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Relationships between regional coastal land cover distributions and elevation reveal data uncertainty in a sea-level rise impacts model

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Introduction

This supplement includes a figure and tables that provide background information on 1) the coastal response model introduced in Lentz et al. (2016), as well as 2) confusion matrices used to compare land cover data sources and predictions of elevation when land cover data were used as inputs (and vice versa). The coastal response model figure is modified from previous publications (Lentz et al., 2015; 2016), and the table shows the general land cover groupings used in Lentz et al. (2016). The confusion matrices show the distributions of data in each category for the full 30 m x 30 m Northeastern U.S. region, totaling more than 42 million grid cells. The diagonal fields in the confusion matrices (upper left cell to lower right) show where predicted values matched observed values; accuracy rates reported in the captions are calculated as the sum of the diagonal divided by the total number of cells. The code used to generate the two-node Bayesian network using Netica software is included at the end of this document.

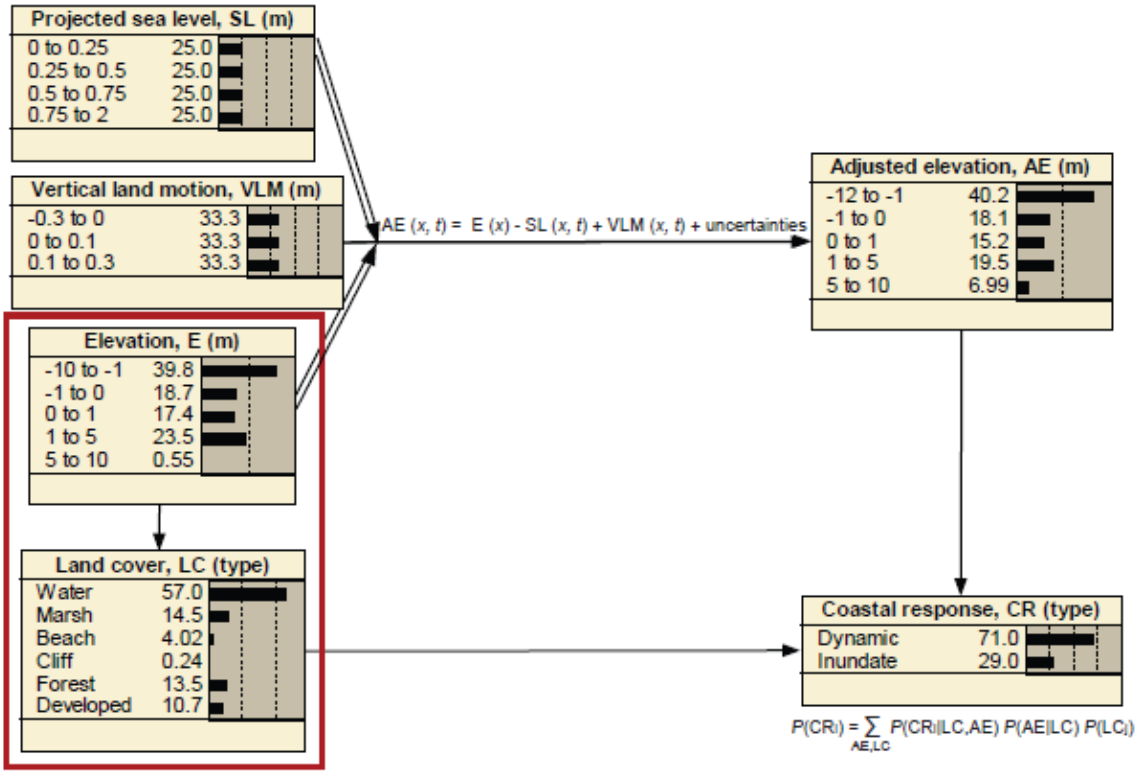

Figure S1. Diagram showing Bayesian network coastal response model, including data inputs (left) and predicted outcomes (right), including adjusted elevation (inundation model equivalent) and coastal response, wherein the response is binary such that dynamic implies "non-inundate". Horizontal bars shown in the boxes represent prior distributions (probability of occurrence) for each parameter. Uniform distributions for sea-level and vertical land motion parameters provide an equal likelihood of occurrence until a time step is specified. Correlation among nodes are shown by the arrows between them. Equations show deterministic and probabilistic equations used to generate conditional probabilities, where *x* and *t* indicate spatial and temporal dependence, and joint correlations of occurrence *i*, at a specific location, *j*. Red box highlights E-LC relationship trained via Bayes theorem (equation 1) and further tested in this paper. Modified from Lentz et al. (2015, 2016).

