Article

Large Wood Debris Contributes to Beach Ecosystems but Colombian Beachgoer's Do Not Recognize It

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Abstract: Large Woody Debris (LWD) accumulation serves essential ecological functions and benefits society's coastal ecosystems (e.g., beaches). Thus far, the ecosystem services perspective has paid little attention to LWD. Therefore, we aim to contrast social perceptions on LWD and its ecological significance in Puerto Velero beach, Caribbean, Colombia. In consequence, the contribution of LWD to the conformation and creation of Puerto Velero beach was analyzed, as well as how beachgoers perceive the importance of LWD and if they were willing to pay to remove LWD in this beach. To achieve this, a quantitative convergent approach was then proposed using GIS analysis and remote sensing to understand the contributions of LWD to the Puerto Velero beach ecosystem; and in addition, a survey was performed to determine how beachgoers perceived LWD and how they valued the phenomenon. Results indicate that LWD contributed to beach maintenance; nevertheless, most people neglected LWD values because of its lack of visual attractiveness. As such, ecosystem services targets become conflicted because people positively perceived ecosystem services provided by beaches, but they did not assign importance to the beach dynamics they deemed unattractive, regardless of their vast importance.

Keywords: beach erosion; ecosystem disservices; coarse woody debris; social perceptions; Caribbean Sea

1. Introduction

Ecosystems are complex. The presence of different ecosystem structures (marine, coastal, or land ecosystems) with their variety of ecological functions [1] provides different types of ecosystem services that produce benefits to society and contribute to human wellbeing [2,3]. Over 625 million people live in coastal areas, and a significant percentage of them directly or indirectly rely on the benefits or ecosystem services that coastal habitats provide [4]. The scope of coastal ecosystem services is broad and the literature about this is considerable (e.g., [5–19]).

The variety of ecosystems found in coastal environments includes estuarine and coastal wetlands such as marshes and mangroves, sand beaches and dunes, seagrass beds, and coral reefs [6], which afford essential benefits for approximately 28% of the global population living by coastal areas [20]. In general, the literature highlights marine and coastal ecosystem services and intends to classify them according to diverse characteristics for management purposes [6,21–23]. Nevertheless, as [24] put it, coastal ecosystems offer new challenges and opportunities for science and for applying an ecosystem services framework.

According to [25], a beach is a sediment deposit (from sand to boulders) formed by waves, tides, and currents along the coast, and one of the most dynamic environments on Earth. Beaches are also areas of great importance due to their diverse ecological functions [26]. In this context, sandy beaches are one of the most essential ecosystems for the generation of beach ecosystem services (BES) [27]. The beach ecosystem comprises about 31% of the ice-free worldwide coasts [28] and at present, nearly 40% of the global population lives within 100 km of the shoreline [29]. The beach itself provides multiple functions such as storm buffering, nutrient cycling, water purification, nursing habitats for resource species, and feeding–breeding habitats for focal species, which in turn contribute to tourism, scenic beauty, and other cultural ecosystem services [30–35].

Beaches can provide ecosystem services such as recreation, and these services will be diminished or even lost if their environmental quality is not optimal, affecting human well- being [36]. The environmental quality of a beach can be improved under different management strategies [37]. One of them is through understanding the local and regional causes and trends of erosion and coastal accretion processes [38,39]. Investigating the phenomena that may cause the loss of the scenic quality of beaches, as well as possible trade-offs between ecosystems services, is another way to manage these spaces.

Literature on beach studies related to scenic quality, water quality, and sustainable tourism supports that the increase in tourism activities on beaches consolidates them as products [40,41], but at the same time accelerates the contamination of these ecosystems [42]. Restaurants, street vendors, and the large influx of tourists are some sources of beach degradation [36]. Users also consider the direct relationship between tourism and environmental impacts in these destinations because social conditions and user perception play an essential role in beach quality management. Then, the landscape is significant as part of the BES [43] and is one of the main factors that a potential tourist considers when choosing a coastal destination [44–47].

Therefore, the social perception of beach quality is mainly based on aesthetic factors such as water and sand color [48], litter [47,49,50], and the presence/absence of shore protection structures [37]. Likewise, this dimension has been highlighted through studies on willingness to pay, where landscape amenities and landscape features have strongly influenced people's well-being [51], satisfaction [51], judgments [52], and motivations to undertake actions to clean up landscape areas [53]. This is a fundamental precedent for our approach, given that landscape is important for beach use [43].

In addition, the literature highlights that beachgoers express willingness to pay (WTP) for improving the scenic prospects of beaches: for example, [54] found WTP for cleaning up litter and man-made waste and [55] found motivation to pay given that beachgoers express a strong aversion to beach litter. Other studies have found WTP such as an entrance fee or increased local taxes to clean up marine litter [56,57], and the rationale is that the accumulation of marine litter will have significant negative impacts on the supply of recreational services [58].

As stated earlier, the literature highlights that scenic features are strong predictors of beachgoers' preferences; they are even willing to pay for improved scenic beach conditions. Therefore, we hypothesize that social preferences and perceptions are negative with respect to LWD given that they are not positive scenic features, regardless of the ecological importance they promote.

1.1. Implications of Large Woody Debris (LWD)

A diverse typology of waste materials deposited by wind, waves, littoral currents, and tidal currents (if the coast is mesotidal or macrotidal) often occupy the beach swash zone along many beaches worldwide. Such materials are known as Beach-Cast [59,60]. According to [34], Woody Debris is an essential beach component because it influences the ecosystem's biological and physical functions and processes; however, the presence of woody debris on beaches might be conflicting with their uses (e.g., tourism, fishing).

Driftwood, coarse or Large Woody Debris (LWD), is an essential agent in coastal environments because of its geomorphic role [61,62]. LWD is produced by terrestrial and oceanic dynamics that lead to wood accumulation on beaches particularly as a result of high-energy events (such as storms) and flooding, and spreads along most marine shores; treefall due to riverbank erosion or landslides are significant causes of LWD, and anthropogenic causes are minor LWD sources [63]. In general, woody debris consists of a substantial number of branches and trunks, root boles, and whole trees [64].

The process of LWD accumulation on beaches promotes essential ecological functions, which ultimately afford beach users benefits (beach ecosystem services). As [65,66] highlighted, where coastal areas are concerned, LWD plays a sedimentological role and performs at least the following three functions: First, LWD acts as an accretion anchor, promoting the accumulation of copious amounts of windblown sand in the backshore; second, LWD deposits are the nuclei for incipient dune and vegetation growth; lastly, LWD is vital for the fauna habitat [63,64,67]. Although many coasts worldwide experience significant accumulations of LWD on their beaches, it is often removed before it can provide any geomorphic benefits [50,61,68]. In Colombia, preliminary studies conducted by [34,43,69–73] across the Caribbean coast have exposed the environmental burden of these areas, mainly by the large presence of marine litter and abundant wood volume (LWD). However, information on the magnitudes, outcomes, impacts, and management of LWD in this area is still incipient.

Large Woody Debris is known as a functional and structural component of beaches [74], but no attention has been paid to its magnitudes and influence over the coastal and marine ecosystems where LWD ultimately accumulates. The above is staggering because several coasts and other marine environments worldwide are characterized by significant amounts of LWD [61,66,75–77]. Furthermore, the literature on the socio-ecological value that beachgoers perceive of beaches receiving organic debris aplenty is limited and centered only on their scenic characteristics [71,78].

