Land Loss Along the Atlantic Coast

Identification

1. Description

This regional feature measures the net area of undeveloped coastal land that has converted to open water since 1996, in approximately five-year increments (lustrums). Separate data series are provided for the net conversion of dry land to water, nontidal palustrine wetlands to water, and tidal wetland to water. The net conversion of land to open water is the sum of these three measures.

The submergence of coastal land is the most fundamental impact of rising sea level. Nevertheless, factors other than rising sea level can convert land to water. Conversion of dry land to wetland can also result from coastal submergence, but such conversions are not included in this regional feature.

Components of this regional feature include:

- Cumulative land area converted to open water, by region (Mid-Atlantic and Southeast) (Figure 1)
- Cumulative undeveloped land area converted to open water, by type of land lost (dry land, tidal wetland, non-tidal wetland) (Figure 2)

2. Revision History

May 2014: Feature published.

Data Sources

3. Data Sources

The regional feature is based on changes in land cover as mapped by the National Oceanic and Atmospheric Administration's (NOAA's) Coastal Change Analysis Program (C-CAP). This program produces a nationally standardized database of land cover and land change information for the coastal regions of the United States. C-CAP provides inventories of coastal intertidal areas, wetlands, and adjacent uplands with the goal of monitoring these habitats by updating the land cover maps every five years (see: https://coast.noaa.gov/digitalcoast/tools/lca). For background information about C-CAP, see Dobson et al. (1995).[1]

C-CAP has coverage for 1996, 2001, 2006, and 2011, making it possible for this feature to provide estimates of change for three lustrums. This data set is derived primarily from the data provided by the Landsat satellites, which have collected images of the Earth's surface since 1972.

---

[1] Dobson et al. (1995) provide extensive details on the original conceptualization of the C-CAP data set, but many of the details in that report do not accurately describe C-CAP as it exists today.

C-CAP is a key contributor to the federal government's Multi-Resolution Land Characteristics Consortium (MRLC), a group of federal agencies dedicated to providing digital land cover data and related information for the nation (Homer et al., 2007). The signature product of that effort is the National Land Cover Database (NLCD), which is the federal government's primary data set depicting land use and land cover in the contiguous United States. For the years 2001, 2006, and 2011, C-CAP is the source for the NLCD within the coastal zone (Vogelmann et al., 2001; Homer et al., 2007; Fry et al., 2011; Xian et al., 2011). C-CAP also has coverage for 1996.[2]

4. Data Availability

The C-CAP data set is available for the contiguous United States for the years 1996, 2001, 2006, and 2011 on NOAA's website at: https://coast.noaa.gov/dataregistry/search/collection/info/ccapregional?redirect=301ocm. This site provides downloadable data files, an online viewer tool, and metadata.

Methods

5. Data Collection

This regional feature is based on the C-CAP data set. Creation of the data involves remote sensing, interpretation, and change analysis.

Remote Sensing

C-CAP is derived from the data provided by a series of Landsat satellites, which have collected imagery of the Earth's surface since 1972. Landsat is jointly managed by the U.S. Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA).

As Irish (2000) explains:

> The mission of the Landsat Program is to provide repetitive acquisition of high resolution multispectral data of the Earth's surface on a global basis. Landsat represents the only source of global, calibrated, high spatial resolution measurements of the Earth's surface that can be compared to previous data records. The data from the Landsat spacecraft constitute the longest record of the Earth's continental surfaces as seen from space. It is a record unmatched in quality, detail, coverage, and value. (Irish, 2000: p.2)

The Landsat satellites have had similar orbital characteristics. For example, Landsat 7 and Landsat 8 orbit the earth 14.5 times each day, in near-polar orbits. The orbit maintains the same position relative to the sun, so as the Earth rotates, each orbital pass collects imagery to the west of the previous orbit—about 1,600 miles to the west at the equator. The "sun-synchronous" orbit means that each pass takes place between about 9:00 a.m. and 10:30 a.m., depending on latitude. Each pass can collect imagery along a path that is approximately 120 miles wide, leaving gaps between successive passes. The gaps are filled

[2] Before 2001, C-CAP and the NLCD diverge. The NLCD's first (and only other) year of coverage was 1992 (Vogelmann et al., 2001). The NLCD's procedure for interpretation changed for subsequent years.

during the following days, because each day's orbits are approximately 100 miles west of the previous day's orbits (at the equator). It takes 16 days to complete the entire pattern.

The Landsat data provide multispectral imagery. That imagery is somewhat analogous to an electronic picture file: for each pixel in a picture, a digital camera measures the intensity of red, blue, and yellow light and stores these data in a file. Similarly, Landsat measures the intensity of light from different portions of the electromagnetic spectrum for each pixel, including data from both the visible and infrared wavelengths. Landsat imagery has a pixel size of approximately 30 x 30 meters.

For more information about the Landsat program, see: http://landsat.gsfc.nasa.gov/ and the resources cited therein.

Interpretation

Just as people can detect most (but not all) of what they see based on the colors their eyes perceive, geospatial analysts are able to detect whether the Earth's surface in a given 30 x 30 meter pixel is open water, vegetated wetlands, forest, grassland, bare intertidal lands (e.g., beaches and mudflats), or developed, based on the visible and infrared energy coming from a given pixel:

- Beach sand strongly reflects in all wavelengths.
- Clear, deep water strongly absorbs in all wavelengths.
- Sediment-laden water reflects visible wavelengths more than clear water, but reflects infrared wavelengths similarly to clear water.
- Vegetation strongly absorbs visible wavelengths and strongly reflects infrared.
- Marshes can be distinguished from dry land because the wet marsh soils absorb more light than the soil surface of the adjacent dry lands.

The classification of pixels based on the light emitted does not identify the land cover class everywhere. For example, tidal wetlands and sloped dry land on the southeastern side of an estuary might be difficult to distinguish with only remote sensing data: pixels may appear darker either because the land absorbs more energy due to wet soil conditions or because it is sloped toward the northwest and thus receives less light in the morning than would the identical land cover on flat ground—and it might even be in a shadow. The geospatial analysts who create the data generally obtain other information. For example:

- Information about land slopes and terrain can distinguish whether the land is sloped or flat.

- Data from the U.S. Fish and Wildlife Service's National Wetlands Inventory (NWI) also help distinguish dry land from wetlands and distinguish wetland types.

- Information on soil drainage characteristics is also useful in identifying wetland areas—for example, data from the U.S. Department of Agriculture's National Cooperative Soil Survey: http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm.

MRLC has developed a standardized approach for using remote sensing imagery to classify land cover (Homer et al., 2007). The C-CAP data set divides the land surface into 24 categories (NOAA, undated) which follow the MRLC classes, except where C-CAP needs more detail. Table TD-1 shows the relationship between C-CAP and NLCD data categories. C-CAP uses the Anderson et al. (1976) Level 2 classification system for dry land.

