MODIFIED COMPUTATIONAL METHOD AND ANALYSES OF CHANGES IN ESTUARINE CONVERGENCE IN SOUTH KOREA BETWEEN 1985 AND 2015

An Undergraduate Research Scholars Thesis

by

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ABSTRACT

Modified Computational Method and Analyses of Changes in Estuarine Convergence in South Korea Between 1985 and 2015

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Estuaries contain important ecosystems with high productivity and benefits to humans, such as storm protection. However, estuaries are under threat from human interference, such as the construction of dams and sea level rise. Ongoing research of the impacts of anthropogenic changes proximal to estuaries can support management of the health and overall function of the imbedded ecosystems. In an effort to better understand how the geomorphology of estuaries are changing due to anthropogenic alterations of estuaries, the TAMUG Coastal Geology Laboratory has been developing algorithms that allow for the automated quantification of these changes. The purpose of this project is to modify the existing R programming language code to automatically process the convergence length of estuaries and provide information on how they have changed over time. While the R code scripts were shown previously to successfully process estuarine convergence, multiple errors were encountered. The methods used to troubleshoot these errors and their resolution are presented. Then, a comparison of convergence length of

South Korean estuaries between the years 1985 and 2015 is provided as a continuation of the comparison conducted previously, with the data acquired from the modified R code scripts. The findings can inform research on the human impacts on estuarine environments in that region.

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I would like to thank my research advisors, Dr. David Retchless and Dr. Tim Dellapenna, for their guidance and support throughout the course of this project.

NOMENCLATURE

DNE	Did Not Evaluate
ESRI	Environmental Systems Research Institute
ETD	Estuary Troubleshooting Datasheet
GIS	Geographic Information System
GSWD	Global Surface Water Dataset
IPCC	Intergovernmental Panel on Climate Change

CHAPTER I

INTRODUCTION

Along coastlines across the globe, where seawater meets freshwater at the mouths of rivers, unique environments known as estuaries can be found. The integrity of the brackish estuarine water depends on a balance of freshwater and seawater input, which may be jeopardized by anthropogenic structures such as dams and sea level rise (Kennish, 2002) (IPCC, 2019). The banks of most estuaries narrow further inland before reaching the river proper, and the distance over which this occurs is known as the convergence length. The width of estuaries has been found to decrease exponentially with convergence length, making it a significant parameter to monitor the health of estuaries over time (Davies, 2010). In order to automate the process of retrieving convergence length data from estuaries in South Korea, an algorithm was previously translated into R code to calculate convergence length from estuary polygons retrieved from a modified Global Surface Water Dataset (GSWD). Although the R code scripts were functioning and significant changes in convergence length of South Korean estuaries were found to have occurred between 1985 and 2015 (Bartlett, 2019), there were unresolved errors thought to be caused by unusually shaped estuaries. The purpose of this project was to first resolve the R code issues through modification of the existing R code scripts, and then re-analyze the estuary data for changes in convergence length between 1985 and 2015.

Background

Estuaries play a critical role in the environment and support local populations, such as provision of fisheries, natural storm protection, and access to the sea via natural ports. Studies indicate that anthropogenic changes proximal to estuaries, such as dams and reservoirs, can have a significant impact to the health and overall function of that ecosystem. Research by Kennish (2002, p. 9) describes the impact of anthropogenic structures such as dams, and states “river-estuarine systems worldwide are subject to similar hydrologic alterations ascribable to an array of human activities, diminished river flow and its impact on biotic organization in affected estuarine waters may be an emerging global problem.” A more recent study showed that construction of dams in South Korean estuaries resulted in significant changes in sediment transport and river flow velocity (Williams et. al., 2013). Related research by Williams et. al. (2014) also provided a specific example for the Yeongsan Estuary, where construction of a dam resulted in a large increase in the rate of sediment deposition on the seaward side of the dam due to tidal prism reduction. Increase in sedimentation can cause changes in the geomorphology of estuaries, such as significant shoaling and narrowing.

The potential for sea level rise due to anthropogenic climate change that threatens estuaries was outlined in the Intergovernmental Panel on Climate Change (IPCC) Summary for Policymakers 2019. The document states that sea level rise brings risk of increased sea water intrusion to estuarine environments, potentially disrupting their brackish water habitat (IPCC, 2019). The current project expands on the recent study by Bartlett (2019) focused on estuaries in South Korea, to further develop an improved analytical method for calculating estuarine convergence which might correlate to anthropogenic changes in the region.

Objectives

The proposed research questions were: 1) could the R code to compute estuarine convergence (i.e., the distance over which estuaries narrow) be modified to work with estuaries with unusual shapes, and 2) does additional data reveal significant changes in estuarine convergence length between 1985 and 2015 in South Korea?

