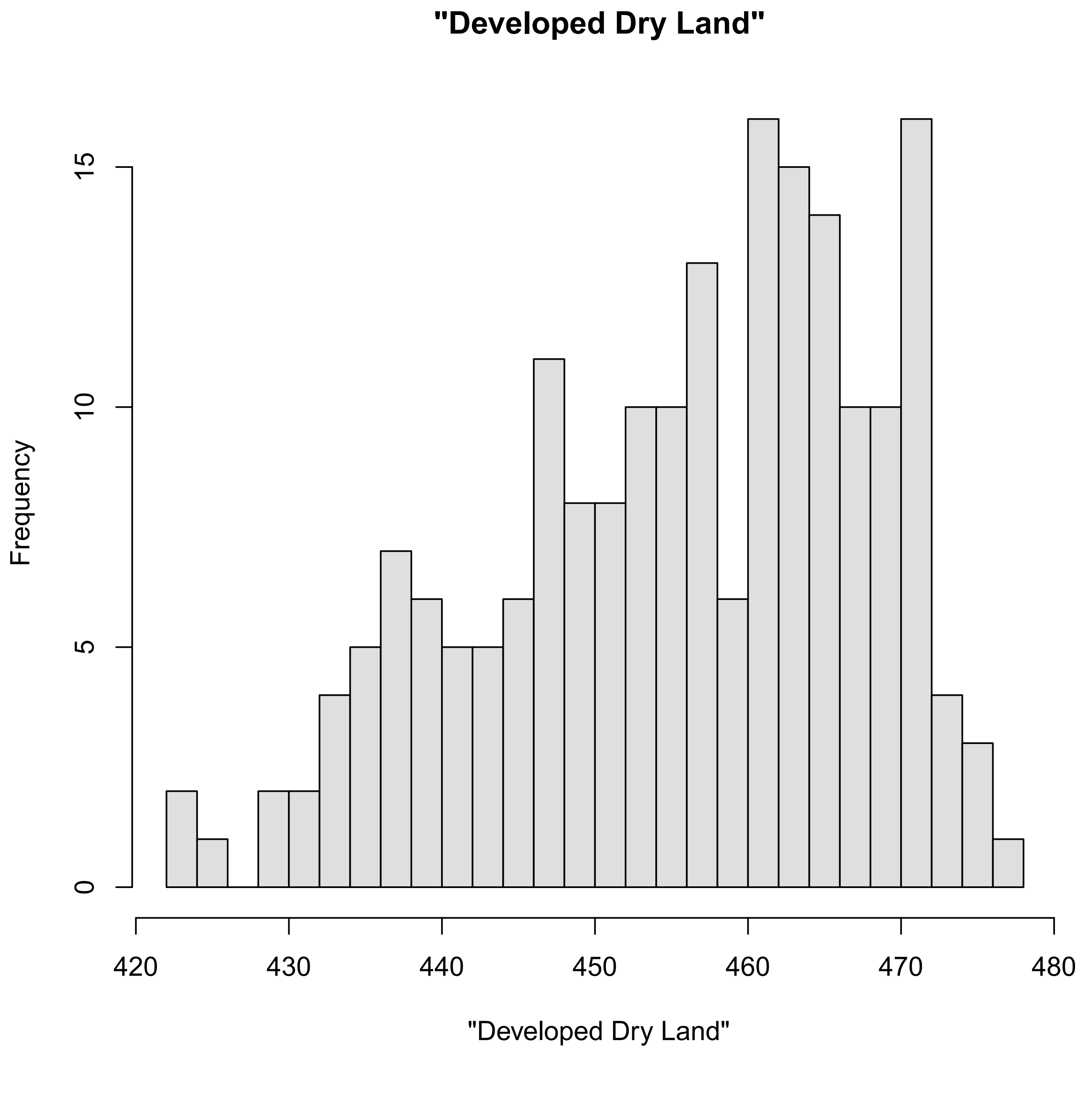

"Inland Open Water"
Frequency
0
10
20
30
40
50
39
40
41
42
43
44
45
46
"Inland Open Water"