Table TD-1. Relationship Between C-CAP Land Cover Categories and Other Classification Systems

Anderson Level 1	NLCD category	C-CAP category[a]
Urban or Built-up Land (1)	Developed, High Intensity (24)	High Intensity Developed (2)
	Developed, Medium Intensity (23)	Medium Intensity Developed (3)
	Developed, Low Intensity (22)	Low Intensity Developed (4)
	Developed, Open Space (21)	Open Space Developed (5)
Agricultural Land (2)	Cultivated Crops (82)	Cultivated Land (6)
	Pasture/Hay (81)	Pasture/Hay (7)
Rangeland (3)	Grassland/Herbaceous (71)	Grassland (8)
	Scrub/Shrub (52)	Scrub Shrub (12)
Forest (4)	Deciduous Forest (41)	Deciduous Forest (9)
	Evergreen Forest (42)	Evergreen Forest (10)
	Mixed Forest (43)	Mixed Forest (11)
Wetlands (6)	Woody Wetlands (90)	Palustrine Forested Wetlands (13)
		Palustrine Scrub Shrub Wetlands (14)
		Estuarine Forested Wetlands (16)
		Estuarine Scrub Shrub Wetlands (17)
	Emergent Herbaceous Wetlands (95)	Palustrine Emergent Wetlands (15)
		Estuarine Emergent Wetlands (18)
Open Water (5)	Open Water (11)	Open Water (21)
		Palustrine Aquatic Bed (22)
		Estuarine Aquatic Bed (23)
Barren Land (7)	Barren Land (31)	Unconsolidated Shore (19)[b]
		Barren Land (20)
Tundra (8)		Tundra (24)
Perennial Ice/Snow (9)	Perennial Ice/Snow (12)	Perennial Ice/Snow (25)

a Category 1 is land that could not be otherwise classified, and does not apply to any locations along the Atlantic coast in the C-CAP data set.

b The Unconsolidated Shore class refers to lands below the daily high water mark. Dry beaches, unvegetated sand spits, and similar areas are classified as Barren Land.

Source: NOAA: https://coast.noaa.gov/dataregistry/search/collection

For wetlands, C-CAP uses the more detailed categories from Cowardin et al. (1979), which are also used by the NWI. C-CAP uses NWI data to distinguish estuarine from freshwater wetlands. The NWI maps by themselves are insufficient for coastal change, because they are updated so infrequently that digital maps are only available for one or two years, which vary from state to state.[3] Nevertheless, the NWI

[3] Along the portion of the Atlantic Coast covered by this feature, NWI maps have been updated since the year 2000 for only five states: New York (2004), Delaware (2007), North Carolina (2010), Georgia (2004–2007), and Florida south of Volusia County (2006–2010). See "Wetlands Mapper" in U.S. FWS (undated).

maps are useful for identifying the wetland class that corresponds to a given spectral signature at a given location.

Even though Landsat provides an image every 16 days, the C-CAP data are intended to represent land cover for a given year, based on data collected throughout that year—and if necessary, the preceding year. Interpretation of the Landsat data to create land cover data may require examination of many Landsat images for each location simply to find one or two that are useful. For some locations, no available imagery from a given year shows the land cover, so NOAA uses the preceding year. Distinguishing dry land and some tidal wetlands from open water requires obtaining images close to low tide. That rules out the majority of images, which are taken when the water is higher than at low tide. During winter, ice and snow cover can prevent a correct interpretation of whether a pixel is even open water or dry land, let alone the type of land. Because some types of vegetation become green sooner than others, distinguishing among those types of land cover may require imagery from a very specific time in the spring. Even when the tides and ground surfaces are perfect for measuring land cover, clouds may obscure the image on the morning that the satellite passes.

C-CAP's five-year increment represents a balance between the cost of data interpretation and the benefits of more observations.

Change Analysis

Most of the climate change indicators in this report depict change over time based on data that are measured in the same way continuously, daily, or at least once a year. While the same instruments might be used from year to year, a different measurement is taken each year, or a different annual measurement is derived from many measurements taken throughout the year. In theory, the C-CAP data could be created by following the same process once every five years, completely reinterpreting the data each time. C-CAP uses a different procedure, though, as NOAA (https://coast.noaa.gov/dataregistry/search/collection) explains:

- Change detection analysis compares the two dates of imagery to identify the areas that have likely changed during this time frame. These areas are then classified through a combination of models, use of ancillary data, and manual edits…. The classified land cover for these areas of change is then superimposed over the land cover from the original date of analysis, to create a new wall-to-wall classification for the second time period.

- Many of the areas that are identified as potentially changed in the change detection and masking may be changes that do not result in a change in class. Agricultural field rotation or forest stand thinning are two examples.

- Remapping only areas that contain change leads to greater efficiency and more consistent data through time than would procedures that remap the full land cover for an area for each time period. By looking only at areas that have changed, we remove any difference that could result from differences in interpretation. This method also reduces cost, since only a small percentage of the total area must be classified in the change product (i.e., typically less than 20% of any area changes in a five-year period).

6. Derivation

This section describes a general approach for measuring coastal submergence with the C-CAP data. Some categories of change are more definitive than others. Although the regional feature focuses on the conversion of undeveloped land to open water, the entire approach is presented to permit a more thorough review of the methods and possible limitations of the data. For the purposes of this analysis, the Mid-Atlantic region is defined as New York, New Jersey, Delaware, Maryland, and Virginia; the Southeast includes North Carolina, South Carolina, Georgia, and the Atlantic coast of Florida (including all of Monroe County).

Simplifying the Land Classification

The first step was to group the C-CAP land classes into four general classes relevant for measuring the possible submergence of coastal land, as shown in Table TD-2: dry land, palustrine (largely nontidal, freshwater) wetlands, tidal wetlands, and open water. The developed land categories are omitted for two reasons:

1. Developed lands are generally protected from shoreline erosion and rising sea level (Titus et al., 2009), and thus rarely convert to tidal wetlands or open water.

2. Although conversion of open water or tidal wetlands into developed land is rare (and strongly discouraged by environmental regulations), the C-CAP data erroneously show it to have occurred in many locations.[4]

Given the exclusion of developed lands, this regional feature should be construed as measuring submergence of undeveloped lands.

Table TD-2. Reclassification for Evaluating Coastal Land Submergence

Land conversion category	C-CAP classification
Undeveloped Dry Land	6–12 and 20
Palustrine Wetlands	13, 14, and 15
Tidal Wetlands	16, 17, 18, 19
Open Water	21–23

Distinguishing Coastal Land Loss from Upland Changes

As a general rule, when all four general categories are present, dry land is inland and higher than nontidal (palustrine) wetlands, which are higher than tidal wetlands, which are higher than open water. Rising sea level tends to cause a higher category to convert to a lower category, and conversion from a higher to lower category might indicate coastal submergence. Conversions from a lower to a higher

[4] When the data show a new coastal development, sometimes pixels along the shore are shown as converting from water to developed land when, in reality, the only change has been that the part of the pixel that was originally undeveloped land has converted to developed land. New docks and boats sometimes show up as new developed land. Pre-existing bridges sometimes show up as open water converting to developed land.

category, by contrast, may indicate natural land accretion or fill activities, which generally require a permit. In addition to actual conversions, the data may show conversions in either direction due to "measurement error" resulting from the imperfections of interpreting remote sensing data.

