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The Biophysical Cross-shore Classification System (BCCS): Defining Coastal Ecological Sequences with Catena Codification to Classify Cross-shore Successions Based on Interpretation of Satellite Imagery

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ABSTRACT

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Coastal classification is a complicated endeavor due to the complexity of coasts and the application of special purpose characterizations for a wide range of tasks. The conundrum of coastal classification in general is also partly related to variable definitions and uses of common terms such as coast, coastline, shore, shoreline, and seashore. This research effort was not aimed at replacing extant systems but rather investigating the possibility of using the new Biophysical Cross-shore Classification System (BCCS) to define or classify cross-shore ecological successions in coastal belts based visual analytics and cognitive interpretation of satellite imagery. Approximately 200 coastal images from equatorial to polar regions showed that specific types of ecological successions were repetitive and could be organized by dominant characteristics. Certain ecological characterizations were so prominent and common that they became identified as Archetypes, which included Barrier, Beach, Beach Ridge, Cliff, Coral Reef, Delta, Dune, Flat, Ice, Lagoon, Mountain, Rock, Till (Glacial Material), Upland, and Wetland. When several archetypes are sequentially linked together based on the cross-shore ecological interpretation of the imagery, a generalized or idealized common master sequence is created and deemed the Dominant Catenary Sequence (DCS; *e.g.*, Beach-Dune-Wetland). The more detailed Coastal Ecological Sequence (CES) of a coastal belt, which is presented as a codification sequence, can be formulated by cognitively linking the Dominant Catenary Sequence with a numbered shore-parallel shape distinction and subscripted sub archetypes that further refine the archetypes present in the DCS. Overall, the BCCS was found to be an effective method for the classification of cross-shore ecological successions in coastal belts. Descriptive headers, extended captions, and Coastal Ecological Sequences are provided for randomly selected satellite images, with some examples shown in this paper.

ADDITIONAL INDEX WORDS: *Ecoregions, marine ecosystems, satellite imagery, coastal scene, image interpretation, ecological succession, catena, coastal ecology.*

INTRODUCTION

Serving as the interface between land and sea, coasts are some of the most complicated places on Earth. When viewed from multiple perspectives, coasts present an omnipresent set of complicated circumstances concerning their morphologies and modes of development. One problem associated with the comprehension of coasts lies in the fact that they are difficult to define. Even though coasts are a major feature of the Earth's surface, separating terrestrial from marine realms (coastal zones occupy about 20% of the Earth's land surface, extending up to 100 km inland by some definitions, *cf*. Burke *et al*. [2001]), the zones of separation may be sharp or diffuse, of high or low angle topographic slope, contain large or small elevational differentials, comprise mostly terrestrial or marine features, and so on. Coastal derivational development is sometimes clearly evident, whereas in other cases, in spite of efforts by the most sedulous researchers, it is mysteriously unclear what forces or processes were operational over variable time frames related to sea-level change, climatic variability, and ecological successions. And, in many cases, coastal morphological features are palimpsest with younger developmental features superimposed on top of older morphologies (*e.g.*, Bird, 2008; Davis, 1996; Woodroffe, 2002). This combination of young and old morphological features and materials occurring in the same coastal section or view often leads to overcomplexification that fosters problematic interpretations that become very convoluted or involved so that no simple rationale is evident. Common approaches to the characterization of complexly intertwined shapes, forms, and materials usually refer to only the dominant coastal characteristics in an effort to understandably simplify complex setups (*e.g.*, Bartley, Buddemeier, and Bennett, 2001; Batista, 2019; Bird, 2008; Davis, 1996; van Rijn, 1998; Woodroofe, 2002). Because dominance is a subjective inference in the eyes of the viewer, or may even be the result of prejudicial interpretations in favor of one point of view or another, coastal classifications tend to be special purpose orientations (*e.g.*, Cooper and McLaughlin, 1998). That is to say, the position of

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the viewer or researcher is not a matter of what is right or wrong (when or if that can be determined), but an attempt to logically deal with intensely complex shores that are imprinted with vestiges of prior land (terrestrial) forming with marine developmental episodes. Any particular coastal stretch thus represents a montage of defunct and ongoing processes that are spatiotemporal in context and palimpsest in view (see summary reviews by Fairbridge [2004] and Finkl [2004]). Coastal characterization therefore attempts to rationalize complexity into simplified constructs that can be comprehended in terms of mappable units (*e.g*., Bartley, Buddemeier and Bennett, 2001; Finkl and Makowski, 2010, 2019a,b; Finkl, Makowski, and Vollmer, 2014; Makowski, 2014; Makowski, Finkl, and Vollmer, 2015, 2016, 2017; Todd and Greene, 2007; Williams *et al*., 2019). There are many reasons for such efforts, but perhaps the most impelling is the need for an accurate inventory of spatiotemporal features that make up the world's coasts. Applications resulting from such efforts are almost endless but are of great value to scientific research and coastal management (*e.g*., Boyd, Dalrymple, and Zaitlin, 1984; Chust, *et al.,* 2008; Costello, 2009; Hayden, Ray, and Dolan, 1984; Kelletat, 1989, 1995; Kelletat, Scheffers, and May, 2013; Klee, 1999; Makowski and Finkl, 2016; Makowski, Finkl, and Vollmer, 2015, 2016, 2017; Makowski *et al*., 2009; Taramelli, Valentini, and Cornacchia, 2015; Vollmer, Finkl, and Makowski, 2015).

Despite hundreds of years of recorded observations, development of descriptive coastal terminologies and navigational terms, and established interpretations of coastal development and sea-level change, the definition of the term "coast" is not in a state of nescience nor is it apodictic, meaning that it remains rather enigmatic to this day. In many ways from a broad point of view, it seems almost absurd to consider that researchers have not properly dictated the best way to describe or characterize coasts, if there is such a thing. On the other hand, upon closer inspection it is not surprising that for the characterization of coasts there is no single system of classification, such as the Linnaean System (*e.g*., Carl Linnaeus, *Systema Naturae*, 1735), which provided the foundation for modern botanical and zoological nomenclature based on a hierarchical ranking classification and resulted in a taxonomic organization of plants and animals. One might wonder if coasts are more diverse than all the plants and animals on the planet? The answer to that query may lie in the fact that plants and animals are discrete units; no matter how many of them there might be, they can be organized according to rules that provide a basis for coherence among groupings. Coasts, in opposition, form a complex morphological continuum that lacks discretization or individuation.

Purpose and Goals

Due to the complexities of interpreting coasts, this study was conducted in an attempt to develop a useful characterization, or indeed an eventual kind of classification of coasts, that was based on a biophysical (geomorphological-ecological) perspective. The hypothesis of this research was that coasts could be characterized (classified) in terms of ecosystems under the aegis of satellite-image interpretation, based on a plethora of previous work (*e.g.,* Burke *et al*., 2001; Drakou *et al*., 2017; Finkl and Restrepo-Coupe, 2007; Finkl and Vollmer, 2011; Kelletat, 1989, 1995; Klemas, Bartlett, and Rogers, 1975; Klemas *et al*., 1993; Makowski, 2014; Makowski, Finkl, and Vollmer, 2015, 2016, 2017; Nayak, 2002; Patias *et al*., 2018; Poursanidis *et al*., 2019; Ramirez-Reyes *et al*., 2019; Scheffers, Scheffers, and Kelletat, 2012; Zhang *et al*., 2011). The original idea was to see whether a broad band or belt could somehow be rationalized into units or descriptors that were meaningful in an environmental-ecological sense by considering the physical (geomorphological) underpinnings of ecosystems while incorporating both into some kind of integrative terminology. Clearly, a methodology had to be devised for obtaining data and information concerning the sections of coast under consideration. In order for this data to be useful, it had to be representative of natural systems; for that reason, developed areas were eschewed. This study also had to be worldwide in perspective so that a wide geographic range of coasts could be included from equatorial to polar regions.

Such an attempt would previously have been very difficult if not impossible due to the lack of readily accessible information concerning remote coasts. Today, this obstacle has been removed by the advent of terrestrial- and marine-based broad scale classifications that can be used to provide a general backdrop to descriptions of coastal environments. Free access to such information is now made possible on the internet, and so it was decided to build on global systems that have been under development for the past several decades. Now more or less perfected and released to the public, these geospatial databases in map format enabled this study to move forward.

To this end, it was decided to attempt the development of a catholic procedure for describing coastal segments using existing electronic databanks combined with image interpretation. Together, it was hoped that this kind of combined effort would prove to be both useful and meaningful. In the beginning it was not certain that such an approach was even attemptable, but perusal of sample databanks and satellite imagery suggested the effort could begin. Key to this approach was the availability and accessibility of appropriate satellite imagery, which is the basis of this study. Global satellite coverage by Google Earth Pro allowed the use of approximately 200 images from around the world to develop a so-called "look see" approach. There are, however, many caveats to this tactic, and they are discussed in the "Methods" section.

Definitions and Terminology

Prior to conducting this study experiment, it was essential to define the set of terms being used to establish what exactly was being observed and described. This may sound rather simplistic; however, terminological bottlenecks abound, and it is necessary to define as carefully as possible what is meant by certain terms such as "shore," "coast," "shoreline," "coastline," "satellite scene," "remotely sensed imagery," *etc*.

As used in common vernaculars, coast is a general term that refers to the land next to the sea, as in seashore for the part of the land adjoining or near the sea. The boundary of a coast, where land meets water, is called the coastline (*e.g*., Bird, 2008; Carter, 1988; Davis, 1996; Klee, 1999; Masselink and Hughes, 2003; Short and Jackson, 2013; van Rijin, 1998). It refers to that narrow strip of land that borders the sea. Synonyms include terms such as "bank," "beach," "coastline," "seaboard," "shore," "shoreline," "littoral," "margin," "seacoast," "seashore," "seaside," and "strand." Without laboriously calling out citations for these kinds of definitions that are readily available online and throughout relevant literature, it is clear that in the broadest sense the term coast is a generic reference to the land next to the sea. More scientific or technical definitions, however, include water areas that are seaward of the coastline and typically subdivide the shoreface into morphodynamic units (*e.g.*, Benedet, Finkl, and Klein, 2006; Bird, 2008; Cowell and Thom, 1994; Finkl and Makowski, 2019a,b; Makowski, Finkl, and Vollmer, 2016; Masselink and Hughes, 2003; Short, 2006; Short and Woodroffe, 2009; van Rijn, 1998). By the same token, the terms shore or shoreline refer to the fringe of land at the edge of a large body of water, such as an ocean, sea, or lake. Again, colloquial emphasis is terrestrial, but technical sources prefer to include reference to offshore characteristics of the seafloor such as the shoreface. Numerous generalized and imprecise synonyms that are often applied in various fields of endeavor in reference to coast or shore include, for example, beach, coastline, seaboard, littoral, and seacoast. No attempt is made here to redact the vagueness of these terms because their historical usage has served the needs of the public and researchers in many diverse disciplines. The following section defines and suggests application of the term coastal belt when characterizing the coast in terms of natural (geomorphological) environments or ecosystems that can be interpreted from satellite scenes.

Concept of a Coastal Belt

For a long time, coastal classification efforts have suffered from a lack of nomenclature that fosters or enhances individuation of the world's shores. Plants and animals are discrete units that can be grouped according to various parameters, but to define coasts as natural bodies that exist conceptually (another example of this occurs in the definition of soils where the units classified must be natural bodies; *cf*. Finkl [2008] and Soil Survey Staff [1999]), the term coast is ill-defined to the point where it is not exactly clear what is to be classified. Initial classifications of natural features recognized as coast were either descriptive or genetic, or combinations of both precepts, whereas today the appreciation of ecological components are more common (*e.g.*, Burke *et al*., 2001; Carter, 1988; Cooper and McLaughlin, 1998; Costello, 2009; Dolan *et al*., 1972; Fairbridge, 2004; Finkl, 2004; Hayden, Ray, and Dolan, 1984; Klee, 1999; Klemas *et al*., 1993; Makowski *et al*., 2009; Zhang *et al*., 2011). Indeed, some aspects of coast were initially recognized in a biological context, such as mangrove coast, coastal marsh, or coral reef. However, biological features do not compose parts of all coasts, and so coastal classifications tend to emphasize environmental or physical aspects. Part of the problem stems from the concept or definition of what properly constitutes a coast. Recognizing this possible problem, many classifications were concerned with shorelines, *per se*, and resulting in shoreline classifications, whereas other researchers provided coastline classifications. These are specialized forms of classification and although of value for their special purposes, such as measuring shoreline change positions over time or attempting to determine shoreline lengths of beaches (globally or locally), they are not really taxonomical nor do they provide information in a cross-shore dimension. For example, classification of linear shore-parallel features is a one-dimensional (1D) view of a very complex system. A multidimensional consideration, on the other hand, includes cross-shore dimensions of offshore, nearshore, inshore, onshore, and back shore features intricately linked in a spatiotemporal dynamic that needs to be encompassed in a way to give an impression of a particular coast (*e.g.*, coastal segment) that has tripartite dimensions of length (alongshore), width (cross-shore distance inland), and depth/elevation (offshore bathymetry and onshore topography).

This idea is not new, having been foreshadowed more than a half century ago by previous workers who applied similar concepts and vernaculars (see discussions in Fairbridge [2004] and Finkl [2004]) where they recognized that for coastal classification to be useful in a universal context, it must classify more than the shoreline or coastline *per se*. That is, a coastal classification system must apply to a zone, not a line, and allow for across-the-shore variation and along-the-shore extent, similar to what Dolan *et al*. (1972) referred to as the orthogonal approach. Lind (1969) earlier posited a similar approach by defining coastal profile types where cross-shore profiles were given alongshore distributive properties so that diabathic sequences were parabathically linked. It has thus been recognized for some time that in order to allow for the complexity of antecedence (inheritance) in coastal landforms, a classification system needs to consider a swath of certain dimension along the shore and not just the length and width of a particular landform or ecosystem. Because most coasts are, to varying degrees, polygenetic and multicyclic over a range of time frames, cross-shore classifications need to consider rather broad areal extents both above and below present sea level. This approach is necessary when questions arise as to which shoreline (1D) feature is being classified and to which spatiotemporal coast does it belong? Further, to comprehend the contemporary coast with its multicyclic elements, it is necessary to understand the relevance or impacts of the hinterland on the present coastal scene. In this vein of thought, McGill (1958) referred to the area or zone that should be classified as the coastal fringe, a swath along the coast that extends for several kilometers on either side of the shoreline to include subaerial and submarine features.

Understanding these prior observations, it seems that in the most logical administrative sense, coasts are perhaps best thought of in terms of zones rather than lines (*i.e.* shoreline, coastline). The term "coastal zone" is useful but mostly as a referential term in managerial strategies by administrative personnel, such as in coastal zone management. Avoiding legalities and administrative venues, the term can have more scientific applications when applied to geological and biological perspectives of the type seen in the classification of coastal features, as defined by geomorphological and ecological aspects (*e.g.*, Bailey, 1998; Bartley, Buddemeier, and Bennett, 2001; Fairbridge, 2004; Finkl, 2004; Finkl and Restrepo-Coupe, 2007; Kelletat, 1989, 1995; Kelletat, Scheffers, and May, 2013; Klemas *et al*., 1993; Makowski, Finkl, and Vollmer, 2015, 2016, 2017; Short, 2006; Short and Woodroffe, 2009; Woodroffe, 2002). To this end, terms such as "fringe," "belt," "band," or "reach" better convey the notion of width versus length or area, as in the case of the term zone. All of these annotative terms, albeit subjective, are nevertheless useful in different contexts. The impetus here is to suggest verbiage that implies at the same time length and width, such as would occur in the metaphor of a belt, which in common parlance as a homograph or homonym has different meanings and sounds, which is the same when used as a verb or noun. The idea being put forth here is to contextualize the term belt as a noun in a coastal framework to mean, in general, an area characterized by some distinctive feature and more specifically an elongated region having particular properties or characteristics that are described not only along the shore but also across the shore as part and parcel of one vernacular. This concept of a 2D or 3D coastal belt has several advantages over a one-dimensional line, as in shoreline or coastline, but is still plagued by lack of vigor when attempting to describe its width in a definitive sense. The concept of a coastal belt is a definitive extension of what Kelletat (1989, 1995) refers to as coastal zonation or zonality in reference to biophysical features, as demonstrated by Kelletat, Scheffers, and May (2013) and Scheffers, Scheffers, and Kelletat (2012) using Google satellite imagery.

Landward and Seaward Extents of a Coastal Belt

This problem can be illustrated in a couple examples of common coastal types using cliffs and mangroves. A coastal cliff in a broad sense approximates the line concept because the face of the cliff may be imagined to represent a nearly vertical plane that extends alongshore (from the shoreline to some indefinite distance skyward) and that has very limited width. Mangrove forests and swamps, such as the Bay of Bengal Sunderbans (in India and Bangladesh) with their associated tropical marshlands and tidal lakes or ponds, extend landward for variable distances primarily depending on tidal range, slope of the land, degree of fluvial input in terms of suspended sediment concentration, fluvial freshwater flood cycles, *etc*. In this case, the coastal belt extends many kilometers landward, emphasizing the need to consider the width or extent of inland penetration of a feature that is part of the coastal biophysical system. From these two oversimplified examples, which were deliberately chosen to emphasize a point, it is evident that the landward boundary of a coastal feature's inland extent is extremely variable. This means the width of any particular coastal belt will be different from another and depends on the nature or characteristic of the coastal feature itself.

Both coastal length and width are scale dependent because the parameterization of length is plagued by fractals (*e.g.*, Mandelbrot, 1967); therefore, iterating patterns will increase shoreline length with increasing (more detailed) scale. Width has a rubber band effect (*i.e*. produces an irregular landward limit of the coastal belt) depending on the landward extent of the selected coastal feature. An alternative to dealing with the rubber band effect is to choose a uniform distance inland from the shore. The term coastal also includes some indeterminate distance offshore, depending on the seaward extent of the biophysical feature being considered. Coral reefs are perhaps the most obvious feature in this regard where they may occur great distances offshore, as in the case of the Great Barrier Reef in Australia, parts of which lie more than 200 km offshore of Queensland. And, of course, there are administrative determinations of what constitutes coastal waters, where a country's sovereign territorial waters can extend to 12 nautical miles (nmi, or 22 km) beyond the shore versus a state's exclusive economic zone(EEZ), which can start at the seaward edge of its territorial sea and extend outward to a distance of 200 nmi.

The Generic Coastal Belt

Even though the term coast is entrenched in the vernacular and literature, the complication that ensues perhaps justifies the selection of a new or different term with a more precise definition. Therefore, use of the term is thus appropriate, but cognizance of the best definitional approach is required. There are, for example, complications of definitions that are either oversimplified or too complex. A risk of puerility in a simple definition can occur, for example, where coast is defined as a belt of specified width regardless of variations at the land-sea boundary. Conversely, a complicated definition of coastal belt that takes into account a multitude of variations may lead to an unmanageable gallimaufry of gross proportions. The concept of a coastal belt is thus useful as long as it is understood that the width of the swath along- and cross-shore is variable, depending on the nature of the biophysical features being studied.

Studies of coastal biophysical features and environments (*e.g*., habitats, ecosystems; Bailey, 1998; Burke *et al*., 2001; Dolan *et al*., 1972; Hayden, Ray, and Dolan, 1984; Isla, 2009; Klemas *et al*., 1993; Wang *et al*., 2015; Zhang *et al*., 2011), which are of primary interest and concern to coastal researchers, require onshore and offshore data to make up the composition of a coastal belt. This is an essential requirement of coastal belt maps and must be presented in some way that is both useful and expedient. Coastal information can be acquired from original research surveys or assimilated from existing sources, both terrestrial and marine. A range of coastal maps are available from various agencies, and coastal belts may be identified on them depending on the specific purpose in mind, including the symbology (*e.g*., Finkl, 1988). Hard copy (paper) maps come in a range of scales that is fixed by the mapping agencies. With the advent of electronic maps, some of these limitations were overcome, but the user is limited to the information provided by the mapping agency. Electronic navigational charts, for example, provide good bathymetric data, but there is a dearth of terrestrial information as that is not relevant to the charts. Topographic maps, on the other hand, provide good land-based information but, as a general rule, lack offshore bathymetric information. A partial solution to the conundrum of precisely defining boundary conditions of the coast *via* original research is offered in the form of aerial photographs or satellite imagery, where features, conditions, and/or environments may be interpreted. Aerial photographs are good for detailed work, but satellite imagery, particularly that provided by Google Earth Pro, can be available in myriametric scales simply by zooming in or out of a selected scene. An additional advantage of Google Earth Pro satellite imagery is global coverage of the world's coasts (see the example of Scheffers, Scheffers, and Kelletat [2012]), providing an invaluable data source that can be interpreted for purposes of coastal research at virtually any desired scale (depending on the resolution of the imagery).