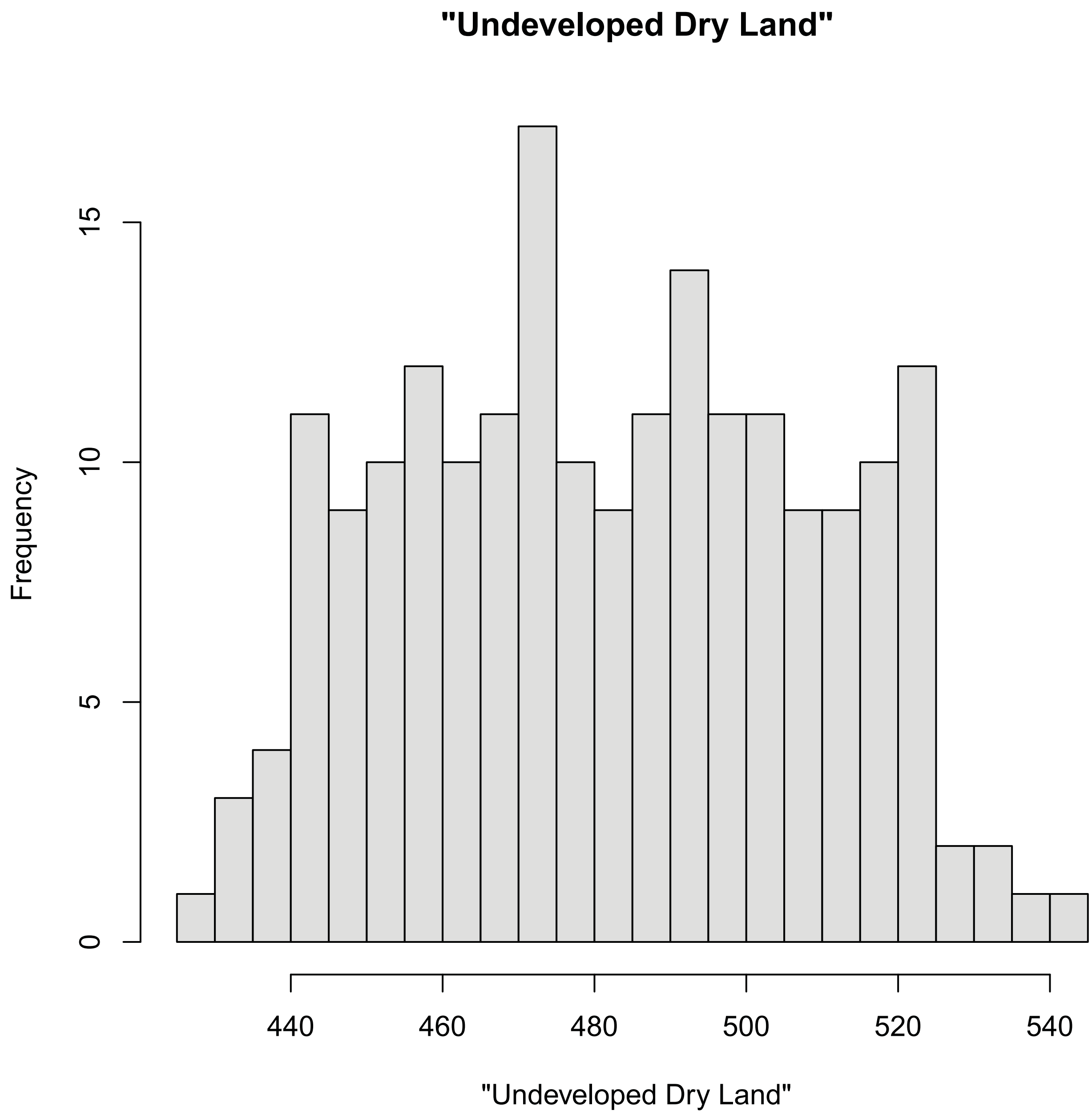

"Estuarine Open Water"
Frequency
0
2
4
6
8
10
12
14
4650
4700
4750
4800
"Estuarine Open Water"

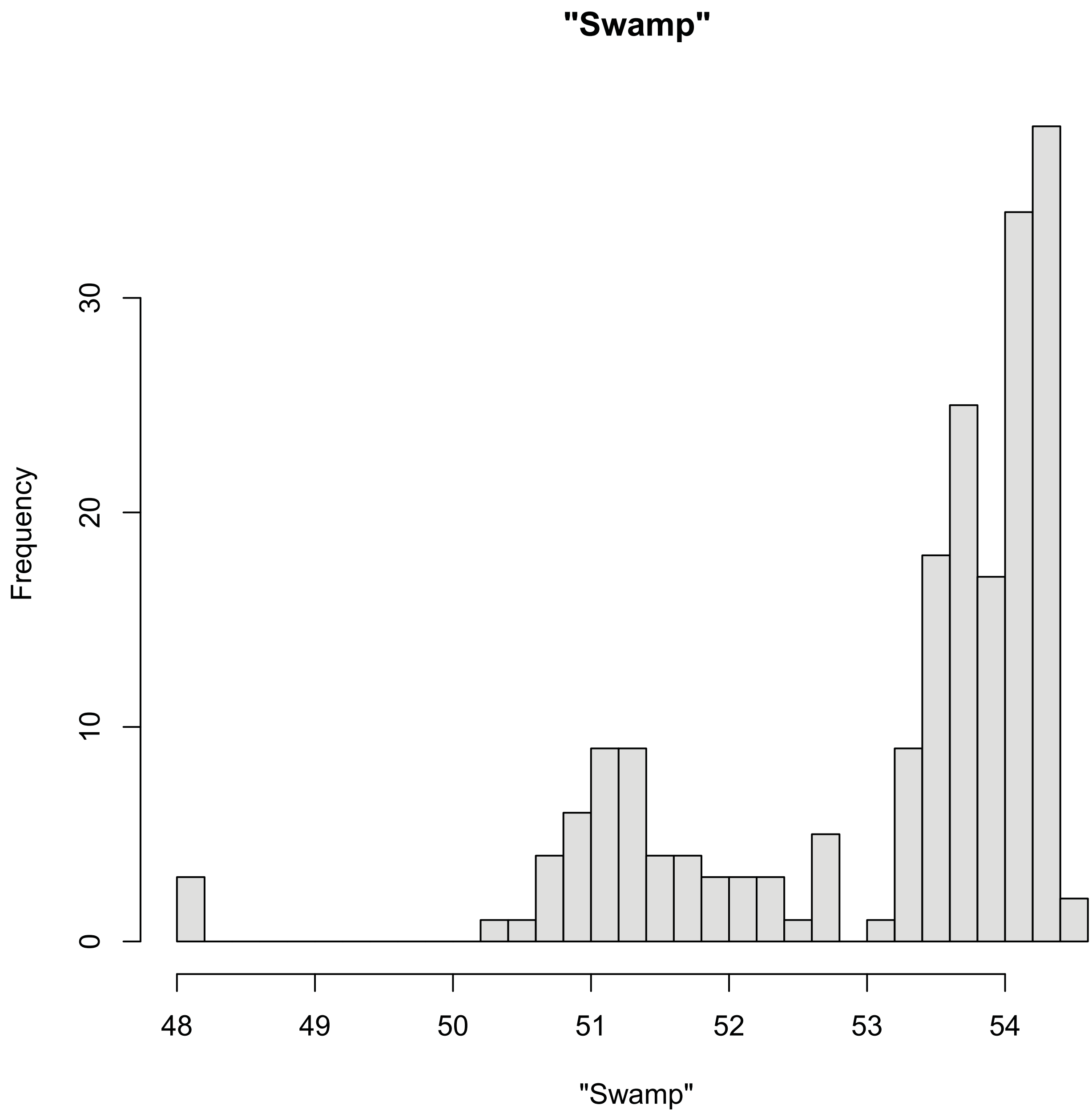

"Irreg.−Flooded Marsh"
Frequency
0
10
20
30
40
5
10
15
20
"Irreg.−Flooded Marsh"

