DEVELOPMENT OF A GEOSPATIAL PROCESS FOR THE ANALYSIS OF CHANGES IN THE COASTAL, EMBAYED, AND ESTUARINE SURFACE WATERS OF SOUTH KOREA

A Thesis

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ABSTRACT

Global coastlines provide vital benefits to both nature and humans alike in the form of embayed and estuarine waters. Often, these coastal interfaces are subject to development and modification by humans and undergo changes which inhibit their natural processes, causing significant damage to the local habitats and removing ecosystem services. This is doubly true in South Korea, where many estuaries have been dammed, eliminating tidal influxes, backfilled to create new land, and finally developed for economic gain. Categorical transitions in surface waters over time may be indicative of these human induced changes, as well as natural processes that have changed due to human modifications of the environment. This thesis attempts to find a way to extract this transitions data for individual coastal features using an automated ArcGIS algorithm. This is done by modifying previous coastal generalization techniques theorized by Julian Perkal and applied by Christensen and Mitropoulos. These works attempt to generalize a coast by rolling a circle along a cartographic line. Depending on the size of this circle, it will draw an arc across areas it cannot fit into which are typically associated with coastal bends like embayments and estuaries. If extents of embayments and estuaries can be defined through modifying coastal generalization methods, surface water transitional coverage can be extracted to provide statistics which can reflect surface water loss and gain in coastal features from 1984 to 2018. High levels of surface water change are expected in locations with dense urban development and damming, while little change is expected in areas with little human influence.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supervised by a thesis committee consisting of Dr. Timothy Dellapenna (Chair), Dr. David Retchless (Co-Chair), and Dr. Wesley Highfield of the Texas A&M University at Galveston – Department of Marine Sciences.

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CHAPTER I - INTRODUCTION

Role of the Coast and Estuaries - Natural and Human

Coastlines on a global scale have been a vital part of the survival and growth of nature and humans alike, providing a morphological and ecological interface between the land and the sea (Martinez et al., 2007). Along the coast, stream mouths serve as a vital discharge point for accumulated freshwaters from inland to flow into the sea, bringing along nutrients, sediments, and other terrestrial materials (Milliman & Farnsworth, 2013). These discharge points come in the way of two coastal geomorphic features: deltas and estuaries. Estuaries in particular can be defined by several components stemming from multiple disciplines, though the most widely adopted definition is that of Pritchard (1967): "*a semi-enclosed coastal body of water, which has free connection with the open sea, and within which sea water is measurably diluted with freshwater derived from land drainage.*" However, estuaries are far more complex than this lone definition; possessing a wide range of hydrologic, biological, physical, geological, and chemical elements which work as one (Elliott & McLusky, 2002; Evans & Prego, 2003). Many common definitions exist which describe estuaries based on their geomorphological characteristics, tidal range, dominant energy process, or a combination of these (Perillo, 1995). Within estuaries are a variety of organisms that rely on estuaries as habitats; shellfish, including oysters, clams, shrimp, and crabs, as well as other benthic and epibenthic organisms use estuarine substrates into which they burrow or adhere, various fish species may use the waters to seek food, birds may use associated wetlands for nesting, to name a few (Thrush et al., 2008; Choy, An, & Kang, 2008; Roger et al., 2006).

Humans also benefit greatly from coasts and estuaries, providing many ecosystem services which have assisted in the development and spreading of modern society (Martinez, 2007). What once began as a source of food and means of transportation, has now become a key driving force behind the global economy. Humans have found ways to utilize and modify the coastline to their advantage, likely continuing to do so as time progresses. Examples of services provided by the coast include: food from finfish and shellfish; storm protection and water filtration from wetlands; touristic and intrinsic value from their often eye-catching views; protected access to the sea for shipping vessels; and overall a valuable source of economic gain and cultural value to the human race (Barbier et al., 2011). When humans utilize these ecosystem services, they often place significant pressure on them causing changes to the natural processes (Little, 2017). Like any other system, when processes are changed within an estuary it becomes increasingly vulnerable to external influences and is susceptible to regime shifts (Thrush et al., 2008; Gunderson, 2001). Such changes can be seen in Korean estuaries and regime shifts are likely to follow suit, crippling coastal ecosystems.

South Korea's Coast

South Korea is located in East Asia on the southern portion of the Korean Peninsula. It can be described as highly mountainous toward the east coast, with gentler topography towards the south and west coasts. These mountains contribute to the formation of the drainage basins within the country, forming four primary rivers (the Han, Geum, Yeongsan, and Nakdong) along with many tributaries that drain into the three seas (West Sea, South Sea, and East Sea) surrounding the peninsula. Along these rivers are many high-density population centers which contribute to downstream discharge and development (Choi et al., 2017). The geography and geological characteristics on the Korean Peninsula lend themselves to the formation of the area's primary estuarine classification, rias. Rias are considered a non-glaciated, incised river valley which has been inundated by the sea over time as sea levels rise (Evans & Prego, 2003; Perillo, 1995). They are characterized by a moderate level of relief and a V-shaped valley. They typically meander inland from the sea with smaller inlets branching outwards, easily recognized from above by their dendritic features (Perillo, 1995). In the context of South Korea, these are found on the low to moderate relief western and southern coast, with few being found on the east due to the much steeper topography. Modern Korean estuaries likely formed at the beginning of the Holocene, when sea levels rose from glacial melt (Lee & Yoon, 1997).

In the past century, South Korea has experienced a great deal of anthropogenically driven change within these systems. This wave of change is motivated by government policies implemented in the late 20th century to boost agricultural and industrial activity, and water policy reforms occurring from the early 1900s to present day (Koh, Ryu, & Khim, 2010; Choi et al., 2017). These policies have encouraged the modification of estuaries and influence upstream activities, both having effects on downstream processes, ecosystem health, and human safety

(Hong et al, 2010; Townend & Pethick, 2002). Much of this coastal change involves the damming of estuaries, subsequent reclamation of the tidal lands behind them, construction of hard structures to protect the newly created land, and development of the land for agriculture, industry, and residential corridors (Williams et al. 2014, 2015). Not only does this process remove habitat space, it also restricts entry of saltwater/discharge of freshwater, disrupts the sediment budget, and impacts long-term morphology of the system (Williams, Dellapenna, & Lee, 2013). It is estimated by Lee et al. (2011), that nearly 49% of the 463 estuaries found in South Korea have been closed by similar techniques. Excluding those which are closed, it is possible that many others have experienced some form of modification that caused similarly disruptive surface water changes. Regardless of whether the change is natural or human induced, these changes may lead to major shifts in an estuaries processes and ecosystem balance.

There are hundreds of estuarine and bay environments in South Korea which show evidence of change by both natural and human activities of varying degrees. Asan Bay, located on the upper western coast of South Korea south of Incheon, provides an overhead example of what these human modifications are capable of from the period of 1984 to 2018 (Figure 1). Note the transitions from surface waters arising along nearly all of the estuaries' inlets and coasts. Associated dams and agricultural land can be seen to take the place of the surface waters, indicating that these changes are human based. These are not the only changes associated with this reclamation activity though; closer inspection of the estuary reveals that a reduction in tidal prism caused by the introduction of human structures has caused changes in the pre-existing sediment grain size distribution and quantities throughout; especially along the mid-estuary sandbar (Chang et al., 2009). Similar changes can be seen throughout the South Korean coastline in response to human activity, with few exceptions being purely natural changes. The Saemangeum region on the western coast is often considered the poster child for this; being home to the world's largest sea dike and one of the largest reclamation projects and extends across the mouth of two adjacent estuaries (Koh, Ryu, & Khim, 2010). Directly north and south of the Saemangeum are the Geum Estuary and Gomso Bay. While land reclamation is not as prevalent in the Geum, what is prevalent is the construction of an mid-estuarine dam.

Construction of this dam is likely the cause of much modern-day variation in the estuaries sediment dynamics Because of the turbid, macrotidal setting, there is overall an abundance of sediment along this coast, however, shifts in the energy regime will result in changes in what type of sediment is preserved (e.g. Williams et al., 2014). Dellapenna et al., (in prep) found that after the Geum estuarine dam construction, there was a significant shift in sediment distribution,

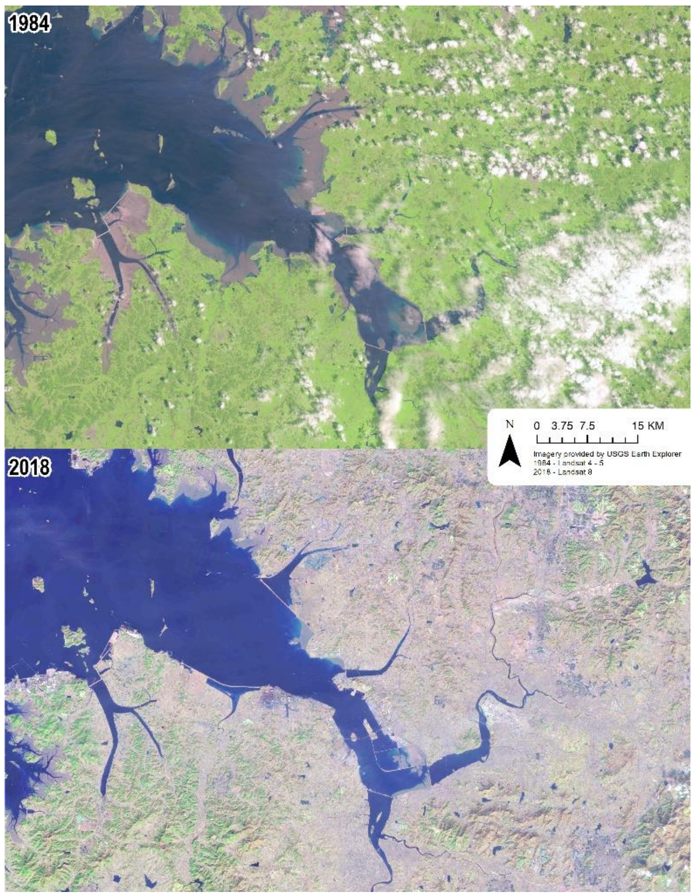


Figure 1- Example of estuarine modifications occurring in Asan Bay. Data provided by USGS Earth Explorer (1984 & 2018)

with the nearshore shifting from sand dominated to mud dominated and the offshore shifting from mud dominated to sand dominated sediment. This shift resulted because the tidal prism was dramatically reduced after the dam was installed, resulting in tidally driven currents and an overall reduction in bottom shear stresses in the nearshore, allowing for the accumulation of mud. In contrast, because the shift in the proximal offshore likely resulted because the fine-grained sediment discharge from the Geum River was dramatically reduced, resulting the accumulation of sand on what had previously been the pro-delta area. The islands within the ebb-tidal delta at the mouth of the Geum estuary are shrinking because of a lack of sand being delivered to the mouth of the river. Gomso Bay is a similar case to the Geum in that it has undergone severe loss of sand supply in its tidal flats, yet these losses are attributed to changes in natural depositional processes (Song et al., 2017).

The southwestern corner of South Korea contains the Yeongsan Estuary, which has undergone comparable modifications as the Geum, as sedimentation rates in the lower estuary have dramatically increased since the construction of a dam in the mid-estuary (Williams et al., 2014). Within the Nakdong, extensive damming and modification of the dual-channel system have caused reduction of the estuaries tidal prism, dramatically higher sedimentation rates, increased by factors of 10 to 20, and eliminated the flow of seawater into the upper system (Williams et al., 2013). This also provides an interesting case in that barrier islands have formed off of the coast since the modification of the system (Williams et al., 2013). These systems are just a few examples of changing and modified systems within the Korean Peninsula, providing a basic background of the changes occurring in the region’s estuaries.

Project Purpose and Hypothesis

The purpose of the project is to develop an algorithm which is capable of automatically delineating, identifying, analyzing, and communicating the spatial change of a coastline and components (embayed waters and estuaries) of South Korea. This is to serve as a testbed for a larger-scale algorithm which is planned to be capable of performing a similar task, but on the continental and eventually global scale. Ideally, such an algorithm would serve as a tool for scientists and resource managers alike to pinpoint coastal areas experiencing drastic change and quantify to what degree coastal areas have reduced or expanded over time. This thesis not only aims to create a tool to detect these waters and analyze their spatial change, but to answer the following questions: How has the spatial coverage of South Korea’s estuaries and embayments changed in terms of surface water transitions from 1984 to 2018 compared to the coastal waters of South Korea as a whole, and how do coastal loss and gain compare over that time from feature to feature? Asan Bay, the Geum Estuary, Gomso Bay, the Yeongsan Estuary, and the Nakdong Estuary will be used to assess the capabilities of the algorithm and provide specific, relevant case studies. If extents of embayments and estuaries can be defined through modifying coastal generalization methods, surface water transitional coverage can be extracted to provide statistics which can reflect surface water loss and gain in coastal features from 1984 to 2018. High levels of surface water change are expected in locations with dense urban development and damming, while little change is expected in areas with minimal human influence.

CHAPTER II - LITERATURE REVIEW

Generalization of the Coast and Its Features

Coastlines, in the context of mapmaking, are generally regarded as having highly complex, often unrepresentable geometry if they were to be symbolized in their completely natural state. The majority of maps representing coastlines, and cartographic lines for that matter, do so by simplifying or generalizing them to level required for the uses of the map in question (Perkal, 1958b). These generalizations are often left to the discretion of the cartographer and its intended use. Numerous techniques have been discussed in generalization of the coastline, specifically the creation of standardized methods to remove human bias. Being that embayment delineation within this method is derived from a coastal generalization method, line generalization techniques and their adaptations play a key role in the work.

Julian Perkal describes the measurement of empirical curves (like coastlines) using epsilon convexity generalization and subsequently attempts to further adapt this method for different uses (Perkal, 1958a, 1958b). Epsilon convexity generalization is described by Perkal (1958a) as floating a large circle of the radius Ɛ along the coastline, attempting to get as close to the land as possible so a part of the circle is always in contact with the coast as it rolls its way along, delineating the epsilon-convex line. Inlets and other narrow parts of the coast less than 2Ɛ across will not be penetrated, as the circle's diameter is too large to fit. Along the circle's arc where it attempts to enter, the line is drawn forming the "Ɛ-generalized edge of the land in the sea" (Perkal, 1958a). This process is repeated in a similar manner with the roles of the land and sea reversed. Instead of the circle delineating a line over an embayment or estuary in the water, that line is drawn over a feature such as a peninsula 2Ɛ or less. This continues into generalizing the coast using the area formed between the landward and seaward epsilon lines. However, for the purposes of this project there is a strict focus on the use of this method's derivatives in determining the seaward extent.

Perkal (1958b) further expands on this method in *An Attempt at Objective Generalization* (1958b), where the finer arbitrary points are discussed. Here, he examines the impossibilities of being able to draw a "true" coastline, the use of different radiuses in epsilon-convexity methods, and the possibilities of radius size applications. Drawing of an empirical line depends upon the desired precision and map scale; does the application require broad coastal features, or does it require each grain of sand on the border of land and sea? This often leads to many decisions at the choice of the cartographer and irregularities across cartographic works. Perkal argues that the application of epsilon convexity in drawing coastlines may remove some of the biases associated with the manual placements of coastlines yet recognizes the lack of geomorphological conformance and variability of a location's geometry. The *degree of generalization*, which Perkal dubs it, is directly related to the circle's Ɛ radius size used to draw the line. Circles with a small-radii tend to exhibit much more detail (lightly generalized) and retain many of the smaller features such as inlets, bays, rivers, etc. Larger radii on the other hand tend to show less detail (highly generalized) and only display larger features, removing the often-smaller features mentioned prior. Choosing which level of generalization to use relies heavily on the application of the map, its scale, and the characteristics of the coastline. It is recommended by Perkal that smaller features that are removed from a highly generalized map, yet still provide necessary orientation to the map should be represented with symbolic features. This, however, proves difficult and unrealistic in the scope of the algorithm being created here.

The methods and theories of Perkal were further grown and modernized through two authors: Christensen (1999) and Mitropoulos et al. (2005). Christensen (1999) uses an intermediate method derived from Perkal's known as waterlining in his pursuit to create generalized shorelines. This uses a computer automated buffering process similar to ArcGIS's Buffer Geoprocessing tool to simulate the rolling of the circles along the coast. This can be compared to taking a broad tipped pin and tracing over a line to create two lines on the exterior over the original line. To accomplish this, one large buffer of size Ɛ is applied to the existing coastline. This creates two lines: one offshore and one inland. To each of these, another buffer of the size Ɛ/2 is applied, creating results mimicking that of Perkals, including gaps in the center representing areas that the "circle" of the second group of buffers could not penetrate to. This work also stresses the need of computer automation of map generalization due to its high complexity and often daunting workloads (Christensen, 1999). Mitropoulos et al. (2005) takes this work, as well as Perkal's, to an extra step, experimenting with different buffer sizes to attribute cartographic line bends in a coastal application. In the context of this application, bends are independent polygons formed from the area between the land and sea epsilon-convex lines.

Mitropoulos (2005) further explores the application of using smaller buffer sizes to determine sub-bends within the primary bends, delineating much smaller areas towards the inland side of each. Geometric attributes of the bends are considered using the bend polygons; with the diameter staying the same throughout, but the size and shape being particular to each bend. It is observed that the size of the bends increases as the scale decreases and Ɛ increases. Also, bends with deeper depths and largest sizes are often the ones retained over bends which are shallow and small. These two works provide an important groundwork for the creation of this process in ArcGIS for use in embayment and estuary delineation.

Defining the Coast

As mentioned, coastlines themselves are often difficult to define due to their high complexity and the subjectivity that one may apply when delineating them. This applies for defining a coastal region as well, which contains many variables that should be considered in determining what is coastal and what is not in both an offshore and inland context. In the work, *A new 30 meter resolution global shoreline vector and associated global islands database for the development of standardized ecological coastal units,* Sayre et al. (2018) considers options for defining the coastal zone in an attempt to define the coast in relation to ecological units. The work adopts the definition of an inland coastal zone as 10 km inland from the coast and nearshore coastal extending from the coast to the 30 m depth contour offshore. A few criteria were evaluated for defining the inland coastal zone including geomorphological characteristics and elevation, yet proved to be a highly complex solution for the global scope of their project. Ten kilometers is chosen for inland as it is simple and already stands as the integrated coastal zone management standard for many environmental applications in the European Union as defined by Lavalle et al. (2011). In terms of offshore, considerations were made to utilize the 200 m depth contour or contour of the continental shelf due to their significance in many ecological applications. 200m was chosen over the continental shelf due to its role in defining the epipelagic zone. Separating this further between coastal nearshore and coastal offshore, a 30 m contour was chosen to define the outer extent of coastal nearshore under the guidelines of the Coastal and Marine Ecosystem Classification Standard. Due to its simplicity, the 10 km range is chosen for use in this work for both the inland and offshore extent of surface waters. However, it is noted that the 30 m depth contour would prove useful in further application of the process of coastal surface water delineation.

CHAPTER III - DATA

Four different sets of data were used within this process with varying levels of involvement; global surface water data (GSWD) in both vector and raster form, stream lines for all of Asia, coastal boundary line vector, and exclusive economic zone (EEZ) line data. The GSWD plays the largest role in that it is the source for coastal water and feature polygons and is also used in the calculation of change within these area's surface waters. An equally important ancillary dataset is the streamlines. These serve in isolating individual landmasses within our determined study area, while also having a later role of a determinant for detecting potential estuaries. Lastly, the coastal boundary data and EEZ data serve as factors to assist in isolating our study nation from the global dataset.

Global Surface Water Data

Global Surface Water data ranging from 1984 to 2018 was derived from the Landsat 5 Thematic Mapper, Landsat 7 Enhanced Thematic Mapper-plus, and Landsat 8 Operational Land Imager archives, compiled, and classified through the methodology of Pekel, Cottam, Gorelick, and Belward (2016) with the intent of finding global surface water changes. These platforms are capable of a 30 meter image resolution of nearly the entire globe. Due to the initial rollout of only one Landsat platform (Landsat 5), as well as technological limitations and issues, some areas of the globe remained unimaged until 1999 (Goward et al., 2006; Chen et al. 2011; Loveland & Dwyer, 2012; Pekal et al., 2016). While this is applicable to all Landsat global datasets (Gutman, 2013), no major gaps in surface water data have been detected for the primary study area encompassing South Korea. Detection of global surface waters took consideration of the multiple environmental factors that may have affected the spectral properties of water for each platform's sensors. This was achieved through the development of an expert system capable of evaluating pixels over varying conditions and assigning classifications of water, land, or "non-valid observations" (Pekal et al., 2016). Within this expert system visual analytics were applied, enabling the system to mimic human thought processes. This allowed it to interact and manipulate data to gain a better understanding prior to classification. Evidential reasoning provided the system the ability to estimate a pixel value in complex temporal or qualitative disputes (Pekal et al., 2016) The system's skill was validated based upon its performance in omission (omitting pixels which are not surface water) and commission (identifying only pixels which are surface water as surface water) when compared against reference datasets (Pekal et al., 2016). Results of the validation concluded less than 5% omission error and 1% commission error. Validation also included results divided by each sensor platform and their performance on permanent and seasonal waters.

Six raster datasets representing various changes in surface water state or presence were created: maximum extent, occurrence, occurrence intensity, annual recurrence, seasonality, and transitions. Of particular importance to this thesis are the maximum extent and transitional waters (Appendix 1 & 2). The maximum extent raster represents the full extent of surface waters over the period of 1984 to 2018 based upon the surface water extent. Simply said, if any water was ever detected at a pixel during the timespan, it was captured in the raster. This raster serves as the base product for creating coastal and coastal feature polygons within the coastal change algorithm. A variant of this raster divided year by year to represent the maximum extent of surface waters annually is also planned to be utilized within the final analysis for calculating rate of change. Transitional waters refer to a change in the waters state from the first year (1984) and last (2018). This is primarily based upon the seasonality of water, where permanent waters can be defined as a location that is underwater year-round and seasonal waters indicate that a location is underwater only a portion of the year ($\leq$11 months). This is broken down into ten separate categories; Permanent, New Permanent, Lost Permanent, Seasonal, New Seasonal, Lost Seasonal, Seasonal to Permanent, Permanent to Seasonal, Ephemeral Permanent, and Ephemeral Seasonal. These indicate if the water of that location stayed the same, land was turned into water, water was turned into land, or the water changed types. The ephemeral categories denote water that was not present in 1984 or 2018, but existed there somewhere in between. Transitional water rasters are expected to be used in the final analysis in finding change of coastal areas and their features.

Global Stream Data

Stream-line data for Asia was retrieved at a 500-meter resolution (15 arc seconds) from the HydroSHEDS (Hydrological Data and Maps Based on Shuttle Elevation Derivatives at Multiple Scales) data. Created from NASA's Shuttle Radar Topography Mission (SRTM) executed in 2000 and by the Conservation Science Program of the World Wildlife Fund, HydroSHEDS was developed to provide broad scale hydrological data on a global scale (Lehner, Verdin, & Jarvis, 2008). While some typical GIS techniques were used to prepare the data for hydrographic applications, other non-traditional methods were applied to accommodate processing specific to the HydroSHEDS platform (Lehner, Verdin, & Jarvis, 2008). Due to the high variability of global environmental conditions, over fifty-thousand manual corrections were applied to the global dataset (Lehner, Verdin, & Jarvis, 2008). These corrections accounted for low-relief flat surfaces, vegetation, and other surface conditions that may affect the quality of radar derived products (Lehner, Verdin, & Jarvis, 2008). Limitations specific to this project relate to the single flow direction of stream data and the inability to represent this in cases where streams may divide or braid. Another is man-made obstacles which "block" stream data. Both of these pose challenges to the often-complex coastal environments and often dense urban centers which encompass them. This project utilizes this data for two applications: identification of landmasses with hydrologic characteristics that may support estuarine processes and actual identification of potential estuarine embayments.

Coastline, and Exclusive Economic Zone (EEZ) Data

One data source was retrieved from NaturalEarthData.com, a project to create a free repository of curated cultural and physical data relating to global boundaries and features (Kelso & Patterson, 2010). This data consists of a 1:10 million small scale physical line vector dataset of global coastlines. This excludes many minor global islands, meaning the study area will be confined to only coastlines included here. This data is to be used in the preprocessing of the surface water polygons in Google Earth Engine to isolate it to the selected study country.

Exclusive economic zone (EEZ) is used in a similar manner to the coastline data, in that it is used to isolate a country's surface water data during pre-processing. The EEZ data stretches 200 nautical miles (approximately 370.4 kms) from the low-water normal baseline and straight baselines as defined by the United Nations Convention on the Law of the Sea (UNCLOS) and United Nations signatories of UNCLOS claims respectively.

CHAPTER IV - METHODS

The Coastal Change Analysis Algorithm is divided among two key software elements; Google Earth Engine (GEE) and ArcGIS (both ArcMap and ArcPro). GEE's primary role is to retrieve the maximum extent of surface water data where it is isolated to a specific study country (South Korea in this case), as well as be used to retrieve the transitional surface water raster datasets used in the final quantification and analysis of surface water transitions. The ArcMap process is divided among three models, each created within ArcGIS Model Builder or ArcPy. Each model contains a sequence of processes created from ArcMap or ArcPro Geoprocessing tools to manipulate the surface water data for final analysis. These occur in the following order; the Landmass Separation Tool (LMS), the Coastal Feature Identification and Delineation Tool (CFID), and the Coastal Surface Water Change Extraction Process (CSWCP). LMS (Appendix 3) serves to isolate land masses for a designated country for individual surface water processing.

