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Latitudinal and Situational Zonation of Coastal Catenary Sequences Observed from Satellite Images Using the Biophysical Cross-shore Classification System (BCCS)

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ABSTRACT

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The Biophysical Cross-shore Classification System (BCCS) was devised as a means for assessing shore-normal ecological and geomorphological successions from offshore to onshore transects within a coastal belt (Finkl and Makowski, 2020). The three-dimensional transects were parameterized in terms of alongshore length, cross-shore width, and depth below or elevation above sea level to codify environments and habitats in the framework of the BCCS. Repetitive ecological successions were so prominent that they were 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. By sequentially linking together several archetypes based on a cross-shore ecological interpretation of the satellite imagery, a common master sequence is generated and referred to as a Dominant Catenary Sequence (DCS; *e.g*., Beach-Dune-Wetland). The more detailed Coastal Ecological Sequence (CES) of a coastal belt, which is defined by a discrete codification sequence built up from the DCS, is formulated by cognitive geovisual-analytics to link the dominant catena with a numbered shore-parallel shape distinction and subscripted sub archetypes to refine the sequential composite archetypes in a DCS. Once the CES has been established, a more thorough header and extended caption can then be composed to disseminate details of the geomorphological-ecological zonation within the geographical purview of latitude, elevation, and situational aspects that can be site-parameterized in terms of intensity of precipitation, temperature, humidity, exposure, windiness, presence of flora and fauna, *etc*. Examples of the BCCS on coastal belts dominated by cliff archetypes are provided in this study through a three-tiered process: Level I: DCS creation; Level II: CES formulation; and Level III: header and extended caption composition. Different latitudes and geographical-biophysical positions illustrate the ubiquity and applicability of identical DCS for broadscale cross-shore characterization of coastal belts, while more detailed ecological definitions are provided by larger-scale (smaller-area) observation of the same types of catenary cross sections for comparative purposes. Derivation of variable CES within identical DCS emphasizes the utility of this cross-shore classification system as it pertains to latitudinal and situational zonation. In this way, variable manifestations of coastal zonation are accommodated in the BCCS for both alongshore and cross-shore coastal belts worldwide.

ADDITIONAL INDEX WORDS: *Satellite imagery, coastal classification, coastal scene, geographical zonation, image interpretation, ecological succession, catena, coastal ecology.*

INTRODUCTION

Application of the Biophysical Cross-shore Classification System (BCCS; Finkl and Makowski, 2020) showed that it is possible to classify cross-shore geomorphological-ecological sequences using Google Earth Pro satellite imagery of the world's coasts. Systematization of cross-shore sequences was codified in terms of commonly occurring archetypes and sub archetypes to the point that it was recognized that certain types of sequences were repeated around the world (Table 1). These commonly occurring sequences mark the first level of the BCCS and are individually termed as Dominant Catenary Sequences (DCS), forming a collage of catenas recognized in all latitudinal zones from equatorial to polar regions. The repeatability of the DCS was not only striking but paved the way to recognizing orderly and cohesive cross-shore ordinations that could be used to formulate three-dimensional (3D) characterizations of coastal belts, providing a basis for broad- and small-scale coastal classifications. Recognition of cross-shore catenas is scale dependent both alongshore and cross-shore, with the latter depending on either the framing of a satellite image or the inland extension of the selected coastal ecological unit. The simplest DCS units were mono-sequent catena initiators, as in the case of Ice, Flat, or Coral Reef archetypes, whereas some of the more complicated sequences were found in coastal barrier island locations, with Barrier, Beach, Dune, Lagoon, Wetland, and Upland archetypes sometimes forming hexa-sequent catenas.

Broad-scale DCS units were refined by the addition of alphanumerical characters, where sequence-initiating numbers refer to coastline configuration in plan or oblique view, and

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Table 1. *Codification of Archetypes and sub archetypes using bolded upper- and lower-case letters as primary archetype designators and lowercase 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). (Adapted from Finkl and Makowski, 2020.)*

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

lowercase subscripts specify relevant properties of the archetype, such as whether a beach was composed of calcium or silicate particles, or a whether a wetland was composed of mangroves, marshes, swamps, or salinas, to form the more detailed Coastal Ecological Sequence (CES); the second level of the BCCS. A simplistic example of second-level BCCS application can be found along the muddy southern coast of China (Figure 1). The DCS is interpreted as Flat-Beach-Wetland (F-Be-W), which is then refined by the CES codified catena $7F_{mu}Be_{si}W_{mr}$. This formulated sequence translates to "straight tropical muddy tidal flats backed by a silica beach grading to wetland marshes."

For descriptive purposes and for comparison and contrast between CES catenas, a third level of the BCCS can be initiated to include informative collateral data, such as geographical information (*e.g.*, the coastal belt in Figure 1 is located about 55 km north of Hainan and 380 km southwest of Hong Kong in an estuary at 20°36′13″ N, 110°25′38″ E that opens to the western South China Sea, landward of Xinliao Dao within the Guangdong Prefecture). These higher-level BCCS compositions are usually in the form of headers and extended captions that provide in-depth local information of the classified coastal belt. A complete and detailed explanation of the BCCS was provided by Finkl and Makowski (2020) for further reference.

Purpose and Goals

The purpose of this paper is to illustrate, using four select Cliff archetype examples, how the BCCS might be used to characterize specific coastal segments and also to compare and contrast different coastal belts. The DCS (Level I) provides a flexible, broad framework for cross-shore classification of coastal belts, whereas the CES (Level II) more closely specifies the nature of archetypical subdivision in the form of sub archetype catenas. Both types of concatenations (DCS and

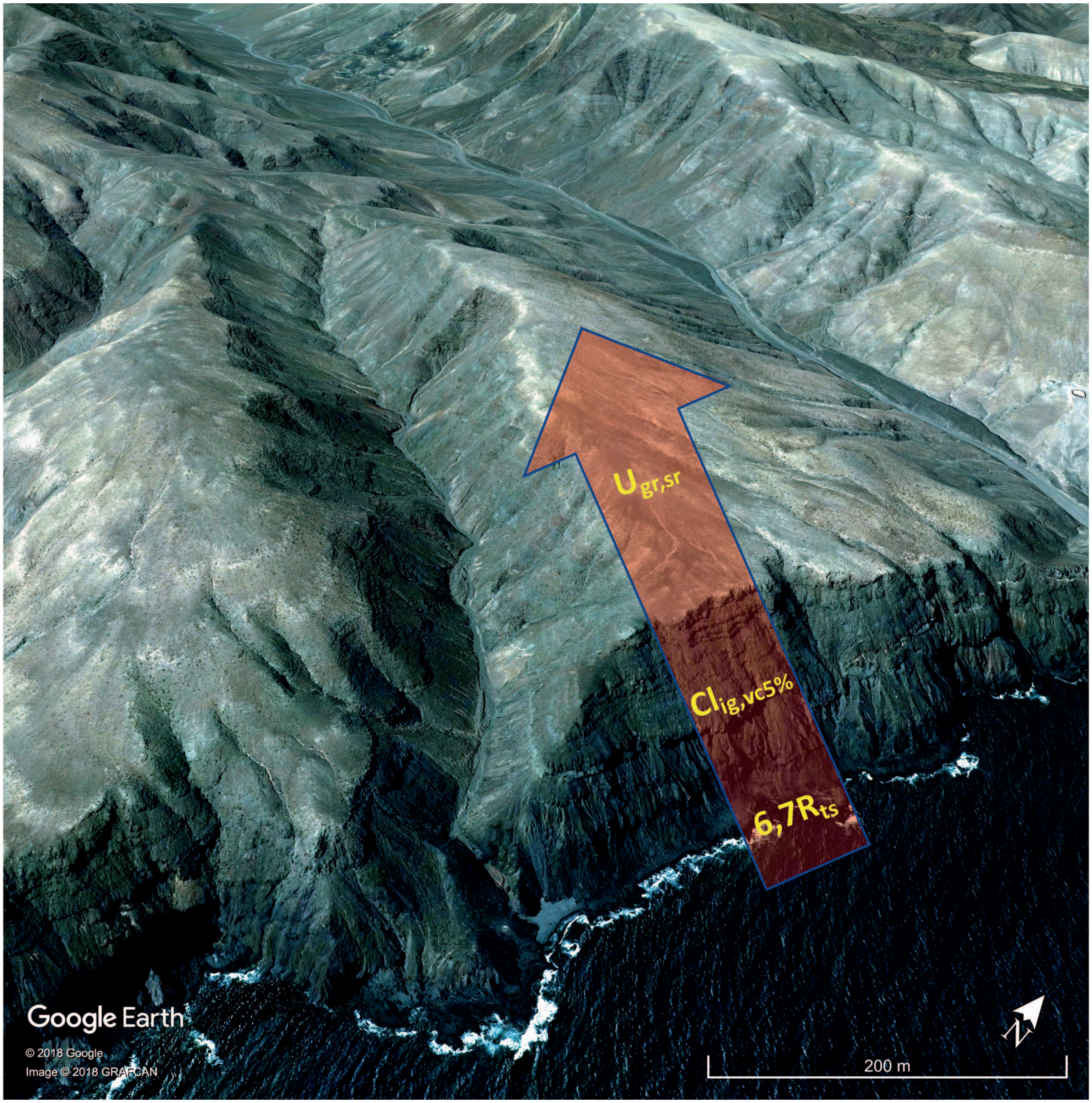
Figure 1. Example of the DCS (Level I) and CES (Level II) application for the Biophysical Cross-shore Classification System (BCCS) on the southern coast of China, with the concatenation: $7F_{mu}Be_{si}W_{mr}$. The "7" numerical distinction relates to a straight shore-parallel coastal belt configuration in plan view. Following the red arrow, the cross-shore sequence is interpreted as tropical muddy tidal flats (F_{mu}) backed by a silica beach (Be_{si}) that grades to wetland marshes (W_{mr}).

