3 SHORELINE CLASSIFICATION METHODOLOGY

Introduction

The ESI scale, as described in Section 2, categorizes coastal habitats in terms of their susceptibility to spilled oil, taking into consideration a number of natural physical and biological factors. Because the scale was constructed on the basis of spill experience and fieldwork in each of the habitat types, the need for extensive fieldwork when assessing a region's sensitivity to spilled oil is reduced. Typically, a state's coastline can be field-classified within weeks, weather and tides permitting. The practical application of the ESI scale relies primarily on recognizing shoreline habitats using maps, literature, remote imagery, low-altitude aerial surveys, and ground observations. Of these, the bulk of the classification takes place via low-altitude aerial surveys. Nevertheless, ESI shoreline classification involves several data sources and a multi-step workflow, of which the aerial survey is just one component. The process involved in a typical ESI survey, as described below, is outlined in Figure 1.

Initial Data

Before shoreline classification can take place in the field, the following basic data set (shown in Figure 1 as the shaded squares) must be obtained and processed:

1. Base maps
2. Shoreline
3. Wetland boundaries
4. Aerial photos
5. Previous shoreline studies

Base map. The base maps used for each project are generally the most current topographic maps available. These maps are used during the field surveys and also serve as a background for the final ESI hard-copy maps. For domestic projects, U.S. Geological Survey (USGS) 7.5-minute quadrangle maps (1:24,000) are most commonly used. In some regions, such as Alaska, the most detailed maps available are at a scale of 1:63,360, and these are used as the base maps. International atlases used U.S. Defense Mapping Agency and foreign government agency maps that are published at a scale of 1:50,000.

