Morphometry of tidal meander cutoffs indicates similarity to fluvial morphodynamics

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Key Points:

- Tidal meander cutoffs are far more common than typically thought and share remarkable morphometric similarities with fluvial counterparts.
- Similar mechanisms trigger cutoffs in both tidal and fluvial landscapes, with differences arising only during post-cutoff evolution.
- Tidal cutoffs seldom disconnect from parent channels and rarely form oxbows due to the high hydrological connectivity of tidal wetlands.

Abstract

Sinuous channels wandering through coastal wetlands have been thought to lack lateral-migration features like meander cutoffs and oxbows, spurring the broad interpretation that tidal and fluvial meanders differ morphodynamically. Motivated by recent work showing similarities in planform dynamics between tidal and fluvial meandering channels, we analyzed meander neck cutoffs from diverse tidal and fluvial environments worldwide, and show that tidal cutoffs are widespread. Their perceived paucity stems from pronounced channel density and hydrological connectivity in coastal wetlands, comparatively small size of most tidal channels, and typically dense vegetation cover. Although these factors do not efface tidal meander cutoffs, they collectively inhibit oxbow formation and make tidal cutoffs ephemeral features that can escape detection. We argue that similar morphodynamic processes drive cutoff formation in tidal and fluvial landscapes, with differences arising only during post-cutoff evolution. Such process similarity has important implications for understanding coastal wetland ecomorphodynamics and predicting their long-term evolution.

Plain Language Summary

The sinuous channels that wander through tidal coastal wetlands look like meandering rivers. However, features of alluvial floodplains that indicate active river meandering over time, such as oxbow lakes and meander cutoffs, are difficult to find in tidal settings. Their apparent absence has led researchers to infer that tidal and fluvial meanders evolve differently. We re-examined this inference by identifying, measuring, and compiling examples of meander cutoffs from a variety of tidal coastal wetlands and fluvial floodplains worldwide. Our analysis suggests that the shapes and geometric properties of tidal and fluvial cutoffs are indeed remarkably similar. This indicates that while tidal and fluvial environments differ in many ways, they nevertheless share the same physical mechanism affecting meander morphodynamical evolution. Differences between tidal and fluvial meanders do arise after a meander is cut off. We observe that tidal meanders remain preferentially connected to the parent channel, preventing the formation of crescent-shaped oxbow lakes and thus making tidal cutoffs more difficult to detect. Our results indicate a close similarity in meandering channel behavior across tidal and fluvial systems, which opens new opportunities for how researchers model tidal wetlands, with important implications for the effective conservation and restoration of these critical ecosystems.

1 Introduction

Sinuous meandering channels are common in fluvial and coastal landscapes (Leopold et al., 1964). Meandering channels migrate laterally through erosion and deposition of sediment along the outer and inner banks, respectively, of individual meander bends. As meanders evolve, channels frequently shortcut themselves through cutoffs and form oxbow lakes (hereinafter "oxbows"; Dunne & Aalto, 2013; Schwenk et al., 2015; Stølum, 1996). Cutoffs, by which oxbows are formed (Dieras, 2013; Thomas et al., 2022) reduce channel sinuosity, modify rates of lateral migration, and affect floodplain sedimentology, stratigraphy, and sediment residence times (Camporeale et al., 2005; Howard & Hemberger, 1991; Zinger et al., 2011). These dynamics have broad implications for the flux, storage, and sequestration of soil organic carbon (Torres et al., 2017). Meandering river floodplains feature visible evidence of meander migration such as scroll bars and oxbows (Constantine & Dunne, 2008; Dunne & Aalto, 2013; Hooke, 2013) In contrast, channels in tidal coastal floodplains have been thought to lack meander cutoffs, indicating an absence of active meandering (Gabet, 1998; Johnson, 1929) (Figure 1). The perceived stability of sinuous tidal channels – or at least the relative subtlety of their meandering dynamics – has often been attributed to the unique ecomorphodynamics of coastal environments, where flow bidirectionality is paramount (Fagherazzi et al., 2004; Hughes, 2012; Solari et al., 2002). However, recent studies highlighted morphodynamic commonalities between fluvial and tidal meanders, with similar planform dynamics, width-adjusted migration rates, and morphodynamic regimes in high-amplitude bends (Finotello et al., 2018, 2022; Gao, Finotello, & Wang, 2022; Leuven et al., 2016, 2018). This motivated us to question the perceived paucity of tidal meander cutoffs, and to further demonstrate the parallels between tidal and fluvial meandering channels. Here, we analyzed the planform geometry of 600 tidal meander cutoffs identified in high-resolution satellite images from settings around the world, characterized by different tidal regimes, vegetation cover, and geomorphological backgrounds. We conducted a direct comparison with 158 cutoffs in meandering rivers, uncovering striking geometric parallels. These similarities, supported by theoretical, numerical, and field research, suggest a fundamental commonality in morphodynamics across both tidal and fluvial domains.

2 Material and Methods

2.1 Data collection

We used high-resolution satellite images, freely available from Google Earth Pro, to detect instances of meander cutoffs undisturbed by anthropic activities. These cutoffs, selected for their geographical diversity, span coastal zones and inland alluvial plains across varied climatic and geological settings. Thus, the sampled cutoffs reflect a range of hydrological and tidal regimes, sediment grain sizes, vegetation types, and land cover (Figure 1a-g). Our full dataset includes over 1200 examples of tidal cutoffs. Of these 1200 examples, 600 tidal cutoffs with clearly discernable boundaries were manually digitized as polygons using Google Earth Pro. The remainder lacked sufficient detail to be digitized due to poor preservation, dense vegetation canopy, low image resolution, complex morphology resulting from multiple cutoffs, or combinations of these factors, and were categorized as “unanalyzed cases” (Gao & Finotello, 2023). Furthermore, we obtained an additional set of 158 fluvial cutoffs specifically digitized for comparative analyses. These cutoffs were extracted from rivers located in various regions, including the Amazon Basin, the conterminous USA and Alaska, Russia, Canada, Kazakhstan, and New Zealand. The selection was

made to ensure a diverse range of channel sizes, with river widths spanning approximately four orders of magnitude (Figure 2).

Tidal cutoffs were also further classified based on several criteria: tidal regime (microtidal n=315; mesotidal n=249; macrotidal n=36), vegetation cover (mangroves n=118; salt marshes n=433; tidal flats n=49), and geomorphological setting (bays n=164; back-barrier lagoons n=219; open coasts n=105; estuaries n=112) (Figure S1 in Supporting Information). The mean tidal range (MTR) at each site was determined by analyzing tidal gauge data from Dong (2020) and the National Oceanic and Atmospheric Administration (https://tidesandcurrents.noaa.gov/), and individual study cases were classified as macro-tidal ($MTR > 4$ m), meso-tidal ($2 < MTR < 4$ m), and microtidal ($MTR < 2$ m).

We focus only on 'neck' cutoffs, formed when a high-amplitude loop gets isolated by the pinching connection of two adjacent bends. In the tidal settings we examined, we found no 'chute' cutoffs, which are formed when a river bend is shortcutted by a new channel cutting through meander point bars – and possibly observed in large, sand-bedded, multi-thread estuarine channels (Leuven et al., 2016).

2.2 Data analysis

To calculate their morphometric parameters, cutoff polygons were projected into appropriate UTM coordinates and converted to binary images. The channel centerline was computed based on a standard skeletonization procedure and then resampled using standard cubic spline-fit polylines. Cutoff endpoints were determined as the two branchpoints of the polygon skeleton (Figure 1l). To further quantify cutoff planform features, we computed the curvature $\mathcal{C}$ ([m^{-1}]) of the channel centerline as $\mathcal{C} = -d\theta/ds$, where θ is the angle between the tangent to the channel axis and an arbitrarily selected reference direction, $x(s)$ and $y(s)$ are the Cartesian coordinates of a given centerline point, and s is the intrinsic (i.e., along-channel) coordinate, assumed to be positive in the upstream (i.e., landward) direction. Because flow orientation within tidal meanders changes with tidal phases, we hereinafter assume a river-like reference system in which the terms 'upstream' and 'downstream' refer to landward and seaward directions, respectively.

After computing curvature, a Savitzky–Golay low-pass filter was applied to smooth noise in the original signal. Then, the apex of any individual cutoff was identified as the locus of maximum curvature (Figure 1l), and the cutoff asymmetry index was computed as $\mathcal{A} = (\ell_u - \ell_d)/(\ell_u + \ell_d)$ ([-]) where ℓ_u and ℓ_d are the distances between the cutoff apex and its upstream and downstream endpoints, respectively (Figure 1l). Negative values of $\mathcal{A}$ correspond to upstream-skewed cutoffs, and positive values of $\mathcal{A}$ to downstream-skewed cutoffs. Other morphometric parameters were also calculated, including: average channel width W ([-]); cutoff intrinsic length $\ell = \ell_u + \ell_d$ ([m]); cutoff cartesian length L ([m]), which is the planar distance between cutoff endpoints; cutoff sinuosity $\chi = \ell/L$ ([-]); cutoff amplitude A ([-]), computed as the maximum point-line distance between the cutoff centerline and the line connecting the two cutoff endpoints; cutoff radius of curvature R ([m]), defined as the radius of the best-fitting circle through all cutoff axis points; and flow-diversion angle Φ between the cutoff and its parent channel (Figure 1l). Because of bidirectional flow through tidal channels, morphodynamically meaningful flow-diversion angles can be identified at both the cutoff upstream (Φ_u) and downstream (Φ_d) ends. By comparison, because of the unidirectional flow through river channels, only the upstream flow-diversion angle (Φ_u) is morphodynamically meaningful for fluvial cutoffs (Dieras, 2013).

To directly compare meander cutoffs of different sizes, dimensional morphometric variables were normalized using channel width (W), such that width-adjusted cutoff radius of curvature, amplitude, and lengths are defined as $R^* = R/W$, $A^* = A/W$, $L^* = L/W$, and $\ell^* = \ell/W$.

3 Results

Dimensional morphometrics – R, A, and ℓ – all exhibit statistically significant power-law relationships to cutoff width W (p-value < 0.01) with matching best-fit power-law exponents and limited separation in power-law scaling constants (Figure 2 and Figure S2 in Supporting Information). We also found a statistically significant quasi-linear relation between L and W (Figure S3 in Supporting Information), with $L \cong W$. The latter has been described previously as the condition leading to neck cutoff (Li et al., 2022), whereas L<W represents a geometrically impossible configuration (Hayden et al., 2021). Similarly, radius of curvature R=$W/2$ represents a physically meaningful lower bound, since the edges of a channel centerline with a radius of curvature smaller than half its width would intersect each other (Hayden et al., 2021). Although theoretically there are no physical limits to the development of both A and ℓ (besides the basic requirements that A>0 and ℓ>L in order for a centerline to be sinuous), the prevalence of smaller curves weights the distribution of meander features toward the physically meaningful lower bound (Vermeulen et al., 2016). For these reasons, the scaling similarity in dimensional metrics reported in Figure 2 is likely due to the finite-width nature of the sinuous features we measured, rather than representing a suitable diagnostic with which to distinguish the fluvial or tidal nature of meander cutoffs. Indeed, previous studies suggest that dimensionless meander morphometrics should be used to infer morphological similarity (Frascati & Lanzoni, 2009; Howard & Hemberger, 1991). We thus performed Kolmogorov-Smirnov (KS) tests (α=0.05) on dimensionless morphometric descriptors to highlight that tidal cutoffs are typically less sinuous (i.e., lower χ) and feature smaller with-adjusted radii (R^*), amplitudes (A^*), and intrinsic lengths (ℓ^*) (Figure 3 and Table S1 in Supporting Information).