Set and Setting of the Coastal Belt

This extended introduction provides a prodrome in an effort to establish the set and setting for a new procedure to elucidate coastal environments in the broad framework of coastal classification. The term "set" is used here in reference to the purpose or mood (orientation) of the researcher wishing to characterize coastal environments, whereas "setting" refers to the geographical perspective of a particular scene in a satellite image. The term "environment" can mean many different things; consequently, it is necessary to hone its usage to specific systems or categorizations that provide a uniform reference system. The advantage of referencing an environmental classification system or regionalization that has already been devised (*e.g*., Bailey, 1998; Burke *et al*., 2001; Dolan *et al*., 1972; Hayden, Ray, and Dolan, 1984; Klemas *et al*., 1993; Sherman, Aquarone, and Adams, 2009; Zhang *et al*., 2011) is that it can be applied to terrestrial and marine portions of a satellite image to help describe the extant environments in the scene. Because of the dual nature of the coast, land- and marine-based systems need to be accessed and merged to provide a cohesive description of the coastal belt that is being observed. Fortunately, there are many options when it comes to selecting established classifications of environments. Perusal of interactive online systems suggests that platforms exist for geographical or locational purposes (*e.g*., World Map - Google My Maps), geology (Macrostrat Geologic Map; Peters, Husson, and Czaplewski, 2018), ecoregions (*e.g*., Ecoregions 2017 – Resolve; Dinerstein *et al*., 2017), marine ecosystems (*i.e*. Large Marine Ecosystems) (*e.g*., Sherman, Aquarone, and Adams, 2009), and climate (*e.g*., Köppen-Geiger Climate Type Map of the World; Kottek *et al*., 2006; Peel, Finlayson, and McMahon, 2007). World Map (2019) uses similar base maps, as seen on the other platforms, and thus provides easy access to locational data that is required for description of satellite scenes. Macrostrat's geologic map is a seamless integration of over 200 geologic maps from around the world and at numerous scales that have been homogenized into a single database. Ecoregions 2017 displays units on the same type of Google map providing comfortable compatibility of use. The Large Marine Ecosystem (LME) maps also conform to World Map for easy use. The Köppen-Geiger climates can be incorporated as a layer in Google Earth Pro, making for ready comparison with satellite scenes. All of these platforms work well together, and some are complementary by containing interdigital information, as in the example of the Macrostrat Geologic Map that also contains ecoregions in a drop-down menu. Use of these resources provides an ideal mechanism for characterizing any particular coastal belt that is selected from Google Earth Pro imagery. Assembly of this information provides enough essential data to characterize a coastal belt in broad terms before detailed analyses are conducted for specific purposes, such as the description of coastal environments explained in this paper.

METHODS

With all of this data at hand, it is a relatively simple procedure to identify and describe the biophysical environments within a coastal satellite scene; however, some scaler issues need to be taken into account because most scenes will typically be spatially smaller (larger scale) than the units displayed on these interactive maps. Study of the various mapping unit descriptions is thus necessary to determine the degree of variability, which usually represents only a small portion of the large unit's variable context. Contextual information is critical to the proper interpretation of what is shown in the satellite scene versus the range of characteristics included in the small-scale (large area) ecological mapping units. The same cognitive skill sets used for aerial photo-interpretation can be applied to satellite imagery, allowing for more detailed analysis than what can be provided by the broad scale interactive online maps (*e.g*., Finkl and Makowski, 2015, 2019a,b; Makowski, 2014; Makowski, Finkl, and Vollmer, 2015, 2016, 2017). This means that collateral data could or should be accessed *via* online searches of the local area. Online search engines can be used, such as Google Scholar, BASE (Bielefeld Academic Search Engine), Mendeley, Scirus, JURN, *etc*. Searching with these engines often produces scientific and/or technical papers that are useful for interpretation of certain aspects of the satellite scene at hand. Searches of websites associated with tourism can provide valuable information related to specific aspects of the local environment; however, this effort can be tedious, and there is a risk of incorrect information stemming from amateurs or promotors trying to entice tourists to their location. It is a case of searchers beware because spurious information abounds on many touristic websites. Experience is thus essential to the development of interpretive skills and should be relied upon when encountering conflicting data.

The background procedural steps to building a biophysical characterization of a coastal belt entail an organized approach to best facilitate compilation of essential information. The suggested basic steps are as follows: (1) select a desired coastal scene using Google Earth Pro, (2) use World Map to determine primary locational features, (3) discern the geological and geomorphological features in the area from the Macrostrat map, (4) ascertain ecoregions from a drop-down menu in Macrostrat or determine separately by reference to the global map (Ecoregions 2017), (5) access the regional climate using the Köppen-Geiger climate layer in Google Earth Pro, and finally (6) determine the marine ecosystem fronting the scene by referencing the Large Marine Ecosystems (LME) maps (Sherman, Aquarone, and Adams, 2009). Completion of these steps provides a wealth of biophysical information for the selected coastal belt. Because of the large-scale (small area) of the satellite image, its footprint will occupy only a small part of these macroscale units, emphasizing that the scene is a small sample of larger environmental units or ecological systems.

A good way to inform the user or reader of the report being generated is to provide a header to the image that summarizes essential information in a succinct manner. The value of doing so provides a quick overview of the coastal belt and allows the reader to visually conceptualize the satellite scene. A typical header would normally follow this sequence of informational flow: (1) Terrestrial Biogeographic Realm and Biome; (2) Ecoregion (with a corresponding reference number); (3) Large Marine Ecosystem (with a corresponding reference number);

(4) Planview (or Oblique View); (5) Shoreline; (6) Environments and Habitats; (7) Dominant Catenary Sequence; and finally, the (8) Coastal Ecological Sequence (with translation).

Assembly and Presentation of Image Header Information

An example of this procedure is given in the example of a tropical coastal wetland in the Stann Creek District of SE Belize, where Figure 1 gives the location of the satellite image and Figure 2 provides the actual image along with additional relevant information. This coastal belt segment, which falls under the Neotropic Mangroves Terrestrial Biogeographic Realm and Biome, is a fairly complex representation because it shows several ecotonal successions, from tidal mudbanks and flats (on the shore and inland) to wetland mangrove forests, marshes, and swamps. The ecoregion name is followed by a number that corresponds to the Ecoregions 2017 global map. This provides a simple and precise identification of the unit in question, as in this case with Mesoamerican Gulf-Caribbean Mangroves Ecoregion (613). The Caribbean Sea Large Marine Ecosystem (12) is next identified from the LME maps (Sherman, Aquarone, and Adams, 2009). The climate could be added at this stage if desired, but it is normally included in the caption below the image. This information is an example of what can be gleaned from existing data that can be abstracted from online data sources, as described previously.

The remainder of the header information is the result of cognitive image interpretation procedures that define the following categories: Planview (or Oblique View), Shoreline, Environments and Habitats, Dominant Catenary Sequence, and finally the Coastal Ecological Sequence with a translation.

Planview or Oblique View

The "Planview" or "Oblique View" category is meant to provide a quick bird's eye impression of the whole coastal belt shown in the scene. Some images, such as those that contain cliffs, can best be interpreted from oblique views as opposed to views looking straight down. Thus, oblique images are included in this general categorization of the coastal belt. The intent of the Planview/Oblique View category is to give the simplest possible, yet accurate, impression of what the image is showing. In this way, the reader can peruse the general coastal scene without undue introspection. The Planview example from the selected Belizean coastal belt ensues as follows: Tidal flats with a mangrove forested coastal fringe and water courses with lagoons and lakes. This is an overall general impression of the scene.

Shoreline

The Planview/Oblique View information is followed by the "Shoreline" category. This description is provided to characterize the shoreline *per se* and is not meant to be a general coastal descriptor. It is specific and in reference to the shoreline only. It is included to emphasize the difference between shoreline and coastal belt environments or ecological systems. The inclusion of the shoreline descriptor is to avoid confusion with the general characterization of the coast, or coastal belt, as is emphasized here. Referring back to the Belizean coastal belt in Figure 2, the shoreline is described simply as muddy.

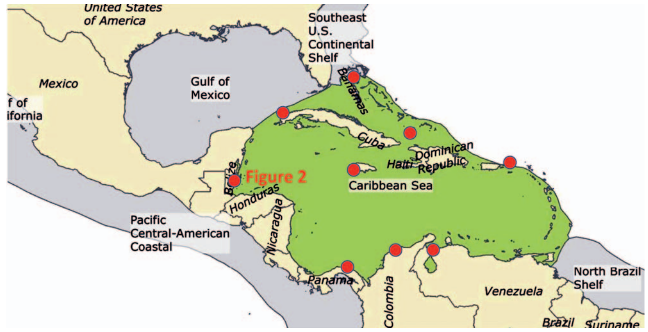


Figure 1. Location of the satellite image in Figure 2 in relation to the Caribbean Sea Large Marine Ecosystem (shown in green). Figure 2 provides an example of a Flat-Wetland cross-shore ecological sequence for a coastal belt in Belize, Central America, while the other red circles show the locations of other satellite images included in the master data set listed in Appendix I (available at www.JCRonline.org). (Figure adapted from: Sherman, Aquarone, and Adams, 2009.)

Environments and Habitats

The "Environments and Habitats" category is a catch-all summation of all obvious macroscale units that can be interpreted from the scene. A rather large number of units may be shown in any particular scene because coastal belts can be complicated by complex ecological zoning. Some ecological units may occupy a large proportion of a coastal belt shown in the satellite image, but often a scene typically contains several types of environments. No effort is made here to differentiate the terms "environment" and "habitat" because they are used more or less interchangeably in a general sense, with the term "niche" being avoided because of its greater specificity, as discussed by Kearney (2006). This convention is applied for ease of use and general comprehension of what facets comprise the ecological systems, as depicted in the scene. In the Belizean example (Figure 2), the Environments and Habitats category is described as follows: muddy mangrove forest and swamp habitats, coastal woodlands and drainage ways, lake and lagoon environments, saline flat habitats, and bare to sparsely vegetated ground surface environments.

Dominant Catenary Sequences versus Coastal Ecological Sequences

Completion of the foregoing categories in an organized template format provides a reliable overview of the biophysical situations that characterize the coastal belt shown in the satellite image. Considerations of aspects of terrestrial biographic realms and biomes, ecoregions, large marine ecosystems, shoreline types, and environments and habitats, as summarized in the caption header (*cf*. Figures 2, 4, and 6), provide a jump start to the systematization and organization of features within coastal belts.

One of the last steps in the development of summary image headers is the creation of a cross-shore transect that provides a statement of biophysical features and ecological systems in terms of a catena codification. By doing so, the major types of environments and habitats that occur sequentially can be identified as a cross-shore sequence. The main biophysical features are referred to as 'Archetypes' as, for example, in the case of Barrier, Beach, Beach Ridge, Cliff, Coral Reef, Delta, Dune, Flat, Ice, Lagoon, Mountain, Rock, Till, Upland, and Wetland. When concatenations (sequences of Archetypes) are systematically linked together based on the ecological interpretation of the imagery, a Dominant Catenary Sequence (DCS) is created. The DCS is useful for small-scale (large area) studies of coastal belts. An example of a DCS can be shown in the coastal belt image from Belize (Figure 2), where the concatenation was interpreted as: Flat-Wetland.

A more refined end product of the classification of coastal belts comes in the form of the Coastal Ecological Sequence (CES). The CES builds on the DCS by adding a numbered shore-parallel configuration (*i.e.* a shape in planview) and sub archetype alpha subscripts. The sub archetypes are subdivisions or specifications of the Archetypes, which offer a more refined interpretation of the ecosystem. The CES, which is usually well-suited for large-scale (small area) coastal belts, is shown as a codification sequence with an accompanying table legend (*e.g.*, Table 1) and translation. An example of a CES from Figure 2 is presented as: $2F_{mu}W_{ma,mr,sw}$. The translation for this CES is based on the legend provided in Table 1: Curved tropical tidal flats backed by wetland mangroves, marshes, and swamps.

Examples of Coastal Ecological Sequences (CES) based on this study's 200-image dataset are shown in Appendix I (available at www.JCRonline.org). The development of a CES is the ultimate goal or purpose of the Biophysical Cross-shore Classification System (BCCS) procedure for coastal belt characterization and should be clearly demarcated by the interpreted biophysical feature's location; size; shape; shadow; tone/color; texture; pattern; height/depth; and site, situation, or association. However, some coastal scenes present complicated spatial distributions of ecological units; in those cases, it is suggested to place a line (not necessarily a straight line) on the image showing where the cross-shore transect is being described. The transect should be initiated some distance offshore, the distance being determined by the nature of marine features, and then proceed cross-shore to some point inland that is likewise determined by the nature of the biophysical features or the edge of the image frame. Examples of such a line are presented as red arrows on Figures 2, 4, and 6.

Captions for Satellite Image Scene Coastal Belts

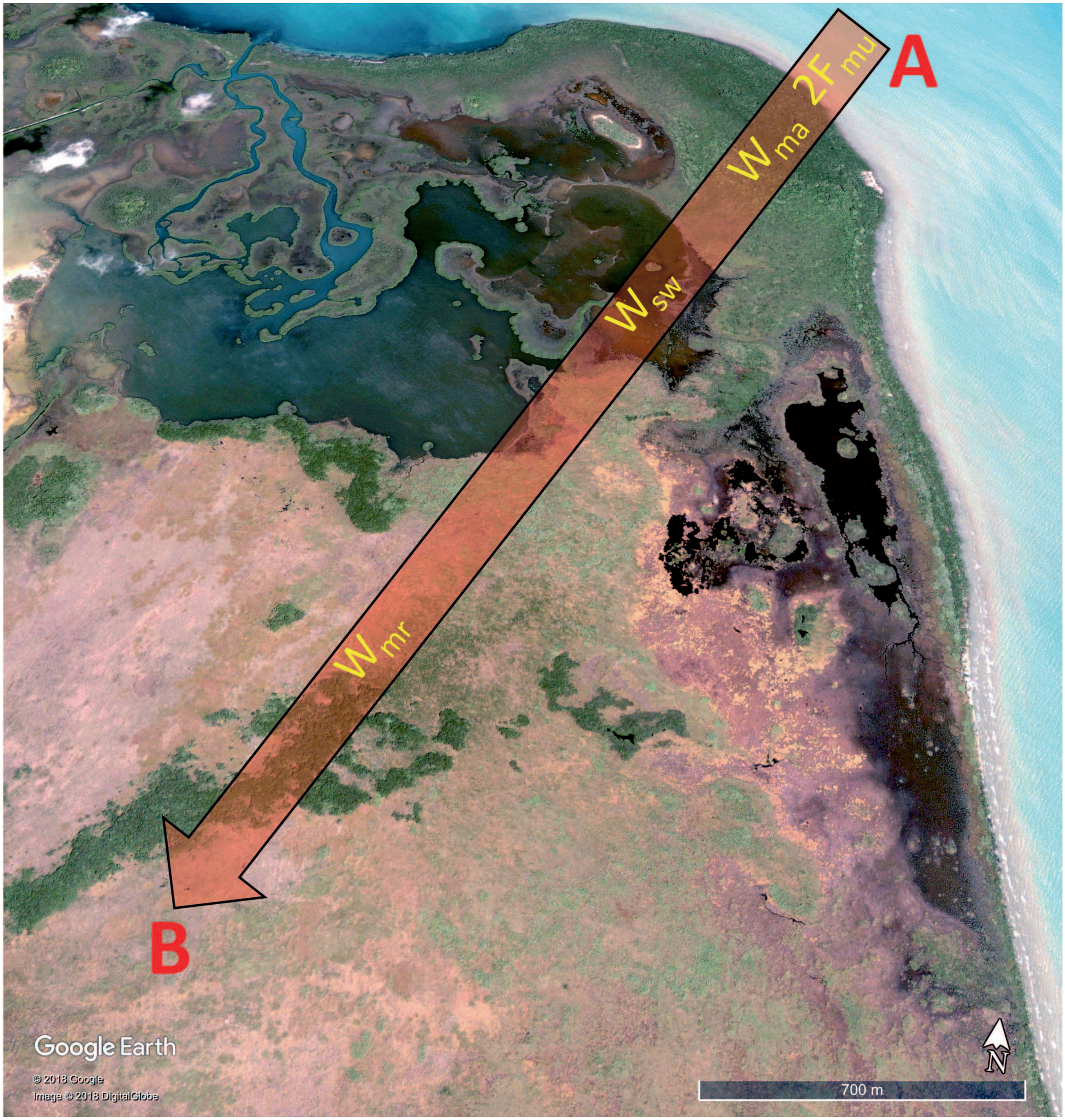
The template format provided in this paper dictates that the image header is followed by the satellite image scene, designated as a figure, which in turn is followed by an extended caption that provides additional information. This extended caption to the figure, part of which is abstracted from interactive online sources and part is the result of cognitive image interpretation procedures, thus follows a specific design that provides the same kind of information flow from one satellite image to the next. Organization of the caption in this way facilitates the location of specialized information and supports easy comparisons and contrasts between images, which is very useful when utilizing numerous images, as would normally be the case in the study and investigation of coastal belts whether on a global, epicontinental, regional, or local level. All captions begin with a general identification of what the image shows and where it is located in terms of geographic coordinates (*e.g.*, latitude and longitude in degrees, minutes, seconds) and in reference to some geographical features, infrastructure, or human settlements. Comments are then provided for the main biophysical features that make up or characterize the scene and usually include remarks about vegetation, landforms, water features, *etc.,* to understand anything unusual or of interest. Then, specific statements about geology are interjected, as abstracted or summarized from Macrostrat, and observed (and interpreted) by the analyst. Recognition of macroclimate culminates the first paragraph, placing the comments within the confines of a definitive geographical context or zonation.

Subsequent paragraphs focus on the procedures for describing the ecology of the coastal belt that has been previously identified within a physical context where geospatial locations, geology, geomorphology, hydrology, pedology, and climate define the foundational parameters upon which ecological successions are built. Ecosystems are then briefly identified and noted with common and scientific names. Next comes a brief listing of flora and fauna that are characteristic of the area and help to define its uniqueness *via* combination of all the other factors.

Compilation of captions requires time and effort, as information for remote areas may be scarce and hard to come by using online search techniques. Nevertheless, the effort is feasible, and with a little practice, researchers become adept at obtaining information that is useful and relevant to the scene depicting part of a coastal belt. Figures 2, 4, and 6 are offered as procedural examples of how the 200 satellite images were formatted in the generic template. Provision of the same kind of information in the same sequence was followed because this methodology facilitates rapid comprehension of the main biophysical features of a coastal belt. Examples from a wide latitudinal range are provided for comparison of treatment for coastal belts in tropical (Belize), middle latitude (Portugal), and polar regions (Alaska, U.S.A.). Codification abbreviations, alpha subscripts, and numerals used in these examples are provided in Table 1. The information shown in these headers and captions primarily constitutes the raw data that resulted from the interpretation of the satellite images and is what was used in the analysis to determine common cross-shore ecological successions in the studied coastal belts. This type of information is included in the header of every coastal belt caption and is part of the method for preparing captions in the template so identified. Because of its length, the master data table containing all codification abbreviations, alpha subscripts, and numerals (*i.e.* Coastal Ecological Sequences; CES) for the complete 200 image dataset is provided in tabular form as Appendix I (available at www.JCRonline.org).

