Designing Sustainable Landscapes: Salt Marsh Ditching Metric

A project of the University of Massachusetts Landscape Ecology Lab

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- University of Massachusetts, Amherst

Reference:

McGarigal K, Compton BW, Plunkett EB, Deluca WV, and Grand J. 2017. Designing sustainable landscapes: salt marsh ditching metric. Report to the North Atlantic Conservation Cooperative, US Fish and Wildlife Service, Northeast Region.

General description

The majority of salt marsh ditches in the Northeast have been ditched, both to facilitate harvest of salt marsh hay and to control mosquitoes (Smith and Niles 2016). Ditching changes the hydrology and flows of sediment and nutrients of marshes in ways that are not well understand, though ditched marshes may have altered invertebrate and shorebird communities, and may be less resilient to sea level rise (LeMay 2007). Marshes with intensive ditching (ca. 10 m spacing) appear to be most strongly affected (Vincent et al. 2013).

The salt marsh ditching metric is an element of the ecological integrity analysis of the Designing Sustainable Landscapes (DSL) project (McGarigal et al. 2014). Consisting of a composite of 21 stressor and resiliency metrics, the index of ecological integrity (IEI) assesses the relative intactness and resiliency to environmental change of ecological systems throughout the northeast. As a stressor metric, salt marsh ditching provides an index of the relative intensity of ditching in salt marshes. Metric values range from 0 (no effect from nearby ditches) to 1 (severe effect).

The metric is based on a custom image analysis process that identifies most ditches in salt marshes throughout the northeast from 1 m LiDAR (Light Detection And Ranging)-based DEMs (Digital Elevation Models). The algorithm (described in detail below), uses a kernel to identify local depressions that could be ditches. It then uses a morphological skeletonize algorithm to draw a 1 m-wide line through the middle of depressions, and then uses an original approach, “clockfacing,” to find linear features in these centerlines of depressions and connect disconnected sections. These potential ditches are converted from raster to linear features, and long, fairly straight sections are tagged as ditches. These linear ditches are converted back to a 1 m raster, then to a 30 m raster, with a value indicating ditch density in each cell. Finally, the ditching metric itself measures the intensity of ditches in the neighborhood of each salt marsh cell using a kernel estimator.

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Use and interpretation of this layer

The salt marsh ditching metric, originally developed for Massachusetts (McGarigal et al. 2011), gives an estimate of the magnitude of ditching in salt marshes. Salt marshes with a high ditching score are more likely to be degraded than those with a low score, all other things being equal.

High resolution 1 m LiDAR, which is required for our approach to identifying salt marsh ditches, is only available for about 64% of the coastal northeast, as mapped in **Fig. 1**. We made no attempt to identify salt marshes in areas without high resolution LiDAR, thus results for these areas have values of NoData. Because areas with unmapped ditches were so extensive, we did not include the salt marsh ditching metric in the Index of Ecological Integrity (IEI), but instead supply it for use at local and sub-regional areas.

Results include the following: (1) a polygon shapefile status map, (2) a line shapefile of mapped ditches, (3) a 30 m geoTIFF raster giving the intensity of ditching in each cell, and (4) the salt marsh ditching metric itself, which indicates ditching intensity in the neighborhood of each cell.