Since meander size and sinuosity are expected to increase with time, our findings indicate that tidal cutoffs are less morphodynamically mature (i.e., less sinuous and planimetrically complex) than their fluvial counterparts. This points to an overall faster evolutionary trajectory from meander inception to cutoffs in tidal settings. However, similar width-adjusted meander migration rates in tidal and fluvial settings (Finotello et al., 2018) contrast with such an interpretation. Furthermore, KS tests demonstrate similar values of asymmetry ($\mathcal{A}$) and upstream flow-diversion angle (Φ_u) in tidal and fluvial cutoffs (Figure 3 and Table S1 in Supporting Information). Given that neither of these parameters are affected by meander size, the observed similarity not only reflects similar morphodynamic maturity but also suggest shared cutoff-triggering mechanisms, likely associated with the planform configuration of the parent channel (Dieras, 2013). Notably, both fluvial and tidal cutoffs exhibit negative median and peak values of the asymmetry index $\mathcal{A}$ (Figure 3e). That is, both types of cutoffs tend to be upstream-skewed, supporting similarity in their dominant morphodynamic regime (*sensu* Seminara et al., 2001). This observation likely stems from the morphodynamic dominance, in tidal channels, of either flood or (more commonly) ebb flows that effectively render tidal meanders similar to their fluvial counterparts featuring unidirectional flows (Fagherazzi et al., 2004; Kleinhans et al., 2009).

We propose that the comparatively smaller size of tidal cutoffs, relative to fluvial ones, is not a result of fundamental differences in their morphodynamics. Instead, it appears to be predominantly influenced by the specific hydrological, ecological, and geomorphological attributes inherent to tidal wetlands. Specifically, we hypothesize that the dense distribution of tidal channels that

typically characterizes tidal wetlands accounts for the reduced size and sinuosity of tidal cutoffs, with enhanced hydrological connectivity explaining the apparent paucity of cutoff traces in tidal environments as we discuss below.

4 Discussion

4.1 Dense channel distribution limits stream meandering and cutoff formation

Meander migration in densely channeled tidal floodplains shapes the landscape differently than in fluvial contexts, where rivers can freely migrate laterally without intercepting other channels and confluences are comparatively infrequent. Tidal wetlands are characterized by high drainage density – taken as the mean shortest distance that a parcel of water placed on the wetland surface would need to travel before reaching the closest channel (Marani et al., 2003). Such enhanced drainage density limits meander dynamics by preventing channels from freely migrating and meanders from fully developing without intercepting adjoining streams (Letzsch & Frey, 1980; Vilas et al., 1999). A similar dynamic is described in multi-thread, anabranching rivers with individual sinuous anabranches, where enhanced channel density limits cutoff formation (Schumm et al., 1996). Accordingly, evidence from modern and ancient deposits shows that channel piracies (i.e., stream captures) in dense tidal networks (Figure S4 in Supporting Information) limit the lateral accretion of point bar bodies and can modify the network-scale distribution of the tidal prism, feeding back into the long term ecomorphodynamic evolution of the entire tidal system (Cosma et al., 2020; Finotello, Ghinassi, et al., 2020). Hence, enhanced channel density limits tidal meander dynamics and cutoff formation.

Our hypothesis is further corroborated by systematic statistically significant differences observed in the distributions of R^*, A^*, L^*, and χ as a function of vegetation cover, with effects of tidal regime and geomorphological background being significant but less systematic (Figure 3 and Tables S2 to S13 in Supporting Information). Tidal cutoffs in salt marshes are smaller and less sinuous than those found in mangrove forests and tidal flats (Figure 3).

This trend resonates with existing research indicating that tidal channel networks are denser in vegetated areas, especially in salt marshes (Kearney & Fagherazzi, 2016; Schwarz et al., 2022).

This evidence supports our contention that in densely channelized tidal wetlands, meander cutoffs are constrained in their size and sinuosity growth due to the increased likelihood of channel piracy during lateral migration. Similar cutoff asymmetries ($\mathcal{A}$) and flow-diversion angles (Φ_u, Φ_d) among distinct tidal settings also support similarity in the morphodynamic processes responsible for cutoff development. Kolmogorov-Smirnov tests reveal significant differences in the distributions of Φ_u, Φ_d, and $\mathcal{A}$ only based on geomorphological setting (Tables S2 to S13 in Supporting Information), but we find no differences in these morphometrics as a function of tidal range and vegetation cover despite the potential influence that both controls can exert on channel bank erosion (Gao, Finotello, D'Alpaos, et al., 2022; Gasparotto et al., 2022; Zhao et al., 2022).

4.2 Hydrological connectivity control on post-cutoff development

To further substantiate that differences in tidal and fluvial cutoff morphology do not stem from dissimilarities in meander morphodynamics, we also examined the connection state of individual cutoffs with their parent channels. Once a river meander is cut off, a plug bar forms in response to flow separation and reduced energy conditions, leading to the rapid deposition of coarse sediment and blockage of both cutoff entrances (Toonen et al., 2012). Eventually, the cutoff becomes completely disconnected from the parent channel and forms an oxbow. Based on the presence and

position of plug bars in our tidal and fluvial examples, we classified cutoffs into four groups: completely connected, upstream connected, downstream connected, and disconnected (Figure 4). The upstream- and downstream-connected cases can also be merged into a broader category of partially connected cutoffs. Whereas more than 43% of fluvial cutoffs in our dataset are entirely disconnected and only 28% are completely connected (Figure 4a), tidal cutoffs tend to remain connected to their parent channels, with 87% of examples completely connected, 9% partially connected, and only 4% entirely disconnected (Figure 4a).

This observed distinction in the connection state of tidal versus fluvial cutoffs appears to be independent of factors such as tidal range, vegetation cover, and geomorphological setting (Figure 4). This finding effectively dispels the notion that the absence of plug bars in tidal cutoffs depends on site-specific landscape characteristics (e.g., sediment grain size; Kleinhans et al., 2024).

Moreover, similar flow-diversion angles are observed in all our study cases, with median values consistently ranging between 105° and 108° (Figure 4b,c) and further pointing to similar cutoff-triggering mechanisms in fluvial and tidal landscapes. Morphological differences thus can be expected to emerge once cutoffs have formed. The percentage of completely connected fluvial cutoffs decreases as the flow-diversion angle increases, implying that larger Φ_u promote the formation of plug bars and oxbows (Figure 4d). In contrast, tidal cutoffs tend to remain connected to their parent channel irrespective of flow-diversion angles, whether upstream or downstream (Figure 4d and Figure S5 in Supporting Information).

Therefore, unlike fluvial analogs, most tidal cutoffs remain hydrodynamically active to some extent: periodic overbank flows in tidal channels result in significant rates of lateral flow injections from the adjoining tidal floodplains during ebb tide, which maintain active flows even in cutoff bends and prevent plug-bar formation by keeping the cutoff entrance flushed. Notably, some tidal cutoffs may also remain connected to other active parts of the network through minor lateral tributaries flowing directly into the cutoff (Figure 1a-i and Figure S6 in Supporting Information). Hence, pronounced hydrological connectivity in tidal wetlands prevents the formation of plug bars and the subsequent evolution of tidal cutoffs into oxbows. Such an evolutionary trajectory clearly differs from fluvial cutoffs, which are typically abandoned and receive water and sediment input almost exclusively during major floods either through minor tie channels carved through the plug bar (Rowland et al., 2009) or as the entire alluvial plain floods (Shen et al., 2021).

Among the partially connected cutoffs in our dataset, the fluvial ones are preferentially connected with their parent channels at the upstream end: plug bars tend to form at the cutoff downstream end where flow separations and recirculation create a zone of dead velocity that hinders mixing and promotes sediment deposition (e.g., Turnipseed et al., 2021). In contrast, the few partially connected tidal cutoffs on record, tend to maintain connectivity at the downstream end (Figure 4a), aligned with the direction of typically dominant ebb flows that seemingly keep the cutoff downstream end periodically flushed.

4.3 Meander cutoffs in tidal coastal landscapes: rare or everywhere?

Abundant tidal cutoffs akin to oxbow-rich alluvial floodplains can be found in some tidal settings with possibly lower drainage density and/or sediment supply that limits cutoff infill and vegetation encroachment (Figure 1f-i; Figures S7, S8 in Supporting Information). This further corroborates the observation that tidal and fluvial meandering channels not only evolve through similar morphodynamic processes, but also that tidal meanders are as prone to form cutoffs as their fluvial counterparts given conducive environmental conditions. Given the apparent ubiquity of cutoffs

across a variety of tidal environments, why has the notion that sinuous tidal channel bends are inherently unlikely to cut off prevailed for so long (Gabet, 1998; Johnson, 1929)?

We suggest that, first, the characteristic width and amplitude of fluvial cutoffs may not vary significantly along a given reach of a meandering river between major tributaries, whereas meander cutoffs within a given tidal wetland can occur across a broad range of meander wavelengths and widths (Finotello, D'Alpaos, et al., 2020). Low-order, narrow tidal creeks are more frequently found than higher-order, wide channels and are thus the most likely to express cutoff development (Figure 1a-i; Figures S7, S8 in Supporting Information). Yet small channels produce small cutoffs, which are especially challenging to observe from a broader spatial vantage, particularly when the vegetation canopy is dense (e.g., in mangrove forests, Figure S9 in Supporting Information).

Another consideration is the sustained rate of vertical accretion that characterizes tidal wetlands, coupled with halophytic vegetation that can tolerate significant waterlogging stress. These factors may becloud cutoff traces (Figure 1b,d,f-i and Figure S9 in Supporting Information) through rapid sedimentation in the less hydrodynamically active portions of the cutoff, and the subsequent encroachment of vegetation. This levels out cutoff geomorphic expressions and further hinders their identification from aerial images. Although similar reasoning could apply to fluvial floodplains, reduced overbank sediment supply and slower rates of riparian vegetation growth in permanently waterlogged areas may prolong the timescale required to fill oxbows, making large river-cutoff scars identifiable from aerial photos for much longer periods (Kleinhans et al., 2024) (Figure 1j,k).

The apparent absence of tidal cutoffs is thus more an artifact of observations than a consequence of physical mechanisms. High drainage densities in tidal wetlands surely constrain the freely meandering of tidal channels (Figure S10 in Supporting Information). Yet the relatively small size of most tidal channels, along with the distinctive hydrological characteristics of tidal wetlands, contribute to the transient nature of tidal cutoffs and make them challenging to record. That is, unlike other features of meandering channels that might jump out at the observer, to find tidal cutoffs one has to go carefully looking for them.

The implied morphodynamic similarity between tidal and fluvial meanders is by no means diminished by the absence of prominent scroll bars in tidal wetlands, standing in stark contrast to river floodplains that often – but not always (Candel et al., 2020, 2021) – showcase intricate arrangements of sub-parallel scrolls indicative of previous channel locations (Figure 1k) (Strick et al., 2018). While there is no consensus on what drives the formation of scroll bars (van de Lageweg et al., 2014), we offer two possible, not mutually exclusive explanations for the absence of scroll bars in tidal meanders. One possibility is that tidal meanders undergo small and yet continuous incremental migrations, unlike fluvial meanders which tend to migrate more episodically during major flood events (Mason & Mohrig, 2019; Wu et al., 2016). Another hypothesis is that sustained rates of vertical aggradation relative to lateral channel migration in tidal wetlands prevent scroll bars by systematically overshadowing any topographic irregularities (Brivio et al., 2016; Cosma et al., 2019). This explanation aligns with the lack of scroll bars in meandering streamflows evolving through curvature-driven fluvial-like mechanisms in aggradational settings such as coastal backwater areas (Swartz et al., 2020), peatlands (Candel et al., 2017), and submarine turbidity-current channels (Jobe et al., 2016; Morris et al., 2024).

