Application of the AMBUR R package for spatio-temporal analysis of shoreline change: Jekyll Island, Georgia, USA

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ARTICLE INFO

ABSTRACT

The AMBUR (Analyzing Moving Boundaries Using R) package for the R software environment provides a collection of functions for assisting with analyzing and visualizing historical shoreline change. The package allows import and export of geospatial data in ESRI shapefile format, which is compatible with most commercial and open-source GIS software. The "baseline and transect" method is the primary technique used to quantify distances and rates of shoreline movement, and to detect classification changes across time. Along with the traditional "perpendicular" transect method, two new transect methods, "near" and "filtered," assist with quantifying changes along curved shorelines that are problematic for perpendicular transect methods. Output from the analyses includes data tables, graphics, and geospatial data, which are useful in rapidly assessing trends and potential errors in the dataset. A forecasting function also allows the user to estimate the future location of the shoreline and store the results in a shapefile. Other utilities and tools provided in the package assist with preparing and manipulating geospatial data, error checking, and generating supporting graphics and shapefiles. The package can be customized to perform additional statistical, graphical, and geospatial functions, and, it is capable of analyzing the movement of any boundary (e.g., shorelines, glacier terminus, fire edge, and marine and terrestrial ecozones).

1. Introduction

The movement of a shoreline, whether located adjacent to a stream, lake, or an ocean, is an expression of the processes that shape natural and developed landscapes. Operating across varying spatial and temporal extents, natural processes govern the mobility of this land/water boundary over time. Within coastal regions, scientists and managers focus on mapping and quantifying the movement of the shoreline not only to gain a better understanding of these processes but also to determine potential impacts on coastal resources and to assist with policy-making decisions. Among the many questions researchers often want to answer when studying a given shoreline, there are four that are central to an analysis: (1) How far has the shoreline moved? (2) How fast did the shoreline move? (3) How variable is the shoreline's movement? (4) Where is the shoreline going to be in the future? To answer these questions, researchers might use GIS software to either perform manual measurements or use automated analysis tools to quantify distances and rates of shoreline movements and make forecasts. Over the past decade, the number of computer-assisted shoreline change analyses has increased as GIS software programs have become more accessible to researchers.

Despite the wide availability of GIS software, there are still only a limited number of GIS-based tools dedicated to shoreline change analyses that are publicly available such as the Digital Shoreline Analysis System (DSAS) (Thieler et al., 2009), SCARPS (Jackson, 2004), and BeachTools (Hoeke et al., 2001; Zarillo et al., 2008). Furthermore, these tools require users to own a commercial GIS software license for ESRI's ArcGIS (or the older ArcView v.3.x) to run them. The Analyzing Moving Boundaries using R (AMBUR) package for the R programming environment (R Development Core Team, 2011) provides a collection of scripts to assist with shoreline change analysis that takes advantage of R's statistical, graphical, and geospatial capabilities, while allowing users the freedom to choose any commercial or open-source GIS software for editing, preparing, and viewing shapefiles. Although primarily intended for shoreline change analyses, AMBUR is able to analyze

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the movements of virtually any physical boundary, such as a glacier terminus, fire edge, and marine and terrestrial ecozones.

Quantifying shoreline movements is usually performed by a "baseline and transect" method using manual and computer-assisted techniques (Dolan et al., 1978; Clow and Leatherman, 1984). Today, the method is typically GIS-based and involves a number of steps following the creation of a historical shoreline database. First, the user constructs a baseline by drawing a reference line either onshore or offshore of the historical shorelines in the GIS. Second, transect lines are cast perpendicular to the baseline at a user-specified spacing along the baseline. Third, the transects are intersected with the historical shorelines to produce a database of points, which record the locations of historical shoreline positions along each transect through time. Finally, statistics are calculated for each transect and stored in a data table. Subsequently, the user might elect to project a future shoreline position based on calculated shoreline rate-of-change statistics. The functions provided in AMBUR assist the user at each one of above-noted steps and contain tools for new "baseline and transect" methods.

1.1. AMBUR development

The initial conception of AMBUR followed the development of another shoreline change analysis tool named SCARPS (Simple Change Analysis of Retreating and Prograding Systems); an ArcView v.3.2 extension written by the author of AMBUR (Jackson, 2004). SCARPS provided tools for quantifying the movements of shorelines and inlet features, shoreline forecasting, and generating an expanded data table with additional calculations not provided by publically available tools at that time. The output from SCARPS was useful in helping to ascertain the influence of various inlet processes over a barrier island's shoreline (Jackson, 2004). Since its inception, the application of SCARPS has included assessing a variety of different shoreline types including sandy and rocky beaches, salt marshes, inlet shoals, and oyster-shell ridges. Lessons learned from applying SCARPS to a variety of shoreline types in different geographic settings provided a basis for the development of AMBUR.