The expectation was the R code could be successfully modified, and analyses of the South Korean data would demonstrate significant decrease in convergence. The findings could support ongoing research on changes correlated to man-made modifications. The modified computational tool might also be helpful to study other data sets and global regions.

Literature Review

The current work focuses on computing estuary convergence length as a key parameter to analyze changes in estuaries, which might correspond with anthropogenic perturbations. Some previous attempts to develop accurate models were time consuming and limited by assumptions due to the many factors involved in the calculation. As an example, Dronkers (2017) concluded that the length was dependent on “mean channel depth, the tidal amplitude, the relative intertidal area and the river flow velocity.” These were also factors identified by Williams et. al. (2013) to have been impacted by the construction of dams in South Korean estuaries. Due to the many variables in modeling convergence length, other previous work was reviewed to determine an alternate approach. Davies and Woodroffe (2010) provided basic formulas for calculating the length described and provided examples of width profiles created by digitizing Landsat 5 data. Notably, their work provided the source for the R code used by other researchers (e.g., Bartlett (2019)) and used in the present study.

As mentioned previously, the current work leverages that of Bartlett (2019) who had some success using the R code to determine significant changes in convergence length of South Korean estuaries, although there were multiple errors. Source data used in the current study was the same as that used by Bartlett (2019, p. 12), which was “cultivated from the Global Surface Water Dataset (GSWD), produced by Pekel et al. (2016) through the Google Earth Engine interface. This dataset provides measurements of global surface water from 1984-2015.” Again, the dataset was limited to South Korean estuaries and Bartlett (2019) provided extensive details on the process to derive that specific data. While the analyses completed by Bartlett (2019) were not comprehensive, contribution of the dataset itself was significant. Note that Kennish (2002, p. 14), stated “although the literature is replete with studies of human impacts on estuaries, significant data gaps exist. For many estuarine systems, especially in developing countries, baseline data on biotic communities and anthropogenic stresses are not sufficient to address informational needs.”

With pertinent references for the R code and data for evaluation, the present study was pursued with the key objective to effectively compute convergence lengths for all types of estuaries to support research studies specific to man-made modifications, such as dams. The importance of this field of study and specific examples are further described in the works of Hodder (2018) and Bartlett (2019)**.**

CHAPTER II

METHODS

For conduct of this work, the ArcGIS software was available on computers at the university and on my personal computer. The faculty mentors, Dr. David Retchless and Dr. Tim Dellapenna, provided guidance for the coding, data processing and overall interpretation of the data results. The recent student researcher, Victoria Bartlett, was also contacted and queried as needed to determine the technical details related to the previous R code issues.

The first task on this project was to resolve the R code issues through modification of the existing R code scripts recently utilized by Bartlett (2019), including runs of the updated code using the RStudio platform. A centralized data table was created in a Microsoft Excel spreadsheet, known as the Estuary Troubleshooting Datasheet (ETD), for the purpose of recording the outputs, errors encountered, and other relevant information for each estuary processed through multiple iterations of the code, including the estuaries processed by Bartlett (2019). As changes to the R code were made, the progress in resolving errors and improving the quality of the data from each modification was recorded.

The R code scripts acquired from the previous work of Bartlett (2019) automate the computation of estuarine convergence using the formulas from Davies (2010). The code begins by identifying a starting point, located at the midpoint between two points at the start of both banks of an estuary. Then from that point, a series of points known as the centerline is calculated equidistant from both banks. The width of the estuary is then calculated at each point along the centerline, and the change in width over distance upstream from the mouth of the estuary is fit to an exponential curve. The length of the estuary convergence is determined to be the point along the curve at which the channel width ceases exponential reduction.

In order to determine the problems afflicting the original R code scripts, they were run with their original data and the results were recorded in the ETD. Classification of errors in the code were used to focus the work for two phases of error identification. Phase 1 errors were those generated while running the R code scripts encountering errors causing the code to crash, such as the original R code script or with early modifications on the R code scripts. The identified errors are described and numerated as shown in Table 1.

Table 1. Phase 1 errors.

Phase 1 Error Numbers	**Description**
1	Error in Exponential Curve Fit
2	Unable to Process Null Values
3	Starting Point Error
4	Estuary Size Too Small to Process

For the phase 1 evaluation, error 1 was the most common error encountered; the cause was determined to be a failure in the code to fit the estuary width profile to an exponential reduction curve. An estuary afflicted with Error 1 failed to output a convergence length. Error 2 was not as common and was speculated to be caused by the code being unable to process null values. An estuary afflicted with Error 2 failed to generate a width profile. Error 3 was associated with starting point errors caused by the code placing the starting point in a location other than the mouth of the estuary, and this error was common in the original starting code. An estuary with Error 3 could produce poor data with either a negative convergence length or a convergence length with an unrealistically small value. Estuaries were diagnosed with Error 3 after a manual review of the data. Error 4 was determined to be most likely caused by the size of the estuary being too small for the code to properly generate a width profile. While there were multiple errors produced in the original code, it was determined that resolving the starting point errors would be the first focus of the project since these occur at the start of the R code script.