CES) are adequate for describing the sequencing of cross-shore environments at many different scales of observation, as provided in satellite imagery. When specifics of a CES in a coastal belt are required, it is necessary and convenient to refer back to the headers and extended captions (Level III) of image scenes because the ecological details contained therein elucidate more specific information on regional and local scales. This information is part and parcel of the geographical zonation and classification (*e.g.*, Fairbridge, 2004; Finkl, 2004; Kelletat, 1989, 1995; Kelletat, Scheffers, and May, 2013; McGill, 1958) of coastal belts worldwide. A sub archetype might, for example, be designated as W_{mr}, which means that this interpreted Wetland archetype contains a marsh environment sub archetype. For many applications, this designation is adequate, but when more detail is required as to the composition of the marsh (for example, flora and fauna for that particular geographic zone), reference to the image header and extended caption provides the necessary collateral information. The same holds true for many CES that terminate landward in an upland environment, and examples are provided here for Cliff archetype cross-shore catenas in subtropical, middle-latitude, and polar-latitudinal zones.

Scope, Orientation, and Point of View

For the sake of simplicity, the scope of this investigation was limited to a recurring tri-sequent archetype catena of Rock-Cliff-Upland (R-Cl-U), with three examples from the Northern Hemisphere and one from the Southern Hemisphere. Orienta-

Terrestrial Biogeographic Realm and Biome: Palearctic Mediterranean Forests, Woodlands, and Scrub. **Ecoregion:** Mediterranean Acacia-Argania Dry Woodlands and Succulent Thickets (796). **Large Marine Ecosystem:** Canary Current (27). **Oblique View:** Precipitous basaltic sea cliffs with steep-to shores and subtropical arid uplands and valleys. **Shoreline:** Rocky. **Environments and Habitats:** High, steep basalt cliffs plunging directly into the sea environments, flat upland and flatiron slope environments, interior rock-sided valleys emptying to the sea environments. **Dominant Catenary Sequence (DCS):** Rock-Cliff-Upland (R-Cl-U). **Coastal Ecological Sequence (CES):** $6{,}7R_{ts}Cl_{ig,vc5\%}U_{gr,sr}$ **Translation:** Straight subtropical promontories and some talus at the base of basaltic cliffs that are mostly bare (~5% vegetative cover) and surmounted by grassy and scrub uplands.



These steep basaltic cliffs (28°16′06″ N, 13°54′52″ W, eye altitude 538 m, imagery date 4 March 2016) occur on the extreme southeast subtropical coast of Fuerteventura, the second largest of Spain's Canary Islands. It sits in the Atlantic Ocean about 100 km off the northwest coast of Africa, northwest of the border between Morocco and Western Sahara. This view is part of the Natural Monument of the Knives of Vigán (Monumento Natural de los Cuchillos de Vigán), a large protected area of some 6000 hectares. These cliffs are about 6 km east of Las Playitas and 6 km west of Pozo Negro. This dramatic scene shows a point where large basaltic lava flows were truncated where they entered the sea after flowing down the flanks of the shield volcano. The cliffs shown here on this steep-to coast are about 100 m high and present a remarkable cliffy coastline. Various layers are evident in the exposure, where each represents a separate flow in an intermittent sequence of volcanic eruptions that produced sufficient volumes of lava to move down the flanks of the volcanic cone. Valleys have been cut into the lava flows, expanding the land surface area and increasing the number of coastal habitats. The cliff faces are largely unstable, and there is little debris downslope where the cliffs meet the water surface. The cliffs extend for great distances below the water surface, making for a steep precipice above and below the ocean surface. Although there is very little colluvial material in the form of talus and scree cones collected at the apparent base of the cliffs at the water surface, there are some small platforms where fine-grained comminuted basalt particles have collected in the form of perched beaches, which are also partly alluvial fans at the mouths of valleys, as seen in the lower center of the satellite image. It is important to recognize that the coastal environments of cliffy coasts include more than the dramatic cliff faces, but also summit levels and valleys that drain to the sea. The bedrock geology here is characterized by initial or shield-stage mafic (mostly basaltic) volcanic rocks that are Pliocene–Pleistocene (5.333–0.0117 Ma) in age. The arid climate of this subtropical island region is classified as BWh, hot low-latitude desert climate.

Ever since the Canary Islands broke free of the ocean, they have been subject to the erosive forces of sea, wind, and rain. Over the millennia, these sterile mounds of lava and volcanic ash have undergone the process of weathering to produce small pockets of soil, in which the first plants, arriving as either wind- or waterborne seeds, were able to gain a tenuous foothold. Currently, more than 2000 species of vascular plants occur in the Canary Islands, with over 1600 arriving without the aid of man, and approximately 40% found nowhere else in the world. Similarly, the first animals to colonize these basaltic islands had to arrive by crossing many kilometers of open water. Isolated from any continental influences, these species were then at liberty to follow their own evolutionary paths, generating a fauna exceptionally rich in endemic taxa. This is perhaps most evident among the reptiles, which include 14 unique species of lizards, skinks, and geckos scattered across the archipelago. Additionally, the Canary Islands are also home to five unique bird species that are only found here: Bolle's pigeon (*Columba bollii*), Laurel pigeon (*Columba junoniae*), Canary Islands stonechat (*Saxicola dacotiae*), Canary Islands chiffchaff (*Phylloscopus canariensis*), and blue chaffinch (*Fringilla teydea*). Four other Canary Island species occur exclusively in Macaronesia, which include the Atlantic canary (*Serinus canaria*), Berthelot's pipit (*Anthus bertholotii*), plain swift (*Apus unicolor*), and the very scarce Macaronesian shearwater (*Puffinus baroli*). Several North African bird species, such as the Barbary falcon (*Falco pelegrinoides*), are also known to have their only European breeding grounds here. The Canary Islands also host two endemic terrestrial mammals: the Canary shrew (*Crocidura canariensis*) and the Canary big-eared bat (*Plecotus teneriffae*).