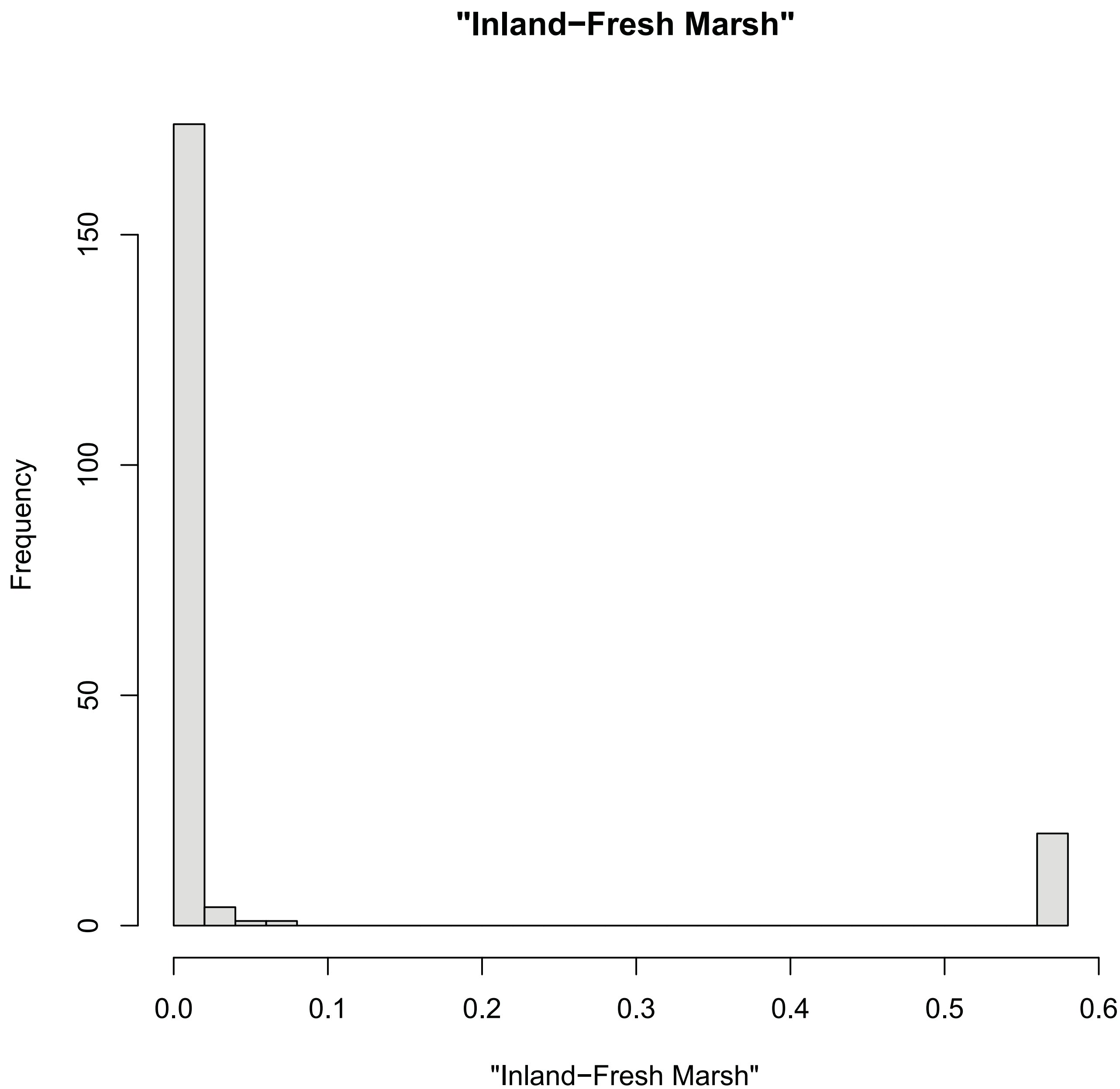

"Tidal Swamp"
Frequency
0
5
10
15
2
3
4
5
6
"Tidal Swamp"

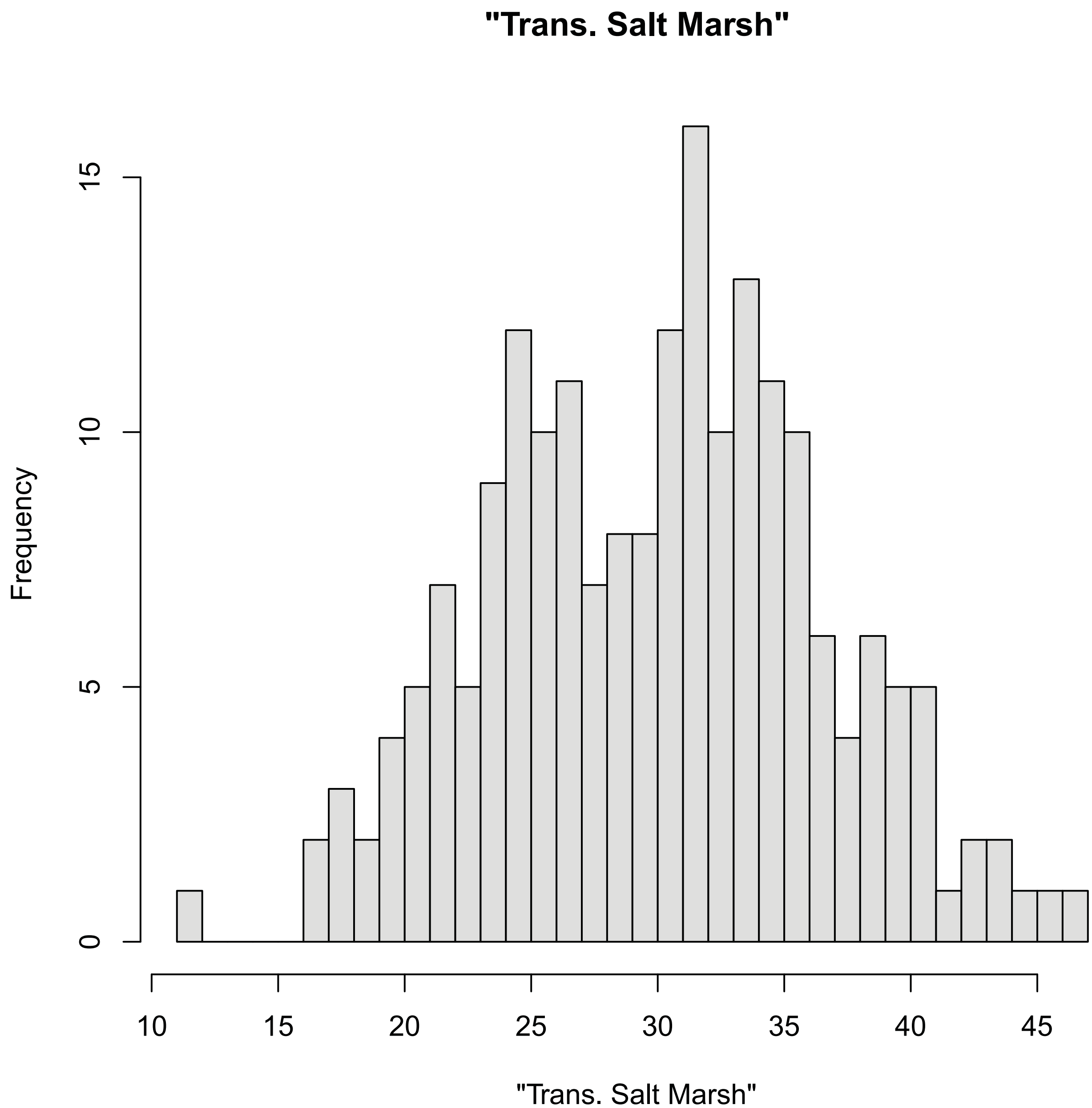

"Flooded Developed Dry Land"
Frequency
0
5
10
15
50
100
150
200
250
300
350
"Flooded Developed Dry Land"