The original code generated a starting point for the estuary centerline at the minimum x coordinate between the two banks and the average y coordinate between the minimum of bank1 and the maximum of bank2. Figure 1 shows an example of where the starting point would be located using the original code. The issue however is that it does not consider the direction in which the estuary opens. The original bank points were projected in unit meters in the "WGS_1984_UTM_Zone_52S" coordinate system per the previous work of Bartlett (2019). However, this was changed, and the bank points were reprojected to "WGS_1984_UTM_Zone_52N" as more appropriate for a study being conducted on a country in the Northern Hemisphere. The value of the x coordinate (longitude) increases to the East and the value of the y coordinate (latitude) increases to the North. Therefore, the original starting point code would determine that the longitude of the starting point of an estuary opening to the East would be at its minimum value, which would therefore be the furthest upstream as shown in Figure 2. This is problematic for analyzing the estuaries of South Korea which can be found on either its Eastern, Western, or Southern coastline.

To remedy the starting point issue, a series of conditional statements was created in the R code script to determine the direction in which the estuary was opening. By calculating the slope

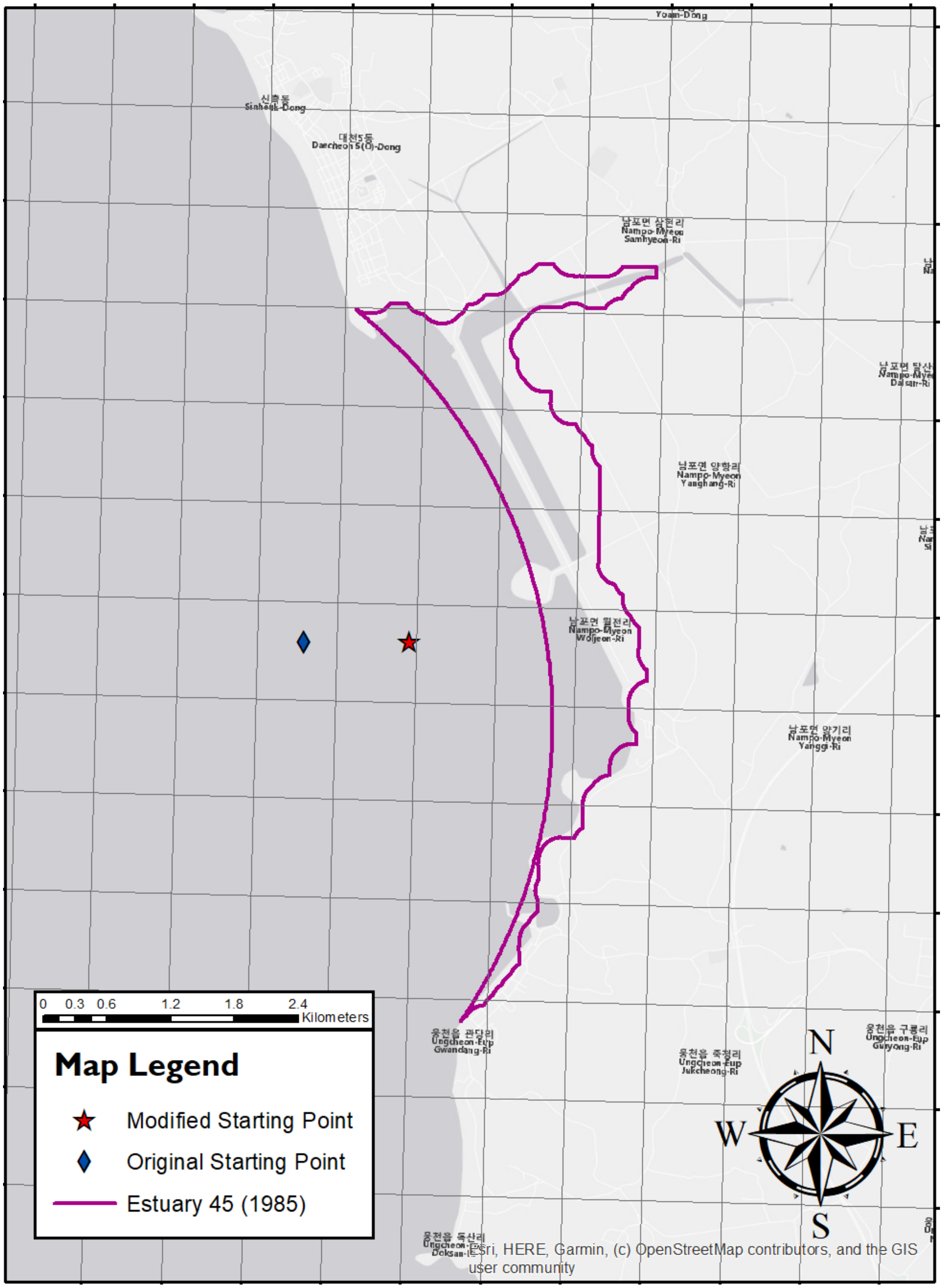

Figure 1. Both the original and modified codes generate starting point locations similarly for an estuary opening to the West.