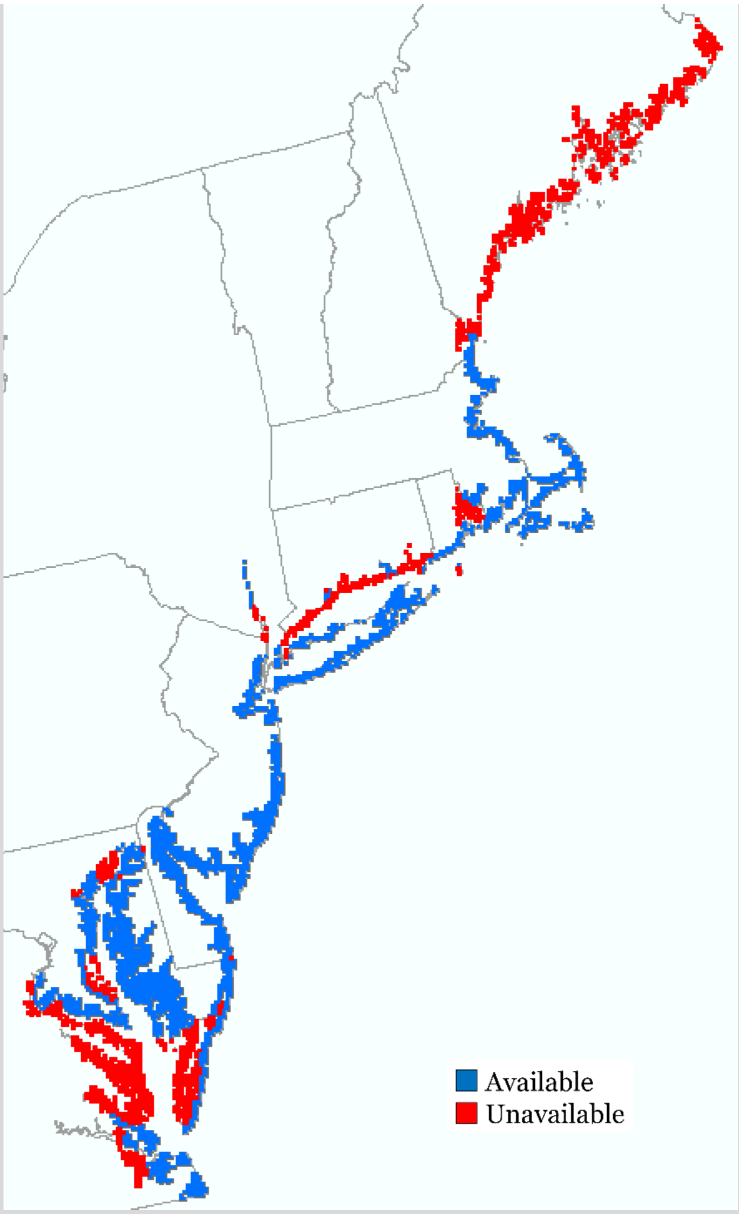


Figure 1. Status map for salt marsh ditching. The model was applied to salt marshes in tiles denoted in blue. Data were unavailable for red tiles.

This metric relies on a number of assumptions:

- Salt marshes are adequately mapped in NWI. In general, this assumption seems to be well-met, as salt marshes are visually distinctive and fairly easy to recognize in aerial photos, and NWI has captured them well.
- High-resolution LiDAR are available for all salt marshes. This is true for 64% of 3 km tiles containing salt marshes.
- The ditch identification process finds all ditches, and doesn't identify natural creek sections or other artifacts as ditches. This assumption is not met: many ditches are missed for various reasons (see below), and some (but not many) natural creek sections are identified as ditches. Over- and under-detection represent a trade-off; in general, our approach identifies most ditches, and rarely identifies spurious ones.
- Ditches are wide enough to be picked up by 1 m LiDAR. Very narrow ditches are likely to appear intermittent in LiDAR, and thus be missed. In the absence of field varication, we're not able to identify an exact cutoff width, but it should be on the order of 1 m.

- Ditches are straight (never deviating more than 5% from a line), and are always at least 75 m long. Ditches shorter than 75 m are never identified.

The following situations gave our algorithm particular trouble:

- Many salt marshes in the southern part of the region (New Jersey to Virginia) have very noisy LiDAR. We believe this represents marsh condition, rather than artifacts in the LiDAR. The noise resulted in a large number of false positives; our solution was to attempt to mask out areas where an unrealistic density of ditches were identified. This masking process helped, but there are still areas with false positives and false negatives.
- Some marshes have large pools that were mapped by NWI as salt marsh, but are obviously open water. We attempted to identify these pools in our algorithm and mask them out. This process was mostly successful.
- Marsh-creek edges were sometimes mapped as marshes due to data misalignment. We removed most of these by masking 10 m from anything not mapped as salt marsh, but some false ditches were still identified.
- Long, straight sections of natural streams (>75 m) were often misidentified as ditches. Conversely, we missed real ditches that were shorter than 75 m. Since our algorithm used straightness as the criteria for whether a potential ditch is natural or anthropogenic, this cutoff represents an imperfect compromise.
- LiDAR in some areas had goofy artifacts. We identified two types of artifacts: (1) in some sources, areas that (apparently) were mapped as open water were masked out and given a constant value. Because of misalignment between mapped open water and open water on the ground, this introduced some minor errors. (2) strange stippled artifacts were present in some USGS data in New Jersey and Delaware; we ended up replacing these areas with NOAA data that did not suffer from these same artifacts.
- Some ditches are visible but very faint in the LiDAR images, sometimes showing as only a few centimeters deeper than the surrounding marsh. Our algorithm often missed these shallow ditches.
- The algorithm consists of a string of operations, many with a number of tunable parameters that represent reasonable compromises between over- and under-detection. Interactions between the steps can introduce errors.