Land Cover Category*	Included DSL Classes*	CCAP/DSL comparison	Included CCAP Classes
Subaqueous	Bays, lakes, rivers, marine and estuarine subtidal, and deepwater	Subaqueous	Open Water, Palustrine Aquatic Bed, Estuarine Aquatic Bed
Marsh	Salt and freshwater marshes, bogs, swamps, fens, wetland forests, intertidal aquatic beds, and reefs	Marsh	Palustrine Forested Wetland, Palustrine Scrub/Shrub Wetland, Palustrine Emergent Wetland, Estuarine Forested Wetland, Estuarine Scrub/Shrub Wetland, Estuarine Emergent Wetland
Beach	Dune and swale/sandy beach (including bluffs), marine and estuarine intertidal unconsolidated shore	Bare Land	Unconsolidated Shore, Bare Land
Rocky	Rocky outcrops and shores, marine and estuarine intertidal rock bottom		
Forest	Forests, woodlands, grasslands, agricultural, shrub lands	Non-Marsh Vegetation	Cultivated Land, Pasture/Hay, Grassland, Deciduous Forest, Evergreen Forest, Mixed Forest, Scrub/Shrub
Developed	All National Land Cover Dataset developed classes (open space, low, medium, and high density), roads, active and abandoned railroad tracks	Developed	High Intensity Developed, Medium Intensity Developed, Low Intensity Developed, Developed Open Space

Table S1. The land-cover classes falling within the six generalized land-cover categories, from Lentz et al. (2015) and as reclassified for use in comparison with Coastal Change Analysis Program (CCAP) data.

	C-CAP Land Cover						
DSL Land Cover	**Subaqueous**	**Marsh**	**Bare land**	**Non-Marsh Vegetation**	**Developed**	**Total**	**User's accuracy (%)**
Subaqueous	**22027171**	625725	238956	121072	170173	23183097	95
Marsh	376230	**5432643**	40901	319470	120669	6289913	86.4
Bare Land	961149	386365	**390012**	63422	39551	1840499	21.2
Non-Marsh Vegetation	69146	1351262	47797	**4509443**	186375	6164023	73.2
Developed	61270	454146	70835	938883	**3750745**	5275879	71.1
Ground truth	23494966	8250141	788501	5952290	4267513	*42753411*	
Producer's accuracy (%)	93.8	65.8	49.5	75.8	87.9		

Table S2. Confusion matrix showing comparison between Coastal Change Analysis Program (C-CAP) and Designing Sustainable Landscapes (DSL) land cover datasets with user's error (accuracy) and producer's error (reliability). The overall accuracy rate in this comparison is 85%, where CCAP data are considered as ground truth.

	Predicted (m)							
Actual	**Water**	**Marsh**	**Beach**	**Rocky**	**Forest**	**Developed**	**Total**	**User's accuracy (%)**
Water	**22091861**	1591392	0	0	446390	12107	24141750	91.5
Marsh	1290019	**2918228**	0	0	1890412	25752	6124411	47.6
Beach	1048226	450741	**0**	0	174218	21048	1694233	0
Rocky	62315	22883	0	**0**	15976	1240	102414	0
Forest	147539	1420429	0	0	**4016932**	80731	5665631	70.9
Developed	139712	925392	0	0	3352471	**90485**	4508060	2
Ground truth	24779672	7329065	0	0	9896399	231363	**42236499**	
Producer's accuracy (%)	89.2	39.8			40.6	39.1		

Table S3a. Confusion matrix showing comparison between predicted land cover and measured (observed) land cover when elevation data are used as inputs with original distributions, with user's error (accuracy) and producer's error (reliability). The overall accuracy rate for this comparison is 69%.