The AMBUR package takes advantage of the advanced statistical and graphical capabilities of the R programming environment and provides the user with analytical tools and expanded output. Furthermore, because the package is R-based, it provides an open-source option for users that is portable, cross-platform, and customizable through access to R's extensive library of functions and packages. The AMBUR package improves on previous shoreline analysis tools by providing functions for new transects casting techniques, detailed output from statistical analyses, generation of summary reports and graphics, and shoreline position forecasting. Furthermore, these improvements allow for accurate and routine analyses of strongly curved coastlines, such as those highly embayed or adjacent to inlets, that prove problematic for earlier tools. Table 1 lists select functions in AMBUR used to perform shoreline change analyses and their output. The functions provided in the AMBUR package are invoked using R's command line interface or through a simple graphical-user-interface (GUI). The GUI contains interactive windows used for selecting and saving files, or choosing various analysis parameters.

The intention of this paper is not to serve as a user's manual, but rather to provide an overview of the capabilities of AMBUR through an example shoreline-change analysis performed for Jekyll Island, a barrier island located along the Georgia coast (Fig. 1). Jekyll Island is an exemplary site where the traditional "baseline and transect" method can be difficult to apply to shoreline segments that are highly curved, such as those adjacent to inlets at the northern and southern ends of Jekyll Island (Fig. 1). The AMBUR package provides new tools to assist with such problems. Source code and a user's manual for AMBUR are available from the author.
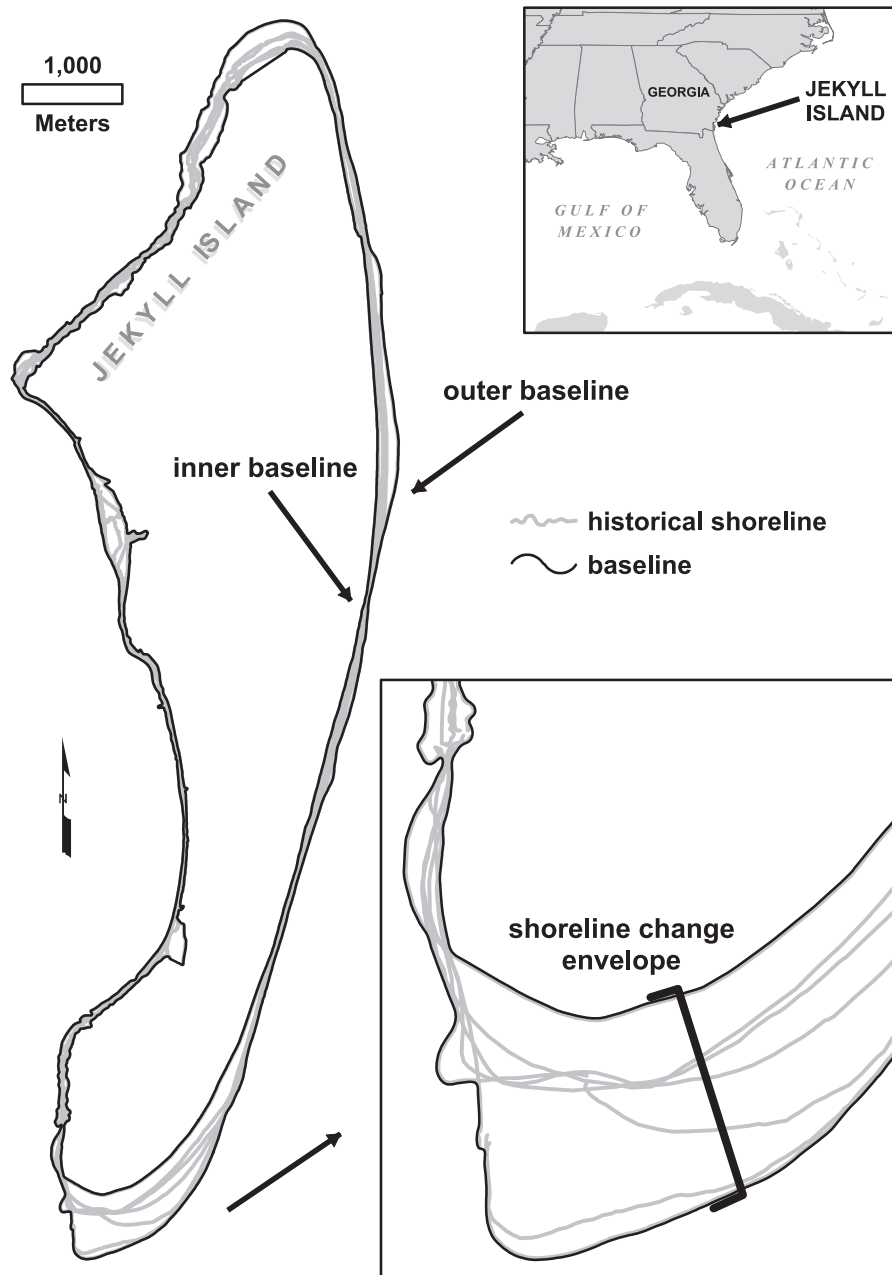
1.2. Shorelines

Currently, building a historical shoreline database is usually accomplished through field surveys and digitizing maps and imagery within a GIS framework. Spatial data might be stored in a variety of file formats that include delimited text files, geodatabases, or ESRI shapefiles. The ESRI shapefile is the standard file format for spatial data in AMBUR because of its open format (ESRI, 1998) and compatibility with most GIS software packages, thus making it one of the most widely used file types for geospatial vector data. In order to use the package, the user must have a polyline shapefile containing historical shorelines and prepared with properly formatted fields in the shapefile's

Table 1
Summary of functions currently available in the AMBUR package for R.