Assessment

We assessed the quality of these data by comparing results of the ditching metric with results of the metric run on photo-interpreted ditch linework in Massachusetts. Massachusetts salt-marsh ditches were photo-interpreted as part of a predecessor project focused on ecological integrity for coastal ecosystems in Massachusetts (McGarigal et al. 2011). Photo-interpretation is presumably fairly accurate, though a number of judgement calls are required. It is also extremely time-consuming—this process took many person-weeks of effort. Doing the comparison based on the results of the metric eliminates minor errors due to exact placement of linework. The correlation in Massachusetts between the photo-interpreted ditch intensity and the automated ditch intensity was $r = 0.43$. The discrepancies seem to be primarily driven by ditches missed by our automated process—including ditches shorter than 75 m that our process intentionally omits, but also many ditches that are visible but faint, often with long breaks. It is possible that many of the ditches captured by photo-interpretation are too shallow and degraded to have much effect, but we're inclined to take the results at face value: the human eye is simply far better at interpolating straight lines than any automated process we could come up with. Obviously, there is no reason to think that Massachusetts ditches are representative of the entire region, but this comparison does give us a coarse assessment of the results.

Derivation of this layer

Data sources

- LiDAR-based DEMs, 1 m resolution. Sources include:

  NOAA. 2014 NOAA Topobathy DEM: Post-Sandy (SC to NY), from Digital Coast web site: https://coast.noaa.gov/digitalcoast/.

  USGSnjde. CoNED TBDEM, New Jersey and Delaware. From USGS Earth Explorer web site, http://earthexplorer.usgs.gov/.

  USGS2. More LiDAR from CoNED. Areas of Connecticut, New York, Maryland, and Virginia. From USGS Earth Explorer web site, http://earthexplorer.usgs.gov/.

  NewHampshire. LiDAR for coastal New Hampshire, from Granit web site, http://www.granit.unh.edu/.

  Massachusetts. LiDAR (various dates, 2002-2011), from MassGIS web site, http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/.

  RhodeIsland. 2014 NOAA Topobathy DEM: Post-Sandy (RI). Digital Coast web site: https://coast.noaa.gov/digitalcoast/.

  Maryland. LiDAR from Maryland's MD iMap web site, http://imap.maryland.gov/Pages/default.aspx.

- Landcover. We used DSLland, TNC's map of ecological systems with a number of modifications for DSL. Coastal wetlands are from the National Wetland Inventory (NWI).

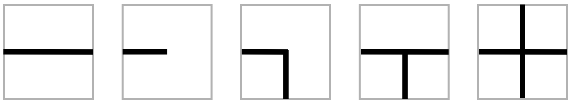
Algorithm

Identifying ditches. Ditches are identified from 1 m LiDAR images using a multi-step algorithm, illustrated for a marsh in Hampton Harbor, New Hampshire (aerial photo, **Fig. 2a**).

1. Identify local depressions with a kernel and threshold. A 5×5 kernel:

1	1	1	1	1
1	-1	-1	-1	1
1	-1	-10	-1	1
1	-1	-1	-1	1
1	1	1	1	1

   is applied to 1 m LiDAR-based elevations (**Fig. 2b**), emphasizing cells that have a lower elevation than their neighbors (**Fig. 2c**). Cells with a value less than the threshold of 0.1 are selected as depressions (**Fig. 2d**).
2. Skeletonize to thin potential ditches. A morphological skeletonizing procedure (http://felix.abecassis.me/2011/09/opencv-morphological-skeleton/) finds centerlines of ditches (**Fig. 2e**).
3. Clockface to distinguish ditches from noise. Potential ditches identified by previous steps are often quite noisy, with numerous non-ditch depressions as well as breaks (either real or due to LiDAR artifacts). Clockfacing, an original algorithm developed for this project, superimposes candidate shapes on the neighborhood of each potential ditch cell, rotating each shape around the clock, scoring the proportion of shape cells that coincide with potential ditch cells. The shape and orientation with the best fit is selected. If the proportion of cells that match is greater than a threshold (we used 50%), the shape is returned in the result (original depression cells are dropped from the result). We used the following shapes, with a focal window of 50 m:

   The clockfacing results identify ditches (**Fig. 2f**).
4. Convert identified ditches to lines. Data are converted from raster to vector, representing potential ditches (**Fig. 2g**).
5. Distinguish straight lines (ditches) from curved lines (natural streams). We used an original algorithm to detect straight lines. Series of line segments are considered straight if they're at least 75 m long and deviate no more than 5% from a straight line (**Fig. 2h**). Lines that fail this test are dropped—they're either too short or too curvy to be considered ditches. Note that this means that ditches shorter than 75 m are never identified. These vector ditches are available in a shapefile as an intermediate result.
6. Convert to raster and summarize in 30 m cells. Finally, linear ditches are converted back to 1 m raster, and 1 m cells are summed within 30 m cells to give ditch density in a regional raster. This intermediate result is available in a 30 m geoTIFF.

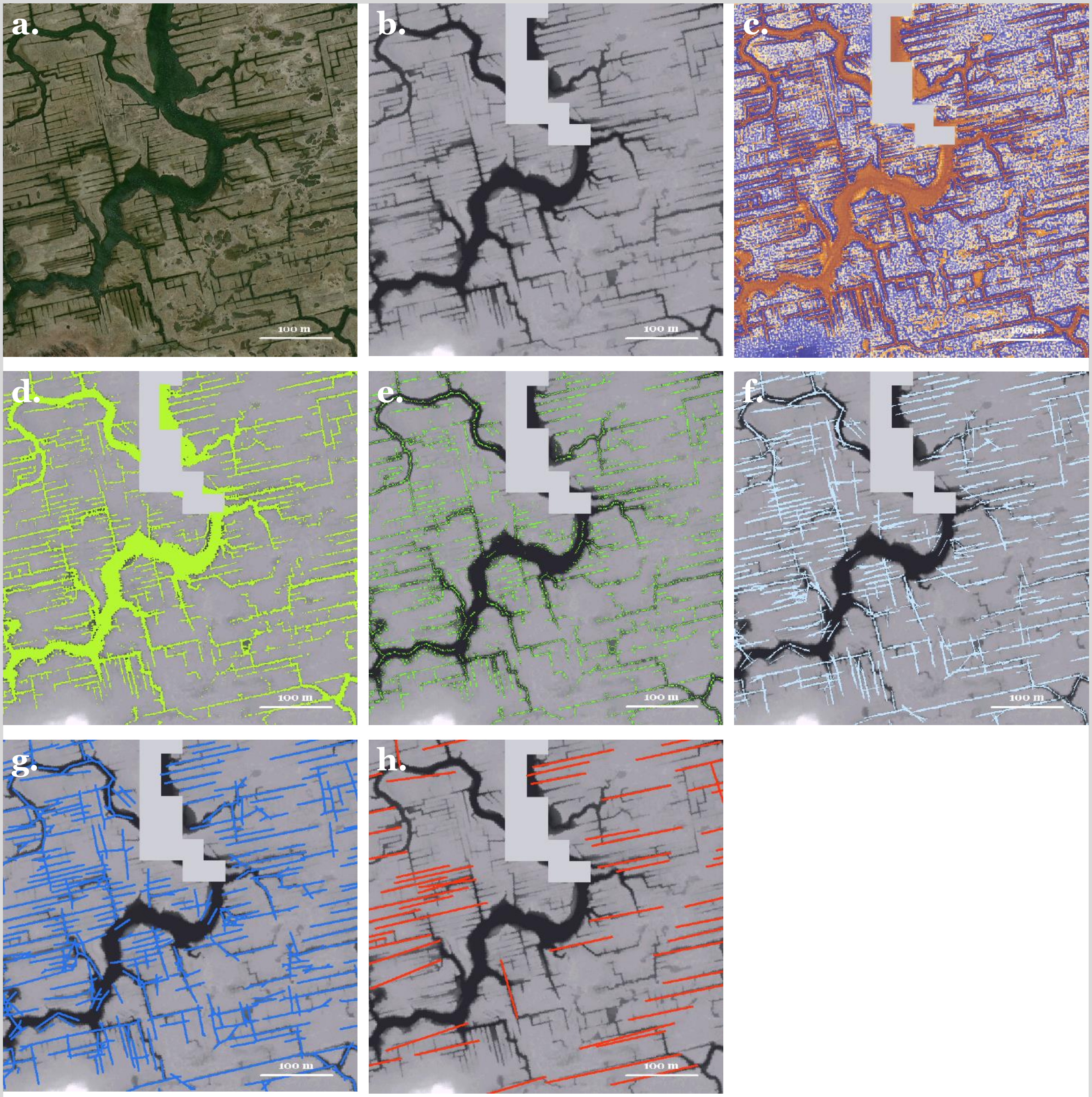


Figure 2. Steps in identifying ditches. a) aerial photo of a New Hampshire salt marsh, b) LiDAR DEM (omitted areas are mapped as streams), c) results of 5×5 kernel emphasizing depressions, d) thresholded kernel, e) results of skeletonize procedure, f) results of clockfacing procedure, g) potential ditch lines extracted from raster, and f) identified ditches (>75 m long).

