Technical report on the coastal dune ecosystem of the Todos Santos delegation, La Paz municipality, Baja California Sur.

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Summary

Coastal dunes are part of a highly dynamic beach-dune system linking land and sea. The beach dune system, of the type known as frontal dunes, forms a geomorphological profile by strips that covers, in a perpendicular section, from the floodplain by the sea, the intertidal, followed by the beach, the embryonic dunes, a cord of dunes (with a lee side, a ridge, and a windward side) and a gully

before another dune cord forms. Plant communities are a fundamental component of this coastal ecosystem because they have adapted to continuously stressed environments (winds, saline air, burial by sand, salty soil, and few nutrients). The coastal dunes offer 25 environmental services, and their existence is threatened by the rise in the sea level, because of Climate Change, and the coastal urbanization that has destroyed them. At a global level, it has been shown that modifying or eliminating coastal dunes entails critical situations of erosion (loss of beach), which severely affects urban infrastructure. In the Todos Santos, La Paz, BCS delegation, a large part of the beach-dune systems has been preserved and are therefore exemplary worldwide. However, real estate development is a strong threat because they impose outdated construction systems that destroy dunes out of an absurd need to be by the sea. For the most part, the Todos Santos dunes form a single cord (flanked by beach and embryonic dunes towards the sea and scrub that are shared with the adjacent desert vegetation). The flora consists of 90 species, with one dominant species, a sand-setting grass (Jouvea pilosa), and various herbs, shrubs, and cacti.

I. Introduction and background

I.1. Importance of the coastal dune ecosystem

Coastal dunes are an ecosystem that gains importance in the scenarios of Climate Change and elevation of the sea level. It is projected that they will disappear under the sea water that will enter land and, where the dunes can "move" they will, but where there are cities, ports, agriculture, or isolated constructions that destroyed the dune vegetation or are on them, they will not be nothing to protect them. This is because one of the most important ecosystem services provided by dunes (and other coastal ecosystems such as mangroves, freshwater wetlands and marshes or salt marshes) is the protection of the coastline against floods of marine origin (Liquete, 2013). These types of floods are projected disastrous in cities by the sea where they have eliminated the dunes or other coastal ecosystems (Pontee, 2013). In Mexico, in the port and city of Veracruz and in Cancun, the negative impact of the destruction of dunes for residential areas and tourist developments has been documented (Martinez, 2014; Mendoza, 2018; Lithgow, 2019). The consequences that real estate and tourism development caused by destroying the ecosystem of dunes (and freshwater wetlands, mangroves, and salt marshes) should not be repeated in other parts of the country or the world.

The costs to protect the constructions, in addition to being only palliative (breakwaters, breakwaters) and or those of restoring beaches (importing sand and fixing dunes with plants) have too high a cost (billions of pesos) Bitrán, 2001; Pérez, 2013; Feagin, 2014). SEMARNAT (2013) mentions. with some updated bibliography, that the Mexican Caribbean coast is the area most dangerous in the presence of hurricanes; In recent decades, hurricanes with an intensity of 1 to 5 on the Saffir-Simpson scale have impacted with relative frequency (Silva, 2003). Hurricane Gilbert (1988) generated waves up to 14 meters high and moved 130,000 m3 of sand (Diez, 2009). The result was devastating, as the erosive force of the storm surge increased and destroyed 200,000 homes, as well as streets and hotels, causing economic damage that amounted to 76 million dollars (Lithgow, 2019). Subsequently, Hurricane Wilma in 2005, with waves of up to 20 m in height (Silva, 2009, 2012), caused the disappearance of almost 13 kilometers of beaches in the area where around 75% of the population of Quintana Roo live. locates 98% of the hotel infrastructure. The total costs of Hurricane Wilma were 18 billion pesos (García, 2005; Mendoza, 2015). And, to attend to them, they occupied almost the entire fund for disaster relief in the country". Let us take these cases as a lesson learned since the coastal areas of Baja California Sur are not exempt from hurricanes of equivalent force and in the sites that are to be developed, let us impose disaster prevention regulations. We want the population of Todos Santos to continue to be exemplary worldwide.

Ecosystem management provides tools to avoid the construction of areas vulnerable to disasters, because disasters are not natural, they are built (Maskrey, 1993; Lavell, 1999). The first step is the protection of coastal ecosystems, in this case the coastal dunes are of interest, so the beginning would be NOT to destroy one more dune. The coasts of the municipality of La Paz are still in the possibility of continuing their coastal development, correctly. Few sites in the municipality have destroyed dunes; They are mostly isolated houses, but real estate pressure is a threat that must be faced with strict authority, ecological knowledge, and coastal management. The dunes form a fragile ecosystem because they are in a strip where the sea and the land meet and, therefore, they are extremely dynamic spaces where there is a constant exchange of sediments (sand) whose balance is lost with constructions, whatever these whatever, since they function as obstacles that interrupt or divert the flow of water and sediments (Martínez, 2014; Panareda, 2008). The decrease in the availability of sand and the interruption of natural transport between the coastal dunes and the beach favors erosion and retreat of the coastline. As the dunes are part of a system made up of beaches and coastal dunes whose sedimentary balance, if it has been modified, tends to stabilize in a different configuration, but which normally leads to the loss of the beach. These changes are not observed immediately because they are hidden between short-term fluctuations, thus reducing the capacity of the beach-dune system to withstand seasonal changes and recover, or not, after an extreme hydrometeorological event, such as hurricanes (Feagin, 2014) or currently, the rise in mean sea level.

I.1. Importance of the coastal dune ecosystem I.1.1. Ecosystem Services (SE)

The **ES** are the direct and indirect benefits that are generally not offered in the market, but from which society obtains goods from the ecosystems that generate them. The Millennium Ecosystem Assessment (MEA, 2005) and Groot et al. 2010), have developed a classification system for ES based on the four basic functions of ecosystems: 1) habitat: they are necessary for the production of the other ES (the nutrient cycle, photosynthesis), 2) provision: are the products that we obtain from ecosystems (food, firewood, fibers), 3) regulation: these are the benefits that are obtained from the regulation of processes that occur thanks to the proper functioning of the ecosystem (such as pollination, disease regulation , and climate regulation) and 4) Information (knowledge and culture): these are the non-material benefits obtained from ecosystems (recreational, tourist, aesthetic, spiritual, cognitive). Other authors mention the support SE (fields of cultivation or
where biodiversity develops, but this has also been included by other authors, within those of habitat or provision).

Coastal dunes are important from an ecological point of view because they exist as ecosystems, but also because of the ecosystem services (ES) they provide to society (Pilkey et al., 1998; Psuty, 2004 and Moreno-Casasola, 2006).

The coastal dune ecosystem forms geomorphological structures that provide various regulatory services, including buffering against events such as storms and rising sea levels, since they are considered natural protectors of the population and the coastal infrastructure (Psuty, 2004). Similarly, some of them provide the function of habitat to important biodiversity nuclei, some have endemism and natural wealth (Rodríguez-Revelo, 2012; Espejel et al., 2015). Also among the information functions (knowledge and culture), they have been the scene of several investigations (Jimenez-Orocio et al., 2015; Rodríguez-Revelo et al., 2018) and of multiple cultural events, they have been used by ancient groups of indigenous people, from whose activity there are archaeological remains known as "concheros"; such as environmental education courses (de la Vega, 2011), filming (Reyes, 2003); concerts and, recently, the provision SE has gained economic importance with the extraction of sand (Rodríguez-Revelo et al., 2019).

Table 1. List of ecosystem functions and services of the world's coastal dunes. Taken from Everard et al. (2010).

Provisioning Functions	
1	**Water supply**
2	**Medicinal resources**
3	**Raw materials**
4	**Military use**
5	**Food**
6	**Genetic resources**
7	**Ornamental resources**
Regulation Functions	
8	**Moderation of disturbances**
9	**Water regulation (stored)**
10	**Maintenance of soil fertility**
11	**Climate regulation**
12	**Biological control**
13	**Air quality regulation**
14	**Water flow regulation**
15	**Waste treatment**
16	**Erosion prevention**
17	**Pollination**
18	**Regulation of erosion**
Habitat functions	
19	**Shelter**
20	**Protection of the germplasm bank of six kingdoms of life (Archaebacteria, Eubacteria, Protista, Fungi, Plantae and Animalia)**

Cultural functions	
21	Aesthetic information
22	Recreation
23	Spiritual experience
24	Inspiration for culture and art
25	Cognitive development

The world's coastal dunes offer 25 Ecosystem Services (Everard, 2010) (Table 1, Figure 1). In the Baja California peninsula, it was estimated that coastal dunes offer 22 of the 25 ecosystem services defined for coastal dunes (Rodríguez, 2018). The most studied ecosystem services are the provision of raw material (sand); the regulation of the microclimate, air quality, moderation of disturbances and erosion (protection) built on its back as in other parts of the world (Liquete, 2013); they provide habitat for a biodiversity adapted to extreme situations and the service of offering an ecosystem with unique characteristics that is the object of research on coastal dynamics, succession, adaptation, use of plants, and they are a source of artistic inspiration.