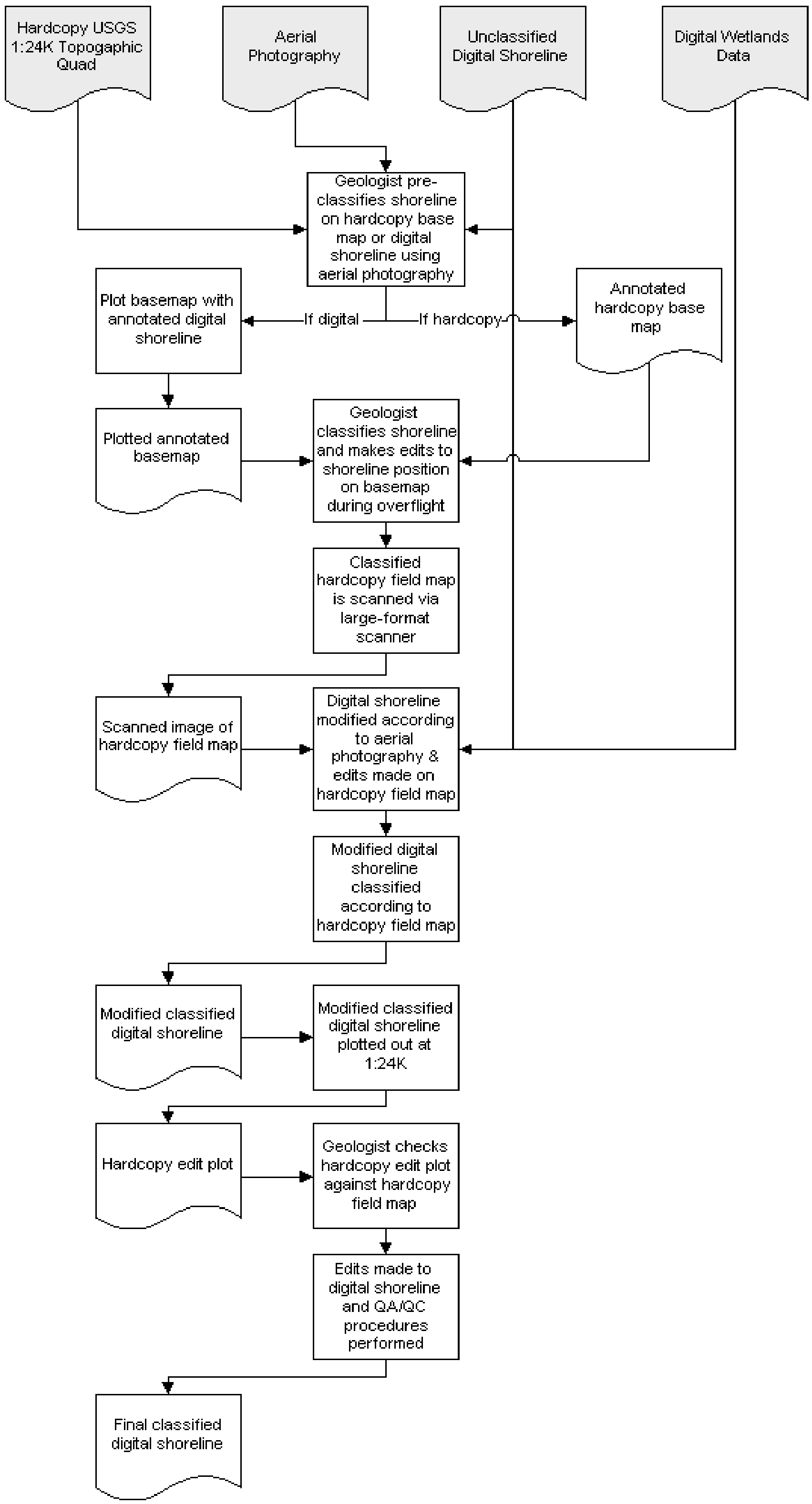

Figure 1. Flowchart of the process for classifying and digitizing the shoreline habitats.

Before field use, all base maps are scanned as grey-scale digital images using a tablet scanner.

In some instances, Digital Raster Graphic (DRG) files have been obtained and plotted at an appropriate scale for use as field base maps, as have digital orthophoto quarter quads (DOQQs) and portions of satellite imagery.

Shoreline. The shoreline used for ESI mapping is a key data layer because many other data layers use the shoreline as a boundary. For example, polygons for shorebirds are created as a buffer around the shoreline; turtle-nesting beaches are digitized buffers around certain sand beaches. Shorelines are digitized in-house or are provided by state or Federal agencies. The shoreline that is used for each ESI project is often dictated by the shoreline that is used by the state and/or Federal agencies for existing mapping projects; most commonly, this shoreline is from 1:24,000 USGS topographic maps or NOAA coastal survey maps. However, in some situations a more current shoreline is digitized from DOQQs or other imagery. When this occurs, the new shoreline is plotted atop the scanned base map and is used in the field during the shoreline surveys. Regardless of the shoreline source, any changes in shoreline position (i.e., new man-made features, inlets, etc.) noted during overflights are incorporated into the final shoreline coverage.

Wetland Boundaries. When wetlands are mapped as polygonal features, an outside source typically provides their boundaries digitally. Commonly, National Wetlands Inventory (NWI) data are used for domestic projects, but State agencies have also contributed data. In some cases, the only available source for the areal extent of wetlands is their delineation as shown on the topographic base map. When this occurs, the boundaries are verified or modified during the project overflights and used in the final ESI data and atlas.

Aerial Photos Copies of recent aerial photos available through Federal and State agencies are generally obtained before overflights. Color, color infrared, and black-and-white photography all provide an overview and generate a preliminary ESI classification. In general, hard-copy photos are most useful for preliminary shoreline classification when they are of a scale comparable to 1:12,000. Photographs available at scales smaller than 1:12,000 (e.g., 1:40,000) are most useful if provided in a digital format, so that they may be enlarged interactively to enhance the detail in the intertidal zone. DOQQs are of particular value since they can be easily geographically registered to match the shoreline to be used in the project and digitally magnified to permit preliminary ESI classification.

Previous Shoreline Studies To become familiar with the field area, the geologist reviews literature (including ESI atlases) pertaining to the map area.

Preliminary Shoreline Classification

The geologist uses aerial photography with shoreline studies to begin classifying the coastal habitats after the data have been acquired and before field-classifying the shoreline , (Figure 1). If the digital shoreline is available at the time of the preliminary classification, the geologist may update shoreline arcs with the appropriate ESI values and replot them atop the scanned base map for use in the field. If the digital shoreline is not ready to be attributed, the hard-copy base maps are hand-annotated. In addition to classifying the shoreline, any sheltered and/or exposed tidal flats that appear may be added to the base map at this time. Once areas with available aerial photos have been pre-classified, the actual field surveys take place.

Field Survey Methodology

The fieldwork involved in an ESI shoreline classification consists of two parts: 1) aerial surveys and 2) ground verification. Aerial surveys are conducted using fixed, high-wing aircraft and/or helicopters. Because the intertidal zone is being mapped, it is critical that the survey takes place within 2.5 hours of low tide so that the maximum area of intertidal substrate is exposed. Surveys are coordinated with spring low tides when possible and flight plans are always scheduled to maximize time on-site during low tide.