Figure 2. Sea cliffs and uplands along a coastal belt on the southeast subtropical coast of Fuerteventura, Canary Islands. This oblique view obtained from Google Earth Pro is generally looking to the northwest off the coast of the boundary between Western Sahara and Morocco. The red arrow that transits the coast in a landward direction shows a typical cross-section that can be used to generalize the nature of the coastal belt. Symbols on the arrow conform to sub archetypes that make up this tri-sequent CES catena: $6,7R_{ts}Cl_{ig,vc5\%}U_{gr,sr}$

tion is provided in the header for each example as the Terrestrial Biogeographic Realm and Biome, Ecoregion, and Large Marine Ecosystem, with emphasis on geographic zonation in subtropical, middle-latitude, and polar latitudinal zones. The perspective or point of view focuses on the subscripts, which define the nature of the sub archetypes. In this way, the CES is elucidated by reference to the extended image caption, which was devised using geovisual analytics (*e.g.*, Andrienko *et al*., 2010; Bianchetti, 2015; Scheffers, Scheffers, and Kelletat, 2012) to collate collateral data in a prescribed format according to the BCCS.

The first example (Figure 2) is from the extreme southeast subtropical coast of Fuerteventura, the second largest of Spain's Canary Islands, where there are steep basaltic cliffs (28°16′06″ N, 13°54′52″ W). These cliffs are part of the Natural Monument of the Knives of Vigán (Monumento Natural de los Cuchillos de Vigán), a large protected area of some 6000 hectares. This dramatic scene shows large basaltic lava flows that were truncated as they entered the sea after flowing down the flanks of a shield volcano. The cliffs along this steep-to coast are about 100 m high and present a remarkable example of a Rock archetype (R) at the shore merging with a Cliff archetype (Cl) that terminates at a summit Upland archetype (U) to form the DCS tri-sequent catena: R-Cl-U.

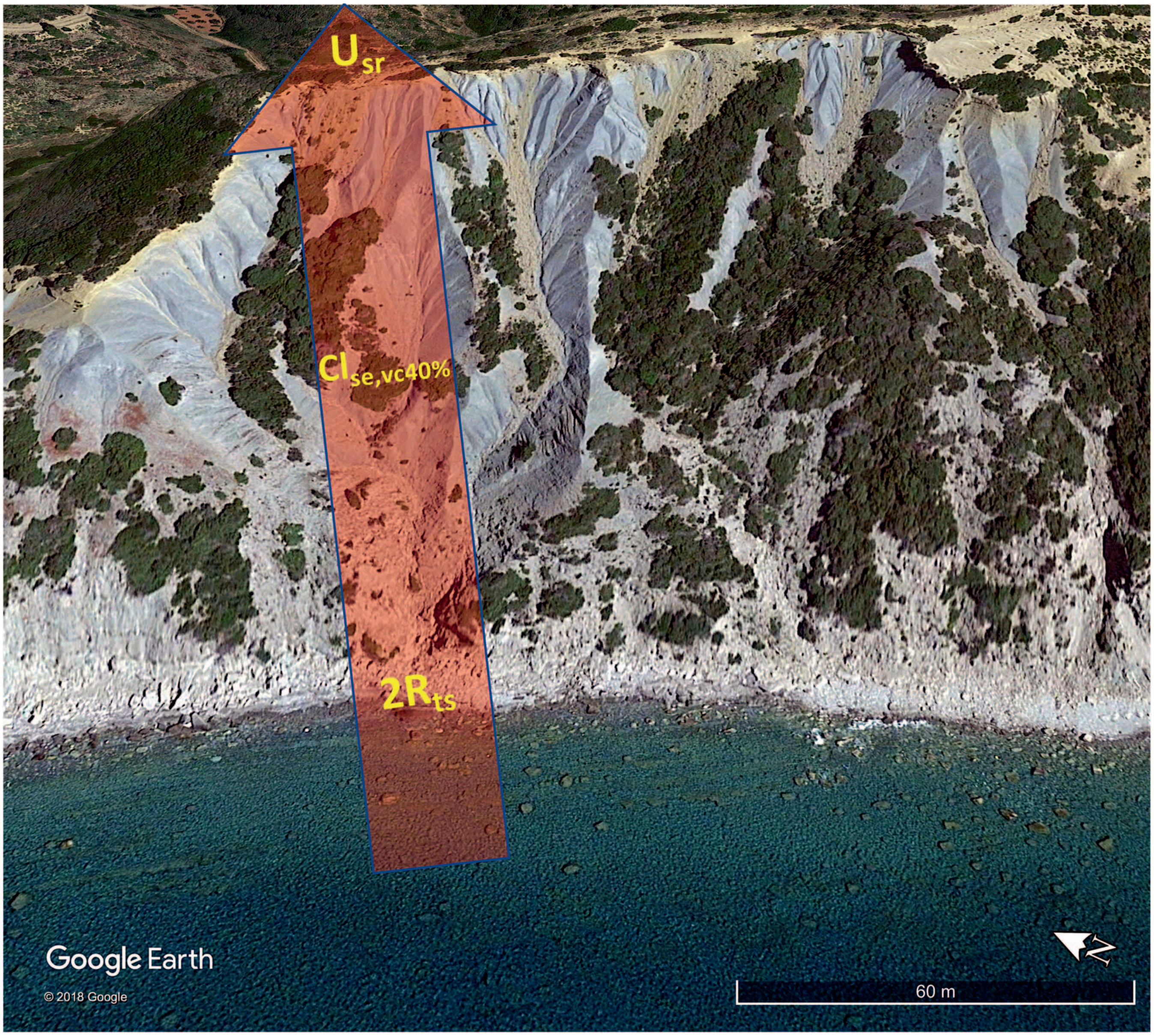
The second example (Figure 3) from the Northern Hemisphere occurs on the middle-latitude southeast coast of the Peloponnese peninsula in southern Greece, which is separated from the central part of the country by the Isthmus of Corinth and the Gulf of Corinth. These eroded coastal cliffs (36°43′34″ N, 21°52′24″ E) occur about 1 km south of Koufosaratsia. The cliff tops rise about 90 m above sea level, with gulches that draw steeply down to the shore. Active mass-wasting areas lack vegetative cover and show up as bare rock surfaces. The shoreline along this microtidal coast contains boulder debris that has rolled or slid down the steep slopes and accumulated as rubble mounds at the cliff base, forming a Rock archetype, which results in the DCS tri-sequent catena: R-Cl-U.

The third example (Figure 4) includes a middle-latitude Southern Hemisphere coastal belt from Three Hummock Island (40°25′54″ S, 144°57′42″ E) off the northwestern tip of Tasmania, Australia. This satellite image of a headland bay contains coves that are protected by rocky headlands, where the shore is made up of hard, intact bedrock and boulders (that constitute a Rock archetype) strewn at the base of low bluffs that are about 3–4 m high, forming a Cliff archetype. Landward parts of the cove and interiors of promontories are surrounded by uplands that range up to 40 m elevation, constituting an Upland archetype. The DCS tri-sequent catena is thus characterized as: R-Cl-U.

The fourth example (Figure 5) from the Northern Hemisphere is from the polar west coast of Ellesmere Island, Canada, where this fjord (80°45′09″ N, 77°31′44″ W) empties to the Arctic Ocean passing Axel Heiberg Island to the south. Although peaks along the margins of the fjord range in elevation from 200 to 800 m, scree aprons that reach from sea level up to 300 m demarcate some cliff faces. These active cliff slopes of mass wasting are mostly bare detrital surfaces, but some areas are stabilized by vegetation. These fjord valley side cliffs, which are footed by talus and scree deposits, rise to uplands to form the DCS tri-sequent catena: R-Cl-U. If the cross-shore transect is extended farther inland, it reaches mountain glaciers to include the Ice archetype (I) and forms the tetra-sequent catena: R-Cl-U-I.