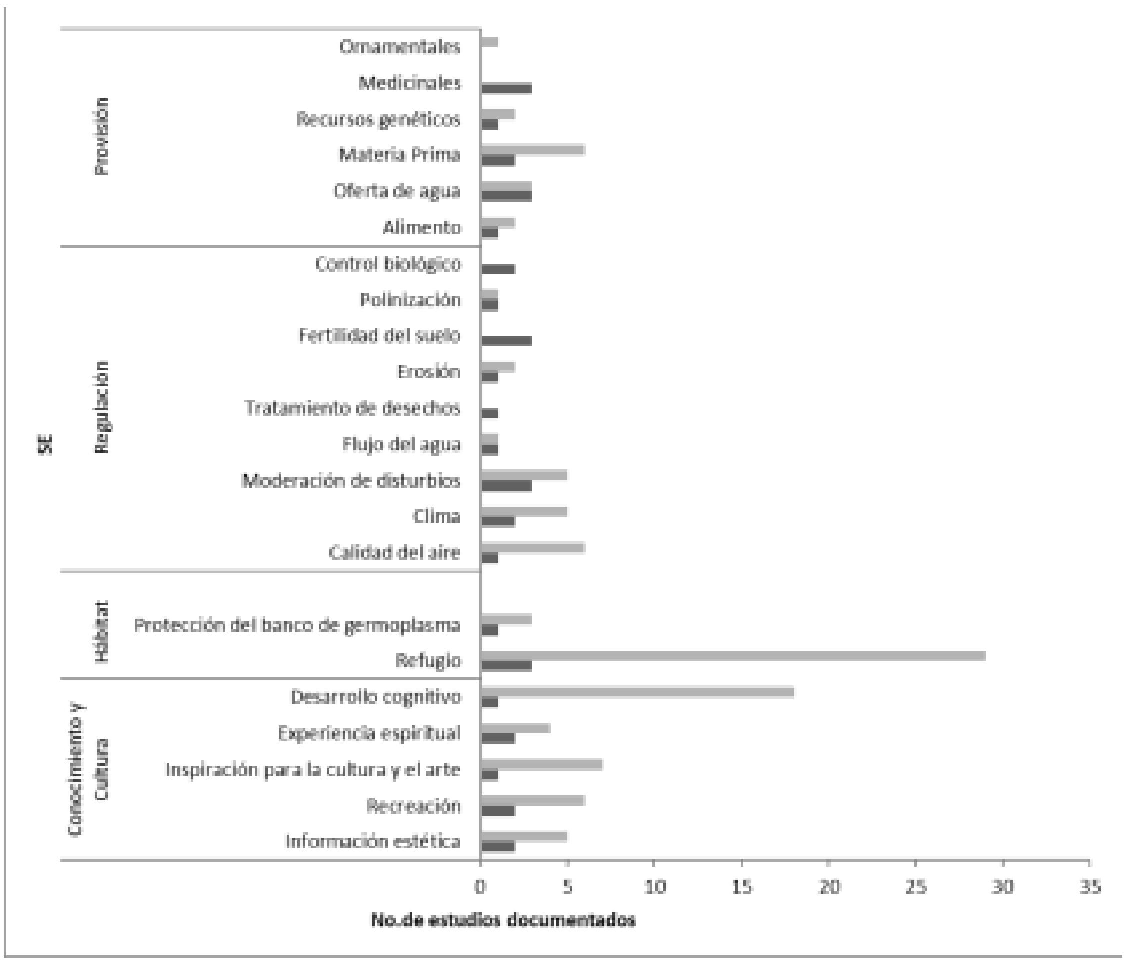

Figure 1. Ecosystem services of the coastal dunes of the Baja California peninsula. This information corresponds to scientific publications that have studied each of the ecosystem services. It can be considered as the value that scientists have given to the functions of the coastal dune ecosystem in the peninsula.

To prevent coastal disasters and protect coastal infrastructure, it is important to define the geomorphology of a coastal dune, especially the frontal dunes that form dune cords * parallel to the beach and are subject to swell and storm surge (Figure 2). Each site has a different dune conformation and therefore it is important to define the intertidal beaches and the beach area, distinguish the embryonic dune area and the dune ridges if there is more than one. These geomorphological strips are part of the dune-beach system, which is dynamic, and it is extremely easy to break the balance if the system is modified.

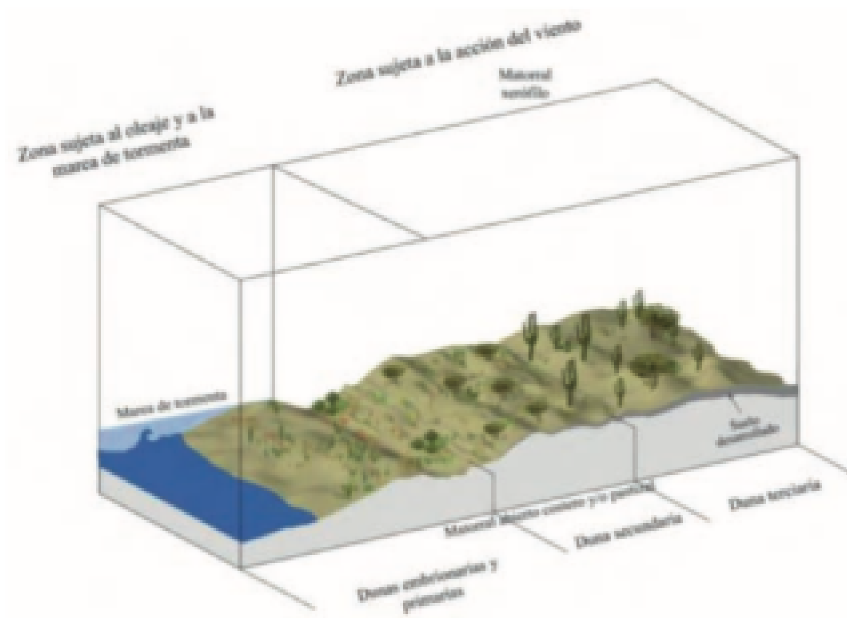

Figura 5. Perfil del sistema de dunas costeras en zonas desérticas.

Figure 2. Profile of the coastal dune system in desert areas according to SEMARNAT ().

Likewise, it is important to describe the vegetation that covers the beach, embryonic dunes, and dune cords, since this is the main sand fixer. The vegetation of the beaches and frontal dunes is creeping or of herbs and small shrubs that are adapted to environmental situations of continuous stress such as sand burial, constant wind, and marine spraying. Defining the vegetation gradients according to the topographic profile of the beach-dune systems is key to understanding the ecological relationships of the plant communities and the environmental factors that allow them, or not, to occupy a space in the dune.

** Un cordón de dunas es una unidad geomorfológica representado por un angosto montículo de arena longitudinal, continuo, paralelo a la línea de costa, producto de una costa progradante con abundante suministro de sedimentos (Healy, 2005). Su característica principal es la presencia de pendiente barlovento (frente de mar), una cresta (cima) bien definida, y una pendiente suave en sotavento. En costas con rango de marea bajo, pendientes poco profundas cerca de la costa y condiciones de oleaje refractado de energía relativamente baja, se pueden encontrar más de un cordón de dunas, donde cada cresta representa la ubicación anterior de una berma de playa, sobre la cual, con el tiempo, se desarrolla una duna frontal baja a partir de un "recubrimiento eólico" (Bird, 1972).*

En la costa del municipio de La Paz, la mayoría de las dunas costeras está representada por un solo cordón de duna frontal, casi siempre antecedido por dunas embrionarias incipientes o en formación, por lo que el cordón de dunas, en esta zona, es un sistema unificado que comienza al final de la berma de playa y termina en la zona de transición con el matorral costero.

This report describes the Todos Santos dunes and provides recommendations for their protection and thereby supporting the efforts of the Todos Santos community to achieve sustainable coastal development.

I.2. Regional background

The Todos Santos dunes were described for the first time by Ann Johnson (1977) who clearly mentions the stripes that characterize the frontal dunes, the windward face (the one facing the sea), the crest and the leeward face (the one facing the land. indoors). According to the descriptions of this author and that precede and coincide with this technical report, the coastal dunes of Todos Santos are formed by strips, according to their orientation (Figure 2) and in most cases they only have a single dune cordon. They are described below:

A. Beach and embryonic dunes

1. The sandy beach lacks vegetation as it is flooded. The intertidal strip can extend to the base of the first dune cordon, in seasons of strong waves. When the tides are not extremely high and there is no swell that floods it, some isolated cosmopolitan plants can grow, that is, they are found on all the beaches of the world. These species are known as "pioneers" because they are the first to occupy the sandy soil that characterizes the beaches.

2. The fringe of embryonic dunes, an area outside the action of tidal waves, where the salty wind is the main limiting factor for the growth of sand-fixing plants. This strip is usually a flat sand base with slight undulations where sand accumulates between the foreign bodies that the tide carries (such as wooden logs or dry algae) and that the plants, adapted to these environments, take advantage of to develop. Generally, there are few species (mainly grasses that grow as creeping vines) that densely cover the sand so that the sand fixing process begins, which is key in the dynamic beach-sea balance. All these species withstand burial and have a strong root system, characteristics that help to fix the sand.

3. Just before the beach itself ends, a slope that can be very steep is called a berm. This is a kind of step, sometimes very marked, others not so much.

B. Windward Front Slope (front of the dune cordon)

1. Dune front or windward slope of the first dune range, has different heights, lengths, and widths; it can have a gentle or steep slope. The diversity of plant species growing on this sea-facing slope is greater than that found in the embryonic dunes. The wind is the main limiting factor for the growth of plant species, as well as the saline humidity from marine spraying. There are plants of different forms, such as the creeping vines of the embryonic dunes and, some erect grasses and small isolated bushes grow that shed their leaves in the dry months; Therefore, a layer of organic matter begins to form on the sand. The combination of roots (fine, dense and superficial and fine or robust and deep) is essential to sustain the sand despite the slope, the constant wind and the scarcity of soil itself.

A. Crest or Top) of the dune

B. Corresponds to the narrowest and highest section of the dune cordon. As there is no physical barrier, the wind passes constantly and with much more force since there is nothing to stop it, for this reason the herbaceous species of low height dominate since the wind "shaves" them and does not let them grow much. Species typical of embryonic dunes (creeping vines) and some of the windward slope can develop, but always smaller... Here, as in the embryonic dunes, are the plant species that best withstand the aggressive conditions typical of coastal environments, strong winds, saline spray, and sand burial.