Function name	Required file(s)	Output/comments	Example(s)
Baselines			
ambur.smooth	baselines [a]	shapefile with local polynomial smoothed polylines	Fig. 1
ambur.critical	baselines [a]	shapefile containing critical points of a polyline	
Transects			
ambur.transects	baselines [a]	shapefiles with perpendicular, perpendicular trimmed, and "near" transects	Fig. 2a–c
ambur.filtertran	transects [a]	shapefile with adjusted transect orientations	Figs. 2d, 3
Analysis tools			
ambur.analysis	shorelines and transects [a]	data tables and graphics	Fig. 4
ambur.statshape	amber.analysis files	multiple point and polyline shapefiles with shoreline change data attributes	
ambur.simplebin	amber.analysis files	graph depicting the shoreline divided up into unique segments	
ambur.forecast	amber.analysis files	shapefiles with polylines of extrapolated shoreline positions for EPR, LRR, and WLR rate calculations	Fig. 5
Utilities			
ambur.addfields	baseline or shoreline [a]	adds required fields to shapefile's attribute table	
ambur.check	shorelines, baselines, or transects [a]	checks the shapefile for missing fields required to run other functions	
ambur.gui	n/a	graphical user interface providing access to functions	
ambur.setup	n/a	installs additional R packages required to run AMBUR	

[a] ESRI Shapefile format.

Fig. 1. Jekyll Island, Georgia, location map depicting historical shorelines from 1855 to 2006 (light gray) and offshore (outer) and onshore (inner) baselines (black). Shorelines and baselines were initially digitized and prepared using desktop GIS software. Baselines were generated using a 5 m buffer of the landward (onshore) and seaward (offshore) extent of the shorelines. The maximum extent of movement of the shoreline landward and seaward is the shoreline change envelope.

attribute table. These fields hold information such as the date and estimated accuracy for each shoreline. The "ambur.addfields" function adds these fields to the shapefile and additional nominal data attribute fields for user-defined classification schemes of the shoreline. The fields containing dates and accuracy of shoreline data are used for distance and rates-of-change calculations and statistics. Nominal data fields are used by AMBUR to determine classification changes that occur at a given shoreline segment across time.

The database for Jekyll Island contains 7 historical shorelines spanning the time period from 1855 to 2006 (Fig. 1 and Table 2). The shorelines were digitized from georectified aerial photographs and US Coast and Geodetic Survey (now the National Ocean Service) topographic survey maps.

1.3. Baselines

A baseline is a reference line, usually constructed as a linear or curvilinear polyline, which attempts to parallel the general orientation of the historical shorelines. Once constructed, transect lines are cast, usually perpendicular to and at a spacing interval of interest, along the baseline, extending across the historical shorelines. The baseline is either landward or seaward of the historical shorelines depending on the user's preference and application. The shape of the baseline is important because it influences the orientation of transects that are cast along it, which can affect the shoreline change calculations. In effect, the baseline "steers" transects across the historical shorelines. Some researchers elect to construct a baseline "by hand" through digitizing a

line onscreen in GIS and estimating a preferred location by eye in order to obtain desired transect orientations across the historical shorelines. Alternatively, researchers use automated techniques that employ geoprocessing tools such as buffering to build a baseline at a given distance either landward or seaward of the shorelines. Besides handling a single baseline created by the aforementioned methods to cast transects along, AMBUR provides

support for transect casting techniques that use two baselines. Instead of using a baseline located on only one side of the historical shorelines, this technique uses both inner (landward side) and outer (seaward side) baselines simultaneously to cast transects and assists with orienting transects around curved shorelines (Fig. 1).

In order to prepare the baseline, the user must first create a polyline shapefile using GIS software either by hand or using a buffer line. In addition to creating buffers using ESRI's ArcGIS, open-source GIS software packages such as QGIS (www.qgis.org/) and GRASS (www.grass.fbk.eu/) can also generate buffer lines and export them as shapefiles that are compatible with AMBUR. Following the creation of the initial baseline, the user might elect to smooth the polylines using tools available in the GIS software or AMBUR to remove extraneous arcuate features that might be present following buffering or during digitizing. Sometimes these features can cause transects to be cast in unfavorable orientations that are highly oblique to, or even directed away from, shorelines if left unsmoothed. Aside from smoothing tools provided by most GIS software, the "ambur.smooth" function provides smoothing capabilities by fitting a local polynomial curve to each polyline using a modified LocFit algorithm (Loader, 1999). The function provides a

Table 2
Historical shorelines and data sources for Jekyll Island, Georgia.