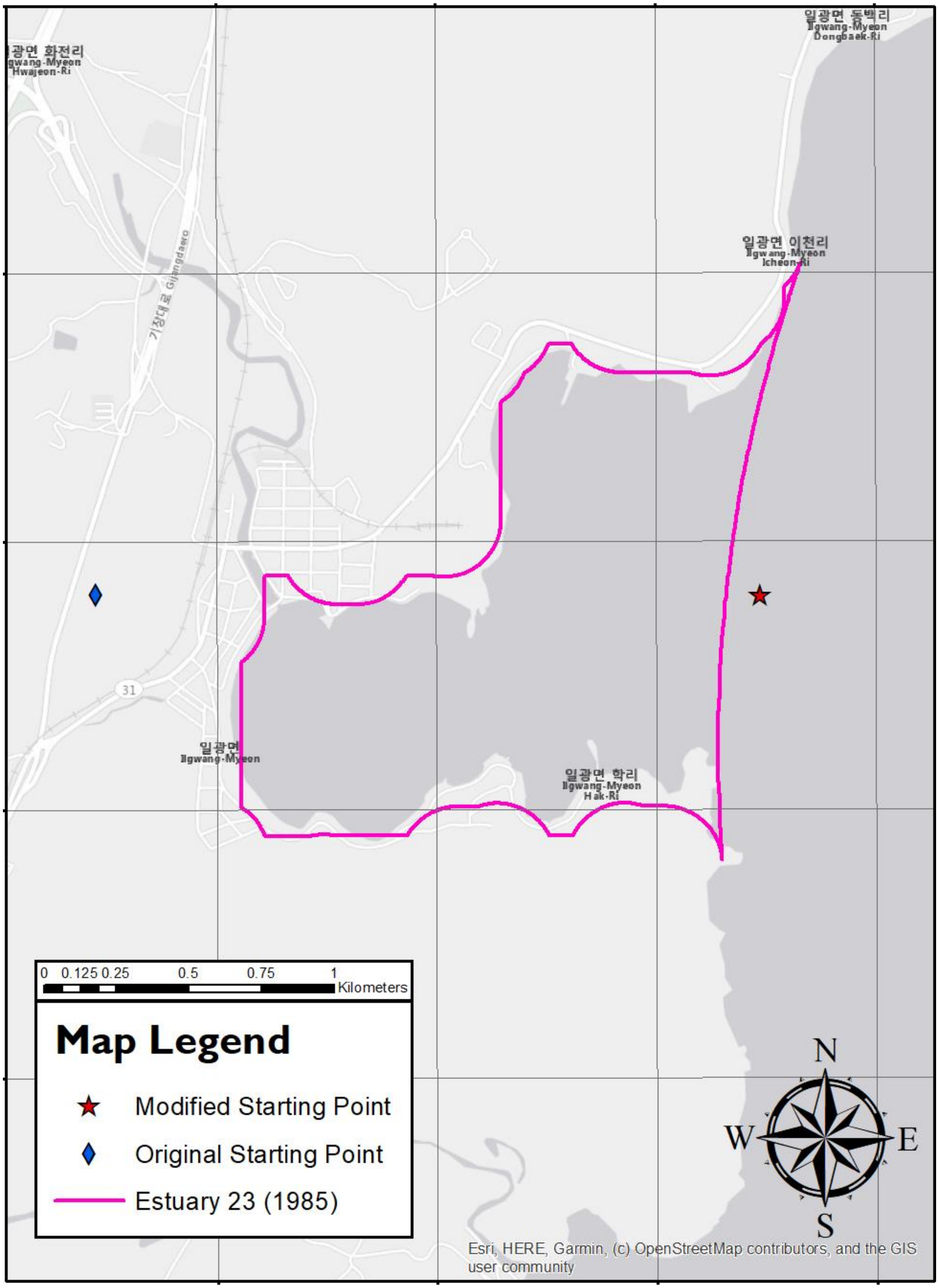

Figure 2. The original starting point code generates an incorrect starting point location for an estuary opening to the East.

of the x or y coordinate versus the bank point number, the direction of each bank could be determined; this was then used to find where the estuary mouth was located based on how the slopes of the two banks converge. Once the direction of the estuary was determined, the modified R code script would pull on either the maximum or minimum x and y values from each bank and generate a starting point at their mean.