Salt marsh ditching metric. The metric algorithm builds a kernel (bandwidth = 72 m) around ditches within salt marshes, and expresses the result as a ratio of the kernel value to the size of the salt marsh. This gives a measure of the intensity of ditching within a marsh, relative to the marsh's size (**Fig. 3**).

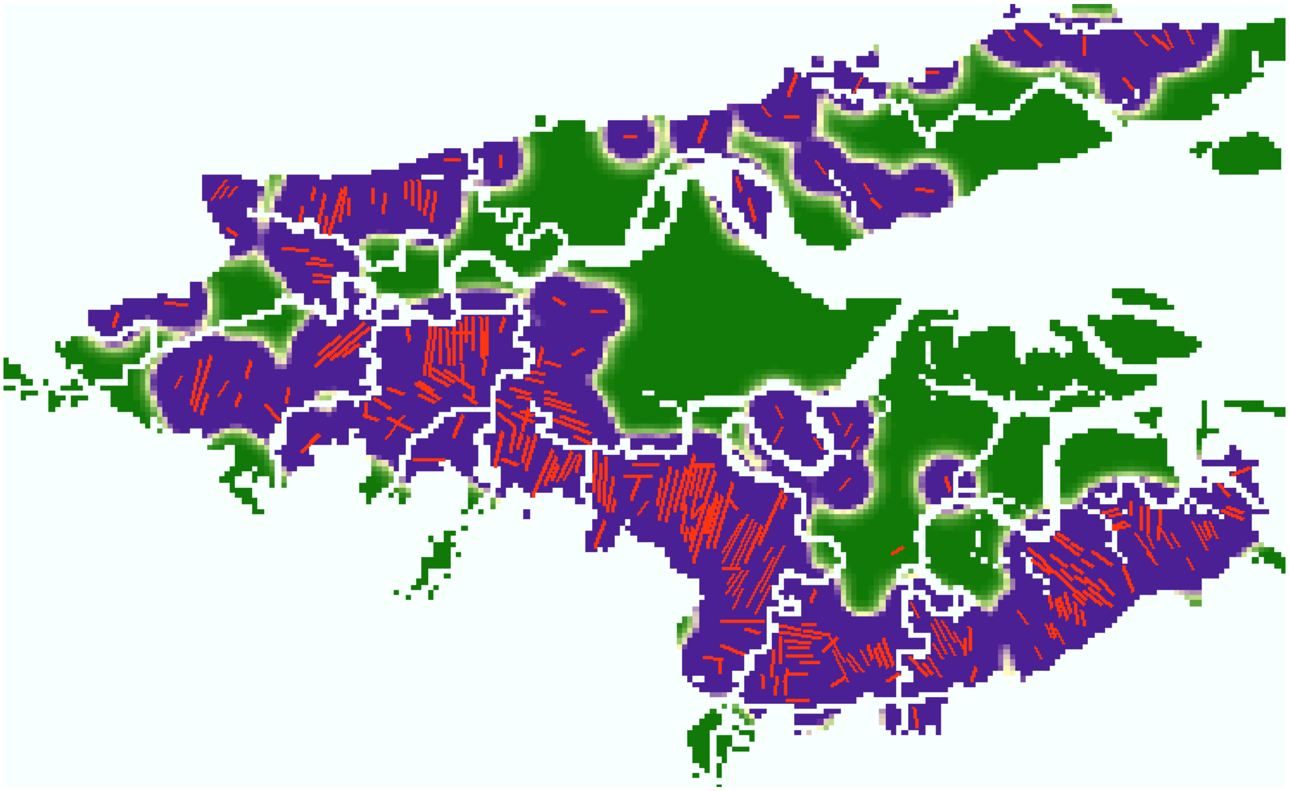


Figure 3. Results of salt marsh ditching metric for Sandy Neck Great Marshes, Massachusetts (green = low ditching intensity, purple = high ditching intensity). Identified ditches are shown in red.