Therefore, this research seeks to highlight the role of LWD in shaping a beach scenario where people enjoy multiple BES, and the approach applied seeks to contrast social perceptions on LWD and the ecological importance of this process. This is relevant because scientific literature highlights evidence on the bias in the social perception of ecosystems, which produces ecosystem service bundles and trade-offs [79]. Then, these perceptions finally could jeopardize ideas for conservation [80]. In this line, positive social perception regarding ecosystem services could be an explicit key element of ecosystem management [81].

Following that LWD is beneficial for the beach and for beachgoers as a general assumption, our study was performed on the conflicting social targets related to ecosystem services offering apparent contradicting benefits to users. In consequence, the contribution of LWD to the maintenance of beaches for a Colombian Caribbean-specific case was analyzed, as well as how beachgoers perceive the importance of LWD and if they were willing to pay to have LWD cleared from beaches.
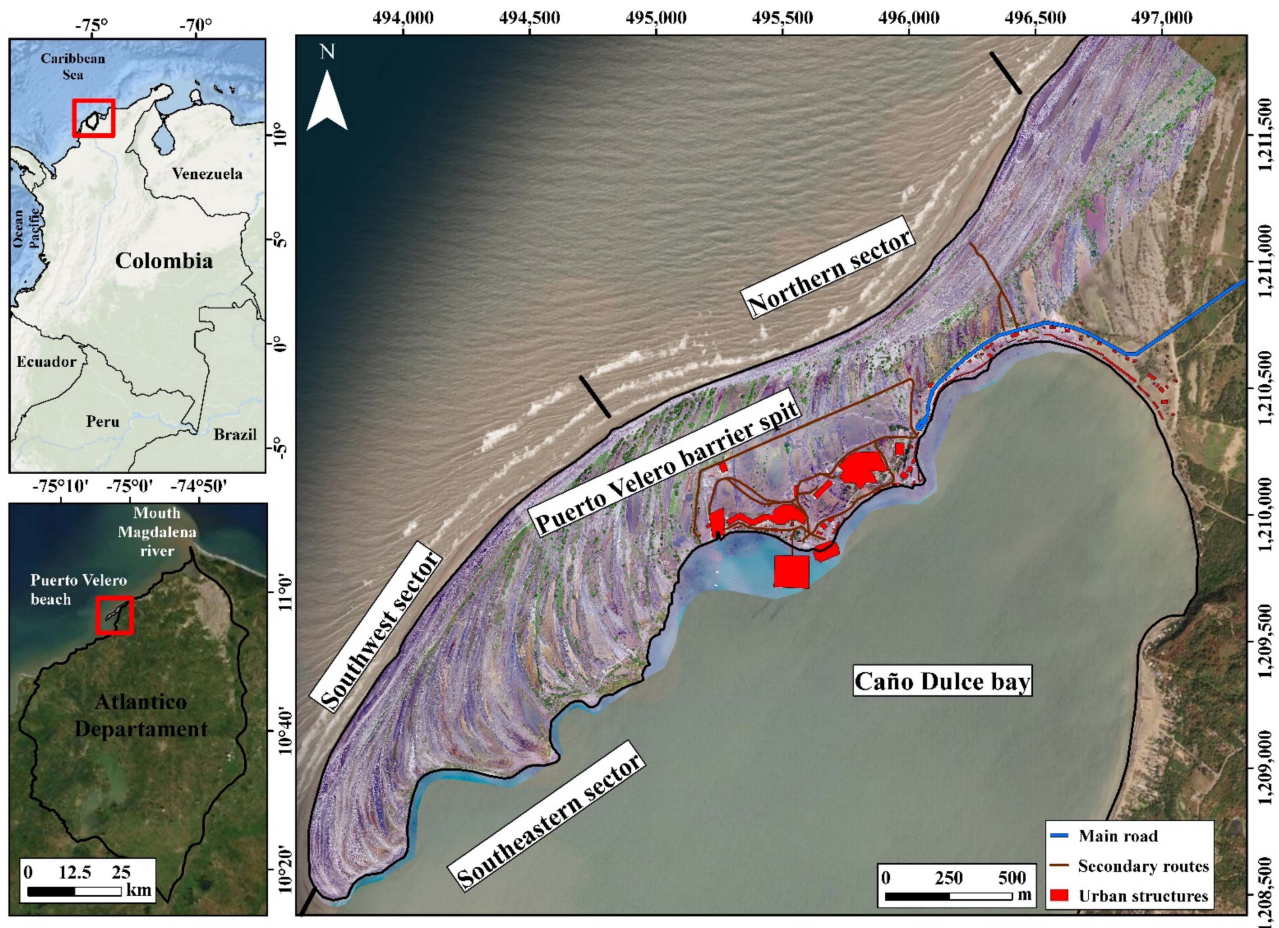
1.2. Study Area

Colombia is the only South American country with coastal areas in the Caribbean Sea and the Pacific Ocean, and 50% of these areas cover its territory and contain invaluable ecosystems in both natural and economic terms [82]. Since past decades, the accretion and erosion processes affect the Caribbean coast. The accretion processes occur mostly on localized river mouth and deltaic zones [83,84], but beach retreat has been the dominant trend [83,85,86].

The Department of Atlántico is a northern region with 64.5 km of coastal zone extension, representing 4% of the Colombian Caribbean [87]. The study area was a beach called Puerto Velero (Figure 1).

Puerto Velero is a Quaternary-origin barrier spit [88]. The southwest and northern sector is exposed to the Caribbean Sea action, and the southeaster sector is a protected beach. Tourism activities are concentrated in the southeastern sector (Figure 2). Geomor-

phologically, this barrier spit is determined by the lateral overlap of hook-shaped beach ridges constituted by accumulated fluvial-marine sediments, mainly consisting of light-to-dark gray fine-to-medium sands grains [85], where there is a considerable accumulation of WD on the beach strip. Its recent evolution is complex, and it has eroded sections and accretional trends, resulting in the progradation of the barrier spit with a narrowing on the neck [86]. Puerto Velero's barrier spit has undergone significant geomorphological and ecological modifications in its shape over the past three decades due to natural and anthropogenic processes [86], allowing visitors an increased use of the beach.

Figure 1. Study area. Puerto Velero beach in the right part along with the main road, is protected by the barrier spit in both northern and southwest sectors.

Puerto Velero is 25 km from the mouth of the Magdalena River, which makes up the most extensive fluvial system in Colombia, extending 1612 km along a drainage basin that covers 257,438 km^2 with an annual sediment load of 144×106 t·yr^{-1} [89,90]. The driftwood accumulated in the shoreline along the Department of Atlántico is influenced by a dominant south-westward longshore drift. The amount of wood accumulated also correlates with meteorological events and increased discharge from the Magdalena River (the principal source of LWD). These periods bring about higher sediment transport along the Magdalena River and driftwood accumulation in the beach area. Previous studies [64,86] have already recorded high concentrations of driftwood on the department's beaches.

The region presents a humid tropical climatic with three different periods in the year. During the dry season (December to April), trade winds from the north and east predominate. The second period is the transition period (May, June, and July), when trade winds are mild and of north and northeast direction. The wet season (August to November) is characterized by a wind regime that can fluctuate depending on ENSO intra-seasonal

phenomena [91,92]. The wave heights regime in this region ranges from 0.1 to 2.5 m. Seasonal changes in wave direction are accompanied by a significant reduction in height, with the lowest values occurring between August and October, while the strongest waves occur between November and July [93]. The tide ranges between 0.2 and 0.3 m, classifying as a microtidal beach [94].