Year	Source	Horizontal accuracy (± meters)
1855	US Coast and Geodetic Survey T-sheet	7
1867	US Coast and Geodetic Survey T-sheet	7
1923	US Coast and Geodetic Survey T-sheet	14
1924	US Coast and Geodetic Survey T-sheet	14
1933	US Coast and Geodetic Survey T-sheet	5
1951	US Coast and Geodetic Survey T-sheet	4
1974	US Geological Survey Orthophotomap	7
2002	National Ocean Service orthophotos	1
2003	National Ocean Service orthophotos	5
2006	US Geological Survey orthophotos	5
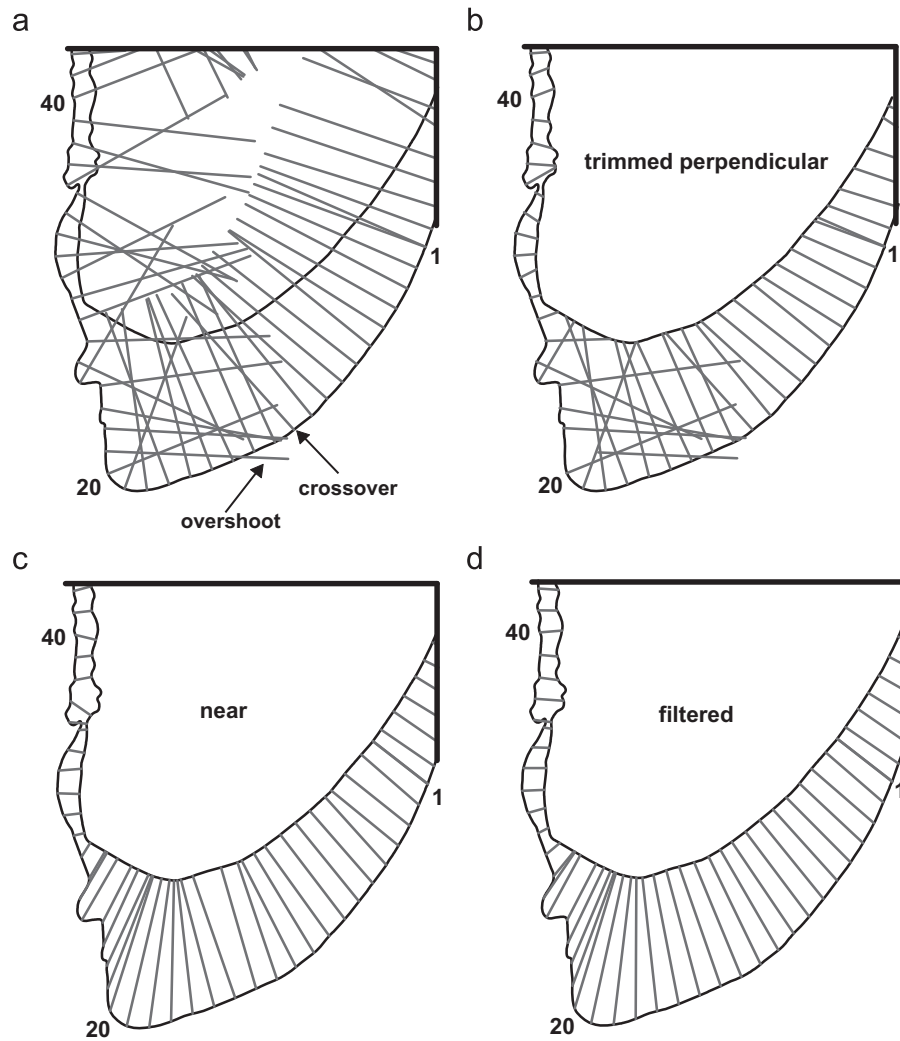
Fig. 2. Maps depicting (a) traditional perpendicular, (b) trimmed perpendicular, (c) near, and (d) filtered transects casting techniques along a curved shoreline at the southern end of Jekyll Island, Georgia. All transects are generated using the outer (offshore) baseline as the point of origin and are spaced 100 m apart. Note that transects generated using the perpendicular method in (a), a technique frequently used by researchers, extend a set length (800 m) across the shorelines and do not terminate at the inner (onshore) baseline. Transect crossovers and overshoots are visible in (a) and (b) whereas none is present in (c) and (d). Larger gaps between "near" transects along the inner baseline in (c) are reduced using filtering transects (d).

robust polyline smoothing method that is comparable to ESRI's PAEK smoothing algorithm (Bodansky et al., 2002), which is only available in ArcGIS for users who purchase an ArcInfo license. Finally, the user must create the required fields in the attribute table of the baseline to be compatible with AMBUR. Using the "ambur.addfields" function to automatically generate fields in the shapefile's attribute table, each baseline is prepared with the necessary attributes for transect casting and analysis in R. Additionally, the "ambur.check" function will check baseline shapefiles for the presence of the fields necessary to run an analysis and notify the user of missing fields.

Fig. 1 displays both an inner and an outer baseline for Jekyll Island offset approximately 5 m landward and seaward, respectively, of the historical shorelines. The methodology used to generate the baselines for Jekyll Island using the buffering technique can be achieved with most commercial and open-source GIS software packages, such as those noted above.

1.4. Transects

Following the creation of the baseline, it is customary to erect transects perpendicular to the baseline at a user-specified spacing and length. The "ambur.transect" function performs the "perpendicular transect" method using baselines positioned either offshore or onshore. Fig. 2a depicts transects erected perpendicular to the outer baseline along the southern end of Jekyll Island with 100 m spacing. If the user provides double baselines, "ambur.transects" will create "trimmed perpendicular transects" (Fig. 2b) to help alleviate transect "overshoots" where a transect might intersect the shoreline in two different geographic settings. For example, if left untrimmed, several northern oceanfront transects in Fig. 2a cross over from the front side to the backside of the island and also capture the positions of those shorelines. In AMBUR, the user has the option to pick the first or last intersection of a transect with a shoreline for transects with multiple intersections sharing the same date. However, if any of the dates of the backbarrier shorelines differ from those of the oceanfront, shoreline change calculations will inadvertently include those data and produce erroneous results. The trimming of transects with a double baseline in AMBUR helps to prevent problems associated with "overshoots" through confining each transect within the shoreline change envelope.