GIS metadata

This data product is distributed as four GIS layers. Note that high-resolution LiDAR (1 m) were only available for about two-thirds of salt marshes in the northeast (**Fig. 1)**. Data are available at http://jamba.provost.ads.umass.edu/web/lcc/DSL_ditches_2010_v3.1.zip.

- **Salt marsh ditching metric** (DSL_ditches_2010_v3.0.tif) – 30 m geoTIFF raster. Values vary from 0 (no effect from salt marsh ditching) to 1 (severe effect). This metric includes values only within salt marshes (Estuarine Intertidal Emergent). All other cells are nodata.

- **Source and status map** (DSL_ditch_source_2010_v3.0.shp) – Polygon shapefile. Maps, in 3 km tiles, the source of LiDAR data (field "source," corresponding to sources listed in Data Sources, above). Tiles are present only where salt marshes are mapped in DSLLand. The 36% of tiles for which LiDAR were unavailable are indicated by "(No data)."
- **Linework of identified ditches** (DSL_ditch_lines_2010_v3.0.shp) -- Vector shapefile. This intermediate shapefile has lines for every ditch that was identified.
- **Ditch intensity grid** (DSL_ditch_intensity_2010_v3.0.tif) -- 30 m geoTIFF raster. This intermediate grid is a sum of the number of 1 m cells mapped as ditches within each 30 m cell. Values range from 0 (no ditches) to (theoretically) 900. Cells falling outside of salt marshes are assigned to nodata.

Literature cited

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Appendix: Detailed data preparation and algorithm

This appendix describes the steps used in modeling. Software used included ArcGIS, ArcInfo, and custom code written in APL, R, and Python

1. Collect data.

   Find and download LiDAR DEMs. Merge tiles into raster for each source/area, reproject each to Albers (used for all other DSL data) and snap to our landcover.

2. Create tiling scheme.

   Create a 3 km tiling scheme, and subset tiles that contain mapped salt marshes in DSLland (= 4,114 tiles). For each tile, select source LiDAR DEM with the best coverage. 2,647 tiles have data available (64% of tiles).

3. Clip LiDAR: **ditchtiles.py**

   Select and clip LiDAR for each tile, buffering each by 120 m to avoid edge effects.

4. Process tiles: **DODIGDITCHES, DIGDITCHES**

   Tiles are processed in parallel under Anthill to detect ditches. The following are run for each 3 km tile:

   i. Find depressions and draw centerlines: **skeletonize.R**, **skeleton.R**

      The R function skeletonize() uses a 5×5 kernel (see Algorithm, above) and a threshold to identify depressions. It then calls skeleton() to find ditch centerlines (using opening() and erode() from the mmand package). Areas with a density of depressions in a 20 m circle higher than 20% are masked (with a 20 m buffer), as these represent “noisy” marshes (perhaps due to LiDAR artifacts or incipient salt marsh breakup?) rather than ditches. Patches > 5000 m^2 with the same elevation (within 10 cm) are also masked, as these likely represent unmapped open water.

   ii. Connect ditches and eliminate noise: **CLOCKFACE**

      Clockfacing (an original approach, implemented in the APL function CLOCKFACE) rotates several candidate shapes (see Algorithm, above) in a 50 m window over each focal cell with an identified depression, selecting the shape and orientation with the highest percentage of hits. Shapes with >50% hit rate are retained, and input data are dropped, thus connecting spotty ditches and eliminating isolated depressions.

   iii. Convert to lines (**AML written by DIGDITCHES**)

      The Arc functions gridline and generalize are used to identify and simplify lines in the clockfacing results.

   iv. Distinguish straight artificial ditches from sinuous natural creeks: **FINDDITCHES**

      This APL function finds series of line segments that are 75 m or longer, deviating from a straight line by no more than 5%.

   v. Generate lines (**AML written by DIGDITCHES**)

      The list of line endpoints written by FINDDITCHES is converted back to vector, and a shapefile is generated for the current tile (these shapefiles are later merged to give the vector ditch shapefile for the region).

   vi. Convert to grid (**AML written by DIGDITCHES**)

The vector ditches are converted to a 1 m raster, then summed within each 30 m cell to give the ditch density within each cell. The result is written to a regional grid.

5. Run ditching metric: **DITCHES**

   The ditching metric runs under CAPS, with a bandwidth of 72 m. It builds a kernel around ditches within salt marshes, and expresses the result as a ratio of the kernel value to the size of the salt marsh.