The next priority was the development of a solution to Error 1 (curve fitting errors) since it was the most common error. The error was thought to be caused by the width of the estuary not fitting the formula for estuarine convergence developed by Davies and Woodroffe (2010). The most probable cause was believed to be unusual shapes of certain estuaries in South Korea. Therefore, the application of Simplify and Smooth tools in ESRI's ArcMap GIS software would help clean the estuary data for processing in the R code script.

Bartlett (2019) created a model in ESRI's Modelbuilder (a program within ArcMap) to iterate through the process of converting estuary polygons to point coordinates along both banks in the proper format of comma-separated values (.csv) for input into the R code scripts. This model was modified by the insertion of Simplify and Smooth tools between the Erase and Generate Points Along Lines tool, steps 3.1.3.1 and 3.1.3.2 in Bartlett (2019) respectively. However, the optimal configuration of Simplify and Smooth techniques and parameters such as tolerance needed to be determined in order to resolve the maximum number of errors. Estuaries were repeatedly processed through the model and R code scripts then compared in the ETD to determine the best combination. The solution could be further complicated by applying smoothing and simplification to estuaries based on their size, as larger estuaries were found to benefit more than smaller estuaries. The update overall worked with reasonable success.

Satisfied with the model for smoothing (though it was determined to need further minor modifications in the future), the focus shifted to resolving null value errors (error 2). It was determined that while the code was using the centerline to generate a width profile, missing values were causing the script to crash. Therefore, the R code script was modified to identify these missing values and remove them based on a similar (but only partially functional) approach by Bartlett (2019). Through this process of removing the missing values it was discovered that any estuary undergoing this process would then encounter a curve-fitting error as a result of the removed data, causing a gap in the width profile and resulting in the curve fitting function crashing. To resolve this issue, the values that were thrown out by previous iterations of the code were instead replaced by the last working value. This method was a crude solution as the artificial data it created had the potential to deteriorate data quality. However, the application resolved any curve fitting or null value errors.

With the majority of crashes in the R code scripts resolved, the focus shifted to monitoring the data quality of the estuaries being processed, especially since the solution to the null value and curve fitting errors affected the data quality. For this purpose, a new set of errors were numerated as shown in Table 2 and labeled by describing how they impact the data quality of the convergence length processed by the code. Although a solution to each of these errors was not pursued, their identification was important in determining which estuaries could be used for analyses of convergence length changes.

Figure 3 shows an ideal estuary width profile generated by the final modifications to the R code script, as compared to Figures 4 and 5 showing examples of phase 2 errors encountered. Error 1 in phase 2 was identified as a “double line” error, where the centerline travels upstream and downstream along an estuary causing the width profile to be inaccurate. This is

Table 2. Phase 2 errors.

Phase 2 Error Numbers	**Description**
1	Double Line Error
2	Too Many Null Values Replaced
3	Non-Validated
4	Estuary Size Too Small to Process