Another problem with the perpendicular method prior to the development of AMBUR is that transects tend to cross over themselves along segments where the baseline or shoreline is highly curved. The shoreline segment along the southern end of Jekyll Island in Fig. 2a and b illustrates this dilemma. If the user elects to employ the double baseline method, the "ambur.transects" function generates a shapefile containing "near" transects by casting transects from the outer baseline to the nearest location on the inner baseline (Fig. 2c). The "near" method of transect casting prevents transects from crossing over themselves and conforms them to curved shoreline segments. The locations of gaps between transects where they meet the inner baseline depend on the smoothness of the baselines and the shape contrasts of the two baselines. Gaps tend to be prevalent when the inner baseline contains multiple cuspate or arcuate shoreline segments. The "ambur.filtertran" function modifies "near" transect shapefiles to create "filtered" transects that help minimize these gaps (Figs. 2d and 3). The "ambur.filtertran" function uses a moving window average of the azimuths of transects within the window and assigns the value to the middle transect of the window. Therefore, a user must select a number of transects to be used in the window that is an odd number of 3 or greater. A window size of 5 was used to generate filtered transects in Figs. 2d and 3. Additional smoothing of the baselines also helps

to reduce the spacing of these gaps. Both "near" and "filtered" transect methods will not solve all issues with highly curved or irregular shorelines; however, initial testing in estuarine and oceanfront areas of the Georgia coast (Jackson, 2009; Jackson et al., 2009) has shown them to reduce the number of problematic transects generated by the perpendicular method that cross over each other and/or are oriented at a highly oblique angle to the direction of shoreline movement.

1.5. Analysis tools and output

Once transect casting and modification are complete, the "ambur.capture" function generates a shapefile containing points of the historical locations of the shoreline along each transect by intersecting both transects and shorelines shapefiles. The function performs a geometric intersection of each historical shoreline with each transect and stores the intersection points in a point shapefile with an GIS table containing the fields and attributes from both shoreline and transect shapefiles. Therefore, both shapefiles containing transects and shorelines must contain the required fields to run various analysis functions. The "ambur.check" function verifies the presence of these fields. Using the point shapefile generated from "ambur.capture," the "ambur.analysis" function performs statistical and graphical analyses of the data. The user has the options to interactively choose dates, set the confidence level of the analysis, and select all or a portion of transects to analyze. Immediately following the execution of the "ambur.analysis" function, a script creates a date and time-stamped folder to store resulting datasets and graphic files. These output files consist of a summary report, data tables, shapefiles, and graphics that include error assessments, plots depicting shoreline change trends, and distribution of dates across the dataset and for each transect. Some of these output files can be used to forecast shoreline positions using the "ambur.forecast" function.
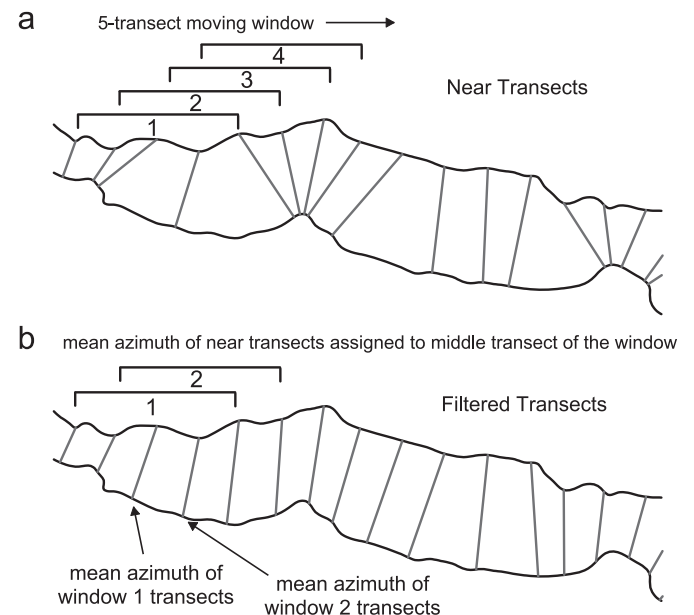

Fig. 3. Example of filtering near transect orientations using a moving-window average of transect azimuths. The "ambur.filtertran" function modifies "near" transects (a) to create "filtered" transects (b) and assists with minimizing gaps along baselines. The "ambur.filtertran" function uses a moving window average of the azimuths of transects within the window and assigns the value to the middle transect of the window. The user must select an odd number of transects to be used in the window that is 3 or greater. A 5-transect window is demonstrated in this example.