Figure 2. Aerial view (taken by drone) of the Puerto Velero barrier spit; (**A**) Tourism activities concentrated in the southeastern sector (protected beach); (**B**) large accumulation of driftwood on the southwest and northern sector (exposed beach).

2. Methods

Our research considered a causal chain approach with respect to the generation of BES [95]. First, we argue that LWD is a driver of ecosystem service generation, as it promotes several functions that support the beach ecosystem, and the promotion of other ecosystem services for beachgoers (Figure 3).

It being our general assumption that LWD provides benefits to the beach ecosystem and to beachgoers, we wanted to test this assumption following a convergent approach, where two quantitative methods converged. On one hand, we applied remote sensing and on the other hand, a questionnaire. We proposed an ecological and a social analysis to understand the importance of LWD in Puerto Velero. For the ecological analysis, we applied remote sensing to understand LWD coverage and shoreline position changes due to LWD accumulation. With this, we address the research question: (i) what are the contributions of LWD in shaping and creating beaches for a specific case in the Colombian Caribbean?

On the other hand, for the social analysis, a questionnaire was applied in which the preferences and perceptions of beachgoers about LWD were collected. As shown in Figure 3, and in accordance with the literature, the hypothesis is that social perceptions have different behaviors: first, the social perception regarding LWD is negative due to aesthetic reasons; second, beachgoers state negative perceptions regarding the functions provided by LWD, but a positive perception regarding ecosystem services (final benefits for them). With this approach, we address the second and third questions of our research: (ii) what are beachgoers' perceptions of the importance of LWDs?, and (iii) are they willing to pay to have LWDs removed from beaches?
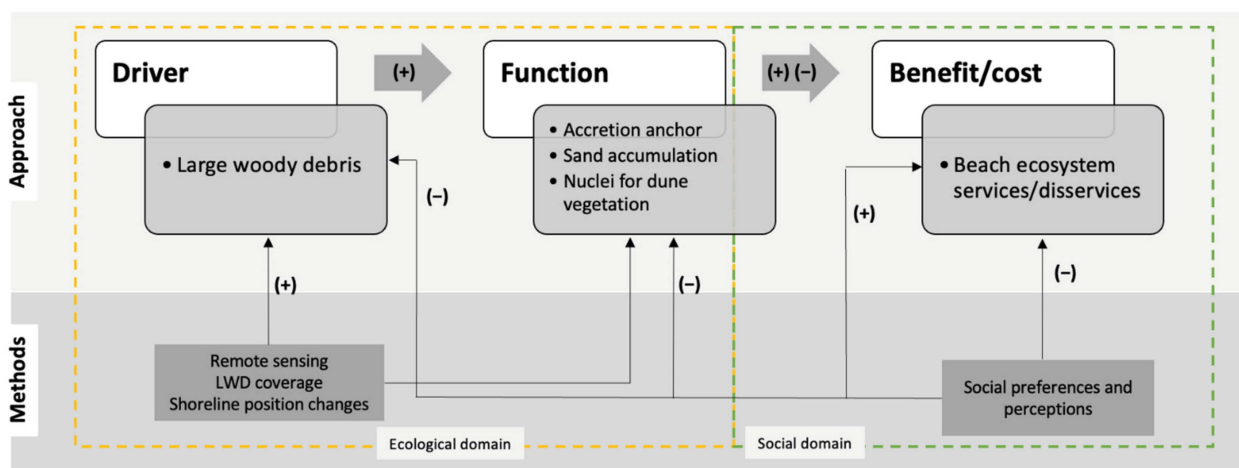
Figure 3. Causality chain approach of BES generation considering LWD as driver.

2.1. First Approach

2.1.1. Remote Sensing Assessment

Remote sensing products, such as high-resolution satellite images from Google Earth® (2004, 2013, 2015, 2017, 2019, and 2020) were used in this study, which is an already well-established technique in several publications [84,96]. Moreover, high-resolution aerial photographs were taken using a Mavic 2 Pro drone in October, 2019. The drone was controlled through a Pix4D application that enabled automatic flight by defining a specific area. Photo overlap was ≈80% longitudinally and ≈76% laterally from each photo's area, and the flight altitude was 250 m. Orthomosaic photo resolution was 6.85 cm.px^{-1}, and we processed the images using the Pix4D program.

All GIS processing was performed using ArcGIS PRO 2.7.3, where the products were reprojected to the UTM projection (zone 18N) and WGS84 datum. Linear distance and polygon area were used to measure the spatial extent and change across all three key characteristics at all locations:

- LWD coverage,
- Variation in the relative position of the shoreline,
- LWD and vegetation coverage variation in a beach-dune profile.

2.1.2. Large Woody Debris Coverage

Mapping the LWD-covered area is the first step to understanding the barrier spit's evolution and the importance of wood to that process, while the wood coverage was quantified using photointerpretation methods with high-resolution orthophotos. In addition, we employed remote sensing and GIS techniques for reducing the amount of wood coverage and a supervised classification technique with the Maximum Likelihood Classifier (MLC) algorithm, which uses signature files per pixel of training samples collected on the RGB image, requiring personal experience in the study area [97]. We used the MLC algorithm on the spectral signature components of different samples (dry sand, wet sand, vegetation, water, and wood on the surface). We conducted 200 training samples in total (40 samples from each category). Moreover, we used different key elements for interpretation, such as color, size, shape, texture, and pattern, to differentiate between categories. We prepared the training sets using the grouped pixels, analyzing the spectral signature for each group, and ensuring "minimum confusion" among the covers to be mapped out [98]. Subsequently, the classified images were converted into polygons, and only the superficial wood category was set aside. Finally, according to [99,100], an accuracy assessment was performed using the polygon comparison technique and the original image. Five hundred independent random samples were used in total.

2.1.3. Shoreline Position Changes

The use of satellite images from Google Earth and drone orthomosaic photos, in conjunction with Geographic Information System (GIS), has progressively improved resolution and versatility for shoreline extraction and mapping of changes in migration [84,86,101–105]. In this study, the changes in the shoreline were analyzed over 16 years (2004–2020). Orthomosaic drone photos were used to rectify and draw the successive crest beach ridges representing the old shoreline. This research considered the shoreline definition, i.e., the position of the land–sea interface in sandy coastal areas, marked by the limit reached during high tide. This limit corresponds to a sharp tonality change for the beach's sand.

Satellite image interpretations were coupled with field visits in 2019 and 2020 to identify geomorphologic features and plant species. Furthermore, the vegetation cover was studied through visual observation using the 0.5 × 0.5 square meters profile of an associated transversal beach and employing a beach transect at the end of the dune system (235 m). The topographic profile analyzed together with the vegetation was traced using drone image processing.