Three examples of how the assembly of contextual information and interpretation of the satellite imagery is formatted in the header and caption template are provided here for illustrative purposes. These examples were taken from low, middle, and high latitudes to show that the BCCS works in all geographic zones. The low-latitude Belizean example (Figures 1 and 2) illustrates the description of a coastal belt characterized by a tropical coastal wetland and can be compared and contrasted with a middle latitude semihumid zone on the SW

Terrestrial Biogeographic Realm and Biome: Neotropic Mangroves. **Ecoregion:** Mesoamerican Gulf-Caribbean Mangroves (613). **Large Marine Ecosystem:** Caribbean Sea (12). **Planview**: Tropical coastal wetlands and forest with lagoons. **Shoreline**: Muddy. **Environments and Habitats**: Muddy mangrove forest and swamp habitats, coastal woodlands and drainageways, lake and lagoon environments, saline flat habitats, bare to sparsely vegetated groundsurface environments. **Dominant Catenary Sequence:** Flat-Wetland (F-W). **Coastal Ecological Sequence:** $2F_{mu}W_{ma,sw,mr}$ **Translation:** Curved tropical tidal mudbanks (and flats) backed by wetland mangroves, swamps, and marshes.



These tropical coastal wetlands (17°02′45′′N by 88°15′15′′W, eye altitude 2 km, imagery date 3/12/2006) are located in the Stann Creek District in the southeast region of Belize, on the northwestern flanks of the Caribbean Sea. For general locational purposes, these wetlands are situated about 6 km southeast of Mullins River and about 7 km north of Dangriga, on a point of land jutting out into the sea. This satellite image is especially interesting because it shows a mosaic of ecotonal successions beginning with beaches and mud banks along the shore *per se* to fringing mangrove forests to marsh grasses to swamps and lakes. The water bodies are different colors due to a variety of factors where the bluish toned Caribbean Sea waters are colored by suspended fine-grained carbonates and flocculated mud suspensions close to shore whereas the interior swamps and lakes present brownish and greenish hues due to the presence of tannic acids and algae. The inlet and tidal creeks at the top of the image have deeper blue tones due to the ingress of clear seawater. The darker green hues in the center of the image are related to phanerophytes growing on slightly higher ground that is drier than the surrounding swamps. Quaternary (2.588 - 0 Ma) sedimentary rocks make up the coastal plain whereas the more interior mountains terrain is composed of older Pennsylvanian - Permian (323.2 - 252.17 Ma) sedimentary rocks. Sediments along the shore are Holocene in age. The tropical climate of this region is classified as Am (Tropical Monsoon Climate or occasionally known as a Tropical Wet Climate or a Tropical Monsoon and Trade-Wind Littoral Climate).

The Belizean mangrove ecosystem comprises an outstanding natural system, with vegetation being predominantly red mangrove (*Rhisophora mangle*) ranging in size from dwarf to tall and majestic, with some black mangrove (*Avicennia germinans*), white mangrove (*Laguncularia racemosa*), coconut palms (*Cocos nucifera*), and silver and green buttonwoods (*Conocarpus erectus*) also present. In addition, epiphytes, which are parasitic plants living on the bark of older trees, can be seen in abundance consuming the nutrients of their hosts. Although the mangrove ecosystems of Belize only make up about 3.5% of the national territory, these ecosystems affect the coastal resources to a great degree. This is because mangroves trap silt which originates on land and in turn protects the mainland during times of hurricane and other storms. Mangroves also serve as an essential fish and invertebrate (*e.g.*, lobster) nursery. Fauna is mainly bird species that vary but include breeding and nesting sites for great egret (*Egretta alba*), cattle egret (*Bubulcus ibis*), boat-billed herons (*Cochlearius cochlearius*), anhinga (*Anhinga anhinga*), neotropical cormorant (*Phalacrocorax olivaceus*), white ibis (*Eudocimus albus*), reddish egret (*Dichromanassa rufescens*), tri-colored heron (*Hydranassa tricolor*), and brown booby (*Sula leucogaster*). Additionally, Belizean mangroves serve as feeding and nursery grounds for over 74 species of fish, and provide habitat for 11 species of amphibians, 30 reptile species, and 40 species of mammals.

Figure 2. Example of a complete BCCS interpretative output that includes: a coastal belt satellite image scene from Belize, Central America; an informative header above the image that contains the Dominant Catenary Sequence (DCS) and Coastal Ecological Sequence (CES); and a comprehensive extended caption written out below the image. This cross-shore tropical coastal wetland ecological sequence is based on cognitive image interpretations, with codification occurring along the red A-B arrow swath starting from offshore (A) and transiting inland (B). The basic DCS for this scene is Flat-Wetland (F-W), while the more detailed CES translates to be a curved (numerical '2′) marine mudflat (F_{mu}) transitioning to a terrestrial wetland with an ecotonal succession of mangroves (W_{ma}), swamps (W_{sw}), and marshes (W_{mr}): $2F_{mu}W_{ma,sw,mr}$

coast of Portugal (Figures 3 and 4); the high-latitude zone is characterized by a subpolar barrier island on the SW coast of Alaska (Figures 5 and 6). Cross-shore ecological sequences (in the form of the DCS and CES) and ancillary contextual information are provided in these examples.

Tropical Coastal Belt Example (Belize, Caribbean Sea, SE Coast)

The geographical location of the satellite scene depicting the Belizean coastal belt is shown in Figure 1 in relation to the western margin of the Caribbean Sea Large Marine Ecosystem, of which it is a part. Figure 2 contains the satellite image scene of a Belizean coastal belt and shows a cross-shore transect from A (sea side) to B (land side) in the form of a red arrow. This cross-shore dissection can be verbally described, but to avoid cumbersome and verbose descriptions, units are codified for ease of use. That is, ecological systems can be given alphanumeric codes (*q.v.* Table 1) to simplify the characterization of coastal features along the transect. In the Belizean example, the dominant catena present in the selected scene is essentially described as a 'Flat-Wetland.' Thus, Flat-Wetland, or F-W ('F' abbreviates the Archetype Flat and 'W' abbreviates the Archetype Wetland according to Table 1), becomes the Dominant Catenary Sequence (DCS). The complete codification, or Coastal Ecological Sequence (CES), of this di-sequent Flat-Wetland ecological continuum is parsed alphanumerically as $2F_{mu}W_{ma,mr,sw}$, where the numeral '2′ refers to the overall general planview shape of the shore, the subscript mu identifies predominance of mud in the Flat Archetype, and the subscripts letters of 'ma', 'mr', and 'sw' signify that the Wetland Archetype is dominantly composed of mangroves, marshes, and swamps. Overall, the CES translation to this tropical coastal belt when transited along the given cross-shore transect (Figure 2) is: Curved tropical tidal mud flats backed by wetland mangrove forests, marshes, and swamps.

The complete header for this sample satellite scene of a Belizean coastal belt, as shown in Figure 2, contains information derived from cognitive image interpretation and accession of collateral data, all of which is provided in a prescribed order and format. The main perceptual or cognitively interpreted biophysical features are listed in the following collaterally derived categories: (1) Terrestrial Biogeographic Realm and Biome; (2) Ecoregion (with corresponding reference number); (3) Large Marine Ecosystem; (4) Planview (or Oblique View); (5) Shoreline; (6) Environments and Habitats; (7) Dominant Catenary Sequence (DCS); and (8) Coastal Ecological Sequence (CES) with translation. This translation provides an elemental deciphering of the CES codification without having to continually refer to the legend table (*e.g.*, Table 1).

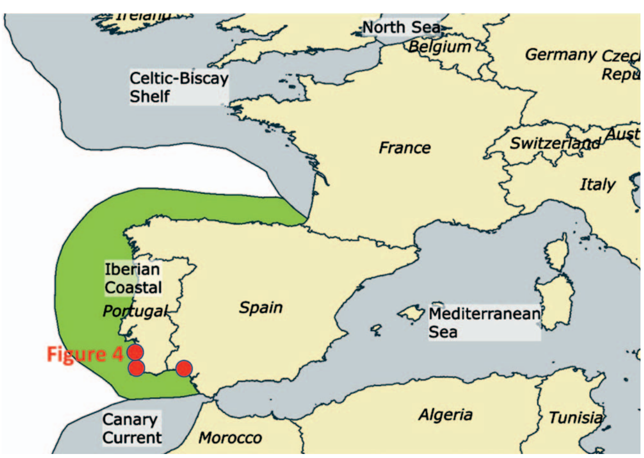


Figure 3. Location of the satellite image in Figure 4 in relation to the Iberian Coastal Large Marine Ecosystem (shown in green). Figure 4 provides an example of a Beach-Rock-Cliff-Upland cross-shore ecological sequence for a coastal belt in southwestern Portugal, while the other red circles show the locations of other satellite images included in the master data set listed in Appendix I (available at www.JCRonline.org). (Figure adapted from: Sherman, Aquarone, and Adams, 2009.)

Middle Latitude Coastal Belt Example (Portugal, SW Coast)

Figure 3 shows the middle latitude location for a warm temperate coastal ecosystem on the SW coast of Portugal, as depicted in the Figure 4 satellite image. This middle latitude cross-shore ecological sequence is vastly different from that

Table 1. *Codification of Archetypes and sub archetypes using bolded upper- and lower-case letters as primary archetype designators and lower-case alphabet subscripts as secondary sub archetype refinements to indicate the composition and nature of barriers, beaches, beach ridges, cliffs, coral reefs, deltas, dunes, flats (and tidal banks), ice, lagoons and lagoonal systems, mountains, rock, (glacial) till, uplands, and wetlands. Numerals are provided for shore-parallel configuration terms (overall alongshore coastal belt configuration in planview).*

Shore-Parallel (Alongshore) Coastal Belt Configuration Terms (Shapes in Planview)
1-Circular, Orbicular, Ovate (*e.g*., atolls, cayes, islets, drumlins)
2-Curved (Crenulated, cuspate, sinusoidal, broadly scoliomorphic)
3-Delta (Triangular-shaped with the apex pointing seaward)
4-Embayed (*e.g*., broadly curved bays, coves, estuaries)
5-Indented (Sharp-cornered, faulted; *e.g*., alcoves, sea caves, fjords, rias)
6-Promontories and Headlands (*e.g*., capes, horns, spurs, peninsulas, points, prominence)
7-Straight (Rectilinear, straight, leiomorphic)
8-Shore or coast not present in image scene
Cross-Shore Archetype and Sub Archetype Descriptors
Ba = Barrier
bb = bay barrier (baymouth, bayhead, mid-bay)
bi = barrier island and spit (undifferentiated)
mb = mainland barrier (undifferentiated)
Be = Beach (Wave-, Tide-dominated, Tide-modified)
br = beachrock
ca = carbonate (*e.g*., calcarenite, shell hash, Halimeda, ooids, *etc*.)
ow = overwash (fan)
rp = rampart (wave-deposited shingle, cobble, gravel ridge)
si = silica, silicates (siliciclastic or non-carbonate)
Br = Beach Ridge
ch = chenier
sp = strandplain (*e.g*., beach-foredune ridge plain)
Cl = Cliff (Includes Bluff, Escarpment, Scarp, and Steep Slopes; Composition, Morphology, and Cover)
ig = igneous (intrusive, extrusive) lithologies
me = metamorphic lithologies
sc = sea cave, arch, sea stack
se = sedimentary lithologies (includes dune calcarenite and aeolianite)
uc = unconsolidated
vc = % vegetative cover (*e.g*., vc50%)
Cr = Coral Reef (Includes Cay, Caye, and Key)
at = atoll
ba = barrier
cp = compound (combinations of patch, fringing, and barrier)
fr = fringing
pa = patch
De = Delta (Wave-, Tide-, River-dominated, Mixed; River Delta)
Du = Dune
bo = blowout
ds = dune sheet (includes transverse dune shapes)
pb = parabolic
sl = salina, salt flat
F = Flat (Includes Tidal Bank and Shoal)
mu = mud
sa = sand
sv = submerged vegetation
tc = tidal channel
I = Ice (Undifferentiated Glacier, Shore, and Nearshore Types)
gl = glacier
st = shore types
L = Lagoon, Lagoonal System (Includes Estuary and River Mouth)
at = atoll
cl = closed
it = intermittently-closed
op = open
sv = submerged vegetation

Table 1. *(continued).*

Cross-Shore Archetype and Sub Archetype Descriptors
M = Mountain (Peaked, Dissected Undifferentiated Topographic Expression)
eb = exposed bedrock
fo = forest
gr = grassland
sr = scrub vegetation
R = Rock
pl = platform
rr = rock reef (includes islets and skerries)
ts = talus and scree
T = (Glacial) Till, Diamicton (Moraines and Till Plains; Tillite, Diamictite)
U = Upland (Higher Elevation, Flat- or Hill-land Vegetation; Ground Surface Cover)
de = desert (*e.g*., dune, sand plain)
eb = exposed bedrock
fo = forest
gr = grassland
sr = scrub vegetation
tu = tundra
W = Wetland (Subtidal, Intertidal, Supratidal)
ma = mangrove forest
mr = marsh (low, middle and high latitude types)
sl = salina, salt flat
sv = submerged vegetation
sw = swamp, pond, lake

portrayed in the Belizean example (Figure 2), but the information supplied in the template comes in the same manner and order to produce a uniform report. The BCCS template easily accommodates information acquired from a different latitudinal zone showing its flexibility and open format. Following the red arrow transect in Figure 4 from the seaward location of A shoreward to the inland location of B, the DCS is manifested in terms of a Beach-Rock-Cliff-Upland (Be-R-Cl-U) tetra-sequent coastal belt catena. The CES of this coastal belt is then formulated by selecting the numeral 7 (see Table 1) as the first digit of the code, which indicates a straight or leiomorphic (*cf*. Finkl, 2004) coastal section, and by adding alpha subscripted sub archeteypes. For example, Be_{rp} is used to identify the beach as a cobble rampart, the rocky cliff base is composed of talus and scree (R_{ts}), the cliff face comprises sedimentary materials that retain about 10% vegetative cover ($Cl_{se,vc10\%}$), and finally, the upland is dominated by scrub vegetation (U_{sr}; *cf*. Table 1). The CES is presented as $7Be_{rp}Ro_{ts}Cl_{se,vc10\%}U_{sr}$. The caption below the image should provide more in-depth information, such as the fact that the oversteepened slopes and cliff faces are mostly devoid of vegetation indicates that the slope is destabilized and that the clastic materials are mobilized as part of ongoing mass wasting processes. Scrub vegetation occurs on some of the more stabilized slopes, but vegetation is completely lacking from the talus and scree along the shore. Information pertaining to the biological, botanical, and ecological state of the coastal belt can also be mentioned in the caption.

Subpolar (Arctic) Coastal Belt Example (Alaska, U.S.A.)

Figure 5 shows the geographical location of a high latitude, subpolar coastal belt on the SW coast of Alaska facing the East Bering Sea. The cross-shore ecological sequence shown in

Figure 6 is a typical example of a cold region barrier island succession, where the coastal barrier fronts the open sea and is backed by a lagoon that, in this case, contains a mainland mudflat that fronts a wetland marsh ecosystem. Following along the red arrowed cross-shore transect, the DCS is a penta-sequent catena in the form of: Barrier-Beach-Lagoon-Flat-Wetland. The CES of this subpolar coastal belt is coded as $7Ba_{bi}Be_{si}L_{op}F_{mu}W_{mr}$, where the numeral '7' indicates a straight or leimorphic shore in planview (*cf*. Table 1). The sub archetypes are identified as the subscripted code letters 'bi' (barrier island), 'si' (silica beach), 'op' (open lagoon), 'mu' (mudflat), and 'mr' (wetland marsh). The overall translation for this CES is given as: Straight subpolar silica barrier island beach grading to an open lagoon with muddy tidal flats backed by wetland marshes. The caption below the image offers more detailed information, for example, how this low-lying barrier island system, which lacks dune buildup, is frequently overwashed with frozen sediment or ice during low sun periods (winter) and is backed by an open (leaky) lagoon (*cf*. Isla, 2009). Muddy tidal flats then front the mainland wetland marsh ecosystem ashore. By laying out the ecological information in this manner of a specific header, coastal belt satellite image scene, and an extended caption, the same template for the classification all coastal images are effectively carried out using the BCCS, regardless of the coastal belt's latitudinal position.

The three examples provided here (Figures 2, 4, and 6) demonstrate the BCCS procedure for describing cross-shore ecological sequences in coastal belts depicted from satellite images. The same methodology applies to all coastal belts regardless of latitudinal or geographic position.

RESULTS

In the present study, about 200 satellite images were accessed from the world's coasts using Google Earth Pro. The images were selected on a random basis from equatorial to polar regions, as determined by (1) the absence of urban-industrial development; (2) presence or lack of quality in image scene parameters (*e.g*., brightness, haze, glare, glint, lack of color-corrected scene boundaries, clarity of coastal waters, presence of airbrushed water fill-ins); (3) definitiveness of biophysical features; and (4) composition of the scene. These main variables were considered to be of high enough resolution to ensure a random selection of scenes versus one conducted on a regimented basis.

Appendix I (available at www.JCRonline.org) contains the master data table for all of the satellite images used in this study. The table is organized by the main Archetype of each coastal belt scene and includes the Coastal Ecological Sequences (CES), the coastal belt location, the latitudinal zonation, latitude and longitude, climate, Large Marine Ecosystem (LME), and ecoregion. Appendix II (available at www.JCRonline.org) is a reference of Large Marine Ecosystems (LME) associated with the satellite images in this study, giving both total area and associated countries for each. This appendix puts the LMEs into a global perspective that can be related back to the satellite images listed in Appendix I (available at www.JCRonline.org). The LMEs with the greatest number of bordering countries include the Caribbean Sea and the Mediterranean Sea. Several LMEs, in contrast, are associated with only one country; *viz*. the Antarctic, Barents Sea, East Bering Sea, East Brazil Shelf, Greenland Sea, Gulf of Alaska, Gulf of California, Hudson Bay Complex, Iceland Shelf, Insular Pacific–Hawaiian, New Zealand Shelf, North Australia Shelf, NE Australian Shelf, NW Australian Shelf, Norwegian Sea, Scotian Shelf, South Brazil Shelf, SE Australian Shelf, and West-Central Australian Shelf. Figures 1, 3, and 5, respectively, show the locations of the Belizean, Portuguese, and Alaskan examples in relation to the Caribbean Sea LME, Iberian Coastal LME, and East Bering Sea LME.