	Predicted (m)							
Actual	**Water**	**Marsh**	**Beach**	**Rocky**	**Forest**	**Developed**	**Total**	**User's accuracy (%)**
Water	**16530433**	1591392	5561428	0	0	458497	24141750	68.5
Marsh	60470	**2918228**	1229549	0	0	1916164	6124411	47.6
Beach	217137	450741	**831089**	0	0	195266	1694233	49.1
Rocky	35964	22883	26351	**0**	0	17216	102414	0.0
Forest	11445	1420429	136094	0	**0**	4097663	5665631	0.0
Developed	26099	925392	113613	0	0	**3442956**	4508060	76.4
Ground truth	16881548	7329065	7898124	0	0	10127762	**42236499**	
Producer's accuracy (%)	97.9	39.8	10.5			34		

Table S3b. Confusion matrix showing comparison between predicted land cover and measured (observed) land cover when elevation data are used as inputs with uniform distributions, with user's error (accuracy) and producer's error (reliability). The overall accuracy rate for this comparison is 56%

	Predicted (m)						
Actual (m)	**-10 to -1**	**-1 to 0**	**0 to 1**	**1 to 5**	**5 to 10**	**Total**	**User's accuracy (%)**
-10 to -1	**16566397**	217137	60470	37544	0	16881548	98.1
-1 to 0	5587779	**831089**	1229549	249707	0	7898124	10.5
0 to 1	1614275	450741	**2918228**	2345821	0	7329065	39.8
1 to 5	462366	174218	1890412	**7369403**	0	9896399	74.5
5 to 10	13347	21048	25752	171216	**0**	231363	0
Ground truth	24244164	1694233	6124411	10173691	0	**42236499**	
Producer's accuracy (%)	68.3	49.1	47.6	72.4			

Table S4a. Confusion matrix showing comparison between predicted elevations and measured (observed) elevations when land cover data are used as inputs with original distributions, with user's error (accuracy) and producer's error (reliability). The overall accuracy rate for this comparison is 66%.

	Predicted (m)						
Actual (m)	**-10 to -1**	**-1 to 0**	**0 to 1**	**1 to 5**	**5 to 10**	**Total**	**User's accuracy (%)**
-10 to -1	**16530433**	217137	60470	11445	62063	16881548	97.9
-1 to 0	5561428	**831089**	1229549	136094	139964	7898124	10.5
0 to 1	1591392	450741	**2918228**	1420429	948275	7329065	39.8
1 to 5	446390	174218	1890412	**4016932**	3368447	9896399	40.6
5 to 10	12107	21048	25752	80731	**91725**	231363	39.6
Ground truth	24141750	1694233	6124411	5665631	4610474	**42236499**	
Producer's accuracy (%)	68.5	49.1	20.1	70.9	73.1		

Table S4b. Confusion matrix showing comparison between predicted elevations and measured (observed) elevations when land cover data are used as inputs with uniform distributions, with user's error (accuracy) and producer's error (reliability). The overall accuracy rate for this comparison is 58%.

Bayesian Network Code

The code provided here is a text-formatted version of the two-node elevation-land cover Bayesian network (BN) models referenced in the paper that can be saved in a file with .dne file extension and opened with Netica (Norsys Software Corp, 2012). The data from the National Elevation Dataset (Gesch, 2007, adjusted to mean high water VDatum conversion grids (National Ocean Service, 2012)), the National Geophysical Data Center's Coastal Relief Model (National Oceanic and Atmospheric Administration, 2014), and McGarrigal et al., 2017 (land cover) can be used to train and run the BN using Netica software and application interfaces.