5 Implications and Conclusions

Our findings demonstrate that meandering channels in tidal wetlands possess the same capacity

to form meander cutoffs as their fluvial counterparts. The morphometric evidence we have gathered suggests that the morphodynamic processes driving the development of both tidal and fluvial cutoffs are fundamentally similar. However, substantial differences arise after cutoffs have formed. Unlike fluvial cutoffs, which tend to form oxbows, tidal cutoffs remain preferentially connected to their parent channel. This distinction is attributed to the pronounced hydrological connectivity characteristic of tidal wetlands. As a result, tidal meander cutoffs continue to actively participate in the draining and flooding of the surrounding wetlands, and maintain their status as integral components of the overall system.

Considered alongside previous studies, our results indicate a complete morphodynamic analogy between tidal and fluvial meandering channels from meander inception to cutoff (Finotello et al., 2018, 2022; Gao, Finotello, & Wang, 2022; Leuven et al., 2018). The unification of tidal and fluvial meander morphodynamics allows for extending classical techniques for modeling meandering rivers (Bogoni et al., 2017; Howard & Knutson, 1984; Parker et al., 2011; Seminara et al., 2001) to tidal wetland contexts, where meandering is ubiquitous and yet routinely omitted. Such an advance in numerical modeling would open new opportunities for how researchers model tidal wetland ecomorphodynamics, with important implications for the effective conservation and restoration of these critical ecosystems.

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Conflict of Interest Statement

The authors declare no conflict of interest.

Open Research

All the data presented and analyzed in this paper are freely available from a public Zenodo folder (Gao & Finotello, 2023)

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Figures and Tables

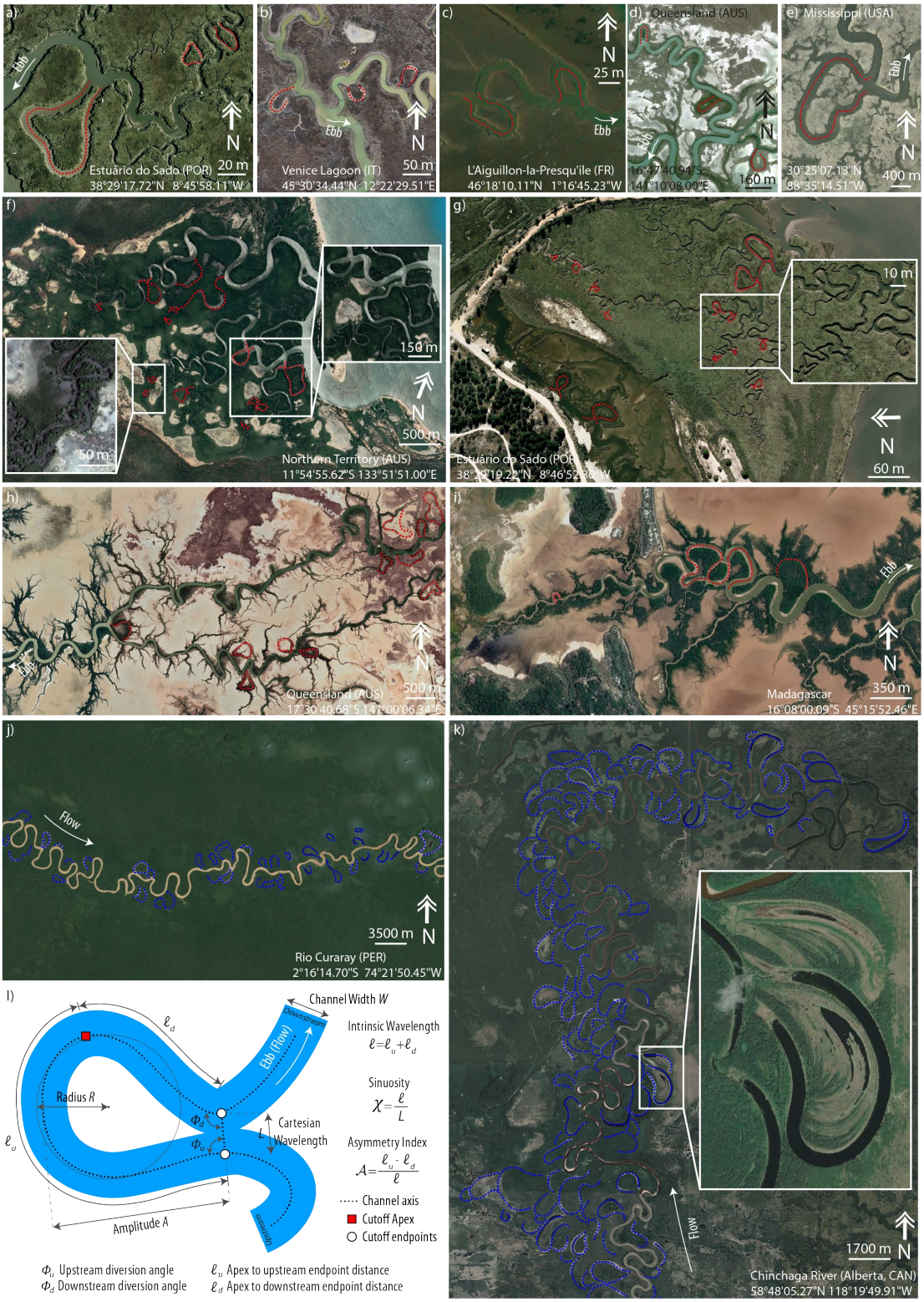

Figure 1. Meander cutoffs in tidal and fluvial landscapes. (a,b,c,d) Examples of individual tidal meander cutoffs from distinct coastal settings worldwide (image© Google, Maxar). (f,g,h,i) Examples of tidal environments characterized by widespread meander cutoffs (image©Google: TerraMetrics, CNES/Airbus,

Maxar, Landsat/Copernicus). (j,k) Examples of river floodplains littered by oxbow lakes and cutoff traces (image©Google: Maxar). Geographic coordinates are reported in each panel. Dotted red and blue lines highlight discernable traces of meander cutoffs in tidal and fluvial landscapes, respectively. l) Sketch illustrating the main morphometric features of meander cutoffs analyzed in this study.

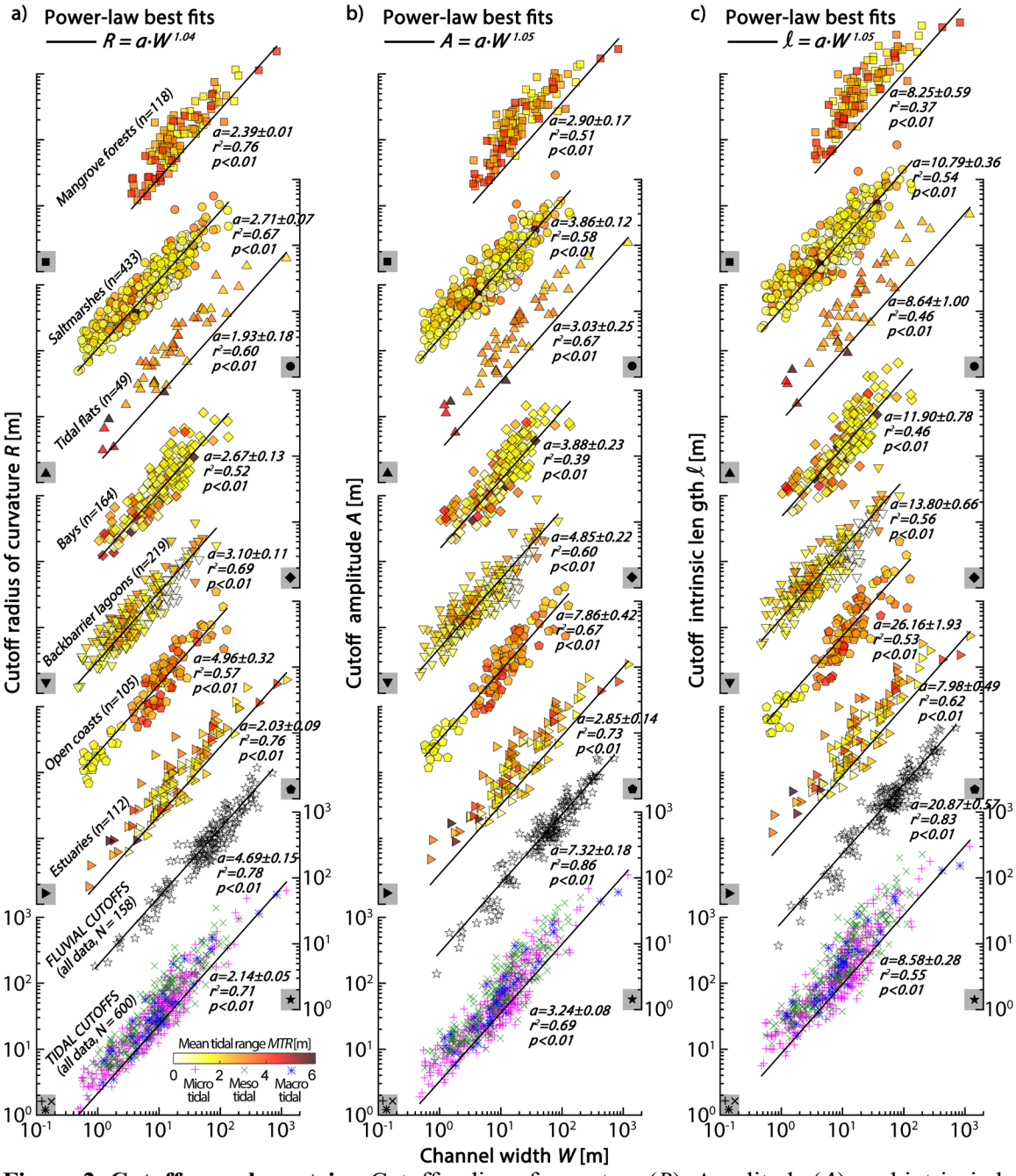

Figure 2. Cutoff morphometrics. Cutoff radius of curvature (R), Amplitude (A), and intrinsic length (ℓ) are plotted against channel width (W) both separately for all tidal and fluvial cutoffs on record and for different tidal-cutoff ensembles based on geomorphological settings and vegetation cover color-coded based on tidal ranges. Continuous black lines represent best-fit power law regressions obtained for different data ensembles, using a common exponent derived from all data and applied to calculate scaling coefficients for each ensemble. Note that the vertical offset among individual data plots is arbitrary: each vertical y-axis ranges from 10^0 to 10^3, and symbols are positioned at the bottom of the axis to aid in identifying the corresponding data plot.