This analysis focuses on the net conversion between categories rather than the total change in each direction, because measurement error and shoreline processes unrelated to submergence have less effect on net conversion than on the conversion in a particular direction. For example, a slight shift in the grid that defines pixel boundaries can cause apparent land gain in some places and land loss in others. Given the relative stability of most shores, these errors are more likely to cause the data to show spurious changes—in both directions—than to hide actual changes. Inlet migration and other shoreline processes may cause the shore to accrete in one place and erode nearby, and such shifts do not represent coastal submergence.

Table TD-3 summarizes the relationship between coastal submergence and the types of coastal change shown by the four land categories. Figure TD-1 illustrates two example environments. Both the table and the figure distinguish three types of conversions: those that are included in the regional feature; those that could generally be included in a land loss indicator, but are excluded from this edition of the regional feature because additional review is needed; and conversions that might result from coastal submergence, but are often caused by unrelated factors.

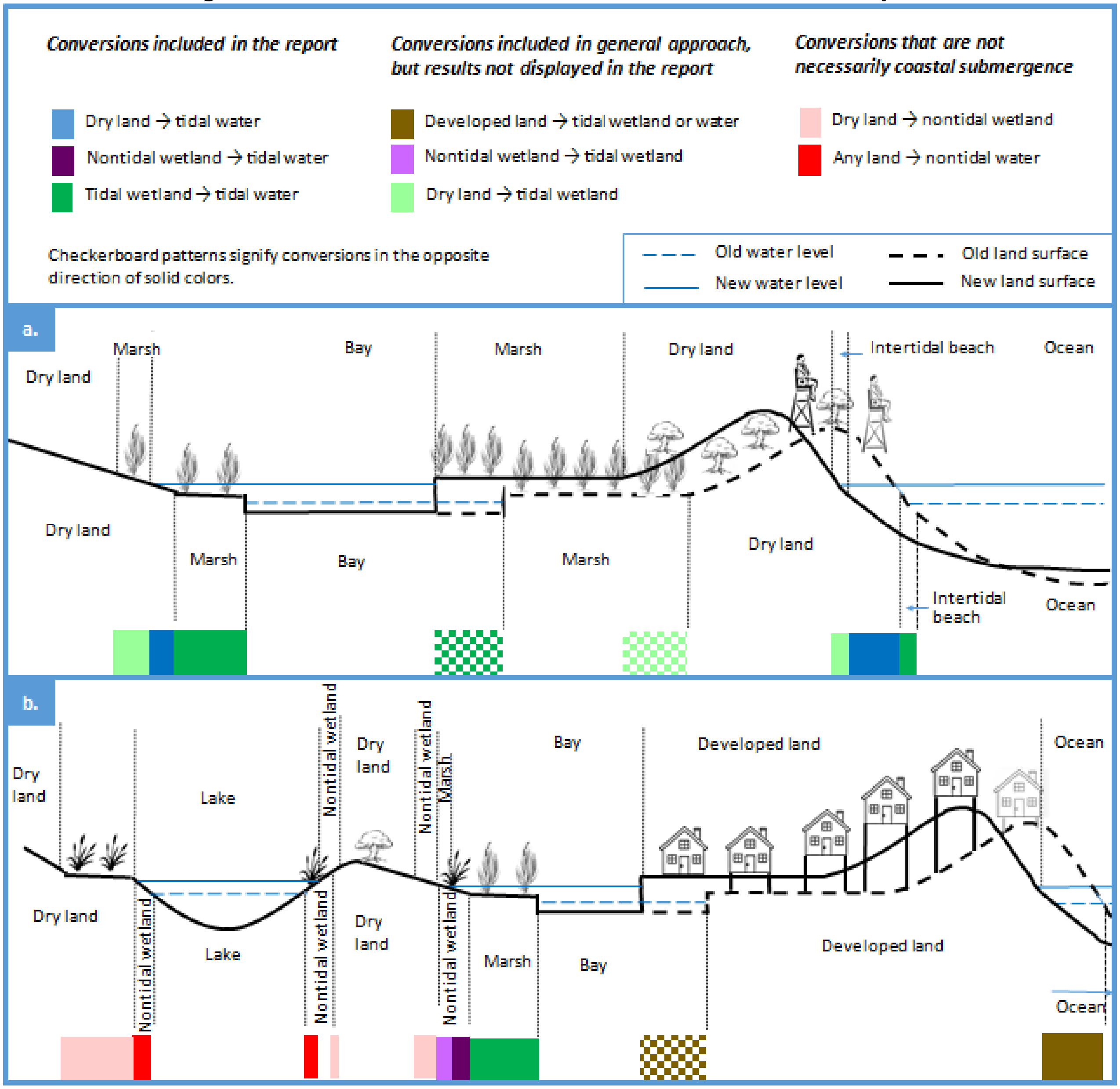
Conversion of land to tidal open water generally is an indicator of coastal submergence. Because remote sensing is well-suited to distinguishing land from open water, the regional feature includes conversion of land to open water, as shown in the final column of Table TD-3.

Table TD-3. Does Conversion Between Classes Generally Represent Coastal Submergence?

From↓ To→	Dry land	Palustrine[b]	Tidal wetland[c]	Open water
Dry land[a]		No	No[e]	If tidal[d]
Palustrine wetland[a]	*		No[e]	If tidal[d]
Tidal wetland[b]	*	*		Yes
Open water	*	*	*	

a Changes involving developed lands, C-CAP categories 2–5, are excluded from the feature, but would represent coastal land loss.
b "Palustrine" includes tidal freshwater wetlands.
c "Tidal wetland" includes both "estuarine wetlands" and "unconsolidated shore," but the C-CAP data set does not distinguish tidal freshwater wetlands from nontidal palustrine wetlands.
d "If tidal" means that an additional data set is used to determine whether the open water is tidal or nontidal.
e Net conversions from dry land and palustrine wetlands to tidal wetlands would generally represent net coastal submergence, but additional review of the data is necessary to ascertain whether C-CAP provides a representative measurement of such conversions.
* Treated as an offset to conversion in the other direction, when calculating net conversion.

Figure TD-1. Land Conversions Included and Excluded in this Analysis



Both sketches show a barrier island that migrates inland and submergence from higher water levels along the mainland shore. (a) On the ocean side, the undeveloped dry land converts to intertidal beach, and beach to open water. The landward transport of sand, however, elevates land surfaces on the bay side, which converts some shallow water to marsh and some marsh to dry land. On the mainland shore, dry land converts to tidal wetland, and tidal wetland coverts to open water. The regional feature in the Indicators report includes the net conversions to open water, but because additional review is required, it does not include conversions between dry land and tidal wetlands. (b) The barrier island migrates as in (a), but the regional feature does not include conversions involving developed lands. Farther inland, the rising bay leads to a higher water table, which in turn saturates some soils enough to convert dry land to nontidal wetlands, and raises the level of the nearby freshwater lake. The higher lake also converts previously dry land to nontidal wetlands, and nontidal wetlands to nontidal open water. Although the conversion in this particular case might be attributed to rising sea level, in general, lake shorelines and the boundaries of nontidal wetlands change for many reasons unrelated to rising sea level. Therefore, this analysis does not treat changes in nontidal open water or conversions of dry land to nontidal wetlands as a form of coastal submergence.