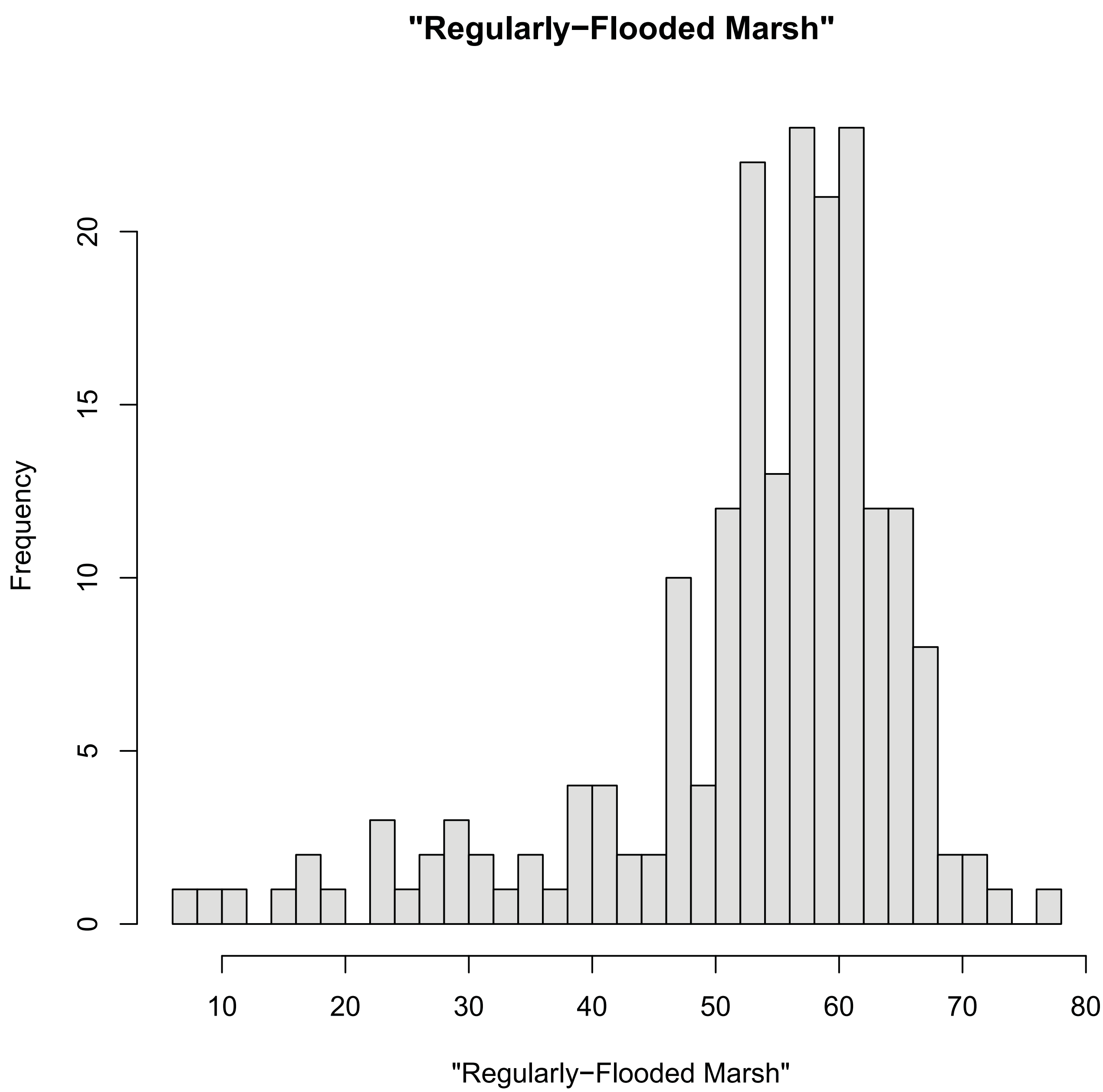

"Developed Dry Land"
Frequency
0
5
10
15
420
430
440
450
460
470
480
"Developed Dry Land"