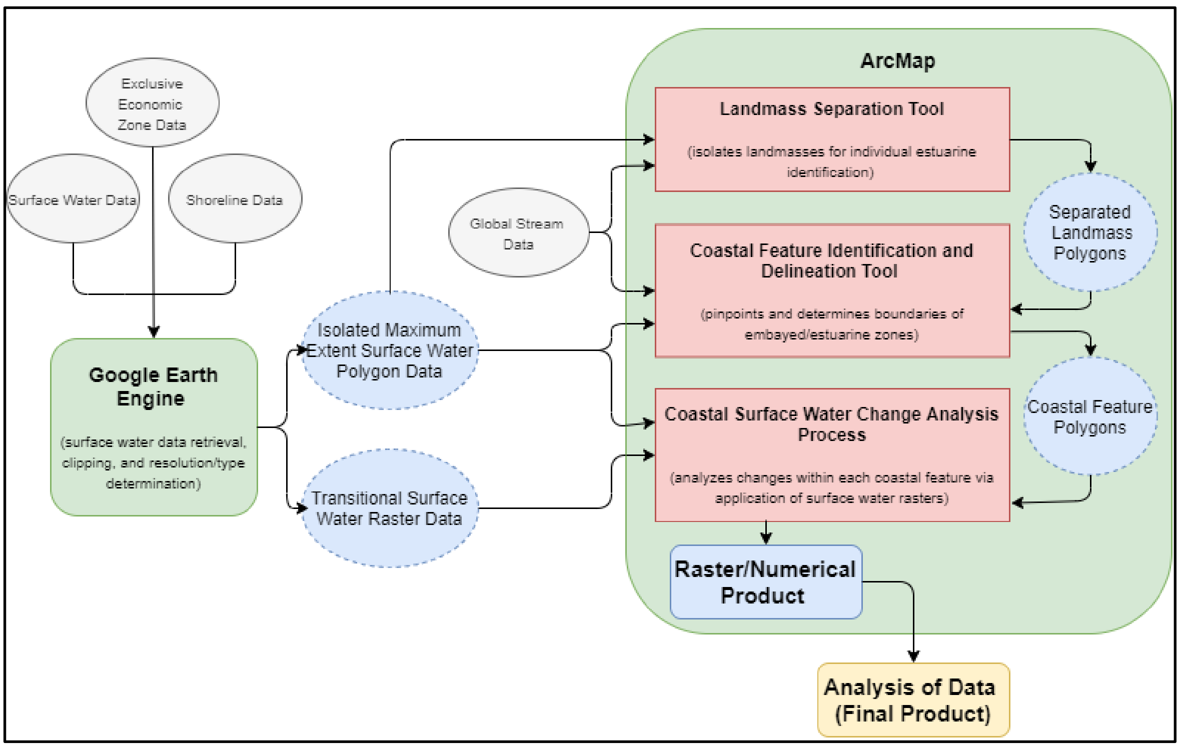


Figure 2 - Simple visualization of the Coastal Change Analysis Algorithm's workflow

CFID (Appendix 4) performs the bulk of the processing, drawing on early experimental applications of empirical curves to generalize cartographic lines by Perkal (1958a & 1958b) and theorized computer automation of Perkal's methods in the application of coastal bend generalization by Mitropoulos (2005). This process builds onto these theories, creating generalized coastal feature polygons under a standardized and semi-automated process. The CSWCE is a simplistic tool which iterates through coastal feature polygons using Model Builder and extracts transitional surface water data for the feature. For each iteration, data is extracted from surface water rasters for later numeric analysis or visualization of changes. Together, these elements make up the Coastal Change Analysis Algorithm (Figure 2).

Google Earth Engine - Data Clipping and Retrieval

The Google Earth Engine (GEE) portion of this process was based off the work of Hodder (2018), who was involved in the initial creation of this algorithm. Some minor modifications were implemented to the code block in order to easily change variables, increase resolution of the output polygons, change the type of data it was producing from individual annual representations to the maximum extent over the time period of 1984 to 2018, and include both seasonal and permanent surface waters. These modifications produced an intermediary set of data which represents the full range of surface waters within the given time frame of 1984 to 2018 which confines the data to the nation's exclusive economic zone (EEZ), and limits extension of the surface waters to 10,000 m (10 kms) inland and seaward (20,000 m extent or 20 kms total). It also plays a role in exporting the data from GEE into a file format (shapefile) compatible with ArcMap.

The desired country is inputted by the user via a three letter (Alpha-3) country code (Ex. Korea = KOR) and the desired resolution (meters) is inputted into the "scale". In this case, Korea (KOR) was chosen as the given study area and 30 m as the resolution (the maximum allowable resolution for this dataset). When run, the code block imports the global surface water data, the shoreline dataset, and the EEZ dataset necessary to process the surface waters to the specified boundary. The shoreline data is then buffered to 10,000 m (10 kms), the extent determined to be considered coastal by Lavalle et al. (2000). This buffered data was then used to clip the desired surface water data along the coast spanning 10 km inland and 10 km seaward (totaling a 20 km extent perpendicular to the coastline). Then, this data was clipped to the specified EEZ extent to isolate only shorelines for the desired study country. A function was applied to mask the water type to only the maximum extent and update the composite mask with the water mask. The data was then converted from a raster to a vector (polygon) type format to make it compatible with the geometrically driven process within ArcGIS. Small "holes", areas within a certain size threshold, were also removed alongside this process to make the data friendlier for the upcoming processing. The created output was displayed to the GEE map interface, flattened for export into a shapefile, and uploaded by GEE to the users Google Drive cloud for export to ArcMap. The resulting vector data represents a singular polygon feature that spans 10 km seaward from the coast and 10 kms inland. Only data connected to the sea is included, meaning no inland waters are included unless they have direct contact with the sea. Due to the 30 m resolution, streams or small embayments less than 30 m in width are likely removed or have their inland extent restricted.

ArcGIS Process - Estuary Identification and Analysis

The model itself is separated into three separate modules which work as a singular unit: the Landmass Separation Tool (LMS), the Coastal Feature Identification and Delineation Tool (CFID), and the Coastal Surface Water Change Extraction Process (CSWCP). Each of these models feed into one another respectively and work together to extract the final raster and numeric product. Together, these create a semi-automated process capable of delineating the embayments and estuaries of a singular country and its respective landmasses via the maximum extent of surface water and a modified coastline generalization algorithm. From these features, the embayments can be used as a geometrically accurate mask to extract surface water rasters.

Landmass Separation Tool (Appendix 3)

In preparation of the CFID, each viable landmass within a study country was separated into its own shapefile. The primary role of the LMS is to eliminate errors for landmasses, which are within proximity to one another due to their consideration as a singular landmass by the algorithm. Without it, surface water data often misrepresents the gap between landmasses as a coastal feature. This also allows for the organization of coastal features by their respective landmass with a logical naming scheme. The LMS accomplishes its goal with two data inputs: the global surface water maximum extent data trimmed down to South Korea by the GEE process and the HydroSHEDs stream data for Asia. The global surface water data serves as a way to create landmasses without needing to include a separate landmass dataset and the stream data allows the process to select land masses which are compatible with the algorithm by determining if stream data is present or not present on a landmass.

Step one of this process is to create a minimum bounding geometry for each landmasses surface water data included for the country in question. This creates a polygon, enveloping the surface water data to create a generalized variant of the landmass. This allows for the next step, which is the inversion of the surface water data into a landmass form. From the minimum bounding polygons, the original surface water polygon is erased. This provides separation of artifact polygons and polygons that would represent actual landmasses. These are separated into their own features so they can be run through the landmass selection process involving the stream dataset. Polygons which intersect with the stream data are selected and those which are not disregarded in order to avoid unnecessary processing time and potential errors associated with lack of stream data input later. This selection represents landmasses which have corresponding intersecting stream data which will be used in later processing. To this new product, a new field was added to its attribute table to represent the area of each landmass and the area in kilometers was calculated for each. Another field was added, the areas were sorted in descending order (greatest to least), and a rank was assigned to each feature based upon their size ("1" being the greatest, continuing in a positive direction). This allows for easy identification and a methodical processing of the landmasses from largest to smallest. Afterwards, each of these features were exported to an exterior file as their own shapefile with their area rank as their file name, ready to be imported into the CFID tool.

Coastal Feature Identification and Delineation Tool (Appendix 4)

The purpose of the Coastal Feature Identification and Delineation (CFID) tool is to run a complex series of ArcMap tools in order to draw the outer extent of the coastal features and then use that outer extent to trim away any seaward water from the feature. The following discusses the tool from a modular standpoint, describing each sub-process in the order created by a series of individual ArcMap tools. These subprocesses center around supporting the larger buffering series process which simulates the described “convex epsilon generalization” to create artifact-free and properly identified final product through semi-automated means.

The work of Mitropoulos (2005), Christensen (1999), and Perkal (1958a, 1958b) are heavily built upon through their core theory of using epsilon convexity and application of a buffer series to delineate coastal bends. Instead of using these methods to strictly draw the generalized line for a coastal bend as Mitropoulos (2005) did, it is modified to use the coastal bend line as the exterior of an embayment, while still maintaining the inner geometry of the coastline and inlets. This is done by mimicking the rolling of the circle around the coastline methods within ArcMap model through the application of a buffer series containing a negative and sequential positive buffer of same value to the coastline. Unlike the sources used, this method only applies the buffer to the coastline instead of both the inland and seaward side. This method effectively delineates the outer extent of the embayment polygons, allowing for the creation of distinct, individual polygons to represent embayed bodies of water. The buffer series is accompanied by numerous other tools which serve to clean, organize, and prepare the data for the buffer series and post-buffer analysis. Optional application of stream data may be used if the user wishes to determine which embayments may be estuaries via intersection of the streams to the polygons.

Sub-Process 1 - Landmass Input and Iteration

The first step of this model begins with an iterator or “loop” that inputs and runs through each of the landmass shapefiles created by the earlier LMS process. This loop allows for the entire model to run through each individual landmass and create a set of coastal features for each. The loop serves little in terms of the final products quality, yet it is vital to automation. Its application enables the management of large quantities of data, reducing the amount of time which the user needs to devote to manual processing and eliminating input errors which may be associated with inputting large sums of data over time.

Sub-Process 2 - Inversion of Landmass to SWD and Buffer Error Prevention

Buffered versions of the landmasses are needed for error reduction during the later application of the “circle method” and removal of artifacts. The first of these needs is to create a “fence” like border polygon for the surface water data to limit later buffering processes and prevent loss of data associated with use of negative buffers on polygons with widths less than the buffer size. This is done by creating a version of the landmass polygon, which is simplified with a 1 km tolerance to reduce future processing time. High detail of the outer bound is not needed for this polygon. This simplified landmass is then extended outward by 250km using the Buffer Geoprocessing Tool. Then, the original surface water polygon is erased from its center. This creates a version of the surface water data for that specific polygon with retained detail in the center and a large outer border.

Sub-Process 3 – Buffer Series Application and Void Removal

At this point, the final geoprocessing steps for producing the embayments begin. In preparation the polygon is simplified to reduce the number of vertices, avoiding conflicts with ArcGIS tools associated with high complexity polygons. This modification does little, if anything, to negatively impact the spatial accuracy of the surface water, as the simplification tolerance is set as the data resolution to not modify the inward areas, only the outer bound of the polygon that will be eventually trimmed. In further preparation holes 50 km^2 or less which may have formed in the previous processes are again filled to avoid unnecessary buffering of unneeded, artifact features.

Using the recently buffered and inverted landmass polygon, a buffer series is applied which will later form the outer extent of the coastal feature. This was done in three passes with a 25km, 5km, and 2.5km buffer series. As mentioned previously this sub-process applies the negative and positive buffers which simulate the method of Mitropoulos (2005). Within this however, another process is applied to remove holes occurring in the center of large embayments. The first portion of the series which consists of a negative buffer distance is applied to “pull” the boundaries of the surface water back. This creates a generalized version of the coastline that sits approximately the input buffer size offshore from the actual coast. Prior to the second buffer, the void removal process is executed. Voids are created after the application of the negative buffer to larger embayed with inland water bodies significantly wider than their mouths. This often leaves a piece of the surface water “stranded” in the center of the embayment and creates large holes in the center if allowed to fully execute through the algorithm. These stranded polygons are always smaller than the manipulated surface water polygon being buffered. Therefore, all polygons which are 0.05% or smaller that the area of the entire polygon are eliminated to avoid this issue. To this new void removed layer, a positive version of the buffer size is applied. This pushes the boundary 25kms back toward the landmass, drawing an outward embayment extent which would be seen if the “rolling circle” method were to be applied to to this coastline.

Sub-Process 4 - Embayment Delineation

The final embayment delineation involves erasing the final buffer product from the product created directly before buffer application. This is crucial to the creation of the embayment polygons, as it removed all unneeded surface water data and only the embayments with their delineated outer bounds remain. This also involves an intermingled artifact removal process, which removes lone pixels occurring on the outer ring of the polygon. The artifact cleaner begins by applying a 150m buffer to the original bounding polygon. This buffer “cleans” the artifacts on the outer bound by overlapping where the pixels would be created during the erase function. This is merged with the final buffer product, a dissolve series is applied, and the erase is applied. The resulting product is a multi-featured polygon, with each individual feature representing an embayed waterbody. This multi-featured polygon is then exported as a shapefile for future analysis by the ESWCET.

Sub-Process 3.3 – Optional Estuarine Zone Identification (under modification)

This sub-process can be omitted based upon the need for identifying just embayed coastal waters or pinpointing potential estuarine zones. It is applied directly before the multipart polygon is created in Sub-Process 3, this process inputs the Asian stream-line data from HydroSHEDS. Estuaries are identified by the intersection of the streamline data with an associated embayment polygon. If an embayment polygon has at least one streamline which intersects, it is classified as a potential estuarine zone. A 30m search distance was applied to the intersection selection to account for the 30m surface water data resolution. After identification, the selection is exported as its own shapefile to the workspace.

Coastal Surface Water Change Extraction Process (CSWCP)

Some manual processing was necessary to prepare the data for extraction. This includes the removal of polygons 0.1 km^2 or smaller and some artifacts, erasing of overlapping embayments among landmasses, reimplementation of smaller land masses for exclusion of them during processing, separation of coastal features into separate shapefiles, and renaming of the embayment/estuary polygons for the upcoming extraction. Some manual removal of feature polygons was needed to streamline the process and remove what would be considered artifacts of the process. These artifacts are usually large “slivers” along shallow, non-embayed areas of the coast or small groups of three to five pixels that do not represent embayments. Based upon visual inspection, the cutoff point of 0.1 km^2 was chosen and all polygons were removed for both estuaries and embayments. A small “horn” on the upper left of the country was removed manually by the user. This horn is an artifact of using geopolitical borders and the impact of its removal on the final results is minimal. In the case of larger buffer series applied to locations with close proximity landmasses, the embayment polygons often overlap and create data which would repeat itself. Merging of the six of the seven smallest polygons and erasing of the largest by the merged was used to solve this. This effectively creates a hole in the large embayment polygons so the data of the smaller embayments will not be extracted and repeated. After erasing, the erased large polygon and merged smaller polygons are merged back together. In completion of the “cleaning” of this data, the original surface water maximum extent polygon is introduced, simplified into large solid polygons by the bounding polygon tool, and erases itself from the simplified version. This simplified version is then erased from the embayment or polygon layer. This effectively removes all small landmasses from each feature, removing land from the equation in the upcoming raster extraction.

Extraction Iteration

Final steps involve the modification of the South Korean embayment polygon layer into uniquely named, individual shapefiles based upon their areas as previous processes to be fed into the upcoming Raster Extraction iteration model. This allows the timely processing of each polygon with the extraction process. Each individual polygons from the transitional water raster to its own uniquely named raster into a workspace. These rasters are now ready for further statistical analysis. It is important to note that an unsplit version of each estuary and embayment buffer size, and the original surface water maximum extent raster was created to facilitate a nationwide statistical creation and analysis.

Some post processing is performed outside of ArcGIS model builder. To perform a rudimentary post-analysis to show how this data may be used in individual cases, 5 significant estuaries were chosen. Database files were extracted from each for all buffer sizes and imported to Excel. Based upon the calculated area of each and count of each transitional water type, area in square kilometers and percent coverage were calculated for each buffer size. Total surface water loss was calculated by summing the Lost Permanent and Lost Seasonal categories; surface water gain by summing New Permanent and New Seasonal; No Loss/Gain by summing Permanent, Seasonal, Seasonal to Permanent, and Permanent to Seasonal; and Ephemeral by summing Ephemeral Permanent and Ephemeral Seasonal. Similar statistics were calculated for each nationwide version. A polygon count was produced for each and the average embayment/estuary size was calculated.

CHAPTER V - RESULTS

Notable results of the current version of the process includes the automation of a workflow which can delineate coastal embayments through modified epsilon-convex coastal generalization methods, extract raster data using said delineations, and produce statistics of surface water transitions for each approximate individual embayment or estuary. Using a 25km, 5km, and 2.5km buffer series and a surface water resolution of 30 m, polygons were created to represent the extent of estimated embayed coastal waters of South Korea above the 0.1 km^2 (1,000,000 m^2) cutoff point. 248 embayments were detected for 25km, 571 for 5km, and 809 for 2.5km (Table 1). Resulting embayed and estuarine polygons have a border at the seaward extent which correlates directly with the size of the buffer applied (Figure 3). The outward extent of the embayment polygons is the furthest landward the "circle" rolling around the coast can reach. It can be identified by its arc-like shape which stretches across the mouth of a feature. By adjusting this buffer size, the outward extent of the embayment can be adjusted to push landward (smaller buffer size) or pull seaward (larger buffer size). With this adjustment, the arc will either lengthen (larger buffer) or shorten (smaller buffer). The inland reach of the polygon is defined by a combination of the data resolution and previously defined 10km buffer in GEE. In terms of resolution, if a water body narrows to less than 30m in width, the rest of its inland extent past the "bottleneck" was excluded. These same embayment polygons were further narrowed down to specific estuaries via the intersection method with the stream data. This included the 30m search distance to account for resolution discrepancies that may account for a non-intersection and subsequent negative identification of a potential estuary. The 25km data yielded 77 potential estuaries, 5km with 116 estuaries, and 2.5km with 129 estuaries (Table 1).

The previous polygons were used to extract transitions in surface waters at a 30m resolution, providing each embayment and estuary with a transitional water raster isolated from other features (Figure 4) and the total coast (Appendix 5) in the shape of the associated polygon. A table displaying the pixel count of each transitional water type (Figure 5) was also provided for each feature. The quantity of individual rasters for both embayments and estuaries of each buffer size is comparable to the count of polygons. From these individual feature tables, comprehensive tabular data was produced comparing the country wide results of each buffer size for both embayments and estuaries to one another, along with the coast. Table 1 contains a feature (estuary or embayment) count of each buffer series, average size of the features created, and percentages of surface water changes in terms of total loss, gain, no change, or ephemeral. Extensive tabulation of these statistics for the total coast, 25km buffers, 5km buffers, and 2.5km buffer can be found in Appendix 6, 7, 8, and 9 respectively. For each country wide results, the embayments and polygons are compared side by side. Five other tables were produced for five separate case study estuaries. Each table contains a side by side comparison of the 25 km, 5 km, and 2.5 km transitional water extraction with area in km^2 of each transition category and normalized to percent coverage. The transitional waters are further simplified into categories of Loss, Gain, No Loss or Gain, and Ephemeral surface water transitions. A comparison of gain to loss in ratio form can be seen in Figure 6 and 7.

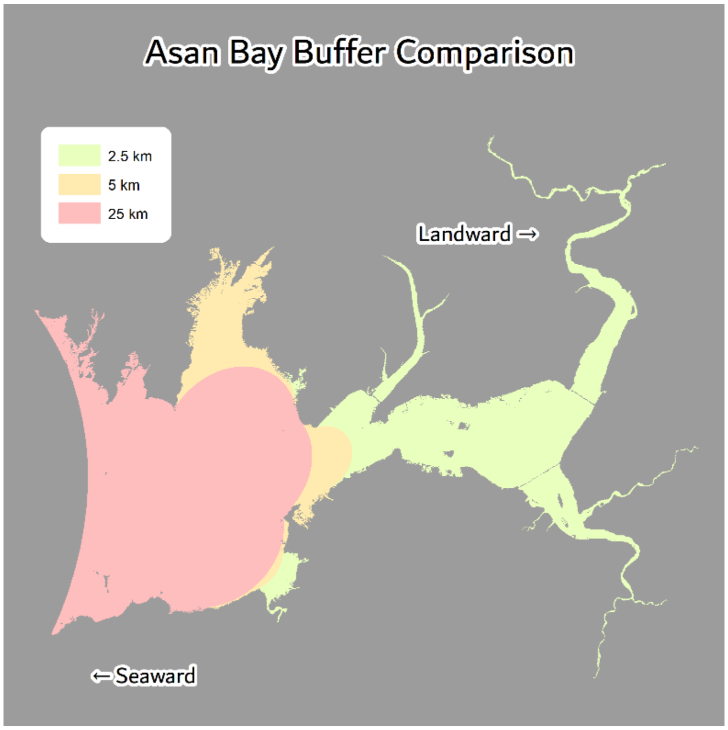


Figure 3 - Example of a feature polygon produced by the 25km buffer series

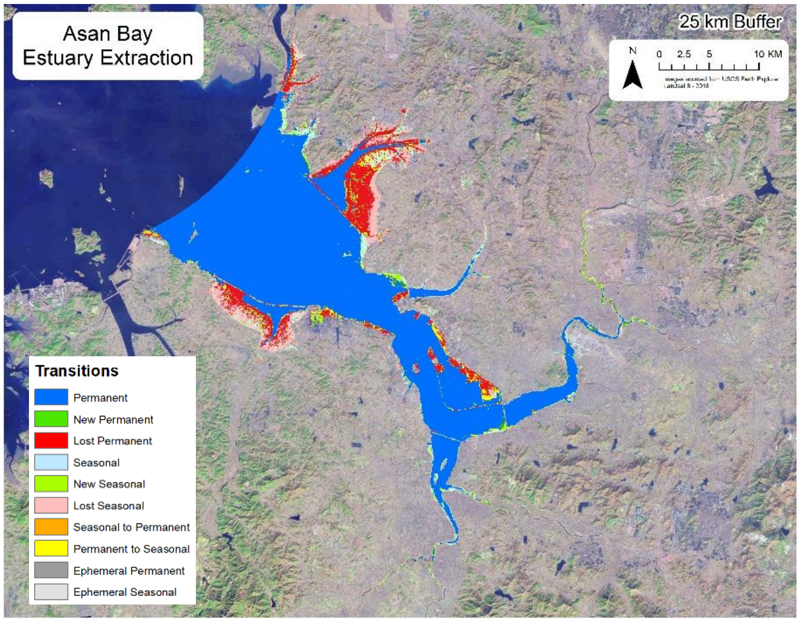


Figure 4 - Example of a features isolated transitional surface water data.

Country Wide Buffer Size Surface Water Change Comparison								
Data Type	Feature Count	Average Size (kmsq)	Total SW Loss (%)	Total SW Gain (%)	No Change (%)	Ephemeral (%)	Total Change (%)	Net Gain to Loss (%)
25km Embayments	248	22.421	7.702	4.239	85.682	2.377	11.941	-3.463
25km Estuaries	77	61.733	8.573	4.562	84.232	2.632	13.135	-4.011
5km Embayments	571	6.022	10.033	5.695	81.144	3.128	15.728	-4.338
5km Estuaries	116	22.324	11.646	5.142	79.755	3.457	16.788	-6.504
2.5km Embayments	809	2.736	12.500	7.475	76.060	3.966	19.975	-5.025
2.5km Estuaries	129	9.288	10.876	6.274	79.129	3.721	17.150	-4.602
Total Coast	1	28935.754	1.969	1.340	96.109	0.583	3.309	-0.629

Table 1 - Summarized version of tabular data. Depicts the feature count, average area (km2), and percent coverage of surface water change for each buffer of embayments and estuaries.

Rowid	VALUE	COUNT
0	0	5009
1	1	430401
2	2	29323
3	3	41209
4	4	30283
5	5	36384
6	6	78409
7	7	1253
8	8	16885
9	9	1808
10	10	35178

Figure 5- Example of transitional water tabular output from an extracted raster. "VALUE" represents a surface water type and "COUNT" represent the number of pixels of said value contained within the raster.

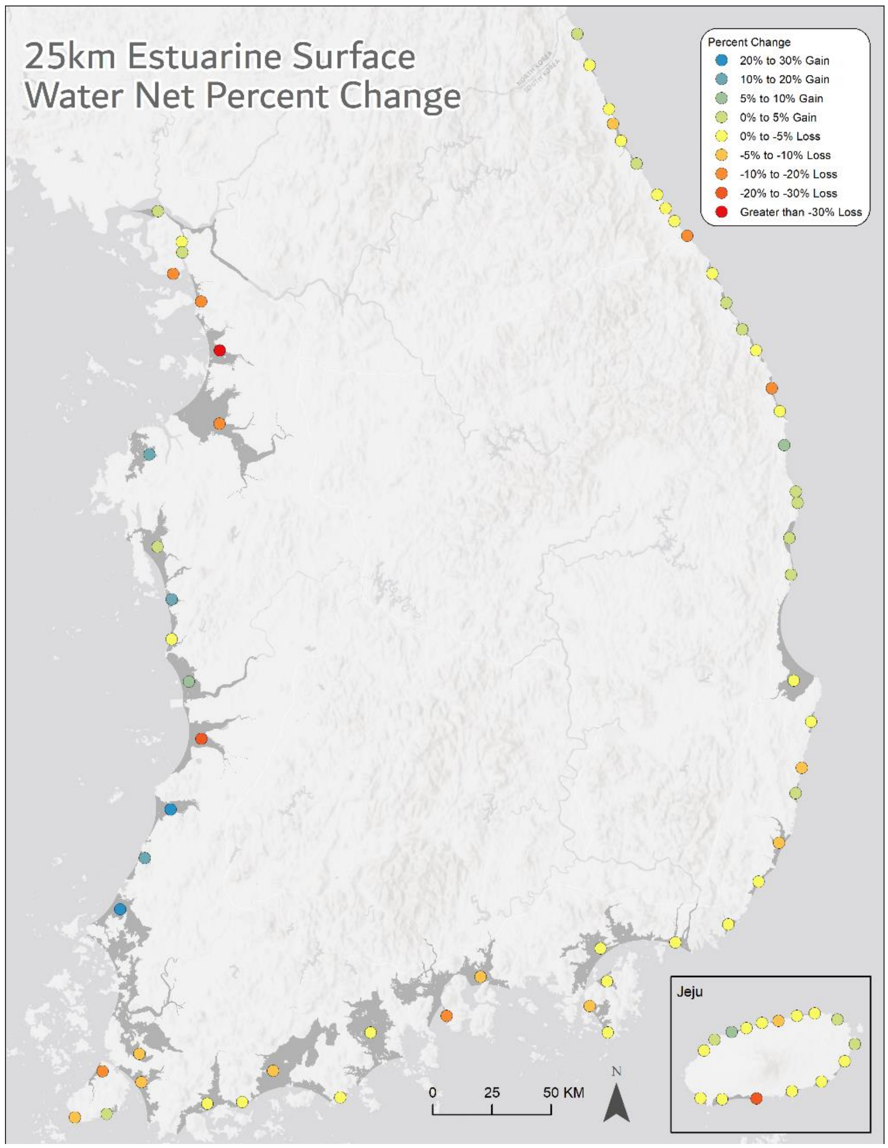


Figure 6 - Comparison of net percent change for the 25km buffer estuaries.