2.2. Second Approach

Social Preferences and Perceptions

Since our research brings a novel approach, we considered using an interdisciplinary approach including possible conflicting objectives in relation to the BES. Although not a stated preference study as such (this is not a contingent valuation study), our research considered some principles of stated preference methods: the survey seeks to contrast baseline conditions, also poses a consequential valuation question [106], and allows for flexibility and highlights respondents' preferences [107]. Some principles borrowed from stated preference methods were the use of a survey for eliciting preferences [108], the creation of a hypothetical situation, where the link between the respondent's answer to a stated preference question does not create a binding [109], and eliciting a willingness-to-pay value. However, we did not intend to provide a monetary valuation of ecosystem services as a fundraising process for policy instruments, but rather view the WTP question as a proxy to highlight the awareness that beachgoers attach to beach LWD and to link that value to the importance of LWD. Thus, it is not intended to be a formal economic valuation to "capture dollars," as our primary aim was to obtain a magnitude of the importance that beachgoers attribute to LWD. Thus, the main concern of this work is that, although LWD is important, it does not enjoy social recognition and value. Therefore, for the survey we established the following sections:

- Beachgoers' demographics;
- Respondents' perceptions about the beach where we included BES rating (hypothetical + outcome);
- Beachgoers' perceptions on LWD in Puerto Velero (hypothetical—outcome);
- Information concerning willingness to pay to have LWD cleared (two questions, hypothetical—outcome) (Figure 2). The variables to the analysis are detailed in the Supplementary Material Table S1.

Subsequently, a multinomial logistic regression was performed to predict whether a person falls into one of the following options: (i) LWD is related to debris/trash/pollution; (ii) LWD is a natural process; and (iii) LWD provides benefits to the beach. We used option (ii) as a baseline result to contrast this nature-based dynamic with the other two human-perceived options (Supplementary Material Table S1, variable 14). In addition, a logit model was applied to identify the probability of a dichotomous (yes/no) willingness to pay (WTP) to have LWD removed from the area, for which the statistical package Stata 14 ® was used.

According to [87], the number of tourists visiting Puerto Velero is approximately 1205/day, so a survey was applied to collect information on perceptions of BES and LWD in the area. A simple random sampling was conducted with 95%; the resulting sampling number reached 222 people. The survey was applied in the first season of 2020. The

survey was conducted by researchers from the Civil and Environmental Department of Universidad de la Costa through an individual survey.

3. Results

3.1. Mapping Large Woody Debris Coverage

The driftwood mainly consists of branches and tree trunks, ranging from small pieces (<10 cm) to large trunks (>10 m). The size of the wood pieces identified by the algorithm was above 0.05 m^2, with classification accuracy at approximately 85%, mainly due to differences in color hue between dry and wet wood and the wood stacking. Figure 4 shows the spatial distribution of the wood-covered surface in the area, including more detailed images of the four specific areas evaluated in this study. The total area assessed was 1,973,850 m^2, representing 80% of the barrier spit surface, where the area covered by wood was 92,225 m^2, accounting for 4.67% of the area.
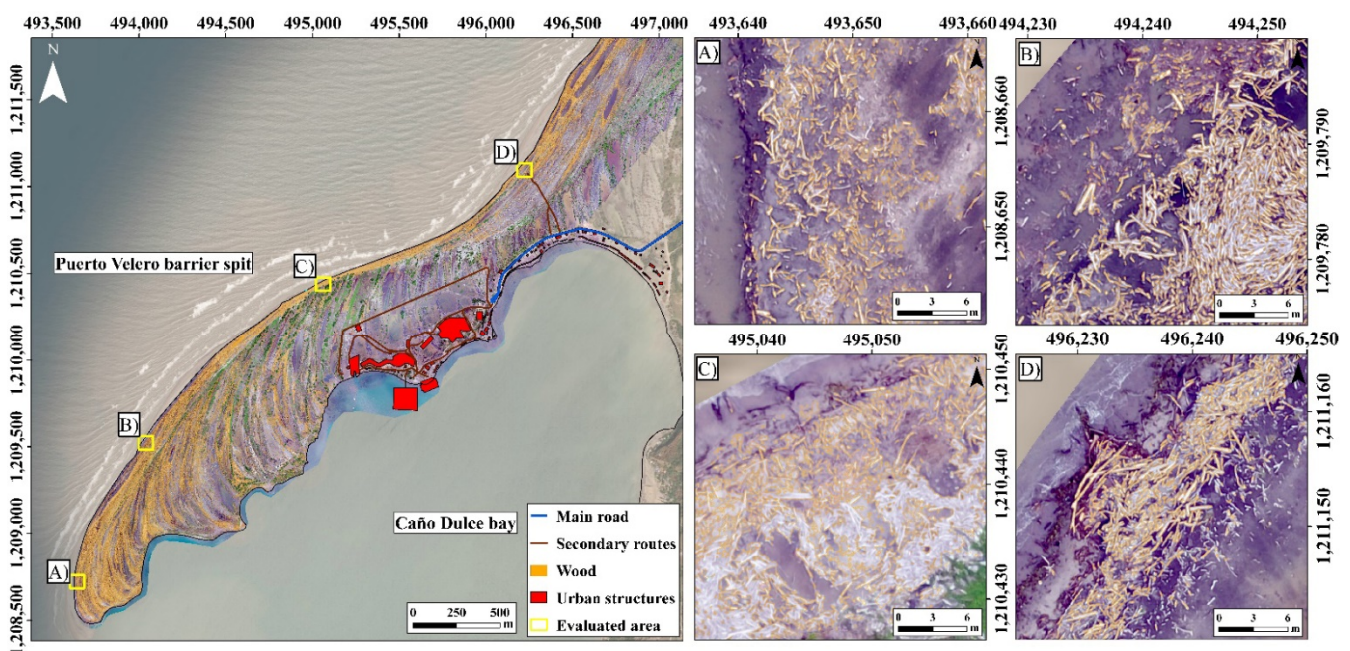
Figure 4. Large woody debris coverage mapping. The figure was elaborated with the orthomosaic obtained with the use of a drone (29 October 2019). The quantification of wood cover was performed through supervised classification (ArcGIS PRO). For the choice of scenes, four zones were randomly determined on the shoreline, covering two (**C**,**D**) in the north sector and two (**A**,**B**) in the southwest sector of the spit.

The highest concentrations of wood were related to the current shoreline's external portion, conditioned by waves, and resulting in driftwood accumulation on the beach area. High concentrations of wood on the crest of beach ridges were found. These old beach lines had accumulated a large stock of wood, attesting to the importance of LWD in the evolutionary process of the barrier spit, and previous research shows that successive stages of spit growth are responsible for the area's migration and growth [86,88].

Wood cover is less dense in the innermost areas of the northern sector of the spit barrier, especially by the only path that gives access to the beach in this sector. Locals have also accumulated wood for later removal and multiple uses. In contrast, the southwest sector is more amply wood-covered, mainly on the crests of the beach ridges. It is possible to observe a reduced amount of wood in the inner beach ridges, resulting from sediment accumulation on the wood and the subsequent colonization thereof by vegetation on the incipient dunes.

3.2. Changes in the Shoreline

Different geomorphological environments are recognized based on their relief: oceanic beach and beach-dune ridges. Oceanic beach occurs on the northwest end of the spit and is directly exposed to the ocean swell. This sector accumulates the largest volumes of driftwood coming from the Magdalena River through coastal drifts. Behind the oceanic beach and along the main subaerial body of the spit, there is a large area of unvegetated and vegetated mobile sand, while the northern border and outer neck of the spit exhibit a large eolian environment, even though the dunes' average height is below a half meter.

The beach ridges consist of sandy sediment and a high concentration of LWD, which, as a result of the longshore drift, form parallel bars due to the interaction of coastal and wind processes. In a plain view, the beach ridges are aligned in the predominant direction of the drift to the west, exposing a curved morphology for the distal portion in the shape of a hook [110].