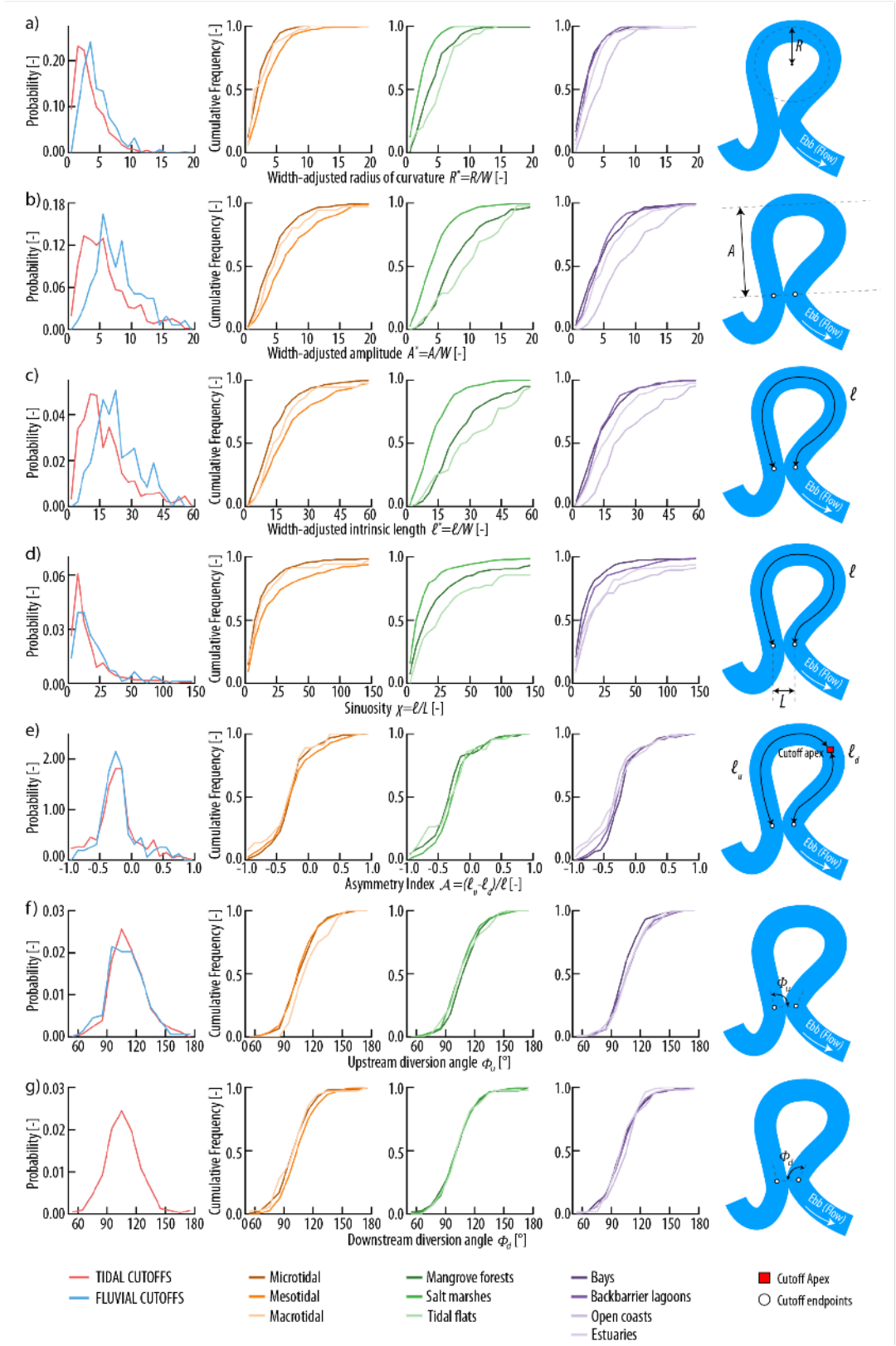

Figure 3. Dimensionless cutoff morphometrics. (a) Width-adjusted radius of curvature; (b) width-adjusted amplitude (c) width-adjusted intrinsic length; (d) sinuosity (χ); (e) asymmetry index ($\mathcal{A}$); (f,g)

upstream and downstream flow-diversion angles (Φ_u and Φ_d). Panels in the first column show empirical probability distributions for tidal (red) and fluvial (blue) cutoffs. Panels in the other columns report empirical cumulative frequency distributions for tidal cutoffs subdivided based on tidal range, vegetation cover, and geomorphological setting. The fifth column contains sketch-up views for each investigated morphometric.

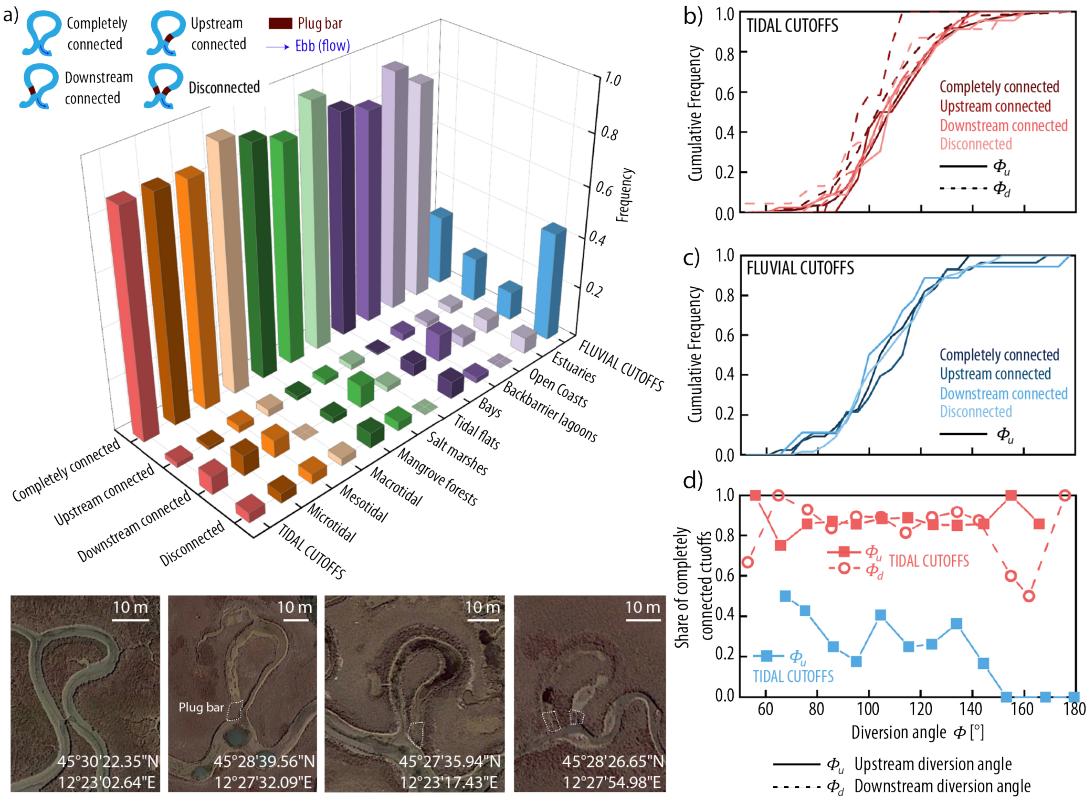

Figure 4. Cutoff connectivity. (a) Barplot showing the relative frequency of different connection types between cutoffs and parent channels, differentiating tidal (red) and fluvial (blue) cutoffs, and further segmenting tidal cutoff ensembles based on tidal range (orange), vegetation cover (green), and geomorphological settings (purple). (b,c) Frequency distributions of flow-diversion angles (Φ) for tidal and fluvial cutoffs. Different colors denote different connectivity with the parent channel. Solid and dashed lines denote upstream and downstream diversion angles, respectively. (d) Share of completely connected tidal (red) and fluvial (blue) cutoffs across uniform 10° diversion-angle intervals. Solid squares and empty dots denote upstream and downstream diversion angles, respectively. (e) Tidal cutoffs found in the microtidal lagoon of Venice (Italy) characterized by different connectivity.

Supporting Information for

Morphometry of tidal meander cutoffs indicates similarity to fluvial morphodynamics

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Figure S1. Examples of tidal cutoffs found in tidal environments characterized by different tidal regimes, vegetation coverages, and geomorphological settings.

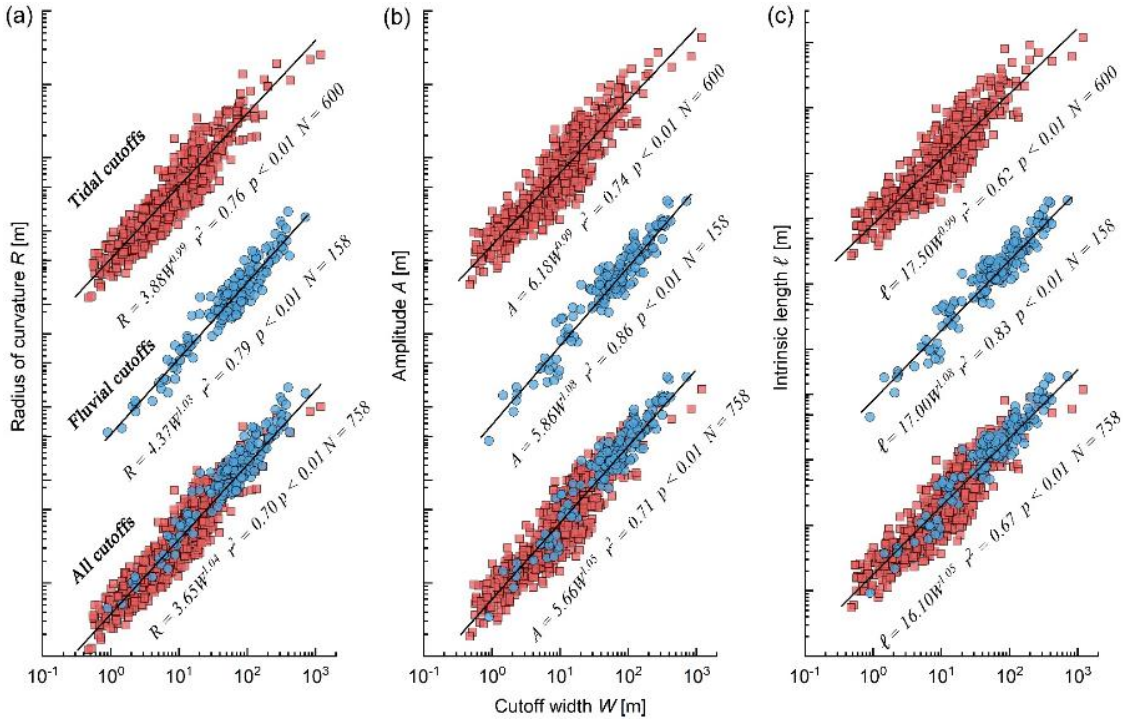

Figure S2. Planform morphometrics of tidal and fluvial meander cutoffs. The cutoff radius of curvature (R), Amplitude (A), and intrinsic length (ℓ) are plotted against channel width (W). Data are plotted both separately and altogether for tidal (red) and fluvial cutoffs (blue). Note that the vertical offset is arbitrary. Continuous black lines represent best-fit power law regressions for each set of data points.

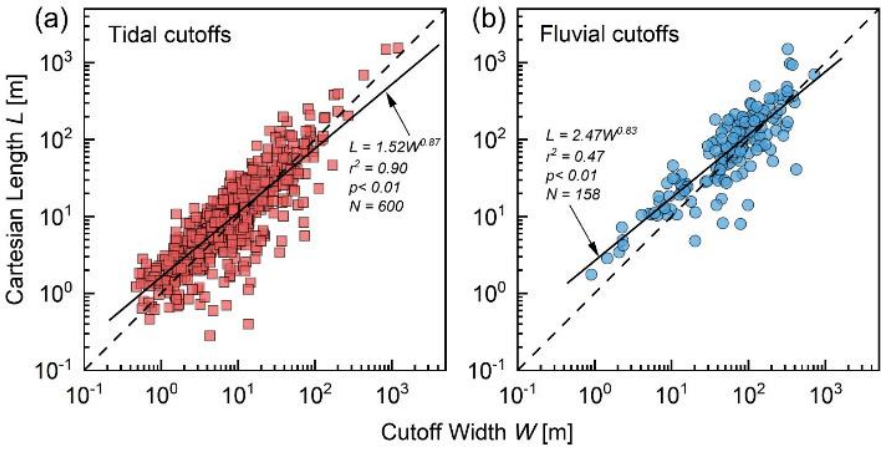

Figure S3. Relationship between cutoff Cartesian length (L) *and channel width* (W) *for (a) tidal and (b) fluvial cutoffs, respectively. The solid lines represent the power-law best fits for all data, whereas dashed lines denote* $L = W$.