Because the cliffs in each example contain rock (talus and scree) at their base, the first archetype in the cross-shore sequence is Rock, designated simply as "R," but the geomorphological-lithological setup in each case is quite different. Rock types in these examples range from basalt (R_{ig}) in the volcanic Canary Islands, to clastic sedimentary materials (R_{se}) on the Greek coast (dolomite, dolostone) and in the Canadian fjord (red beds, quartz arenite, arkose, conglomerate, and evaporites), to felsic intrusive rocks (granite, tonalite, and migmatite) (R_{ig}) on the Tasmanian headland coast, all of which form sub archetypes that together occur in a catenary sequence

Terrestrial Biogeographic Realm and Biome: Palearctic Mediterranean Forests, Woodlands, and Scrub. **Ecoregion:** Aegean and Western Turkey Sclerophyllous and Mixed Forests (785). **Large Marine Ecosystem:** Mediterranean Sea (26). **Oblique View:** Middle-latitude eroding cliffs with steep-sided valleys and gullies cut into unconsolidated carbonates with scree deposits littering the shore. **Shoreline:** Rocky. **Environments and Habitats:** Mediterranean scrub vegetation habitat, bare (unstabilized) valley side slope habitats, rocky intertidal shoreline environment, uncolonized foreshore environment. **Dominant Catenary Sequence (DCS):** Rock-Cliff-Upland (R-Cl-U). **Coastal Ecological Sequence (CES):** $2R_{ts}Cl_{se,vc40\%}U_{sr}$ **Translation:** Curved middle-latitude dolomite cliffs, with talus and large boulders along the shore, which are partly vegetated (~40% cover) and surmounted by upland scrub vegetation.



This example of middle-latitude coastal cliff erosion (36°43′34″ N, 21°52′24″ E, eye altitude 147 m, imagery date 27 April 2017) occurs on the southeast coast of the Peloponnese peninsula and geographic region in southern Greece, which is separated from the central part of the country by the Isthmus of Corinth and the Gulf of Corinth. The peninsula has a mountainous interior with deeply indented coasts. These eroded coastal cliffs occur about 1 km south of Koufosaratsia. The cliff tops are about 90 m above sea level, with gulches that draw steeply down to the shore. Active mass-wasting areas lack vegetative cover and show up as bare rock surfaces. The shoreline along this microtidal coast contains boulder debris that has rolled or slid down the steep slopes and accumulated as rubble mounds. Some of the larger blocks have tumbled into the sea and are clearly visible underwater. The shoreface is about 150 m wide here and covered by crystal clear waters. The gully mouths lack alluvial cones, suggesting that the rock waste materials are dispersed alongshore during stormy periods in the Ionian Sea. This type of shore is typical of many with eroding bluffs or low cliffs and shallow, narrow shelves offshore. The lithology of the distal part of the peninsula is characterized by Late Triassic (237–201.3 Ma) dolomite and dolostone. Although some of these carbonate rocks can be quite resistant to erosion, unconsolidated beds are susceptible to mass wasting, as seen here. The warm temperate climate here is classified as Csa, hot dry-summer climate or Mediterranean.

The green patches throughout the image show the opportunistic nature of the coastal Greek flora. Even within an eroded cliff area, many species of trees, bushes, flowers, and herbs find a foothold to grow. Among them are a variety of poplars, plane trees, oaks, and cypress trees. At the foot of the trees, there is usually a collection of different bushes and flower growth. These can include roses, daisies, poppies, orchids, lilies, and various other wildflowers. Animals common along this coast include the Mediterranean monk seal, four species of dolphin (*i.e.* the bottlenose, common, stripped, and Risso's), and the loggerhead sea turtle.

Figure 3. Sea cliffs and uplands along a coastal belt on the southeast coast of the Peloponnese peninsula, southern Greece. This oblique view obtained from Google Earth Pro is generally looking from the southwest to the southwest coast of Peloponnisos Dytiki Ellada ke Ionio, about 90 km southwest of Tripoli, on the coast of the Ionian Sea. The red arrow that transits the coast in a landward direction shows a typical cross-section that can be used to generalize the nature of the coastal belt. Symbols on the arrow conform to sub archetypes that make up this tri-sequent CES catena: $2R_{ts}Cl_{se,vc40\%}U_{sr}$

to form a CES. The nature of the rubble at the cliff bases also characterizes the composition of the cliffs *per se*, but these features are also differentiated on the basis of other important ecological factors, such as percent of vegetative cover, which help to define each archetype even further.

METHODS

Once an ecological cross-shore sequence is established, it may be accepted as a general description or classification of a part of a coastal belt, as in the case of a DCS, or as a CES, as in the case of a more detailed, larger-scaled view. If more information is still required after CES formulation, then preparation of a complete header and extended image caption is initiated per instructions in the BCCS (Finkl and Makowski, 2020). This latter stage is heavily based on geovisual analytics, where image interpretation techniques (*e.g.*, Costa, 2019; Finkl and Makowski, 2015, 2019a,b; Finkl, Makowski, and Vollmer, 2014; Klemas, Bartlett, and Rogers, 1975; Klemas *et al.*, 1993; León-Pérez, Hernández, and Armstrong, 2019; Makowski, 2014; Makowski, Finkl, and Vollmer, 2015, 2016, 2017; Patias *et al.*, 2018) are merged with the collation of collateral data from various sources on the Internet or in reference books. Procedures for this aspect involve referencing an environmental classification system or regionalization that has already been devised (*e.g.*, Bailey, 1998; Bartley, Buddemeier, and Bennett, 2001; Burke *et al.*, 2001; Dolan *et al.*, 1972; Hayden, Ray, and Dolan, 1984; Klemas *et al.*, 1993; Makowski, 2014; Makowski, Finkl, and Vollmer, 2015, 2016, 2017; Makowski *et al.*, 2009; Sherman, Aquarone, and Adams, 2009; Zhang *et al.*, 2011) to assist with descriptions of the extant terrestrial and marine portions of a satellite image.

Geovisual Analytics of the BCCS

The dual nature of the coast requires that both land- and marine-based systems need to be accessed and merged when providing cohesive descriptions of the coastal belt. Interactive online systems provide platforms for geographical or locational purposes (*e.g.*, Apple+Google World Map [2019], Google My Maps), geology (Macrostrat geologic map; Peters, Husson, and Czaplewski, 2018), and for discovering ecoregions (*e.g.*, RESOLVE Ecoregions 2017; Dinerstein *et al.*, 2017), marine ecosystems (*i.e.*, Large Marine Ecosystems; 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). Apple+Google World Map (2019) provides easy access to locational data that are helpful for descriptions of satellite scenes. Macrostrat's geologic map integrates over 200 geologic maps at a myriad of scales from around the world into a homogenized single database. Ecoregions 2017 and the Large Marine Ecosystem (LME) maps conform to the Apple+Google World Map for easy use, and the Köppen-Geiger climates can be incorporated as a layer in Google Earth Pro for comparison with satellite scenes. These platforms work well together, and some contain interdigital information, as in the Macrostrat geologic map, where ecoregions are shown in a drop-down menu. Assembly of this information usually provides enough detailed information to characterize environments and habitats in a coastal belt.