C. Leeward Slope

1. It is the strip of the dune whose slope has the greatest protection from the wind, so the sand has less mobility than on the crest (top) or on the slopes facing windward. The leeward slope of the dune cordon is very gentle and long. The same species grow as on the top (ridge) and windward slope, but the biodiversity on these slopes is already enriched with plant species from the adjacent scrublands, species maladaptive to wind, salinity, and burial. The density of plants is greater than in the other sections of the dune cord, so the roots of creeping, erect grasses, shrubs, trees, and cacti stop the sand and the layer of organic matter on the sand begins to form soil itself.

E. Hollow or end of the dune if there is no other cord.

Where the leeward slope of the first dune cord ends, on flat or undulating terrain. Here, the thickness of the sand layer is thinner, and its own inland soil underlies it, which is why it gradually incorporates elements of shrubs or perennials, typical of desert scrub.

In general, in Todos Santos, as in all the sandy coasts of the municipality of La Paz, there is only one dune cord that limits, inland, with the desert scrub under a sandy soil condition, or with the saltpeter if it presents an impoundment. of rainwater runoff. Many species of the scrub and salt flats can grow on the sandy soils of the dunes, this increases their diversity and is more heterogeneous than the vegetation of the fringes facing the sea.

In some isolated cases, two dune ridges have been found. The hollows that form between them can be dry or temporarily flooded. The second dune cord has the same sections as the first dune cord, windward slope, top, and leeward slope and ends in a hollow where other types of vegetation can already grow (desert scrub or coastal wetlands).

What is more, inland, there are fossil dune ridges thousands of years old covered in desert scrub. In this work, we are only interested in the cordon of dunes closest to the sea since it is the most threatened by real estate growth and the one that, if destroyed, puts the now balanced coastal dynamics and in the future the same constructions at risk of breaking.

In Ann Johnson's results (Figure 3) she describes two dune profiles and mentions that the pioneer plants of the Todos Santos dunes were two grasses that grow together (Sporobolus virginicus and Jouvea pilosa) and form a vegetative cover that fixes the sand of the dunes of this region, which the author calls the Cape Region. In this area, dominated by J. pilosa, it is interspersed with small grasses of Chamaecyse leucophyla (swallow; current name: Euphorbia leucophylla) and Oenothera drummondi variety thalassaphila. At Pescadero, Johnson reports the presence of Abronia maritima, the characteristic species of the dunes of northwestern Mexico, and Palafoxia leucophylla (possibly Palafoxia linearis); both with few current records in Pescadero.

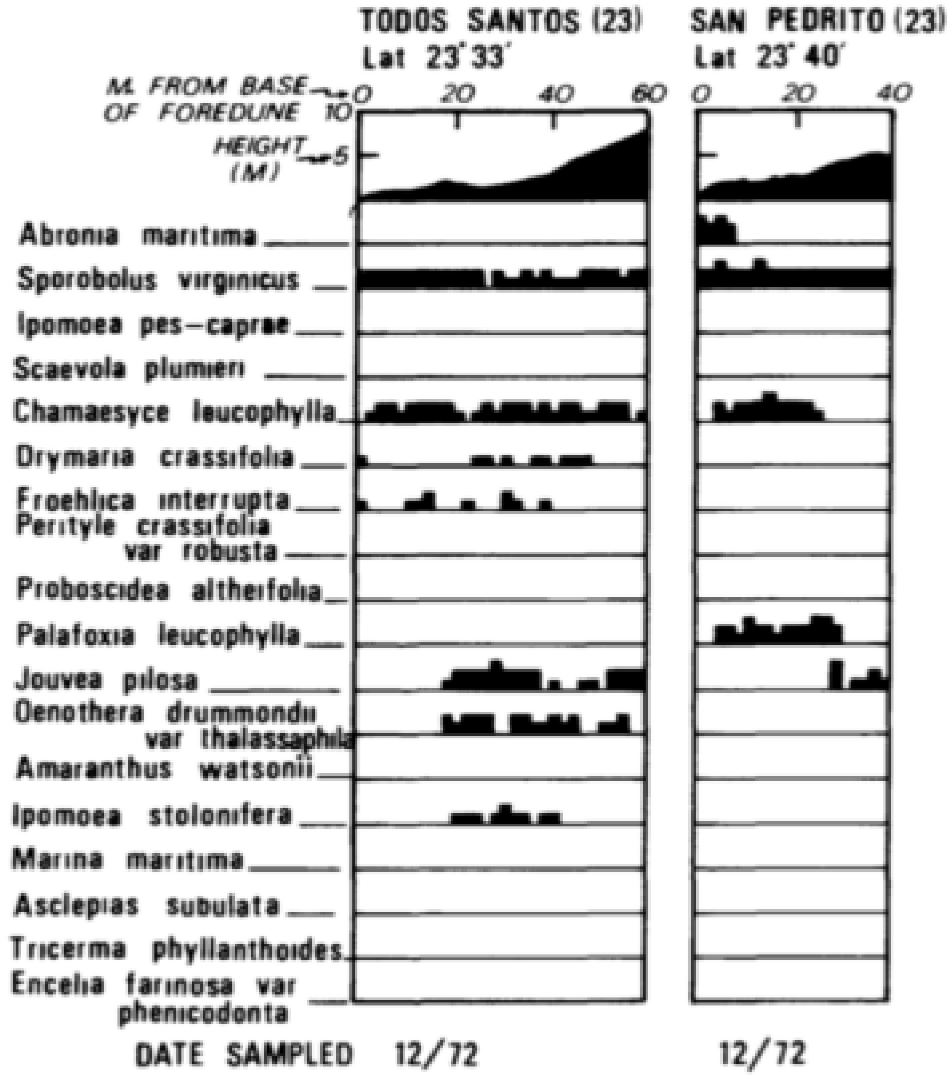

Figure 3. Vegetation profiles of the coastal dunes of Todos Santos sampled in 1972 and published in 1977 (21) by Ann Johnson of the University of Davis, California. By the coordinates, Todos Santos corresponds to Playitas and San Pedrito is in Pescadero.

In 1995, Pérez-Navarro, resumed his interest in the Todos Santos dunes. This author drew more detailed vegetation profiles than Johnson's (1977), which also show a single dune cordon. One profile describes a dune in Punta Lobos (18 species) and another in Playitas, Todos Santos (18 species) (Figure 4). The species and their distribution remain like that described by Johnson (1977) in the sense that the two dominant grasses J. pilosa and S. virginicus cover almost the entire width and length of the dunes. This work indicates the presence of a common creeper on the country's beaches, Ipomoea pes-caprae, which Johnson did not find in these dunes in 1977. Likewise, on the lee side and towards the end of the dune cord, this researcher finds species of desert scrub, such as jojoba (Simmondsia chinensis) and cacti (Cylindropuntia cholla and C. alcahes), and the marshes and salt marshes that flank the dune cordon.

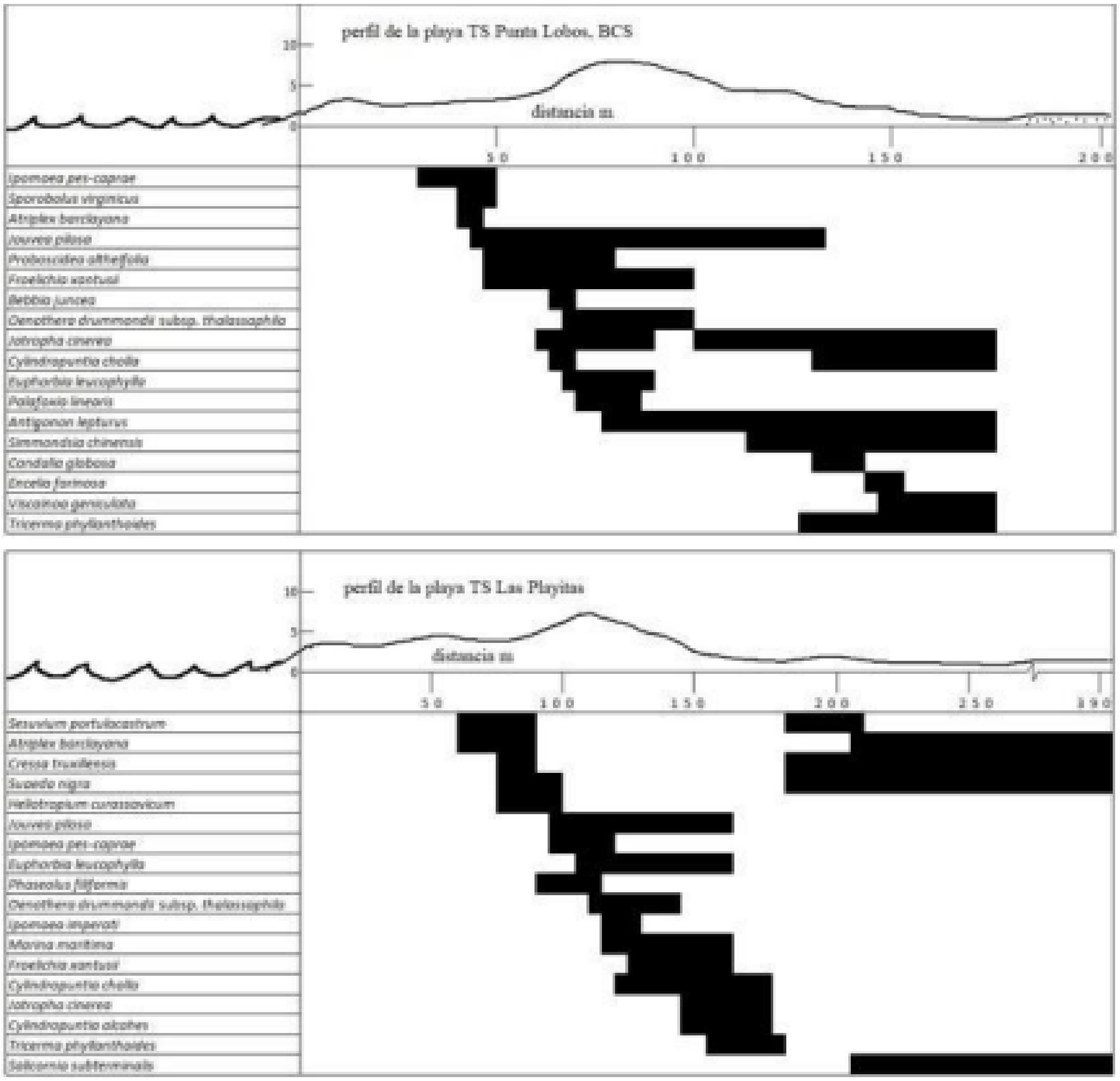

Figura 4. Perfiles de vegetación de dos dunas costeras de Todos Santos, Baja California muestreados por José Juan Pérez Navarro (Cibnor) en 1995.