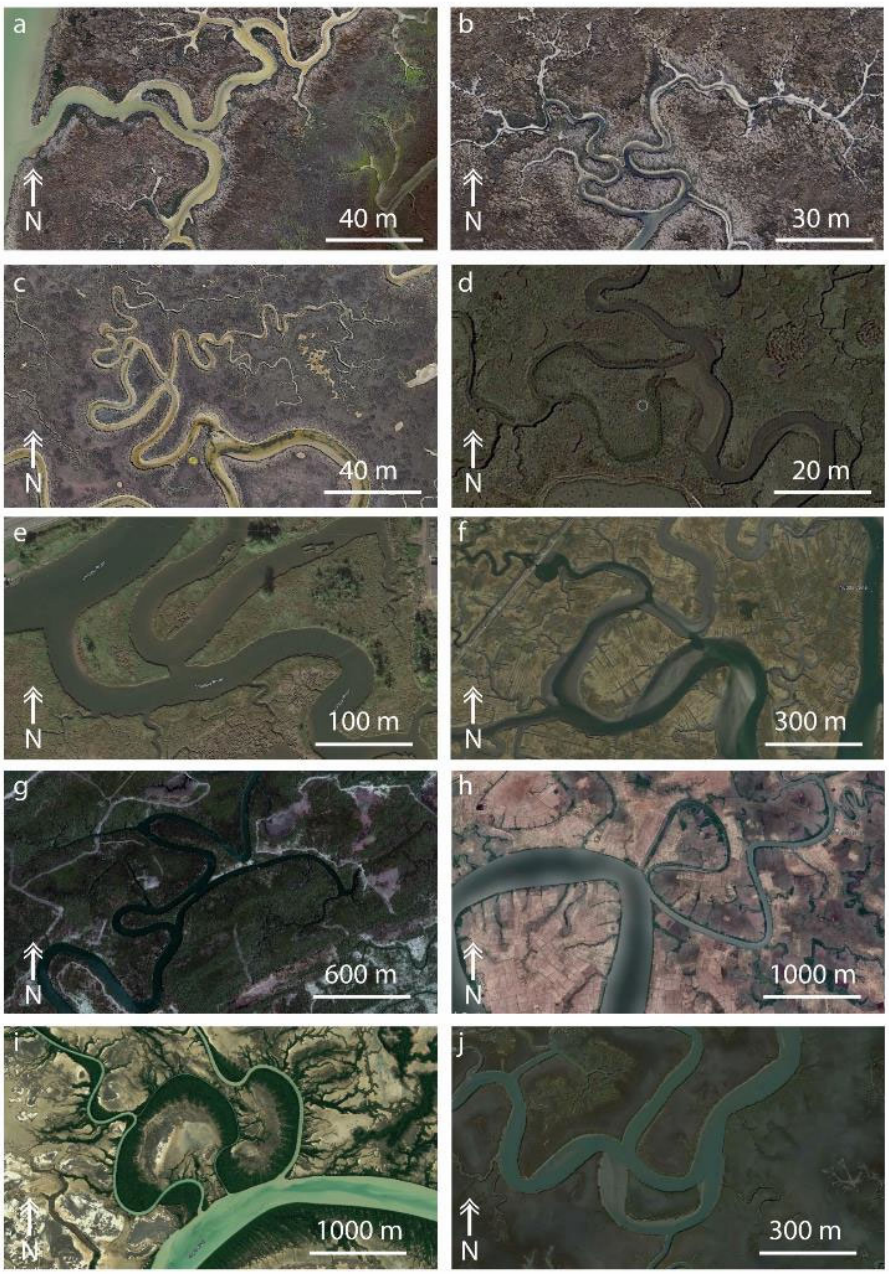

Figure S4. Examples of tidal channel piracies (i.e., captures) from different tidal environments worldwide. a,b,c,) Pagliaga salt marsh, Venice Lagoon, Italy (image ©Google, unknown). d) Ile aux Oiseaux, Aranchon Bay, France (image ©Google, unknown). e) Willapa River, Washington, USA (image ©Google, unknown). f) Hampton, New Hampshire, USA (image ©Google, unknown). g) Pyin Ah Lan/Poe Laung, Myanmar (image ©Google, Maxar technologies). h) Irawaddy River Delta, Myanmar (image ©Google, Maxar technologies). i) Rope River Estuary, Northern Territory, Australia (image ©Google, Maxar technologies). l) Cape Romain National Wildlife Refuge, South Carolina, USA (image ©Google, unknown).

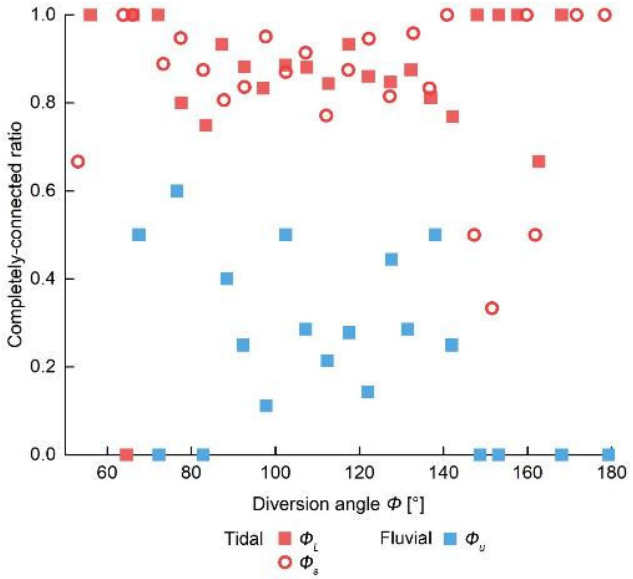

Figure S5. Shares of completely connected cutoffs as a function of diversion angle, computed by binning data based on equally spaced Φ interval (bin size = 5°) and then dividing the number of completely connected cutoffs by the total number of cutoffs in each interval. Tidal and fluvial cutoff data are plotted in red and blue colors, with solid squares and empty dots denoting upstream and downstream diversion angles, respectively.

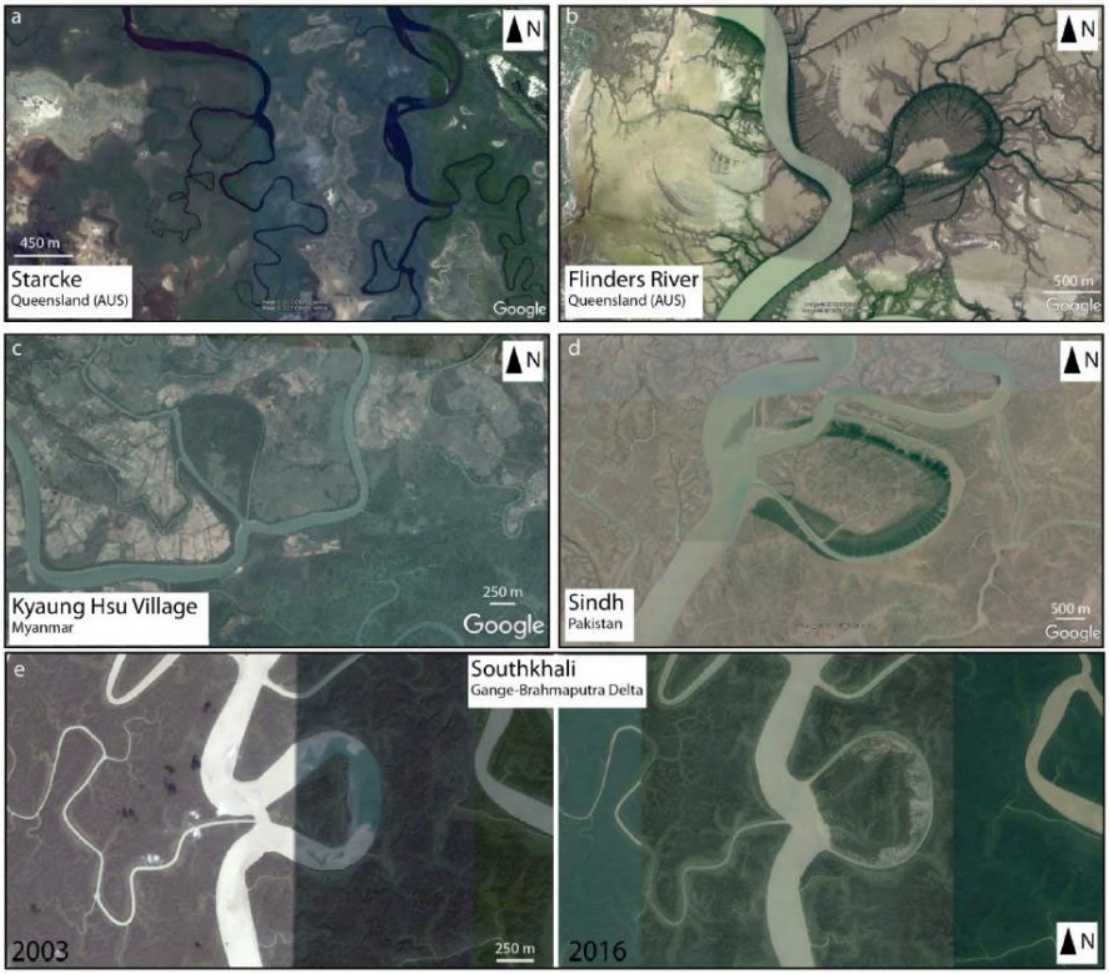

Figure S6. Examples of tidal cutoff remaining either partially or completely connected to their parent channels while keep draining water from the surrounding intertidal areas.