Conversion of dry land or palustrine wetlands to tidal wetlands is one of the more commonly discussed consequences of sea level rise (e.g., Titus et al., 2009; Titus, 2011), and it would generally indicate coastal submergence. Additional review is necessary, however, to ensure that the C-CAP data provide a representative estimate of the net conversion of these relatively high lands to tidal wetlands.

Finally, this feature excludes net conversion of dry land to palustrine wetlands, because those conversions do not necessarily indicate coastal submergence. Rising sea level can cause low-lying dry land to convert to palustrine wetlands under a variety of circumstances. Yet most palustrine wetlands are substantially above sea level, and conversions of dry land to palustrine wetlands at substantial elevations are unrelated to coastal submergence. No multi-state data set is available to distinguish conversions caused by submergence from those that are not.

Classifying Open Water Conversions as Tidal or Nontidal

If dry land converts to *tidal* open water (e.g., beach erosion or bluff erosion), then coastal land is lost. Yet dry land might convert to *nontidal* open water if a pond is excavated for agricultural, stormwater, or industrial purposes—or if the water level in a lake happens to be higher because it was a wet year. C-CAP does not distinguish between tidal and nontidal open water, so it was necessary to use additional data sets, discussed below.

Many wetlands data sets keep track of whether open water is tidal or nontidal. Unfortunately, they are not revised with a regular five-year frequency, and many of them are relatively old. Thus, using them to distinguish coastal land loss from upland land conversion might require considerable interpretation, analogous to the effort that was necessary to distinguish tidal from nontidal wetlands in the C-CAP data set.

An alternative approach, followed here, is to use available elevation data as a proxy for whether land converts to or from tidal or nontidal open water. While the vintage of high-resolution elevation data varies, it is generally more recent than 2006 and in some cases more recent than 2011. With the exception of high bluffs in a few areas, if high-elevation land becomes open water, it is not coastal land loss, and if land of any elevation becomes high-elevation water, it is virtually never coastal land loss. Similarly, it is virtually never coastal land gain when water becomes land if either the land or the water has a high elevation.

Conversely, nontidal open water is rare within 1 meter above mean high water (MHW), except for artificially managed bodies of water such as Florida's water management canals. If newly created land has an elevation within about 50 centimeters (cm) above spring high water, it is likely to be coastal land accretion; and if land below 1 meter converts to open water, it is almost always tidal open water. The same situation largely pertains when the elevation of the water surface is close to sea level, with one caveat: Elevation of water bodies based solely on lidar sometimes provides an erroneously low reading, so a different data source is necessary for elevation of water surfaces.

In light of these considerations, EPA's approach defines the coastal area vulnerable to inundation as follows:

- Include land and water within 100 meters of the open coast—including large bays and sounds—to account for shore erosion and accretion.[5]

- Include land and water less than 3 feet above mean higher high water (MHHW), based primarily on the NOAA sea level rise viewer data for land elevations, but also based on USGS 7.5-minute quadrangles where lidar elevation data are unavailable (i.e., open water areas and certain locations not yet covered by lidar). Exclude dry land, nontidal wetlands, and open water above that elevation.

- Include all tidal wetlands regardless of measured elevation.

- Exclude conversions that are clearly the result of mining or construction projects, unless the water elevations are below MHHW. Beach nourishment projects that reclaim land from the sea are treated as land gain; excavations near the shore that create open water are treated as land loss.

The 3-foot elevation cutoff was chosen to ensure that all lands within approximately 1 foot above the tidal wetland boundary are included. In areas with a large tide range, high marsh generally extends up to spring high water, which can be 1 to 2 feet above MHHW. In areas with negligible tides, high marsh can extend 1 to 2 feet above MHHW as a result of wind generated tides. The 3-foot layer would thus include all land that is within 1 to 2 feet above the tidal-wetland boundary.

To account for potential measurement error in the lidar data, the NOAA sea level rise viewer provides a confidence layer, i.e., lidar-based data sets that identify land whose measured elevation is—with a high degree of confidence—less than a given distance above MHHW. For example, the 3-foot layer (which this analysis uses) includes all land whose elevation above MHHW is less than 3 feet plus the root mean squared error of the elevation data. For further details, see Schmid et al. (undated).

NOAA's data layer does not include elevations for lakes and ponds, because lidar does not measure elevations of water surfaces. (The data layer provides values for the purposes of the viewer, but those values do not represent measured elevations.) Fortunately, other elevation data sources with less accuracy, such as USGS topographic maps, avoid this problem. Thus, EPA used a second data set to remove any locations shown to be above 10 feet in places where lidar does not provide an elevation, such as inland lakes.[6]

Results: Land Cover Change Matrices

Tables TD-4 and TD-5 are region-specific change matrices, which quantify changes between the four primary land cover categories for each of the three lustrums, along with the corresponding cumulative net change. Each table provides the extent of change in square miles, which is found by dividing pixel counts by 2,878 (the number of 30 x 30 meter pixels per square mile).

---

[5] This version of the regional feature relies on visual inspection of the results to ensure that shoreline areas are not excluded, which was feasible because bluff erosion is not a major factor in the Mid-Atlantic or Southeast. This step could also be automated using a shoreline data file.

[6] This version of the regional feature relies on visual inspection of inland lakes and USGS 7.5-minute quadrangles, but it could also be automated using the USGS National Elevation Data Set.

The final column in each table shows the net change of undeveloped land to open water compared with the 1996 baseline, as shown in Figures 1 and 2 of this regional feature. For transparency, the tables below include the other conversion categories.

Table TD-4. Results for the Mid-Atlantic Region

Change matrix: 1996 2001 (square miles)				
From↓ To→	Upland	Palus-trine	Tidal wetland	Water
Upland	1,555.90	2.19	2.22	1.28
Palus-trine	3.37	995.57	0.25	0.09
Tidal wetland	0.95	0.28	1,148.9	0.91
Water	1.44	0.73	29.23	9,165.5

Net change: 1996 2001 (square miles)				
From↓ To→	Upland	Palus-trine	Tidal wetland	Water
Upland	NA	-1.18	1.27	-0.16
Palus-trine		NA	-0.02	-0.64
Tidal wetland			NA	-0.76
Water				NA
Total change	0.07	-0.51	2.00	-1.56

Change matrix: 2001 2006 (square miles)				
From↓ To→	Upland	Palus-trine	Tidal wetland	Water
Upland	1,562.63	0.26	0.34	3.03
Palus-trine	10.72	999.42	0.05	2.07
Tidal wetland	5.03	0.11	1,136.58	6.56
Water	3.53	0.50	23.22	9,162.81

Net change: 1996 2006 (square miles)				
From↓ To→	Upland	Palus-trine	Tidal wetland	Water
Upland	NA	-11.64	-3.42	-0.66
Palus-trine		NA	-0.08	0.92
Tidal wetland			NA	4.80
Water				NA
Total change	15.71	-12.48	-8.30	5.07

Change matrix: 2006 2011 (square miles)				
From↓ To→	Upland	Palus-trine	Tidal wetland	Water
Upland	1,601.01	2.73	2.51	2.22
Palus-trine	4.59	964.30	0.14	0.52
Tidal wetland	0.56	0.03	1,132.68	1.43
Water	0.76	0.80	23.92	9,135.99