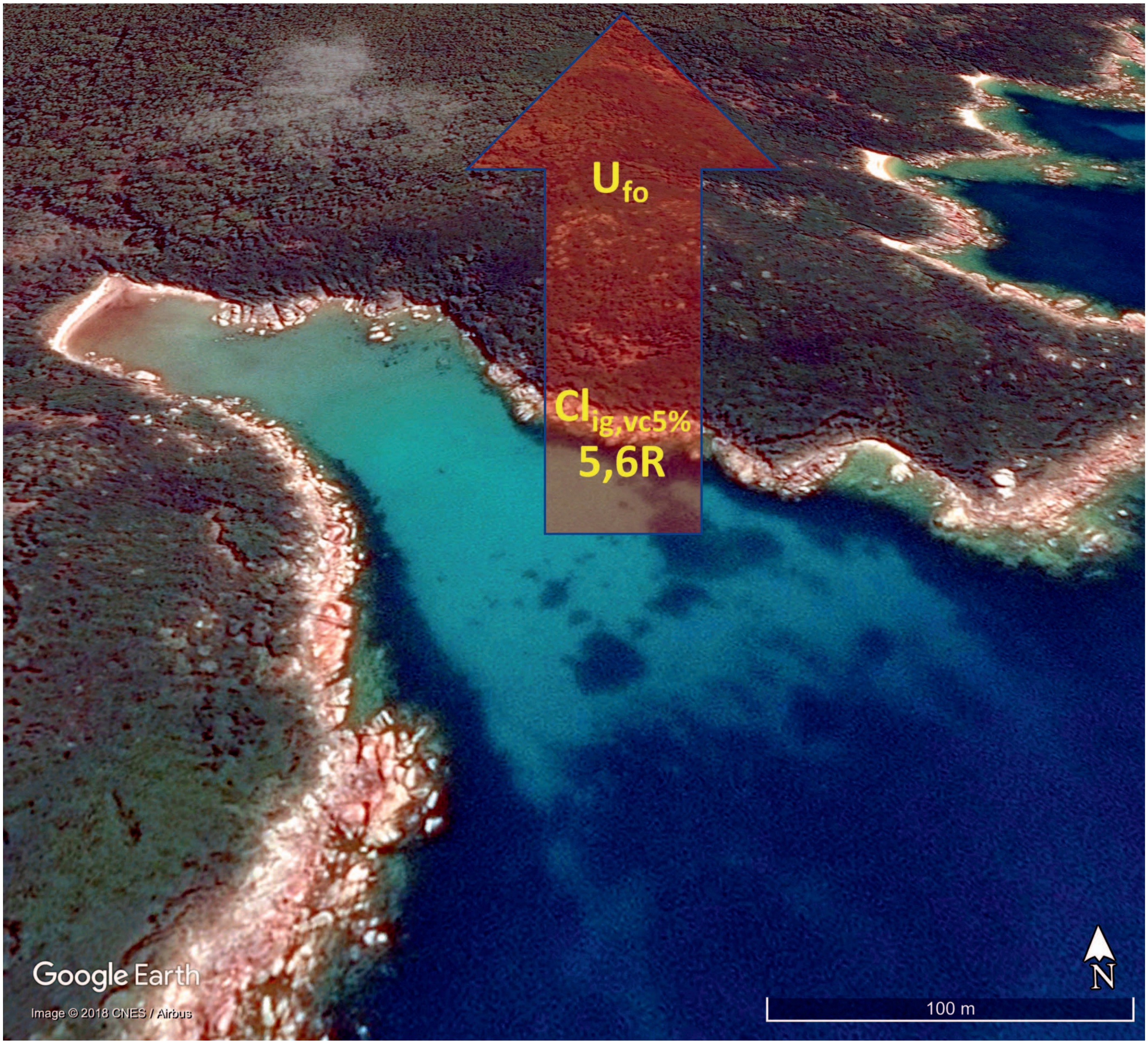
This information is presented in a specified format, as described for the BCCS by Finkl and Makowski (2020), in the following order: a header, followed by the satellite image with annotations, and an extended caption that usually includes ecological (biological), geographical, geological, pedological, climatic, hydrologic, and environmental information. The content of the header is the combined result of cognitive image interpretation procedures and geovisual analytics that define the following categories: Planview (or Oblique View), Shoreline, Environments and Habitats, Dominant Catenary Sequence (DCS), and finally the Coastal Ecological Sequence (CES). The purpose of these classificatory procedures is to facilitate comparisons of different coastal belts *via* the elucidation of archetypes and sub archetypes. By delving three levels deep (Level I = DCS, Level II = CES, and Level III = the header and extended caption) into the BCCS, a large amount of information can be acquired that is extremely useful for detailed studies of coastal cross-shore catenas. Such a diverse collection of data might at first appear to be a haphazard *omnium-gatherum*, but in fact its assembly provides a cogent acroamatic perspective of linked but discrete facets of cross-shore environments and habitats that are formalized in terms of catenas composed of sequenced archetypes and sub archetypes.

Differentiation of Cliff Archetype Exemplars

A factor that is relevant to application of BCCS methods is a clear understanding of geomorphological-ecological terms, in this case, the terms cliff and upland, which themselves constitute district archetypes. Cliff and Upland archetypes occur as a couplet or di-sequent catena along many coastal belts of the world because cliffs terminate in uplands. In the four examples discussed here, the cliff line or base, usually (but not necessarily) at the water level, is characterized by talus, rubble, or scree derived from mass wasting of the cliff face. Consequently, the Rock archetype is the first archetype encountered in a cross-shore transect interpretation. These brief definitional comments here are not meant to be an exposé of the conceptualization of these terms in different fields of study but rather just to indicate how they are used in image interpretation and the breadth of what they might include.

From a *sensu stricto* geomorphological point of view, the term "sea cliff" refers to any high, very steep to perpendicular or overhanging face of rock or precipice (Jackson, 1997). Cliffs are

Terrestrial Biogeographic Realm and Biome: Australasia Temperate Broadleaf and Mixed Forests. **Ecoregion:** Tasmanian Temperate Rain Forests (179). **Large Marine Ecosystem:** Southeast Australian Shelf (42). **Oblique View:** Middle-latitude shallow water cove flanked by forested rocky headlands. **Shoreline:** Rocky. **Environments and Habitats:** Upland forest, bayhead sandy beach and dune habitats, rocky shore with cliff habitats, sandy seafloor environments. **Dominant Catenary Sequence (DCS):** Rock-Cliff-Upland (R-Cl-U). **Coastal Ecological Sequence (CES):** $5{,}6RCl_{ig,vc5\%}U_{fo}$ **Translation:** Indented promontories and headlands on a middle-latitude rock shore leading to mostly bare (~5% vegetative cover) igneous cliffs/bluffs surmounted by upland forests.



This middle-latitude rocky cove and headland bay beach (40°25′54″ S, 144°57′42″ E, eye altitude 281 m, imagery date 11 January 2017) occurs on Three Hummock Island off the northwestern tip of Tasmania, Australia. The island lies about 30 km northwest of Perkins Bay and 44 km northwest of the town of Stanley, the second-last major township on the northwest coast of Tasmania. A cove is a type of small, sheltered bay on the coast of an ocean, lake, or river. Coves usually have narrow entrances that protect the water of the cove from turbulent currents and waves of the larger body of water, as in the case here of Bass Strait. The word *cove* comes from Old English *cofa*, which means shelter or hut. As shown in this image, this cove is protected by rocky headlands, where the shore is made up of hard, intact bedrock and boulders strewn at the base of bluffs that are about 3–4 m high. The headward margins of the cove contain a small sandy beach that is somewhat less than 10 m wide and backed by low sand dunes. Landward parts of the cove are surrounded by forested uplands that range up to 40 m elevation. The shallow seafloor of the cove is sandy but drops off to deeper water at a line that is parallel to the main shore facing open waters of Bass Strait. Bedrock on Three Hummock Island is Middle Devonian–Mississippian (393.3–323.2 Ma) felsic intrusive rocks that range in composition from alkali feldspar granite to tonalite; associated rocks include migmatite and minor gabbro and diorite. The climate of this region is classified as Cfb, oceanic climate, also known as a marine, maritime, or marine west coast climate.

Coastal rain-forest vegetation in Tasmania shows greater diversity and complexity on low-nutrient soils, as shown in the image. For example, this lowland rain-forest ecosystem is dominated by *Nothofagus* spp., with species of *Atherosperma*, *Eucryphia*, *Phyllocladus*, and *Andopetalum* increasing in frequency as the soil quality decreases. Distinctive rain-forest species include Australia's only winter-deciduous tree, *Nothofagus gunnii*, as well as myrtle beech (*Nothofagus cunninghamii*), sassafras (*Atherosperma moschatum*), King Billy pine (*Athrotaxis selaginoides*), pencil pine (*Athrotaxis cupressoides*), horizontal scrub (*Anodopetalum biglandulosum*), Huon pine (*Lagarostrobus franklinii*), celery-top pine (*Phyllocladus asplenifolius*), and chestnut pine (*Diselma archeri*). Various other communities occur here, including wet sclerophyll forest, buttongrass moorlands, scrub, and heath. Twenty-one species of native birds regularly utilize this rain-forest habitat, including the grey goshawk (*Accipiter novaehollandiae*), brown scrubwren (*Sericornis humilis*), and black currawong (*Strepera fulignosa*). Mammals found here include the dusky antechinus (*Antechinus swainsonii*) and the spotted-tail quoll (*Dasyurus maculatus*), as well as several Tasmanian endemic species, including the Tasmanian long-tailed mouse (*Pseudomys higginsi*), Tasmanian pademelon (*Thylogale billardierii*), and Tasmanian devil.