Elevation – Land Cover Bayesian Network

```
// File created by LentzE at USGS using Netica 5.12 on Apr 12, 2019 at 16:06:03.

bnet LCENet {
AutoCompile = TRUE;
autoupdate = TRUE;
whenchanged = 1430849925;

visual V1 {
        defdispform = BELIEFBARS;
        nodelabeling = TITLE;
        NodeMaxNumEntries = 50;
        nodefont = font {shape= "Arial"; size= 9;};
        linkfont = font {shape= "Arial"; size= 9;};
        windowposn = (70, 28, 1189, 712);
        resolution = 72;
        drawingbounds = (1895, 973);
        showpagebreaks = FALSE;
        usegrid = TRUE;
        gridspace = (6, 6);
        NodeSet Node {BuiltIn = 1; Color = 0x00E1E1E1;};
        NodeSet Nature {BuiltIn = 1; Color = 0x00F8EED2;};
        NodeSet Deterministic {BuiltIn = 1; Color = 0x00D3CAA6;};
        NodeSet Finding {BuiltIn = 1; Color = 0x00C8C8C8;};
        NodeSet Constant {BuiltIn = 1; Color = 0x00FFFFFF;};
        NodeSet ConstantValue {BuiltIn = 1; Color = 0x00FFFFB4;};
        NodeSet Utility {BuiltIn = 1; Color = 0x00FFBDBD;};
        NodeSet Decision {BuiltIn = 1; Color = 0x00DEE8FF;};
        NodeSet Documentation {BuiltIn = 1; Color = 0x00F0FAFA;};
        NodeSet Title {BuiltIn = 1; Color = 0x00FFFFFF;};
        PrinterSetting A {
                margins = (1270, 1270, 1270, 1270);
                };
        };

node demMHW_m {
        kind = NATURE;
        discrete = FALSE;
        chance = CHANCE;
        statetitles = ("-10 to -1\n", "-1 to 0", "0 to 1", "1 to 5", "5 to 10");
        levels = (-10, -1, 0, 1, 5, 10);
```

```
        parents = ();
        probs =
                // -10 to -1    -1 to 0      0 to 1       1 to 5       5 to 10
                  (0.4001461,   0.1883747,   0.1748023,   0.2360343,   6.426296e-4);
        numcases = 4.19277e+07;
        title = "Elevation (m)";
        whenchanged = 1430849924;
        belief = (0.4001461, 0.1883747, 0.1748023, 0.2360343, 6.426295e-4);
        visual V1 {
                center = (162, 150);
                height = 1;
                };
        };

node landclass {
        kind = NATURE;
        discrete = TRUE;
        chance = CHANCE;
        states = (Subaqueous, Marsh, Beach, Rocky, Forest, Developed);
        levels = (1, 2, 3, 4, 5, 6);
        parents = (demMHW_m);
        probs =
                // Subaqueous   Marsh        Beach        Rocky        Forest       Developed     //
demMHW_m
        (0.9790752,   0.003672352, 0.0129401,   0.002128477, 6.657562e-4, 0.001518107,  // -
10 to -1
          0.6987546,   0.1605342,   0.1057159,   0.003326611, 0.01712418,  0.01454446,   // -
1 to 0
           0.2107605,   0.4047149,   0.0618361,   0.003098211, 0.1902146,   0.1293757,    // 0
        to 1
         0.04109905,  0.1948352,   0.01759592,  0.001539552, 0.3962848,   0.3486456,    // 1
to 5
        1.113214e-4, 0.9992579,   3.710713e-5, 3.710713e-5, 2.226428e-4, 3.339642e-4); // 5
to 10    ;
        numcases =
                                // demMHW_m
                    (1.688155e7,   // -10 to -1
                     7.898128e6,   // -1 to 0
                     7.329068e6,   // 0 to 1
                     9.896386e6,   // 1 to 5
                     26949);       // 5 to 10    ;
        title = "Land Cover (six classes)";
        comment = "MACT_final\n% 1 Water\n% 2 Marsh\n% 3 Beach\n% 4 Cliff\n% 5
Forest\n% 6 Developed";
        whenchanged = 1430849925;
        belief = (0.5699431, 0.1490851, 0.04005449, 0.002383337, 0.1302791, 0.108255);
        visual V1 {
                center = (150, 354);
                height = 2;
                };
        };
ElimOrder = (demMHW_m, landclass);
};
```