Data tables and shapefiles generated from the "ambur.analysis" function contain geospatial and statistical calculations and include net, minimum, maximum, mean, and standard deviation of shoreline change for each transect, which are useful in ascertaining how far the shore has moved and its variability. This dataset also includes rates of shoreline change using end-point rate (EPR), linear regression rate (LRR), and weighted linear regression (WLR) calculation methods widely employed by researchers (Dolan et al., 1991). The function also generates a dataset containing shoreline change distances and EPR rates for all possible combination of dates for each transect, which is useful in investigating the variability of shoreline movement during select eras within the dataset. A detailed description of these and other tabular data output files from the AMBUR analysis function can be found in the basic user guide (Jackson, 2010).

Error estimates of EPR rates are calculated using horizontal accuracies supplied by the user of the oldest and youngest shoreline in the original shoreline shapefile. Initially, the horizontal accuracy of a shoreline is determined by the user based on error estimates of a number of parameters that might include map/photo shrinkage and tears/folds, radial lens distortion, scale of maps/photos, topography, and error in delineating a shoreline feature/type (Crowell et al., 1991). These accuracy values are entered in by the user in the shoreline shapefile's attribute table for each historical shoreline prior to analysis in AMBUR. In the EPR error calculation in AMBUR, the accuracy value of each
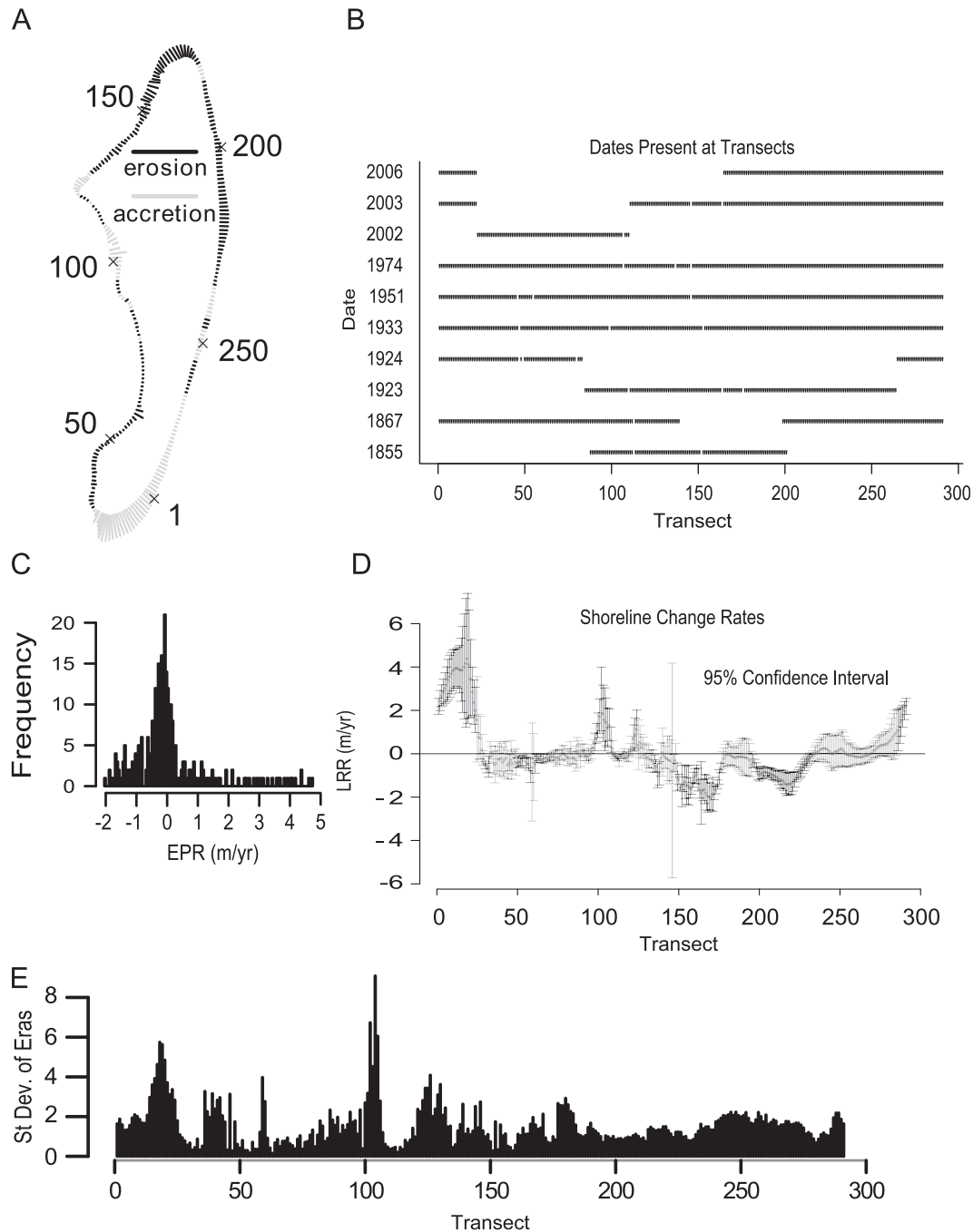

Fig. 4. Examples of various graphical plots generated by the "ambur.analysis" function. Output graphics include a plot of erosion and accretion trends color-coded at each transect (A), dates recorded at each transect (B), histogram of shoreline change rates (C), shoreline change rates with confidence intervals (D), and standard deviation of shoreline change rates for each era of time (E).

shoreline is squared and both values are added together. Next, the square root is taken of the sum of those values. Finally, the resulting value is divided by the elapsed time between the oldest and the youngest shorelines. The result is a number that estimates the plus/minus error of the EPR rate based on horizontal accuracy of the shoreline as determined by the user. The estimated error of LRR and WLR rate calculations are determined by a confidence level set by the user in the "ambur.analysis" function, which is used to calculate upper and lower limits of the confidence interval. Additionally, other calculations are included in the output files such as R-squared, standard error of the residuals, standard error of the coefficients, and P value to assist the user with assessing the fit of the regression for each transect.