Figure 4. This oblique view of sea bluffs and interior uplands, obtained from Google Earth Pro, is looking northwards to the northeast coastal belt of Three Hummock Island off the northwestern tip of Tasmania, Australia, which faces Bass Strait. The red arrow that transits the coast in a landward direction shows a typical cross-section that can be used to generalize the nature of the coastal belt. Symbols on the arrow conform to sub archetypes that make up this tri-sequent CES catena: $5,6RCl_{ig,vc5\%}U_{fo}$

usually formed by erosion and less often by faulting. On the other hand, the term from a *sensu lato* perspective may refer to any steep slope or declivity (>45°). A headland characterized by a cliff, as forms during the development of an embayed coastal belt, and commonly encountered in the BCCS, is recognized as the Cliff archetype with the symbolization "Cl." For the purposes of the BCCS, the term "bluff" is subsumed under the Cliff archetype. Bluffs generally refer to high banks or bold headlands with a broad, precipitous, sometimes rounded cliff face overlooking a plain or body of water—any cliff with a steep broad face (Jackson, 1997). Although these terms are used interchangeably in the BCCS, all visually similar landforms fall under the Cliff archetype regardless of extremely low or high relative elevation compared to a coastal plain or adjacent sea level.

In the BCCS, the term "upland' is used in the broadest sense possible to simply mean land elevated above other land in a coastal belt. The difference in elevation may be small, on the order of a few decimeters for example, or great, as in the case of land above a cliff or escarpment. On low-lying coastal segments, "upland" may be an area of land lying above the level where water flows or flooding occurs. From a hydrologic point of view, upland may include any area that does not qualify as a wetland because the associated hydrologic regime is not sufficiently wet to elicit development of vegetation, soils, and/or hydrologic characteristics associated with wetlands. From a geological perspective, "upland" is generally considered to be land that is at a higher elevation than an alluvial plain, coastal plain, or stream terrace, which are considered to be "lowlands." The term "bottomland" refers to low-lying alluvial land near a river, as often occurs on coastal plains. For sake of brevity and simplicity, the Upland archetype in the BCCS applies in its essence to land elevated above other land. The Wetland-Upland ecotone, which is a narrow band of habitat where wetlands and uplands meet, and which contains vegetation types from both habitats, is procedurally ignored in cross-shore concatenations and simply shown as a contact between Wetland (W) and Upland (U) archetypes. The same situation occurs with ecotonal boundaries between Rock, Cliff, and Upland archetypes.

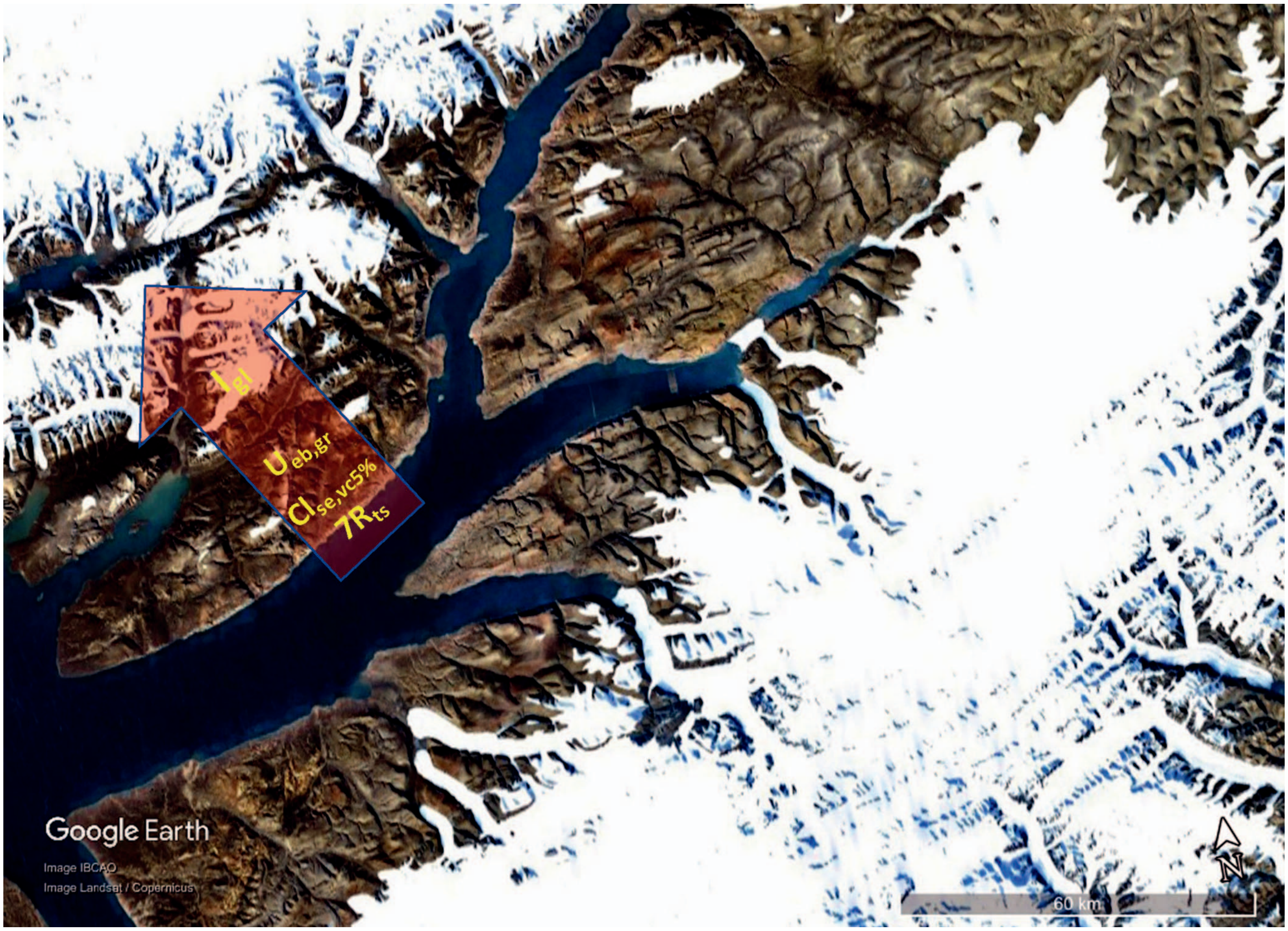
RESULTS

The ultimate goal of satellite frame selection, image interpretation, and collection of appropriate collateral data from online sources is the production of a figure that includes an orienting header, annotated satellite image, and extended informative caption in a Level III investigation. The resulting header orients the reader to major ecological features within which the satellite scene is couched, such as Terrestrial Biogeographic Realm and Biome, Ecoregion, and Large Marine Ecosystem. Because the smaller satellite images are really subsumed within the much larger ecological units of realms, biomes, and ecoregions, it is important to discern relevant aspects of the image in relation to its biogeographical setting. Results of geovisual analytical procedures place the coastal belt scene in the context of biogeographic units that help to define the nature or character of the local area in relation to regional environments.