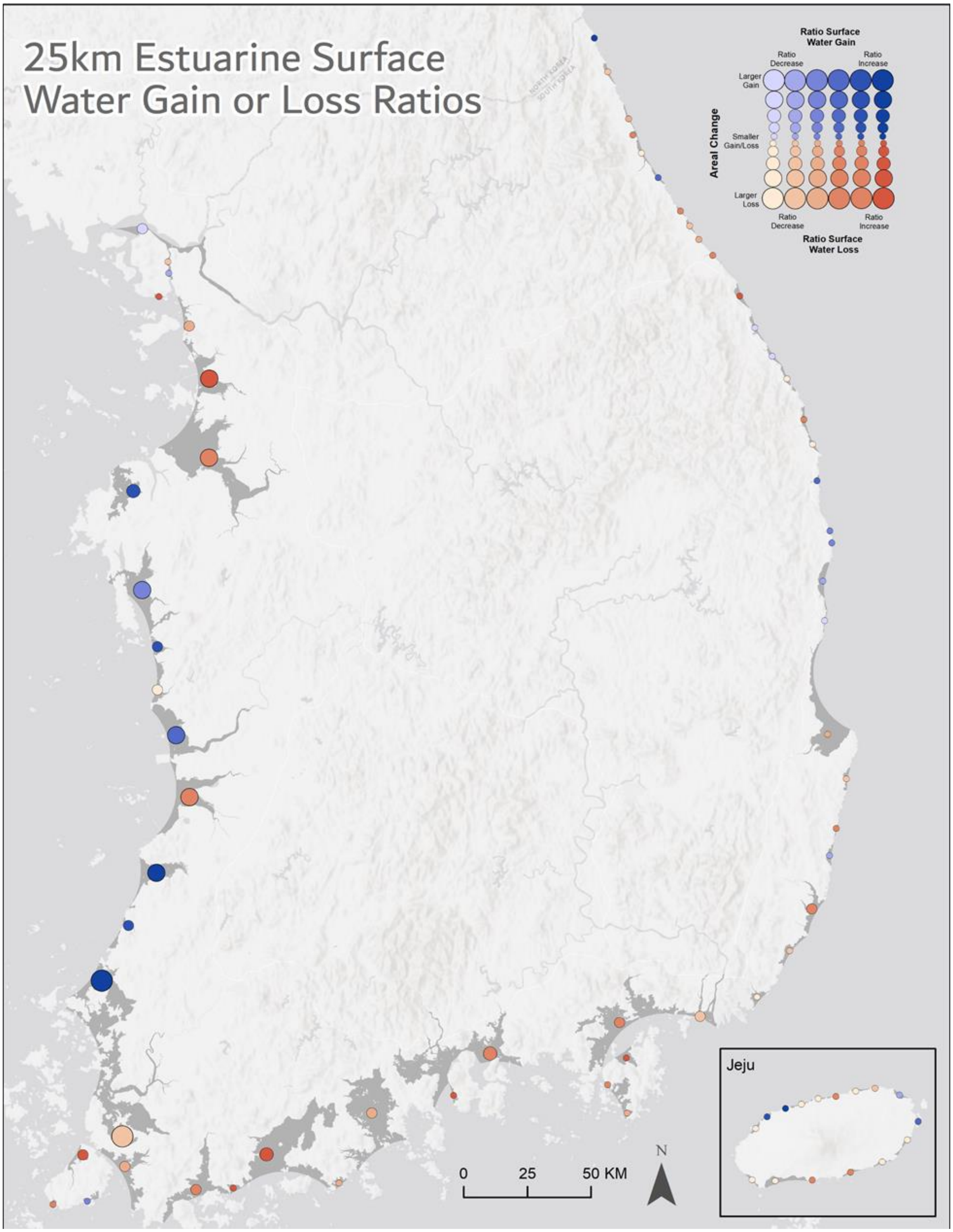


Figure 7 - Comparison of Gain and Loss in ratio form for the 25km buffer estuaries.

CHAPTER VI - DISCUSSION AND LIMITATIONS

Discussion

Upon visual inspection, results of the algorithms raster outputs and tabular compilations support the hypothesis that this methodology can be utilized to isolate and detect spatial changes in South Korea’s embayed or estuarine waters. Five specific coastal features were chosen to display this which all have had previous studies looking at possible anthropogenic or natural morphological changes. These cases studies include Asam Bay, the Geum Estuary, Gomso Bay, the Yeongsan Estuary, and the Nakdong Estuary. Buffer size comparisons can be found in Appendix 10, extraction of each feature polygon for each buffer size at Appendix 11.1 to 11.5, and tabular data of the extractions at Appendix 12.

Case Study 1 - Asan Bay

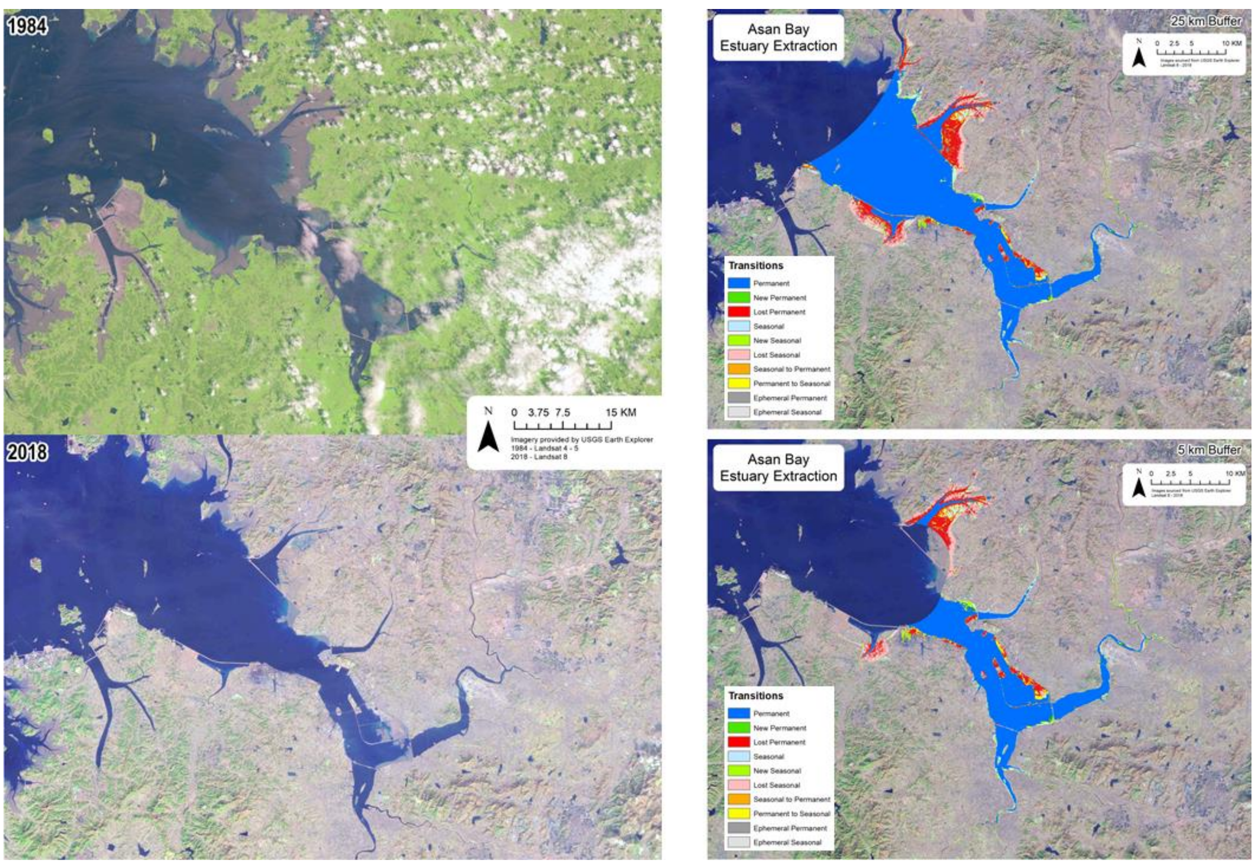


Figure 8 - Comparison of Asan Bay from 1984 to 2018 and relevant raster extractions.

Asan Bay (Figure 8) can be seen to have extensive modification between 1984 and 2018 throughout, especially within its sub-embayed areas. Satellite imagery shows the building of dam/dike across the faces of many of these sub-embayments and land reclamation having occured behind or around them. Comparison of the surface water transitional raster to the imagery shows surface water loss consistent with these modifications. Of the three buffer sizes applied to Asan Bay (Appendix 10), the 25 km series appears to best capture its geographical extent. The 5km and 2.5km series tend to push too far into the feature (eastward), failing to capture large number of prominent seaward inlets. 5kms excludes much open, permanent water to the west and partially excludes inlets, which have undergone considerable heavy surface water loss to the north and south near the inner side of the features mouth. These differences can be observed in the tabular data, with the exclusion of the open water area, inflating the 5 km loss to nearly 20% compared to the approximate 15% for the 25 km buffer.

Case Study 2 - Geum Estuary

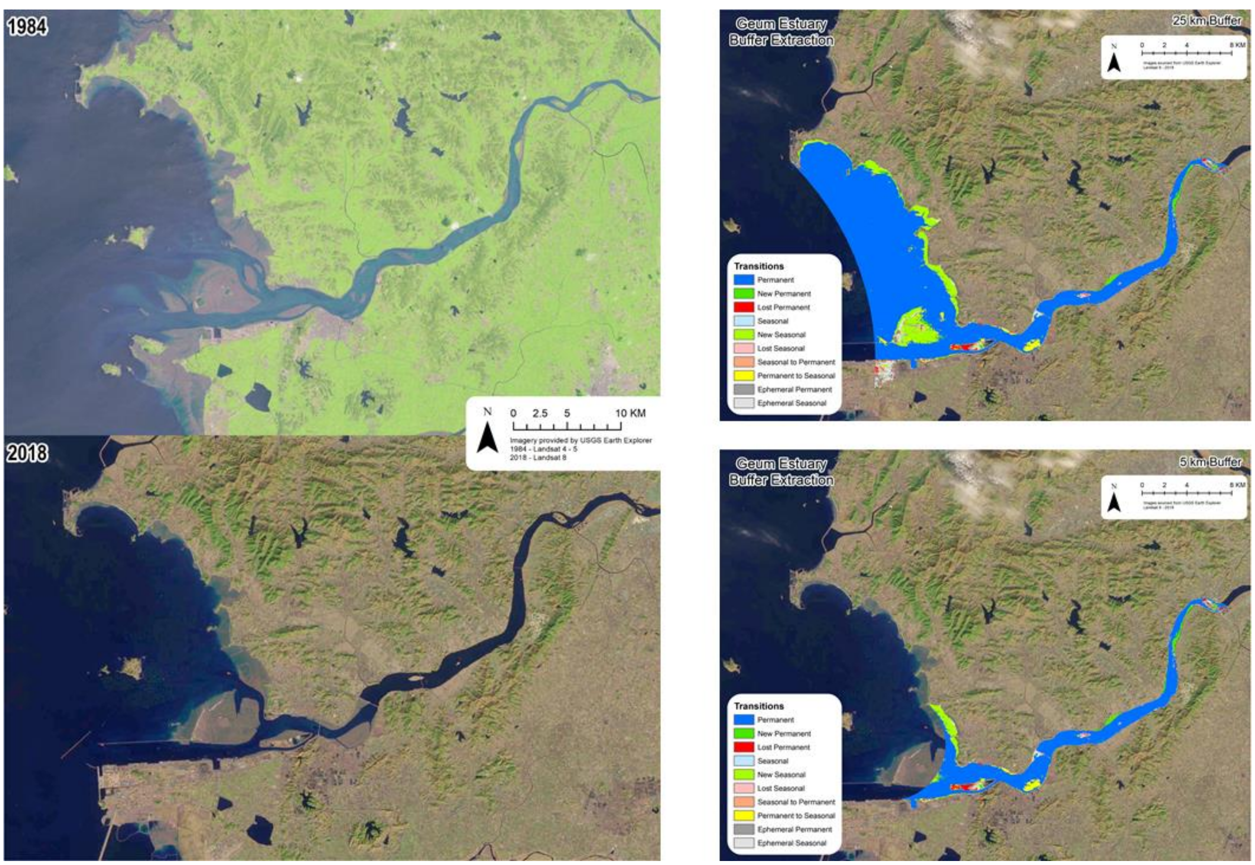


Figure 9 - Comparison of Geum Estuary from 1984 to 2018 and relevant raster extractions.

The majority of the losses of surface water on the Geum Estuary (Figure 9) can be seen on river bar islands which are part of the flood tidal delta, which appear to have expanded when the dam closed. This was also seen in the Nakdong estuary (Williams et al., 2013), because after the dam was closed, the tidal prism was dramatically reduced along with the tidal currents, consequently with the reduction in currents, the ability to flush out the lower river/estuary was lost. This likely is the case here as well. Transitional water data shows that these many sites along the upper coast, as well as the ebb tidal delta island have transitioned from land to seasonal water. Dellapenna et al. (in prep.) found that the nearshore area transitioned from sand to mud dominated with the installation of the dam, cutting off the sand delivered by river. It is likely that the shoreline to the north is eroding as a result of the cut off of the river derived sand as is the ebb tidal delta island. Due to the increased presence of human structures between 1984 and 2018, these changes are primarily anthropogenic or have had natural processes modified by the presence of an upstream dam (Dellapenna et al., in prep.)). Similar to Asan Bay, visual inspection of the three buffer series indicates that the 25km buffer best captures the full extent of the estuary. 25kms captures a 1.295% loss of surface water, but 9.284% gain. It could be said that in some cases the 25km buffer captures areas to the north that would not necessarily be estuarine. The 5km buffer seems to reign this into a realistic extent, yet fails to capture much of the deposition, where the estuary begins to widen at the river outlet. This case may provide some justification to test a buffer size between 25km and 5km in attempt to provide a polygon with a "better fit".

Case Study 3 - Gomso Bay

While experiencing much anthropogenic change prior to 1984, the transitions occurring in Gomso Bay (Figure 10) are resonant of prior modifications of the estuaries coastline and streams and their impact on natural processes, though do not reflect the modifications themselves (reclamation or damming). This has lead to major variations in the intensity and patterns of sediment deposition throughout the bay. Transitional water data indicates this area has undergone heavy transition from land to seasonal water along a wide portion of the southern coast, with some transitions occurring along a thin line tightly along the north coast. A large pocket which has transitioned from seasonal water to permanent is present near the mid-southern coast (denoted by the large orange blotch seen in the surface water changes in Figure 10). This likely denotes a deepening of the area, as a move from seasonal to permanent indicates an area which was once exposed during low tide is no longer so. The 5 km buffer series, which by visual inspection best represents the extent of this feature, captures a 31.926% (approximately 21 km^2) gain in surface waters from 1984 to 2018. Of this, nearly 24% was new seasonal water and approximately 8% new permanent. The seasonal to permanent transitions accounts for nearly 3% of the estuaries changes. It is worth noting that the 25 km buffer stretches down the coast to capture a small estuary and the 2.5 km buffer pushes far enough inland that it excludes a large sum of the new seasonal and new permanent waters.

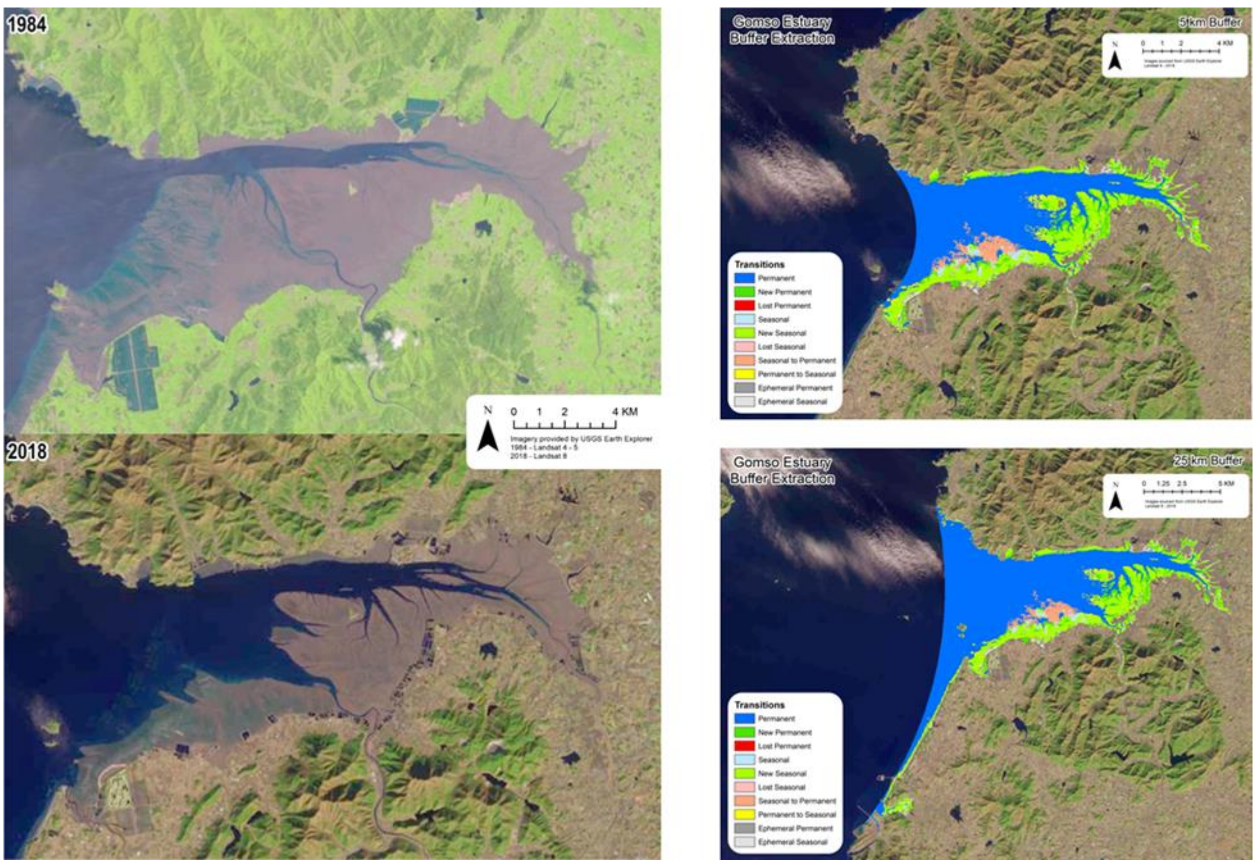


Figure 10 - Comparison of Gomso Bay from 1984 to 2018 and relevant raster extractions.

Case Study 4 - Yeongsan Estuary

The Yeongsan (Figure 11) case study provides an example of the advantages of the 2.5 km buffer series and need for small sized buffers in general. The 25 km and 5 km here grossly overstate the extent of the Yeongsan and in return provide faulty statistical data. In reality this estuary is approximately 50 km^2, yet the 25 km and 5 km buffer make it out to be 489 km^2 and

281 km^2 respectively. This is likely due to the high complexity and close proximity of the embayed areas. It could be said this example justifies the need for another buffer interval between the 5 km and 2.5 km to better capture and define some of the outward features of the estuaries mouth including a large island feature. This estuary is seen to be dammed before the 1984 start point as the structure does not register within the surface water data as change. Change within the area is noted as 3.252% loss and 4.175% gain in surface waters. The majority of the loss occurs due to a pocket of land reclamation along the northwestern lower estuary and a small inlet further into the estuary now occupied by agricultural fields. Gain is primarily due to a

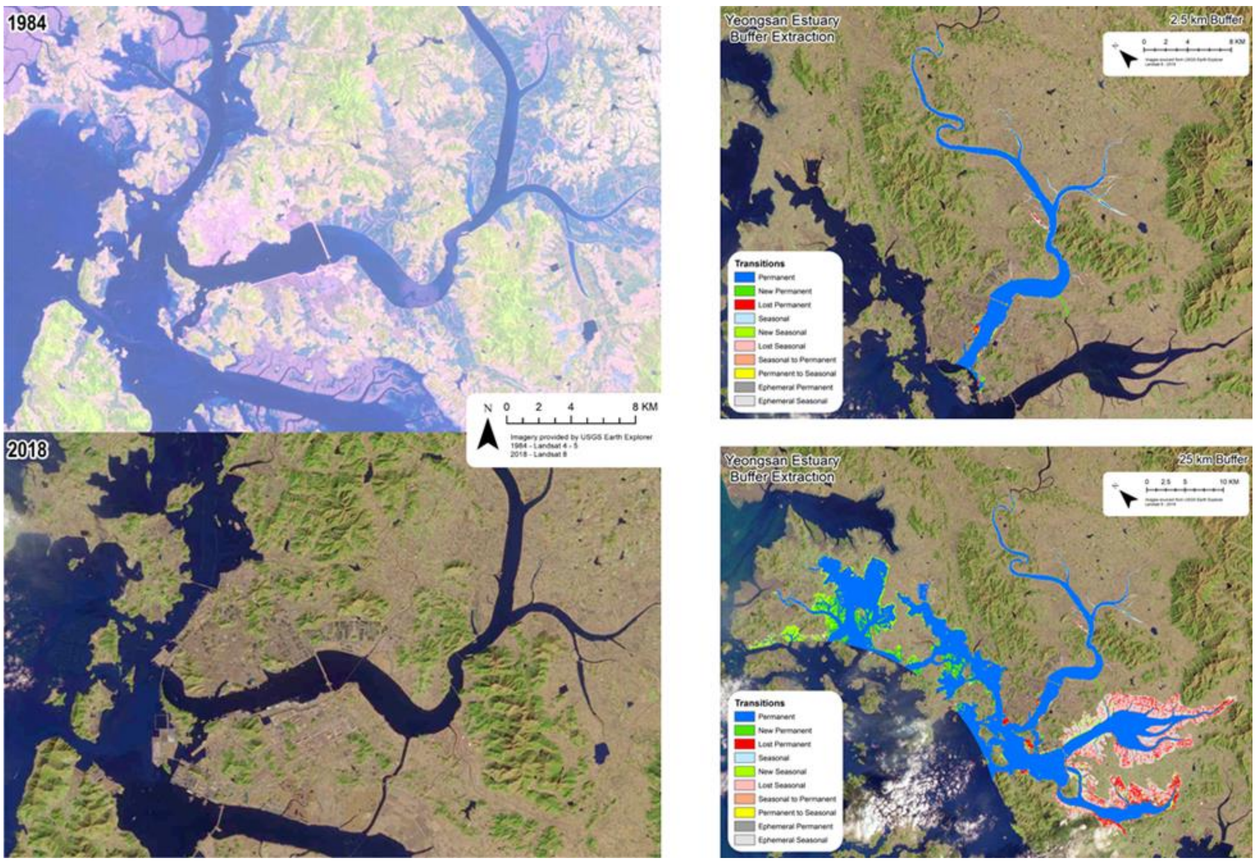


Figure 11 - Comparison of Yeongsan Estuary from 1984 to 2018 and relevant raster extractions.

channel which partially connects to a southerly adjacent embayment which appears to be human made and creation of some fisheries near the southern side of the estuaries mouth.

Case Study 5 - Nakdong Estuary

The Nakdong (Figure 12) provides an outlook on the algorithms outputs in an estuary that has been highly modified and dammed pre-1984. Due to this estuarie's unique dual-channel form, it is best represented by the 25 km buffer of the site. While the 5 km and 2.5 km bisect the estuary into two separate eastern and western rasters, the 25 km produces one cohesive piece, which captures changes in the seaward interface that connects the two. This allows for the inclusion of reclamation activity at the tip of the "island" separating the two and manages to capture the formation of some of the barrier islands extending across the estuarie's mouth. This results also manages to include a large swath of land reclamation to the west, though it is debatable that this area should be classified as part of the estuary. Change statistics for Nakdong yield a 8.657% loss in surface waters and 5.207% gain. The majority of this loss can be

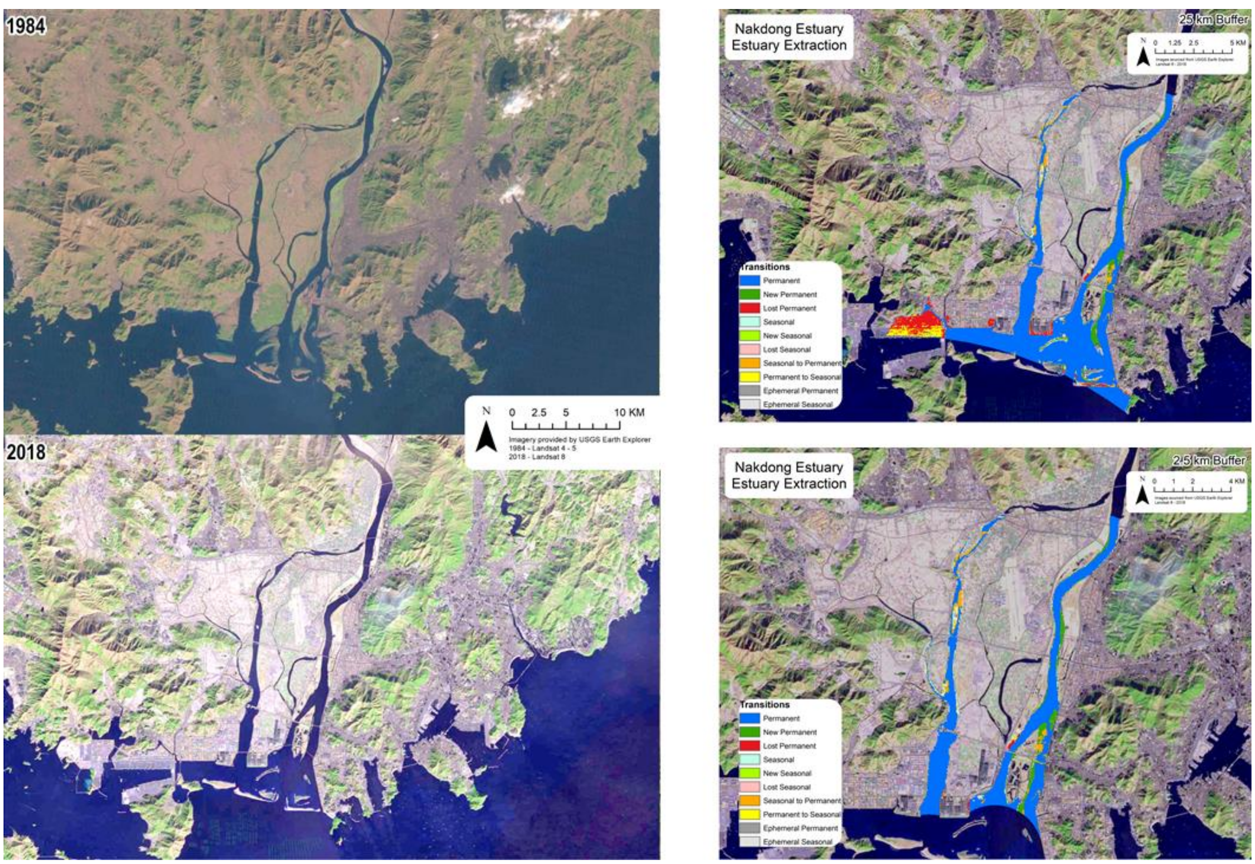


Figure 12 - Comparison of Nakdong Estuary from 1984 to 2018 and relevant raster extractions.

attributed to the western swath of land reclamation, but also includes the offshore bars and reclamation at the direct mouth. The gain in surface water mostly occurs to the eastern side of the island within the eastern channel. This seems to be a result of the construction of a set of sluice gates and subsequent dredging for a navigable gate on the channels west side.