Between 2012-2014, an investigation of the coastal dunes was carried out at the national level (Espejel et al., 2014) in a project of Conabio-Semarnat-Conacyt-HJ007. All states were analyzed and the lists and profiles for Todos Santos were updated by researcher José Luis León de la Luz del Cibnor (Center for Biological Research of the Northwest). As a result of this project, the results were published in Espejel et al., (2017). In 2014, Conafor also published a book on the coastal dunes of the country Martínez et al., (2014) where there is a chapter from Baja California Sur.

Between 2019 and 2020, previous studies have been carried out in specific lots of Todos Santos, also now addressed, and a diagnosis was made for the Ecology Directorate of the municipality of La Paz. The results of both antecedents are incorporated into this technical report. The reason for using all the research antecedents in this strip of coastal dunes is to
use the same methodology, highlight the coincidences and particularize the recommendations.

II. Objective

Characterize and delimit the coastal dunes of the coastline of the Todos Santos delegation, municipality of La Paz, Baja California Sur and provide recommendations for coastal management.

III. Methodology

III.1. Field work

Four sections of the coastline with the presence of coastal dunes were visited in the delegation of Todos Santos municipality of La Paz from February 16 to 21, 2021, the four sections correspond to the towns of Todos Santos, El Pescadero, Cerritos and Ejido Plutarco Elías Calles (Figure 5). In each of the localities, reconnaissance tours were made, photographs were taken, a vegetation profile was made, each kilometer, and ecological samplings in the beach-dune system (Table 2); In addition, a topographic survey was carried out every 500 m and sand samples were taken (at strategic points), for granulometric analysis (see granulometry section).

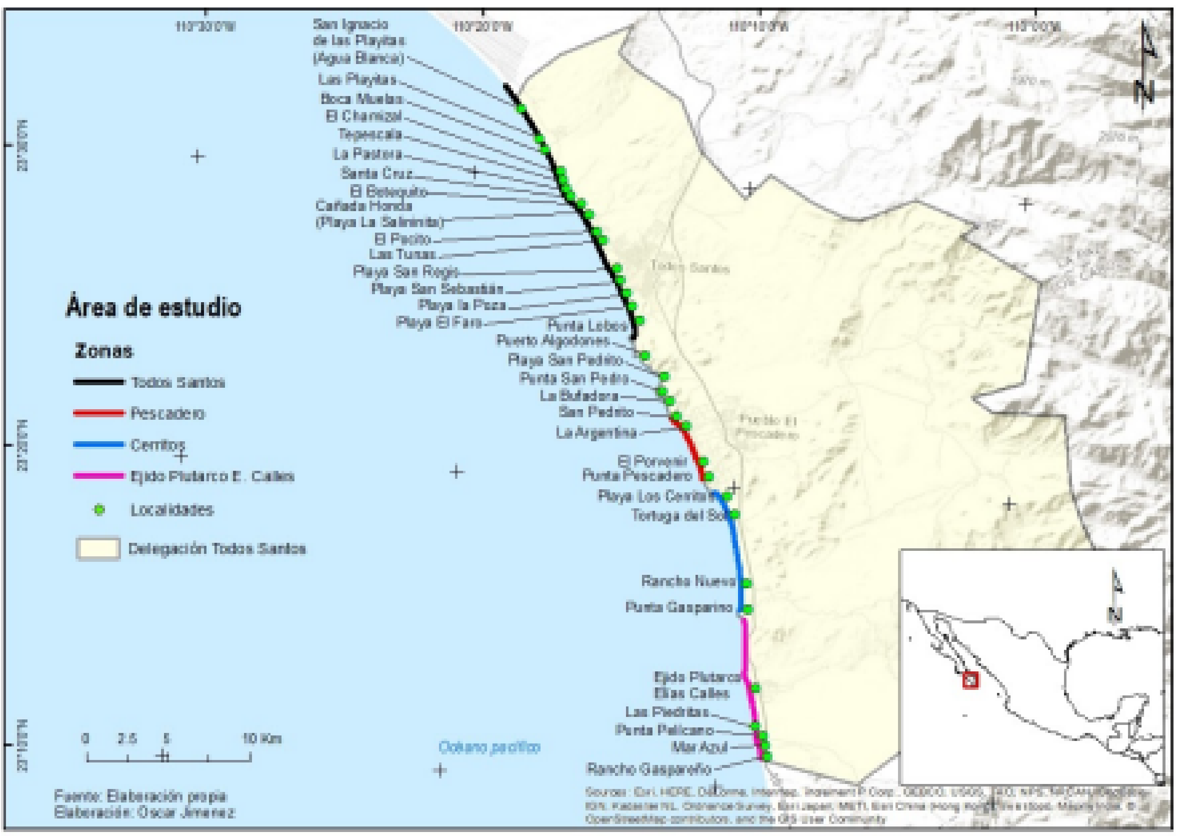

Figure 5. Study area. The beach and coastal dunes of the Todos Santos delegation, La Paz, Baja California Sur are indicated.

III.2. Vegetation sampling

The type of sampling applied in this study is the so-called relevé. This methodology is used in coastal dune investigations throughout the country. They are quick samples, which allow evaluations to be made when there is little time available. A mixed abundance and coverage scale is used for the species within a 10x10 m quadrant. For each plant species, within the relevé, the abundance and cover are calculated, using an ordinal category that ranges between 1 and 9. The numbering from 1 to 5 refers to the number of organisms per species and is useful to count, for example, columnar cacti, which have no cover, but are indicative of a surrounding vegetation type. From 6 to 9 is used for species with coverage 6 = 10 to 25%, 7 = 25 to 50%, 8 = 51 to 75% and 9 = 76 to 100% coverage of the quadrant. In addition, data on the average height of the vegetation and the outstanding species, the type of soil, the vegetation that surrounds it, the distance to the sea and the degree of deterioration or conservation of the site are recorded, for each of the quadrants, to get a better ecological description of coastal dunes. The quadrants are located on a transect, perpendicular to the coast, which begins at the beach and ends where the coastal dune ends.

Tabla 2. Sitios de muestreo y número de transectos realizados en Todos Santos, municipio de La Paz, BCS. En cada sitio se hizo un perfil para medir el ancho del cordón de dunas y colocar las especies de flora a lo largo de cada perfil.

Sites with dune profiles	
1. Todos Santos	
2. Pescadero	
3. Cerritos	
4. Elías Calles	

III.3. Topographic profile and geomorphological description of the beach-dune system

Cross-sectional beach profile measurements were taken using differential GPS, which is an instrument that consists of the use of two GPS antennas (Base and Mobile) taking measurements at the same time, every second. The base antenna remains placed in a fixed point with known coordinates, this after a triangulation of the data from our base antenna with the data from the base antennas of the National Geodetic System of INEGI. The mobile antenna is used on the beach by measuring every second while walking along the cross-section of the beach.

Subsequently, the data measured by both antennas are post-processed to correct the ambiguities of the measurements received by the satellites in both antennas, thus obtaining a result of greater precision both horizontally and vertically (+ - 0.05 meters).

To correct the ellipsoidal height, measured by GPS, at a local tide level (Lower Mean Low Tide Level, NBMI), measurements of the water mirrors were taken under calm conditions and with a known tide level (obtained from tables local tide). In this case, the correction applied was 32.8239 meters.

A total of 76 beach profiles were measured over a four-day period. The profiles were measured without considering spring tides and start at the point where the water level is covering the face of the beach. In this way, the measurement start place is affected by both the tide level and the storm surge that exists at that time. For this reason, there are profiles that start at 4 m elevation and others at one meter.

III.4. Granulometry

Beach sediment samples, front dune top and dune transition zone (dune boundary with scrub) were obtained from 10 randomly selected sites from the analyzed coastal sections. To obtain the sand samples, it was dug to a depth of 30cm; the samples were stored in self-sealing bags, which were labeled with the date and coordinates. Later, the samples were sent to a specialized laboratory for analysis.

In the laboratory, 37 sediment samples were placed in 600 ml beakers and dried in an oven at 60 ° C for 24 hours, as the sample is required dry for analysis. Subsequently, they were placed in a cracker to obtain representative sub-samples of approximately 100 g. For the granulometric analysis, a series of U.S. brand sieves was used. Standard Sieve, from -2.0 to 4.0 phi (4.0 to 0.063 mm mesh opening) in 0.5 phi intervals. Each sample is sieved for 10 minutes and weighed to determine the percentage of each grain size fraction. With the weight obtained, the individual weight percentage, the accumulated weight percentage passing through each sieve and their respective graphs were determined.

Finally, the following statistical parameters were determined: mean, median, sorting, asymmetry and kurtosis, as well as the percentages of gravel, sand and silt-clay.

III.5. Cabinet work

A bibliographic search and cartographic databases were carried out to develop a baseline that would allow contextualizing the coastal area of the Todos Santos delegation, which consists of the identification and description of the climatic, hydrographic, type and land use characteristics, vegetation cover and demography. With this information, charts and cartographic maps of the area were made.