Net change: 1996 2011 (square miles)				
From↓ To→	Upland	Palus-trine	Tidal wetland	Water
Upland	NA	-13.49	-1.46	0.80
Palus-trine		NA	0.03	0.65
Tidal wetland			NA	2.10
Water				NA
Total change	14.16	-14.17	-3.54	3.55

Table TD-5. Results for the Southeast Region

Change matrix: 1996 2001 (square miles)				
From↓ To→	Upland	Palus-trine	Tidal wetland	Water
Upland	3,178.58	30.65	3.48	4.97
Palus-trine	37.30	4,044.46	2.37	3.24
Tidal wetland	3.97	1.74	2,222.16	8.44
Water	3.07	2.13	155.28	11,485.13

Net change: 1996 2001 (square miles)				
From↓ To→	Upland	Palus-trine	Tidal wetland	Water
Upland	NA	-6.65	-0.49	1.91
Palus-trine		NA	0.63	1.12
Tidal wetland			NA	5.35
Water				NA
Total change	5.23	-8.40	-5.21	8.38

Change matrix: 2001 2006 (square miles)				
From↓ To→	Upland	Palus-trine	Tidal wetland	Water
Upland	3,235.55	0.38	0.71	3.89
Palus-trine	16.12	4,115.13	0.02	1.35
Tidal wetland	3.08	0.21	2,243.94	4.02
Water	1.94	0.70	150.37	11,568.98

Net change: 1996 2006 (square miles)				
From↓ To→	Upland	Palus-trine	Tidal wetland	Water
Upland	NA	-22.39	-2.86	3.87
Palus-trine		NA	0.44	1.76
Tidal wetland			NA	7.40
Water				NA
Total change	21.39	-24.59	-9.83	13.03

Change matrix: 2006 2011 (square miles)				
From↓ To→	Upland	Palus-trine	Tidal wetland	Water
Upland	3,258.45	1.52	1.75	2.92
Palus-trine	12.10	4,101.05	0.03	3.24
Tidal wetland	3.60	0.10	2,228.67	2.94
Water	1.98	1.97	150.25	11,570.33

Net change: 1996 2011 (square miles)				
From↓ To→	Upland	Palus-trine	Tidal wetland	Water
Upland	NA	-32.97	-4.71	4.81
Palus-trine		NA	0.38	3.03
Tidal wetland			NA	8.60
Water				NA
Total change	32.87	-36.38	-12.93	16.43

7. Quality Assurance and Quality Control

Thorough documentation of the quality assurance and quality control (QA/QC) methods and results is available in the technical references for the NLCD and C-CAP. Publications are available at: https://coast.noaa.gov/dataregistry/search/collection. Accuracy assessments have been conducted for the NLCD (Wickham et al., 2010, 2013) and for C-CAP (e.g., Washington Department of Ecology, 2013; NOAA, 2013).

Analysis

8. Comparability Over Time and Space

The same general data collection and analytical techniques have been applied for all of the time periods covered by this regional feature. Nevertheless, the methods are not precisely the same for all periods of time, because the C-CAP data for the year 2001 are based on remote sensing from that year, while the C-CAP data for other years are based on a combination of the remote sensing from 2001 and change analysis using 2001 as a base year.

C-CAP employs the same procedures for all locations, except for those differences that inherently result from differences in land cover. The use of ancillary wetlands data, for example, is greater in areas with the greatest amount of wetlands.

9. Data Limitations

Factors that may affect the confidence, application, or conclusions drawn from this regional feature generally fall into two categories: limitations in scope and limitations of accuracy.

1. The scope of this feature does not perfectly match the submergence of coastal land caused by changing climate. By design, the feature is under-inclusive because it omits the following types of coastal submergence:

    - Conversion of developed land to water
    - Conversion of dry land to tidal wetland
    - Conversion of dry land to nontidal wetlands resulting from higher water levels

    The feature is also over-inclusive, in that:

    - Only a portion of relative sea level rise is caused by climate change, so only a portion of land conversions from sea level rise are attributable to climate change.
    - Land can convert to tidal open water for reasons unrelated to relative sea level rise, including wave-induced erosion, invasive species or changes in hydrology that kill marsh vegetation, and construction of canals. Also, shore protection and infrastructure projects can convert water to dry land.

2. The accuracy of this feature has not been assessed, and there are reasons to expect significant error. See Section 10 for additional discussion of accuracy and possible sources of uncertainty.

10. Sources of Uncertainty

This regional feature is based on the sum of many pixels, relying on the assumption that the land or water class assigned to a given pixel applies to the entire pixel. Along the shore, however, pixels are part land and part water. Thus, the feature's accuracy is limited by both the accuracy and interpretation of individual pixels (map accuracy), and by the extent to which errors at the pixel level tend to accumulate or offset one another (bias).

Map Accuracy: Interpretation of Individual Pixels

Accuracy Assessments

Accuracy of C-CAP pixels is limited by the factors present in all land cover data sets. Accuracy assessments of the NLCD (Wickham et al., 2010, 2013) suggest that individual pixels are mapped with approximately 79 percent accuracy for all of the NLCD (Anderson Level 2) categories, and 84 percent accuracy when aggregated to the Level 1 categories (Wickham et al., 2013). These assessments do not differentiate coastal from inland areas—and they may have excluded some shorelines.[7]

Accuracy assessments of C-CAP in Washington state and the western Great Lakes found similar overall accuracy. When categories are aggregated to dry land, wetland, and open water—as this feature does—the accuracy was 95 percent and 96 percent, respectively (Washington Department of Ecology, 2013; NOAA, 2013).

The most recent accuracy assessment of the NLCD has also evaluated the accuracy with which the data capture *changes* in land cover between 2006 and 2011. Wickham et al. (2013) found that the overall accuracy of whether land cover changed was approximately 95 percent—higher than the accuracy of individual pixels, although that higher accuracy is largely driven by the fact that an overwhelming majority of pixels do not change and that fact is correctly captured by the data. Within the sample, the NLCD and the high-resolution information agreed that there was no change for 97.24 percent of the cells, and that there was a change for 1.43 percent of the cells. For 1.04 percent of the cells, however, the NLCD failed to notice actual change, while for 0.263 percent, the NLCD incorrectly found that change had occurred. Thus, 84.5 percent of the change detected by NLCD actually occurred (user accuracy), but the NLCD only picked up 57.4 percent of the actual change (producer accuracy). The higher-resolution data showed that 2.5 percent of the pixels changed, while the NLCD only shows 1.7 percent of the cells as having changed. Stehman and Wickham (2006) show, however, that this type of analysis cannot necessarily provide a statistically valid estimate of the accuracy of estimates of net change, and that the necessary accuracy assessment for all of the NLCD classes of change would be cost-prohibitive.

Land loss or land gain detected by NLCD appears to be more accurate than estimated shifts from one class of land to another. Wickham et al. (2013) found accuracies of 76 percent, 80 percent, and 93 percent when the NLCD detected land loss, land accretion, or open water remaining as water, respectively (user accuracy). NLCD is considerably less successful at detecting actual land loss and land gain (producer accuracy): when a high resolution data source detected land loss, land accretion, or water remaining as water, C-CAP matched the high-resolution data for only 21 percent, 39 percent, and 86 percent of the cells, respectively (Wickham et al. 2013, p. 301).