Country Wide

As observed in the previous case studies, individual buffer sizes applied across an entire region may not prove to be the best metric of measuring spatial change in specifically estuaries or embayments, as each feature is different and will require a unique buffer size if their extents are to be properly defined. However, these results may prove to be a useful metric in how each buffer size interacts with the coast in general and provide useful data in how to "calibrate" future attempts in selecting buffer sizes for regions and their features. It is difficult to say if the subjectiveness of the embayment and estuary process will ever be fully removed due to the wide range of definitions these locations often have in both a global and sometimes local context. The 25km buffer series is observed to perform well in areas which have less complex, wide mouthed coastal features with Asan Bay serving as a good example. However, consistent errors are seen in higher complexity and narrower inlets. Often on large coastal bends, the 25km buffer will stretch long distances and encompass many different features that should be considered as separate. This often captures large swaths of near offshore open waters in some cases, inflating the ratio of no change to change. The issue with narrow areas is similar to this in that the buffer may often follow the coast along the mouth in some areas, capturing areas that are questionably estuarine. The 5km buffer extents provide a decent middle ground, capturing areas which have fairly wide mouths which narrow down rapidly as seen in the Geum Estuary. Yet, there are still some situations where the buffer "overextends" and pushes too far inland or captures too much of the seaward extent. This likely justified the need for testing of further buffer series between 25km and 5km, and 2.5km and 5km to fill cases in the middle ground. 2.5km does an excellent job at capturing features along complex coasts and small openings (or a combination of the two), seen best in the Yeongsan case study. Though, this smaller size is much more prone to producing artifact polygons and extending to far inland on wide mouthed features. To summarize, there is no "one size fits all" buffer series. Embayments and estuaries are all unique, natural features which will require unique buffer sizes to properly define their extents.

In terms of estuary selection, it is observed that not all estuaries were selected with the automated selection process. This is likely due to the very coarse resolution of the HydroSHEDs stream data (500 m) and to some extent, slight variations in the surface water data that either failed to be in close enough proximity for selection. Of the 463 estuaries pinpointed in South Korea by Lee et al. (2011), what is provided by this process does not compare with the 2.5 km series yielding only 129. This number can likely be raised to Lee's by introducing higher resolution stream data and providing custom buffer sizes for each individual embayment.

Comparing transitional water coverage among the coast, embayments, and estuaries the statistics do suggest that there is an elevated amount of change in and around coastal features when compared to the South Korean coast as a whole (Appendix 6). While the entire coastline yields a 1.969% loss and 1.340% gain, the 25km, 5km, and 2.5km embayments yield nearly 8%, 10%, and 12% respectively in loss and 4%, 5.6%, and 7.5% in gain. Notice that as the buffer series shrinks and the polygons are generally closer inland, the change in both categories rises, likely indicating that surface water changes are more prevalent deeper into embayed areas. Similar results are seen for the countrywide estuarine polygons in terms of surface water gain, yet with one exception. When going from the 5 km to 2.5 km estuarine polygons in terms of surface water loss, the trend deviates from 11.646% (5km buffer) to 10.876% (2.5km buffer). This may be due to an increased association with streams in the estuary dataset, as estuarine areas often have extents which stretch further inland and capture higher amounts of permanent and seasonal waters which have not undergone change. This could also be related to the gathering of water behind dams in upstream areas. Note that the surface water loss outweighs gain in these areas by approximately 3 to 4% across all buffer sizes in embayments and 4 to 6% in estuaries, suggesting that South Korean embayments and estuaries area in fact shrinking in size and being transitioned to new land

Limitations

Currently, there are three major limitations which must be identified and improved upon if possible. These are the poorly yielding estuarine identification system, definition of coastal on the seaward side based upon the 10km buffer, and choosing of the buffer size for the delineation of the outer bound of estuarine polygons.

The current method used to differentiate embayment polygons from estuarine ones does not yield what should be expected based upon past research. One likely improvement would be replacing the current HydroSHEDS dataset with another global stream dataset known as MERIT Hydro. HydroSHEDs high resolution of nearly 500m tends to overgeneralize the location of streams, causing them to be mislocated in another nearby area or not extend as far as they do in reality. MERIT Hydro is likely to provide a higher resolution, a more complete collection of global streams, and other useful data relating to their hydrology that could curb these issues and improve the stream to polygon intersections (Yamazaki et al., 2019). However, this dataset will require further processing to accommodate the model than HydroSHEDS due to its native raster form. It is expected that this datasets implementation will yield higher accuracy estuary detection than HydroSHEDS due to the increased resolution (90m at the equator).

A second limitation is the current implementation of the 10km coastal zone buffer to both the landward and seaward size. It is possible that by using this some amount of water that should not be considered coastal is being included in the statistical outputs for the 10km coastal raster. Instead, it is preferred that a depth contour border at the seaward side is used instead of the current 10km buffer in Google Earth Engine. The 10km buffer is a coastal zone centric metric and does not depict what should be considered coastal in a seaward extent. A depth contour border (likely 30m as offered by Sayre et al. (2018)) will capture areas related to the regions coast better than a buffer distance, as these shallow waters are what contain much of the surface water changes. The depth contour border will also allow for customization of the study area based off of the areas morphological features and proven oceanographic data.

The final, and arguably most important, limitation is the methodology that standardizes the buffer size or “circle” which draws the outer extent of the features. The current application of this is purely subjective and based upon the user’s knowledge or personal definition of what they believe is an embayment or estuary. Representing estuaries and embayments from a singular buffer size doesn't account for the changes in geometry from feature to feature and landmass to landmass. A method is needed to “customize” the buffer size for each estuary based upon the size of its mouth, inland depth, and other components that define it. Currently, manual inspection of the polygons tend to yield the best results, though does not remove the subjectivity which human interaction brings. While it is unknown what the change requires may be, a change here is certainly needed if this algorithm is to be applied on larger scales in a fully automated fashion.

CHAPTER VII - CONCLUSION

As was proposed, a semi-automated GIS algorithm was created which was capable of extracting the embayed and estuarine transitional water data from a raster via a modified coastal generalization method. From this, it was possible to produce a statistical product for the nation's coastline, embayments, and estuaries that was observed to be approximate to the changes which had occurred in each feature over the time of 1984 to 2018 for comparison across similar buffer sizes. Of the 5 case studies performed, when a properly fitting estuarine polygon was applied, the raster and statistical extraction appeared to provide accurate numeric data for each feature and tended to back previous peer reviewed works which indicated varying change of both natural and human origin in each feature.

While the capabilities of this on a country-wide scale are likely not applicable until a way to standardize or customize the buffer size is found, this tool may find uses in small scale applications in which a low quantity set of embayments or estuaries require analysis. While surface water transitions are used here, it should be noted that likely any raster could be extracted with this tool to produce spatial coverage statistics for a coastal feature. Either could prove useful in small scale management applications where a practitioner wishes quantify surface water and related morphological changes and compare them within their coastal features. As seen in the case studies, it may also be used as a tool to quantify levels of spatial change in comparison to studies in sediment dynamics, coastal geomorphology, and provide a proximate indicator of anthropogenic change. Long term, there is some potential for this work to be taken to a global scale, providing an analysis of changes of coastal features worldwide. However, the changes stated earlier must be applied along with methods to manage such large amounts of data. Ideally, this tool would allow for an inventory of coastal, embayment, and estuarine change across the globe. Likely, such an extensive analysis would allow for comparison of these features across varying geographic areas including different environmental factors and management practices. This could be used as a valuable tool to compare the effectiveness of management practices along coastal zones and how different practices impact the outcome of surface water change and related morphology of a location.

CHAPTER VIII - REFERENCES

Barbier, E. B., Hacker, S. D., Kennedy, C., Koch, E. W., Stier, A. C., & Silliman, B. R. (2011). The value of estuarine and coastal ecosystem services. Ecological monographs, 81(2), 169-193.

Chang, T. S., Kim, S. P., Yoo, D. G., Lee, S., & Lee, E. (2010). A large mid-channel sand bar in the macrotidal seaway of outer Asan Bay, Korea: 30 years of morphologic response to anthropogenic impacts. Geo-Marine Letters, 30(1), 15-22.

Choi, I. C., Shin, H. J., Nguyen, T., & Tenhunen, J. (2017). Water policy reforms in South Korea: A historical review and ongoing challenges for sustainable water governance and management. Water, 9(9), 717.

Choy, E. J., An, S., & Kang, C. K. (2008). Pathways of organic matter through food webs of diverse habitats in the regulated Nakdong River estuary (Korea). Estuarine, Coastal and Shelf Science, 78(1), 215-226.

Christensen, A. H. (1999). Cartographic line generalization with waterlines and medial-axes. Cartography and Geographic Information Science, 26(1), 19-32.

Elliott, M., & McLusky, D. S. (2002). The need for definitions in understanding estuaries. Estuarine, coastal and shelf science, 55(6), 815-827.

Evans, G., & Prego, R. (2003). Rias, estuaries and incised valleys: is a ria an estuary?. Marine geology, 196(3-4), 171-175.

Flanders Marine Institute (2018). Maritime Boundaries Geodatabase: Maritime Boundaries and Exclusive Economic Zones (200NM), version 10. Available online at http://www.marineregions.org/ https://doi.org/10.14284/312.

Gunderson, L. H. (2001). Panarchy: understanding transformations in human and natural systems. Island Press.

Harris, P. T., Macmillan-Lawler, M., Rupp, J., & Baker, E. K. (2014). Geomorphology of the oceans. Marine Geology, 352, 4-24.

Hodder, J. H. (2018). Time Series Analyses of Changes in Surface Area of South Korean Estuaries from 1985-2015: Developing New Tools and Protocols Using Global Surface Water Datasets Within Google Earth Engine and ArcGIS (Masters Thesis).

Hong, S. K., Koh, C. H., Harris, R. R., Kim, J. E., Lee, J. S., & Ihm, B. S. (2010). Land use in Korean tidal wetlands: impacts and management strategies. Environmental management, 45(5), 1014-1026.

Johnston, S. A. (1981). Estuarine dredge and fill activities: a review of impacts. Environmental management, 5(5), 427-440.

Kelso, N. V., & Patterson, T. (2010). Introducing natural earth data-naturalearthdata. com. Geographia Technica, 5, 82-89.

Kim, H. J., Suh, S. W., Seok, J. S., & Park, W. K. (2017). Sedimentation for a Flood-dominant Estuarine Harbor Induced by Anthropogenic Activities. Journal of Coastal Research, 79(sp1), 339-343.

Koh, C. H., Ryu, J. S., & Khim, J. S. (2010). The Saemangeum: history and controversy. Journal of the Korean Society for Marine Environment & Energy, 13(4), 327-334.

Lavalle, C., Gomes, C. R., Baranzelli, C., & e Silva, F. B. (2000). Coastal Zones. Policy alternatives impacts on European Coastal Zones, 2050.

Lehner, B., Verdin, K., & Jarvis, A. (2006). HydroSHEDS technical documentation, version 1.0. World Wildlife Fund US, Washington, DC, 1-27.

Lee, H. J., & Yoon, S. H. (1997). Development of stratigraphy and sediment distribution in the northeastern Yellow Sea during Holocene sea-level rise. Journal of Sedimentary Research, 67(2), 341-349.

Lee K.-H., Rho, B.-H., Cho H.-J., Lee. C.-H., (2011). Estuary classification based on the characteristics of geomorphological features, natural habitat distributions and land uses. Journal of the Korean Society for Oceanography, 16, pp. 53-69.

Lee, Y. K., Ryu, J. H., Choi, J. K., Lee, S., & Woo, H. J. (2015). Satellite-based observations of unexpected coastal changes due to the Saemangeum Dyke construction, Korea. Marine pollution bulletin, 97(1-2), 150-159.

Little, S., Spencer, K. L., Schuttelaars, H. M., Millward, G. E., & Elliott, M. (2017). Unbounded boundaries and shifting baselines: Estuaries and coastal seas in a rapidly changing world.

Martínez, M. L., Intralawan, A., Vázquez, G., Pérez-Maqueo, O., Sutton, P., & Landgrave, R. (2007). The coasts of our world: Ecological, economic and social importance. Ecological economics, 63(2-3), 254-272.

Milliman, J. D., & Farnsworth, K. L. (2013). River discharge to the coastal ocean: a global synthesis. Cambridge University Press.

Mitropoulos, V., Xydia, A., Nakos, B., & Vescoukis, V. (2005, July). The use of epsilonconvex area for attributing bends along a cartographic line. In International Cartographic Conference, la Corona, Spain.

Park, S. J., Achmad, A. R., Syifa, M., & Lee, C. W. (2019). Machine Learning Application for Coastal Area Change Detection in Gangwon Province, South Korea Using High-Resolution Satellite Imagery. Journal of Coastal Research, 90(sp1), 228-235.

Pekel, J. F., Cottam, A., Gorelick, N., & Belward, A. S. (2016). High-resolution mapping of global surface water and its long-term changes. Nature, 540(7633), 418.

Perillo, G. M. (1995). Definitions and geomorphologic classifications of estuaries. In Developments in Sedimentology (Vol. 53, pp. 17-47). Elsevier.

Perkal, J. (1958a). On the length of empirical curves: Discussion paper 10. Ann Aabor MI. Michigan Inter-University community of Mathematical Cartographers.

Perkal, J. (1958b). An attempt at objective generalization. Discussioi Paper No. 10. Ann Arbor, Mich: Michigan Inter-Universit Community of Mathematical Geographers.

Pritchard, D. W. (1967). What is an estuary: physical viewpoint. American Association for the Advancement of Science.

Rogers, D. I., Moores, N. I. A. L., & Battley, P. F. (2006). Northwards migration of shorebirds through Saemangeum, the Geum estuary and Gomso bay, South Korea in 2006. Stilt, 50, 73-89.

Ryu, J. H., Kim, C. H., Lee, Y. K., Won, J. S., Chun, S. S., & Lee, S. (2008). Detecting the intertidal morphologic change using satellite data. Estuarine, Coastal and Shelf Science, 78(4), 623-632.

Sayre, R., Noble, S., Hamann, S., Smith, R., Wright, D., Breyer, S., ... & Hopkins, D. (2018). A new 30 meter resolution global shoreline vector and associated global islands database for the development of standardized ecological coastal units. Journal of Operational Oceanography, 1-10.

Sayre, R., Noble, S., Cress, J., Burton, D., Martin, M., & Steiner, J. (2019). A New Map of Global Islands.

Song, B., Yi, S., Chang, T. S., Kim, J. C., Mao, L., Nahm, W. H., & Jia, H. (2017). Holocene environmental change inferred from multiple proxies in the mouth of Gomso Bay on the west coast of South Korea. Quaternary Research, 88(2), 193-205.

Thrush, S. F., Halliday, J., Hewitt, J. E., & Lohrer, A. M. (2008). The effects of habitat loss, fragmentation, and community homogenization on resilience in estuaries. Ecological Applications, 18(1), 12-21.

Townend, I., & Pethick, J. (2002). Estuarine flooding and managed retreat. Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences, 360(1796), 1477-1495.

Williams, J. R., Dellapenna, T. M., & Lee, G. H. (2013). Shifts in depositional environments as a natural response to anthropogenic alterations: Nakdong Estuary, South Korea. Marine Geology, 343, 47-61.

Williams, J., Dellapenna, T., Lee, G. H., & Louchouarn, P. (2014). Sedimentary impacts of anthropogenic alterations on the Yeongsan Estuary, South Korea. Marine Geology, 357, 256-271.

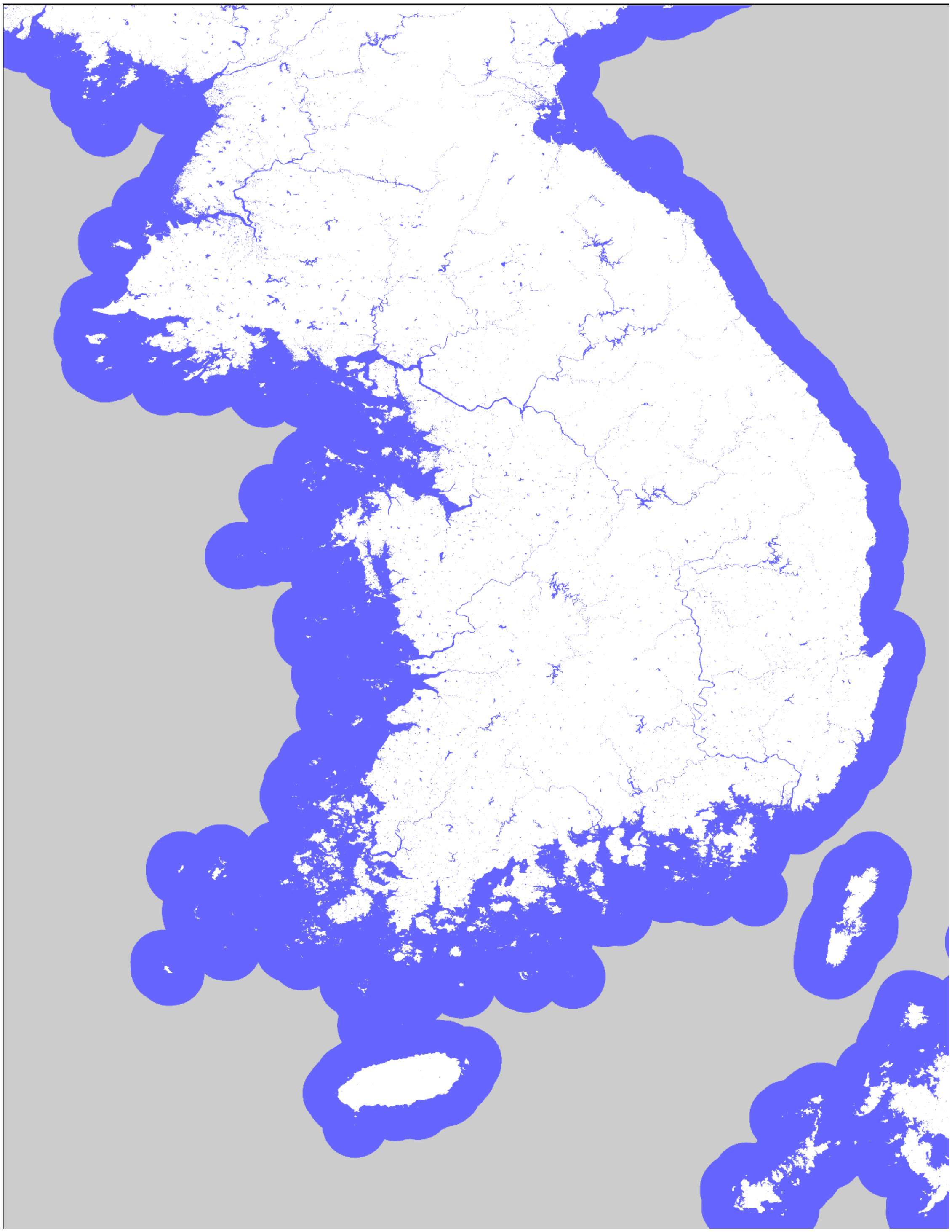
Williams, J., Lee, G. H., Shin, H. J., & Dellapenna, T. (2015). Mechanism for sediment convergence in the anthropogenically altered microtidal Nakdong Estuary, South Korea. Marine Geology, 369, 79-90.

Yamazaki, D., Ikeshima, D., Sosa, J., Bates, P. D., Allen, G., & Pavelsky, T. (2019). MERIT Hydro: A high-resolution global hydrography map based on latest topography datasets. Water Resources Research.

CHAPTER IX - APPENDICES

APPENDIX 1

RAW MAXIMUM EXTENT SURFACE WATER DATA FOR SOUTH KOREA SOURCED FROM PEKEL ET AL. (2016) GLOBAL SURFACE WATER DATASET.

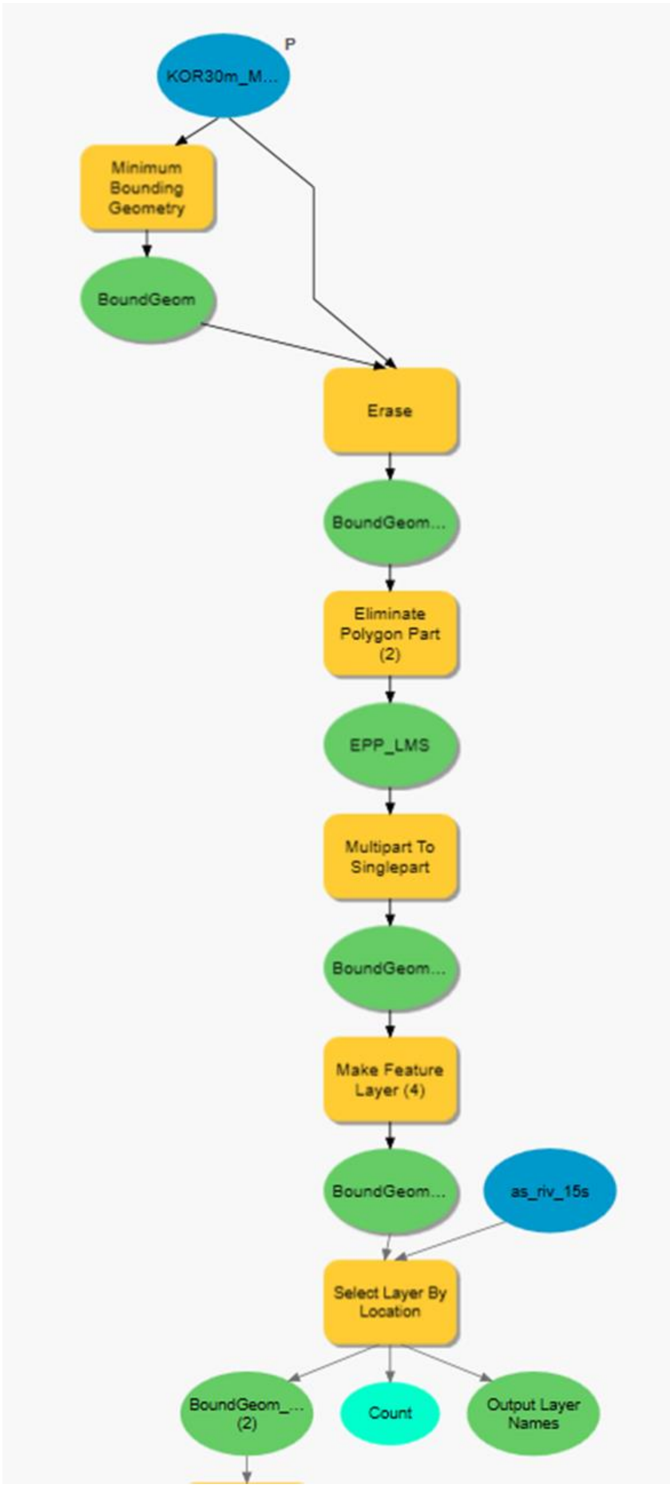


APPENDIX 2

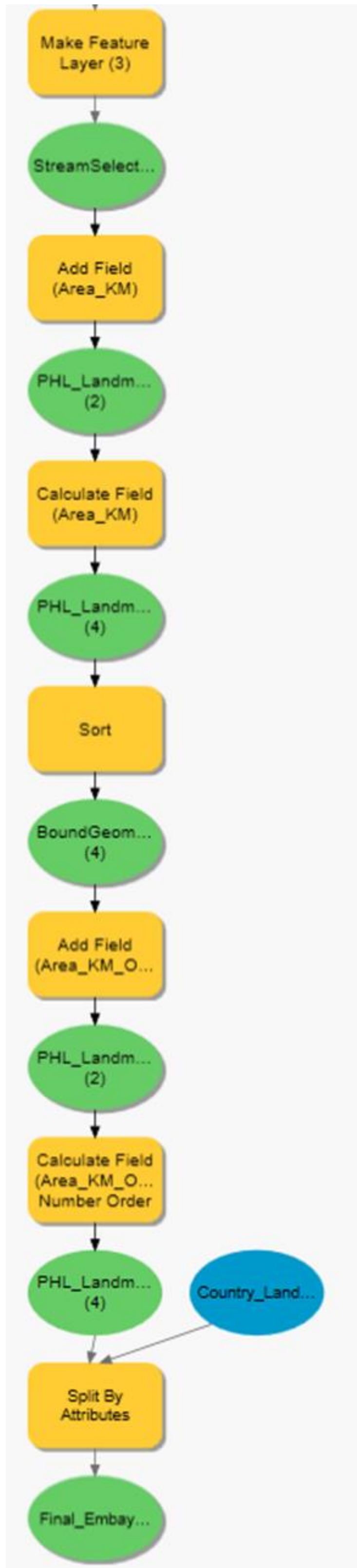
RAW TRANSITIONAL SURFACE WATER DATA FOR SOUTH KOREA SOURCED FROM PEKEL ET AL. (2016) GLOBAL SURFACE WATER DATASET.