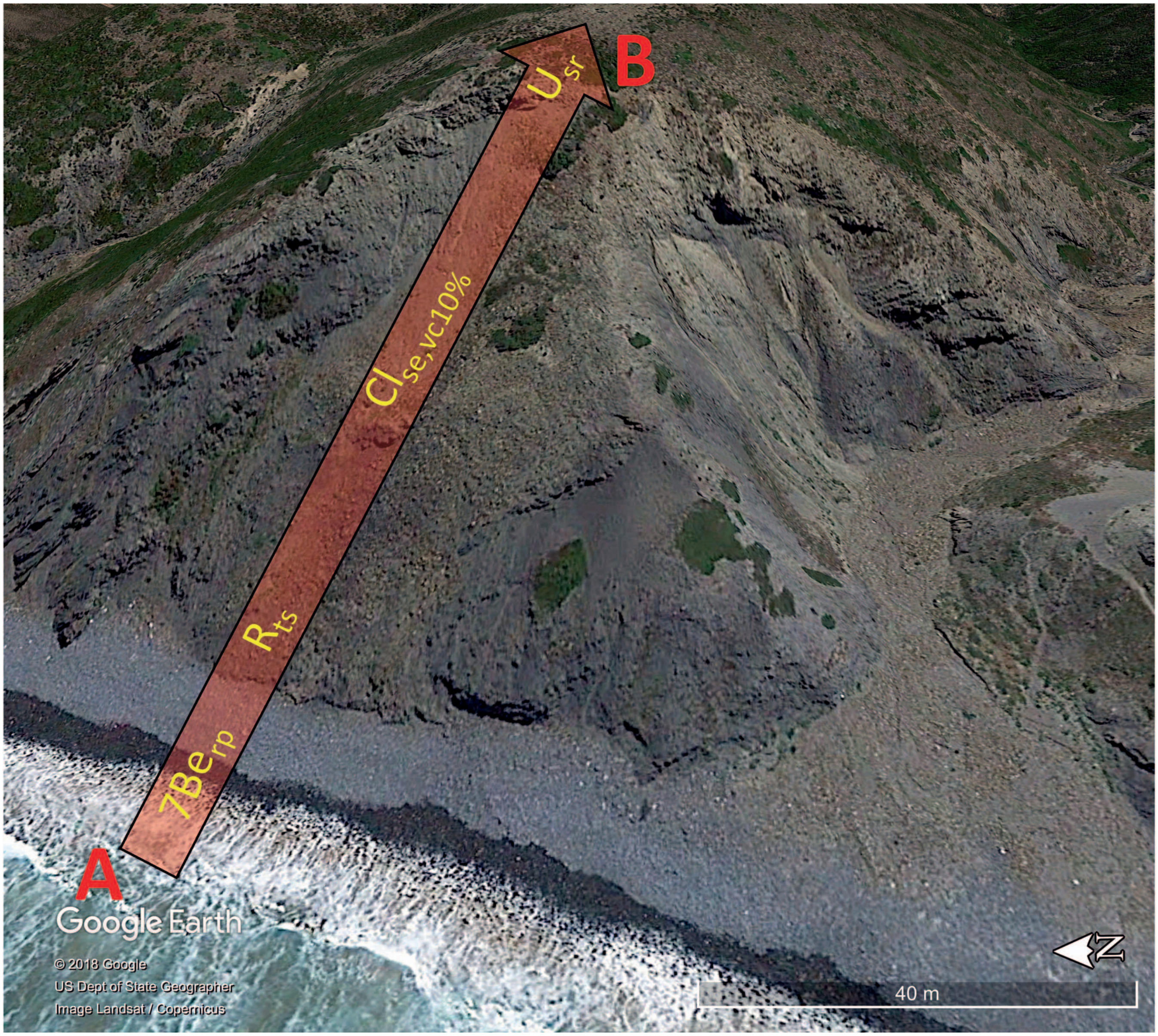
Codification of Cross-Shore Ecological Sequences

The codification of cross-shore ecological sequences is summarized in Table 1. The alphanumeric abbreviations are not meant to be definitive or exhaustive because they are derived from the 200 images used in this study. It is postulated that the images used for this research are representative of a worldwide context, but that assumption can only be tested by a larger sample size. There is a high level of confidence in the veracity of the units selected mainly because the cross-shore ecological sequences identified were consistently replicated around the world, regardless of latitudinal position. Nevertheless, there is little doubt that other units (Archetypes and sub archetypes alike) need to be included (see Table 3). Thus, it is suggested that the proposed Biophysical Cross-shore Classification System (BCCS) procedure be an open-ended method to include new units as they are recognized and appropriated for the coastal belt being classified. In this way, the BCCS can be adjusted to accommodate new information as it becomes available through additional and future research efforts. Study of the 200 test images showed replication of the fifteen (15) primary biophysical units (Archetypes) listed in Table 1. When these primary units are linked together in succession, the Dominant Catenary Sequence (DCS) of a coastal belt is formulated (Table 2). The Archetypes are further refined by fifty-four (54) secondary descriptors (sub archetypes) that are appended as subscripts to the codification of the Coastal Ecological Sequence (CES). In this way, greater specificity is attached to the main Archetype biophysical units. It also allows a translation of the codifications into plain English descriptions of the cross-shore ecological sequences (starting from offshore and moving landward). In other words, the code simplifies what would otherwise be a somewhat cumbersome description of the cross-shore ecological sequence. The third main category of the codification format is a numerical identification of shore-parallel (alongshore) coastal belt configurations (*i.e*. shapes) in planview. Eight main planview configurations were identified from the imagery used in this study. In this way, numerals precede the alpha coding to identify whether a shoreline shape is curved, straight, indented, embayed, *etc*. (Table 1).

Coastal Belt Cross-Shore Catenary Sequences

Table 2 summarizes some of the most common cross-shore Dominant Catenary Sequences (DCS) for all the images used in this study. It was found that certain catenary sequences tend to be repetitive, further suggesting the possibility of simplification. The repetitive catenas in Table 2 are organized in terms of Archetypes, based on the dominant biophysical or macro-ecological feature encountered in a shoreward transect from

Terrestrial Biogeographic Realm and Biome: Palearctic Mediterranean Forests, Woodlands, and Scrub. **Ecoregion:** Southwest Iberian Mediterranean Sclerophyllous and Mixed Forests (805). **Large Marine Ecosystem:** Iberian Coastal (25). **Oblique View**: Middle latitude eroding coastal cliffs with coarse-grained fluvial discharge to the coast and cobble beach. **Shoreline**: Cobble and gravel beach. **Environments and Habitats**: Unvegetated, unstable slope environments, ephemeral stream valleys environments, cobble beach habitats. **Dominant Catenary Sequence:** Beach-Rock-Cliff-Upland (Be-R-Cl-U). **Coastal Ecological Sequence:** $7Be_{rp}R_{ts}Cl_{se,vc10\%}U_{sr}$ **Translation:** Straight middle latitude cobble rampart beach and talus at the foot of mostly bare ($\sim$10% vegetative cover) limestone cliffs that are surmounted by scrub uplands.



This middle latitude cobble beach (37°15′31″N by 8°51′48″W, eye altitude 87 m, imagery date 5/15/2015) occurs on the southwest coast of Portugal about 2.5 km northwest of Monte Novo in the municipality of Aljezur in the District of Faro. Aljezur, located along the western coast of the Algarve, lies within the Southwest Alentejo and St. Vincent Coast Nature Park. This region is known for its cliff top landscapes and dramatic sea fronts. The cliff top shown here rises about 65 m above sea level with steep slopes leading down to a cobble beach. This close-up image shows the instability of the sedimentary materials that are prone to creep and downhill slides. Wave action undercuts the cliff base and in so doing destabilizes the slopes that readily shed clastic materials. The instability of the slopes is indicated by the lack of vegetative cover and exposure of bare rock surfaces. The dark gray coarse fragments making up the cobble beach are derived from the predominantly limestone sequences. The cobbles are concentrated along the high-energy beach that is about 20 m wide with a narrower dry beach of about 8 m in width. On the right side of the image is an arroyo that leads down to the sea. It contains sedimentary materials of a different provenance, as reflected in the brownish hues of the coarse fluvial bed load that is transported to the beach. Mixture of the two different sediments is clearly visible in terms of color. The porous nature of the beach face is evident by the distance from the wetted perimeter to the zone of uprush and back wash. The beach face, which grades into the shoreface, is gradual as waves break several (4-5) times before reaching the shore with uprush that quickly infiltrates into the coarse-grained beach face. This section of coast is geologically characterized by Jurassic (201.3-145 Ma) limestone formations that contain inclusions of marlstone, sandstone, and claystone. The warm temperate climate of the region is classified as Csa (Dry-Summer Climate).

As shown in the image, the cobble beaches along the coastal belt and the beautiful flora among the cliffs, coupled with numerous wildflower meadows and mixed cork oak-pine woodlands, showcase the ecosystems of the western Algarve. These windswept cliffs are dominated by *Cistus palhinhae*, which closely resembles the gum cistus found throughout the rest of the Algarve. Other plants that grow within this coastal belt include Algarve toadflax, *Linaria algarviana*, *Astragalus tragacantha*, and shrubby violet (*Viola arborescens*), a rare plant found only here along the St. Vincent coast and at Cape Trafalgar in Spain. This is also home to many of the wild orchids, such as the mirror orchid (*Ophrys speculum*), the bumblebee orchid (*Ophrys bombyliflora*), the heart-flowered tongue orchid (*Serapias cordigera*), and many broad-leaved Helleborines (*Epipactis helleborine*). Apart from the unique plant life within the park, the area is also famous for its birds, some of which nest on the rocks and cliffs while others use this 'first and last post' in southwestern Europe on their migratory journeys. Nightingales and Golden Orioles arrive along with many other passerines, as vast numbers of migrating birds move along the coast. These include griffons, white and black storks, Egyptian vultures, booted eagles, choughs, shags, and swifts. Other animals can be found in these areas, such as otters, gennets, badgers, the Egyptian mongoose, and wild boar.

Figure 4. Example of a complete BCCS interpretative output that includes: a coastal belt satellite image scene from southwestern Portugal; an informative header above the image that contains the Dominant Catenary Sequence (DCS) and Coastal Ecological Sequence (CES); and a comprehensive extended caption written out below the image. This cross-shore middle latitude coastal clastic-based ecological sequence is based on cognitive image interpretations, with codification occurring along the red A-B arrow swath starting from offshore (A) and transiting inland (B). The basic DCS for this scene is Beach-Rock-Cliff-Upland (Be-R-Cl-U), while the more detailed CES translates to be a straight (numerical '7') cobble rampart beach (Be_{rp}) with talus rock (R_{ts}) at the foot of mostly bare limestone cliffs ($Cl_{se,vc10\%}$) that are surmounted by scrub uplands (U_{sr}): $7Be_{rp}R_{ts}Cl_{se,vc10\%}U_{sr}$

the sea. Based on the study imagery, the following archetypical categories were identified and used to formulate the DCS: Barrier, Beach, Beach Ridge, Cliff, Coral Reef, Delta, Dune, Flat, Ice, Lagoon, Mountain, Rock, Till (Glacial Material), Upland, and Wetland. For example, for those images that are listed under the Beach Archetype, common DCS successions included Beach-Beach Ridge, Beach-Cliff, Beach-Dune, Beach-Lagoon, Beach-Rock, Beach-Upland, and Beach-Wetland. These are the generalized master cross-shore consecutions for beach ecosystems of the world, as seen in the satellite images for all latitudinal zones. As shown in Table 2, there are multiple variable combinations of DCS linkages for all Archetypes identified. This can sometimes be difficult to discern because of features and associated ecosystems that are gradational, as determined by tidal fluctuations, seasonal sediment influx, erosion attributable to storminess (*e.g.*, downdrift migration, inlet cutting, overwash, welding to other features), avulsion of tidal channels, advancing or retreating vegetative growth of mangroves, *etc*. Even so, this concatenation of Archetypes into the DCS forms the backbone of the Biophysical Cross-shore Classification System (BCCS) and ultimately leads to the formulation of the coastal belt's Coastal Ecological Sequence (CES), which includes the coastal configuration and sub

Figure 5. Location of the satellite image in Figure 6 in relation to the East Bering Sea Large Marine Ecosystem (shown in green). Figure 6 provides an example of a Barrier Island-Beach-Lagoon-Flat-Wetland cross-shore ecological sequence for a coastal belt in southwestern Alaska, U.S.A. (Figure adapted from: Sherman, Aquarone, and Adams, 2009.)

archetype ecological refinements. The results presented in Figures 2, 4, and 6, as well as in Appendix I (available at www.JCRonline.org), show that the BCCS is an effective means to determine the cross-shore ecological successions of coastal belts worldwide.

ANALYSIS

The 200 satellite images were analyzed along methodological and procedural lines, as described conceptually by Bianchetti and MacEachren (2015); Caballero and Stump (2019); Finkl and Makowski (2015, 2019a,b); Finkl, Makowski, and Vollmer (2014); and Finkl and Vollmer (2011) for cognitive interpretation of salient features via a geovisual analytics framework (*e.g.*, Andrienko *et al.*, 2010; Bianchetti, 2015). The determination of biophysical features and ecological systems was based initially on the overall impression of the satellite scene in either a plan or oblique view, which was then refined by reference to cross-shore transects superimposed on the imagery (*cf*. Figures 2, 4, and 6). The results of those transects can be viewed in Appendix I (available at www.JCRonline.org), and were used to analyze the nature of cross-shore ecological sequences in coastal belts. After a thorough examination of the raw data, common catenary patterns began to emerge suggesting the presence of naturally repetitive ecological series occurring in coastal belts. The recognition of repeating sequences made it possible to organize the 200-image dataset by breaking the list into associative units that were referred to as Archetypes at the highest level and sub archetypes at a secondary level (Table 1). The dataset was further organized by commonly occurring cross-shore ecological catenas in the form of Dominant Catenary Sequences (Table 2). Finally, the Coastal Ecological Sequence was codified for each coastal belt with the addition of shore-parallel configurations and sub archetype distinctions, as shown in Appendix I (available at www.JCRonline.org).

For example, when analyzing a coastal belt that shows a barrier island beach cross-section in the image, there is a specific code and catena that may correspond to ecosystems interpreted along the predetermined transect. According to Table 2, a common barrier island catena that occurs is denoted as BaBeDuLW, which identifies the following penta-sequent concatenation of ecological archetypes: Barrier (Ba), Beach (Be), Dune (Du) on the barrier island *per se*, a Lagoon

Terrestrial Biogeographic Realm and Biome: Nearctic Tundra. **Ecoregion:** Beringia Lowland Tundra (409). **Large Marine Ecosystem:** East Bering Sea (1). **Planview**: Subpolar open ocean and barrier island (left side of image), lagoon (center of image), thermokarst alluvial plain (right side of image). **Shoreline**: Sandy beach. **Environments and Habitats**: Muddy and sandy barrier island habitats, lagoonal and tidal flat environments, vegetated thermokarst, pond, lake, and hummock settings. **Dominant Catenary Sequence:** Barrier-Beach-Lagoon-Flat-Wetland (Ba-Be-L-F-W). **Coastal Ecological Sequence:** $7Ba_{bi}Be_{si}L_{op}F_{mu}W_{mr}$ **Translation:** Straight subpolar silica barrier island beach grading to an open lagoon with muddy tidal flats backed by wetland marshes.

This example of a subpolar Arctic barrier island (59°49′49′′N by 164°08′15′′W, eye altitude 9.5 km, imagery date 8/12/2012) occurs on the southwest coast of Alaska between Norton Sound in the north and Bristol Bay in the south. Pingurbek Island, as it is called, lies about 14 km southwest of Kipnuk, Bethel Census Area, Alaska, USA. The whole barrier island is about 13 km in length, the northern 3 km missing from this image. The barrier island system is separated from the mainland by a shallow-water sound (or lagoon) that is about 3 to 4 km wide. The seaward side of the barrier island facing the open waters of the Bering Sea is marked by small tidal inlets, an offshore bar and trough sequence, a low-tide terrace with poorly developed ridges and runnels, and incipient beach ridges that are backed by low dune flats. Sporadic low-lying barchanoid dunes are found on the central part of the barrier. A mostly frozen subaqueous zone about 500 m or so in width occurs on the landward margin of the island. Pingurbek Island lies seaward of a typical tundra landscape where there is permafrost below the ground surface. Seasonal and permanent melting of the permafrost produces various types of patterned ground such as boggy wetlands with many lakes and ponds, as shown on the right side of this image. The macrogeology of this coastal region is characterized by Quaternary (2.588 - 0 Ma) unconsolidated surficial deposits that are undivided being complexly composed of older beach, estuarine, alluvial, and probably glacial deposits. The climate of this microthermal coastal zone is classified as Dfc (Subarctic or Subpolar Climate).

As shown by the different shades of green and brown in the image, several Arctic plant communities are formed in this ecosystem. *Puccinellia phryganodes* occurs at the seaward limit of vascular plant growth, *Carex subspathacea* is found at midtidal levels, and *Carex rumenski subsparhacea* can be seen at the upper limits of the tidal zone. While *Duponria fisheri* is the dominant species found in the upper storm zone above the tidal communities, vegetation upon the raised Arctic beaches and coastal dunes become floristically variable, with *Salix* spp. and *Elymus arenarius* consistently in high abundance due to their success in tolerating sand deposition and blowouts. Also forming in dune areas are mat-forming dicots, such as *Salix ovalifolia*, *Artemisia borealis*, *Oxytropis nigrescens*, and *Chrysanthemum bipinnatum*. Bristol Bay hosts one of the largest annual land-based walrus haulouts in the Western Hemisphere. Each spring, 2,000 to 10,000 male walruses bask on the rocky beaches of Round Island for days at a time. Steller sea lions have a rookery nearby and gray whales swim offshore along the coast. In spring and summer, red foxes feed and play on the island slopes and enormous brown bears patrol the shorelines. Hundreds of thousands of seabirds, including kittiwakes, murres, puffins, cormorants, parakeet auklets, and pigeon guillemots breed along the coast during summer.

Figure 6. Example of a complete BCCS interpretative output that includes: a coastal belt satellite image scene from southwestern Alaska, U.S.A.; an informative header above the image that contains the Dominant Catenary Sequence (DCS) and Coastal Ecological Sequence (CES); and a comprehensive extended caption written out below the image. This cross-shore subpolar coastal barrier island ecological sequence is based on cognitive image interpretations, with codification occurring along the red A-B arrow swath starting from offshore (A) and transiting inland (B). The basic DCS for this scene is Barrier-Beach-Lagoon-Flat-Wetland (Ba-Be-L-F-W), while the more detailed CES translates to be a straight (numerical '7') silica barrier island beach ($Ba_{bi}Be_{si}$) grading to an open lagoon (L_{op}) with muddy tidal flats (F_{mu}) backed by wetland marshes (W_{mr}): $7Ba_{bi}Be_{si}L_{op}F_{mu}W_{mr}$

(L) that separates the barrier island from the mainland, and finally a Wetland (W) that backs the Lagoon. This Dominant Catenary Sequence (DCS) of Ba-Be-Du-L-W can be further enhanced with the addition of sub archetype subscript annotations. The Barrier Archetype in this example has been identified as an undifferentiated barrier island sub archetype, thus, the codification becomes: Ba_{bi}. If the Beach Archetype is known to be composed of carbonates, then the code is: Be_{ca}. Perhaps the Dune Archetype is not developed enough to add a sub archetype refinement, which is at the discretion of the one performing the interpretations. In that case, Du is used without a subscript. Next, if the Lagoon is determined to be an open system, then the code would be L_{op}. Finally, if the Wetland includes both mangroves and marshes, the code is: $W_{ma,mr}$. After these sub archetypes have been added, along with a shore-parallel configuration (in this example a straight configuration is denoted with the numeral '7'), an overall Coastal Ecological Sequence (CES) is formulated as $7Ba_{bi}Be_{ca}DuL_{op}W_{ma,mr}$.

This is just one example, and numerous variations can be found. For instance, if a very low-elevation barrier island lacked a dune ecosystem because of overwash, the DCS would become a tetra-sequent catena of: Barrier-Beach-Lagoon-Wetland (Ba-Be-L-W). The subsequent CES, drawing from the previous example, would be $7Ba_{bi}Be_{ca}L_{op}W_{ma,mr}$. Because of variation in coastal configurations, geography, and conditions present at the time of image capture, this analysis shows that many different possibilities for the classifying of ecological catenary successions exist.

Another example of variation in ecological succession linking occurs when cross-shore transects show cliffs being fronted by beach or rocky ecosystems, except in the case of steep-to shores where the cliff face enters the water without seaward detrital materials. Where there is Rock (R) at the base of a Cliff (Cl), without a beach, leading to an Upland (U) the codification for the tri-sequent DCS would read: R-Cl-U. The 'U' is present for all cliffs as they terminate upward at their summits in uplands of some kind, forming a Cliff-Upland Archetype couplet. Therefore, the simplest example of a cliff coastal belt DCS would be the di-sequent: Cl-U. Alternatively, a cross-shore tri-sequent DCS might be Beach-Cliff-Upland (Be-Cl-U), where a beach ecosystem is first encountered on the shore as opposed to rock.