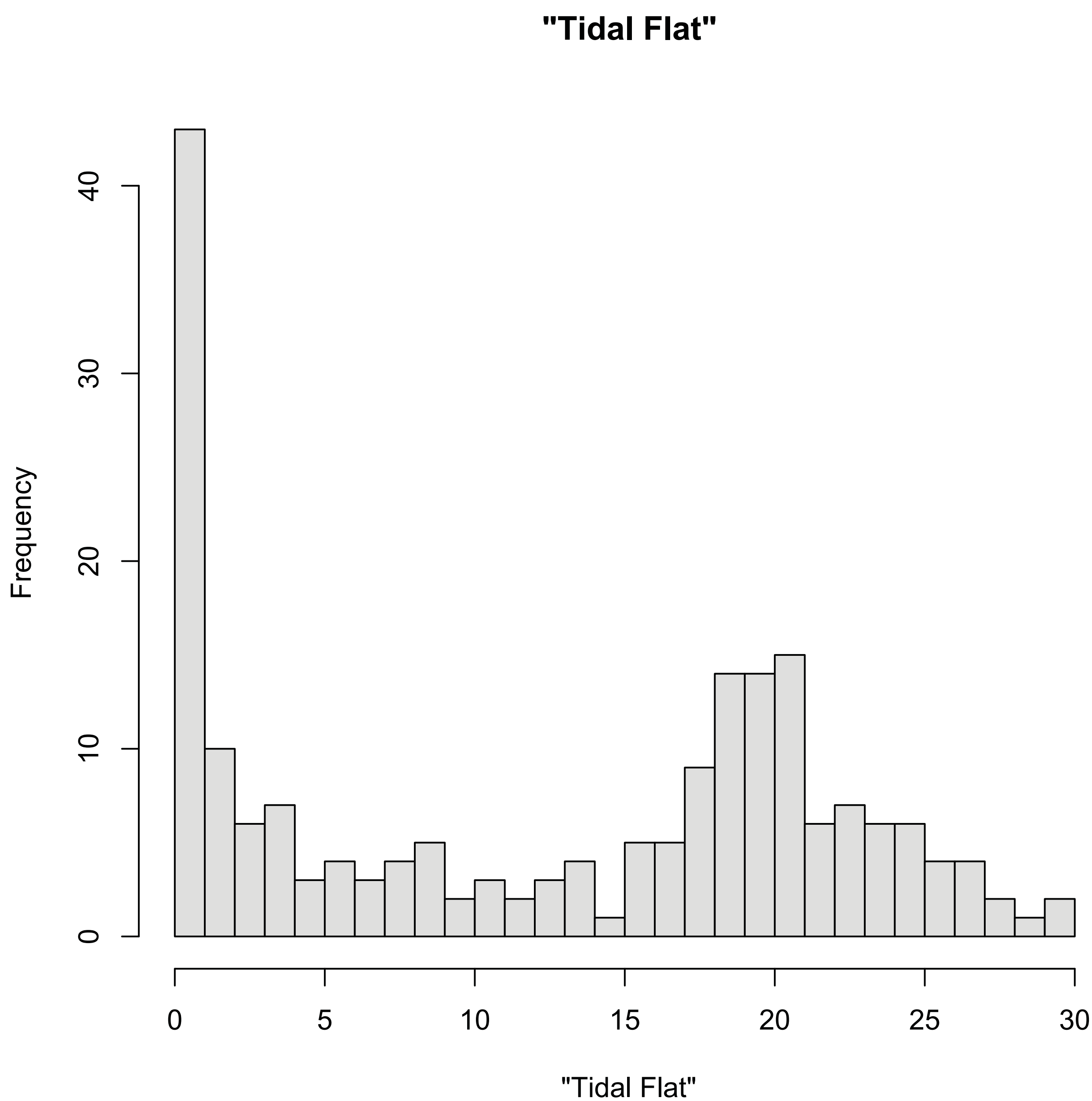

"Undeveloped Dry Land"
Frequency
0
5
10
15
440
460
480
500
520
540
"Undeveloped Dry Land"

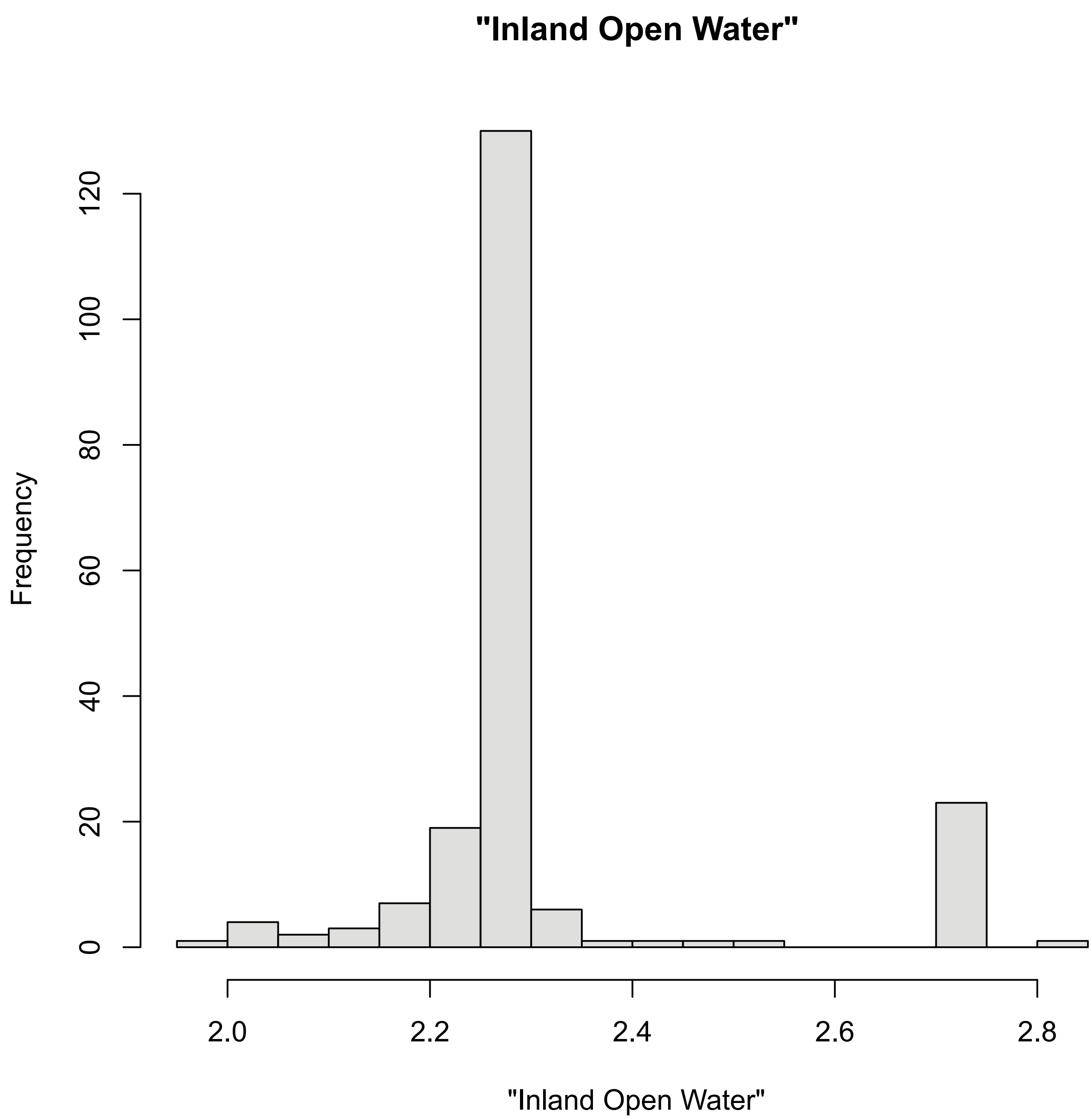

"Swamp"
Frequency
0
10
20
30
48
49
50
51
52
53
54
"Swamp"