APPENDIX 3

MODEL 2 (COASTAL FEATURE IDENTIFICATION AND DELINEATION TOOL)

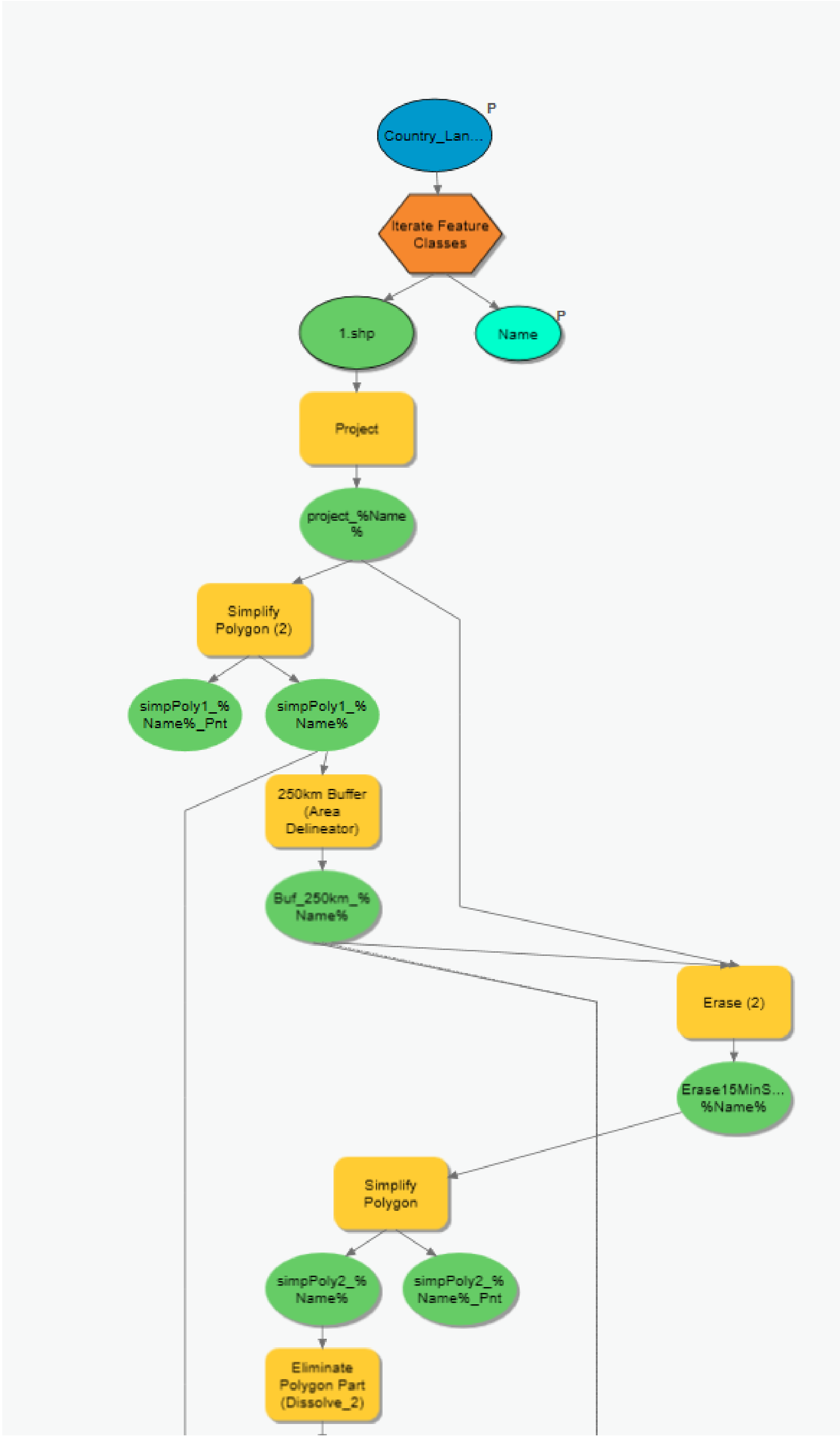


APPENDIX 3 CONT.

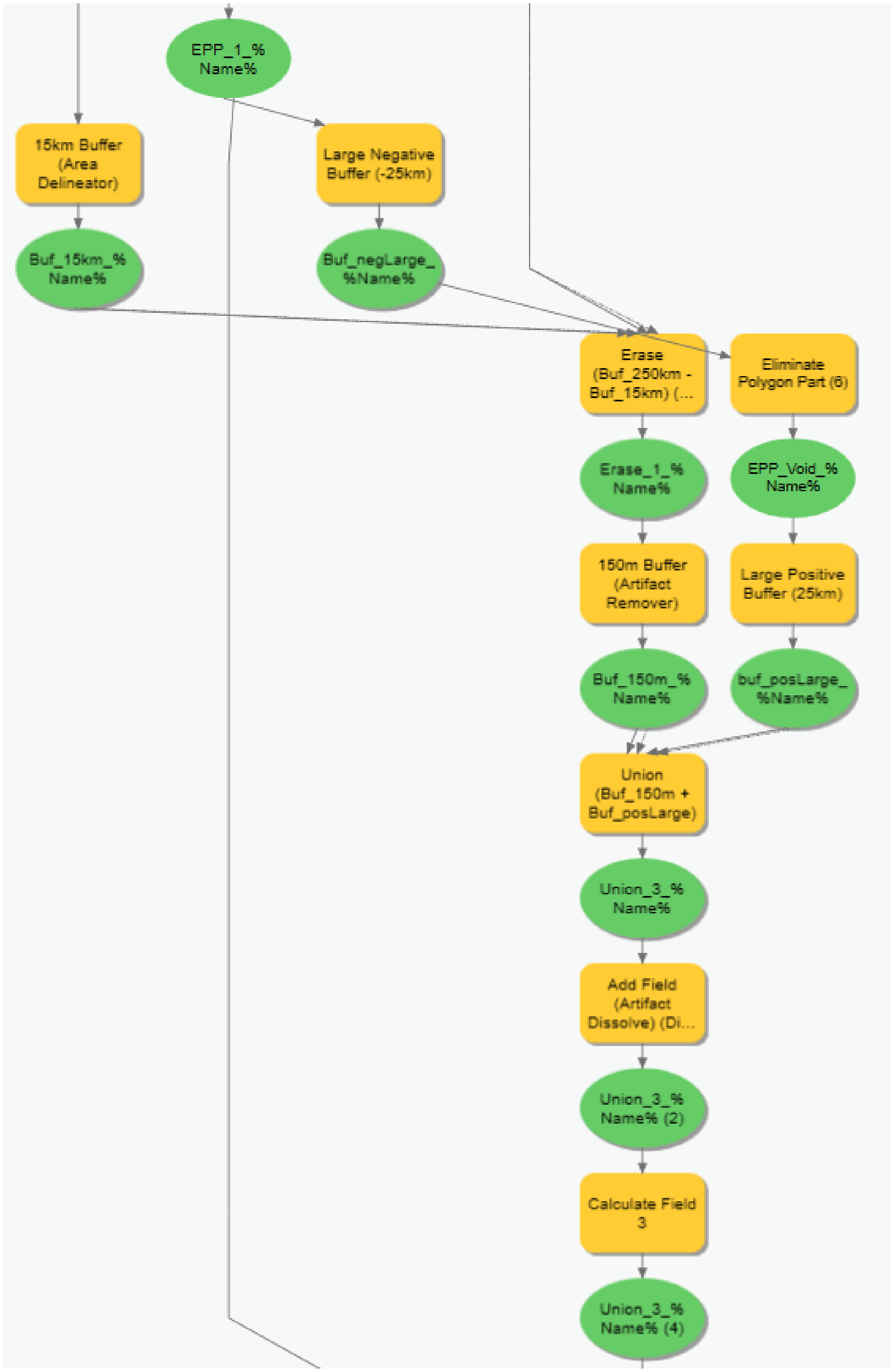


APPENDIX 4

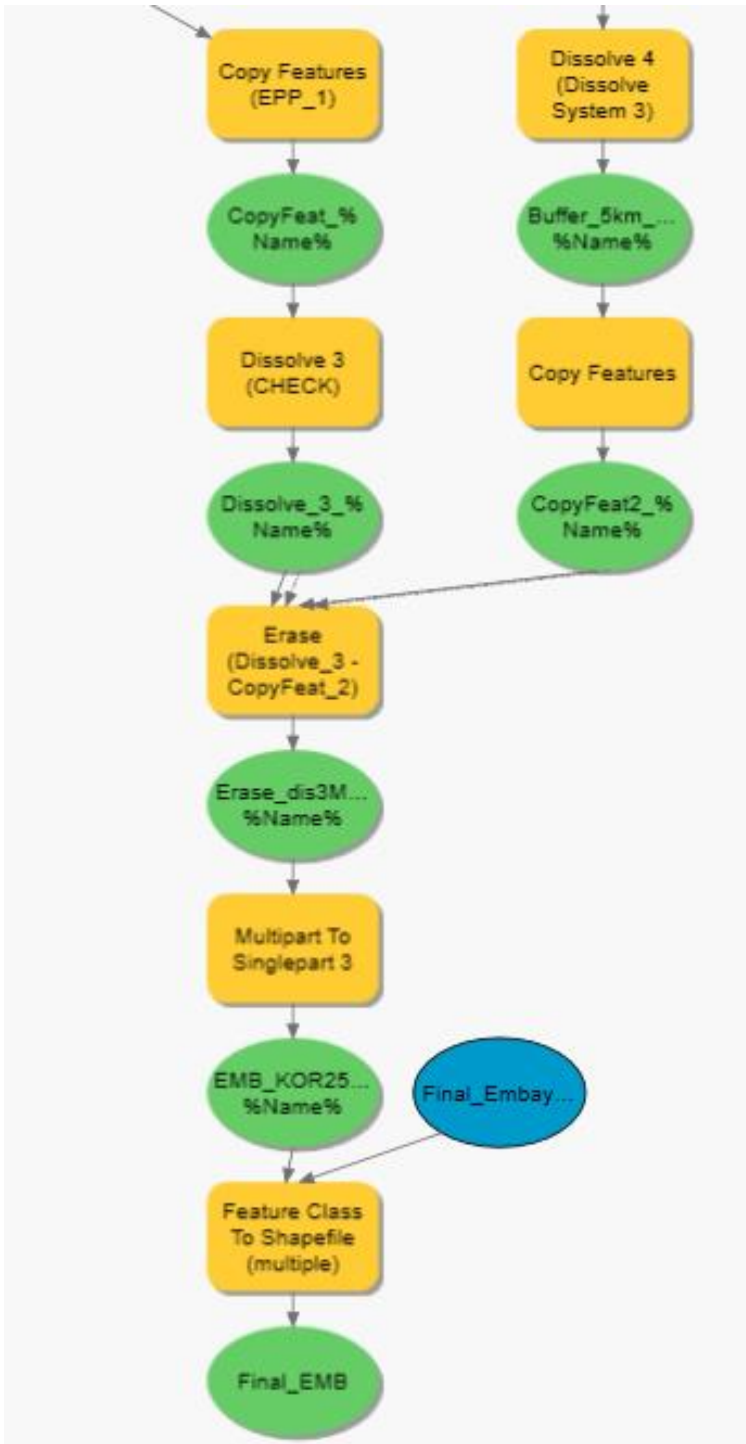
MODEL 1 (LANDMASS SEPARATION TOOL)



APPENDIX 4 CONT.

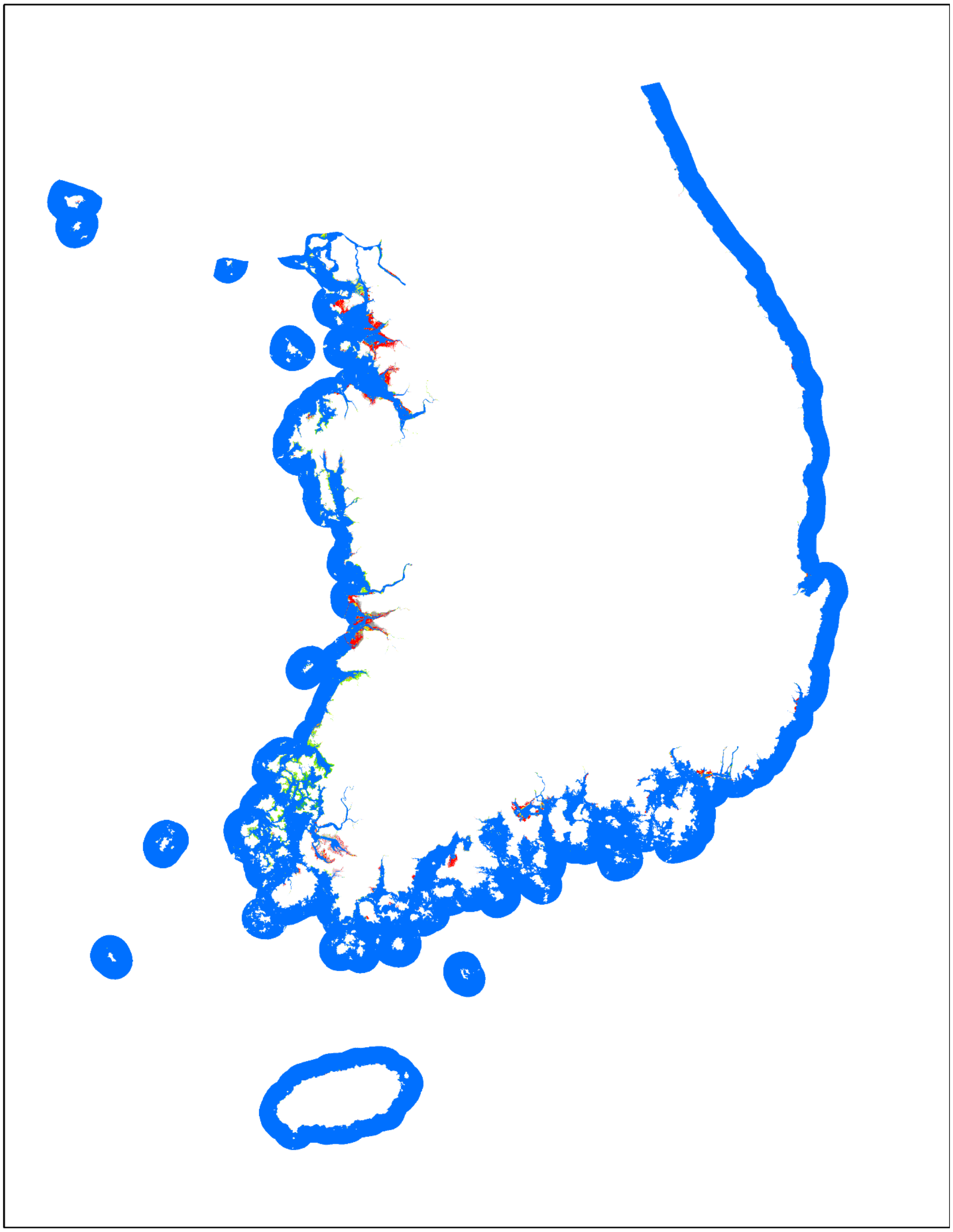


APPENDIX 4 CONT.



APPENDIX 5

EXTRACTION OF TOTAL COAST TRANSITIONAL WATER RASTER WITH THE 10KM BUFFER RANGE.



APPENDIX 6

TOTAL COAST EXTRACTION TABULAR DATA.

Change Type	All Coasts		
	COUNT	Percent Cover	Area (km)
Permanent	39480053	94.791%	27428.376
New Permanent	169946	0.408%	118.068
Lost Permanent	540211	1.297%	375.306
Seasonal	261127	0.627%	181.415
New Seasonal	387970	0.932%	269.538
Lost Seasonal	279727	0.672%	194.338
Seasonal to Permanent	41695	0.100%	28.967
Permanent to Seasonal	246135	0.591%	171.000
Ephemeral Permanent	93995	0.226%	65.302
Ephemeral Seasonal	148895	0.357%	103.443
TOTAL COUNT/TOTAL AREA	**41649754**		**28935.754**
Loss of Surface Water	819938	1.969%	569.644
Gain of Surface Water	557916	1.340%	387.607
No Loss or Gain	40029010	96.109%	27809.758
Ephemeral Water	242890	0.583%	168.745

APPENDIX 7

25KM BUFFER EXTRACTION TABULAR DATA FOR EMBAYMENTS AND ESTUARIES

Change Type	25km Embayments			25km Estuaries		
	COUNT	Percent Cover	Area (km)	COUNT	Percent Cover	Area (km)
Permanent	6458081	81.064%	4507.484	5417784	79.517%	3779.778
New Permanent	101446	1.273%	70.805	97290	1.428%	67.875
Lost Permanent	376799	4.730%	262.991	359475	5.276%	250.792
Seasonal	178456	2.240%	124.555	154015	2.260%	107.450
New Seasonal	236233	2.965%	164.881	213539	3.134%	148.978
Lost Seasonal	236806	2.972%	165.281	224651	3.297%	156.730
Seasonal to Permanent	32312	0.406%	22.552	29846	0.438%	20.822
Permanent to Seasonal	157120	1.972%	109.664	137416	2.017%	95.870
Ephemeral Permanent	76556	0.961%	53.433	74928	1.100%	52.274
Ephemeral Seasonal	112801	1.416%	78.731	104417	1.533%	72.848
TOTAL COUNT/TOTAL AREA	7966610		5560.377	6813361		4753.418
Loss of Surface Water	613605	7.702%	428.272	584126	8.573%	407.522
Gain of Surface Water	337679	4.239%	235.687	310829	4.562%	216.853
No Loss or Gain	6825969	85.682%	4764.255	5739061	84.232%	4003.920
Ephemeral Water	189357	2.377%	132.164	179345	2.632%	125.122

APPENDIX 8

5KM BUFFER EXTRACTION TABULAR DATA FOR EMBAYMENTS AND ESTUARIES

Change Type	5km Embayments			5km Estuaries		
	COUNT	Percent Cover	Area (km)	COUNT	Percent Cover	Area (km)
Permanent	3672253	74.775%	2570.979	2709148	73.142%	1894.075
New Permanent	85482	1.741%	59.847	59943	1.618%	41.909
Lost Permanent	269649	5.491%	188.784	231468	6.249%	161.829
Seasonal	163965	3.339%	114.793	129346	3.492%	90.431
New Seasonal	194226	3.955%	135.979	130498	3.523%	91.236
Lost Seasonal	223061	4.542%	156.167	199902	5.397%	139.760
Seasonal to Permanent	28617	0.583%	20.035	25189	0.680%	17.611
Permanent to Seasonal	120192	2.447%	84.148	90420	2.441%	63.216
Ephemeral Permanent	52732	1.074%	36.918	49255	1.330%	34.436
Ephemeral Seasonal	100892	2.054%	70.635	78784	2.127%	55.081
TOTAL COUNT/TOTAL AREA	4911069		3438.286	3703953		2589.584
Loss of Surface Water	492710	10.033%	344.951	431370	11.646%	301.588
Gain of Surface Water	279708	5.695%	195.826	190441	5.142%	133.145
No Loss or Gain	3985027	81.144%	2789.956	2954103	79.755%	2065.333
Ephemeral Water	153624	3.128%	107.554	128039	3.457%	89.517