Land Cover – Elevation Network

```
// File created by LentzE at USGS using Netica 5.12 on Apr 12, 2019 at 16:06:25.

bnet LCENet_rev2 {
AutoCompile = TRUE;
autoupdate = TRUE;
whenchanged = 1555099577;

visual V1 {
	defdispform = BELIEFBARS;
	nodelabeling = TITLE;
	NodeMaxNumEntries = 50;
	nodefont = font {shape= "Arial"; size= 9;};
	linkfont = font {shape= "Arial"; size= 9;};
	windowposn = (39, 24, 379, 624);
	resolution = 72;
	drawingbounds = (1895, 973);
	showpagebreaks = FALSE;
	usegrid = TRUE;
	gridspace = (6, 6);
	NodeSet Node {BuiltIn = 1; Color = 0x00E1E1E1;};
	NodeSet Nature {BuiltIn = 1; Color = 0x00F8EED2;};
	NodeSet Deterministic {BuiltIn = 1; Color = 0x00D3CAA6;};
	NodeSet Finding {BuiltIn = 1; Color = 0x00C8C8C8;};
	NodeSet Constant {BuiltIn = 1; Color = 0x00FFFFFF;};
	NodeSet ConstantValue {BuiltIn = 1; Color = 0x00FFFFB4;};
	NodeSet Utility {BuiltIn = 1; Color = 0x00FFBDBD;};
	NodeSet Decision {BuiltIn = 1; Color = 0x00DEE8FF;};
	NodeSet Documentation {BuiltIn = 1; Color = 0x00F0FAFA;};
	NodeSet Title {BuiltIn = 1; Color = 0x00FFFFFF;};
	PrinterSetting A {
		margins = (1270, 1270, 1270, 1270);
		};
	};

node landclass {
	kind = NATURE;
	discrete = TRUE;
	chance = CHANCE;
	states = (Subaqueous, Marsh, Beach, Rocky, Forest, Developed);
	levels = (1, 2, 3, 4, 5, 6);
	parents = ();
	probs =
		// Subaqueous   Marsh       Beach       Rocky       Forest      Developed
		  (0.4811089,   0.1756256,   0.04858441,  0.002936886, 0.1624695,
0.1292746);
	numcases = 3.4872e+07;
	title = "Land Cover (six classes)";
	comment = "MACT_final\n% 1 Water\n% 2 Marsh\n% 3 Beach\n% 4 Cliff\n% 5
Forest\n% 6 Developed";
	whenchanged = 1550025712;
	belief = (0.4811089, 0.1756256, 0.04858441, 0.002936886, 0.1624695, 0.1292746);
```

```
        visual V1 {
                center = (150, 354);
                height = 2;
                };
        };

node demMHW_m {
        kind = NATURE;
        discrete = FALSE;
        chance = CHANCE;
        statetitles = ("-10 to -1\n", "-1 to 0", "0 to 1", "1 to 5", "5 to 10");
        levels = (-10, -1, 0, 1, 5, 10);
        parents = (landclass);
        probs =
                // -10 to -1    -1 to 0      0 to 1       1 to 5       5 to 10       // landclass
                  (0.6847238,   0.2303656,   0.0659187,   0.01849041,  5.015377e-4,  //
Subaqueous
                   0.009873758, 0.200762,    0.476491,    0.3086683,   0.004204972,  // Marsh
                   0.1281626,   0.4905391,   0.2660441,   0.1028303,   0.01242387,   // Beach
                   0.3511555,   0.257296,    0.2234351,   0.1559964,   0.01211689,   // Rocky
                   0.00202025,  0.02402113,  0.2507097,   0.7089995,   0.01424942,   // Forest
                   0.005789624, 0.02520239,  0.205275,    0.743661,    0.02007203);  //
Developed  ;
        numcases =
                                // landclass
                  (2.414176e7,   // Subaqueous
                   6.124416e6,   // Marsh
                   1.694238e6,   // Beach
                   1.02419e5,    // Rocky
                   5.665636e6,   // Forest
                   4.508065e6);  // Developed  ;
        title = "Elevation (m)";
        whenchanged = 1555099577;
        belief = (0.3394955, 0.1778388, 0.1962494, 0.2798874, 0.006528887);
        visual V1 {
                center = (162, 150);
                height = 1;
                };
        };
ElimOrder = (landclass, demMHW_m);
};
```

References:

Gesch, D.B, The national elevation dataset, chap. 4 of Maune, D.F., ed., *Digital elevation model technologies and applications—The DEM users manual (2d ed.*) (pp.99-118). Bethesda, Md.: American Society for Photogrammetry and Remote Sensing.

McGarigal K, Compton BW, Plunkett EB, Deluca WV, & Grand J.: *Designing sustainable landscapes: DSLland and Subsysland.* Report to the North Atlantic Conservation Cooperative, US Fish and Wildlife Service, Northeast Region: (http://jamba.provost.ads.umass.edu/web/LCC/DSL_documentation_DSLland.pdf), 2017.

National Oceanic and Atmospheric Administration National Geophysical Data Center, U.S. coastal relief model: National Oceanic and Atmospheric Administration National Geophysical Data Center Web page, last access 9 June 2014 at http://www.ngdc.noaa.gov/mgg/coastal/crm.html.