During the overflight, the pilot maintains an altitude between 300 and 600 ft and speeds of 80 to 90 knots. The geologist annotates the shoreline with ESI rankings as it appears on the base map, carefully noting transitions in habitats. Shorelines with more than one ESI type in the intertidal zone are annotated on the map in order from landward to seaward ESI classifications (e.g., a seawall fronted by a fine-grained sand beach is noted as 1B/3A). Because of GIS limitations, a maximum of three ESI classes may be assigned to one segment of coastline. In addition to classifying the shoreline, the observer takes low-altitude, oblique photographs representating each ESI habitat. In areas where the coastline significantly differs from the base map, through natural or artificial processes, the geologist modifies the base map coastline by hand, while the pilot circles the area at a higher altitude. This new coastline is then classified.

Tidal flats are mapped using aerial photographs, maps, and field observations. While aerial photographs provide an overview of intertidal features, they are often not obtained during low tide, making tidal flat boundaries taken from them somewhat unreliable. Field observation provides the most reliable information and the geologist must hand-sketch the extent of any tidal flats. Only tidal flats exposed subaerially are mapped. In some cases, tidal flats are portrayed accurately on the base map and are simply annotated during the overflight with the appropriate ESI class. In some areas, the tidal flat is so narrow that it is not mapped as an individual polygonal feature, but as the seaward component of a double ESI class shoreline. Because of the mobility of exposed tidal flats and the nature of the method used to map them, their location on an ESI map should be considered approximate.

Wetland classification and map detail depends on the complexity of the map region and the availability of polygonal data. When available, polygonal data are incorporated into the final ESI map. The existing ESI categories pertaining to wetlands (10A-10E) are in part the result of use of NWI and other datasets. It is often not possible to clearlyidentify freshwater vs. salt- and brackish water marsh from the air. Typically, the only field modification of the wetland data provided is to cross out or sketch tracts of wetlands that no longer exist or have been modified by coastal engineering. In the cases when no digital wetland data exist, the areal extent of wetlands is generally not defined and only their presence and classification along the outer-shoreline is shown. In areas where extensive tracts of wetlands in the coastal zone have no polygonal data, the geologist may verify boundaries during overflights, from existing topographic maps, and by analyzing aerial photographs. Human-use features, such as marinas, boat ramps, and aquaculture sites, are also mapped during the aerial photograph analysis and overflights.

Ground verification takes place daily, depending on the timing of the overflights. Ideally, an example of each habitat should be visited and photographed on the ground. At a minimum, ground verification concentrates on confirming grain-size classifications for sedimentary substrates, since this can be difficult to recognize from the air. If a portion of the coast is identified during the overflights as problematic or difficult to classify, that segment or one like it is ground-checked and the maps are updated according to the ground observations. In regions with complex wetland habitats, it is essential to field-verify classifications made from the air.

Shoreline Classification Revision and Editing

Once the field component of the project is complete, the maps are scanned and the digital shoreline arcs are updated with the ESI attributes noted in the field (Figure 1). For a full explanation of this process see Chapter 5. The shape and position of the digital shoreline is also changed at this time to reflect field observations. After the information from the field maps has been incorporated into the digital database, the now-ESI color-coded shoreline is replotted at the same scale as the original base maps. The classified shoreline plots are then compared by the geologist to the original field-annotated base maps and any errors in shoreline attributes as recorded in the GIS database are corrected. Also at this time, any inconsistencies relating to exposure to wave energy are corrected. This pertains more to man-made or rocky substrates than sedimentary (e.g., exposed riprap adjacent to sheltered seawall). After these revisions and the performance of GIS QA/QC procedures, the ESI shoreline classification is complete.

Spatial Accuracy of Classification Methodology and Sources of Error

The only quantitative test of the spatial accuracy of the ESI shoreline classification was conducted during the Hawaii ESI mapping in August 2000. In the test, boundaries between ESI categories as mapped from the air (specific coastal habitats such as coarse-grained sand beaches, wave-cut platforms, and salt marsh) were located in the field and their positions were recorded with a handheld global positioning system (GPS). Coordinates were collected for over 60 points. The field-recorded GPS coordinates were then compared to the coordinates of the same points in the final digital ESI data to determine the spatial accuracy of ESI breaks or nodes as mapped.