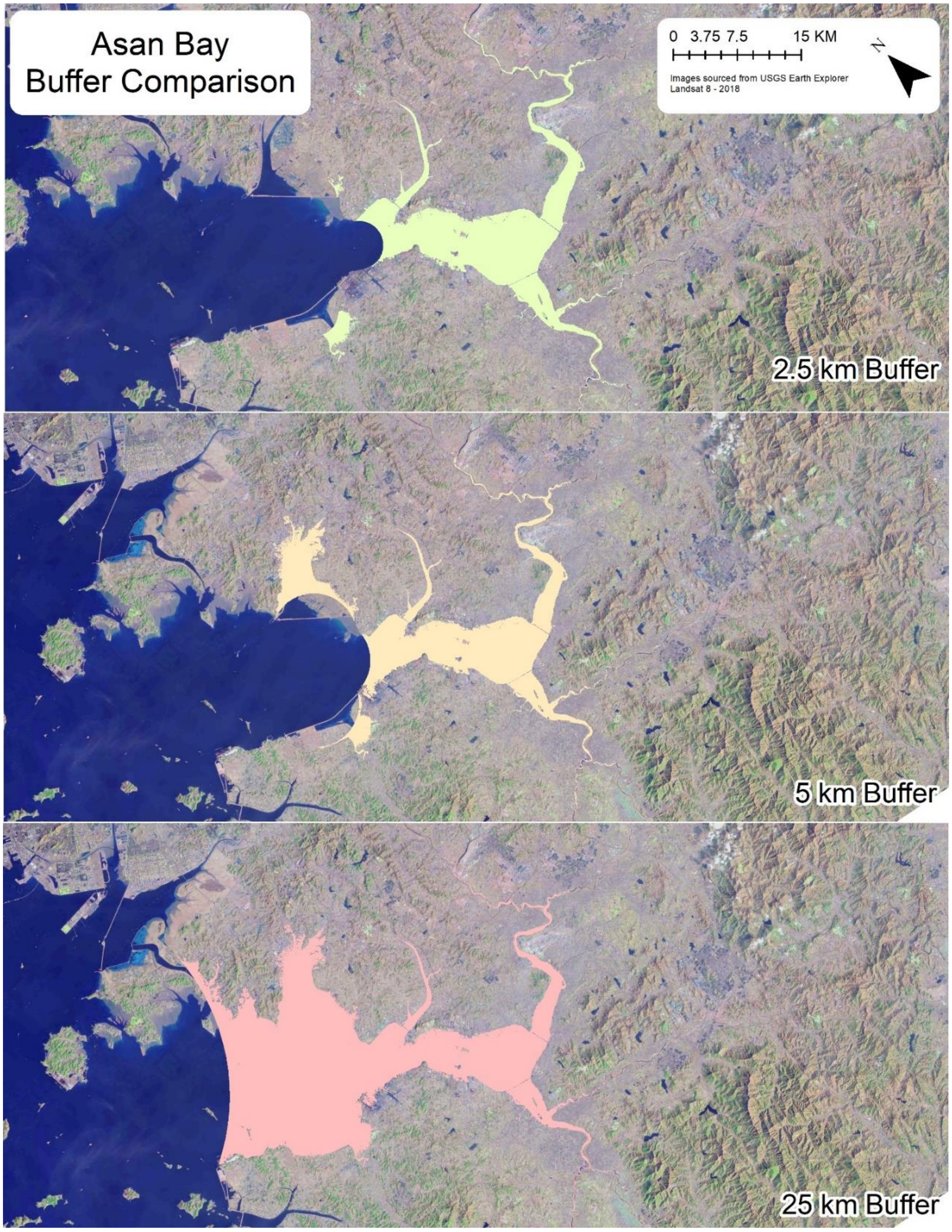
APPENDIX 9

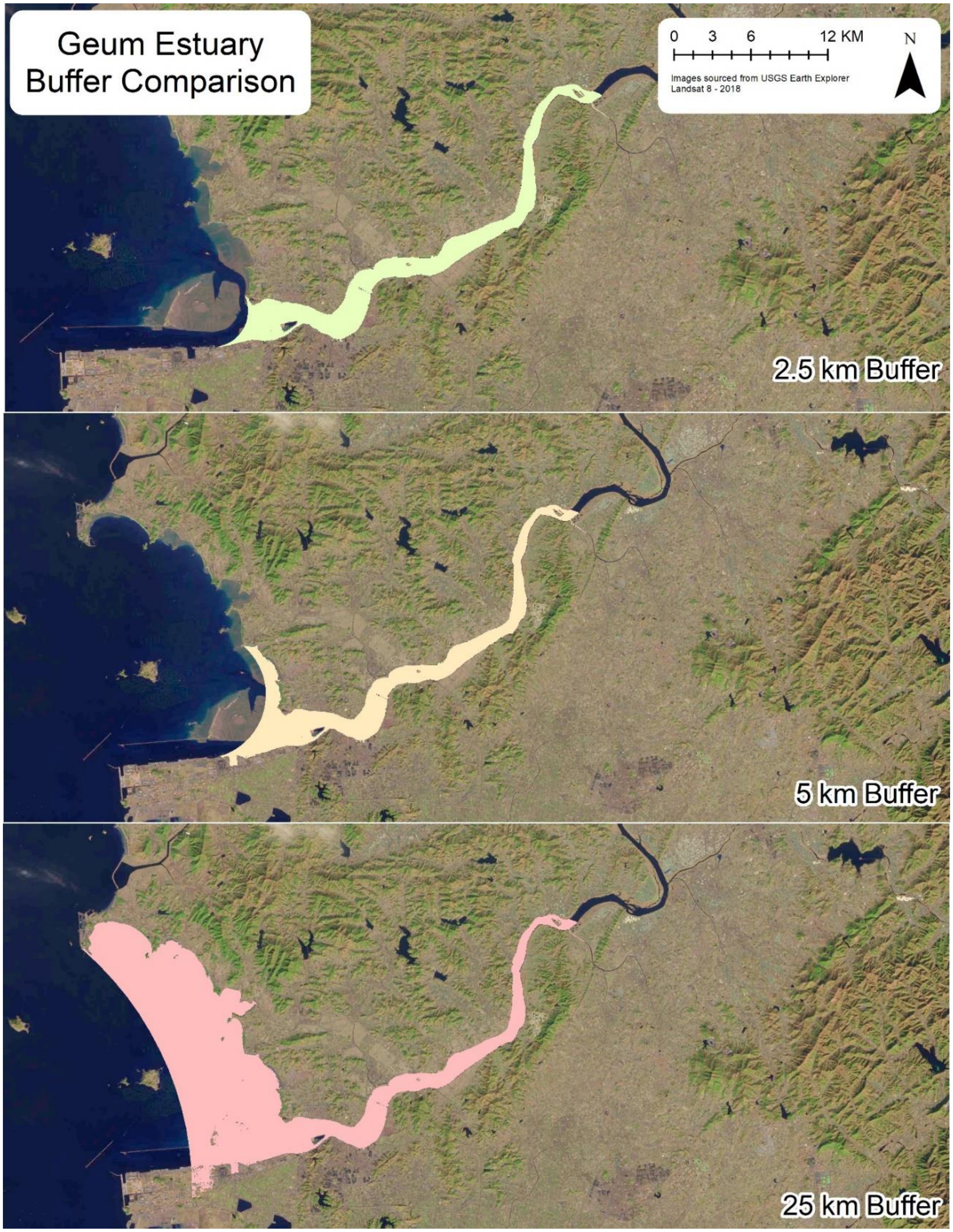
2.5KM BUFFER EXTRACTION TABULAR DATA FOR EMBAYMENTS AND ESTUARIES

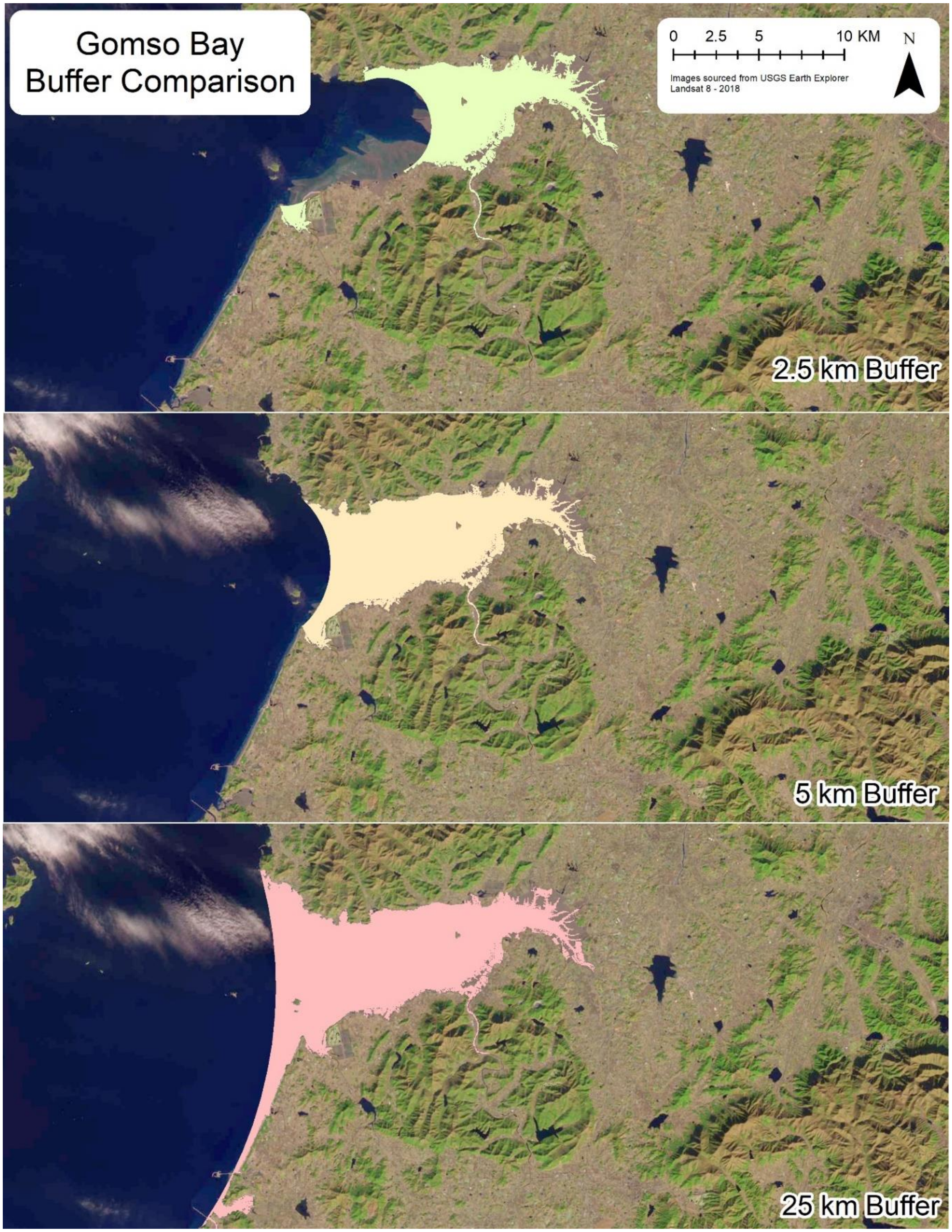
Change Type	2.5km Embayments			2.5km Estuaries		
	COUNT	Percent Cover	Area (km)	COUNT	Percent Cover	Area (km)
Permanent	2132890	67.726%	1498.937	1205840	70.653%	846.519
New Permanent	68662	2.180%	48.254	36098	2.115%	25.341
Lost Permanent	186644	5.927%	131.168	91345	5.352%	64.126
Seasonal	150568	4.781%	105.815	83820	4.911%	58.843
New Seasonal	166738	5.294%	117.179	70974	4.159%	49.825
Lost Seasonal	207012	6.573%	145.482	94276	5.524%	66.183
Seasonal to Permanent	22266	0.707%	15.648	16904	0.990%	11.867
Permanent to Seasonal	89635	2.846%	62.993	43936	2.574%	30.844
Ephemeral Permanent	34511	1.096%	24.253	29284	1.716%	20.558
Ephemeral Seasonal	90386	2.870%	63.521	34220	2.005%	24.023
TOTAL COUNT/TOTAL AREA	3149312		2213.251	1706697		1198.129
Loss of Surface Water	393656	12.500%	276.651	185621	10.876%	130.309
Gain of Surface Water	235400	7.475%	165.433	107072	6.274%	75.166
No Loss or Gain	2395359	76.060%	1683.393	1350500	79.129%	948.073
Ephemeral Water	124897	3.966%	87.774	63504	3.721%	44.581

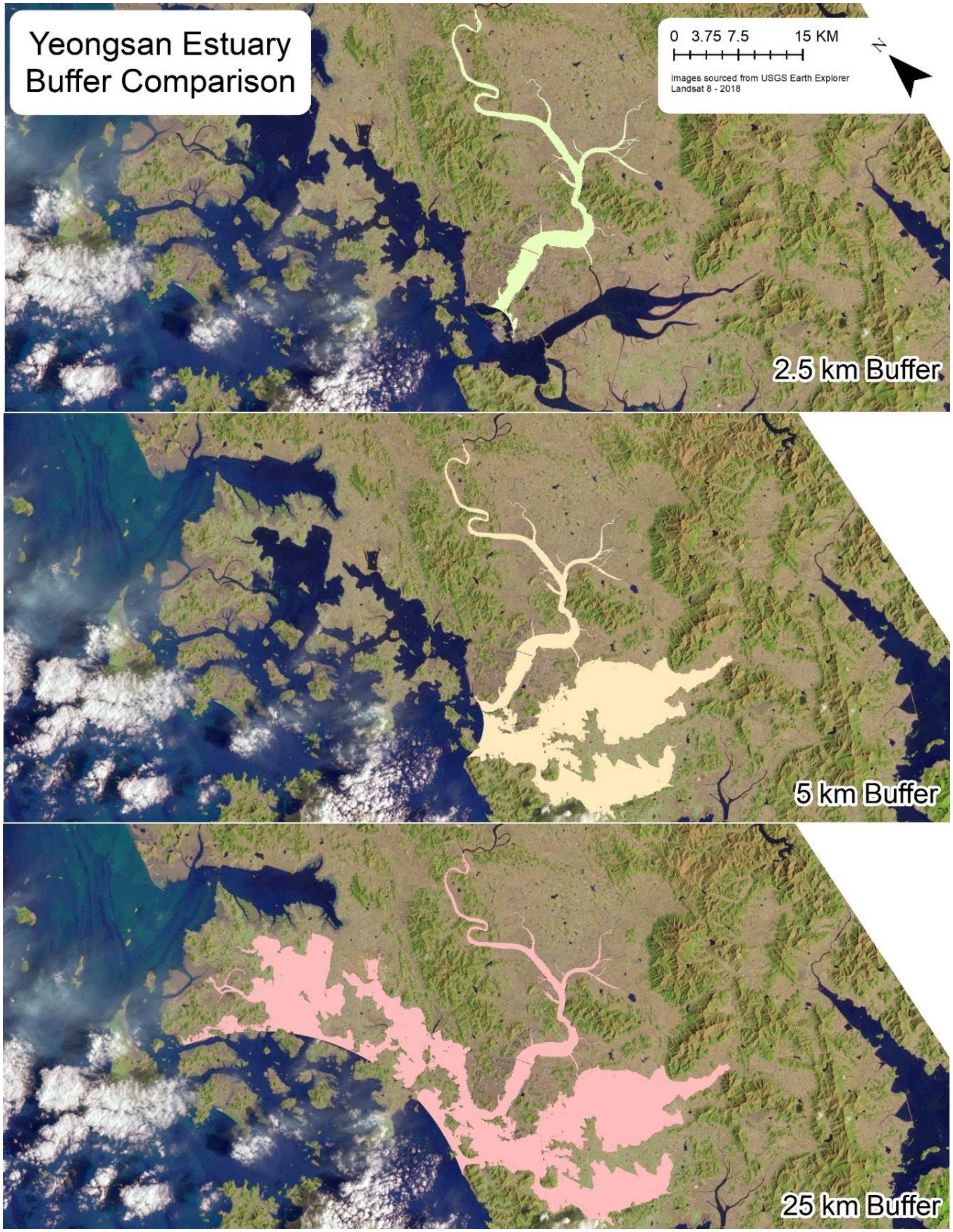
APPENDIX 10

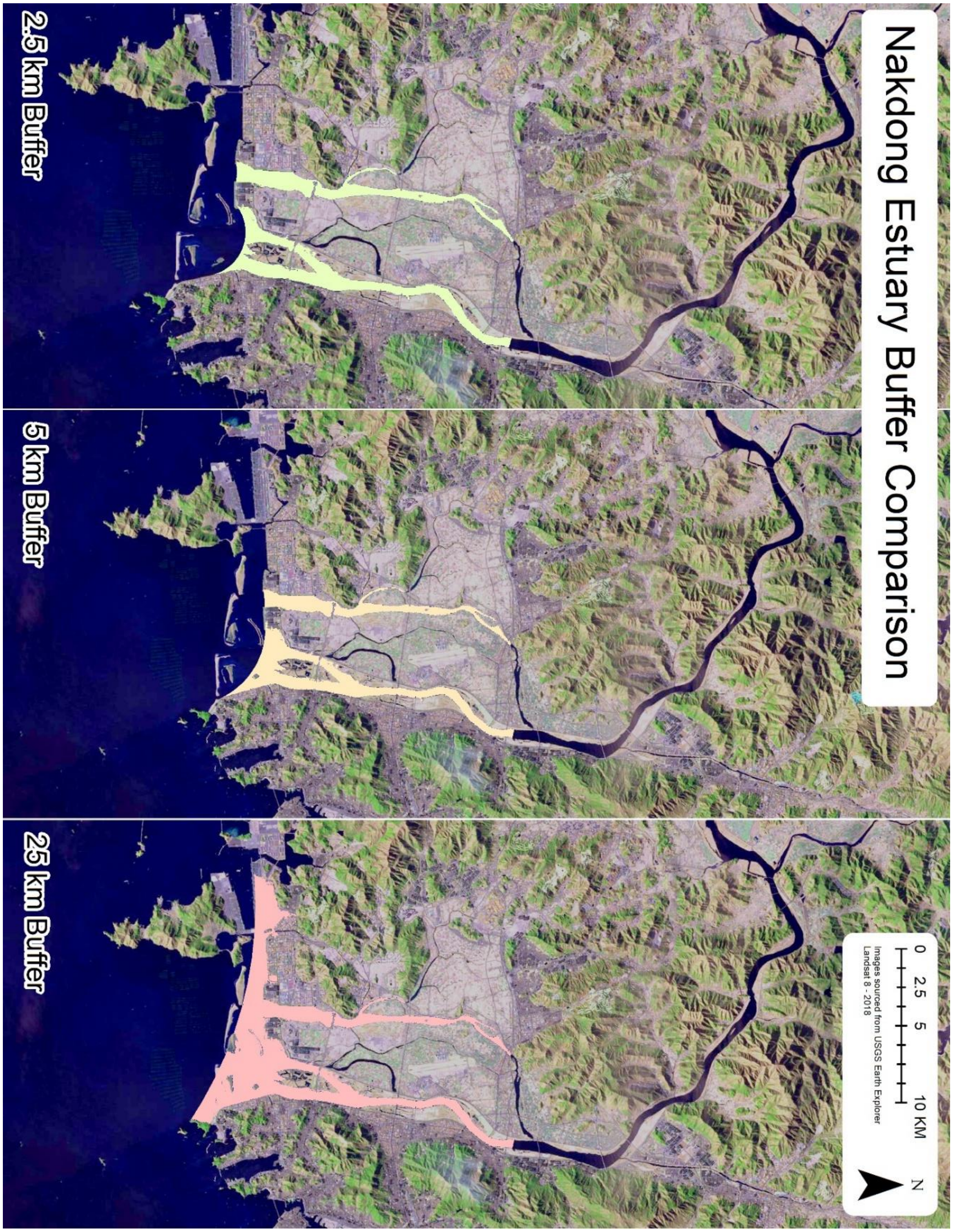
25KM, 5KM, AND 2.5KM BUFFER COMPARISON FOR EMBAYMENTS AND ESTUARIES IN CASE STUDY 1 THROUGH 5.




Geum Estuary
Buffer Comparison
0 3 6 12 KM
N
Images sourced from USGS Earth Explorer
Landsat 8 - 2018
2.5 km Buffer
5 km Buffer
25 km Buffer

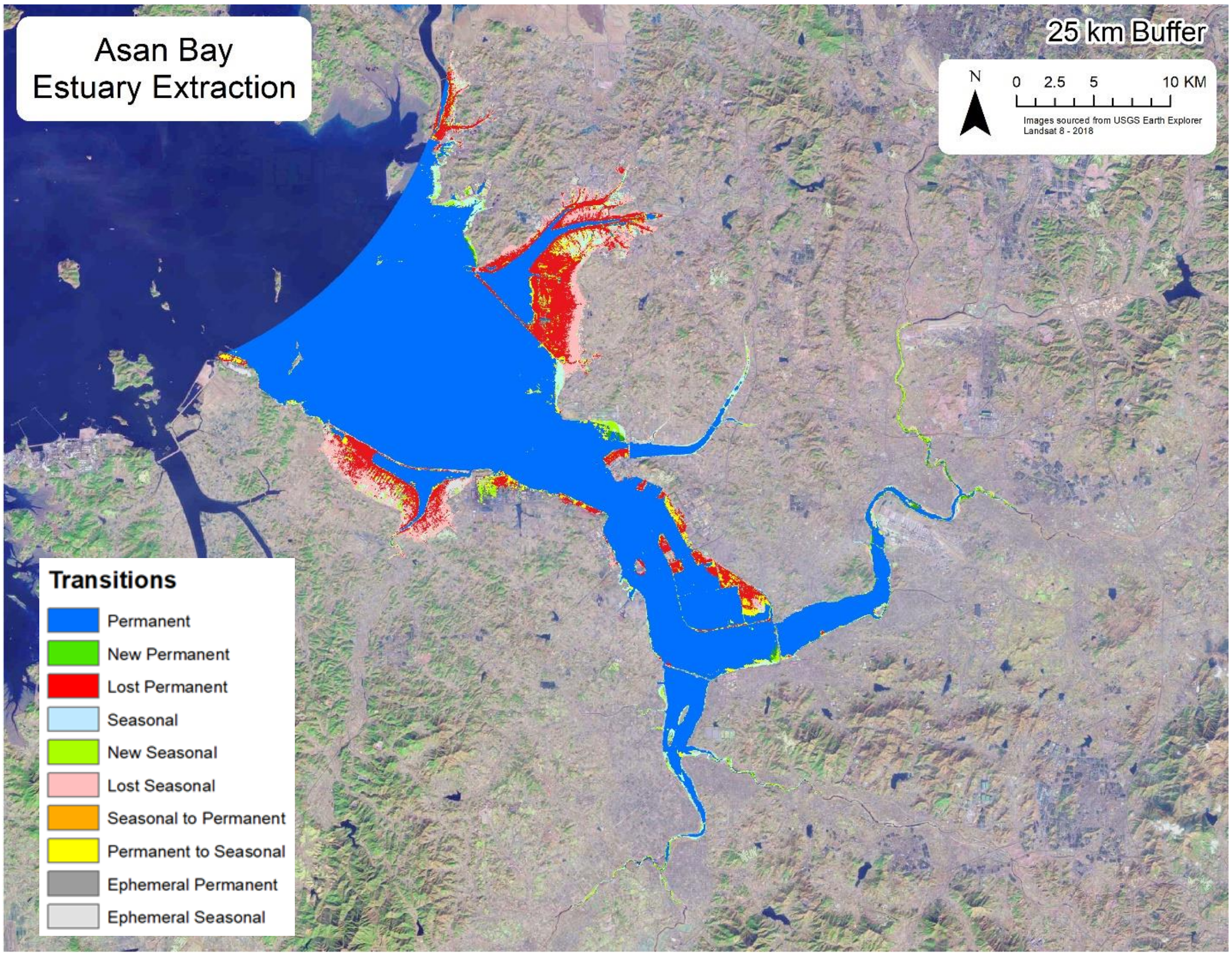

Gomso Bay
Buffer Comparison
0
2.5
5
10 KM
N
Images sourced from USGS Earth Explorer
Landsat 8 - 2018
2.5 km Buffer
5 km Buffer
25 km Buffer

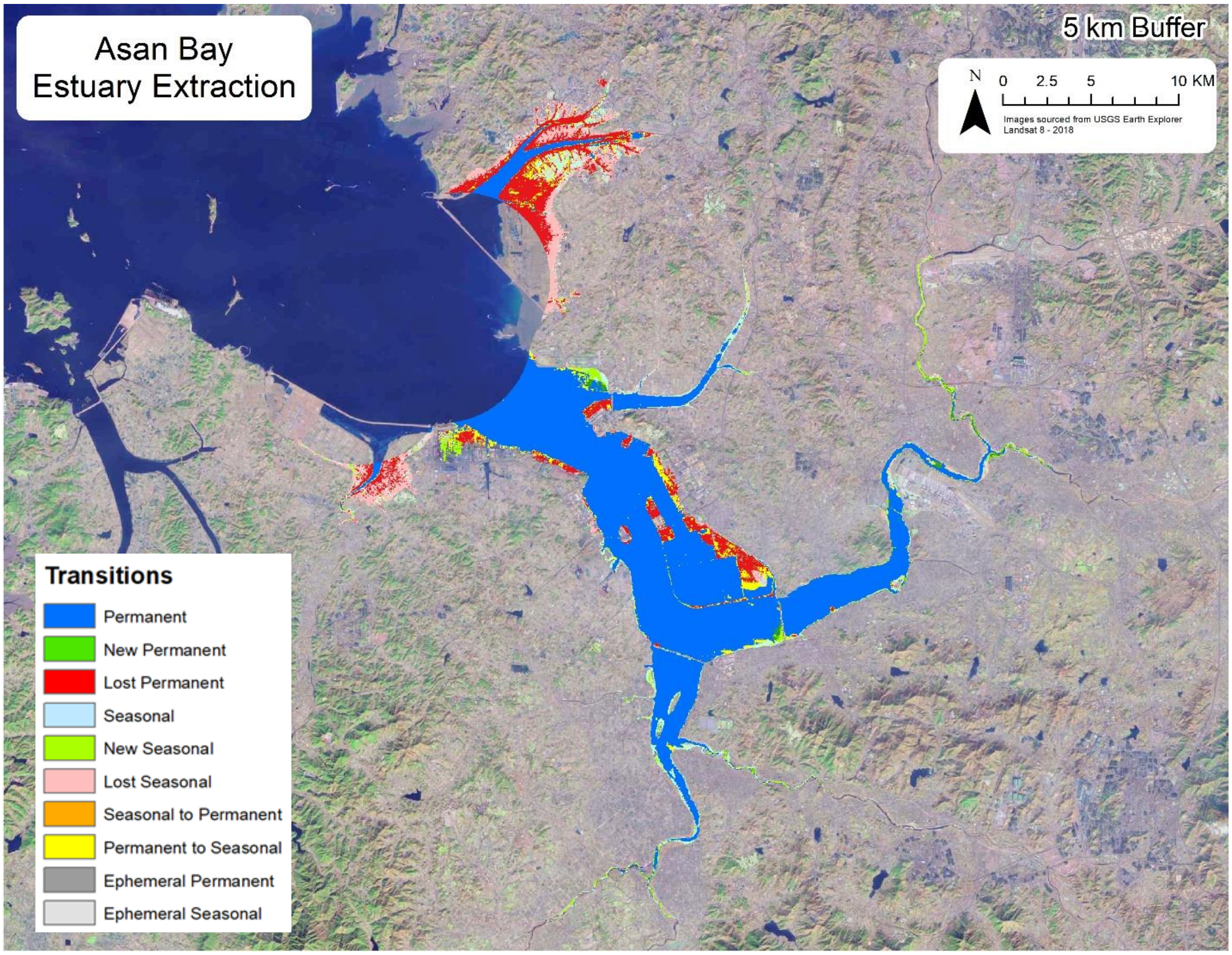

Yeongsan Estuary
Buffer Comparison
0 3.75 7.5 15 KM
Images sourced from USGS Earth Explorer
Landsat 8 - 2018
N
2.5 km Buffer
5 km Buffer
25 km Buffer

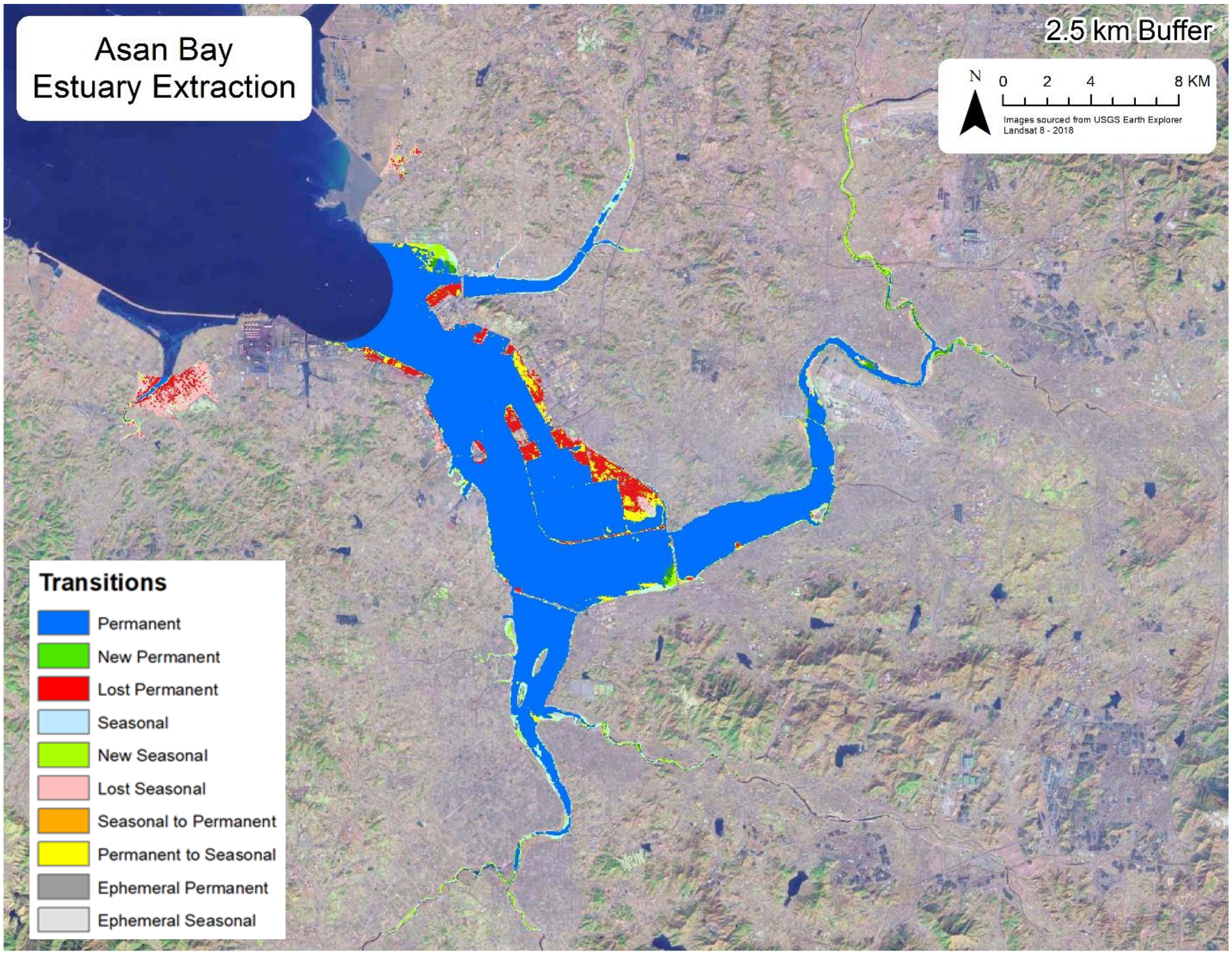

Nakdong Estuary Buffer Comparison
2.5 km Buffer
5 km Buffer
25 km Buffer
0 2.5 5 10 KM
Images sourced from USGS Earth Explorer
Landsat 8 - 2018
N

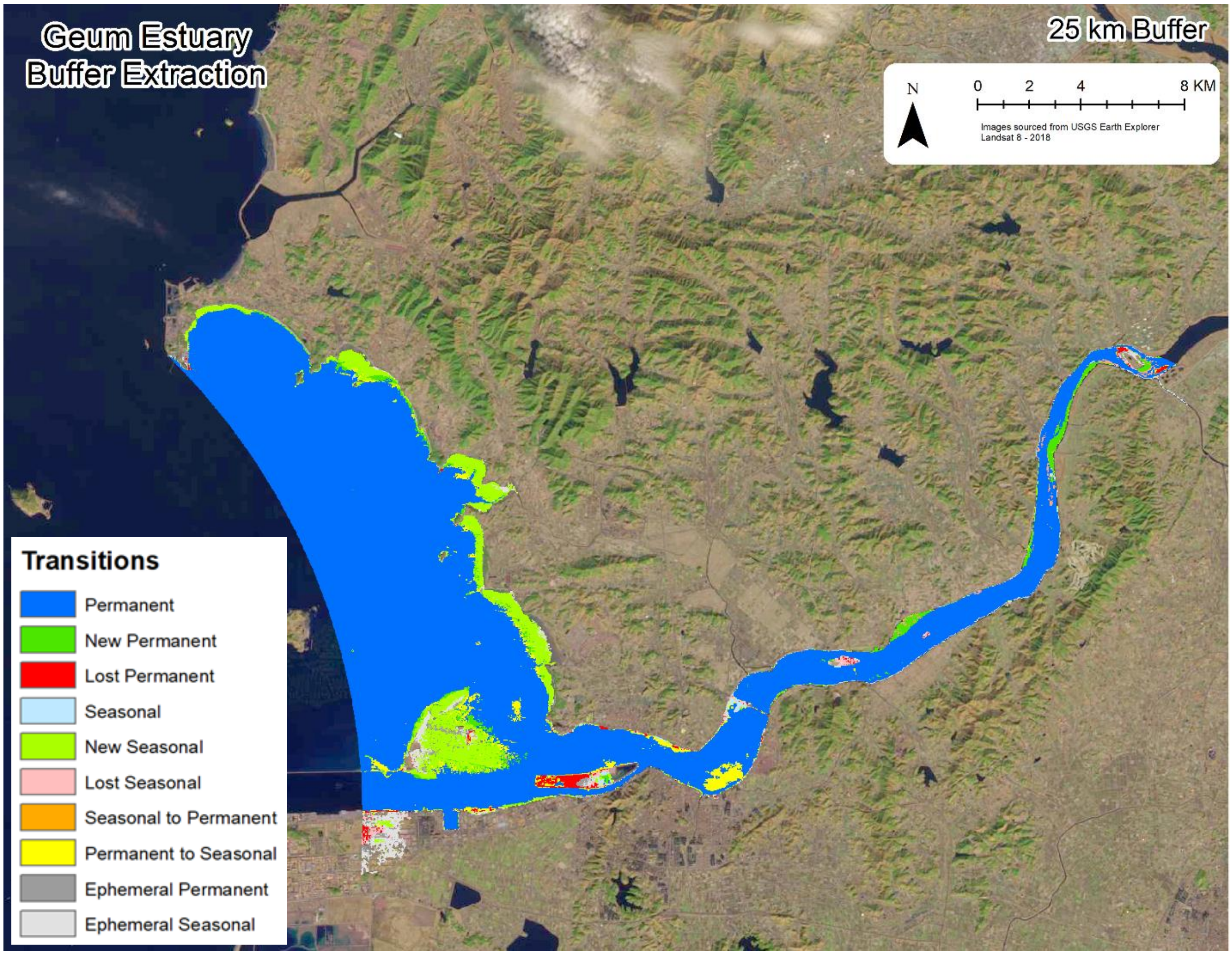
APPENDIX 11

25KM, 5KM, AND 2.5KM BUFFER COMPARISON FOR EMBAYMENT AND ESTUARY TRANSITIONAL WATER EXTRACTIONS.