After the beach ridge is formed, usually between six months to a year (estimated by counting the ridges divided by the period in the images available), a new sandbar is attached to the nearshore system. Accumulated large volumes of wood facilitate sediment retention and, concomitantly with colonization by the vegetation, remains a stable landform (Figure 5). A new beach ridge crest formation creates a swale that separates it from its predecessor, displaying a lower topography; each crest of beach ridge is an old shoreline, and the ridge succession is evidence of the progradation process.
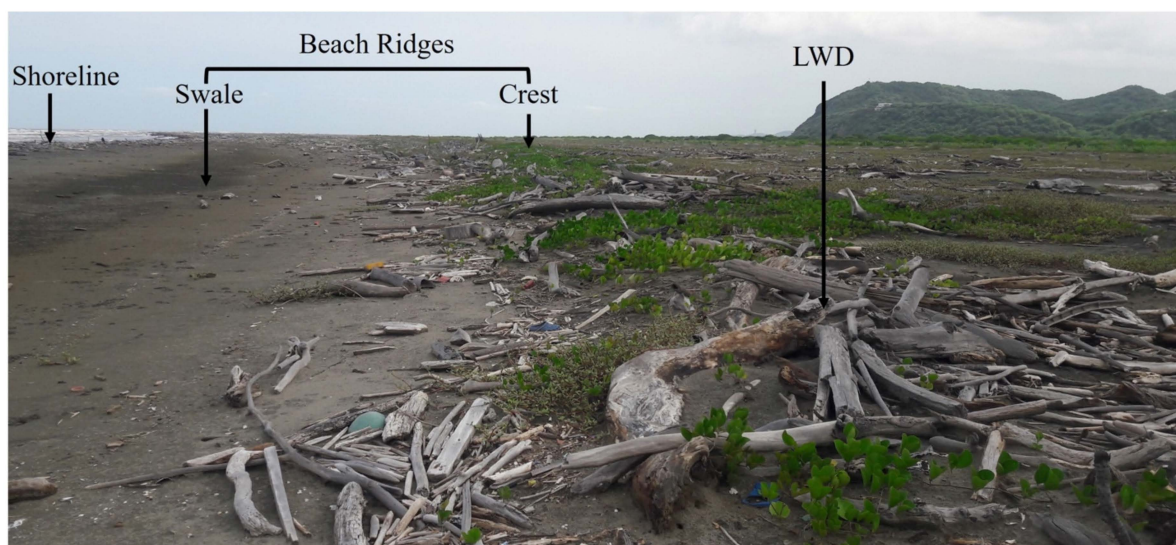
Figure 5. Morphologic feature of the beach ridge system, evidencing the LWD on the ridges with the associated vegetation.

The flat-shaped Puerto Velero barrier spit grew continuously between 2004 and 2020 (Figure 6). Coast position change values show an overall positive trend in almost all sectors, indicating a maritime progradation trend, with the SW sector accounting for the highest accretion and the inner neck for low erosion and accretion rates. In the period 2004 to 2019, the maximum net shoreline migration for the northern sector (N) was 422.82 m, while the SW sector presents the highest accretion, with 1752.04 m [86].

Figure 6 displays (in detail) the different old shoreline in the SW sector and the LWD lines arrayed in the same direction as the crests. Woody debris accumulation is the focus for sediments to develop and later be colonized by coastal vegetation. Together, driftwood and coastal vegetation act as roughness and windbreakers that trap sediment and drive the formation of embryonic dunes, which aid in preserving the beach ridge landforms.
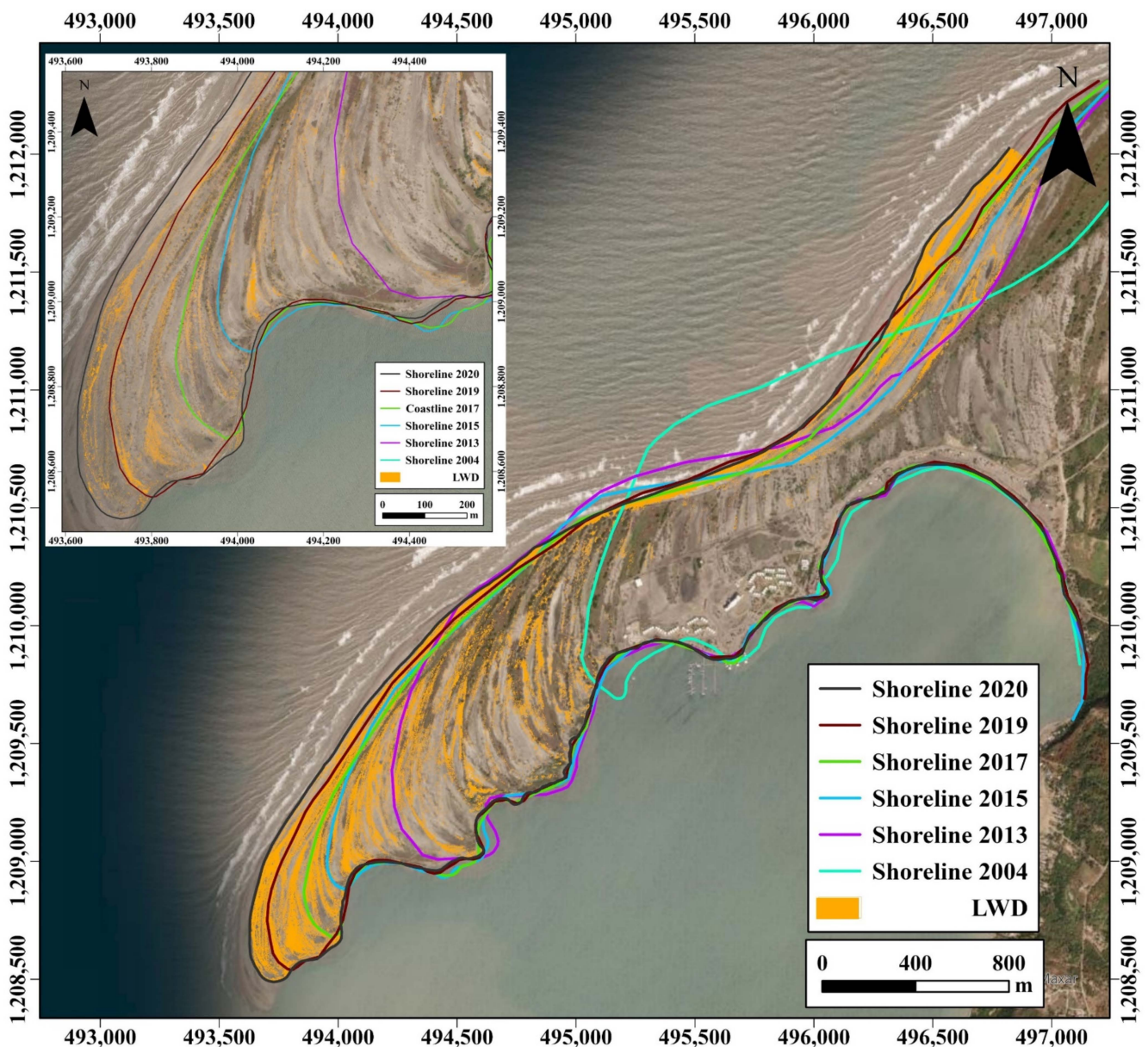
Figure 6. Satellite images of Puerto Velero barrier spit and shoreline migration between 2004 and 2020.