The information collected in the field was captured and analyzed with the use of basic packages.

In addition, a zoning of the beach-dune system was carried out through the photointerpretation of composite satellite images (Google Earth), and with the help of the photographic compendium and drone images (Provided by Ricardo Madrazo, resident of Todos Santos). The zoning consists of the identification of each of the strips that make up the system (already verified and located with control points (GPS).

With the refined and analyzed information from the vegetation samples, the topographic profiles and the zoning, graphics (drawings) were prepared for a summarized description of the beach dune system of the analysis area.

IV. Results

IV.1. Description of the study area

Todos Santos is in the municipality of La Paz, Baja California Sur state. Its exact location is at 23 ° 26 ' 55 ″ N 110 ° 13 ' 24 ″. It sits on a plateau at the foothills of Sierra La Laguna, and was, in its heyday, the most fertile place in Baja California Sur. It is located 81 km from the city of La Paz and 85 km north of the city of Cabo San Lucas. The location of this town is strategic and highly attractive for the development of tourist activity, since it has huge extensions of beaches and areas in a natural state for surfing, whale watching, recreational fishing, among other activities.

Climate: It is observed that the climate of the region, along the coastline, is classified as type BW (h ') hw (x'), which corresponds to a dry, semi-warm climate, with rains in summer and a winter precipitation between 5 and 10.2%. This type of climate is modified towards the flanks of the topographic elevations that are located inland, passing to a BSohw (w) climate that is dry, extremely hot, and warm. Towards the upper parts of the mountains, the climate changes again to present type C (wo), which belongs to the range of temperate, sub-humid climates, with rains in summer.

The average annual temperature varies from 22 °, which is recorded on the coast, to 18 ° C in the upper part of the mountains. According to the data registered in the station 03-051 Todos Santos, the annual average registered in its area of influence is 22 ° C.

During the November-April period, the average minimum, and average maximum temperatures of 12 ° C and 27 ° C respectively are presented for the coastline, and 6 ° C and 24 ° C, which are recorded in the mountains. In the May-October period, the maximum average temperature in the coastal area is higher than 33 ° C.

According to the records of station 03-051 (Todos Santos), the annual average registered is 161 mm. In the coastal zone, during the November-April period there is rainfall of less than 50 mm, while values that vary from 50 and 75 mm are recorded on the flanks of the mountains. In contrast, for the May-October period, the average rainfall varies from just under 175 to 325 mm for both areas: coastal and flanks of the mountains, respectively. The region is characterized by prolonged periods of drought, which are drastically interrupted by the incidence of tropical storms and hurricanes.
Next, the climate graphs of three meteorological stations located in the study area are presented (Figure 6.1 to 6.3). This information is statistics based on observations taken between 01/2016 - 02/2021. (https://es.windfinder.com).