Graphical plots of shoreline change data and shapefiles using different methods assist with visualizing trends or erosion and accretion and complement these tabular datasets. Fig. 4A–E depict some of the graphical output of the "ambur.analysis" function that provides the user with an overview of the major trends in the dataset without having to manually plot them after each analysis. Furthermore, this allows the user to identify potential errors more efficiently in the dataset through a visual inspection of the plots and identification of outliers and missing data (Fig. 4B). Fig. 4D is a plot of the LRR shoreline change rate calculation for Jekyll Island with error bars set at the 95% confidence interval (set by the user). A plot of the standard deviation of shoreline change for each era is also provided to help visually assess the variability of shoreline movements (Fig. 4E). Higher values, such as those found between transects 10 and 25 at the southern end of Jekyll Island, indicate that the shoreline's movement is more variable and tends to shift greater distances and rates. Conversely, from transects 60 to 100, the shoreline's position does not fluctuate as much over time. Although the variability of shoreline movement might appear higher or lower along certain transects, missing shoreline dates can influence the standard deviation calculation due to time gaps present at some transects. The output plot in Fig. 4B assists the user with identifying the locations of such time gaps or missing data when interpreting and comparing transects.

In addition to quantifying distances and rates, the function also determines changes of nominal data at each transect if classification data are present in the historical shorelines shapefile. For example, if the user classifies a given segment of the shoreline as sandy beach for one date and then a seawall for a subsequent date, then the function detects a classification change for those transects located along that shoreline segment. The output file containing classification changes for each transect is useful for subsequent analyses or comparisons with the aforementioned numerical datasets. Data output from the "ambur.analysis" function provides a step forward in assisting researchers with linking shoreline movement with its morphology, surrounding geologic framework, and anthropogenic activities. Table 3 provides a summary of erosion trends for Jekyll Island based on shoreline classified by their location (e.g., oceanfront, backbarrier,

north inlet facing, and south inlet facing) and the percentage of those transects where the shoreline is artificially stabilized by seawalls or hard structures. The results in Table 3 are based on the filtered transect method. More than half of the island's shoreline experienced erosion from 1855 to 2006. A majority of erosion is concentrated along the northern half of the oceanfront
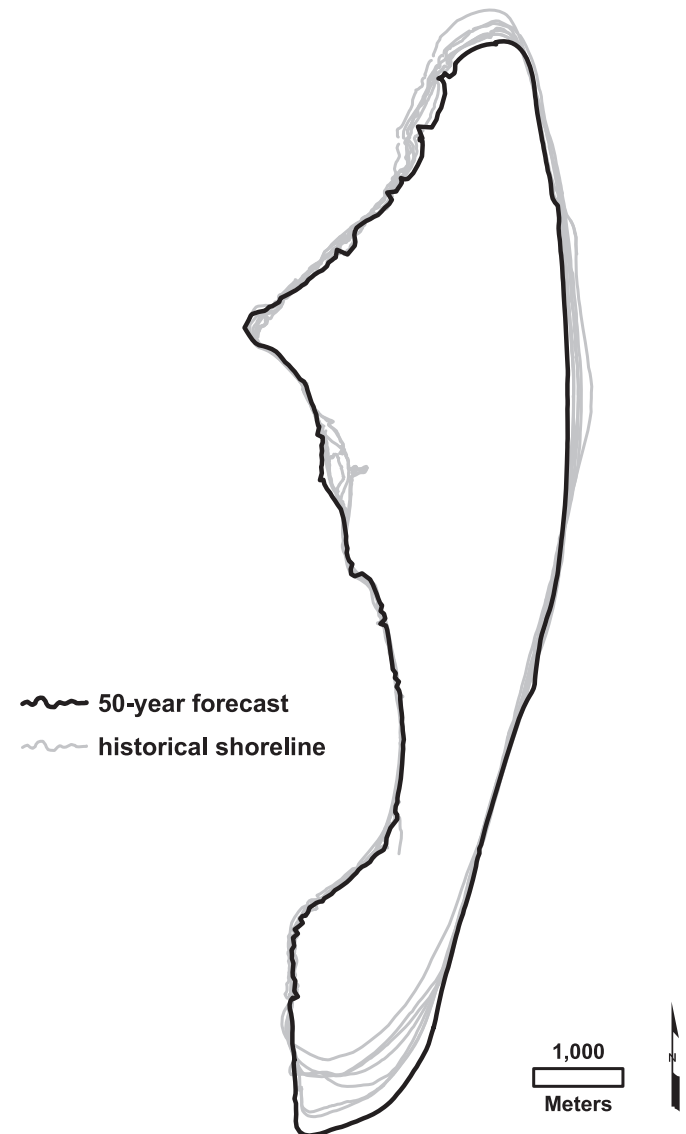
Fig. 5. Forecasted shoreline position for the year 2056 based on the linear regression rates (LRR) of shoreline change calculated at each transect. The orientations of filtered transects were used to project future shoreline movement. Other shoreline change rate calculation models, such as EPR and WLR, can also be used to forecast potential shoreline positions.