3.3. Prograded Surface and Attendant Vegetation

The Puerto Velero beach ridges experienced a decreased active sand surface area resulting from driftwood distribution and colonization by the vegetation during the observation period. Sediments are transported by littoral drift currents, later remobilized by the wind, and transported to the inner zone of the barrier. Vegetation traps the sediments the winds carry to the continent and fix large areas of dunes, thus maintaining the sands in the beach/dune system.

An analysis of the Northern sector shows that after the shoreline's 2013 stabilization and subsequent progradation, the vegetation cover expanded rapidly, mainly in connection with the ridges (Figure 4). The topographic profile in Figure 7 indicates variation along the beach's ridges and in the amount of vegetation and driftwood. As such, the by-profile vegetation cover was considered moderate, following the ridge's morphologies and the humid areas in the swale. On the other hand, the main vegetative species covering this eolian environment are *Sesuvium Portulacastrum*, *Ipomoea pes-caprae*, *Cyperus ligularis*, and *Calotropis procera*. These species were also identified by [86]. Vegetation cover follows the

presence of wood on the ridges to a greater or lesser degree (Figures 5 and 6), and the driftwood favors the accumulation of sediments and facilitates colonization by the sector's dominant species.
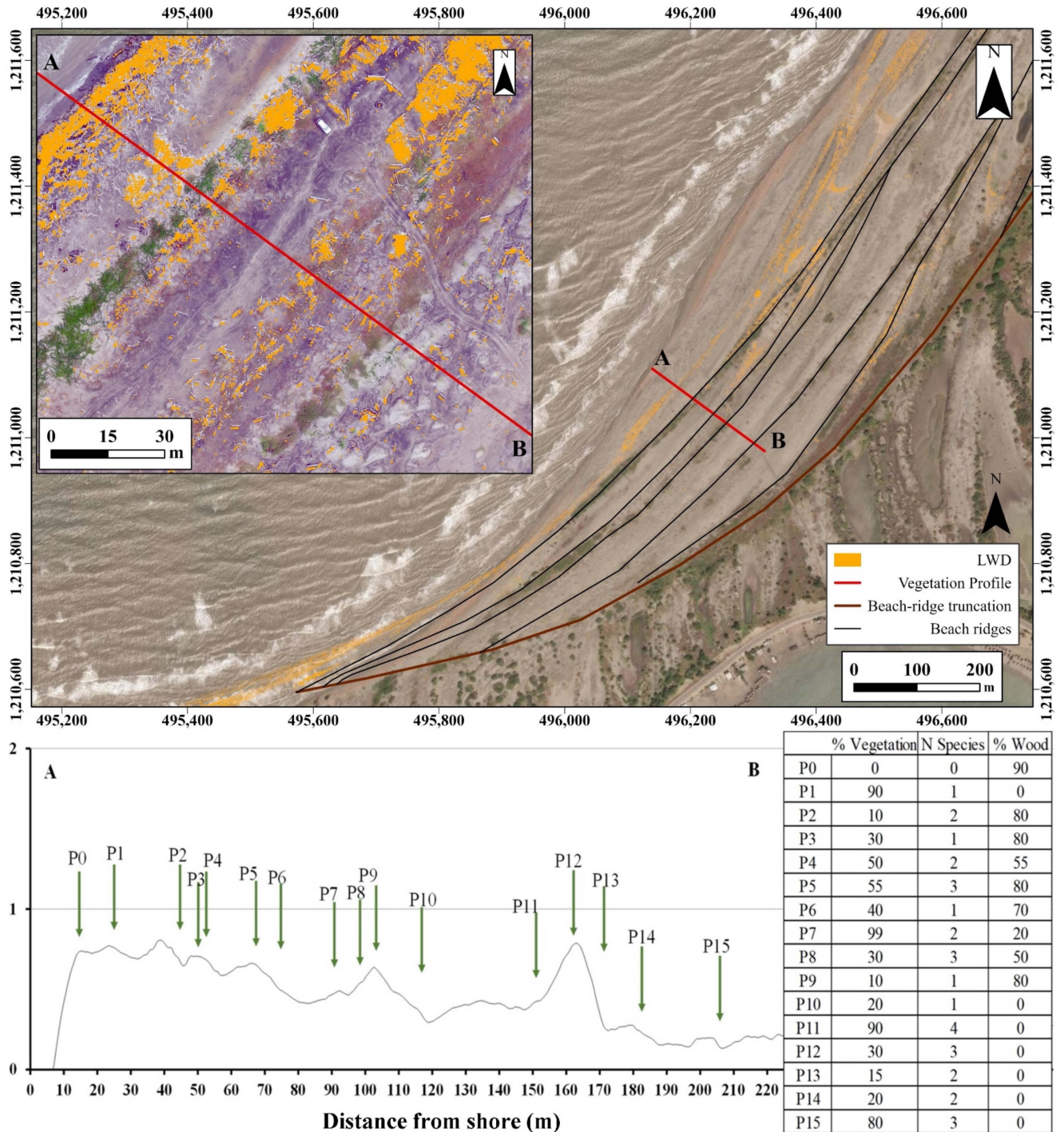
Figure 7. Satellite image indicating topographic and vegetation profiles (**A**,**B**). Table displays amounts of vegetation (%), number of species (N species), and driftwood (%).

3.4. Beachgoers Awareness along the Causality Chain

The sample consisted of 222 people from the Puerto Velero beach. Most respondents were male (77%), with an average age of 30 years, and most respondents earned less than one Colombian legal minimum wage (53%). On the other hand, about 79% believed that

the beach was in good condition, while 40% stated that the beach was safe for activities (e.g., drowning, contact with animals with health risks). The frequency of visitation was dispersed for all the proposed categories, and respondents gave medium importance to the cleanliness of the beach (mean = 3.8/5). Table 1 depicts further information.

Table 1. Sampling general information (n = 222).

Gender	Frequency	%	Safety in Beach	Frequency	%
Male	172	77	Very safe	12	4
Female	50	23	Safe	36	36
Incomes			Middle	75	34
<1 MCLW *	117	53	Little safe	46	21
2–3 MCLW	72	32	Unsafe	3	3
3–4 MCLW	16	7	**Visit Frequency**		
>4 MCLW	17	8	Almost never	151	68
Beach State			Very few times	39	18
Very good	26	12	Sometimes	32	14
Good	148	67	Often	0	0
Bad	43	19	Frequently	0	0
Very bad	5	2			

* MCLW = minimum Colombian legal wage (980,657 COP) (1 USD = 3870 COP; 14 April 2020).

However, in relation to respondents' perceptions of LWDs (as drivers and as function providers), only 29% of respondents considered that LWDs provided ecological benefits to the beach; and 18% have used the wood on the beach. About 45% of respondents were aware of LWD in some areas of Puerto Velero, and when asked about the appearance of woody debris in the area, 69% viewed LWD negatively. In addition, when asked about their opinion of LWD in the area, the responses were mostly negative, with LWD being perceived as "debris, pollution or garbage" (59%). In addition, 73% of respondents want to remove LWD from the beach.

In terms of BES ratings, we found that people assign high levels to tranquility (4.3/5), sea food (4.1/5), and clean air (4.3/5), and lower levels to scenic beauty (3.8/5), spirituality (3.4/5), or identity (3.1/5). Most respondents do not recognize LWDs as beach protectors: only 19% believe that LWDs keep sand in place and let plants grow, 21% believe that LWDs promote beach stability, and 21% believe that they promote biodiversity refuge. Finally, 78% of respondents stated that they do not perceive any benefits from LWD.