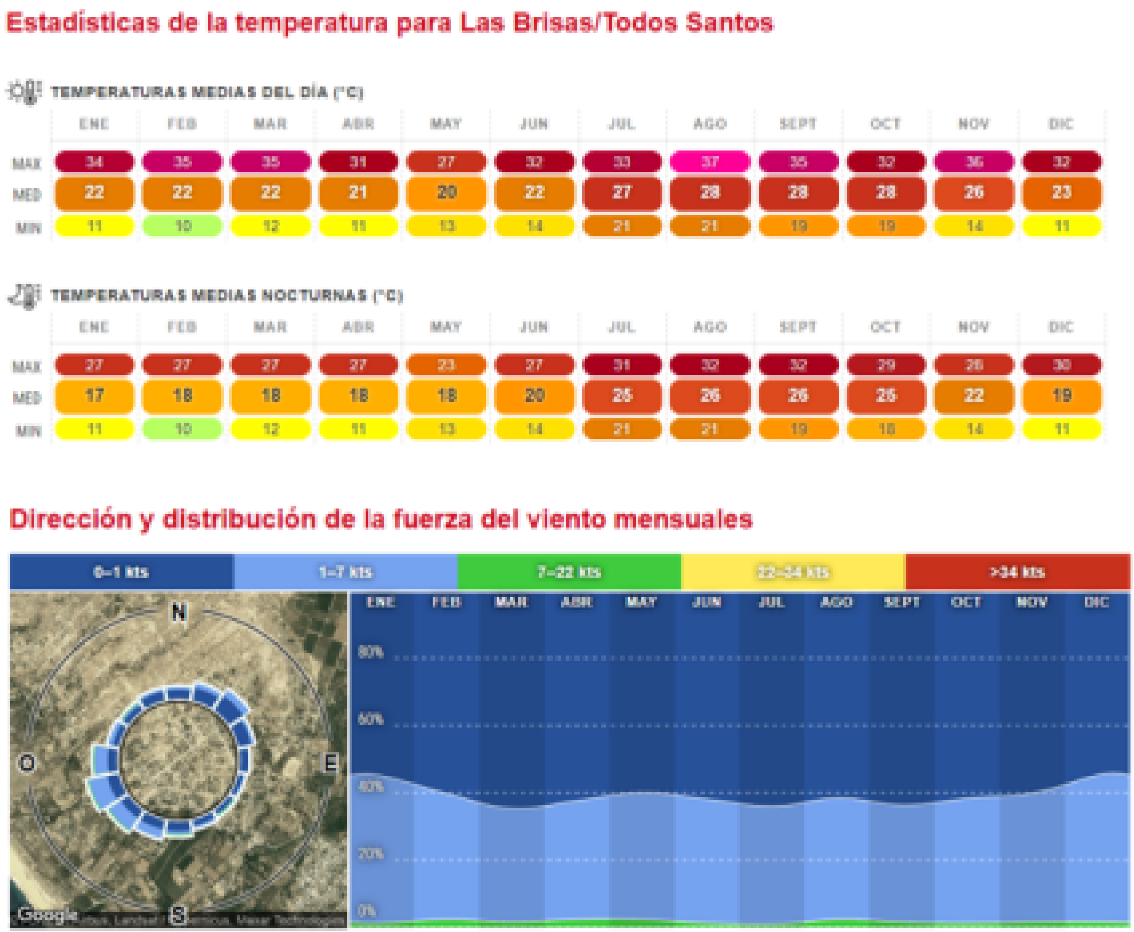

Figure 6.1 Weather and wind data for Todos Santos

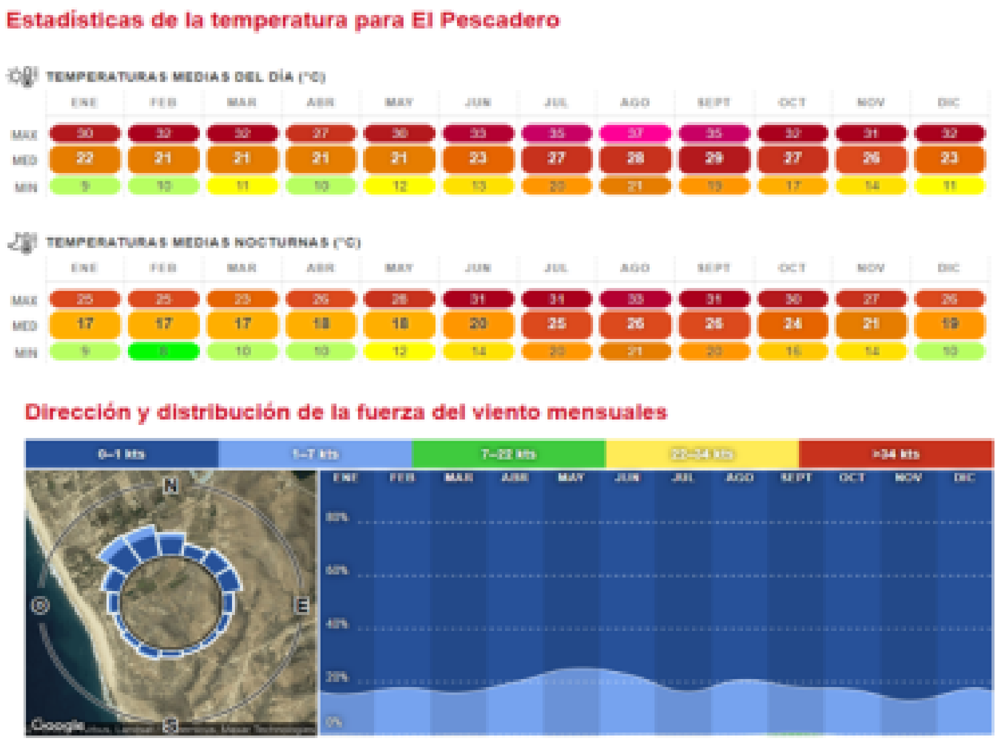

Figure 6.2 Climate and wind data for Pescadero

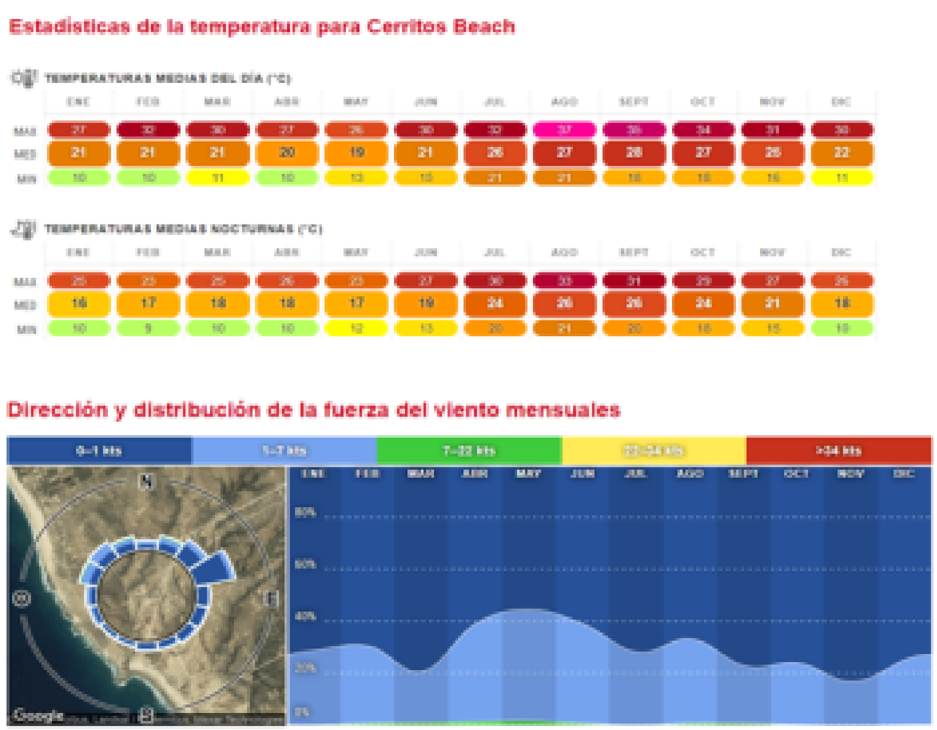

Figure 6.3. Weather and wind data for Playa Cerritos

Hydrometeorological phenomena: The coast of Todos Santos is located on the fringes of the Tropics, so tropical storms and hurricanes increase humidity, which gives it a subtropical climate (INEGI, 2000). In this sense, a historical analysis of the hydrometeorological events that have impacted the coast of the study area was carried out. The data indicate that, for the coastal area of the municipality of La Paz, in the period between 1945 and 2019 there have been 34 events, of which 11 of them were tropical storms, about hurricanes, five of them they reached category four, same number of category three events, four more were registered with categories two and nine were given category one (Figure 7 and 8).

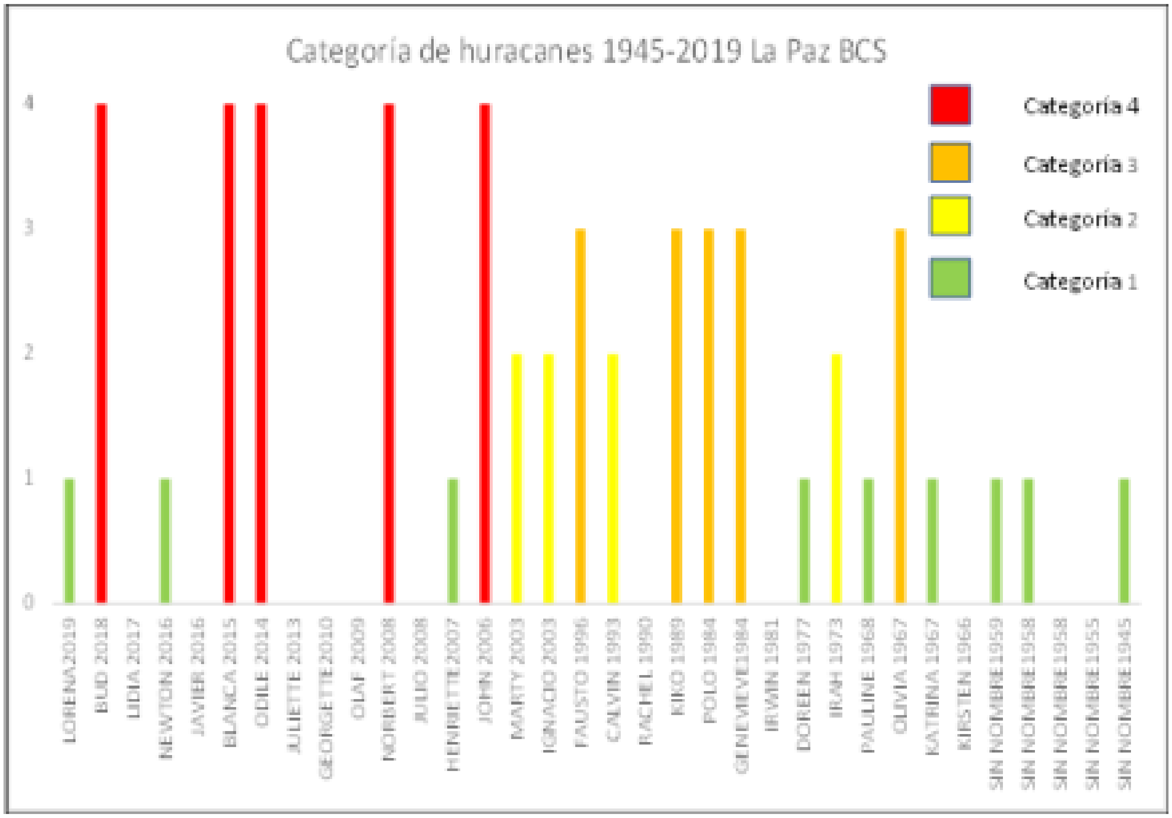

Figure 7. Category of hurricanes in the period 1945-2019 for La Paz BCS

Figure 8. Hurricanes registered for the municipality of La Paz in the period 1945-2019..

The previous image shows the hurricanes and their classification, as well as the tropical storms that occurred in La Paz BCS during a period of 74 years, of which the most prominent event is Hurricane Odile, which had category 4 with maximum winds of 222 km / h. Hurricane Odile, category III (Figure 9), made landfall on approximately September 14 in the vicinity of Cabo San Lucas with VMS of 205 km / h and gusts of 240 km / h, and dissipated as a tropical storm on September 17 (Chávez, 2015). The consequences of the hurricane in the state of Baja California Sur were significant. 95% of the state's users were left without electricity service, 100% of the drinking water supply was interrupted before it passed, and 30% of the total cultivated hectares were affected (Chávez, 2015).

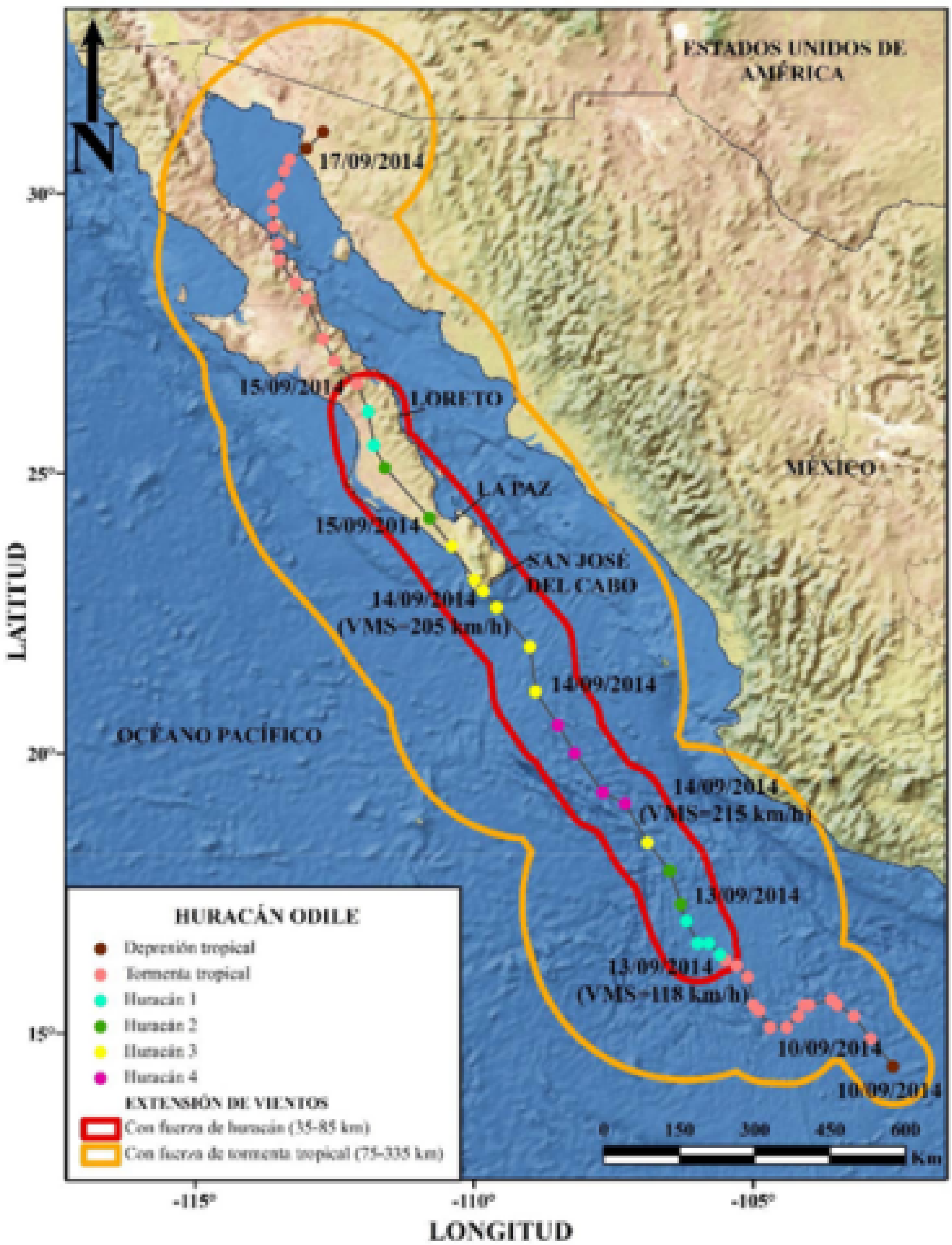

Figure 9. Path and extent of winds from Hurricane Odile. The maximum sustained wind speeds (VMS) are indicated from information from the SMN

and NOAA, taken from Chávez, 2015

Regarding the damage caused to the Todos Santos delegation, what Chávez and collaborators reported were effects on agricultural activity and local infrastructure. According to local testimonies, in the coastal area the impact of Odile was reflected in the impact of the waves on the base of the coastal dune, which caused erosive cliffs and deposition of debris on the beach.