Table 3
Summary of shoreline erosion trends for Jekyll Island (from 1855 to 2006).

Location	Transects	% erosion transects	Mean erosion rate [a] (m/yr) (± 0.08 m/yr)	% of shoreline artificially stabilized
Oceanfront	179–291	58	−0.53	45
Backbarrier	27–162	75	−0.44	7
North inlet facing	163–178	100	−1.42	1
South inlet facing	1–26	0	0	0
Island-wide	1–291	63	−0.56	21

Erosion rates were calculated using the end-point rate (EPR) method.

[a] Erosion transects only.

and the backbarrier. Conversely, the southern end of the island experienced accretion throughout the study period. Almost half of the oceanfront of the island is artificially stabilized with seawalls in order to combat shoreline retreat (Table 3).

The "ambur.forecast" function provides users with the capability of extrapolating shoreline change rates at each transect to a given time in the future. The forecasting function generates a new shapefile that contains a polyline of the forecasted shoreline (Fig. 5). The shoreline forecasted in Fig. 5 is extrapolated along the orientations of the filtered transects; however, the user can use perpendicular or near transects for forecasting. Currently, the implemented method of predication in AMBUR is a simple forward extrapolation of the EPR, LRR, and WLR rates. Although the same extrapolation method is used by many researchers (e.g., Crowell et al., 1997), there is no standard method of forecasting or predicting future shoreline positions that is applicable to all shoreline settings. Furthermore, the current "ambur.forecast" function does not take into account shoreline type and if it is artificially stabilized with a seawall or hard structure. In those cases where the shoreline is hard stabilized, the shoreline is unable to retreat beyond the structure. If a user extrapolates erosion rates in those areas based on historical shorelines before stabilization, then the resulting forecast shoreline will be positioned landward or behind the stabilized shoreline, an unlikely scenario. A revised version of the forecasting function is needed to address this and other limitations of linear extrapolations where processes involving sea level rise, sediment supply, and storms are not taken in to account.

While the extrapolation method using linear regression techniques can be useful when it comes to simple linear forecasting, functions that incorporate other linear and nonlinear statistical methods have been shown to be equally, if not more reliable, for predicting future trends (Fenster et al., 1993). Recently, Frazer et al. (2009a, 2009b) and Genz et al. (2009) propose new shoreline forecasting techniques using basis functions and compare their reliability when applied to select Hawaiian shorelines. Currently, programming code obtained from the authors of those studies is being converted from Matlab in to R code and being tested in AMBUR along with methods found in previously published and unpublished research.

2. Conclusions

This paper introduces the main functions of the AMBUR (Analyzing Moving Boundaries Using R) package, which allows rapid assessment of shoreline change trends and forecasting of future locations of the shore. The package is written in the R software environment to provide researchers with an open-source software option for analyzing shoreline change. Advantages of the AMBUR package being open-source include that it is freely available, can work with GIS software programs that output ESRI shapefiles, and is customizable to perform additional tasks and analyses. Although the primary application presented above is for historical shoreline change analysis, AMBUR can analyze the movements of virtually any physical boundary over time.

Advanced functions for new baseline and transect casting techniques in AMBUR improve on the traditional transect method and yield results that are more consistent with the direction and magnitude of shoreline movements, in particular for highly curved coastlines. The output of each shoreline analysis provides the user with a series of data tables, summary reports, and graphics with which to quickly assess trends and identify potential problems within their shoreline change datasets, without having to manually plot data following each analysis. If desired, the results of a shoreline analysis are easily converted to point

and polyline shapefiles for further analysis in a GIS. Forecasts can also be made using rate calculation methods, such as the EPR, LRR, and WLR, to extrapolate future shoreline positions.

Appendix A. Resources needed for running AMBUR.

Both R and the AMBUR package are freely distributed and compiled for use within Windows, Linux, and Mac operating systems. Developed versions of R and the AMBUR package are available for direct download through CRAN (http://www.r-project.org/) and R-Forge (http://ambur.r-forge.r-project.org/). User manuals and sample data for AMBUR are also available at R-Forge (http://ambur.r-forge.r-project.org/user/). In addition to code and scripts provided by the author, researchers will be able to submit code for the AMBUR package to assist with the further development of existing and new functions at the AMBUR R-Forge website. The following steps are needed to install and execute the AMBUR package functions:

1. Download and install the R software environment (http://www.r-project.org/).
2. Download and install the AMBUR package and dependent R packages (http://ambur.r-forge.r-project.org/).
3. Load the AMBUR package by typing the following at the R command prompt: library(ambur).

Users can also download the AMBUR package manually at the R-Forge website. However, dependent packages needed to run AMBUR must also be downloaded through CRAN manually or through the R interface using the CRAN repository. A list of dependent packages can be found in the DESCRIPTION file in the AMBUR package file.

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