The list of 15 possible Archetypes and 54 possible sub archetypes shown in Table 1 is not exhaustive, but shows what was actually observed in the 200 coastal belt images from this study. The complete dataset in Appendix I (available at www.JCRonline.org) is provided for reference and documentation of the extensive sampling that was done to analyze the possibility of segregating types of coastal belts using satellite imagery. Because cognitive interpretations are subjective, designations depend somewhat on the experience of the researcher or the special purpose of the study at hand. Classification of biophysical features and ecological sequences also depend on the satellite view where only parts of a continuum are shown. If a complete continuum exists in the scene, recognition of its component parts is a relatively simple task compared to attempting interpretation based on parts of the overall sequence. Repeatedly zooming in and out of the satellite scene usually resolves the uncertainty as component parts can be better differentiated than from a fragmented view.

Although some complications occur when it comes to analyzing the various combinations of codes for cross-shore ecological sequences, careful attention to the order of code letters helps to break down the bewildering array of symbolization into manageable parts, as differentiated from Appendix I (available at www.JCRonline.org). Such efforts resulted in the recognition of similarities and differences within coastal ecological sequences when organized in the first instance by biophysical features and physiographic units. This kind of analysis proved to be most beneficial as an organizational tool for the main archetypes used in this study, as shown for Barrier (Table 4), Beach (Table 5), Cliff (Table 6), Coral Reef (Table 7), Delta (Table 8), Dune (Table 11), Flat (Table 9), Ice (Table 11), Lagoon (Table 11), Rock (Table 10), Till (Table 11), and Wetland (Table 11). These tables were compiled and grouped on the basis of the first letters of the codification as this provided a logical way to formulate an organizational system that was easy to use and immediately informative to the reader. The Dominant Catenary Sequences (DCS, Table 2) for each of these main Archetypes are briefly described and analyzed in the following paragraphs.

Barrier Archetype Dominant Catenary Sequences (DCS)

The Barrier Archetype was divided into three main sub archetypes, *viz*. bay barriers, barrier islands and spits, and mainland barriers. A total of twenty-seven (27) DCS were identified for those coastal belts that began a cross-shore

Table 2. *Cross-shore Dominant Catenary Sequences (DCS) arranged by Archetype and sub archetype showing actual ecological successions identified in the satellite data set of approximately 200 images. Hyphenated long-form sequences and equivalent alpha codes in upper- and lower-case letters are indicative of Table 1. These biophysical associations represent the most commonly occurring sequences identified in this study. The scale-dependent catenas listed here are definitive of the 200-image dataset, however, other possibilities exist depending on details of observation (c.f. Table 3).*

I. BARRIER ARCHETYPE
Dominant Catenary Sequences (sub archetype)
(bay barrier)
Barrier-Beach-Lagoon-Wetland = Ba-Be-L-W
Barrier-Beach-Wetland-Lagoon-Wetland = Ba-Be-W-L-W

(barrier island and spit)
Barrier-Beach-Beach Ridge-Dune-Wetland = Ba-Be-Br-Du-W
Barrier-Beach-Dune-Flat-Wetland-Lagoon = Ba-Be-Du-F-W-L
Barrier-Beach-Dune-Lagoon-Wetland = Ba-Be-Du-L-W
Barrier-Beach-Dune-Lagoon-Wetland-Upland = Ba-Be-Du-L-W-U
Barrier-Beach-Dune-Lagoon-Upland = Ba-Be-Du-L-U
Barrier-Beach-Dune-Wetland = Ba-Be-Du-W
Barrier-Beach-Dune-Wetland-Lagoon = Ba-Be-Du-W-L
Barrier-Beach-Dune-Wetland-Lagoon-Beach-Lagoon-Beach-Wetland = Ba-Be-Du-W-L-Be-L-Be-W
Barrier-Beach-Flat-Lagoon-Wetland-Upland = Ba-Be-F-L-W-U
Barrier-Beach-Lagoon-Beach-Wetland-Upland = Ba-Be-L-Be-W-U
Barrier-Beach-Lagoon-Dune-Wetland = Ba-Be-L-Du-W
Barrier-Beach-Lagoon-Flat-Wetland = Ba-Be-L-F-W
Barrier-Beach-Lagoon-Till-Ice = Ba-Be-L-T-I
Barrier-Beach-Lagoon-Upland = Ba-Be-L-U
Barrier-Beach-Wetland-Lagoon = Ba-Be-W-L
Barrier-Flat-Beach-Dune-Beach Ridge-Wetland = Ba-F-Be-Du-Br-W
Barrier-Flat-Beach-Dune-Wetland = Ba-F-Be-Du-W

(mainland barrier)
Barrier-Beach-Upland = Ba-Be-U
Barrier-Beach-Dune-Lagoon-Flat-Wetland = Ba-Be-Du-L-F-W
Barrier-Beach-Dune-Lagoon- Wetland = Ba-Be-Du-L-W
Barrier-Beach-Dune-Wetland = Ba-Be-Du-W
Barrier-Beach-Dune-Wetland-Lagoon = Ba-Be-Du-W-L
Barrier-Beach-Dune-Wetland-Lagoon-Upland = Ba-Be-Du-W-L-U
Barrier-Beach-Dune-Wetland-Upland = Ba-Be-Du-W-U
Barrier-Beach-Wetland-Lagoon-Upland = Ba-Be-W-L-U

II. BEACH ARCHETYPE
Dominant Catenary Sequences (sub archetype)
(beachrock)
Beach-Cliff-Upland = Be-Cl-U

(carbonate)
Beach-Beach Ridge-Upland = Be-Br-U
Beach-Beach Ridge-Wetland = Be-Br-W
Beach-Dune-Cliff-Upland = Be-Du-Cl-U
Beach-Dune-Mountain = Be-Du-M
Beach-Dune-Upland = Be-Du-U
Beach-Dune-Wetland = Be-Du-W
Beach-Dune-Wetland-Lagoon = Be-Du-W-L

(silica)
Beach-Beach Ridge-Upland = Be-Br-U
Beach-Beach Ridge-Wetland = Be-Br-W
Beach-Cliff-Upland = Be-Cl-U
Beach-Cliff-Till-Upland = Be-Cl-T-U
Beach-Dune = Be-Du
Beach-Dune-Upland = Be-Du-U
Beach-Dune-Wetland = Be-Du-W
Beach-Dune-Wetland-Upland-Lagoon = Be-Du-W-U-L
Beach-Lagoon-Wetland = Be-L-W
Beach-Lagoon-Wetland-Upland = Be-L-W-U
Beach-Rock-Cliff-Dune-Upland = Be-R-Cl-Du-U
Beach-Rock-Cliff-Upland = Be-R-Cl-U
Beach-Wetland-Upland = Be-W-U

Table 2. *(continued).*

II. BEACH ARCHETYPE (continued)
(carbonate + silica)
Beach-Beach Ridge-Lagoon = Be-Br-L
Beach-Beach Ridge-Wetland = Be-Br-W
Beach-Cliff-Upland = Be-Cl-U
Beach-Dune-Cliff-Upland = Be-Du-Cl-U
Beach-Dune-Mountain = Be-Du-M
Beach-Dune-Upland = Be-Du-U

(carbonate + silica + overwash)
Beach-Dune-Upland = Be-Du-U

(silica + overwash)
Beach-Dune-Upland = Be-Du-U

(rampart)
Beach-Cliff-Upland = Be-Cl-U
Beach-Rock-Cliff-Upland = Be-R-Cl-U

III. CLIFF ARCHETYPE
Dominant Catenary Sequences (sub archetype)
(igneous)
Cliff-Upland = Cl-U

(metamorphic)
Cliff-Upland = Cl-U

(sedimentary)
Cliff-Upland = Cl-U
Cliff-Upland-Beach-Upland = Cl-U-Be-U

IV. CORAL REEF ARCHETYPE
Dominant Catenary Sequences (sub archetype)
(atoll)
Coral Reef-Beach-Upland-Beach-Lagoon = Cr-Be-U-Be-L
Coral Reef-Lagoon-Beach-Wetland = Cr-L-Be-W

(barrier)
Coral Reef = Cr (no visible coast)
Coral Reef-Lagoon-Coral Reef-Beach-Upland = Cr-L-Cr-Be-U

(compound)
Coral Reef-Barrier-Beach-Wetland = Cr-Ba-Be-W
Coral Reef-Beach-Dune-Upland = Cr-Be-Du-U
Coral Reef-Beach-Upland = Cr-Be-U
Coral Reef-Beach-Wetland = Cr-Be-W
Coral Reef-Lagoon-Beach-Wetland = Cr-L-Be-W
Coral Reef-Lagoon-Beach-Wetland-Upland = Cr-L-Be-W-U

(fringing)
Coral Reef-Barrier-Beach-Dune-Lagoon-Wetland-Upland = Cr-Ba-Be-Du-L-W-U
Coral Reef-Beach-Cliff-Upland = Cr-Be-Cl-U
Coral Reef-Beach-Mountain = Cr-Be-M
Coral Reef-Beach-Upland = Cr-Be-U
Coral Reef-Beach-Wetland = Cr-Be-W
Coral Reef-Beach-Wetland-Lagoon = Cr-Be-W-L
Coral Reef-Beach-Wetland-Upland = Cr-Be-W-U
Coral Reef-Cliff-Upland = Cr-Cl-U
Coral Reef-Lagoon-Beach-Upland = Cr-L-Be-U
Coral Reef-Wetland = Cr-W
Coral Reef-Wetland-Mountain = Cr-W-M

(patch)
Coral Reef-Flat-Beach-Wetland = Cr-F-Be-W

(atoll + fringing)
Coral Reef-Beach-Upland = Cr-Be-U
Coral Reef-Flat-Beach-Upland = Cr-F-Be-U

Table 2. *(continued).*

V. DELTA ARCHETYPE
Dominant Catenary Sequences
Delta = De (no visible coast)
Delta-Barrier-Beach-Dune-Wetland = De-Ba-Be-Du-W
Delta-Beach-Beach Ridge-Wetland = De-Be-Br-W
Delta-Flat-Beach-Upland = De-F-Be-U
Delta-Flat-Beach-Flat-Wetland = De-F-Be-F-W
Delta-Flat-Wetland = De-F-W
Delta-Flat-Wetland-Upland = De-F-W-U

VI. DUNE ARCHETYPE
Dominant Catenary Sequences
Dune-Lagoon-Wetland = Du-L-W

VII. FLAT ARCHETYPE
Dominant Catenary Sequences (sub archetype)
(mud)
Flat-Beach-Wetland = F-Be-W
Flat-Beach-Wetland-Upland = F-Be-W-U
Flat-Lagoon-Wetland = F-L-W
Flat-Lagoon-Wetland-Upland = F-L-W-U
Flat-Rock-Beach-Upland = F-R-Be-U
Flat-Wetland = F-W
Flat-Wetland-Flat-Upland = F-W-F-U

(sand)
Flat-Beach-Dune-Upland = F-Be-Du-U
Flat-Beach-Upland-Wetland = F-Be-U-W
Flat-Wetland-Upland = F-W-U

(mud + sand)
Flat-Beach-Dune-Flat-Wetland = F-Be-Du-F-W
Flat-Beach-Dune-Wetland = F-Be-Du-W
Flat-Beach-Wetland = F-Be-W

(mud + tidal channels)
Flat-Wetland = F-W

(sand + tidal channels)
Flat = F (no visible coast)
Flat-Beach-Beach Ridge-Wetland = F-Be-Br-W
Flat-Beach-Dune-Wetland = F-Be-Du-W
Flat-Beach-Upland = F-Be-U
Flat-Till-Ice = F-T-I
Flat-Wetland-Upland = F-W-U

(mud + sand + tidal channels)
Flat-Beach-Wetland = F-Be-W
Flat-Upland = F-U

VIII. ICE ARCHETYPE
Dominant Catenary Sequences (sub archetype)
(shore types)
Ice = I (no visible coast)
Ice-Barrier-Beach-Lagoon-Flat-Wetland = I-Ba-Be-L-F-W

IX. LAGOON ARCHETYPE
Dominant Catenary Sequences (sub archetype)
(open)
Lagoon-Coral Reef = L-Cr
Lagoon-Flat-Wetland = L-F-W
Lagoon-Wetland = L-W

X. ROCK ARCHETYPE
Dominant Catenary Sequences (sub archetype)
(undifferentiated)
Rock-Cliff-Upland = R-Cl-U
Rock-Ice = R-I

Table 2. *(continued).*

X. ROCK ARCHETYPE (continued)
(platform)
Rock-Beach = R-Be
Rock-Beach-Cliff-Upland = R-Be-Cl-U
Rock-Cliff-Upland = R-Cl-U

(rock reefs)
Rock-Flat-Beach-Cliff-Upland = R-F-Be-Cl-U
Rock-Cliff-Upland = R-Cl-U

(talus and scree)
Rock-Cliff-Upland = R-Cl-U
Rock-Cliff-Upland-Ice = R-Cl-U-I

(platform + talus and scree)
Rock-Cliff-Upland = R-Cl-U

(platform + rock reefs + talus and scree)
Rock-Cliff-Upland = R-Cl-U

XI. TILL ARCHETYPE
Dominant Catenary Sequences
Till-Ice = T-I

XII. WETLAND ARCHETYPE
Dominant Catenary Sequences (sub archetype)
(marsh)
Wetland-Upland = W-U

(marsh + submerged vegetation)
Wetland-Lagoon = W-L

interpretation transect with a barrier feature. Of those 27 DCS, two (2) were bay barriers, seventeen (17) were barrier islands and spits, and eight (8) were mainland barriers (Table 2). Barrier Archetypes are almost always associated seaward by beaches as part of their cross-shore concatenation (occasionally they are fronted by the Flat Archetype) and this repetitive nature helped to form tri-sequent catena successions, such as the Ba-Be-Du and Ba-Be-L, the two most common sequences to begin a Barrier DCS. The fact that the same Barrier cross-shore successions were interpreted from equatorial latitudes (*e.g.*, Sierra Leone, Southern Coast) to the polar regions (*e.g.*, Russia Federation, Murmansk Oblast) shows that these catenas are not random but that they follow succinct configurations that can be prescribed as global patterns (Appendix I; available at www.JCRonline.org). In addition to the catenas observed from satellite images in the dataset, as reported in Table 2, other possibilities exist as natural potentialities (see Table 3). The boldfaced archetypes in Table 3 represent the most commonly occurring di- and tri-sequent catena successions, whereas the archetypes in parentheses are suggested possibilities that might in some instances be added to or replace an identified catenary sequence. It is not suggested that all of the possibilities would be obtained, and it is thus suggested, and indeed expected, that only one of the parenthetical archetypes would be added to the sequence changing its ordering. The length of the cross-shore transect also affects the catenary sequence as, for example, in the case of a mainland barrier of Barrier-Beach-Lagoon that could be extended across the lagoon to include additional archetypes in the order Beach-Till-Ice-Wetland-

Table 3. *Potential cross-shore ecological associations based on concatenation of observed Archetypes and sub archetypes to form additional generalized, hypothetical, or idealized possibilities for developing Dominant Catenary Sequences (DCS) that may occur around the world's coasts. These potential naturally-occurring catenas should be compared with actual sequences identified in the study images, as listed in Table 2. Note that the cross-shore sequences presented here may be variable with Archetypes and sub archetypes occurring in any order subsequent to the initiating Archetype. The Archetype extensions in brackets are suggestions for possible DCS that are initiated by common di- or tri-sequent catenas (as shown in the boldfaced concatenations). These DCS are based on initiation from offshore to onshore.*

I. BARRIER ARCHETYPE

Potential Cross-shore Catenary Sequences (sub archetype)

(bayhead barrier)

Ba-Be-[Du-L-U-W] = **Barrier-Beach-[**Dune-Lagoon-Upland-Wetland]

(barrier island and spit)

Ba-Be-Br-[Du-W-U] = **Barrier-Beach-Beach Ridge-[**Dune-Wetland-Upland]
Ba-Be-F-[Du-Br-L-W-U] = **Barrier-Beach-Flat-[**Dune-Beach Ridge-Lagoon-Wetland-Upland]
Ba-Be-L-[Be-T-I-W-U] = **Barrier-Beach-Lagoon-[**Beach-Till-Ice-Wetland-Upland]
Ba-Be-W-[L-U] = **Barrier-Beach-Wetland-[**Lagoon-Upland]

(mainland barrier)

Ba-Be-[Du-W-L-U] = **Barrier-Beach-[**Dune-Wetland-Lagoon-Upland]
Ba-Be-Du-[F-W-L] = **Barrier-Beach-Dune-[**Flat-Wetland-Lagoon]
Ba-Be-L-[Be-T-I-W-U] = **Barrier-Beach-Lagoon-[**Beach-Till-Ice-Wetland-Upland]

II. BEACH ARCHETYPE

Potential Cross-shore Catenary Sequences (sub archetype)

(beachrock)

Be-Br-[U-W] = **Beach-Beach Ridge-[**Upland-Wetland]
Be-Du-[U] = **Beach-Dune-[**Upland]

(carbonate)

Be-Br-[U-W] = **Beach-Beach Ridge-[**Upland-Wetland]
Be-Cl-[U] = **Beach-Cliff-[**Upland]
Be-Du-[Cl-L-M-U-W] = **Beach-Dune-[**Cliff-Lagoon-Mountain-Upland-Wetland]
Be-L-[W-U] = **Beach-Lagoon-[**Wetland-Upland]
Be-R-[Cl-U-Du] = **Beach-Rock-[**Cliff-Upland-Dune]
Be-W-[U] = **Beach-Wetland-[**Upland]

(silica)

Be-Br-[U-W] = **Beach-Beach Ridge-[**Upland-Wetland]
Be-Du-[Cl-U-L-W] = **Beach-Dune-[**Cliff-Upland-Lagoon-Wetland]

(carbonate + silica)

Be-Br-[L-W] = **Beach-Beach Ridge-[**Lagoon-Wetland]
Be-L-[W-U] = **Beach-Lagoon-[**Wetland-Upland]
Be-R-[Cl-U-Du] = **Beach-Rock-[**Cliff-Upland-Dune]
Be-W-[U] = **Beach-Wetland-[**Upland]

(carbonate + silica + overwash)

Be-Br-[L-W] = **Beach-Beach Ridge-[**Lagoon-Wetland]
Be-Cl-[U] = **Beach-Cliff-[**Upland]

(silica + overwash)

Be-Br-[L-W] = **Beach-Beach Ridge-[**Lagoon-Wetland]
Be-Cl-[U] = **Beach-Cliff-[**Upland]

Table 3. *(continued).*

III. CLIFF ARCHETYPE

Potential Cross-shore Catenary Sequences

Cl-U-[Du] = **Cliff-Upland-[**Dune]

IV. CORAL REEF ARCHETYPE

Potential Cross-shore Catenary Sequences (sub archetype)

(atoll)

Cr-Be-[F-L-U] = **Coral Reef-Beach-[**Flat-Lagoon-Upland]
Cr-L-[Be-W-U] = **Coral Reef-Lagoon-[**Beach-Wetland-Upland]

(compound)

Cr-Be-[Du-W-U] = **Coral Reef-Beach-[**Dune-Wetland-Upland]

(fringing)

Cr-Be-[W-L-Cl-M-U] = **Coral Reef-Beach-[**Wetland-Lagoon-Cliff-Mountain-Upland]
Cr-W-[Be-M] = **Coral Reef-Wetland-[**Beach-Mountain]

(patch)

Cr-F-[Be-W] = **Coral Reef-Flat-[**Beach-Wetland]
Cr-L-[Be-W] = **Coral Reef-Lagoon-[**Beach-Wetland]

(atoll + fringing)

Cr-Be-[U] = **Coral Reef-Beach-[**Upland]
Cr-F-[Be-U] = **Coral Reef-Flat-[**Beach-Upland]

V. DELTA ARCHETYPE

Potential Cross-shore Catenary Sequences

De-Br-[Be-W-U] = **Delta-Beach Ridge-[**Beach-Wetland-Upland]
De-F-[Be-W-U] = **Delta-Flat-[**Beach-Wetland-Upland]

VI. DUNE ARCHETYPE

Potential Cross-shore Catenary Sequences

Du-L-[U] = **Dune-Lagoon-[**Upland]
Du-W-[Cl-U] = **Dune-Wetland-[**Cliff-Upland]