Oceanic climate and projection of sea level rise for 2050: The local tide is mixed semi-diurnal, with an average high tide of 0.457 m and low tide of 0.609 m (CICESE, 1990). This has been considered a high-energy shoreline due to the relatively low variability and persistence of local winds and due to the presence of large wind and swell waves (Wright et al., 1973). **According to Climate Central (2017) it is projected that by the year 2050 the towns of the Todos los Santos delegation that will have the most changes in their coastline due to the rise in sea level are: Playa Tortugas, Todos Santos, Cerritos and Punta Lobos, the latter two, the projection indicates that some of the constructions will be flooded by the rise in sea level (Fig. 10).**

Figure 10. Localities most affected by sea level rise in the Todos Santos delegation according to Climate Central

For the remaining localities, the rise in sea level will also modify the coastline, however, it will not have an impact on the buildings that are close to them, with Agua Blanca being the least affected followed by El

Pescadero and Plutarco Elías Calles (Fig. 11).

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Figura 11. Localidades con menor impacto por nivel del mar en la delegación Todos Santos BCS de acuerdo a Climate Central.

Soil types and erosive processes: Figure 12 shows the types of soil present in the Todos los Santos delegation, with the *regosol* type predominant (soils with little development that are generally clear or poor in organic matter, they are quite similar to the rock that gives rise to them); followed by l*eptosol* soil (very thin, stony and poorly developed soils that may contain a large amount of calcareous material) and with less presence the *fluvisol* types (very poorly developed soils, moderately deep and generally have a weak or loose structure) and *arenosol*. The type of soil on the coastline is sandy, typical of sandy beaches. The following image shows that *regosol*-type soil dominates and only the northern portion of the study area shows *arenosol*-type soil. It is important to mention that *regosol*-type soils are included in this group, coastal sandy soils.

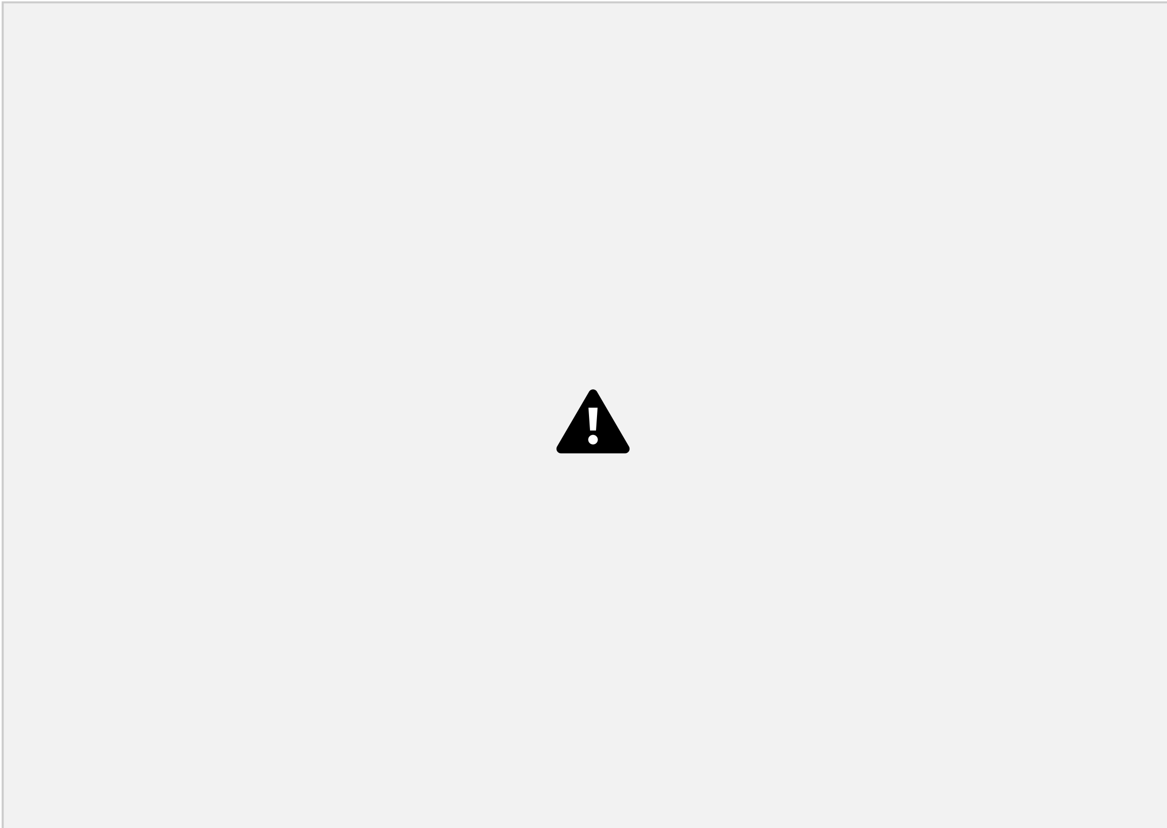

Figure 12 Types of soil present in the Todos los Santos delegation.

On the other hand, in the Todos Santos delegation, soil erosion of the hydric type is observed (Fig. 13), that is, it occurs when the causal agent of erosion is water in its forms of torrent, rain, streams, flooding of rivers and the effect of irrigation. Water is a very energetic erosive agent. When the soil has been left unprotected from vegetation and subjected to rain, torrents carry soil particles into streams and rivers. The soil, devoid of the surface layer, loses organic matter (humus) and enters a process of degradation by hardening that can lead to a decertified area. The type of soil erosion is generally the laminar and gully type, the first associated with the gradual and uniform removal of thin layers of soil, generally parallel to the surface, while that of gullies is identified since its structure is shaped. of trench with steep walls of 50 cm or deeper, where slopes and abrupt breaks can be generated.

This information is important for the description of the dune system as it corroborates the main origin of the sediments that make up the coastal dune system. In the study area, alluviums are observed, in which the sediment is a detrital material composed of sand, gravel, clay or silt, which accumulate in stream channels and flood plains. Through these fluvial currents, the sediment travels towards the sea and, thanks to the coastal currents and by the process of the waves of the sea, they are deposited on the beach; and thus begins the sedimentary dynamics in the beach
dune system.

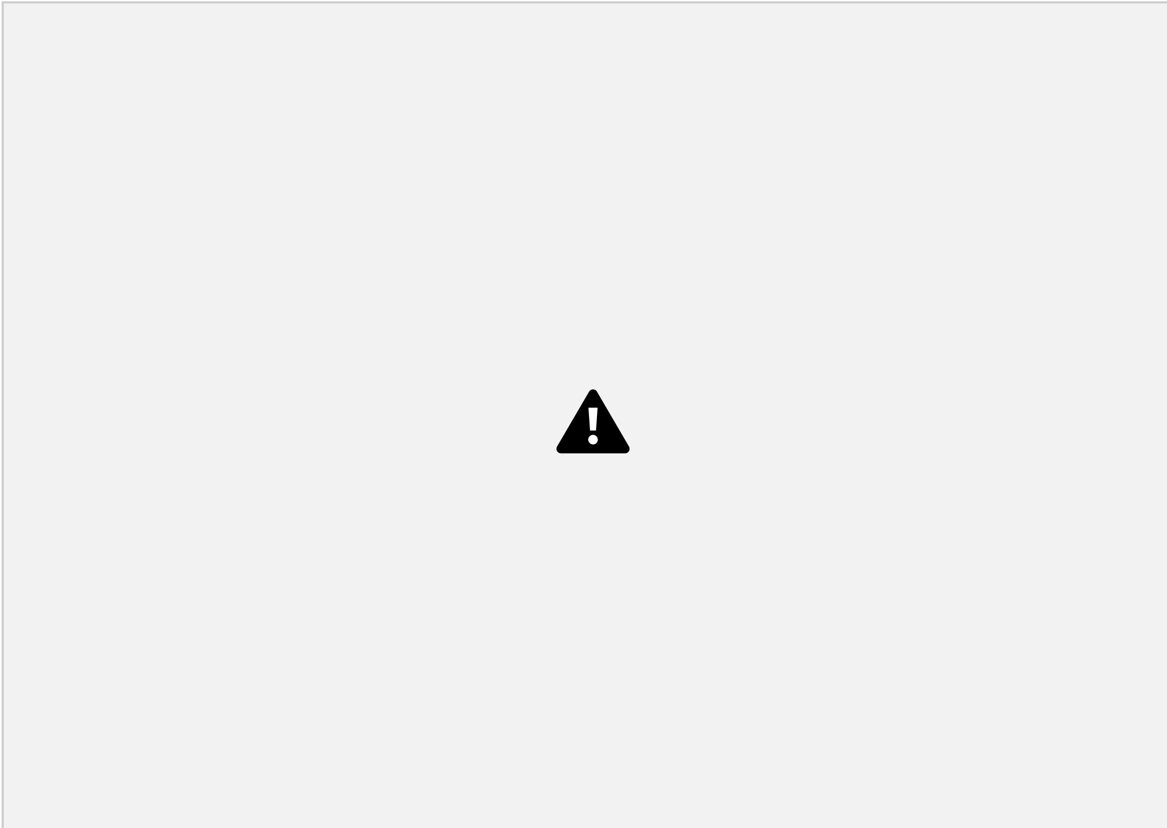

Figure 13 Soil erosion in the Todos Santos INEGI 2014 delegation.