Biogeographical Interpretation of Coastal Belts

Biogeographical comparison of the Rock-Cliff-Upland (R-Cl-U) tri-sequent catena for the figures shows environmental variations that occur in response to distinct locations. Such variation is expected, and thus is the reason the given header places the image location within a regional environmental context. In the four examples selected to illustrate the principle and application in the BCCS, Terrestrial Biogeographic Realms and Biomes, Ecoregions, and Large Marine Ecosystems were identified in each figure header. The coastal belt on the southeast subtropical coast of Fuerteventura, Canary Islands (Figure 2), occurs within the following biogeographic units: Palearctic Mediterranean Forests, Woodlands, and Scrub Terrestrial Biogeographic Realm and Biome; Mediterranean Acacia-Argania Dry Woodlands and Succulent Thickets Ecoregion (796); and the Canary Current Large Marine Ecosystem (27). The environments on the middle-latitude southeast coast of the Peloponnese peninsula in southern Greece (Figure 3) occur in the same broad Terrestrial Biogeographic Realm and Biome as the Canary Islands (*i.e*. Palearctic Mediterranean Forests, Woodlands, and Scrub), but in a different Ecoregion and Large Marine Ecosystem, which were identified as the Aegean and Western Turkey Sclerophyllous and Mixed Forest Ecoregion (785) and the Mediterranean Sea Large Marine Ecosystem (26). In the Southern Hemisphere on Three Hummock Island off the northwestern tip of Tasmania, Australia (Figure 4), the coastal belt there is completely different, as indicated by the following environmental and ecological associations: Australasia Temperate Broadleaf and Mixed Forests Terrestrial Biogeographic Realm and Biome; Tasmanian Temperate Rain Forests Ecoregion (179); and Southeast Australian Shelf Large Marine Ecosystem (42). Returning to a Northern Hemisphere example, the polar west coast fjord of Ellesmere Island, Canada (Figure 5), which empties to the Arctic Ocean passing Axel Heiberg Island to the

Terrestrial Biogeographic Realm and Biome: Nearctic Tundra. **Ecoregion:** Canadian High Arctic Tundra (412). **Large Marine Ecosystem:** Canadian High Arctic–North Greenland (66). **Planview:** Polar-latitude unvegetated uplands with ice caps, glaciers, and deep-water glacial valleys (fjords). **Shoreline:** Rocky; scree and talus deposits. **Environments and Habitats:** Rocky upland environments, ice cap, mass-wasting slope deposit environments. **Dominant Catenary Sequence (DCS):** Rock-Cliff-Upland-Ice (R-Cl-U-I). **Coastal Ecological Sequence (CES):** $7R_{ts}Cl_{se,vc5\%}U_{eb,gr}I_{gl}$ **Translation:** Polar fjords with a straight valley side, steep-to talus foot slopes, and mostly bare (~5% vegetative cover) sedimentary cliffs with exposed rock and grassy uplands leading to glacial ice.



Occurring on the polar west coast of Ellesmere Island, Canada, this fjord (80°45′09″ N, 77°31′44″ W, eye altitude 185 km), empties to the Arctic Ocean passing Axel Heiberg Island to the south. The proximal reaches of the fjord head in glacial snouts in the hinterland, whereas the Ellesmere Ice Shelf fronting the Arctic Ocean blocks the distal end during the low sun period. The Ellesmere Ice Shelf was approximately 100 m thick and extended 500 km along the coast, but by 2000, it had mostly collapsed into disjunct segments. The Petersen Ice Shelf, near the mouth of the fjord, continued to crumble for a number of years, and by 2008, it had lost one-third of its area. The mountainous terrain surrounding the fjord is partly covered by ice fields and glaciers. Valley glaciers feed into the fjord, where they have icebergs for at least 1 month during the high sun period with temperatures above freezing. A good example of iceberg calving occurs in the image center, where a glacial snout is partially grounded in a shallower reach of the fjord. Water in the fjord shows low turbidity, except immediately alongshore, as seen by the blue color of the water. Some arms of the fjord show high levels of suspended solids in the water column where glacial rock flour is entrained in meltwater rivers, as in the center left of the image. Although peaks along the margins of the fjord range in elevation from 200 to 800 m, scree aprons that reach from sea level up to 300 m demarcate some shoreline slopes. These active slopes of mass wasting are mostly bare detrital surfaces, but some areas are stabilized by vegetation. Continental clastic sedimentary materials that are Carboniferous–Permian (358.9–252.17 Ma) in age surround the fjord. The lithology is dominantly composed of red beds, quartz arenite, arkose, conglomerate, and evaporites. The climate of the region is classified as ET, tundra climate.

At approximately 196,236 km^2, Ellesmere Island is the third-largest island in Canada, the 10th largest island in the world, the largest island of the Queen Elizabeth Islands, and the most northerly island in the Arctic Archipelago. It is a true polar desert, with only 70 mm of precipitation annually in some places. Consequently, vegetation is very sparse, although the island has a surprisingly diverse flora for such a High Arctic region, including 151 species of moss. In 1988, Quttinirpaaq National Park, meaning "top of the world" in the native Inuktitut language, was created over one-fifth of the island in the northern part. Ellesmere Island is distinguished by a spectacular landscape, as well as an exceptional and harsh environment. Small herds of musk oxen are dispersed across the Hazen Plateau, with numerous species of birds and several other land mammals present (*e.g.*, caribou, polar bears, Arctic hare, Arctic tern). Marine mammals are very rare in occurrence, because the coastal sea ice discourages their presence. Surprisingly, 13 species of spiders, two species of bumblebee (*Bombus polaris* and *B. hyperboreus*), and the Arctic woly bear moth (*Gynaephora groenlandica*) are all found on Ellesmere Island. Though the climate is extreme, a peculiar "thermal oasis" at Lake Hazen produces surprisingly warm summers, with the frost-free period averaging around 55 days.

Figure 5. This planview of sea cliffs, obtained from Google Earth Pro, shows part of a fjord coastal belt on the polar west coast of Ellesmere Island, Canada, that empties to the Arctic Ocean passing Axel Heiberg Island to the south. The steep-sided valley cliffs of the fjord coastal belt rise up to 800 m above sea level to locations where there are ice fields. The red arrow that transits the coast in a landward direction shows a typical cross-section that can be used to generalize the nature of the coastal belt. Symbols on the arrow conform to sub archetypes that make up this tetra-sequent CES catena: $7R_{ts}Cl_{se,vc5\%}U_{eb,gr}I_{gl}$

south, offers a high-latitude set of ecological conditions that characterize this coastal belt as occurring in the following units: Nearctic Tundra Terrestrial Biogeographic Realm and Biome; Canadian High Arctic Tundra Ecoregion (412); and Canadian High Arctic–North Greenland Large Marine Ecosystem (66).

Geovisual Analytical Discernment of Cliff Archetypes

The examples shown here for the same tri-sequent catena occur within the very large and diverse Terrestrial Biogeographic Realms and Biomes of: Nearctic (Ellesmere Island, Canada), Palearctic (Canary Islands and Greece), and Australasia (Three Hummock Island off the northwestern tip of Tasmania, Australia). The Large Marine Ecosystems (LMEs) are vastly different in each example, ranging from the Canary Current, Mediterranean Sea, Southeast Australian Shelf, and the Canadian High Arctic–North Greenland, all of which impart a distinctive biophysical character to the coastal belt. The Ecoregions (*i.e*. Mediterranean Acacia-Argania Dry Woodlands and Succulent Thickets; Aegean and Western Turkey Sclerophyllous and Mixed Forest; Tasmanian Temperate Rain Forests; Canadian High Arctic Tundra) are also different, as expected, as more localized ecologies come into play in these divergent coastal belt environments. Ecoregions are the most specific environmental units used in the BCCS to help characterize the coastal belt ecologies. The name of each Ecoregion is followed by a number that corresponds to the Ecoregions 2017 Global Map (*e.g*., RESOLVE Ecoregions 2017; Dinerstein *et al*., 2017). This provides a simple and precise identification of the unit in question, such as the Mediterranean Acacia-Argania Dry Woodlands and Succulent Thickets Ecoregion (Ecoregion Reference #796) for the Canary Island coastal belt (Figure 2).