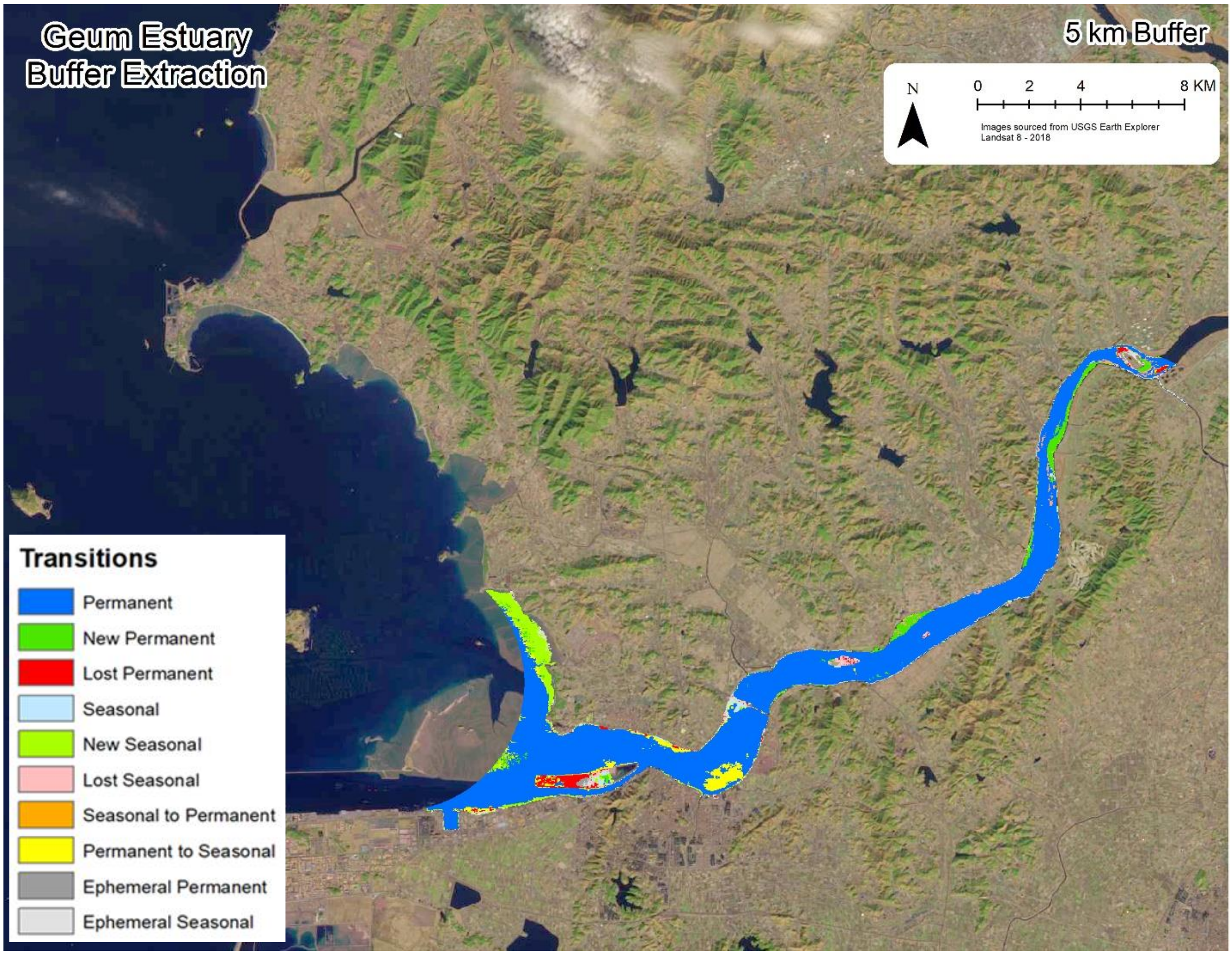



Asan Bay
Estuary Extraction
5 km Buffer
N
0 2.5 5 10 KM
Images sourced from USGS Earth Explorer
Landsat 8 - 2018
Transitions
Permanent
New Permanent
Lost Permanent
Seasonal
New Seasonal
Lost Seasonal
Seasonal to Permanent
Permanent to Seasonal
Ephemeral Permanent
Ephemeral Seasonal

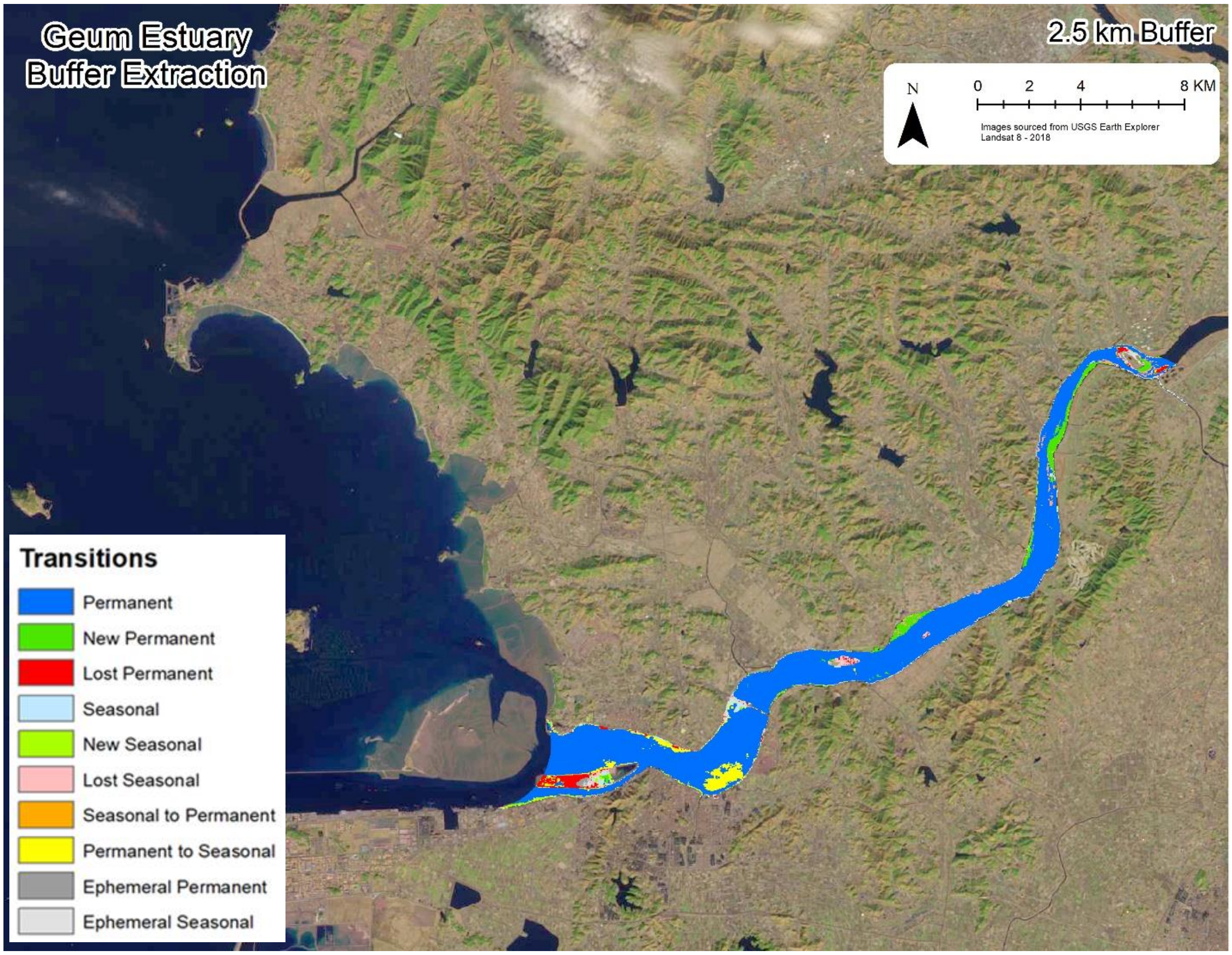

Asan Bay
Estuary Extraction
2.5 km Buffer
N
0 2 4 8 KM
Images sourced from USGS Earth Explorer
Landsat 8 - 2018
Transitions
Permanent
New Permanent
Lost Permanent
Seasonal
New Seasonal
Lost Seasonal
Seasonal to Permanent
Permanent to Seasonal
Ephemeral Permanent
Ephemeral Seasonal

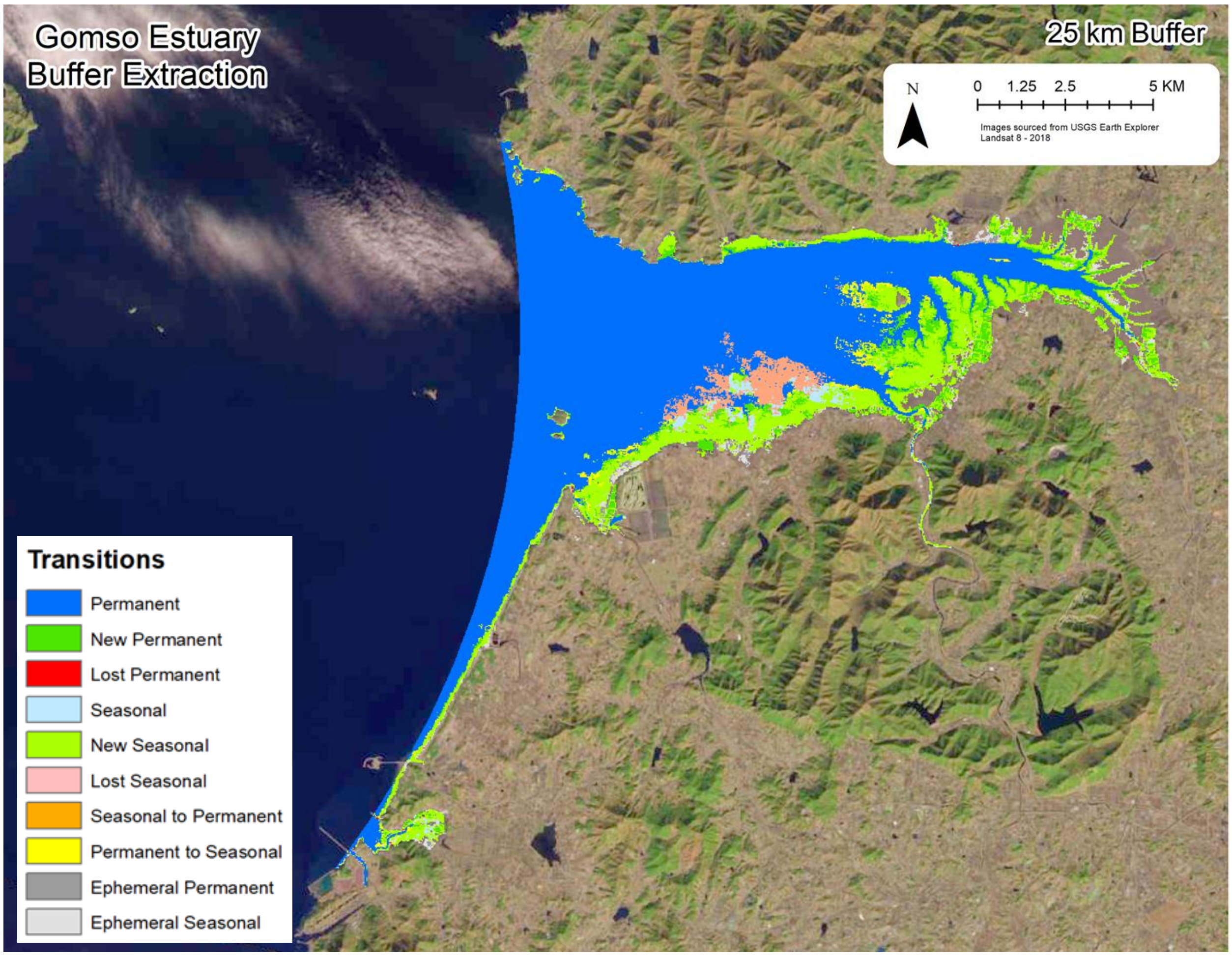


Geum Estuary
Buffer Extraction
25 km Buffer
N
0 2 4 8 KM
Images sourced from USGS Earth Explorer
Landsat 8 - 2018
Transitions
Permanent
New Permanent
Lost Permanent
Seasonal
New Seasonal
Lost Seasonal
Seasonal to Permanent
Permanent to Seasonal
Ephemeral Permanent
Ephemeral Seasonal



Geum Estuary
Buffer Extraction
5 km Buffer
N
0
2
4
8 KM
Images sourced from USGS Earth Explorer
Landsat 8 - 2018
Transitions
Permanent
New Permanent
Lost Permanent
Seasonal
New Seasonal
Lost Seasonal
Seasonal to Permanent
Permanent to Seasonal
Ephemeral Permanent
Ephemeral Seasonal


Geum Estuary
Buffer Extraction
2.5 km Buffer
N
0
2
4
8 KM
Images sourced from USGS Earth Explorer
Landsat 8 - 2018
Transitions
Permanent
New Permanent
Lost Permanent
Seasonal
New Seasonal
Lost Seasonal
Seasonal to Permanent
Permanent to Seasonal
Ephemeral Permanent
Ephemeral Seasonal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Buffer Extraction
25 km Buffer
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Images sourced from USGS Earth Explorer
Landsat 8 - 2018
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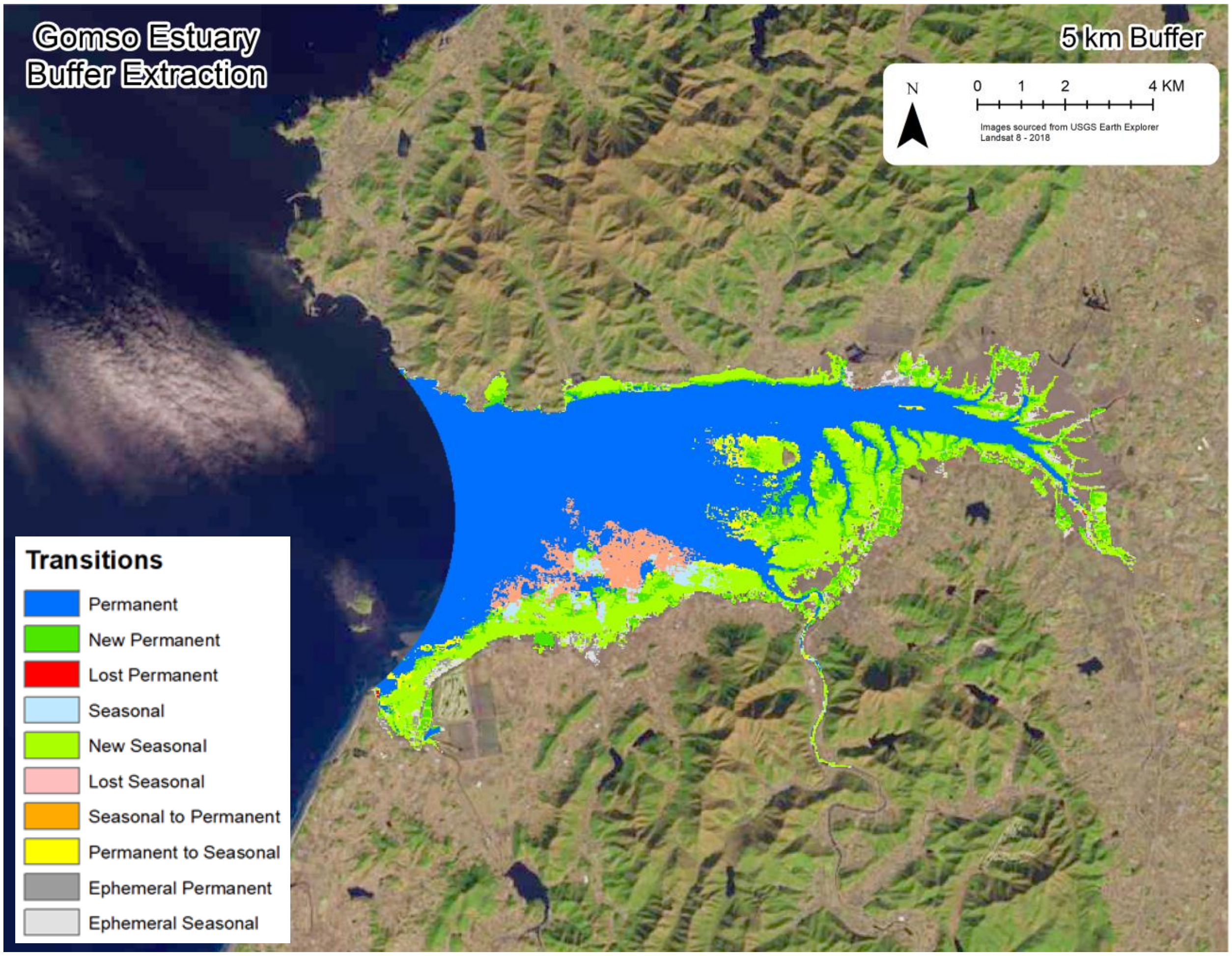
Lost Permanent
Seasonal
New Seasonal
Lost Seasonal
Seasonal to Permanent
Permanent to Seasonal
Ephemeral Permanent
Ephemeral Seasonal


Gomso Estuary
Buffer Extraction
5 km Buffer
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Images sourced from USGS Earth Explorer
Landsat 8 - 2018
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Lost Permanent
Seasonal
New Seasonal
Lost Seasonal
Seasonal to Permanent
Permanent to Seasonal
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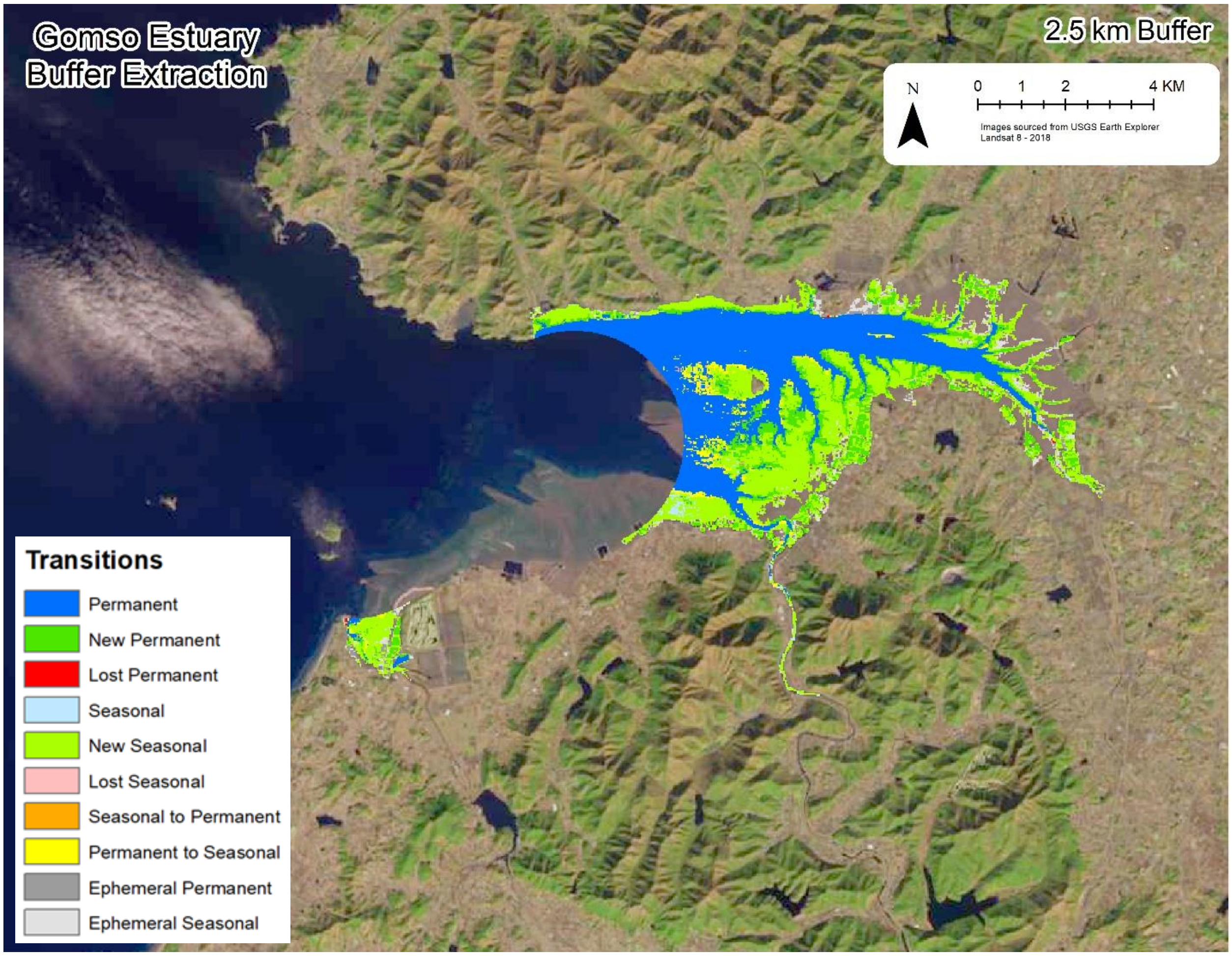
Ephemeral Seasonal