VII. FLAT ARCHETYPE

Potential Cross-shore Catenary Sequences (sub archetype)

(mud)

F-Be-[Du-W-U] = **Flat-Beach-[**Dune-Wetland-Upland]
F-W-[U] = **Flat-Wetland-[**Upland]

(sand)

F-Be-[Du-W-U] = **Flat-Beach-[**Dune-Wetland-Upland]
F-L-[W-U] = **Flat-Lagoon-[**Wetland-Upland]
F-R-[Be-U] = **Flat-Rock-[**Beach-Upland]

(mud + sand)

F-L-[W-U] = **Flat-Lagoon-[**Wetland-Upland]
F-R-[Be-U] = **Flat-Rock-[**Beach-Upland]
F-W-[U] = **Flat-Wetland-[**Upland]

(mud + tidal channels)

F-L-[W-U] = **Flat-Lagoon-[**Wetland-Upland]
F-W-[U] = **Flat-Wetland-[**Upland]

(sand + tidal channels)

F-Be-[Ba-Du-W-U] = **Flat-Beach-[**Barrier-Dune-Wetland-Upland]
F-T-[I-M-U] = **Flat-Till-[**Ice-Mountain-Upland]

(mud + sand + tidal channels)

F-L-[W-U] = **Flat-Lagoon-[**Wetland-Upland]
F-W-[U] = **Flat-Wetland-[**Upland]

Table 3. *(continued).*

VIII. ICE ARCHETYPE
Potential Cross-shore Catenary Sequences
I-Be-[Du-L-U] = **Ice-Beach-[**Dune-Lagoon-Upland]
I-Cl-[U] = **Ice-Cliff-[**Upland]

IX. LAGOON ARCHETYPE
Potential Cross-shore Catenary Sequences (sub archetype)
(open)
L-Cr-[F-U] = **Lagoon-Coral Reef-[**Flat-Upland]
L-F-[Cr-W] = **Lagoon-Flat-[**Coral Reef-Wetland]
L-W-[F-U] = **Lagoon-Wetland-[**Flat-Upland]

(closed)
L-W-[F-U] = **Lagoon-Wetland-[**Flat-Upland]

X. ROCK ARCHETYPE
Potential Cross-shore Catenary Sequences (sub archetype)
(undifferentiated)
R-I-[T] = **Rock-Ice-[**Till]

(platform + talus and scree)
R-Cl-[Upland-Ice] = **Rock-Cliff-[**Upland-Ice]

XI. TILL ARCHTYPE
Potential Cross-shore Catenary Sequences
T-Cl-U = **Till-Cliff-Upland**

XII. WETLAND ARCHETYPE
Potential Cross-shore Catenary Sequences (sub archetype)
(mangrove)
W-De-[F-U] = **Wetland-Delta-[**Flat-Upland]
W-U-[F] = **Wetland-Upland-[**Flat]

(marsh)
W-De-[F-U] = **Wetland-Delta-[**Flat-Upland]
W-U-[F] = **Wetland-Upland-[**Flat]

(marsh + submerged vegetation)
W-L-[F-U] = **Wetland-Lagoon-[**Flat-Upland]

Upland to give the potential octa-sequent catena that is codified as Barrier-Beach-Lagoon-Beach-Till-Ice-Wetland-Upland (Ba-Be-L-Be-T-I-W-U). Also note that catenary sequence may repeat across sub archetypes, as would be expected but which was not necessarily observed in the extant dataset.

Beach Archetype Dominant Catenary Sequences (DCS)

For the purposes of this study, the Beach Archetype was morphologically undifferentiated in satellite view because it was generally too difficult to categorize most beaches in a morphodynamic classification where scalar parameters prohibited detailed views (*e.g.*, Short, 2006; Short and Wright, 1983; Wright and Thom, 1977). Depending on scale and image quality, it was however possible in some cases to determine the morphodynamic status of a beach system. The lithological composition of beaches was purely estimated on the basis of geographic zonation, macrogeology of the coastal belt, and collateral data. Using these techniques, specific DCS patterns emerged and analysis among the sub archetypes commenced.

The Beach Archetype was divided into five sub archetypes *viz*. beachrock, carbonate, overwash, rampart, and silica. A total of thirty-one (31) DCS were identified for those coastal belts that began a cross-shore interpretation transect with a beach ecological system. Of those 31 DCS, one (1) was beachrock, seven (7) were carbonate, thirteen (13) were silica, six (6) were a mixture of carbonate and silica, one (1) was a mixture of carbonate, silica, and overwash fans, one (1) was a mixture of silica and overwash fans, and finally two (2) were rampart catenas (Table 2). Even though the Beach-Dune (Be-Du) couplet was by far the most common association to begin a Beach Archetype DCS, other couplets demonstrated the validity of variable concatenations. Beaches are a nearly ubiquitous feature of coastal belts and are consequently found in association with many other archetypes the world over, including Beach-Beach Ridge (Be-Br), Beach-Cliff (Be-Cl), Beach-Lagoon (Be-L), Beach-Rock (Be-R), and Beach-Wetland (Be-W) (Appendix I; available at www.JCRonline.org). As shown in Table 3, some beach concatenations repeat across archetypes to produce a range of possibilities that emphasize the potential for the Beach Archetype to occur in a wide range of coastal belt settings. In addition to catenary replications across sub archetypes, additional possibilities are indicated in parentheses. This recombination of archetype strings in a cross-shore direction emphasizes the repeatability of archetypical sequences across sub archetypes. The di-sequent catena of Beach-Beach Ridge, for example, repeats for the following sub archetypes: beachrock, carbonate, silica, carbonate plus silica, carbonate plus silica plus overwash, and silica plus overwash. This occurrence shows the value of the BCCS for identifying cross-shore ecological sequences, both observed and potential.

Cliff Archetype Dominant Catenary Sequences (DCS)

The DCS for Cliff Archetypes tend to be relatively simple because cliffs are always coupled by an upland: Cl-U. This is true for the three (3) main sub archetypes of Cliff: igneous, metamorphic, and sedimentary. A total of four (4) Cliff Archetype DCS were identified: one (1) for igneous, one (1) for metamorphic, and two (2) for sedimentary. The DCS Cliff-Upland couplet persisted throughout all Cliff sub archetypes and was found from equatorial (*e.g.*, Papua New Guinea, East New Britain, NE Coast) to subpolar regions (*e.g.*, Chile, Isla Wollaston, NE Coast).

Because coastal cliffs may be composed of nearly any type of consolidated or partly indurated geological material, it is consequently useful to indicate the nature of the composition. Analysis of the satellite imagery showed that the appearance of cliff materials is distinctive and has implications for the types of associated ecological systems. For example, tombolos made of sedimentary materials present a special case when the cliff is an anchor point along the coast. With the tombolo landward and fronting the Beach Archetype, the tetra-sequent DCS of Cliff-Upland-Beach-Upland (Cl-U-Be-U) is formulated (Table 2) and observed in a tropical location (*e.g.*, Mexico [State of Veracruz, Central Coast] [Appendix I; available at www.JCRonline.org]). Table 3 shows that an additional concatenation of Cliff-Upland-Dune (Cl-U-Du) may be present but was not observed in this study.

Table 4. *Classification of coastal cross-shore ecological sequences based on interpretation of satellite imagery: Coastal Ecological Sequence (CES) codes beginning with the Barrier Archetype. The actual Google Earth location of the satellite image and the latitudinal zonation are also provided.*

Archetype	Google Earth Satellite Image Location	Coastal Ecological Sequence (CES)	Latitudinal Zonation
Barrier	Argentina (Balneario San Cayetano, Buenos Aires Province)	$7Ba_{mb}Be_{si}Du_{bo}W_{mr}L_{cl}$	Middle Latitude
Barrier	Australia (Tasmania, Northeastern Coast)	$7Ba_{mb}Be_{ow,si}Du_{bo}W_{mr,sl}$	Middle Latitude
Barrier	Canada (Manitoba, Northeastern Coast)	$7Ba_{bi}F_{mu}Be_{si}DuBr_{sp}W_{mr}$	Subpolar
Barrier	Colombia (Peninsula da la Guajira)	$2Ba_{bi}Be_{ca}Br_{sp}DuW_{mr,sl}$	Tropical, ITCZ
Barrier	Colombia (Rincon del Mar Coast)	$2Ba_{bi}Be_{ca}W_{ma}L_{op}$	Equatorial, ITCZ
Barrier	El Salvador (Tropical Pacific Coast)	$7Ba_{mb}Be_{ca}DuW_{ma}U_{fo}$	Tropical
Barrier	Guatemala (Central Pacific Coast)	$7Ba_{bi}Be_{ca}DuL_{op}W_{ma,mr}$	Tropical, ITCZ
Barrier	Iceland (Southern Coast)	$7Ba_{bi}Be_{si}L_{op}U_{eb}$	Subpolar
Barrier	India (Northeastern Tropical Coast)	$2Ba_{bi}F_{sa,mu}Be_{ca,ow}Du_{bo}W_{ma,mr}$	Tropical
Barrier	Ivory Coast	$7Ba_{mb}Be_{ca}DuW_{ma}L_{it}$	Equatorial, ITCZ
Barrier	Japan (Hokkaido Island, Southeastern Coast)	$7Ba_{mb}Be_{si,ow}DuL_{op}W_{mr}$	Middle Latitude
Barrier	Madagascar (Southeastern Coast)	$7Ba_{mb}Be_{ca,si}DuW_{ma,mr}L_{cl}U_{gr}$	Subtropical
Barrier	Mexico (Baja California, Guardian Angel Island)	$2Ba_{bi}Be_{ow,si}F_{sa}L_{op}W_{mr,sv}U_{de,eb}$	Subtropical
Barrier	Mexico (Northeastern Coast)	$7Ba_{bi}Be_{ca,si}Du_{bo}W_{mr,sv}L_{op}$	Subtropical
Barrier	Mexico (State of Chiapas, Pacific Coast)	$7Ba_{mb}Be_{si,ca}U_{sr}$	Tropical
Barrier	Mexico (State of Tamaulipas)	$7Ba_{bi}Be_{ca,si}Du_{bo}W_{mr}L_{op}Be_{ca,si}L_{op}Be_{ca,si}W_{mr}$	Subtropical
Barrier	New Zealand (Canterbury Region, South Island)	$7Ba_{bi}Be_{ow,si}DuL_{op}U_{fo}$	Middle Latitude
Barrier	New Zealand (Parengarenga Harbour, Northland Peninsula)	$7Ba_{mb}Be_{si}Du_{bo}L_{op}F_{sa,tc}W_{mr}$	Subtropical
Barrier	Russia Federation (Kamchatka Peninsula, Chukchi Sea)	$7Ba_{bi}Be_{si}DuL_{op}W_{mr}$	Subpolar
Barrier	Russia Federation (Murmansk Oblast)	$5,7Ba_{bb}Be_{si}L_{op}W_{mr}$	Polar
Barrier	Russia Federation (Sakhalin Island)	$7Ba_{bb}Be_{si}Br_{ch}W_{mr}L_{op}W_{mr,sw}$	Middle Latitude
Barrier	Sierra Leone (Baoma Island)	$2Ba_{bi}Be_{ca}L_{it}Du_{ds}W_{ma,mr,sl}$	Equatorial, ITCZ
Barrier	Sierra Leone (Southern Coast)	$7Ba_{mb}Be_{ca}DuL_{cl}W_{ma}$	Equatorial, ITCZ
Barrier	Ukraine (Obytichna Gulf Coast, Sea of Azov)	$2Ba_{bi}Be_{si}DuW_{mr}L_{cl}$	Middle Latitude
Barrier	Uruguay (Southern Coast)	$4,7Ba_{mb}Be_{si}W_{mr}L_{it}U_{gr}$	Subtropical
Barrier	USA (Alabama, Petit Bois Island)	$7Ba_{bi}Be_{si}Du_{bo}W_{mr}$	Subtropical
Barrier	USA (Alaska, Pingurbek Island)	$7Ba_{bi}Be_{si}L_{op}F_{mu}W_{mr}$	Subpolar
Barrier	USA (Alaska, Resurrection Bay)	$2Ba_{bi}Be_{si}L_{op}TI_{gl}$	Subpolar
Barrier	USA (Alaska, St. Lawrence Island)	$2Ba_{bi}Be_{ow,si}DuL_{it}W_{mr}U_{tu}$	Subpolar
Barrier	USA (California, Humboldt County)	$7Ba_{bi}Be_{si}L_{op}Be_{si}W_{mr}U_{fo}$	Middle Latitude
Barrier	USA (Georgia, Georgia Sea Island)	$2,4Ba_{bi}Be_{si}DuF_{mu,tc}W_{mr}L_{op}$	Subtropical
Barrier	USA (North Carolina, Onslow Beach)	$7Ba_{bi}Be_{si}DuW_{ma,mr}L_{op}$	Subtropical
Barrier	USA (Oregon, Central Coast)	$7Ba_{mb}Be_{si}DuW_{mr}$	Middle Latitude
Barrier	USA (Oregon, Southern Coast)	$7Ba_{mb}Be_{si}DuW_{mr}$	Middle Latitude
Barrier	USA (Texas, Hog Island)	$7Ba_{bi}Be_{si,ow}Du_{bo}W_{mr}L_{op}$	Subtropical

Coral Reef Archetype Dominant Catenary Sequences (DCS)

The Coral Reef Archetype is divided into five sub archetypes: atoll, barrier, compound, fringing, and patch (*e.g.*, Guilcher, 1988; Hopley, Smithers, and Parnell, 2007; Riegl and Dodge, 2008). A total of twenty-four (24) DCS were identified for those coastal belts that began a cross-shore interpretation transect with a coral reef. Of those 24 DCS, two (2) were considered atolls, two (2) were barrier reefs, six (6) were compound reefs, eleven (11) were fringing reefs, one (1) was a patch reef, and two (2) were an atoll + fringing reef complex (Table 2). Common DCS couplets found throughout equatorial (*e.g.*, Zanzibar, Southern Coast), tropical (*e.g.*, Jamaica, Caribbean Sea, SW Coast), and subtropical (*e.g.*, Japan, Okinawa, Central Western Coast) latitudes included Coral Reef-Beach (Cr-Be) and Coral Reef-Lagoon (Cr-L). The simplest Coral Reef DCS would either occur in midocean locations associated with seamounts, tablemounts, and volcanic islands, or in the case of this study, the Great Barrier Reef off the Queensland coast. This DCS would simply be Cr because the barrier reef is many kilometers offshore and the mainland interface is not included in the coastal belt satellite scene. One consistent tri-sequent DCS association occurs in the form of the Coral Reef-Beach-Upland (Cr-Be-U) catena, which were interpreted for sub archetypes of compound (*e.g.*, Indonesia, West Papua, Central Northern Coast), fringing (*e.g.*, Java, SW Coast), and atoll + fringing complexes (*e.g.*, Indonesia, Nurseen Island) (Table 2, Appendix I; available at www.JCRonline.org). These coastal belt DCS associations may then be backed onshore by another beach and lagoon system, making it a penta-sequent DCS: Cr-Be-U-Be-L (*e.g.*, Republic of Palau, South Pacific coast). Other coral reefs, conversely, do not have hinter lagoons or uplands, and thus transit directly into either barriers, wetlands, or flats.

Flat Archetype Dominant Catenary Sequences (DCS)

The Flat Archetype DCS was divided into three main sub archetypes: mud, sand, and tidal channels. A total of twenty-two (22) possible DCS linkages were interpreted from the 200 images, as seven (7) were associated with mud, three (3) with sand, three (3) with a mud + sand mixture, one (1) a combination of mud + tidal channels, six (6) a combination of sand + tidal channels, and two (2) a combination of mud + sand + tidal channels (Table 2). The simplest example of a Flat DCS comes in the form of a mono-sequent code: F. This occurs when offshore carbonate sandbanks contain submerged vegetation and tidal channels without any visible land interface, as was the case with examples from the Grand Bahama Bank and the Marquesas Keys. Common di-sequent DCS associations found within several Flat sub archetypes were: Flat-Beach (F-Be),

Table 5. *Classification of coastal cross-shore ecological sequences based on interpretation of satellite imagery: Coastal Ecological Sequence (CES) codes beginning with the Beach Archetype. The actual Google Earth location of the satellite image and the latitudinal zonation are also provided.*

Archetype	Google Earth Satellite Image Location	Coastal Ecological Sequence (CES)	Latitudinal Zonation
Beach	Argentina (Gulfo San Matias, Northern Coast)	$7Be_{si}Du_{bo,pb}U_{sr}$	Middle Latitude
Beach	Australia (Flinders Island, Northeastern Coast)	$2Be_{ca,si}Br_{sp}W_{mr,sl}$	Middle Latitude
Beach	Australia (Tasmania, Southern Coast)	$2{,}6Be_{si}Du_{bo}W_{mr}$	Middle Latitude
Beach	Australia (Tasmania, Southwestern Coast)	$7Be_{si}DuU_{fo}$	Middle Latitude
Beach	Australia (Victoria, Southwestern Coast)	$7Be_{si}Du_{bo,pb}W_{mr}$	Middle Latitude
Beach	Australia (Western Australia, Central Reach of the Coral Coast)	$7Be_{ca,si}Du_{bo,ds,pb}U_{sr}$	Subtropical
Beach	Brazil (State of Bahia)	$7Be_{ca}Br_{sp}W_{mr}$	Tropical
Beach	Brazil (State of Ceará)	$2Be_{ca,si,ow}Du_{pb}U_{sr}$	Equatorial, ITCZ
Beach	Canada (British Columbia, Graham Island)	$2Be_{si}Br_{sp}W_{mr}$	Middle Latitude
Beach	Canada (Nova Scotia, Cape Breton)	$1{,}2Be_{si}Cl_{se,vc80\%}TU_{mr,fo}$	Middle Latitude
Beach	Chile (Isla Wollaston, Northeastern Coast)	$2Be_{si}DuU_{mr}$	Subpolar
Beach	Costa Rica (Playa Esplandilla Sur, Manuel Antonio Parque Nacional)	$2{,}6Be_{ca}DuM_{fo}$	Equatorial, ITCZ
Beach	Democratic Republic of Timor-Leste (Central Southern Coast)	$7Be_{ca}DuU_{fo}$	Equatorial, ITCZ
Beach	Denmark (Skagen Coast)	$2{,}7Be_{si}Br_{sp}U_{fo,sr}$	Subpolar
Beach	Ecuador (Galapagos Islands, Isla Isabela)	$2{,}6Be_{rp}Cl_{ig,vc5\%}U_{fo,sr}$	Equatorial, ITCZ
Beach	Egypt (Gulf of Suez Coast)	$7{,}2Be_{si}R_{ts}Cl_{se,vc5\%}U_{de}$	Subtropical
Beach	Ghana (Gulf of Guinea Coast)	$7Be_{ca}DuW_{ma,sw}L_{cl}$	Equatorial, ITCZ
Beach	Honduras (Northeast Caribbean Coast)	$7Be_{ca,si}Br_{sp}W_{mr}$	Tropical
Beach	Iran (Southeastern Coast)	$2Be_{si}Cl_{se,vc0\%}U_{de}$	Subtropical
Beach	Ireland (Clew Bay)	$1Be_{si}Cl_{se,vc5\%}U_{fo}$	Middle Latitude
Beach	Japan (Hokkaido Island, Eastern Coast)	$7Be_{si,ow}Du_{bo,ds}U_{fo}$	Middle Latitude
Beach	Latvia (Baltic Sea Coast)	$7Be_{si}DuU_{fo}$	Subpolar
Beach	Mauritania (Atlantic Coast)	$2Be_{si}Du_{bo,ds,pb}U_{de}$	Tropical
Beach	Morocco (Southwestern Coast)	$2Be_{br}Cl_{se,vc30\%}U_{sr}$	Subtropical
Beach	Namibia (Namib Desert Coast)	$2Be_{si}Du_{bo,ds,pb}U_{de}$	Subtropical
Beach	Namibia (Skeleton Coast)	$7Be_{si}Du_{ds,pb,sl}$	Subtropical
Beach	Pakistan (Balochistan Province)	$7Be_{ca,si}Cl_{se,sc,vc0\%}U_{de}$	Subtropical
Beach	Portugal (Southwestern Coast)	$7Be_{rp}R_{ts}Cl_{se,vc10\%}U_{sr}$	Middle Latitude
Beach	Sardinia (Southwestern Coast)	$7Be_{si,ow}Du_{bo}U_{fo,sr}$	Middle Latitude
Beach	Solomon Islands (Guadalcanal Province)	$7Be_{ca,si}DuM_{fo}$	Equatorial, ITCZ
Beach	Somalia (Shabeellaha Hoose Region)	$7Be_{ca,si}Du_{bo,ds}U_{de,sr}$	Equatorial, ITCZ
Beach	South Africa (Western Cape Province, Northeastern Coast)	$7Be_{ca,si}Du_{bo,pb}U_{fo,sr}$	Subtropical
Beach	Spain (Gulf of Cádiz, Southern Coast)	$7Be_{si}R_{ts}Cl_{se,vc5\%}Du_{bo}U_{sr}$	Middle Latitude
Beach	Sri Lanka (Kiragalla Bay, Indian Ocean)	$7Be_{ca}Du_{bo,ds}W_{ma,mr,sl}$	Equatorial, ITCZ
Beach	USA (Alaska, North Slope Borough)	$7Be_{si}W_{mr}U_{tu}$	Polar
Beach	USA (California, Point Reyes National Seashore)	$7Be_{si}DuW_{mr}U_{gr,sr}L_{op}$	Middle Latitude
Beach	USA (Florida, St. Vincent Island)	$7Be_{ca,si}Br_{sp}L_{op}$	Subtropical
Beach	USA (Hawaii, Moloka'I)	$2Be_{ca,si}DuCl_{ig,vc5\%}U_{fo}$	Tropical
Beach	USA (Oregon, Central Coast)	$7Be_{si}L_{cl}W_{fo}$	Middle Latitude
Beach	USA (Oregon, Central Coast)	$2{,}6Be_{si}L_{op}W_{mr}U_{fo}$	Middle Latitude
Beach	USA (Oregon, Northern Coast)	$2{,}6Be_{si}Cl_{ig,vc20\text{-}90\%}U_{fo}$	Middle Latitude
Beach	Venezuela (Caracubana Region)	$2Be_{ca}Br_{sp}U_{sr}$	Tropical, ITCZ
Beach	Yemen (Island of Socotra)	$7Be_{ca}Du_{ds}Cl_{se,vc10\%}U_{de}$	Tropical