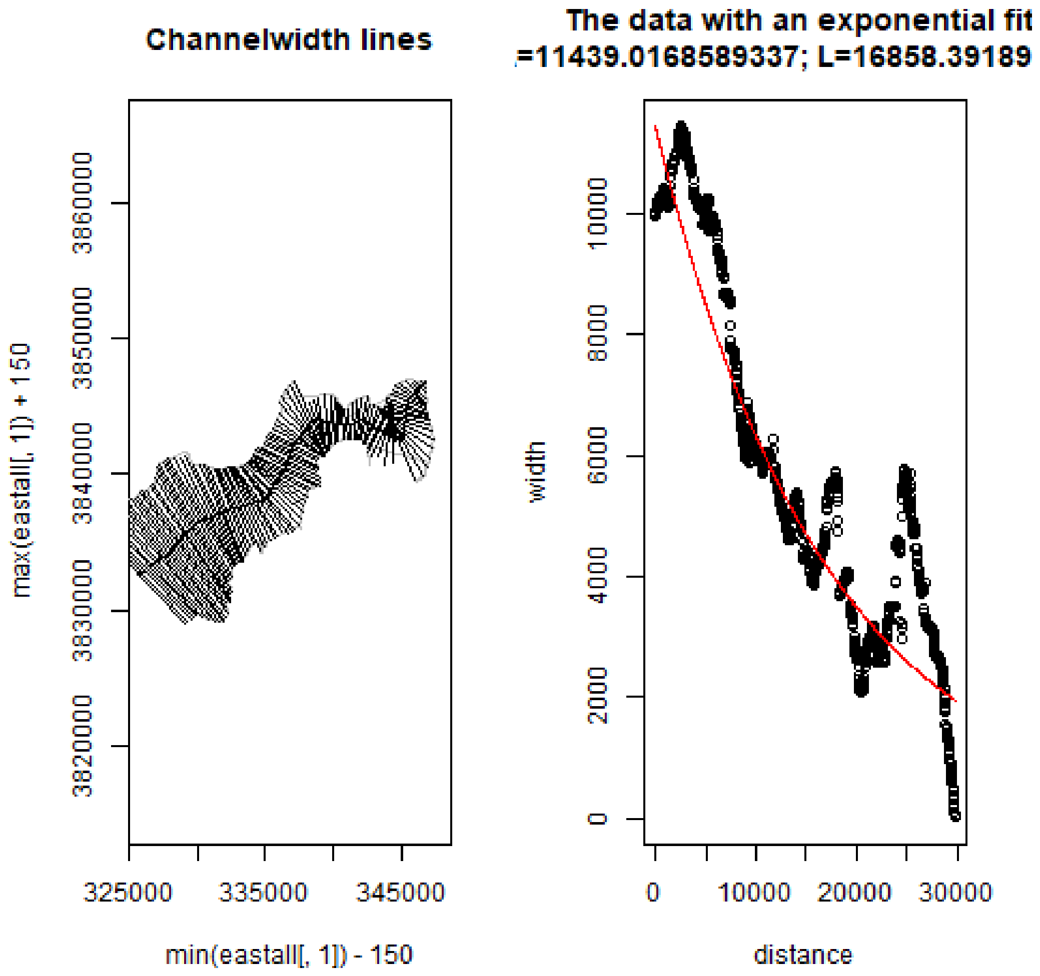

Figure 3. Results for a 1985 estuary showing an ideal centerline generation and width profile.

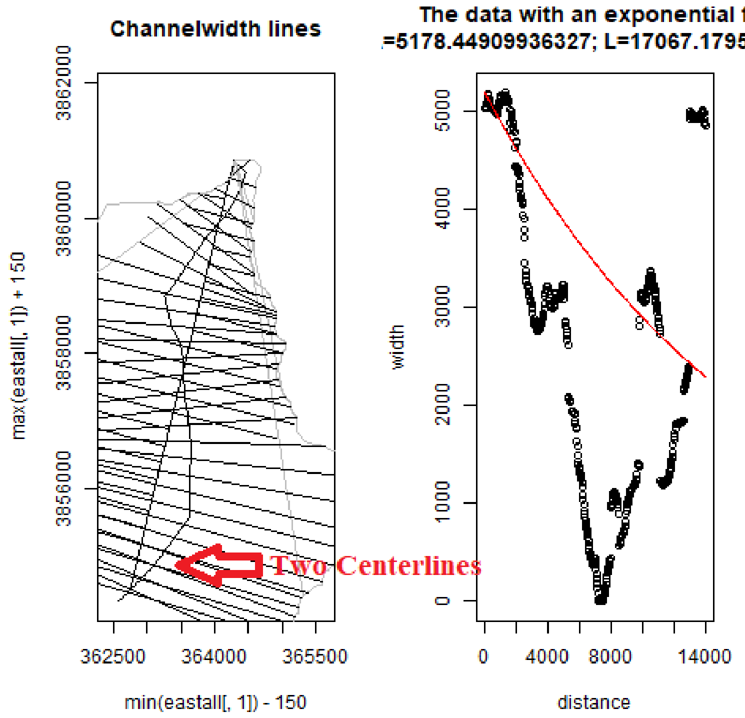

Figure 4. Results for a 1985 estuary showing the double line error (phase 2, error 1).

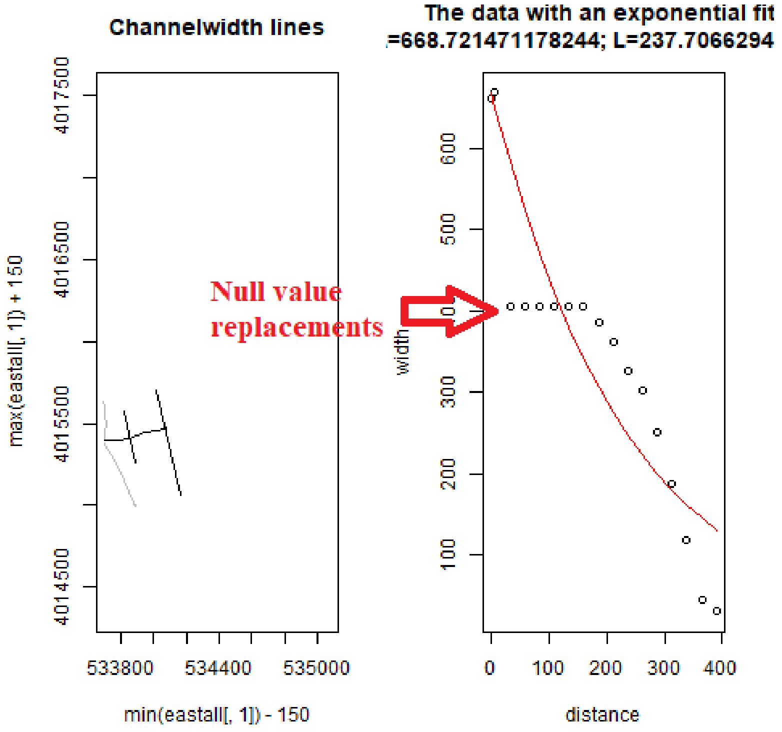

Figure 5. Results for a 1985 estuary showing the null value replacements error (phase 2, error 2).