Error analysis showed that occurrences of error were unsystematic and, therefore, genuinely random. It was initially assumed that errors in the x and y dimensions were independent of one another and normally distributed about the true location with an equal variance, or that there was no directional bias in the error. This assumption was verified by examining a circular plot of all measured deviation vectors from the mapped locations. The relatively circular distribution of points about the center of the plot illustrated that error was occurring unsystematically in all directions. When the angles of the error vectors were normalized based upon the orientation of the shoreline at the mapped point of measurement, it was shown once again that error was distributed in a more-or-less circular pattern about the center or "true location." Error vectors clustered parallel to the shore would have indicated positional inaccuracy parallel to the shoreline that likely would have resulted from field or aerial survey work. The error analysis concluded that, regardless of error magnitude, there was no evidence of directional bias in the data.

The magnitude of the error present and the probability of its occurrence were analyzed statistically. There are a variety of statistical methods accepted as measures of map accuracy. Three of the most commonly used and accepted are the root mean squared (RMS) error value, the 95-percent error bound, and the circular error probable (CEP) or 50-percent error bound. The RMS value is derived directly from the data, whereas the percent error bounds are based on a probability function that incorporates the RMS value. Table 5 contains the three error reporting methodologies used and the accompanying values derived from the data collected in the August 2000 study.

Table 5. Error reporting methods and values from the Hawaii test of the spatial accuracy of the breaks between shoreline types.

Reporting method	Error (m)	Percentage of errors smaller
Circular Error Probable (CEP)	28.0	50%
Root Mean Squared (RMS)	33.5	63%
95% Error Bound	58.2	95%

In a practical sense the information presented in Table 5 means, using the RMS as an example, that the map user can be sure that 63 out of every 100 of ESI breaks mapped and included in digital databases are at least within 33.5 meters of their true geographic position. It should be noted that the numbers in Table 5 are statistical generalities, describing the data overall. In many cases, the mapped ESI break is likely closer to the true geographic location. The amount of error occurring at an individual ESI break fluctuates depending on the habitats mapped, among other factors (Table 6). For example, more positional error would be expected in the case of adjacent mobile, sedimentary substrates (that grade laterally into one another), than in the case of a seawall abutting a riprap structure. In general, there are three primary causes of error:

1) Error associated with mapping natural, gradual changes as discrete points;
2) Error associated with inaccuracies in the shoreline(s) used (hard-copy and digital); and
3) Human error (in the field).

The three primary sources of error listed above are the most readily identifiable and perhaps most significant. However, as outlined in Table 6, they are only part of a range of error sources. The degree to which these sources compound each other or cancel out one another is difficult to determine. As such, one can only measure and describe the total error that results from a combination of all these factors.

While there are still unknowns about the individual error sources, the magnitude of spatial error found in the August 2000 study is such that it would be almost imperceptible on the hard-copy product, either at the compilation scale 1:24,000 or at the typical publication scale of 1:48,000. At 1:24,000, 58.2 m (the 95-percent error value) translates to roughly .095 inches or about a 1/10th of an inch error in final ESI break placement. The results presented are given as representative for ESI shoreline classification data, though they will vary to some degree for each atlas. As a greater body of data accumulates, these results will undoubtedly be refined. In the case of ESI maps generated in Alaska and Central America, where base maps of 1:63,360 and 1:50,000 scales, respectively, are used for ESI mapping, these results cannot be considered representative.

The spatial accuracy of the ESI mapping process becomes more important when the ESI data are disseminated and used in digital form. The difficulty in applying traditional

Table 6. Factors contributing to spatial error in ESI data.

Base map Error
1. Trends in shoreline associated with mappable coastal habitat change may be generalized on a base map scale of 1:24,000 2. Hard-copy shoreline may be inaccurate (due to map's age, tidal stage mapped, and/or human error)
ESI Process Error
1. The field geologist may misplace the ESI break (varying degrees of error depending on map reference points available) 2. Width of pencil mark used to indicate ESI break (10m error @1:24,000). 3. Digital shoreline used may not match base maps used in the field 4. If provided by an outside source, the digital shoreline may be digitized from maps that are not the same edition as those used in the field.

Table 6. Cont.

5. Error introduced when pencil marks are digitized as points 6. Error associated with re-projection of shoreline or warping of map during digitization
Cartographic Error
1. ESI break may not be a discrete point (i.e., gradual natural transitions in coastal geomorphology)
Thematic Factors Affecting Spatial Error
1. The field geologist may misidentify ESI types 2. The field geologist may merge ESI types to simplify mapping (a visual interpretation of minimum mapping unit)

concepts of scale such as the representative fraction (e.g., 1:24,000) to digital data is a problem that is of great concern to those that produce and use such data. Interactive mapping applications and tools, which allow you to reproduce and present data at scales greater than that at which the data was collected, make it critical that results of studies such as these be made available to the user community of digital ESI data through accompanying metadata or similar means.