Flat-Lagoon (F-L), and Flat-Wetland (F-W; *e.g.*, French Guiana, Central Coast). This could then be expanded to several repetitive tri-sequent DCS associations, as found with Flat-Beach-Wetland (F-Be-W; *e.g.*, Canada, Quebec, Hudson Bay Coast), Flat-Lagoon-Wetland (F-L-W; *e.g.*, Guyana, Berbice River Estuary), and Flat-Wetland-Upland (F-W-U; *e.g.*, Canada, Northwest Territories, MacKenzie River Delta). These examples spanned large geographical areas from equatorial to polar regions. The complexity of the Flat Archetype, which occurs in all latitudinal zones, is emphasized by reference to

Table 6. *Classification of coastal cross-shore ecological sequences based on interpretation of satellite imagery: Coastal Ecological Sequence (CES) codes beginning with the Cliff Archetype. The actual Google Earth location of the satellite image and the latitudinal zonation are also provided.*

Archetype	Google Earth Satellite Image Location	Coastal Ecological Sequence (CES)	Latitudinal Zonation
Cliff	Albania (Karaburun Peninsula, Southwestern Coast)	$5Cl_{se,sc,vc80\%}U_{sr}$	Middle Latitude
Cliff	Australia (Tasmania, Southwestern Coast)	$5{,}6Cl_{se,vc0\%}U_{fo}$	Middle Latitude
Cliff	Chile (Isla Wollaston, Northeastern Coast)	$4{,}6Cl_{ig,vc0\%}U_{gr}$	Subpolar
Cliff	Corsica (Strait of Bonifacio, Southern Coast)	$2Cl_{se,sc,vc0\%}U_{fo,sr}$	Middle Latitude
Cliff	Mexico (State of Veracruz, Central Coast)	$2Cl_{se,vc0\%}U_{fo}Be_{ca,si,ow}U_{fo}$	Tropical
Cliff	Nicaragua (Southwestern Tola Coast)	$4{,}6Cl_{se,sc,vc70\%}U_{sr}$	Equatorial, ITCZ
Cliff	Papua New Guinea (East New Britain, Northeastern Coast)	$2Cl_{ig,vc0\%}U_{de,sr}$	Equatorial, ITCZ
Cliff	Peru (Lobos de Tierra)	$4{,}5{,}6Cl_{se,vc5\%}U_{de,eb}$	Equatorial, ITCZ
Cliff	Sultanate of Oman (Southeastern Coast)	$4{,}5{,}6Cl_{me,0\%}U_{eb}$	Tropical
Cliff	USA (Hawaii, Ni'ihau Island)	$2Cl_{ig,vc5\%}U_{eb}$	Tropical
Cliff	USA (Oregon, Central Coast)	$2Cl_{ig,sc}U_{eb,sr}$	Middle Latitude

Table 7. *Classification of coastal cross-shore ecological sequences based on interpretation of satellite imagery: Coastal Ecological Sequence (CES) codes beginning with the Coral Reef Archetype. The actual Google Earth location of the satellite image and the latitudinal zonation are also provided.*

Archetype	Google Earth Satellite Image Location	Coastal Ecological Sequence (CES)	Latitudinal Zonation
Coral Reef	Australia (Queensland, Great Barrier Reef)	$7Cr_{ba}$	Tropical
Coral Reef	Australia (Queensland, Milman Islet)	$1Cr_{at,fr}F_{sa}Be_{ca}U_{fo}$	Tropical, ITCZ
Coral Reef	Australia (Western Australia, Ningaloo Coast)	$2Cr_{fr}L_{op}Be_{ca}U_{de,sr}$	Tropical
Coral Reef	Australia (Western Australia, Ningaloo Coast)	$2Cr_{fr}L_{op}Be_{ca}U_{de,sr}$	Tropical
Coral Reef	Barbuda (Caribbean Sea, Northwestern Coast)	$7Cr_{fr}Ba_{mb}Be_{ca}DuL_{op}W_{ma,mr}U_{sr}$	Tropical
Coral Reef	British Virgin Islands (Anegada)	$2Cr_{cp}L_{op}Be_{ca}W_{ma,mr,sl}$	Tropical
Coral Reef	Colombia (Playa Cinto, Caribbean Coast)	$4,6Cr_{fr}Be_{ca}M_{fo}$	Tropical, ITCZ
Coral Reef	Cuba (Caribbean Sea, Northwestern Coast)	$2,4Cr_{fr}Be_{ca}W_{ma,sv}L_{op}$	Tropical
Coral Reef	East Timor (Jaco Island)	$1Cr_{fr}Cl_{se,vc10\%}U_{fo}$	Equatorial, ITCZ
Coral Reef	Eritrea (Red Sea, Central Coast)	$2,4Cr_{cp}Be_{ca}W_{ma,mr,sl}$	Tropical
Coral Reef	Fiji (Viti Levu, Southeastern Coast)	$2Cr_{fr}W_{ma,sw}M_{fo}$	Tropical
Coral Reef	Haiti (Caribbean Sea, Southwestern Coast)	$2Cr_{fr}Be_{ca}W_{ma,sw,mr}$	Tropical
Coral Reef	Honduras (Roatán Island, Eastern Coast)	$7Cr_{fr}Be_{ca}W_{ma}$	Tropical
Coral Reef	Indonesia (Gulf of Boni Coast)	$2,4Cr_{cp}Be_{ca}DuU_{fo}$	Equatorial, ITCZ
Coral Reef	Indonesia (Nurseen Island)	$1Cr_{at,fr}Be_{ca}U_{fo}$	Equatorial, ITCZ
Coral Reef	Indonesia (Selaru Island)	$1Cr_{fr}Be_{ca}W_{ma}U_{fo}$	Equatorial, ITCZ
Coral Reef	Indonesia (Southeastern Coast)	$1Cr_{at}L_{op}Be_{ca}W_{ma}$	Equatorial, ITCZ
Coral Reef	Indonesia (West Papua, Central Northern Coast)	$1Cr_{cp}Be_{ca}U_{fo}$	Equatorial, ITCZ
Coral Reef	Jamaica (Caribbean Sea, Southwestern Coast)	$2,4Cr_{fr}Be_{ca}W_{ma}$	Tropical
Coral Reef	Japan (Okinawa, Central Western Coast)	$2,4Cr_{fr}L_{op}BeU_{fo}$	Subtropical
Coral Reef	Java (Southwestern Coast)	$2Cr_{fr}Be_{ca}U_{fo}$	Equatorial, ITCZ
Coral Reef	Mozambique (Northeastern Coast)	$2Cr_{cp}L_{op}Be_{ca}W_{ma}U_{sr}$	Tropical
Coral Reef	New Caledonia (Western Coast)	$2Cr_{ba}L_{op}Cr_{fr}Be_{ca}U_{mr,sr}$	Tropical
Coral Reef	Panama (Caribbean Sea, Northern Coast)	$2Cr_{fr}W_{ma}$	Equatorial, ITCZ
Coral Reef	Panama (Caribbean Sea, Northwestern Coast)	$7Cr_{cp}Be_{ca}U_{fo}$	Equatorial, ITCZ
Coral Reef	Republic of Palau (South Pacific Coast)	$1,2Cr_{at}Be_{ca}U_{fo}Be_{ca}L_{op}$	Equatorial, ITCZ
Coral Reef	Solomon Islands (San Cristobol Island)	$2,4Cr_{fr}Be_{ca}W_{ma}$	Tropical, ITCZ
Coral Reef	Turks and Caicos Islands	$2Cr_{cp}Ba_{mb}Be_{ca}W_{ma,mr,sl}$	Tropical
Coral Reef	USA (Marquesas Keys; Offshore in the Florida Keys National Wildlife Refuge)	$2Cr_{pa}F_{mu,sa,tc}Be_{ca}W_{ma,mr}$	Subtropical
Coral Reef	Yemen (Gulf of Aden Coast)	$2Cr_{fr}Be_{ca,si}Cl_{ig,vc0\%}U_{de}$	Tropical
Coral Reef	Zanzibar (Southern Coast)	$2Cr_{fr}Be_{ca}W_{ma}$	Equatorial, ITCZ

additional potential concatenations that show repetitive catenary sequences across sub archetypes (Table 3). Parenthetical archetypes are indicated for potential recombinations that may or may not occur depending on location.

Rock Archetype Dominant Catenary Sequences (DCS)

The Rock Archetype DCS, which were divided into three sub archetypes (platform, rock reef, and talus/scree), are predominantly associated with cliffs or bluffs that, in turn, are backed by uplands. A total of eleven (11) DCS linkages were interpreted for the Rock Archetype, with three (3) associated with platforms, two (2) with rock reefs, two (2) with talus/scree, two (2) undifferentiated, one (1) a platform + talus/scree combination, and one (1) a platform + rock reef + talus/scree combination. The most common DCS, which occurs with every sub archetype, was the tri-sequent catena: Rock-Cliff-Upland (R-Cl-U). Examples of this DCS were found in subpolar (*e.g.*, Finland, Gulf of Finland, Southern Coast), middle latitude (*e.g.*, United Kingdom, Wales, SW Coast), and tropical (*e.g.*, U.S.A., Hawaii, Moloka'I) regions.

Occasionally, this DCS would be expanded to a tetra-sequent catena with the addition of an Ice Archetype component (usually in the form of glacial ice) beyond the upland. Therefore, the new DCS would be Rock-Cliff-Upland-Ice (R-Cl-U-I), which was identified under the talus/scree sub archetype at middle latitudes (*e.g.*, New Zealand, South Island, SW Coast), subpolar areas (*e.g.*, Greenland, Nuuk Fjord, SW Coast), and polar regions (*e.g.*, Canada, Nunavut, Ellesmere Island). Further potentialities, such as the addition of the Till

Table 8. *Classification of coastal cross-shore ecological sequences based on interpretation of satellite imagery: Coastal Ecological Sequence (CES) codes beginning with the Delta Archetype. The actual Google Earth location of the satellite image and the latitudinal zonation are also provided.*

Archetype	Google Earth Satellite Image Location	Coastal Ecological Sequence (CES)	Latitudinal Zonation
Delta	Argentina-Uruguay (Río de la Plata Delta)	$2DeF_{mu,tc}W_{mr}U_{fo,gr}$	Subtropical
Delta	Brazil (Amazon River Delta)	$2DeF_{mu}W_{ma}$	Equatorial, ITCZ
Delta	Canada (Northwest Territories, MacKenzie River Delta)	$2DeF_{mu}W_{mr,sw}U_{fo}$	Polar
Delta	Ecuador (Santiago River Delta, Northern Coast)	$2DeF_{mu}Be_{ca,si}W_{ma}$	Equatorial, ITCZ
Delta	Egypt (Nile River Delta)	$2DeBa_{mb}Be_{si}DuW_{mr}$	Subtropical
Delta	Pakistan (Indus River Delta, Southeastern Coast)	$2DeF_{mu,sa,tc}Be_{si}F_{mu,tc}W_{ma,mr}$	Subtropical
Delta	Panama (Azeuro Peninsula, Eastern Coast)	$2DeF_{mu,sa,tc}Be_{ca,si}U_{fo}$	Equatorial, ITCZ
Delta	Romania (Danube River Delta)	$7DeBe_{si}Br_{sp}W_{mr}$	Middle Latitude
Delta	USA (Alaska, Ivishak River)	8De	Polar
Delta	USA (Alaska, Susitna River Delta)	$2DeF_{mu,sa}W_{mr}$	Subpolar

Table 9. *Classification of coastal cross-shore ecological sequences based on interpretation of satellite imagery: Coastal Ecological Sequence (CES) codes beginning with the Flat Archetype. The actual Google Earth location of the satellite image and the latitudinal zonation are also provided.*

Archetype	Google Earth Satellite Image Location	Coastal Ecological Sequence (CES)	Latitudinal Zonation
Flat	Australia (Northern Territory, Blue Mud Bay)	$7F_{mu}W_{ma}F_{mu,tc}U_{sr}$	Tropical
Flat	Australia (Northern Territory, Buckingham Bay)	$2F_{sa,tc}W_{ma,mr,sl}U_{sr}$	Tropical, ITCZ
Flat	Australia (Northern Territory, Dundee Beach)	$2F_{sa,tc}W_{ma}U_{sr}$	Tropical, ITCZ
Flat	Australia (Queensland, Central Coast)	$2F_{sa}Be_{ca,si}U_{sr}W_{mr}$	Tropical
Flat	Australia (Tasmania, Northwestern Coast)	$7F_{sa,tc}Be_{si}Du_{bo}W_{mr,sl}$	Middle Latitude
Flat	Australia (Western Australia, Exmouth Gulf Coast)	$2F_{sa,tc}W_{ma,sl}U_{sr}$	Tropical
Flat	Australia (Western Australia, Pilbara Region Coast)	$2,4F_{sa}W_{ma,sl}U_{sr}$	Tropical
Flat	Australia (Western Australia, Shark Bay)	$7F_{sa,sv,tc}Be_{ca,si}U_{sr}$	Subtropical
Flat	Bahamas (Acklins Island)	$2F_{sa,sv,tc}Be_{ca}Br_{sp}W_{mr}$	Tropical
Flat	Bahamas (Great Bahama Bank; Offshore around the Southern and Eastern Margins of the Tongue of the Ocean [TOTO])	$2F_{sa,sv,tc}$	Tropical
Flat	Bangladesh (Putney Island, Bay of Bengal)	$2F_{mu,sa}Be_{ow,si}Du_{bo}F_{mu,sa,tc}W_{ma}$	Tropical
Flat	Bangladesh-India (Bay of Bengal Coast)	$2F_{mu,tc}W_{ma}$	Tropical
Flat	Belize (Carribbean Sea, Southeastern Coast)	$2F_{mu}W_{ma,sw,mr}$	Tropical
Flat	Brazil (State of Ceará, Northeastern Coast)	$2F_{mu,sa,tc}U_{fo}$	Equatorial, ITCZ
Flat	Canada (New Brunswick, Bay of Fundy Coast)	$7F_{mu}RBe_{si}U_{fo}$	Middle Latitude
Flat	Canada (Quebec, Hudson Bay Coast)	$2F_{mu,sa}Be_{si}W_{mr}$	Middle Latitude
Flat	China (Southern Coast)	$7F_{mu}Be_{si}W_{mr}$	Tropical
Flat	Denmark (Island of Læs)	$2,4F_{sa,tc}Be_{si}U_{fo}$	Subpolar
Flat	French Guiana (Central Coast)	$2,4F_{mu}W_{ma}$	Equatorial, ITCZ
Flat	Germany (Borkum Island, Northwestern Coast)	$2F_{mu,sa,tc}Be_{si}W_{mr}$	Middle Latitude
Flat	Guyana (Berbice River Estuary)	$2F_{mu}L_{op}W_{ma}$	Equatorial, ITCZ
Flat	Kazakhstan (Caspian Sea Coast)	$2F_{mu}W_{mr,sl,sv}$	Middle Latitude
Flat	Kenya (Lamu Archipelago, Indian Ocean)	$2F_{mu}W_{ma,mr,sl}$	Equatorial, ITCZ
Flat	Latvia (Gulf of Riga Coast)	$2F_{sa}Be_{si}Du_{ds}U_{fo}$	Subpolar
Flat	Mexico (State of Yucatan, Central Northern Coast)	$2F_{sa,mu}Be_{ca,si}Du_{bo}W_{ma,mr}$	Tropical
Flat	Myanmar (Sittaung Delta, Gulf of Martaban Coast)	$2F_{mu,tc}W_{ma,mr,sl}$	Tropical
Flat	Russia Federation (Novaya Zemlya, Northeastern Coast)	$2F_{sa,tc}TI_{gl}$	Polar
Flat	USA (Florida, Everglades Coast)	$2,4,6F_{mu}L_{it}W_{ma,mr}$	Subtropical
Flat	USA (Florida, Southern Peninsula Coast)	$2,4,6F_{mu}L_{it}W_{ma,mr}U_{fo}$	Subtropical
Flat	USA (Marquesas Keys; Offshore in the Florida Keys National Wildlife Refuge)	$2F_{sa,sv,tc}$	Subtropical
Flat	USA (Maryland, Chesapeake Bay)	$5F_{mu}Be_{si}W_{mr}U_{fo}$	Middle Latitude
Flat	USA-Mexico (Colorado River Delta, Isla Montague)	$7F_{mu,tc}W_{mr,sl}$	Subtropical

Table 10. *Classification of coastal cross-shore ecological sequences based on interpretation of satellite imagery: Coastal Ecological Sequence (CES) codes beginning with the Rock Archetype. The actual Google Earth location of the satellite image and the latitudinal zonation are also provided.*