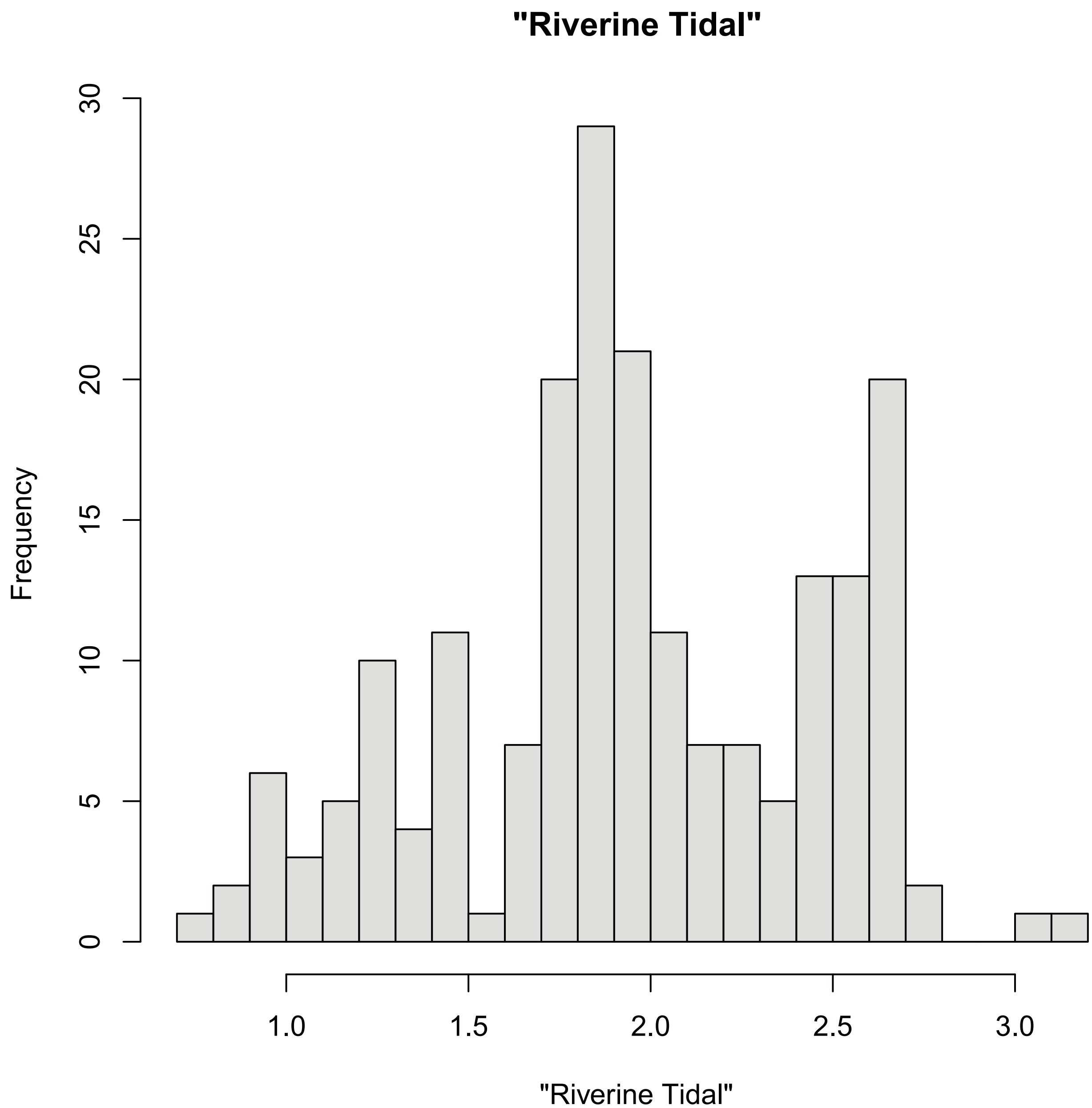

"Inland−Fresh Marsh"
Frequency
0
50
100
150
0.0
0.1
0.2
0.3
0.4
0.5
0.6
"Inland−Fresh Marsh"

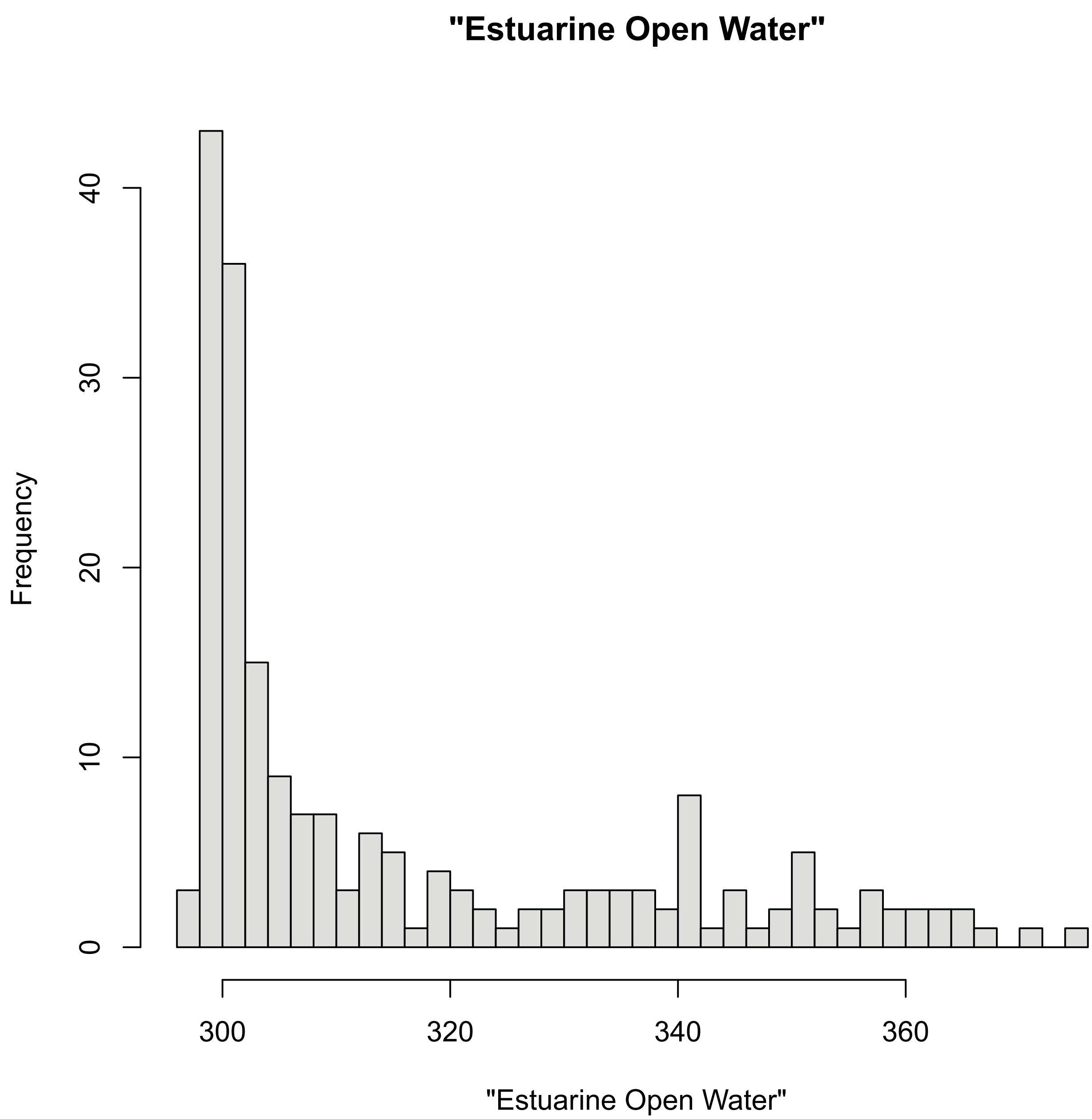

"Trans. Salt Marsh"
Frequency
0
5
10
15
10
15
20
25
30
35
40
45
"Trans. Salt Marsh"