The results of these geovisual analytical efforts help to place the satellite scene within a spatial environmental context that in turn helps to define the coastal belt cross-shore transect beyond the codification symbolization. This broadscale environmental information thus serves as a backdrop to the Coastal Environmental Sequence (CES), which is the aim of a Level II investigation in the BCCS cross-shore coastal classification system. Following the header and actual satellite image scene, there is an extended caption, the intent of which is to provide detailed locational information and other relevant facts such as comments relating to climate, geomorphology, geology, flora, and fauna in a Level III investigation. The following passage includes such information for an overall ecological impression of the cross-shore transect.

In the example of the Canary Island coastal belt, the oblique satellite scene shows truncated basaltic lava flows where they entered the sea after flowing down the flanks of a shield volcano. The arid climate of this subtropical island region is classified as BWh, hot low-latitude desert climate, where annual desert temperatures are equal to or greater than +18°C. The cliffs on this steep-to coast are about 100 m high, and various layers are evident in the cliff face, which shows separate flows in an intermittent sequence of volcanic eruptions. The cliffs extend for great distances below the water surface, making for a steep precipice above and below the ocean surface. Although there is very little colluvial material in the form of talus and scree cones collected at the apparent base of the cliffs at the water surface, there are some small platforms where fine-grained comminuted basalt particles have collected in the form of perched beaches, which are also partly alluvial fans at the mouths of valleys, as seen in the lower center of the satellite image. The shield-stage mafic (mostly basaltic) volcanic rocks are Pliocene–Pleistocene (5.333–0.0117 Ma) in age. Over the millennia, these sterile mounds of lava and volcanic ash have undergone the process of weathering to produce small pockets of soil, in which the first plants, arriving as either wind- or waterborne seeds, were able to gain a tenuous foothold. Similarly, the first animals to colonize these basaltic islands had to arrive by crossing many kilometers of open water. This is perhaps most evident among the reptiles, which include 14 unique species of lizards, skinks, and geckos scattered across the archipelago. Additionally, the Canary Islands are also home to five unique bird species that are only found here: Bolle's pigeon (*Columba bollii*), Laurel pigeon (*Columba junoniae*), Canary Islands stonechat (*Saxicola dacotiae*), Canary Islands chiffchaff (*Phylloscopus canariensis*), and Blue Chaffinch (*Fringilla teydea*).

DISCUSSION

These four simple examples of cliff coastal belts show how the BCCS can be applied with various degrees of simplicity or complexity. The DCS is the simplest case possible in this new cross-shore classification that emphasizes the linkage between geomorphology and ecology and produces recognition of salient environments from offshore to onshore. This first stage of the BCCS procedure requires little effort as a Level I investigation other than cognitive interpretation of satellite imagery to determine different types of environments that are encountered in a cross-shore transect. The second stage (production of a 3D CES) is offered as a Level II investigation that results in a penultimate or ultimate stage of classification, depending on the details of research requirements. A Level II investigation requires the collection of some collateral data so that subscript designators can be ascertained, such as whether a particular cliff is composed of sedimentary or igneous rocks, to define sub archetypes. If the details of the research being conducted are satisfied with the information acquired at this time, then a Level II investigation becomes the ultimate goal of the BCCS procedure. Cross-shore coastal classification at this level of detail provides a wealth of information in the form of coastal belt archetypical sequences that heretofore was normally not available from alongshore classifications.

The purpose of showing a simplistic case of a tri-sequent catena of Rock-Cliff-Upland (R-Cl-U) was to illustrate the flexibility of the BCCS and also to emphasize that Level II investigations do not need to mark the completion of classificatory efforts. If more detail is required, a third level of inquiry may be conducted that delves deeper into the context of cross-shore transects. When a greater amount of detail is desired, Level III investigations may be regarded as an ultimate goal. By taking the same tri-sequent catena for examples of coastal belts with dominant Cliff archetypes, it was possible to show how some further digging within the framework of geovisual analytics can secure additional information that further differentiates coasts with similar orderings of sub archetypes. A key factor here in this final stage of inquiry is the incorporation of geographical zonality that recognizes realms, biomes, ecoregions, and marine ecosystems. Even though the satellite scene being studied is but a small part of these large biogeographical units, recognition of these generally expansive zonations helps to couch the coastal belt in a global framework that will facilitate contrasts and comparisons.

The BCCS provides a formula for presenting collateral data along with the image scene so that a large amount of information can be absorbed with a glance at the caption. This procedure is described here as an advanced Level III investigation. In addition to including interesting miscellaneous information about a particular coastal belt site, perhaps the most important collateral data concern the dominant or characteristic flora and fauna. These latter attributes, referred to as such because they are presented last in the caption, provide much useful information that is not normally included in alongshore coastal classifications, which tend to favor coastal processes, geomorphology, tectonics, shoreline position, *etc*. Last, but not least, as demonstrated here, flora and fauna are essential environmental characteristics that can pin down discrete or specialized types of coastal belts that are not further differentiated at the second stage (Level II) of classification, as in the case of similar CES units.

In order for a cross-shore classification of sub archetype catenas to achieve the most advantageous use, accession to the third stage (Level III) of inquiry is required. Experience in developing procedures for the BCCS shows that the additional time and effort needed to compile an extended informative caption is well worth it. To some, the collection of this amount of data may seem excessive, but that opinion depends on research requirements and the amount of time, effort, and resources that are available. It is thus a judgement call whether a three-tiered classification effort is invoked. Should a greater amount of information be required beyond that provided in stage two or a Level II investigation to produce a CES, this additional avenue of investigative prowess is offered in a format specified in the BCCS. This order of presentation is suggested to facilitate comparison of similarities or differences between coastal belts *via* a cross-shore classification. It should be noted as a word of caution that at Level III investigation and in the case of close-order cross-shore transects, differences in flora and fauna would not normally be expected. Ranges of variation in other physical and biogeographic variables will be diminutively observed in large-scale (small-area) studies. However, it is relevant to emphasize that even in large-scale studies, there can be rapid or pronounced change over short distances in coastal belts, as in the case of lithology, pedology, hydrology, or even climatic conditions, where coastal mountains, for example, may cause rain shadows (which effect the ecology) or produce situations where there are copious amounts of rainfall as moist air masses are rapidly uplifted. Words of caution abound, but it is assumed that most researchers are familiar with the intricacies of their study areas and will thus be able to apply the BCCS as a Level I, II, or III effort.

In sum, the initial goal of applying the BCCS is the development of the Dominant Catenary Sequence (DCS) for broad scale studies (Level I type of investigation) and the Coastal Environmental Sequence (CES) for more detailed studies (Level II type of investigation). Beyond that, there is the assembly of more detailed collateral data that are required to prepare a header and extended caption according to the formula of the BCCS (Level III type of investigation). Although construction of a DCS or CES may be sufficient for most cross-shore classificatory efforts, the more detailed header and extended caption formulary produces the ultimate goal of a comprehensive coastal classification based on geomorphological-ecological attributes.

CONCLUSIONS

The Biophysical Cross-shore Classification System (BCCS) is a new approach to traditional alongshore rationalizations that typically focus on geomorphological (landform) types, tectonics, shoreline position, coastal processes, *etc*. In contradistinction to these approaches for special purposes and better understanding of one-dimensional shorelines and coastlines, recognition of 3D cross-shore biophysical sequences offers an opportunity to view coasts in terms of coastal belts that have length, width, and elevation. Commonly recurring cross-shore environments are referred to as archetypes and sub archetypes, which can be ascertained from cognitive interpretation of satellite imagery that is provided by Google Earth Pro for the world's coasts. The simplest level of classificatory effort is designated as a Level I inquiry that produces the Dominant Catenary Sequence (DCS), followed by a Level II investigation that produces the Coastal Ecological Sequence (CES). Both types of catenary associations are sufficient for most broad and intermediate-scale coastal classifications. When detailed local information is required, a CES may be refined by a Level III study (in the form of a header and extended caption) that delves into the intricacies of site-specific CES cross-sections. These detailed studies help to differentiate similar sub archetype designations on the basis of parameters such as biogeographic realm, biome, ecoregion, and marine ecosystems in addition to aspects of geography, geology, geomorphology, biology, climate, flora, and fauna.

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