A multinomial logistic regression (Table 2) was completed to identify factors influencing the probability of choosing one of the categories related to how LWD is perceived in the area. After performing the Wald post-estimation test to obtain more efficient estimators, the model showed two significant variables: benefits of LWD for people (Benefit_people) and willingness to eliminate LWD (Remove). In the first comparison (Pollution/trash = A, option; Natural process = C), it was observed that considering that LWD are not beneficial to people increases the probability that option (A) is chosen, and that people's desire to have LWD eliminated increases the probability that option (A) is chosen. As for comparison (B, C), the variable Benefit_people gave the same responses, as did comparison (A, C). The variable "Remove" was not significant.

In addition, this study found that 40% of respondents were willing to pay to have woody debris removed. To identify the probability of obtaining a positive response regarding willingness to pay for woody debris removal and to estimate the beta coefficients explaining the positive responses and how these vary by perceived characteristics, a logit test was applied (Table 3). The model was correctly specified according to the errors (*p* > 0.05), classified 66% of the responses, and the goodness of fit of the regression is adequate (*p* > 0.05) according to the Hosmer–Lemeshow test. The following variables affecting WTP response were identified: having a neutral perception about WTP (*p* = 0.019)

and expressing willingness to eliminate WTP ($p = 0.000$) were predictors of positive WTP responses. Finally, an open-ended question on WTP was asked for the elimination of LWD, the mean value of which was 11,917 COP per visit (3.8 USD).

Table 2. Multinomial logistic regression on perception about driftwood on the area.

Perception_LWD		Coef.	Std. Err.	z	P > z	95% Conf.	Interval
(A) Pollution/garbage							
Benefit_people		−3.700482	0.8922283	−4.15	0.000 *	−5.449217	−1.951746
Remove		3.410407	0.8279969	4.12	0.000 *	1.787563	5.033252
_cons		1.421383	0.8822431	1.61	0.107	−0.3077817	3.150548
(B) Benefit beach							
Benefit_people		−2.669508	0.830699	−3.21	0.001 **	−4.297648	−1.041368
Remove		0.6570714	0.7540309	0.87	0.384	−0.820802	2.134945
_cons		2.813847	0.8096268	3.48	0.001	1.227008	4.400686
(C) Base outcome (Natural process)							
Number of obs	=	222					
LR chi2(4)	=	116.59					
Prob > chi2	=	0.0000					
Pseudo R2	=	0.2942					

sig. * $p < 0.01$; ** $p < 0.05$.

Table 3. Logit model on the willingness to clear the LWD in the beach.

WTP		Coef.	Std. Err.	z	P > z	95% Conf.	Interval
Freq_visit		0.2811561	0.2421747	1.16	0.246	−0.1934975	0.7558097
Scenic_beauty		0.1347372	0.1687186	0.80	0.425	−0.1959452	0.4654196
Cleanness		0.0668799	0.1750229	0.38	0.702	−0.2761587	0.4099185
Know_LWD		−0.2692252	0.3313447	−0.81	0.416	−0.9186488	0.3801984
LWD_percep							
Negative		2.096124	1.151398	1.82	0.069	−0.1605745	4.352822
Neutral		2.783407	1.189003	2.34	0.019 **	0.4530046	5.113809
Remove		3.01064	0.5903367	5.10	0.000 *	1.853602	4.167679
_cons		−6.045796	1.504322	−4.02	0.000	−8.994213	−3.09738
Number of obs	=	222					
LR chi2(6)	=	55.09					
Prob > chi2	=	0.0000					
Pseudo R2	=	0.1843					
Log likelihood	=	−121.94511					

* sig < 0.01; ** sig < 0.05.

4. Discussion

4.1. Large Woody Debris Coverage and Beach Dynamics

The high density of driftwood on the beach is associated with the influence of the Magdalena River system. LWD is a crucial geomorphic agent to fluvial environments [34,111], especially for drainage basins with the presence of forests. The evolution of Puerto Velero is recent, the barrier spit started to form in the 1990s, and it has grown at a rate above 100 m·yr^{-1} during the past 15 years [86]. High-density LWD lines were identified through

drone images, which increase beach surface roughness, and encourage sediment deposition [61]. Wind-transported sediments and deposition thereof in the beach systems are complex and involve several factors, such as mean wind velocity, grain size, and sedimentary supply rate, in addition to other factors like surface heterogeneities [112,113].

Heterogeneity in the surface of beaches and coastal dunes may be the result of native vegetation or even materials deposited on the beaches brought by the currents and waves. These play an essential role in beach system morphodynamics, acting as a shield against wind sediments and providing substrate for incipient dunes to develop [64,67,114–117]. The importance of LWD to the sediment retention process depends on its density and disposition, as well as the magnitude and recurrence of events capable of eliciting erosive processes; moreover, the waves rearrange the LWD matrix on the beach area, increasing the degree of sediment retention even further [118].

LWD is associated with vegetation in the area since LWD favors sediment accumulation, facilitating colonization by predominant species in the sector, such as *Sesuvium Portulacastrum* and *Ipomoea pes-caprae* [86]. Removing woody debris also removes the associated organic matter, which a variety of organisms use for food and habitat, including the invertebrate macro-fauna that uses the organic matter as a food source. There is also meiofauna to the sediments and shorebirds that prey on many such organisms [119–121]. The images made it possible to record embryonic dunes along the barrier spit since the partially sediment covered LWD provides a safe house for vegetation to develop [118]. Hence, vegetation development-enabling wood fosters the formation and development of embryonic dunes in the area, a bond capable of mediating the shoreline's growth and evolution rates; also, a robustly evolved dune system provides physical protection against erosive processes. In Wickaninnish Bay, Pacific Rim National Park, British Columbia, this promoted shoreline advance rates as rapid as 1.5 m·yr^{-1} [114]; but, as has been found in Puerto Velero´s beach, spit progradation reach up to 100 m·yr^{-1} [86].

Furthermore, some studies have recognized the importance of LWD's role, especially in trapping sediment [61,66,118]; this material provides a natural barrier that hinders erosion in established coastal ecosystems [114]. When assessing the influence of wood on long term spit evolution, the Puerto Velero shows evidence that its ridges develop during periods with higher wood deposition on the beach, specifically during rainy seasons.

In Puerto Velero beach, LWD performs three specific geomorphologic roles by creating:

- An area of increased surface roughness and (or) airflow stagnation, trapping appreciable amounts of windblown sand in the backshore;
- Dune growth hubs;
- A diversion or dam for small stream channels in the backshore to create and/or preserve lakes and mangroves [34].

LWD can also offer varying plant and animal species an optimal habitat. Moreover, LWD can supply:

- Structures for nests, dens, and burrows [122];
- A habitat for microbial decomposers [123];
- A hide-out for predators and a protective cover for the prey [124]; and
- A refuge during disturbances.

4.2. Large Woody Debris Convergent Analysis

Our convergent approach depicts that while geomorphological assessment demonstrated the importance of LWD for the beach ecosystem in Puerto Velero, the social perceptions did not show the same trend. It means that ecological valuation differed from the social valuation regarding LWD. One important aspect was that people failed to recognize the ecological importance of LWD in protecting the beach. In Puerto Velero, people highlighted scenic beauty over ecosystem dynamics such as LWD accumulation, which suggests an emerging target conflict regarding BES.