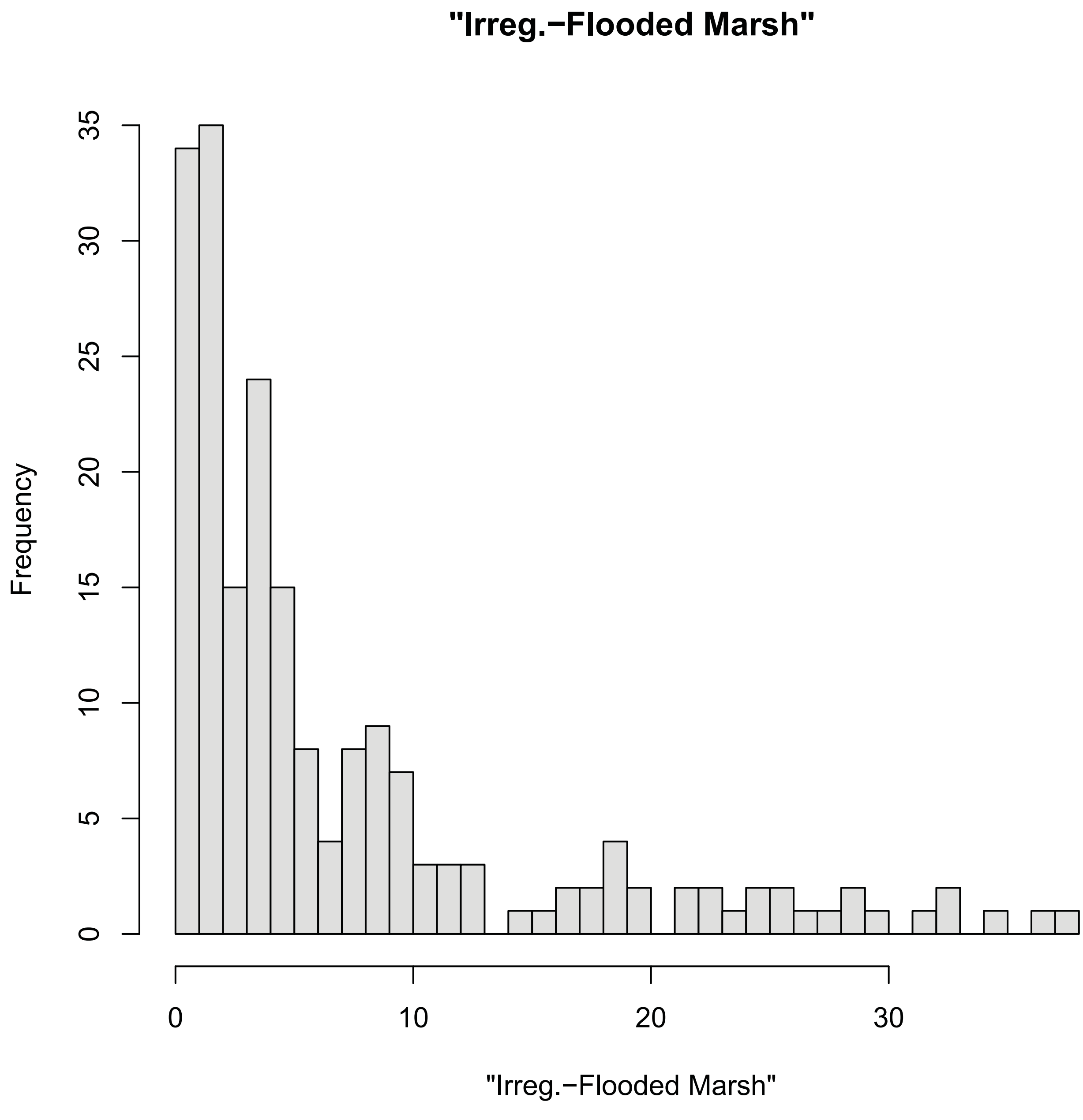

"Regularly−Flooded Marsh"
Frequency
0
5
10
15
20
10
20
30
40
50
60
70
80
"Regularly−Flooded Marsh"