demonstrated in Figure 4. An estuary with too many null values replaced in the modified R code script is shown in Figure 5, and labeled as error 2, since the artificial data compromises the authenticity of the results. Error 3 was given to estuaries whose results did not make sense, such as negative convergence lengths or convergence lengths greater than the estuary's approximate length. The issues afflicting these estuaries were usually symptomatic of starting point errors, but their cause was never confirmed. Error 4 was the same error as in phase 1, resulting in the code crashing because the estuary being processed was too small.

The process of the second phase of error analyses was a manual inspection of the results of each estuary. The starting point generated for each estuary was recorded and determined to be correct or incorrect. Then, the approximate length of the estuary from the starting point to upstream was measured in ArcMap. The measured length was used to determine whether or not the estuarine convergence results seemed reasonable; if the estuary's computed convergence length was much larger than that measured, there was likely an error during processing.

Once the phase 2 evaluations were complete, the next step was to re-analyze the newly produced estuary data for South Korea, to evaluate changes in convergence length between 1985 and 2015. To provide continuity with the previous efforts of Bartlett (2019) in this analysis, a similar format was used. Estuaries without errors from each year were matched. However, not all estuaries existed for both years according to the updated dataset used in this work, and therefore some had no match (designated as "DNE"). Lastly, the change in estuarine convergence between 1985 and 2015 was calculated as the percent change which was calculated as the percent difference between the two years.

Additional modifications made to the R code script and estuary data deserve some elaboration. First, the data was reprojected into "WGS_1984_UTM_Zone_52N" coordinate system in ArcMap, but this change had minimal impact on the results. Second, the R code script was modified to handle the .csv files containing the estuary bank data, with no modifications to its format after generation using the model created by Bartlett (2019). Third, errors encountered in the R Code script do not cause it to halt with the addition of a “try” function within the loop rotating through estuaries to process. These modifications improved the ease of use of the R code script, and its application in future studies will be more efficient.

At the completion of each modification to the convergence procedure R code, the estuaries were reprocessed. The new results were examined for improvements in the quantity of estuaries without error and the quality of the resulting data. Errors were identified and noted for each estuary processed with the code. The changes in identified errors with each modification to the procedures are reported in the Results.

CHAPTER III

RESULTS AND DISCUSSION

Beginning with the data from 1985, Table 3 shows the number of each phase 1 error generated in processing the selected South Korean estuaries using the original code (Bartlett, 2019). Then, the initial results using the modified code of this work, with correction of the estuary starting point, are shown in Table 4. The overall aim of changing the starting point code was achieved as many estuaries with poor results, such as reversed width profiles causing convergence length values to be negative, were restored.

Table 3. Phase 1 errors encountered with the original code processing the 1985 estuaries.

Phase 1 Errors	**Quantity**
1	26
2	8
3	29
4	2

Note: 90 total estuaries processed

Total estuaries working: 25

Based on run analyses, the smooth tool (embedded in the ArcMap software) was applied and seemed to work the best at reducing curve fitting errors for larger estuaries. The results of applying smoothing specifically to estuaries with a size greater than 15km^2 are shown in Table 5.

Table 4. Phase 1 errors encountered with the modified starting point code processing the 1985 estuaries.

Phase 1 Errors	**Quantity**
1	27
2	12
3	8
4	1

Note: 90 total estuaries processed

Total estuaries working: 42

Table 5. Phase 1 errors encountered with the modified starting point code and smoothing for the 1985 estuaries.

Phase 1 Errors	**Quantity**
1	22
2	8
3	8
4	2

Note: 90 total estuaries processed

Total estuaries working: 50

While this provided some success in reducing curve fitting errors, it was often marred by the fact that its application could also cause curve fitting errors, especially to estuaries of smaller sizes.

Table 6 shows the results of the null error replacements that resolved both errors 1 and 2 in their entirety. These were performed without simplification or smoothing, as the null value error solution had made that application towards resolving curve fitting errors redundant.

Table 6. Phase 1 errors encountered with the final version of the code, including the fixes to the null value errors and reprojected 1985 estuaries, with no simplification or smoothing.

Phase 1 Errors	**Quantity**
1	0
2	0
3	15
4	2

Note: 90 total estuaries processed

Total estuaries working: 73

Based on the results of the phase 1 error analyses, modifications to the R code script were finalized and a new classification of errors was introduced (phase 2 errors described earlier in the Methods section, Table 2). With the exception of error 4 which was not modified from phase 1, the new errors did not cause crashes in the R code script. Rather, these errors represented estuaries that were successfully processed but were not viable for analysis due to problems in their width profile, some unresolved starting point errors, or too many values being replaced in the null value fix.