Archetype	Google Earth Satellite Image Location	Coastal Ecological Sequence (CES)	Latitudinal Zonation
Rock	Antarctica (South Georgia Island, Central Eastern Coast)	$5,7R_{ts}Cl_{ig,vc10\%}U_{eb}I_{gl}$	Middle Latitude
Rock	Australia (Tasmania, Southwestern Coast)	$7R_{ts}Cl_{me,se,vc90\%}U_{fo,gr}$	Middle Latitude
Rock	Australia (Tasmania, Three Hummock Island)	$5,6RCl_{ig,vc5\%}U_{fo}$	Middle Latitude
Rock	Brazil (State of Rio de Janeiro, Southeast Coast)	$2R_{pl}Cl_{ig,vc0\%}U_{fo}$	Tropical
Rock	Canada (Nunavut, Ellesmere Island)	$7R_{ts}Cl_{se,vc5\%}U_{eb,gr}I_{gl}$	Polar
Rock	Croatia (Dalmatian Coast)	$5,6RCl_{se,vc0\%}U_{de}$	Middle Latitude
Rock	Cyprus (Mediterranean Sea, Southwestern Coast)	$2,6R_{pl}Cl_{se,vc50\%}U_{sr}$	Middle Latitude
Rock	Finland (Gulf of Finland, Southern Coast)	$2R_{rr}Cl_{ig}U_{fo}$	Subpolar
Rock	Greece (Archangelos Laconia, Peloponnese Coast)	$2R_{ts}Cl_{se,vc40\%}\ U_{sr}$	Middle Latitude
Rock	Greece (Archangelos Laconia, Peloponnese Coast)	$4,6R_{ts}Cl_{se,vc30\%}U_{eb,sr}$	Middle Latitude
Rock	Greece (Gavdos, Southern Coast)	$7R_{ts}Cl_{se,vc20\%}U_{sr}$	Subtropical
Rock	Greenland (Nuuk Fjord, Southwestern Coast)	$5,7R_{ts}Cl_{ig}U_{eb,gr}I_{gl}$	Subpolar
Rock	Greenland (Southeastern Coast)	$5RI_{st}$	Polar
Rock	Ireland (County Cork, Southwestern Coast)	$7R_{rr}Cl_{se,vc5\%}U_{sr}$	Middle Latitude
Rock	New Zealand (South Island, Southwestern Coast)	$5,7R_{ts}Cl_{ig,me,vc80\%}U_{fo}I_{gl}$	Middle Latitude
Rock	Norway (Offshore in the Norwegian Sea)	$2,7R_{rr}F_{sa,sv}Be_{si}Cl_{me}U_{fo}$	Subpolar
Rock	Norway (Southwest Coast)	$5,7R_{ts}Cl_{ig,vc80\%}U_{fo}I_{gl}$	Subpolar
Rock	Portugal (Southwestern Coast)	$5,6R_{pl,rr,ts}Cl_{se,vc0\%}U_{sr}$	Middle Latitude
Rock	Spain (Canary Islands, Fuerteventura)	$6,7R_{ts}Cl_{ig,vc5\%}U_{gr,sr}$	Subtropical
Rock	United Kingdom (England, White Cliffs of Dover)	$2R_{ts}Cl_{se,uc,vc85\%}U_{gr,sr}$	Middle Latitude
Rock	United Kingdom (Wales, Southwestern Coast)	$4,6R_{pl,ts}Cl_{se,vc0\%}U_{fo,gr}$	Middle Latitude
Rock	USA (California, Central Northern Coast)	$2R_{pl}Be_{si}Cl_{se,vc10\%}U_{gr}$	Middle Latitude
Rock	USA (California, Whitesboro Cove)	$2R_{rr}Cl_{se,vc5\%}U_{gr,fo}$	Middle Latitude
Rock	USA (Hawaii, Moloka'I)	$2R_{ts}Cl_{ig,vc5\%}U_{fo}$	Tropical
Rock	Western Sahara (Barbary Coast)	$7R_{pl}Be_{ca,si}$	Subtropical

Table 11. *Classification of coastal cross-shore ecological sequences based on interpretation of satellite imagery: Coastal Ecological Sequence (CES) codes beginning with the Dune, Ice, Lagoon, Till, and Wetland Archetypes. The actual Google Earth location of the satellite image and the latitudinal zonation are also provided.*

Archetype	Google Earth Satellite Image Location	Coastal Ecological Sequence (CES)	Latitudinal Zonation
Dune	Turkmenistan (Caspian Sea, Central Coast)	$2DuL_{cl}W_{mr,sl}$	Middle Latitude
Ice	Antarctica (Southern Ocean, Princess Astrid Coast)	$2I_{st}$	Polar
Ice	Russia Federation (Chukotka Autonomous Okrug, Eastern Siberia)	$2I_{st}Ba_{mb}Be_{si}L_{op}F_{sa,mu}W_{mr}$	Polar
Lagoon	Myanmar (Gulf of Martaban Coast)	$2L_{op}F_{mu,tc}W_{ma}$	Tropical
Lagoon	Papua New Guinea (Nemto Island Coast)	$2L_{op}Cr_{cp}$	Equatorial, ITCZ
Lagoon	USA (Louisiana, Mississippi River)	$2,7L_{op}W_{mr}$	Subtropical
Till	USA (Alaska, Gulf of Alaska Coast)	$2TI_{gl}$	Subpolar
Wetland	Iceland (Southeastern Coast)	$8W_{mr}U_{gr}$	Subpolar
Wetland	USA (Louisiana, Mississippi River Delta)	$2W_{mr,sv}L_{cl}$	Subtropical

Archetype, are indicated in Table 3 as possible parts of the Rock Archetype catenary sequence.

Delta, Dune, Ice, Lagoon, Till, and Wetland Archetype Dominant Catenary Sequences (DCS)

Because some archetypes are not encountered as a prime codification on the shore as the first ecological system encountered moving inland, they are normally of a less common occurrence. Examples of this include the Delta, Dune, Ice, Lagoon, Till, and Wetland Archetypes (Appendix I; available at www.JCRonline.org).

The Delta Archetype was purposely not differentiated into sub archetypes; therefore, all DCS linkages are of a general nature. A total of seven (7) Delta Archetype DCS occurred, with the most common tri-sequent catenas being: Delta-Flat-Beach (De-F-Be) and Delta-Flat-Wetland (De-F-W). Examples of these DCS occurred from equatorial (*e.g.*, Brazil, Amazon River Delta) to polar regions (*e.g.*, U.S.A., Alaska, Ivishak River). Parenthetical archetypes that may supplement the di-sequent catenas of Delta-Barrier (De-Br) and Delta-Flat (De-F) are indicated as potential variations in Table 3.

The Dune Archetype rarely began the DCS for a coastal belt. Because dune archetypes are commonly fronted by Beach Archetypes, they are not the first ecological system encountered when moving from offshore onto land. In fact, only one example of such a DCS occurred in the entire 200-image dataset. That example was a tri-sequent DCS in the form of a Dune-Lagoon-Wetland (Du-L-W) catena that occurred in the middle latitudes (*e.g.*, Turkmenistan, Caspian Sea, Central Coast). Possibilities for dune cross-shore catenary sequences no doubt exist in coastal belts where dune fields are marching into the sea, as, for example, along the coast of Mauritania, Namibia, and Western Sahara where the possibility exists for concatenations such as Dune-Lagoon-Upland (Du-L-U) and Dune-Wetland-Cliff-Upland (Du-W-Cl-U) (Table 3).

The Ice Archetype is the one outlier in this section, as shore ice can be very common in polar, subpolar, and colder middle latitude regions, being especially prevalent during low sun periods. Even so, only two (2) DCS were identified for those coastal belts beginning with an Ice Archetype. Both fell under the shore types sub archetype in polar latitudes and included a very simple mono-sequent DCS example of Ice (I; *e.g.*, Antarctica, Southern Ocean, Princess Astrid Coast) and a more complex hexa-sequent DCS example of Ice-Barrier-Beach-Lagoon-Flat-Wetland (I-Ba-Be-L-F-W; *e.g.*, Russia Federation, Chukotka Autonomous Okrug, Eastern Siberia). Because of the ubiquitous nature of the Ice Archetype in cold region coastal belts, additional potential catenary sequences other than those observed in this dataset probably exist, for example, Ice-Beach-Dune-Lagoon-Upland (I-Be-Du-L-U) and Ice-Cliff-Upland (I-Cl-U) (Table 3).

The Lagoon Archetype DCS was limited to a single sub archetype (*i.e.* open) with three (3) catenas from equatorial (Lagoon-Coral Reef [L-Cr]; *e.g.*, Papua New Guinea, Nemto Island Coast), tropical (Lagoon-Flat-Wetland [L-F-W]; *e.g.*, Myanmar, Gulf of Martaban Coast), and subtropical (Lagoon-Wetland [L-W]; *e.g.*, U.S.A., Louisiana, Mississippi River) regions. It is noted that lagoons normally are not the first archetype encountered onshore as part of the cross-shore characterization of a coastal belt. Lagoons are, however, commonly encountered as secondary features in cross-shore DCS linkages being most commonly associated with Barrier, Beach, Flat, and Wetland Archetypes (Table 2). Additional possibilities for catenary sequences are indicated in Table 3 for the Lagoon Archetype with open and closed sub archetypes.

The Till Archetype is characterized by coastal belts with morainic shores composed of glacial deposits, such as diamicton, tillite, diamictite, *etc*. These coastal belts now reside in marginally drowned, formerly glaciated terrain and form important archetypical cross-shore catenas. Only one (1) Till Archetype DCS was identified: Till-Ice (T-I). This DCS was undifferentiated without a sub archetype and occurred in a subpolar region (*e.g.*, U.S.A., Alaska, Gulf of Alaska Coast). Table 3 indicates the possibility for a tri-sequent catena of Till-Cliff-Upland (T-Cl-U), where Cliff Archetypes also occur.

The Wetland Archetype rarely occurred as the first biophysical system in a cross-shore DCS, as it is most commonly a subsequent archetype occurring in an ecological sequence. Only two (2) DCS were identified for those coastal belts beginning with a Wetland Archetype. Both were di-sequent catenas that fell under two different sub archetypes. The Wetland-Upland (W-U) DCS was associated with a marsh sub archetype and occurred in a subpolar region (*e.g.*, Iceland, SE Coast), whereas the Wetland-Lagoon (W-L) DCS was associated with a marsh + submerged vegetation sub archetype environment and occurred in a subtropical region (*e.g.*, USA, Louisiana, Mississippi River Delta). Although not observed in this dataset, it is possible that Delta and Flat Archetypes are associated with Wetland Archetype catenas (Table 3).

DISCUSSION

Coastal classification is a complicated issue, as briefly discussed in the introduction to this paper. The purpose of this research project was to ascertain whether it is possible to look at coasts in a different way than from purviews of the past that tended to focus on shoreline or coastline classifications. Although useful in their own regard for special purpose applications, the intent here was to discern coasts as a belt of variable width in terms of environments and more specifically from the point of view of cross-shore eco-physiological successions. The concept of a coastal belt was presented here in an attempt to convey the notion of an alongshore variable width swath that included both marine and terrestrial ecosystems. The notion of viewing the coast as a cohesive multidimensional natural entity that has length, width, and elevation was posited as a possible alternative to the traditional one-dimensional (length) approach. Due to the complexities of coastal environments and especially when attempting to incorporate width (distance from offshore to inland), it was necessary to condense the data into some kind of shorthand notation to avoid lengthy descriptions that verged on the verbose. To this end, the Biophysical Cross-shore Classification System (BCCS), an alphanumeric codification system, was devised to provide a glimpse of the salient cross-shore ecological successions.

Using the BCCS Methodology

Acquisition of large amounts of data meant that an expedient means of presenting it in a comprehendible manner was imperative. To this end, a header format was developed that would precede the actual satellite image. The idea of the header is to give the reader a thumbnail sketch of the satellite image in such a way that critical aspects of the image become immediately apparent by glancing at the header. The format of the header is organized in such a way that the reader is guided toward the Coastal Ecological Sequence (CES), which occurs at the end of the paragraph and is presented as shorthand code translated into plain English. Below the header is the actual satellite image depicting the coastal belt with a scale and north arrow. The image is then followed by an extended caption that includes more detailed information, such as geographic location, latitude and longitude coordinates, climate designation, geomorphological features, botanical presence, and associated animal species. It is anticipated that the similar formats for headers and captions will facilitate understanding and comprehension of the coastal belt depicted in the satellite image. The BCCS was developed for use with satellite images and it is hoped that this methodology will find application in various aspects of coastal research. One essential key to this technique is the interpretation of coastal belt satellite imagery. Some degree of image interpretative skill is thus required to fulfill the mission of characterizing a multidimensional view of a coastal belt of variable and indefinite width, depending on the actual satellite scene.

The Dominant Catenary Sequences (DCS) and Coastal Ecological Sequences (CES) presented in this paper are merely suggestions as to how Archetypes and sub archetypes might be linked and subdivided to show the nature or characteristics of cross-shore ecological sequences in a coastal belt. The master table provided in Appendix I (available at www.JCRonline.org) represents all the raw data obtained from the 200 test images from around the world. Clearly, the examples are not exhaustive, nor do they represent every possibility that might have been encountered. But they did provide enough data to visualize the utility of recognizing Archetype and sub archetype master ecological features that can be further linked into cross-shore catenas. These common reoccurring DCS associations are then expanded upon to include shore-parallel configuration numerical codes, as well as sub archetype descriptor subscripts, to ultimately derive a cross-shore CES. More possibilities exist than what has been shown in this study (*cf*. Table 3), and because the BCCS is an open-ended methodology, it can be expanded or modified as needed. Other coastal researchers are thus encouraged to modify or expand upon what has been initiated here. Collation of more test images will expand the data base and provide opportunity to improve the BCCS and develop more comprehensive codification of ecological successions that make up coastal belts.

Caveats and Challenges

The codifications of ecological sequences were developed for use with the cognitive interpretation of satellite imagery in association of geovisual analytics. Depending on the requirements of the researcher, it may be important to note that sometimes it can be challenging to select scenes that are devoid of color differences across match lines. This minor problem can be resolved in most instances by zooming in or out to change the scale or to slightly reposition the view so that match lines disappear. Advantages to using satellite imagery stem from the fact that all of the world's coasts are available as scenes of alongshore environments and that the digital imagery is amenable to enhancement and interpretation using standard methodologies. To this end, Google Earth Pro provided an ideal platform for acquiring coastal imagery at almost any scale desired by simply using the zoom function. This aspect of the program is essential because coastal biophysical features are scale dependent, meaning that some features or environments can be viewed at small scales (large areas) and still be meaningful, while other ecological systems require large scale (small areas) inspection. For this project, the image scenes are at various scales because a global range of coastal belts was sought in vastly different settings, from equatorial zones to polar regions. In this way, the degree of zooming more or less determined the length and width of the coastal belt being inspected.

Although the end results of the process seem to be useful, the methodology was not without difficulties. For example, several interactive online platforms (*e.g.*, Google Earth Pro, Macrostrat, World Map, Ecoregions 2017) needed to be used in conjunction to achieve a satisfying result. Fortunately, these computer programs are compatible by using the same base map, which facilitated easy movement back and forth between the online platforms. It is probably worthwhile to note that slightly different versions of the LME maps exist on the Internet. Nevertheless, these online resources now enable rapid assimilation of relevant data for specified coastal areas without intensive online searches by the researcher. Accomplishing the same results without these online resources would be difficult and very tedious, if not impossible, for especially remote areas where there is little published scientific information.

An area of possible concern with this methodology focuses on the complexity of determining the position of mean sea level along a shore as there are many different conventions depending on the country and how the boundary between land and water is defined. In Germany, for example, land was previously measured as above NN (normalnull, meaning normal zero), which was related to an old tide gauge in Amsterdam, The Netherlands. The Normalhöhennull (standard elevation zero) or NHN is a vertical datum that today is more commonly used. In geographical terms, NHN is the reference plane for the normal height of a topographical eminence height above mean sea level used in the 1992 German Mean Height Reference System (*Deutsches Haupthöhennetz*). Similarly, in the United States, sea level was previously determined from the National Geodetic Vertical Datum of 1929 (NGVD 29) that was subsequently replaced by the North American Vertical Datum of 1988 (NAVD 88) where the former was determined by minimum-constraint adjustment of geodetic leveling observations in Canada, the United States, and Mexico, whereas the latter uses the Helmert orthometric height to calculate the location of the geoid. This kind of information is relevant to coastal classification because conventional navigational charts scale their bathymetry mostly from the lowest low water tide level, often with a secure addition of a few decimeters to be on the safe side for navigational purposes. Theoretically, maps in the coastal belt may miss a vertical span up to meters and a horizontal one from meters to hundreds of meters. This difference could potentially introduce a conflict in the classifications used in maps and data banks sourced as background information on the internet. Satellite images, as opposed to maps and charts, on the other hand fortuitously show the border or boundary between land and water, depending on the datum and exact time of acquisition as well as tides, wind, swell, *etc*. Codification of cross-shore ecological sequences could conceivably be affected to a minor degree in areas where extreme tide levels occur, including NW Western Australia, Bay of Fundy in Canada, Cook Inlet in Alaska, Rio Gallegos (Reduccion Beacon) in Argentina, and the Magellan Strait in Chile, *etc*.

CONCLUSION

This study showed that it is possible to use satellite images as a basis for interpreting coastal ecological successions within scenes that themselves defined coastal belts. The concept of a coastal belt was presented here as part of an effort to develop the Biophysical Cross-shore Classification System (BCCS), a methodology for characterizing coasts in terms of length and width. It was thus concluded that acquisition of the desired coastal belt permitted interpretation of cross-shore ecological sequences that in turn facilitated comprehension of a 2D and 3D visualization versus an alongshore one-dimensional shoreline classification. Compilation of shorthand codes for different types of coastal ecological systems found in 200 test sites from around the world enabled the recognition of repetitive main features that could be designated as archetypical occurrences. Fifteen (15) primary Archetypes were identified and linked together (based on the cognitive interpretation of the satellite imagery) to form catenas. Those catenas that were considered persistent throughout the coastal belt imagery became known as Dominant Catenary Sequences (DCS). Expansion of the seaward-landward DCS concept to include shore-parallel configuration and sub archetype refinements led to the formulation of cross-shore Coastal Ecological Sequences (CES), which were identified for each of the cognitively interpreted satellite images. To facilitate the description of coastal belts, the presentation of the CES was formalized in terms of a template that included a header for the satellite image, which in turn was followed by an expanded explanatory caption. Use of this template format, which is shown in Figures 2, 4, and 6, was found to provide a convenient basis for comparing and contrasting ecological systems in different latitudinal zones across equatorial, tropical, middle latitude, and polar zones.

The codification of cross-shore ecological sequences presented in this study is provisional and open ended, being amenable to modification as required by different kinds of studies. The codes or alphanumeric symbolization for different ecological systems, which are suggestions for what may be useful in future studies, are limited by the scope of variability found in the 200 global study images. Nevertheless, the interpretation of this satellite image data set resulted in the recognition of discrete offshore to onshore consecutions that provide enhanced visual perceptions of what coastal belts really look like versus one-dimensional shoreline or coastline classifications. In conclusion, it was found that recognition of the concept of a coastal belt always facilitated a 2D view, and sometimes a 3D view when water depth and/or land elevation was taken in account, for studying relationships between adjacent cross-shore ecosystems in terms of ecological sequences or catenas. Such prioritization was found to emphasize coastal width over length.

The main finding of this study, which was based on cognitive interpretations of satellite images that were of limited scope but global in extent, fell to the realization that the number of kinds of cross-shore ecological sequences was finite and not indeterminate. Because repetition of catenas comprising archetypes and sub archetypes occurs, it is possible to classify coasts in terms of cross-shore environmental successions that repeat on a macroscale the world over. Even though coastal belts display great ecological variation according to geographical, geological, geomorphological, botanical, and latitudinal zonation, this study suggests that ecological sequences can be systematized and incorporated into the Biophysical Cross-shore Classification System (BCCS), a new multidimensional approach for looking at coasts. Singularities occur in specialized circumstances with unique ecologies and at least provide spectacular coastal scenes (*e.g.*, El Nido, Philippines; the Galapagos Islands, Ecuador; the Great Ocean Road, Australia; Ha Long Bay, Vietnam; Palau, Micronesia; Legzira, Morocco; White Cliffs of Dover, England), but the general rule is that cross-shore ecological sequences can be shortened to a relative few possibilities that are manageable in terms of classifying coastal belts. Because the coastal ecology needs a foundation upon which to build, it is closely linked to geomorphology, coastal zonality, and ecotonal successions, all of which are incorporated into this newly proposed methodology. Overall, the BCCS was found to be an effective method for the classification of cross-shore ecological successions in coastal belts worldwide and provides the steps for obtaining comprehensive codifications in association with geovisual cognitive analytics.

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