Our results align with other valuation studies conducted in beaches where people undervalue some ecosystem elements that promote functions such as seagrasses, neglecting their ecological importance for supporting beaches [125]. In this context, the ecosystem services theory highlights two ways to understand some negative implications regarding ecosystem functioning: on the one hand, there are the ecosystem disservices [110,126–128] and, on the other hand, ecosystem services trade-offs [53,129–131].

Understanding LWD as a trade-off may not be appropriate in Puerto Velero's context at present. According to [130], ecosystem services trade-offs occur when the increased use of one diminishes the provision of another ecosystem service. This perspective means that—-for this case study—-there is a management option to preserve the benefits offered by LWD, regardless of implications on scenic beauty; hence, the above affirmation falls out of place. Instead, the influence of LWD on the beach is regarded as a conflicting perspective over a natural dynamic in an extensively used ecosystem such as sandy beaches, wherefore more research is needed in the matter to promote genuine social and economic synergies regarding beach management.

The problematic context of this case study should be understood from the ecosystem disservices perspective, in which ecosystem functions, processes, and attributes result in perceived or actual adverse impacts on human wellbeing [128]. Our results show that where the "non-beauty" function of LWD could affect social perceptions about the beach, LWD brings ecological benefits to the beach system; but, in some cases, the apparition of LWD can be a concern, nonetheless. As [34] sustain, LWD accumulates on the most productive areas of the nearshore, where large volumes of LWD may produce various kinds of biotic disturbances; for instance, woody debris shifting and consistent accumulation on the nearshore environment prevents biota from thriving and gathering the native, healthy substrate. Furthermore, the presence of LWD undesirably affects a coastal area's attractiveness to tourists, for, as [37,47] have put it, beach environmental quality is a paramount concern and a crucial requirement if coastal tourist activities are to take place. Seen from a socio-economic point of view, large amounts of LWD on a beach might cause beachgoers to reject it due to uncleanliness [44] and poor scenery [71].

Finally, let us highlight that much research has elicited monetary valuation on ecosystem services in coastal areas, which stresses WTP for preserving marine biodiversity and ecosystem services [27,132–134], protecting cold-water corals [135], or for beach restoration and conservation projects [136–138]. Although the WTP analysis could be understood as a proxy for BES monetary value, this research does not intend to bring monetary units into the analysis; instead, WTP was used to discern respondents' awareness of an undervalued and misunderstanding ecological process, like LWD. Attention is also drawn to the fact that such a lack of awareness could lead to management trade-offs in the future since LWD is sometimes removed before it can provide a geomorphic service [61]; perhaps beachgoers and tourists exerted pressure to have scenic beauty improved.

4.3. Implication for Management

The results of our case study highlight the relevance of a question already posed by other researchers [34,63,71,114,118,139]: Should LWD be left in place, or should it be removed from beaches? The answer is not simple. As stated by [71], strategies for coastal erosion management must consider severity, property rights, funding, and legislation, and, finally, aesthetics. Since LWD must be "recognized" to ensure BES, it is necessary to establish the local authorities' direct involvement and users' agreement not to remove LWD unauthorized and promote tourist awareness regarding this process. Currently, wood is generally perceived as a nuisance, and a beach is perceived clean only if free of waste and any pollutant, regardless of whether natural or not. Such a negative perception concerning natural wood has been corroborated by several studies [71], for the lack of beachgoer acceptance of natural wrack is also among the chief reasons for removal from beaches [68].

This is also stated in our results because most users in Puerto Velero regarded LWD negatively by prioritizing the beach aesthetics before its protection purpose, thus the

importance of promoting its functions to tourists not only by local authorities and coastal related institutions, but local services providers could help as well to foment the beach as a whole ecosystem that depends on LWD.

Beachgoer education is one solution likely to change beachgoer's perception of natural debris. On a larger scale, future beach advertisement campaigns should portray beaches that feature natural wrack debris, potentially changing visitors' outlook on desirable beach conditions. School education about the role of organic debris on beaches could also positively, albeit slow, help build the outlook of desirable beach conditions from an early age. In this context, volunteers' involvement through citizen science and school field trips is widely accepted and brings desirable results regarding increased environmental awareness [139–141], while on-site solutions may include interpretative messages effectively useable for environmental education [142].

Management's lack of solutions focused on leaving LWD on beaches stems from the fact that even though some natural debris might not elicit negative perceptions, an excessive amount of wrack on tourist beaches is unlikely to be accepted due to safety reasons (physical and biological) [143]. An LWD removal scheme could be implemented in this context, whereby a beach gets divided into an area for beachgoers' use and a stretch left ungroomed throughout the year [119,121,144]. This approach is a compromise that might be implemented on those more extensive beaches that are not used for tourism in their entirety. Moreover, a closer approach between communities and environmental authorities is of the essence to discuss potential uses for the wood, both for protection as well as a cultural service. It could be an opportunity to try Community Based Tourism (CBT) initiatives, due to Puerto Velero locals depending solely on the tourism as the main source of income.

LWD is one of the most primitive and straightforward means to create art and corresponds to cultural penchants toward environmental protection; some driftwood sculpture exhibitions have been held and attracted tourists. However, LWD may also add unique habitat structures and resources to sandy beaches since numerous bird species are drawn to LWD accumulated on beaches and within estuaries [63]. Puerto Velero beach management should ground its actions and scope in beach uses (cultural and socio-economic perspectives) and frequently assess LWD conditions on the beach to determine a course of action, which might include taking no action at all, removal along with litter in general, or minimal to complete harvesting. These kinds of responsibilities should be addressed by environmental authorities to control its maintenance as well as other consequences from the increase in LWD along the coast. Furthermore, LWD disadvantages require further assessment [34,64] to improve management thereof because the LWD along the coast is unsightly and unwelcoming to tourists or beachgoers, resulting in a loss of revenue from tourism, and has even caused beach closures in the past. Removing litter eliminates nutrients while removing LWD takes away the fauna's habitat [145].

5. Conclusions

Beaches are ecosystems that provide multiple benefits, and the Puerto Velero spit is valorized for its beach ecosystem services. This research highlighted the importance of large wood debris in the construction and evolution of the Puerto Velero spit. It was also evidenced that LWD is very important as a primary agent for the ecosystem services provided by Puerto Velero beach, for this natural process conjures up the development and growth of the spit, as well as the maintenance of the beach system without monetary costs for local authorities. In this context, LWD is fundamental for maintaining and preserving this fragile ecosystem with mainly a high pressure of tourism and recreation uses.

However, as found hereby, most beachgoers did not recognize the great importance of LWD for the natural maintenance of the environment. Hence, they failed to see LWD's positive contributions to their socio-ecological wellbeing. Therefore, our convergent analysis upon LWD demonstrated a divergent outcome: what was geomorphologically valuable, was not socially. Thus, this study highlights how those social targets were conflicted

since, on one hand, people positively valued beach-provided BES, but, on the other hand, they did not positively view those elements of the ecosystems that are unattractive to them (LWD).

In this line, as a limitation for the present study, it is worth mentioning the possible cognitive load for the respondents, which does not produce the understanding of ecological functions, correlation with biodiversity, of habitat creation and nutrient recycling, which leads to not giving importance to LWD. Further studies could address this dimension.

Furthermore, the above-illustrated pathways for beach management by considering the positive perspectives on beach ecosystem services and considering processes that lead to human wellbeing. Moreover, one could suggest as a solution for the management of this area the partial removal of LWD, in conjunction with the clean-up of marine litter, which could provide awareness of the multiple processes, structures, and benefits of intensively used beach ecosystems.

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