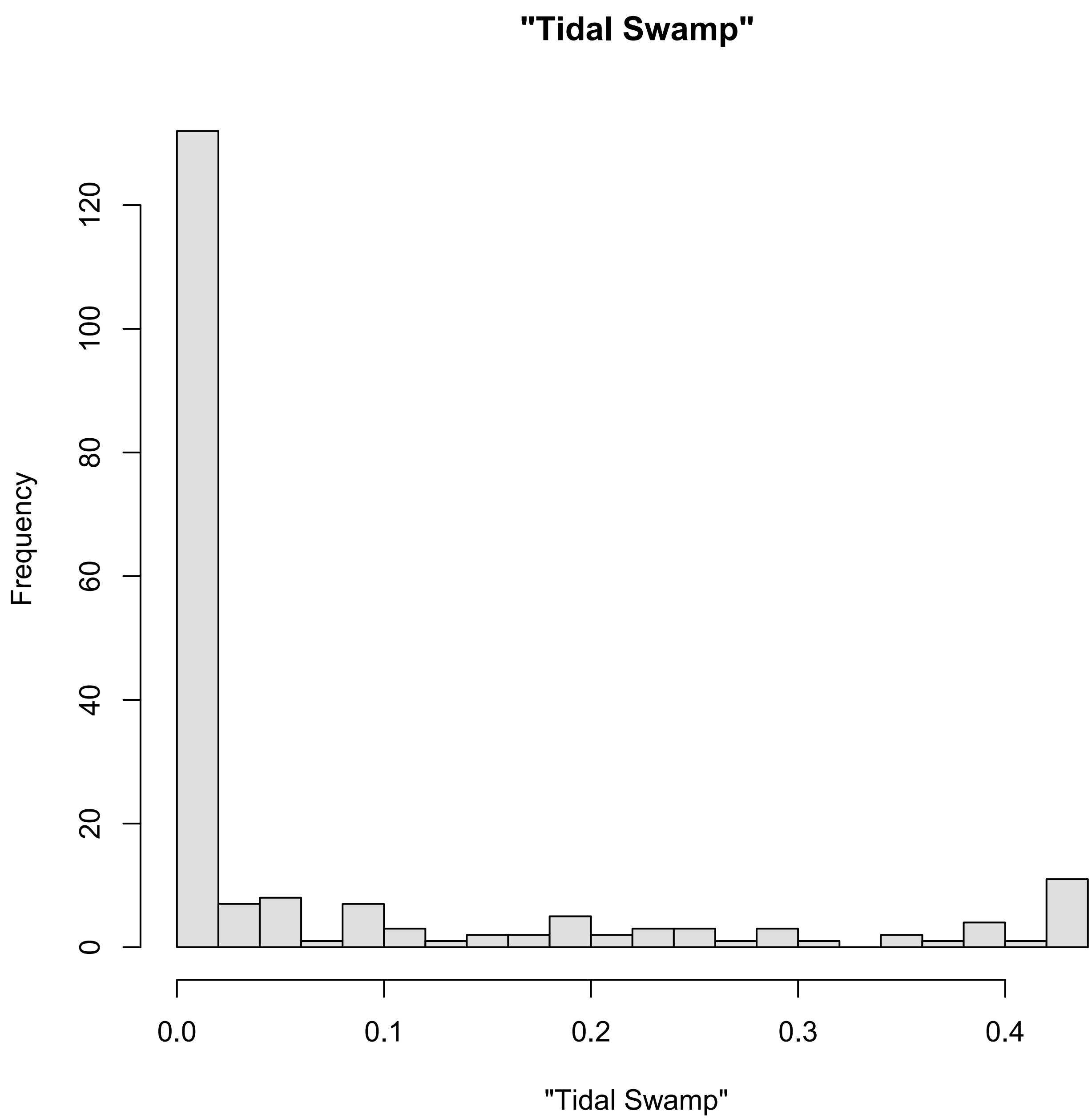

"Tidal Flat"
Frequency
0
10
20
30
40
0
5
10
15
20
25
30
"Tidal Flat"

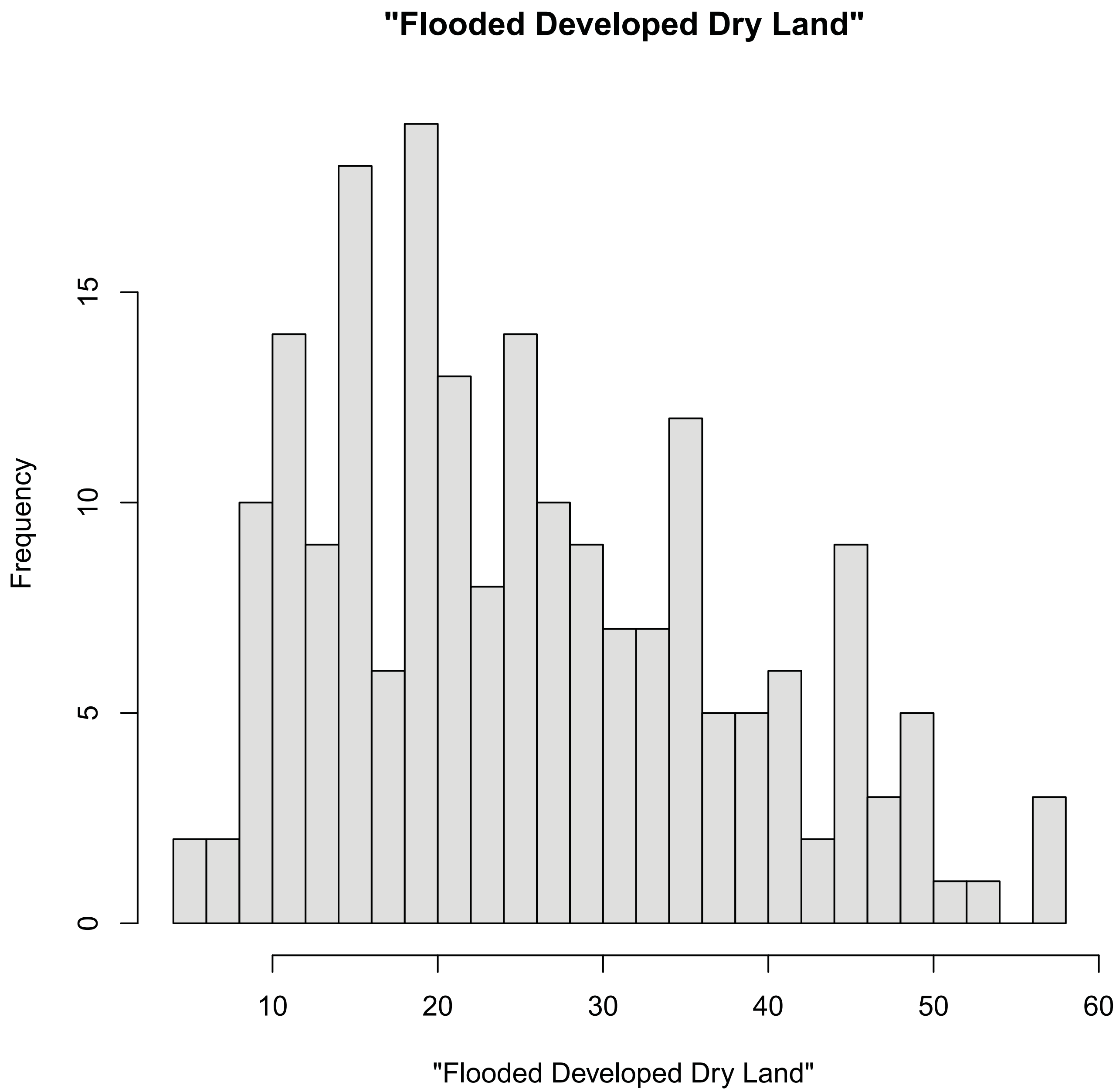

"Inland Open Water"
Frequency
0
20
40
60
80
100
120
2.0
2.2
2.4
2.6
2.8
"Inland Open Water"


"Riverine Tidal"
Frequency
0
5
10
15
20
25
30
1.0
1.5
2.0
2.5
3.0
"Riverine Tidal"


"Estuarine Open Water"
Frequency
0
10
20
30
40
300
320
340
360
"Estuarine Open Water"


"Irreg.−Flooded Marsh"
Frequency
0
5
10
15
20
25
30
35
0
10
20
30
"Irreg.−Flooded Marsh"


"Tidal Swamp"
Frequency
0
20
40
60
80
100
120
0.0
0.1
0.2
0.3
0.4
"Tidal Swamp"


"Flooded Developed Dry Land"
Frequency
0
5
10
15
10
20
30
40
50
60
"Flooded Developed Dry Land"