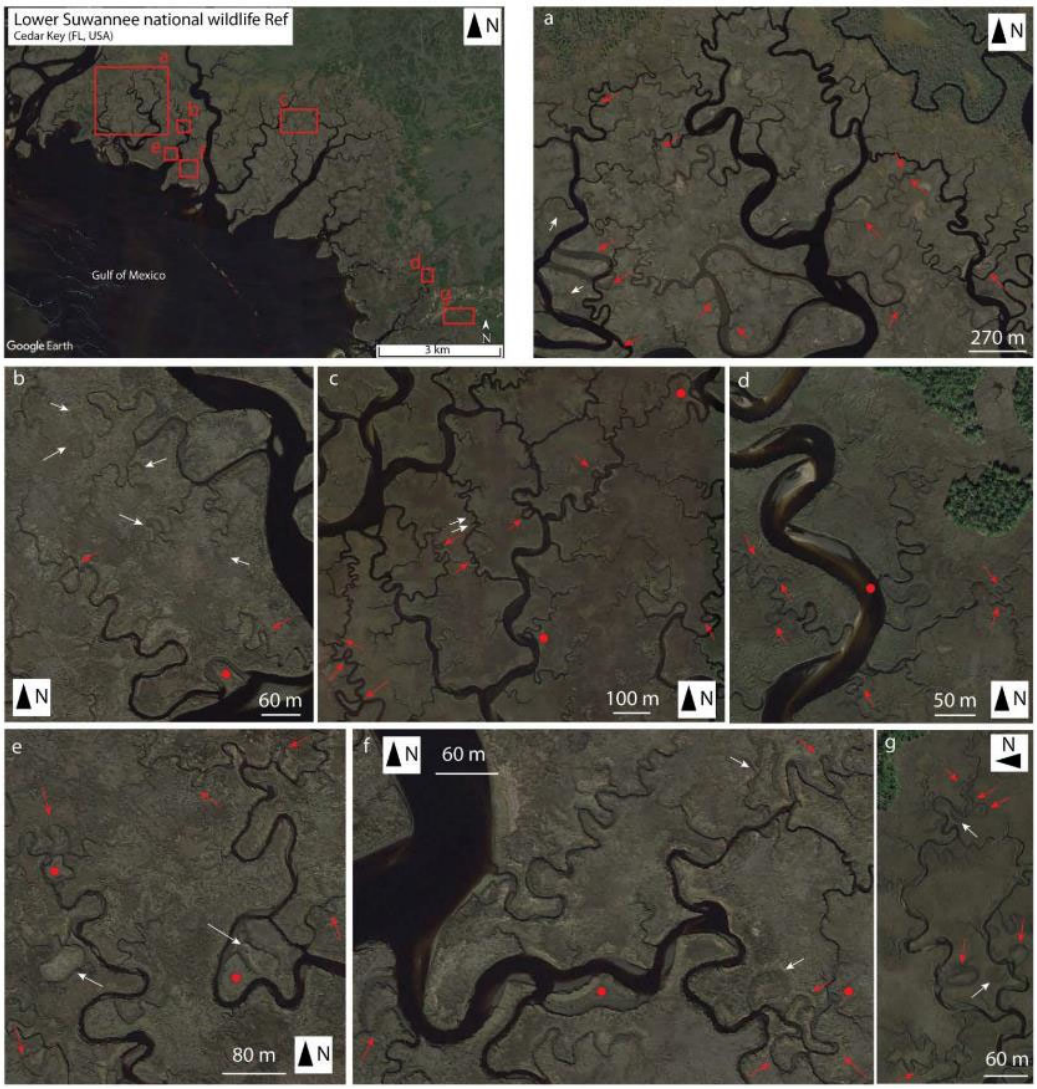

Figure S7. Identification of tidal meander cutoffs within the lower Sawannee National wildlife Ref (FL, USA). Red and white arrows indicate active and relic (i.e., unanalyzed) cutoffs, respectively, whereas red dots identify abandoned channels produced by piracies (i.e., captures) of two adjoining channels.

Figure S8. Identification of tidal meander cutoffs in different tidal settings worldwide. Red and white arrows indicate active and relic (i.e., unanalyzed) cutoffs, respectively.

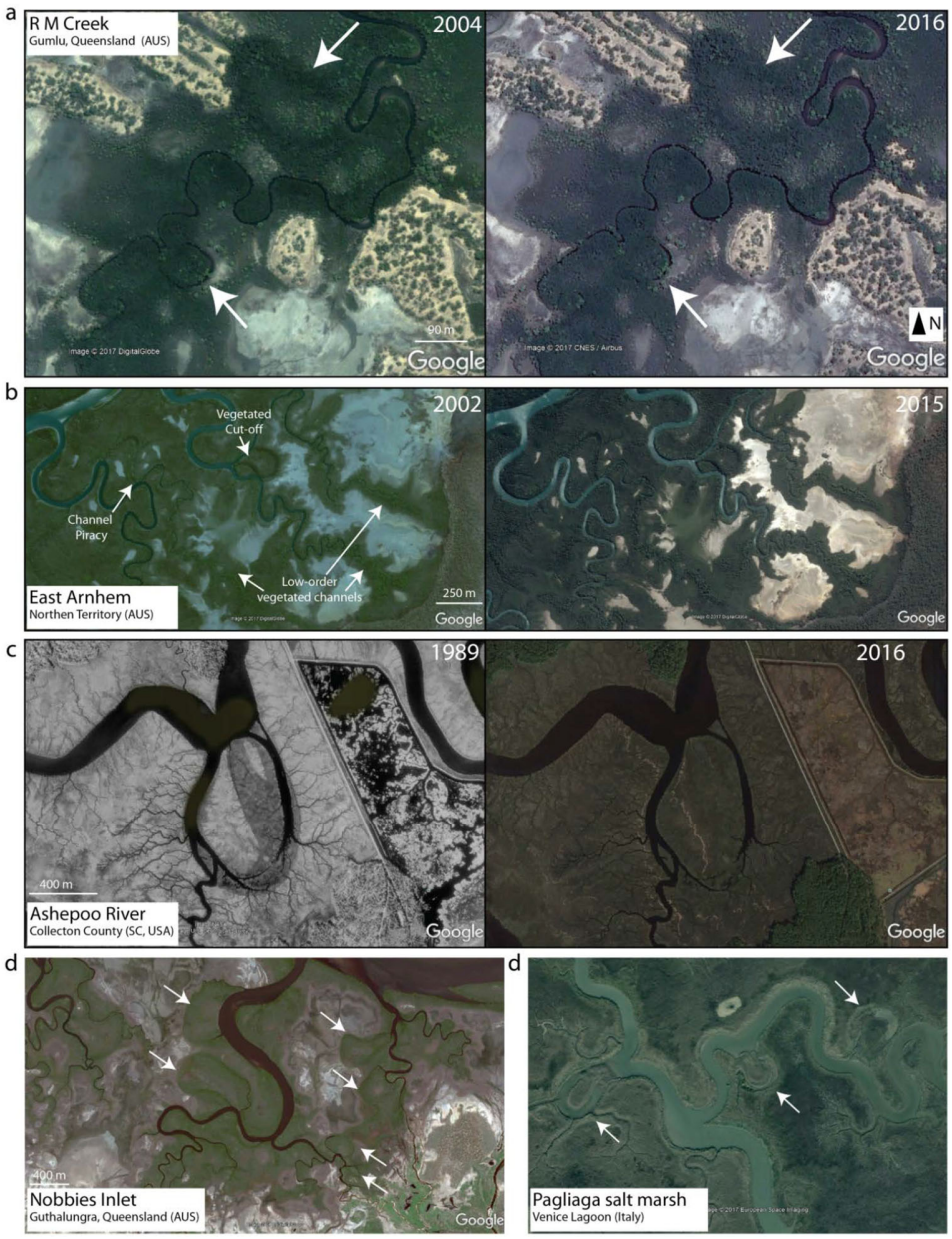

Figure S9. Examples of tidal meander cutoffs colonized by dense halophytic vegetation and/or incorporated into broader drainage network.

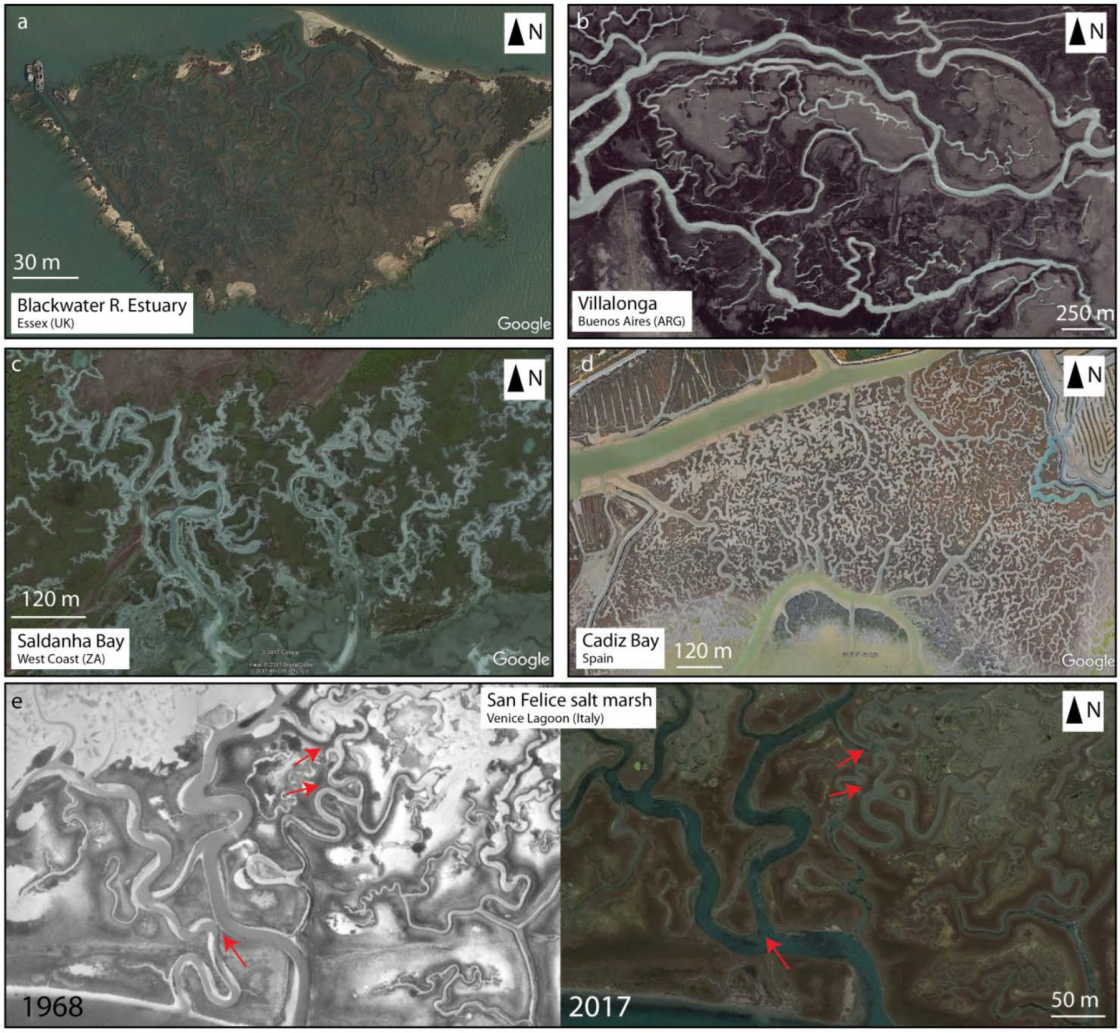

Figure S10. Examples of tidal wetlands characterized by high drainage densities that potentially limit freely meandering of tidal streams, as illustrated by the example reported in the bottom panel.