The accuracy assessments of the C-CAP change analyses did not collect sufficient data to make class-specific estimates of accuracy. Unlike the assessments of the NLCD, the C-CAP accuracy assessments

[7] To ensure that the accuracy assessment results for open water were not unduly affected by large bodies of water, large bodies of water such as Pamlico Sound, Chesapeake Bay, and the oceans were deliberately excluded. Imprecision in the shoreline files used to exclude large bodies of water may have also excluded the shore itself.

generally show that C-CAP detects *more* change than higher-resolution data. For example, the Washington state assessment found a user accuracy of 45 to 50 percent and a producer accuracy of 63 to 80 percent for the case where land cover changes (Washington Department of Ecology, 2013, pp. 6–8). That study did not measure the accuracy associated with conversions between land and water.

Possible Sources of Mapping Error

No comprehensive catalogue of mapping error is available for C-CAP. The following three sources are potentially significant:

- **Tidal variations.** From lustrum to lustrum, the remote sensing imagery may be based on different positions of the tides. NOAA attempts to ensure that all data are based on a consistent position of the tides, but some variation is inevitable because the time of the tides varies. With approximately 22 observations per year and a low tide every 12½ hours, only two images per year would be taken during the hour of low tide.[8] (See discussion of remote sensing in Section 5.) Those two images may both be obscured by clouds or leaves in some locations, requiring the use of images more than 30 minutes before or after high low. Even if neither clouds nor trees obscure the image, the elevation of low tide varies greatly over the course of the year. The spring tide range (full and new moons) is often about 50 percent greater than the neap-tide range (quarter moons), and the two low tides on a given day also have different heights. Winds can also cause water levels to diverge from what would be expected based solely on the astronomic tides. Thus, even in an area where the shoreline does not change, C-CAP might show land loss for a given time period if the first image is taken at a relatively low tide while the second image was taken at a relatively high tide. This is especially the case along mudflats and beaches, where wet soils rather than vegetation lines control the zonation.

- **Conversion to tidal open water from excavation of ponds or lake-level changes.** Although remote sensing can detect the difference between land cover and open water, it cannot detect whether the open water is tidal. Instead, this regional feature relies on classifying open water based on elevation. This approach has several limitations:

    - High resolution elevation data are lacking for South Carolina and part of Florida.

    - High-resolution elevation data often mischaracterize water elevations, requiring visual inspection and/or reliance on secondary elevation data sources.

    - Nontidal open water exists at very low elevations in very flat areas.[9]

- **Conversion of land to coastal development.** C-CAP might erroneously show some cells along the shore as converting from water to land as a result of coastal development. A cell that is 50 percent water and 50 percent undeveloped land, for example, might be classified as water. If such a cell is developed as part of a larger development, the cell might be reclassified as

8 That is, the time of day is within the hour of high tide about 8 percent of the time, and 8 percent of 22 images per year is 1.7.

9 Including conversion of land to nontidal open water in very low-lying areas would not always be an error. For example, ponds may expand because sea level rise causes water tables to rise; or ponds are created by the mining of sand used to elevate the grade and thereby prevent inundation of other lands.

developed land. Thus, the cell might be classified as a change from water to developed land instead of a change from undeveloped to developed land.

Accuracy of this Regional Feature

Published accuracy assessments generally focus on the accuracy of individual pixels, not on the accuracy of the resulting estimates of proportions or sums. These assessments show that land cover data contribute a substantial amount of information and are often more useful than the available alternatives. Yet mixed pixels and systematic error can impair the reliability of an indicator based on the sum of many pixels, even when they are drawn from a reasonably accurate map. The focus of existing accuracy assessments on individual pixels does not address whether or not limitations in the data undermine the usefulness of the data for creating an indicator.

Methods have been developed and applied for assessing estimates of net change (Stehman and Wickham, 2006), but they have not been applied to C-CAP results. An accuracy assessment of this regional feature is necessary before confidence in it can be high. Comparison with an independent data set such as that used for the NWI Status and Trends reports (e.g. Dahl, 2006; Dahl, 2011; Dahl and Stedman, 2013) would be appropriate.

Mixed Pixels

Like most quantifications of land cover, this analysis makes the fundamental oversimplification that land cover is uniform within each cell. Challenges related to this "mixed pixel" problem (Fisher, 1997) can be safely disregarded if areas with homogenous land cover are large relative to the cell size. Conversely, in constructing an indicator of shoreline migration, the implications of mixed pixels must be part of the analysis because the shoreline consists of mixed pixels. The fact that shorelines generally change very little compared with the size of a pixel affects both accuracy at the pixel level and the accuracy of an indicator or feature based on the sum of pixel-level changes.

Over the course of five or even 15 years, most shorelines change by a small fraction of the 30-meter pixel width. Thus, a land-loss indicator based on the sum of many 30-meter pixels will only be useful if the pixels where the change is too small to be detected (and thus assumed to be zero) are roughly offset by pixels where the change is detected (and thus assumed to be 900 m^2). The error introduced by assuming that the entire mixed pixel is either water or land is a type of "scale error;" that is, the error becomes less, and eventually negligible, as pixel size decreases.[10]

Figure TD-2 illustrates the general case of small shoreline change relative to pixel size. The figure assumes that pixels with a majority of water are classified as water. While that threshold is usually higher,[11] the same concepts apply regardless of the threshold. Initially, seven of the 15 pixels along the