Gomso Estuary
Buffer Extraction
2.5 km Buffer
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Landsat 8 - 2018
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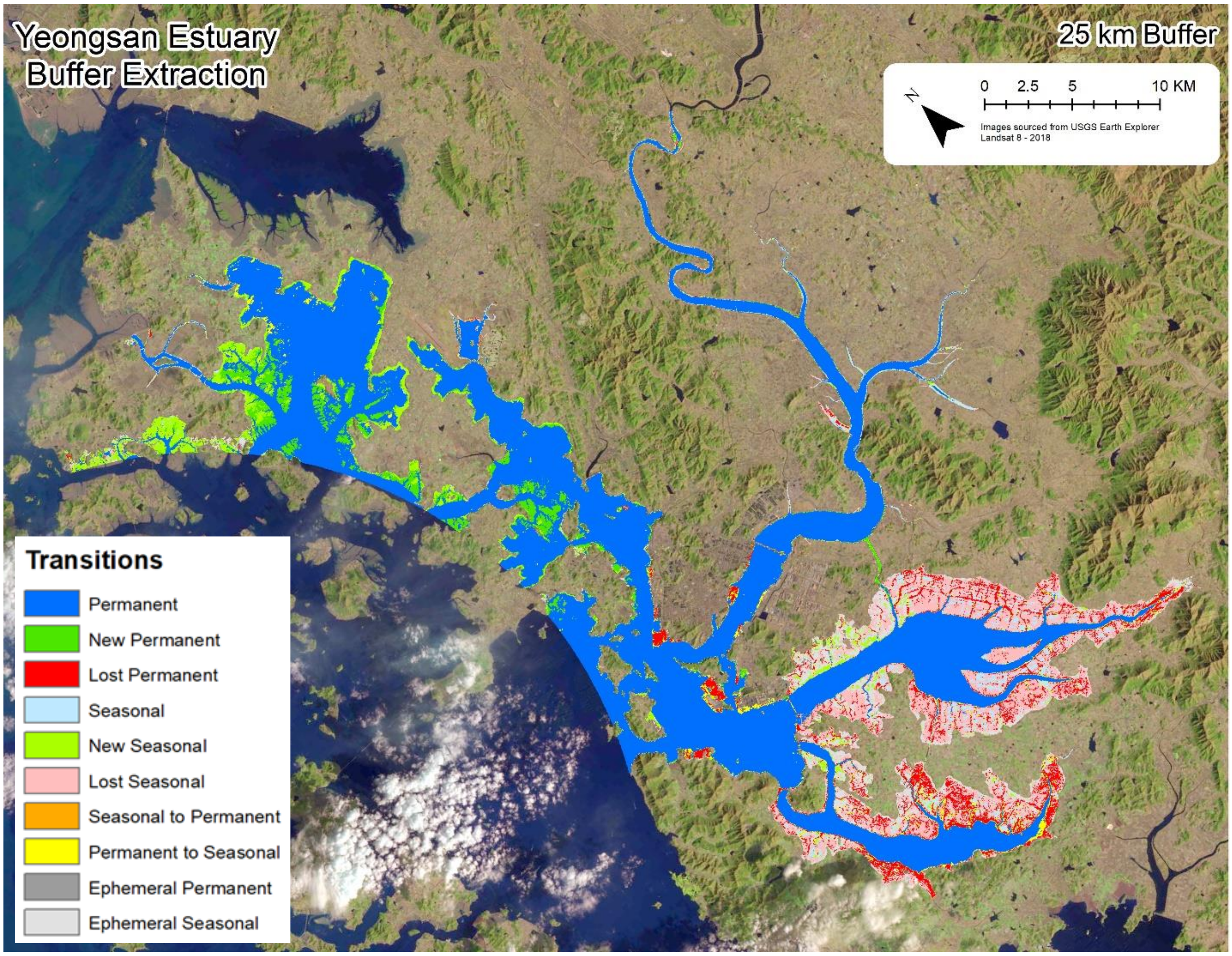
New Permanent
Lost Permanent
Seasonal
New Seasonal
Lost Seasonal
Seasonal to Permanent
Permanent to Seasonal
Ephemeral Permanent
Ephemeral Seasonal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Buffer Extraction
25 km Buffer
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Images sourced from USGS Earth Explorer
Landsat 8 - 2018
Transitions
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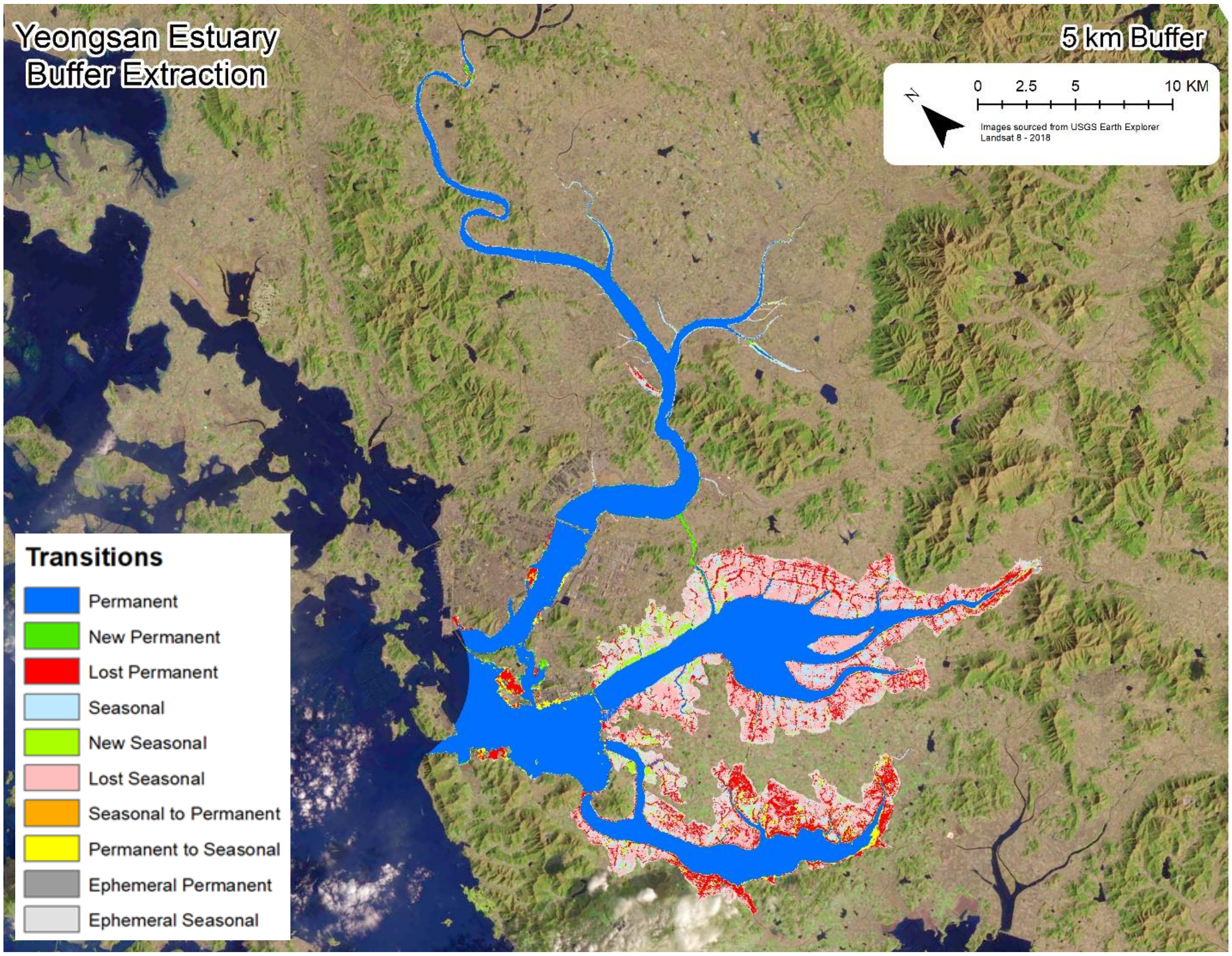
Lost Permanent
Seasonal
New Seasonal
Lost Seasonal
Seasonal to Permanent
Permanent to Seasonal
Ephemeral Permanent
Ephemeral Seasonal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Buffer Extraction
5 km Buffer
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Images sourced from USGS Earth Explorer
Landsat 8 - 2018
Transitions
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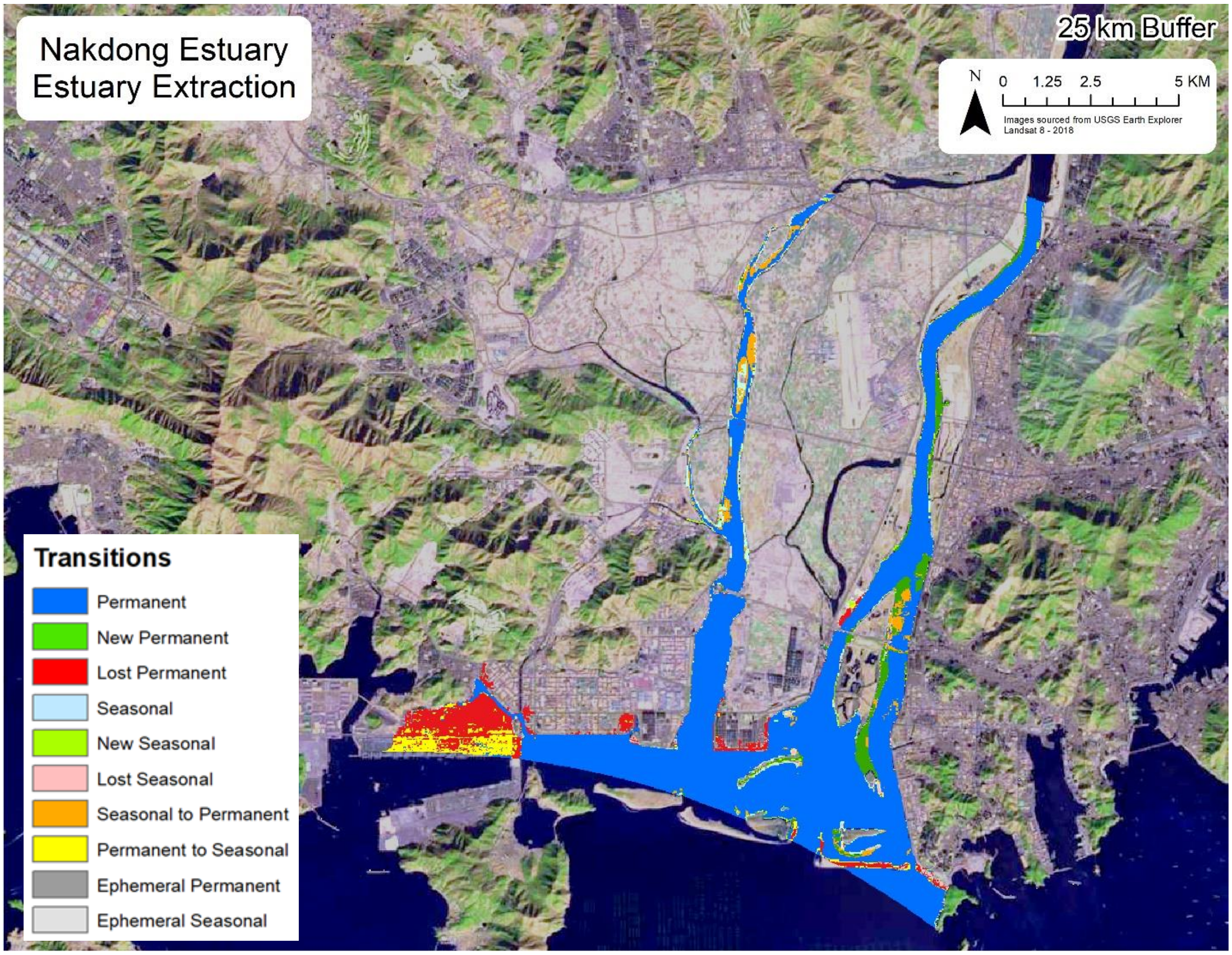
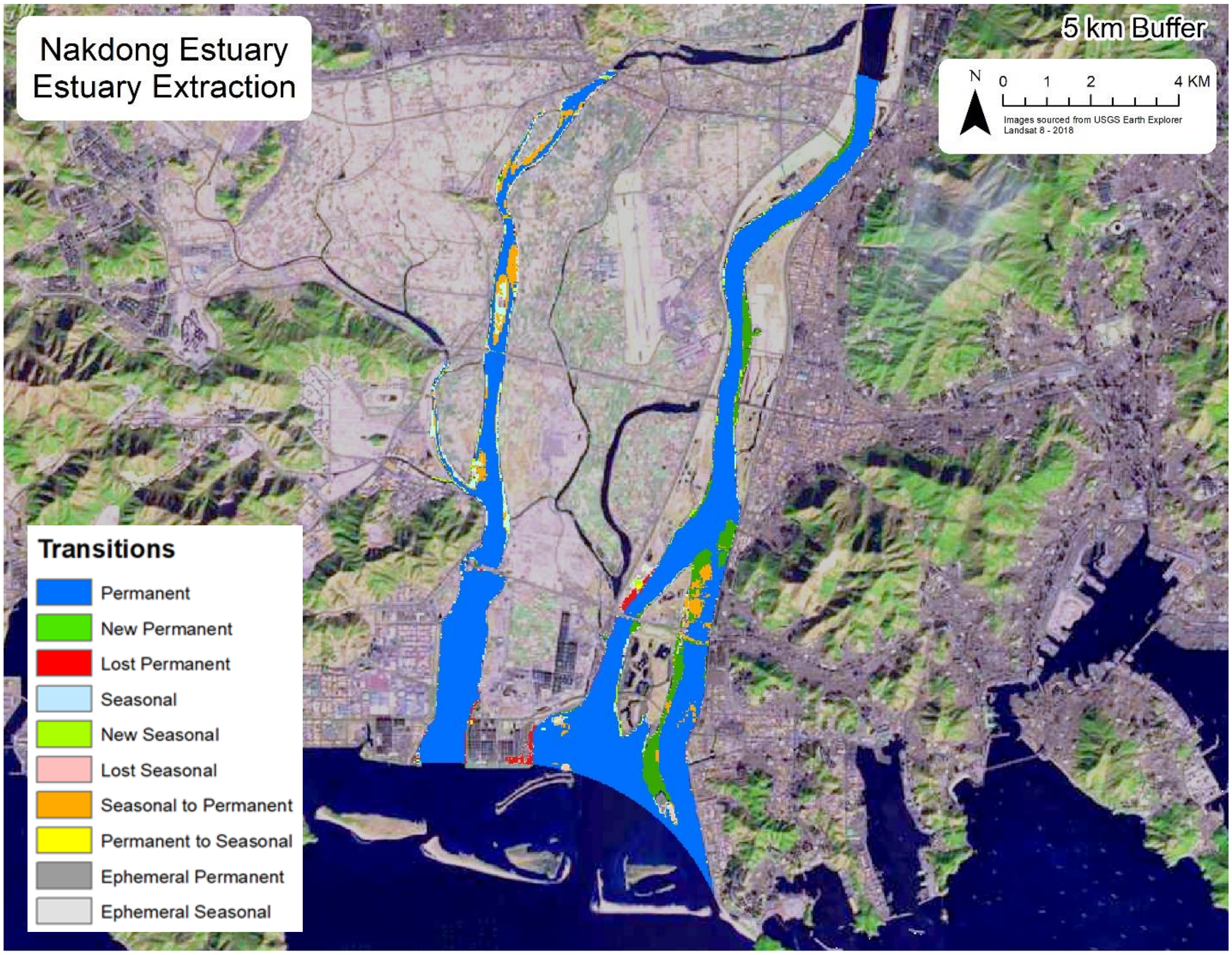
New Permanent
Lost Permanent
Seasonal
New Seasonal
Lost Seasonal
Seasonal to Permanent
Permanent to Seasonal
Ephemeral Permanent
Ephemeral Seasonal


Yeongsan Estuary
Buffer Extraction
2.5 km Buffer
N
0 2 4 8 KM
Images sourced from USGS Earth Explorer
Landsat 8 - 2018
Transitions
Permanent
New Permanent
Lost Permanent
Seasonal
New Seasonal
Lost Seasonal
Seasonal to Permanent
Permanent to Seasonal
Ephemeral Permanent
Ephemeral Seasonal



Nakdong Estuary
Estuary Extraction
25 km Buffer
N
0
1.25
2.5
5 KM
Images sourced from USGS Earth Explorer
Landsat 8 - 2018
Transitions
Permanent
New Permanent
Lost Permanent
Seasonal
New Seasonal
Lost Seasonal
Seasonal to Permanent
Permanent to Seasonal
Ephemeral Permanent
Ephemeral Seasonal


Nakdong Estuary
Estuary Extraction
5 km Buffer
N
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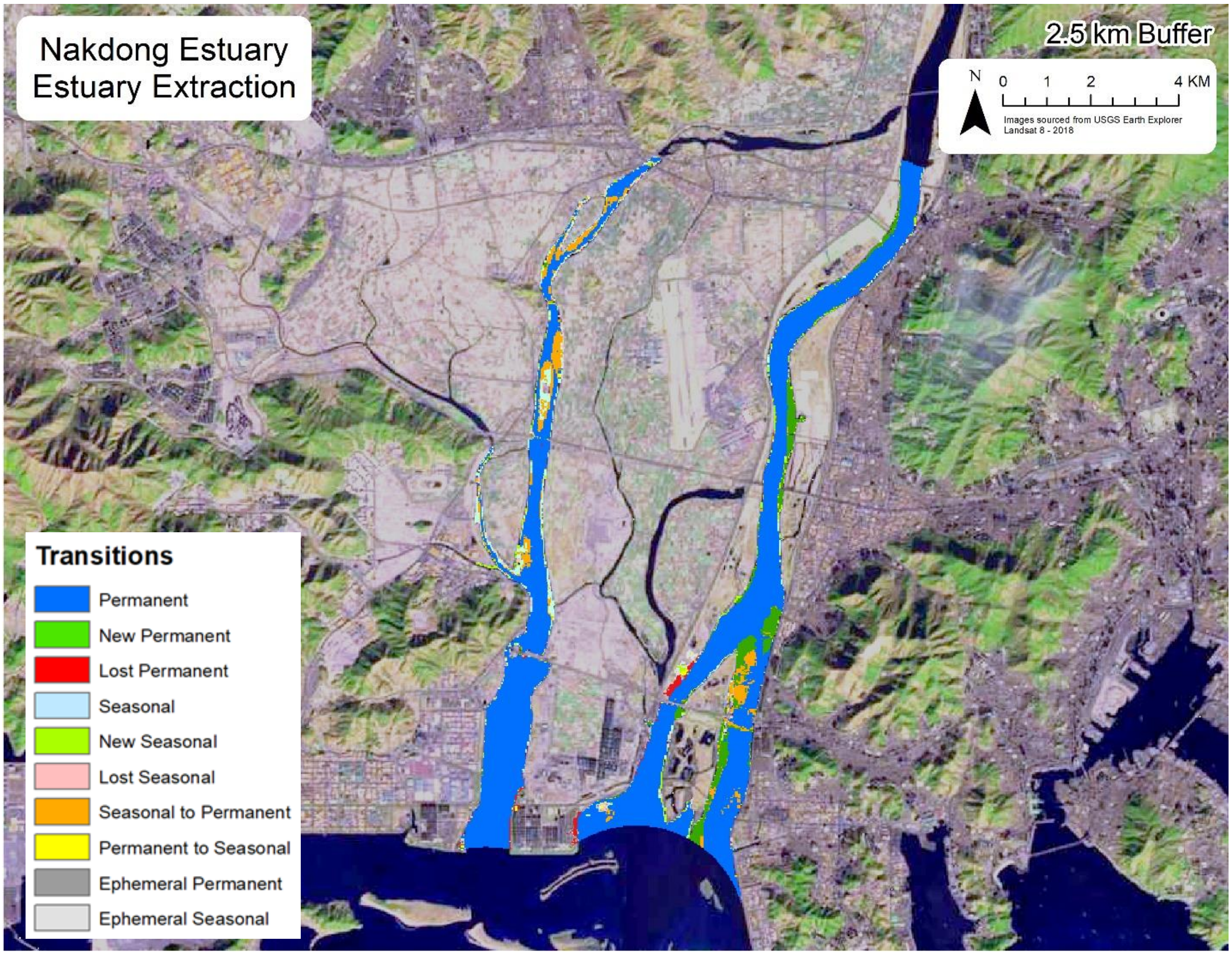
Images sourced from USGS Earth Explorer
Landsat 8 - 2018
Transitions
Permanent
New Permanent
Lost Permanent
Seasonal
New Seasonal
Lost Seasonal
Seasonal to Permanent
Permanent to Seasonal
Ephemeral Permanent
Ephemeral Seasonal


Nakdong Estuary
Estuary Extraction
2.5 km Buffer
N
0 1 2 4 KM
Images sourced from USGS Earth Explorer
Landsat 8 - 2018
Transitions
Permanent
New Permanent
Lost Permanent
Seasonal
New Seasonal
Lost Seasonal
Seasonal to Permanent
Permanent to Seasonal
Ephemeral Permanent
Ephemeral Seasonal

APPENDIX 12

25KM, 5KM, AND 2.5KM BUFFER EXTRACTION TABULAR DATA FOR EMBAYMENTS AND ESTUARIES IN CASE STUDY 1 THROUGH 5.

Asan Bay Buffer Attempts

Change Type	25km Estuaries			5km Estuaries			2.5km Estuaries		
	COUNT	Percent Cover	Area (km)	COUNT	Percent Cover	Area (km)	COUNT	Percent Cover	Area (km)
Permanent	542037	75.927%	377.950	201785	64.804%	141.412	173517	75.853%	121.593
New Permanent	2459	0.344%	1.715	1926	0.619%	1.350	1810	0.791%	1.268
Lost Permanent	64860	9.085%	45.225	36632	11.764%	25.672	12970	5.670%	9.089
Seasonal	25592	3.585%	17.845	17021	5.466%	11.928	12075	5.279%	8.462
New Seasonal	10609	1.486%	7.397	8462	2.718%	5.930	6955	3.040%	4.874
Lost Seasonal	38581	5.404%	26.902	26447	8.494%	18.534	10430	4.559%	7.309
Seasonal to Permanent	1157	0.162%	0.807	699	0.224%	0.490	655	0.286%	0.459
Permanent to Seasonal	19877	2.784%	13.860	13660	4.387%	9.573	8569	3.746%	6.005
Ephemeral Permanent	1820	0.255%	1.269	595	0.191%	0.417	162	0.071%	0.114
Ephemeral Seasonal	6900	0.967%	4.811	4151	1.333%	2.909	1611	0.704%	1.129
TOTAL COUNT/TOTAL AREA	713892		497.781	311378		218.215	228754		160.301
Loss of Surface Water	103441	14.490%	72.127	63079	20.258%	44.206	23400	10.229%	16.398
Gain of Surface Water	13068	1.831%	9.112	10388	3.336%	7.280	8765	3.832%	6.142
No Loss or Gain	588663	82.458%	410.462	233165	74.882%	163.403	194816	85.164%	136.518
Ephemeral Water	8720	1.221%	6.080	4746	1.524%	3.326	1773	0.775%	1.242

Geum Estuary Buffer Attempts

Change Type	25km Estuaries			5km Estuaries			2.5km Estuaries		
	COUNT	Percent Cover	Area (km)	COUNT	Percent Cover	Area (km)	COUNT	Percent Cover	Area (km)
Permanent	222484	83.857%	154.777	62932	78.676%	43.902	49672	80.863%	34.688
New Permanent	5223	1.969%	3.634	2983	3.729%	2.081	2519	4.101%	1.759
Lost Permanent	1987	0.749%	1.382	1579	1.974%	1.102	1449	2.359%	1.012
Seasonal	1714	0.646%	1.192	1561	1.952%	1.089	1491	2.427%	1.041
New Seasonal	19410	7.316%	13.503	4494	5.618%	3.135	986	1.605%	0.689
Lost Seasonal	1450	0.547%	1.009	956	1.195%	0.667	913	1.486%	0.638
Seasonal to Permanent	871	0.328%	0.606	850	1.063%	0.593	824	1.341%	0.575
Permanent to Seasonal	6118	2.306%	4.256	3553	4.442%	2.479	2781	4.527%	1.942
Ephemeral Permanent	1306	0.492%	0.909	285	0.356%	0.199	281	0.457%	0.196
Ephemeral Seasonal	4752	1.791%	3.306	796	0.995%	0.555	511	0.832%	0.357
TOTAL COUNT/TOTAL AREA	265315		184.573	79989		55.802	61427		42.897
Loss of Surface Water	3437	1.295%	2.391	2535	3.169%	1.768	2362	3.845%	1.649
Gain of Surface Water	24633	9.284%	17.137	7477	9.348%	5.216	3505	5.706%	2.448
No Loss or Gain	231187	87.137%	160.831	68896	86.132%	48.063	54768	89.159%	38.247
Ephemeral Water	6058	2.283%	4.214	1081	1.351%	0.754	792	1.289%	0.553

Gomso Bay Buffer Attempts

Change Type	25km Estuaries			5km Estuaries			2.5km Estuaries		
	COUNT	Percent Cover	Area (km)	COUNT	Percent Cover	Area (km)	COUNT	Percent Cover	Area (km)
Permanent	95941	67.507%	67.014	52803	55.651%	36.926	20189	41.503%	14.197
New Permanent	8091	5.693%	5.652	7694	8.109%	5.381	6387	13.130%	4.491
Lost Permanent	38	0.027%	0.027	25	0.026%	0.017	25	0.051%	0.018
Seasonal	2171	1.528%	1.516	1911	2.014%	1.336	514	1.057%	0.361
New Seasonal	25181	17.718%	17.589	22598	23.817%	15.803	17210	35.379%	12.102
Lost Seasonal	218	0.153%	0.152	135	0.142%	0.094	109	0.224%	0.077
Seasonal to Permanent	4327	3.045%	3.022	4317	4.550%	3.019	111	0.228%	0.078
Permanent to Seasonal	2512	1.768%	1.755	2139	2.254%	1.496	1614	3.318%	1.135
Ephemeral Permanent	884	0.622%	0.617	836	0.881%	0.585	569	1.170%	0.400
Ephemeral Seasonal	2758	1.941%	1.926	2425	2.556%	1.696	1917	3.941%	1.348
TOTAL COUNT/TOTAL AREA	142121		99.271	94883		66.354	48645		34.208
Loss of Surface Water	256	0.180%	0.179	160	0.169%	0.112	134	0.275%	0.094
Gain of Surface Water	33272	23.411%	23.240	30292	31.926%	21.184	23597	48.509%	16.594
No Loss or Gain	104951	73.846%	73.308	61170	64.469%	42.777	22428	46.105%	15.772
Ephemeral Water	3642	2.563%	2.544	3261	3.437%	2.280	2486	5.110%	1.748

Nakdong Estuary Buffer Attempts

Change Type	25km Estuaries			5km Estuaries			2.5km Estuaries		
	COUNT	Percent Cover	Area (km)	COUNT	Percent Cover	Area (km)	COUNT	Percent Cover	Area (km)
Permanent	59216	76.033%	41.460	32471	78.465%	22.829	27664	77.349%	19.486
New Permanent	3101	3.982%	2.171	2771	6.696%	1.948	2285	6.389%	1.610
Lost Permanent	6091	7.821%	4.265	460	1.112%	0.323	347	0.970%	0.244
Seasonal	1943	2.495%	1.360	1612	3.895%	1.133	1552	4.339%	1.093
New Seasonal	954	1.225%	0.668	736	1.779%	0.517	733	2.049%	0.516
Lost Seasonal	651	0.836%	0.456	476	1.150%	0.335	391	1.093%	0.275
Seasonal to Permanent	2642	3.392%	1.850	2389	5.773%	1.680	2343	6.551%	1.650
Permanent to Seasonal	2854	3.665%	1.998	155	0.375%	0.109	137	0.383%	0.097
Ephemeral Permanent	12	0.015%	0.008	10	0.024%	0.007	10	0.028%	0.007
Ephemeral Seasonal	418	0.537%	0.293	303	0.732%	0.213	303	0.847%	0.213
TOTAL COUNT/TOTAL AREA	77882		54.529	41383		29.094	35765		25.193
Loss of Surface Water	6742	8.657%	4.720	936	2.262%	0.658	738	2.063%	0.520
Gain of Surface Water	4055	5.207%	2.839	3507	8.474%	2.466	3018	8.438%	2.126
No Loss or Gain	66655	85.585%	46.668	36627	88.507%	25.751	31696	88.623%	22.327
Ephemeral Water	430	0.552%	0.301	313	0.756%	0.220	313	0.875%	0.220

Yeongsan Estuary Buffer Attempts

Change Type	25km Estuaries			5km Estuaries			2.5km Estuaries		
	COUNT	Percent Cover	Area (km)	COUNT	Percent Cover	Area (km)	COUNT	Percent Cover	Area (km)
Permanent	430401	61.386%	300.441	201139	49.899%	140.370	60054	82.609%	42.285
New Permanent	29323	4.182%	20.469	1421	0.353%	0.992	970	1.334%	0.683
Lost Permanent	41209	5.877%	28.766	40012	9.926%	27.923	964	1.326%	0.679
Seasonal	30283	4.319%	21.139	27679	6.867%	19.316	4794	6.594%	3.376
New Seasonal	36384	5.189%	25.398	8344	2.070%	5.823	2065	2.841%	1.454
Lost Seasonal	78409	11.183%	54.733	77318	19.181%	53.958	1400	1.926%	0.986
Seasonal to Permanent	1253	0.179%	0.875	673	0.167%	0.470	333	0.458%	0.234
Permanent to Seasonal	16885	2.408%	11.787	12766	3.167%	8.909	1497	2.059%	1.054
Ephemeral Permanent	1808	0.258%	1.262	1424	0.353%	0.994	19	0.026%	0.013
Ephemeral Seasonal	35178	5.017%	24.556	32320	8.018%	22.555	601	0.827%	0.423
TOTAL COUNT/TOTAL AREA	701133		489.426	403096		281.310	72697		51.187
Loss of Surface Water	119618	17.061%	83.499	117330	29.107%	81.881	2364	3.252%	1.665
Gain of Surface Water	65707	9.372%	45.867	9765	2.422%	6.815	3035	4.175%	2.137
No Loss or Gain	478822	68.293%	334.242	242257	60.099%	169.065	66678	91.720%	46.949
Ephemeral Water	36986	5.275%	25.818	33744	8.371%	23.549	620	0.853%	0.437