Table S1. *KS test for tidal cutoffs and fluvial cutoffs (α = 0.05)*

Variable	*Null Hypothesis* H_0	*Alternative Hyp.* H_1	*Rejected Null Hypothesis*	*p-value*
R^*	$cdf_{tidal} = cdf_{fluvial}$	$cdf_{tidal} \neq cdf_{fluvial}$	*Yes*	$4.53e^{-9}$
	$cdf_{tidal} = cdf_{fluvial}$	$cdf_{tidal} > cdf_{fluvial}$	*Yes*	$2.27e^{-9}$
A^*	$cdf_{tidal} = cdf_{fluvial}$	$cdf_{tidal} \neq cdf_{fluvial}$	*Yes*	$3.17e^{-12}$
	$cdf_{tidal} = cdf_{fluvial}$	$cdf_{tidal} > cdf_{fluvial}$	*Yes*	$1.58e^{-12}$
ℓ^*	$cdf_{tidal} = cdf_{fluvial}$	$cdf_{tidal} \neq cdf_{fluvial}$	*Yes*	$8.56e^{-12}$
	$cdf_{tidal} = cdf_{fluvial}$	$cdf_{tidal} > cdf_{fluvial}$	*Yes*	$4.28e^{-12}$
χ	$cdf_{tidal} = cdf_{fluvial}$	$cdf_{tidal} \neq cdf_{fluvial}$	*Yes*	$6.28e^{-4}$
	$cdf_{tidal} = cdf_{fluvial}$	$cdf_{tidal} > cdf_{fluvial}$	*Yes*	$3.14e^{-4}$
$\mathcal{A}$	$cdf_{tidal} = cdf_{fluvial}$	$cdf_{tidal} \neq cdf_{fluvial}$	*No*	$4.90e^{-1}$
Φ_u	$cdf_{tidal} = cdf_{fluvial}$	$cdf_{tidal} \neq cdf_{fluvial}$	*No*	$4.22e^{-1}$

Table S2. *KS test for microtidal cutoffs and mesotidal cutoffs (α = 0.05)*

Variable	*Null Hypothesis* H_0	*Alternative Hyp.* H_1	*Rejected Null Hypothesis*	*p-value*
R^*	$cdf_{micro} = cdf_{meso}$	$cdf_{micro} \neq cdf_{meso}$	*Yes*	$2.49e^{-7}$
	$cdf_{micro} = cdf_{meso}$	$cdf_{micro} > cdf_{meso}$	*Yes*	$1.25e^{-7}$
A^*	$cdf_{micro} = cdf_{meso}$	$cdf_{micro} \neq cdf_{meso}$	*Yes*	$1.42e^{-8}$
	$cdf_{micro} = cdf_{meso}$	$cdf_{micro} > cdf_{meso}$	*Yes*	$7.10e^{-9}$
ℓ^*	$cdf_{micro} = cdf_{meso}$	$cdf_{micro} \neq cdf_{meso}$	*Yes*	$3.62e^{-7}$
	$cdf_{micro} = cdf_{meso}$	$cdf_{micro} > cdf_{meso}$	*Yes*	$1.81e^{-7}$
χ	$cdf_{micro} = cdf_{meso}$	$cdf_{micro} \neq cdf_{meso}$	*Yes*	$1.62e^{-6}$
	$cdf_{micro} = cdf_{meso}$	$cdf_{micro} > cdf_{meso}$	*Yes*	$8.12e^{-7}$
$\mathcal{A}$	$cdf_{micro} = cdf_{meso}$	$cdf_{micro} \neq cdf_{meso}$	*No*	$3.60e^{-1}$
Φ_u	$cdf_{micro} = cdf_{meso}$	$Cdf_{micro} \neq cdf_{meso}$	*No*	$6.80e^{-1}$
Φ_d	$Cdf_{micro} = cdf_{meso}$	$Cdf_{micro} \neq cdf_{meso}$	*No*	$3.00e^{-1}$

Table S3. *KS test for microtidal cutoffs and macrotidal cutoffs (α = 0.05)*

Variable	*Null Hypothesis* H_0	*Alternative Hyp.* H_1	*Rejected Null Hypothesis*	*p-value*
R^*	$cdf_{micro} = cdf_{macro}$	$cdf_{micro} \neq cdf_{macro}$	*No*	$6.30e^{-1}$
A^*	$cdf_{micro} = cdf_{macro}$	$cdf_{micro} \neq cdf_{macro}$	*No*	$5.10e^{-1}$
ℓ^*	$cdf_{micro} = cdf_{macro}$	$cdf_{micro} \neq cdf_{macro}$	*No*	$3.90e^{-1}$
χ	$cdf_{micro} = cdf_{macro}$	$cdf_{micro} \neq cdf_{macro}$	*No*	$7.30e^{-1}$
$\mathcal{A}$	$cdf_{micro} = cdf_{macro}$	$cdf_{micro} \neq cdf_{macro}$	*No*	$8.30e^{-1}$
Φ_u	$cdf_{micro} = cdf_{macro}$	$cdf_{micro} \neq cdf_{macro}$	*No*	$3.00e^{-1}$
Φ_d	$cdf_{micro} = cdf_{macro}$	$cdf_{micro} \neq cdf_{macro}$	*No*	$6.70e^{-1}$

Table S4. *KS test for mesotidal cutoffs and macrotidal cutoffs (α = 0.05)*

Variable	*Null Hypothesis* H_0	*Alternative Hyp.* H_1	*Rejected Null Hypothesis*	*p-value*
R^*	$cdf_{meso} = cdf_{macro}$	$cdf_{meso} \neq cdf_{macro}$	*No*	$1.00e^{-2}$
A^*	$cdf_{meso} = cdf_{macro}$	$cdf_{meso} \neq cdf_{macro}$	*No*	$1.90e^{-1}$
ℓ^*	$cdf_{meso} = cdf_{macro}$	$cdf_{meso} \neq cdf_{macro}$	*No*	$3.70e^{-1}$
χ	$cdf_{meso} = cdf_{macro}$	$cdf_{meso} \neq cdf_{macro}$	*No*	$2.70e^{-1}$
$\mathcal{A}$	$cdf_{meso} = cdf_{macro}$	$cdf_{meso} \neq cdf_{macro}$	*No*	$8.20e^{-1}$
Φ_u	$cdf_{meso} = cdf_{macro}$	$cdf_{meso} \neq cdf_{macro}$	*No*	$5.00e^{-2}$
Φ_d	$cdf_{meso} = cdf_{macro}$	$cdf_{meso} \neq cdf_{macro}$	*No*	$2.70e^{-1}$

Table S5. *KS test for mangrove swamp cutoffs and salt marsh cutoffs (α = 0.05)*

Variable	*Null Hypothesis* H_0	*Alternative Hyp.* H_1	*Rejected Null Hypothesis*	*p-value*
R^*	$cdf_{mangrove} = cdf_{marsh}$	$cdf_{mangrove} \neq cdf_{marsh}$	*Yes*	$3.20e^{-9}$
	$cdf_{mangrove} = cdf_{marsh}$	$cdf_{mangrove} > cdf_{marsh}$	*No*	*1.00*
	$cdf_{mangrove} = cdf_{marsh}$	$cdf_{mangrove} < cdf_{marsh}$	*Yes*	$1.60e^{-9}$
A^*	$cdf_{mangrove} = cdf_{marsh}$	$cdf_{mangrove} \neq cdf_{marsh}$	*Yes*	$2.33e^{-15}$
	$cdf_{mangrove} = cdf_{marsh}$	$cdf_{mangrove} > cdf_{marsh}$	*No*	*1.00*
	$cdf_{mangrove} = cdf_{marsh}$	$cdf_{mangrove} < cdf_{marsh}$	*Yes*	$1.17e^{-15}$
ℓ^*	$cdf_{mangrove} = cdf_{marsh}$	$cdf_{mangrove} \neq cdf_{marsh}$	*Yes*	$9.66e^{-17}$
	$cdf_{mangrove} = cdf_{marsh}$	$cdf_{mangrove} > cdf_{marsh}$	*No*	*1.00*
	$cdf_{mangrove} = cdf_{marsh}$	$cdf_{mangrove} < cdf_{marsh}$	*Yes*	$4.83e^{-17}$
χ	$cdf_{mangrove} = cdf_{marsh}$	$cdf_{mangrove} \neq cdf_{marsh}$	*Yes*	$5.58e^{-6}$
	$cdf_{mangrove} = cdf_{marsh}$	$cdf_{mangrove} > cdf_{marsh}$	*No*	*1.00*
	$cdf_{mangrove} = cdf_{marsh}$	$cdf_{mangrove} < cdf_{marsh}$	*Yes*	$2.79e^{-6}$
$\mathcal{A}$	$cdf_{mangrove} = cdf_{marsh}$	$cdf_{mangrove} \neq cdf_{marsh}$	*No*	$2.00e^{-2}$
Φ_u	$cdf_{mangrove} = cdf_{marsh}$	$cdf_{mangrove} \neq cdf_{marsh}$	*No*	$2.10e^{-1}$
Φ_d	$cdf_{mangrove} = cdf_{marsh}$	$cdf_{mangrove} \neq cdf_{marsh}$	*No*	$6.70e^{-1}$

Table S6. *KS test for mangrove swamp cutoffs and tidal flat cutoffs (α = 0.05)*

Variable	*Null Hypothesis* H_0	*Alternative Hyp.* H_1	*Rejected Null Hypothesis*	*p-value*
R^*	$cdf_{mangrove} = cdf_{flat}$	$cdf_{mangrove} \neq cdf_{flat}$	*Yes*	$7.00e^{-3}$
	$cdf_{mangrove} = cdf_{flat}$	$cdf_{mangrove} > cdf_{flat}$	*Yes*	$3.00e^{-3}$
A^*	$cdf_{mangrove} = cdf_{flat}$	$cdf_{mangrove} \neq cdf_{flat}$	*No*	$3.00e^{-2}$
ℓ^*	$cdf_{mangrove} = cdf_{flat}$	$cdf_{mangrove} \neq cdf_{flat}$	*No*	$4.00e^{-2}$
χ	$cdf_{mangrove} = cdf_{flat}$	$cdf_{mangrove} \neq cdf_{flat}$	*No*	$1.00e^{-1}$
$\mathcal{A}$	$cdf_{mangrove} = cdf_{flat}$	$cdf_{mangrove} \neq cdf_{flat}$	*No*	$2.50e^{-1}$
Φ_u	$cdf_{mangrove} = cdf_{flat}$	$cdf_{mangrove} \neq cdf_{flat}$	*No*	$8.70e^{-1}$
Φ_d	$cdf_{mangrove} = cdf_{flat}$	$cdf_{mangrove} \neq cdf_{flat}$	*No*	$9.90e^{-1}$

Table S7. *KS test for salt marsh cutoffs and tidal flat cutoffs (α = 0.05)*

Variable	Null Hypothesis H_0	Alternative Hyp. H_1	Rejected Null Hypothesis	p-value
R^*	$cdf_{marsh} = cdf_{flat}$	$cdf_{marsh} \neq cdf_{flat}$	Yes	$1.84e^{-11}$
	$cdf_{marsh} = cdf_{flat}$	$cdf_{marsh} > cdf_{flat}$	Yes	$9.20e^{-12}$
A^*	$cdf_{marsh} = cdf_{flat}$	$cdf_{marsh} \neq cdf_{flat}$	Yes	$6.05e^{-13}$
	$cdf_{marsh} = cdf_{flat}$	$cdf_{marsh} > cdf_{flat}$	Yes	$3.02e^{-13}$
ℓ^*	$cdf_{marsh} = cdf_{flat}$	$cdf_{marsh} \neq cdf_{flat}$	Yes	$2.77e^{-12}$
	$cdf_{marsh} = cdf_{flat}$	$cdf_{marsh} > cdf_{flat}$	Yes	$1.38e^{-12}$
χ	$cdf_{marsh} = cdf_{flat}$	$cdf_{marsh} \neq cdf_{flat}$	Yes	$2.69e^{-6}$
	$cdf_{marsh} = cdf_{flat}$	$cdf_{marsh} > cdf_{flat}$	Yes	$1.34e^{-6}$
$\mathcal{A}$	$cdf_{marsh} = cdf_{flat}$	$cdf_{marsh} \neq cdf_{flat}$	No	$6.00e^{-2}$
Φ_u	$cdf_{marsh} = cdf_{flat}$	$cdf_{marsh} \neq cdf_{flat}$	No	$7.00e^{-1}$
Φ_d	$cdf_{marsh} = cdf_{flat}$	$cdf_{marsh} \neq cdf_{flat}$	No	1.00