The results of identifying phase 2 errors encountered using the final version of the modified R code scripts, which included the new starting point generation and resolution of the null value errors, for the 1985 and 2015 estuary data are shown in Tables 7 and 8. Through manual review, the results of about half of the estuaries from each year were deemed to be unreliable because of the errors described previously. Table 9 provides a summary of the estuaries successfully processed, and also includes the number of estuaries where the starting point was accurately corrected.

Table 7. Phase 2 errors encountered with the final version of the code, including fixes to the null value errors and reprojected 1985 estuaries, with no simplification or smoothing.

Phase 2 Errors	**Quantity**
1	25
2	7
3	11
4	2

Note: 90 total estuaries processed

Table 8. Phase 2 errors encountered with the final version of the code, including fixes to the null value errors and reprojected 2015 estuaries, with no simplification or smoothing.

Phase 2 Errors	**Quantity**
1	12
2	13
3	14
4	2

Note: 91 total estuaries processed

Table 9. Summary of the final results from processing the 1985 and 2015 estuaries.

Total Working Estuaries 1985	**Total Working Estuaries 2015**	**Working Starting Points 1985**	**Working Starting Points 2015**
45	49	81	81

Note: 90 total estuaries processed 1985, 91 total estuaries processed 2015

A comparison of computed convergence length between the 1985 and 2015 estuaries in South Korea was performed only between estuaries that were determined to have valid results. Notably there were several cases where a valid estuary for one year was found to have not existed in the other year according to the data derived from the GSWD. The total compared was 39 estuaries, 26 of which had valid results for both years. The results of the comparison in Table 10 showed that changes in convergence length varied significantly. The overall average was a 12% gain in convergence length between 1985 and 2015.

Table 10. Summary of the final results from 1985 and 2015 estuaries.

Estuary #	**1985 Convergence (m)**	**2015 Convergence (m)**	**Convergence Change (%)**
0	1962	1887	-4
3	733	DNE	N/A
6	11271	7597	-33
7	2243	2202	-2
8	227	316	40
10	958	871	-9
11	16858	16482	-2
15	5528	5415	-2
16	2135	2244	5
18	7511	5461	-27
22	19605	18969	-3
23	957	967	1
28	6814	6683	-2
32	792	DNE	N/A
33	362	964	166
37	3616	4873	35
39	1083	847	-22
40	1455	1161	-20
43	545	540	-1
47	493	578	17
53	35509	8173	-77
57	14552	16803	15
58	7775	9987	28
59	13793	14089	2
60	619	DNE	N/A
64	151	414	174

68	1634	2042	25
69	761	DNE	N/A
70	1169	DNE	N/A
78	227	204	-10
81	809	1028	27
90	DNE	973	N/A
91	DNE	1166	N/A
92	DNE	812	N/A
93	DNE	12230	N/A
94	DNE	1821	N/A
95	DNE	6851	N/A
96	DNE	1520	N/A
98	DNE	562	N/A

Note: Included are 39 estuaries, 13 of which do not have a partner estuary for comparison as they did not exist in the dataset for that year.

CHAPTER IV

CONCLUSION

The first objective of this work was to modify the existing R code script to automatically calculate estuarine convergence without crashing, thus resolving errors in the original code. The script processing was improved, but some results were still found to be inaccurate, which may be related to the underlying formulas or scripts used to compute convergence length. However, the developed R code script did successfully process 39 estuaries that were valid for a convergence length comparison over time on the South Korean peninsula, which is an increase of 25 estuaries processed as compared to the original code.

While errors causing the R code script to crash were resolved, other issues were encountered that translated into poor data quality for a subset of estuaries. Some methods were attempted to work around those errors, but in many cases this compromised results of the code for the afflicted estuaries. Modifying the underlying formulas in the R Code used to compute convergence length was not attempted, as this was deemed to be outside of the scope of the project but might be considered for future work.

The additional data successfully produced with the modified script allowed for an updated comparison of convergence lengths in South Korean estuaries. The computed change of each estuary varied significantly, and the overall average calculated was a 12% gain in convergence length between 1985 and 2015. This is a significant increase compared to the average change of -6% in convergence length as reported by Bartlett (2019).

Given the significant variation in calculated convergence length over time in the South Korean estuaries, the updated R code script results should be utilized as guidance for further review of estuaries, including study of additional parameters indicative of their health. The improved code can support this work in providing an automated process to determine estuarine convergence, which is difficult to calculate by hand. Again, additional modifications to the R code script could also be pursued, such as edits to the functions and formulas executed. Overall, this work demonstrates the potential for using R code to automate convergence length computations, which can support monitoring the health of estuaries under threats from human modifications, sea level rise, etc. across the globe.

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