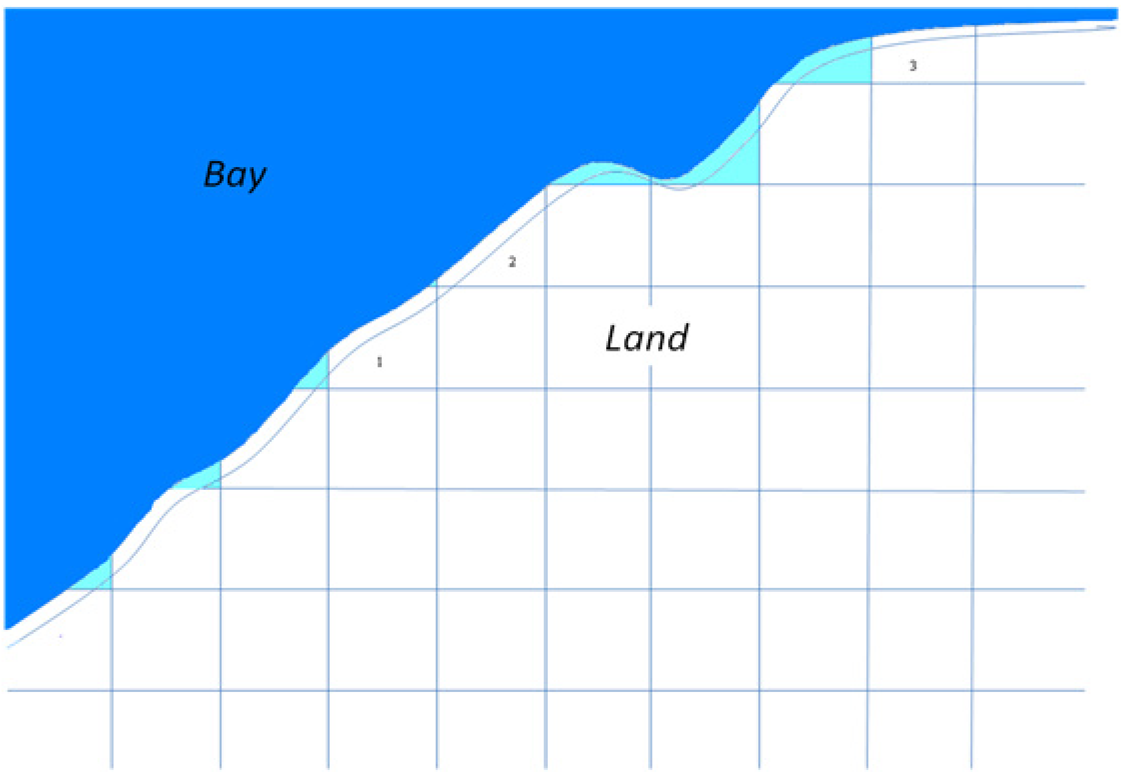
---

[10] Scale error is the rounding error necessitated by classifying a mixed pixel as one category or the other. One might define classification error as follows: $e_i = X_i - C_i$, where *X* is the true area of water and *C* is either 0 or 900 m^2. If there is no measurement error (i.e., $|e_{i,}|$<450 m^2 so that measurement error has no impact on C_i), then all error is scale error.

[11] In general, a pixel is classified as "water" if the spectral signature is more consistent with water than with land. The threshold for classifying a pixel as water varies with locations. The NLCD has consistently defined open water as areas with open water, "generally with less than 25% cover of vegetation or soil." See MRLC (undated) and Wickham et al. (2013), p. 295.

shore are more than 50 percent water, and the shoreline is about the length of 12 pixels. During a given time period, the shore retreats by about 1/6 of the width of a pixel, so the total land loss is about 2 pixels. Two pixels that had been entirely dry land become partly open water, and one pixel loses the small amount of land it originally had. At the end of the time period, the majority of the pixels labeled "2" and "3" are water; pixel "1" is approximately 50 percent water as well. With the assumed classification procedure, two or three pixels convert from land to water, which reasonably reflects the actual land loss of two pixels. The other 14 pixels where the land loss is undetected and rounded to zero are offset by these two or three pixels where land loss is detected and assumed to be the entire pixel.

Figure TD-2. Illustration of the "Mixed Pixel" Problem



This figure shows the impact of the "mixed pixel" problem when shoreline retreats a small fraction of the width of a pixel. In this conceptual map, dark blue represents open water and white represents land. Light blue shows the dry land portion of pixels classified as water at the beginning of the time period. Cells 1, 2, and 3 might be classified as open water after the shore erodes.

Scale error does not necessarily compromise the validity of an indicator based on the sum of all pixels. The grid that defines the pixel boundaries is set independently of the shoreline, so the pixel-specific scale error is random with a mean of zero.[12] Thus, while the scale error can be large at the scale of a

[12] The scale error for the mixed pixels would have a rectangular distribution from –450 m^2 to +450 m^2. Given the well-established moments of a rectangular distribution, the mean scale error is zero and σ_e^2 = 67,500 m^4; i.e., σ_e=260 m^2.

pixel, it should be very small for a shoreline 100 kilometers long.[13] Random measurement errors also tend to cancel and make a negligible contribution to a total.

Systematic Error

Measurement error is not always random. Systematic measurement errors tend to accumulate rather than cancel out as one calculates the total (e.g., see Cochran, 1977). Nevertheless, a systematic error concerning the *area* of water in a sum of mixed pixels does not necessarily provide a poor estimate of the *change* in the area of water (i.e., land loss). For example, if it were shown that C-CAP classifies cells with at least *H* percent water as being water, and *H* varies but is on the order of 20 or 30 percent, then C-CAP would overestimate the area of water among the mixed pixels in possibly unpredictable ways. Yet the estimated change could still be reasonably accurate,[14] as long as the procedure overestimates the area of water consistently.

The consistency of C-CAP's measurement error from period to period is not known. The procedures used to classify land cover during the base year differ from the procedures used during subsequent years, so it is possible that the measurement error is not consistent from year to year. Significant classification errors are possible: The tendency for the change analysis to discount small changes could mean that an indicator based on a sum of pixels does not fully reflect the land loss or gain caused by

---

[13] If scale error is uncorrelated across pixels and measurement error is negligible, the variance of the sum of pixels would be $\sigma_S^2 = \sum_i^N \sigma_e^2 = N$ 67,500 m^4. If the shoreline is 100 km, $N \approx 3{,}333$ so $\sigma_S^2 \approx$ 225,000,000 m^4 and $\sigma_S \approx$0.015 km^2. As Figure B shows, the scale error between adjacent cells is correlated, but that correlation becomes negligible more than five to 10 cells out. Conservatively assuming perfect correlation between the 10 adjacent cells, the standard deviation would be a factor of 10 greater, which is still negligible for a shoreline of 100 km or longer.

[14] For example, suppose that the probability that a pixel will be classified is an unknown function of X_i:

prob(class=water) ≡ prob(C_i=1) = F(X_i), with F(0)=0 and F(1)=1.

In this note, all areas are expressed in pixels rather than m^2. Among the mixed pixels, X_i is uniformly distributed between 0 and 1, so the expected value of the sum of pixels S_1 would be:

$$E(S_1) = N_w + N_m \int_0^1 F(y)dy,$$

where N_w and N_m are the number of all-water and mixed pixels, respectively. In the ideal case with no measurement error where F is a step function

$$F(X) = 0 \text{ for } X < 0.5 \text{ and } F(X) = 1 \text{ for } X \geq 0.5, \; E(S_1) = N_w + N_m/2.$$

Suppose shores erode by a consistent amount and convert an area of land equal to N_m z pixels to open water, where z is a small fraction (e.g., shores erode by approximately 30z meters, a small fraction z of the pixel dimension). The amount of water increases in every pixel by z, except for those pixels for which 1-X_i<z. Given the uniform distributions, z is the fraction of pixels for which this occurs; that is, zN_m mixed pixels become all water. Those zN_m pixels lose less than z because they have less than z to give, but as Figure TD-2 shows, there are adjacent pixels that previously were all land, which each lose the land that the zN_m pixels would have lost had they been farther landward with more land to give. At the end of the lustrum, there must still be a uniform probability distribution of the values of X for the same reason the distribution was uniform initially. Over long periods of time, the total shoreline may change—for example, as islands disappear. Yet in the short run, the shoreline and hence the total number of mixed pixels is constant. Therefore, the pixels that convert from land to mixed must offset those that convert from mixed to all water, and

$$E(S_2) = N_w + zN_m + N_m \int_0^1 F(y)dy, \text{ so}$$
$$E(S_2 - S_1) = zN_m,$$

which would make the land loss indicator unbiased with a relatively small variance similar to σ_S^2, though possibly twice as great if errors from period to period are random, and less if some persist.

small changes.[15] Moreover, classification errors may be biased or highly correlated across cells, but in different ways for different years. Along beaches and mudflats, the classifications of land and water are sensitive to whether water levels in estuaries were atypically low or high when the imagery was taken. Errors may be correlated across pixels because a single Landsat pass may obtain imagery for a large section of coast; if estuarine water levels are high or low due to rainfall, such conditions may persist and apply elsewhere. Interpretation errors may also be systematic to the extent that they result from the consistent application of an imperfect procedure.