Table S8. *KS test for bay cutoffs and lagoon cutoffs (α = 0.05)*

Variable	Null Hypothesis H_0	Alternative Hyp. H_1	Rejected Null Hypothesis	p-value
R^*	$cdf_{bay} = cdf_{lagoon}$	$cdf_{bay} \neq cdf_{lagoon}$	No	$2.62e^{-1}$
A^*	$cdf_{bay} = cdf_{lagoon}$	$cdf_{bay} \neq cdf_{lagoon}$	No	$1.50e^{-1}$
ℓ^*	$cdf_{bay} = cdf_{lagoon}$	$cdf_{bay} \neq cdf_{lagoon}$	No	$1.58e^{-1}$
χ	$cdf_{bay} = cdf_{lagoon}$	$cdf_{bay} \neq cdf_{lagoon}$	No	$5.67e^{-2}$
$\mathcal{A}$	$cdf_{bay} = cdf_{lagoon}$	$cdf_{bay} \neq cdf_{lagoon}$	No	$1.28e^{-1}$
Φ_u	$cdf_{bay} = cdf_{lagoon}$	$cdf_{bay} \neq cdf_{lagoon}$	Yes	$3.09e^{-2}$
	$cdf_{bay} = cdf_{lagoon}$	$cdf_{bay} > cdf_{lagoon}$	Yes	$1.55e^{-2}$
Φ_d	$cdf_{bay} = cdf_{lagoon}$	$cdf_{bay} \neq cdf_{lagoon}$	No	$8.75e^{-1}$

Table S9. *KS test for bay cutoffs and coast cutoffs (α = 0.05)*

Variable	Null Hypothesis H_0	Alternative Hyp. H_1	Rejected Null Hypothesis	p-value
R^*	$cdf_{bay} = cdf_{coast}$	$cdf_{bay} \neq cdf_{coast}$	Yes	$2.04e^{-8}$
	$cdf_{bay} = cdf_{coast}$	$cdf_{bay} > cdf_{coast}$	Yes	$1.02e^{-8}$
A^*	$cdf_{bay} = cdf_{coast}$	$cdf_{bay} \neq cdf_{coast}$	Yes	$3.93e^{-9}$
	$cdf_{bay} = cdf_{coast}$	$cdf_{bay} > cdf_{coast}$	Yes	$1.97e^{-9}$
ℓ^*	$cdf_{bay} = cdf_{coast}$	$cdf_{bay} \neq cdf_{coast}$	Yes	$7.95e^{-10}$
	$cdf_{bay} = cdf_{coast}$	$cdf_{bay} > cdf_{coast}$	Yes	$3.98e^{-10}$
χ	$cdf_{bay} = cdf_{coast}$	$cdf_{bay} \neq cdf_{coast}$	Yes	$2.16e^{-5}$
	$cdf_{bay} = cdf_{coast}$	$cdf_{bay} > cdf_{coast}$	Yes	$1.08e^{-5}$
$\mathcal{A}$	$cdf_{bay} = cdf_{coast}$	$cdf_{bay} \neq cdf_{coast}$	Yes	$1.2e^{-3}$
	$cdf_{bay} = cdf_{coast}$	$cdf_{bay} > cdf_{coast}$	No	$9.84e^{-1}$
	$cdf_{bay} = cdf_{coast}$	$cdf_{bay} < cdf_{coast}$	Yes	$5.85e^{-4}$
Φ_u	$cdf_{bay} = cdf_{coast}$	$cdf_{bay} \neq cdf_{coast}$	No	$9.89e^{-2}$
Φ_d	$cdf_{bay} = cdf_{coast}$	$cdf_{bay} \neq cdf_{coast}$	Yes	$3.05e^{-2}$
	$cdf_{bay} = cdf_{coast}$	$cdf_{bay} > cdf_{coast}$	Yes	$1.53e^{-2}$

Table S10. *KS test for bay cutoffs and estuary cutoffs (α = 0.05)*

Variable	*Null Hypothesis* H_0	*Alternative Hyp.* H_1	*Rejected Null Hypothesis*	*p-value*
R^*	$cdf_{bay} = cdf_{estuary}$	$cdf_{bay} \neq cdf_{estuary}$	Yes	$1.70e^{-2}$
	$cdf_{bay} = cdf_{estuary}$	$cdf_{bay} > cdf_{estuary}$	Yes	$8.5e^{-3}$
A^*	$cdf_{bay} = cdf_{estuary}$	$cdf_{bay} \neq cdf_{estuary}$	Yes	$3.71e^{-2}$
	$cdf_{bay} = cdf_{estuary}$	$cdf_{bay} > cdf_{estuary}$	Yes	$1.85e^{-2}$
ℓ^*	$cdf_{bay} = cdf_{estuary}$	$cdf_{bay} \neq cdf_{estuary}$	No	$6.37e^{-2}$
χ	$cdf_{bay} = cdf_{estuary}$	$cdf_{bay} \neq cdf_{estuary}$	Yes	$6.39e^{-4}$
	$cdf_{bay} = cdf_{estuary}$	$cdf_{bay} > cdf_{estuary}$	Yes	$3.20e^{-4}$
$\mathcal{A}$	$cdf_{bay} = cdf_{estuary}$	$cdf_{bay} \neq cdf_{estuary}$	Yes	$1.50e^{-3}$
	$cdf_{bay} = cdf_{estuary}$	$cdf_{bay} > cdf_{estuary}$	No	$8.21e^{-1}$
	$cdf_{bay} = cdf_{estuary}$	$cdf_{bay} < cdf_{estuary}$	Yes	$7.55e^{-4}$
Φ_u	$cdf_{bay} = cdf_{estuary}$	$cdf_{bay} \neq cdf_{estuary}$	No	$7.27e^{-2}$
Φ_d	$cdf_{bay} = cdf_{estuary}$	$cdf_{bay} \neq cdf_{estuary}$	No	$5.74e^{-1}$

Table S11. *KS test for lagoon cutoffs and coast cutoffs (α = 0.05)*

Variable	*Null Hypothesis* H_0	*Alternative Hyp.* H_1	*Rejected Null Hypothesis*	*p-value*
R^*	$cdf_{lagoon} = cdf_{coast}$	$cdf_{lagoon} \neq cdf_{coast}$	Yes	$6.08e^{-8}$
	$cdf_{lagoon} = cdf_{coast}$	$cdf_{lagoon} > cdf_{coast}$	Yes	$3.04e^{-8}$
A^*	$cdf_{lagoon} = cdf_{coast}$	$cdf_{lagoon} \neq cdf_{coast}$	Yes	$4.95e^{-11}$
	$cdf_{lagoon} = cdf_{coast}$	$cdf_{lagoon} > cdf_{coast}$	Yes	$2.47e^{-11}$
ℓ^*	$cdf_{lagoon} = cdf_{coast}$	$cdf_{lagoon} \neq cdf_{coast}$	Yes	$5.48e^{-12}$
	$cdf_{lagoon} = cdf_{coast}$	$cdf_{lagoon} > cdf_{coast}$	Yes	$2.74e^{-12}$
χ	$cdf_{lagoon} = cdf_{coast}$	$cdf_{lagoon} \neq cdf_{coast}$	Yes	$1.39e^{-2}$
	$cdf_{lagoon} = cdf_{coast}$	$cdf_{lagoon} > cdf_{coast}$	Yes	$6.90e^{-3}$
$\mathcal{A}$	$cdf_{lagoon} = cdf_{coast}$	$cdf_{lagoon} \neq cdf_{coast}$	No	$5.76e^{-2}$
Φ_u	$cdf_{lagoon} = cdf_{coast}$	$cdf_{lagoon} \neq cdf_{coast}$	No	$9.83e^{-1}$
Φ_d	$cdf_{lagoon} = cdf_{coast}$	$cdf_{lagoon} \neq cdf_{coast}$	No	$1.83e^{-1}$

Table S12. *KS test for lagoon cutoffs and estuary cutoffs (α = 0.05)*

Variable	*Null Hypothesis* H_0	*Alternative Hyp.* H_1	*Rejected Null Hypothesis*	*p-value*
R^*	$cdf_{lagoon} = cdf_{estuary}$	$cdf_{lagoon} \neq cdf_{estuary}$	No	$5.65e^{-2}$
A^*	$cdf_{lagoon} = cdf_{estuary}$	$cdf_{lagoon} \neq cdf_{estuary}$	Yes	$4.9e^{-3}$
	$cdf_{lagoon} = cdf_{estuary}$	$cdf_{lagoon} > cdf_{estuary}$	Yes	$2.5e^{-3}$
ℓ^*	$cdf_{lagoon} = cdf_{estuary}$	$cdf_{lagoon} \neq cdf_{estuary}$	Yes	$2.17e^{-2}$
	$cdf_{lagoon} = cdf_{estuary}$	$cdf_{lagoon} > cdf_{estuary}$	Yes	$1.09e^{-2}$
χ	$cdf_{lagoon} = cdf_{estuary}$	$cdf_{lagoon} \neq cdf_{estuary}$	Yes	$1.58e^{-2}$
	$cdf_{lagoon} = cdf_{estuary}$	$cdf_{lagoon} > cdf_{estuary}$	Yes	$7.9e^{-3}$
$\mathcal{A}$	$cdf_{lagoon} = cdf_{estuary}$	$cdf_{lagoon} \neq cdf_{estuary}$	No	$6.06e^{-2}$
Φ_u	$cdf_{lagoon} = cdf_{estuary}$	$cdf_{lagoon} \neq cdf_{estuary}$	No	$7.48e^{-1}$
Φ_d	$cdf_{lagoon} = cdf_{estuary}$	$cdf_{lagoon} \neq cdf_{estuary}$	No	$5.96e^{-1}$

Table S13. *KS test for coast cutoffs and estuary cutoffs (α = 0.05)*

Variable	*Null Hypothesis* H_0	*Alternative Hyp.* H_1	*Rejected Null Hypothesis*	*p-value*
R^*	$cdf_{coast} = cdf_{estuary}$	$cdf_{coast} \neq cdf_{estuary}$	*Yes*	$9.88e^{-5}$
	$cdf_{coast} = cdf_{estuary}$	$cdf_{coast} > cdf_{estuary}$	*No*	$9.65e^{-1}$
	$cdf_{coast} = cdf_{estuary}$	$cdf_{coast} < cdf_{estuary}$	*Yes*	$4.94e^{-5}$
A^*	$cdf_{coast} = cdf_{estuary}$	$cdf_{coast} \neq cdf_{estuary}$	*Yes*	$8.66e^{-4}$
	$cdf_{coast} = cdf_{estuary}$	$cdf_{coast} > cdf_{estuary}$	*No*	$9.65e^{-1}$
	$cdf_{coast} = cdf_{estuary}$	$cdf_{coast} < cdf_{estuary}$	*Yes*	$4.33e^{-4}$
ℓ^*	$cdf_{coast} = cdf_{estuary}$	$cdf_{coast} \neq cdf_{estuary}$	*Yes*	$3.26e^{-4}$
	$cdf_{coast} = cdf_{estuary}$	$cdf_{coast} > cdf_{estuary}$	*No*	$9.91e^{-1}$
	$cdf_{coast} = cdf_{estuary}$	$cdf_{coast} < cdf_{estuary}$	*Yes*	$1.63e^{-4}$
χ	$cdf_{coast} = cdf_{estuary}$	$cdf_{coast} \neq cdf_{estuary}$	*No*	$1.00e^{-1}$
$\mathcal{A}$	$cdf_{coast} = cdf_{estuary}$	$cdf_{coast} \neq cdf_{estuary}$	*No*	$2.43e^{-1}$
Φ_u	$cdf_{coast} = cdf_{estuary}$	$cdf_{coast} \neq cdf_{estuary}$	*No*	$7.76e^{-1}$
Φ_d	$cdf_{coast} = cdf_{estuary}$	$cdf_{coast} \neq cdf_{estuary}$	*Yes*	$3.39e^{-2}$
	$cdf_{coast} = cdf_{estuary}$	$cdf_{coast} > cdf_{estuary}$	*No*	$6.82e^{-1}$
	$cdf_{coast} = cdf_{estuary}$	$cdf_{coast} < cdf_{estuary}$	*Yes*	$1.69e^{-2}$