11. Sources of Variability

As with the other time series indicators and features in this report, estimates of change from period to period have far more uncertainty than estimates over the entire period. Coastal erosion in a given region may be episodic, resulting from storms or an unusually high rate of sea level rise over a given five-year period. Rates of sea level rise may also be greater during one time period than during the next. The geography of the U.S. coast is highly variable, and there is no reason to expect land loss or gain at one location to be similar to land loss or gain elsewhere.

12. Statistical/Trend Analysis

The data in this feature have not been analyzed to determine whether they reflect statistically significant changes over time.

References

Anderson, J.R., E.E. Hardy, J.T. Roach, and R.E. Witmer. 1976. A land use and land cover classification system for use with remote sensor data. Geological Survey Professional Paper 964. U.S. Geological Survey. http://landcover.usgs.gov/pdf/anderson.pdf

Cochran, W.G. 1977. Sampling Techniques. New York. Wiley and Sons.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Fish and Wildlife Service. www.fws.gov/wetlands/Documents/Classification-of-Wetlands-and-Deepwater-Habitats-of-the-United-States.pdf.

Dobson J.E., E.A. Bright, R.L. Ferguson, D.W. Field, L.L. Wood, K.D. Haddad, H. Iredale III, J.R. Jenson, V.V. Klemas, R.J. Orth, and J.P. Thomas. 1995. Coastal Change Analysis Program (C-CAP): Guidance for regional implementation. NOAA Technical Report, Department of Commerce, NMFS 123. http://spo.nwr.noaa.gov/tr123.pdf.

Fisher, P. 1997. The pixel: A snare and a delusion. Int. J. Remote Sens. 18:679–685.

[15] The key assumption in the previous footnote is that the same, possibly flawed, F(X) classification applies for both periods of time. If different procedures are applied in different years, then our demonstration that the indicator should be unbiased no longer applies.

Fry, J.A., G. Xian, S. Jin, J.A. Dewitz, C.G. Homer, L. Yang, C.A. Barnes, N.D. Herold, and J. Wickham. 2011. Completion of the 2006 National Land Cover Database for the conterminous United States. Photogramm. Eng. Rem. S. 77:858–864.

Homer, C., J. Dewitz, M. Coan, N. Hossain, C. Larson, N. Herold, A. McKerrow, N. VanDriel, and J. Wickham. 2007. Completion of the 2001 National Land Cover Database for the conterminous United States. Photogramm. Eng. Rem. S. 73:337–341.

Irish, R.R. 2000. Landsat 7 science data user's handbook. Report 430-15-01-003-0. National Aeronautics and Space Administration.

MRLC (Multi-Resolution Land Characteristics Consortium). Undated. National Land Cover Dataset 1992: Product legend. U.S. Geological Survey. Accessed April 1, 2014. www.mrlc.gov/nlcd92_leg.php.

NOAA (National Oceanic and Atmospheric Administration). 2013. Western Great Lakes 2010 Coastal Change Analysis Program Accuracy Assessment. Charleston, SC: Coastal Services Center.

Schmid, K., B. Hadley, and K. Waters. Undated. Mapping and portraying inundation uncertainty of bathtub-type models. J. Coastal Res. (in press).

Smith, L.C. 1997. Satellite remote sensing of river inundation area, stage, and discharge: A review. Hydrol. Process. (11):1427–1439.

Stehman, S. V. and J. D. Wickham. 2006. Assessing accuracy of net change derived from land cover maps. Photogramm. Eng. Rem. S. 72(2):175–186.

Titus, J.G. 2011. Rolling easements. Washington, D.C. U.S. EPA. EPA-430-R-11-001. www.epa.gov/learn-issues/water-resources#our-waters.

Titus, J.G., E.K. Anderson, D.R. Cahoon, S. Gill, R.E. Thieler, and J.S. Williams. 2009. Coastal sensitivity to sea-level rise: A focus on the Mid-Atlantic region. U.S. Climate Change Science Program and the Subcommittee on Global Change Research. https://downloads.globalchange.gov/sap/sap4-1/sap4-1-final-report-all.pdf.

Titus J.G., and J. Wang. 2008. Maps of lands close to sea level along the Middle Atlantic coast of the United States: An elevation data set to use while waiting for LIDAR. Section 1.1 in: Titus, J.G., and E.M. Strange (eds.). Background documents supporting Climate Change Science Program Synthesis and Assessment Product 4.1, U.S. EPA. EPA 430R07004. http://papers.risingsea.net/federal_reports/Titus_and_Strange_EPA_section1_1_Titus_and_Wang_may2008.pdf.

U.S. FWS (U.S. Fish and Wildlife Service). Undated. National Wetlands Inventory. www.fws.gov/Wetlands.

Vogelmann, J. E., S.M. Howard, L. Yang, C.R. Larson, K.K. Wylie, and J.N. Van Driel. 2001. Completion of the 1990s National Land Cover Dataset for the conterminous United States. Photogramm. Eng. Rem. S. 67:650–652.

Vogelmann, J.E., T.L. Sohl, and S.M. Howard. 1998. Regional characterization of land cover using multiple sources of data. Photogramm. Eng. Rem. S. 64:45–57.

Vogelmann, J.E., T.L. Sohl, P. V. Campbell, and D.M. Shaw. 1998. Regional land cover characterization using Landsat Thematic Mapper data and ancillary data sources. Environ. Monit. Assess. 451:415–428.

Washington Department of Ecology. 2013. Assessment report of wetland mapping improvements to NOAA's Coastal Change Analysis Program (C-CAP) land cover in western Washington state. Olympia, WA: State of Washington Department of Ecology. http://www.ecy.wa.gov/programs/sea/wetlands/pdf/C-CAPWetlandAssessmentReport.pdf.

Wickham, J.D., S.V. Stehman, L. Gass, J. Dewitz, J.A. Fry, and T.G. Wade. 2013. Accuracy assessment of NLCD 2006 land cover and impervious surface. Remote Sens. Environ. 130:294–304.

Wickham, J.D., S.V. Stehman, J.A. Fry, J.H. Smith, and C.G. Homer. 2010. Thematic accuracy of the NLCD 2001 land cover for the conterminous United States. Remote Sens. Environ. 114:1286–1296.

Wickham, J., C. Homer, J. Fry, J. Vogelmann, A. McKerrow, R. Mueller, N. Herold, J. Coulston. In review. The Multi-Resolution Land Characteristics (MRLC) Consortium - 20 years of development and integration of U.S. national land cover data. Unpublished manuscript under review.

Xian, G., C. Homer, J. Dewitz, J. Fry, N. Hossain, and J. Wickham. 2011. Change of impervious surface area between 2001 and 2006 in the conterminous United States. Photogramm. Eng. Rem. S. 77:758–762.