Hydrographic characteristics: The Todos Santos delegation belongs to the RH3 Baja California Southwest Hydrological Region (Magdalena) and is part of Basin A, corresponding to the slope that drains into the Pacific Ocean (Conagua, 2020). This region is characterized by presenting rainy conditions in summer with low precipitation values and water scarcity, which are occasionally altered due to the presence of hurricanes. Therefore, the availability of water in the region depends on the five identified aquifers: La Matanza, Cañada Onda, Todos Santos, El Pescadero and Plutarco Elías Calles. To know the availability of water in the region and associate it with the population growth in the coastal zone, and the impact it could have on the coastal dune system, the aquifer data presented in table 3 were analyzed.

Table 3. Average annual availability of groundwater of the five aquifers of the Todos Santos Baja California Sur delegation in 2020. Own elaboration based on CONAGUA 2020. R: total annual average recharge; DNC: compromised natural discharge; VEAS: volume of groundwater extraction; VCAS: concessioned / assigned volume of groundwater; VEALA: volume of water extraction in the zones of provisional suspension of free birth and those registered in the Permanent National Registry; VAPTYR: volume of water extraction pending titration and / or registration in REPDA; VAPRH: volume of water corresponding to water reserves, regulations and programming; DMA: mean annual availability of groundwater.

Chart 3. Average annual availability of groundwater of the five aquifers of the Todos Santos Baja California Sur delegation in 2020. Own elaboration based on CONAGUA 2020. R: total annual average recharge; DNC: compromised natural discharge; VEAS: volume of groundwater extraction; VCAS: concessioned / assigned volume of groundwater; VEALA: volume of water extraction in the zones of provisional suspension of free birth and those registered in the Permanent National Registry; VAPTYR: volume of water extraction pending titration and / or registration in REPDA; VAPRH: volume of water corresponding to water reserves, regulations and programming; DMA: mean annual availability of groundwater.

CODE	AQUIFER			DNC VEAS				DMA	
				VCAS	V		VAP	VAPRI	PO NEC
		NUMBERS IN MILLIONS OF CUBIC METERS ANNUALLY							
311	LA MATANZA			2.6		0.00 0		0.00 0.	0
312	CAÑADA HONDA			2.8 1.8 0		0.00 0		0.00 0.	-0
313	TODOS SANTOS		18.4	14.7		0.00 0		0.00 0.	-1
314	EL PESCADERO			8.3 5.1 3.01715		0.00 0		0.00 0.	0
315	PLUTARCO ELÍAS CALLES			1.8		0.00 0		0.00 0.	-0

Surface runoff is of an intermittent type that generally disappears by infiltration towards the coastal plain, and surface runoff only occurs during the rainy season. **In the study area, 14 streams that flow into the sea**

are identified. Of these, the most important streams are Arroyo Grande, El Salado, El Palmar de Enmedio, El Salvioso and El Gazpareño (Figure 14).

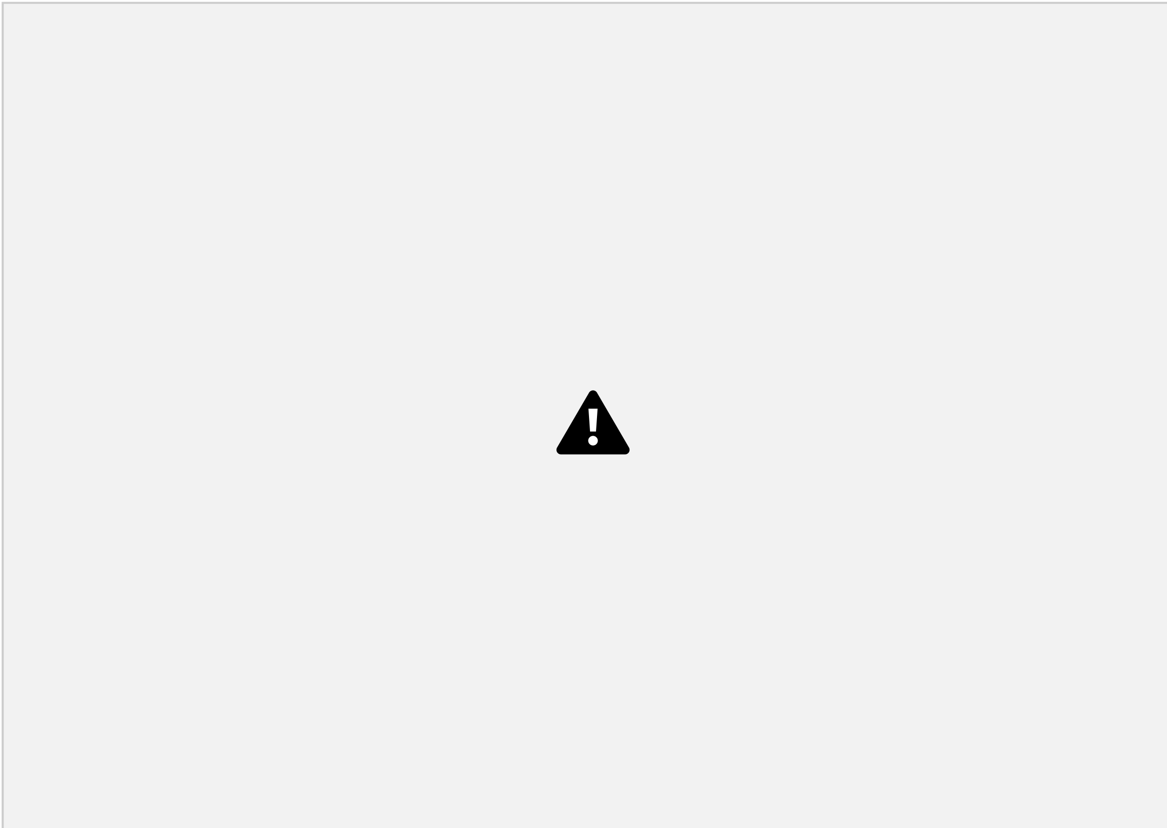

Figura 14 Hidrografía Todos Santos BCS INEGI 2021

Uses of soil and vegetation: The typical vegetation of the area corresponds to the *sarcocaule* scrub (Figure 15), characterized by an extensive richness of species of cacti, shrubs and low trees, mainly of the genre *Bursera*. The scrubland extends to the coastal area where the vegetation has been modified by agricultural activities. Agricultural activities are scattered since they are associated with the low plains and alluvial channels. Agricultural fields are identified in each of the coastal sections analyzed, but always behind the coastal dune system.

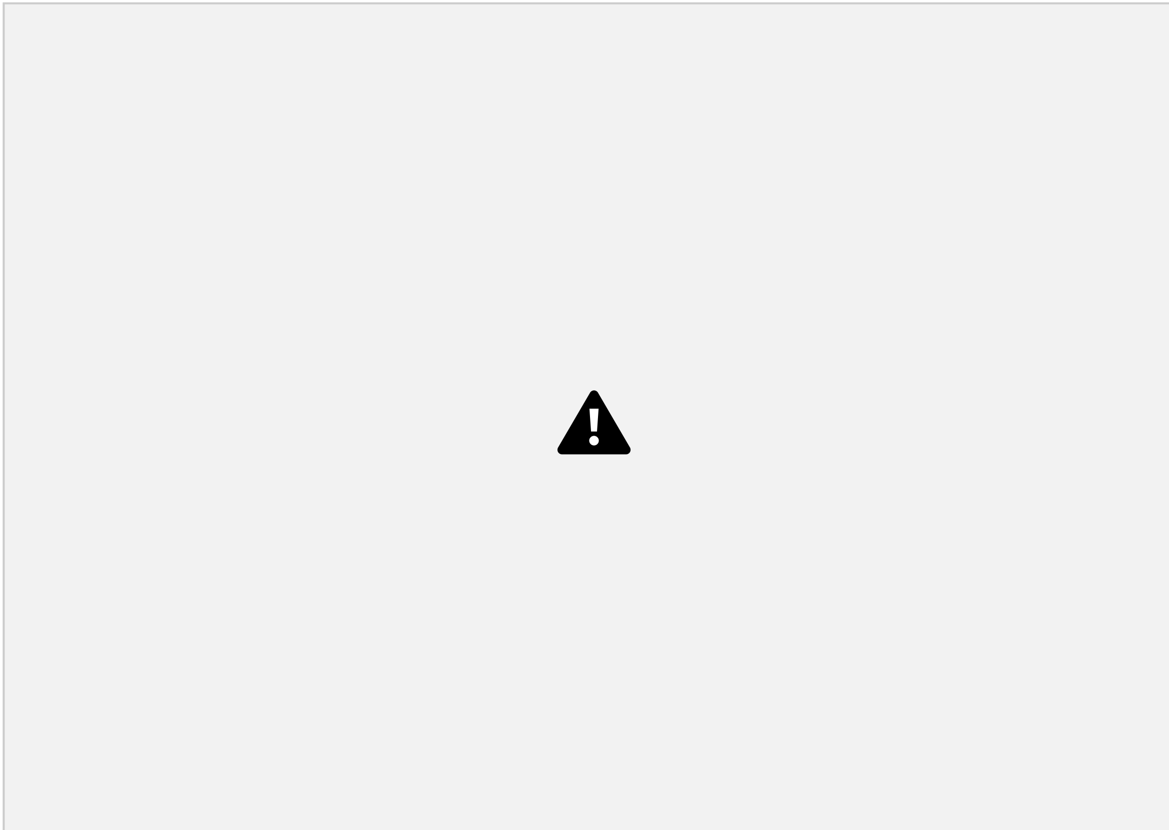

Figure 15. Uses of soil and vegetation, Todos Santos INEGI 2017 delegation..

Population: The Todos Santos delegation is made up of 128 towns (Figure 16), with a total of 12,717 inhabitants. The towns with the largest population are Todos Santos with 7185 inhabitants, El Pescadero with 4245 inhabitants, Cerritos with 128 inhabitants and Elías Calles with 111 inhabitants (Figure 17).

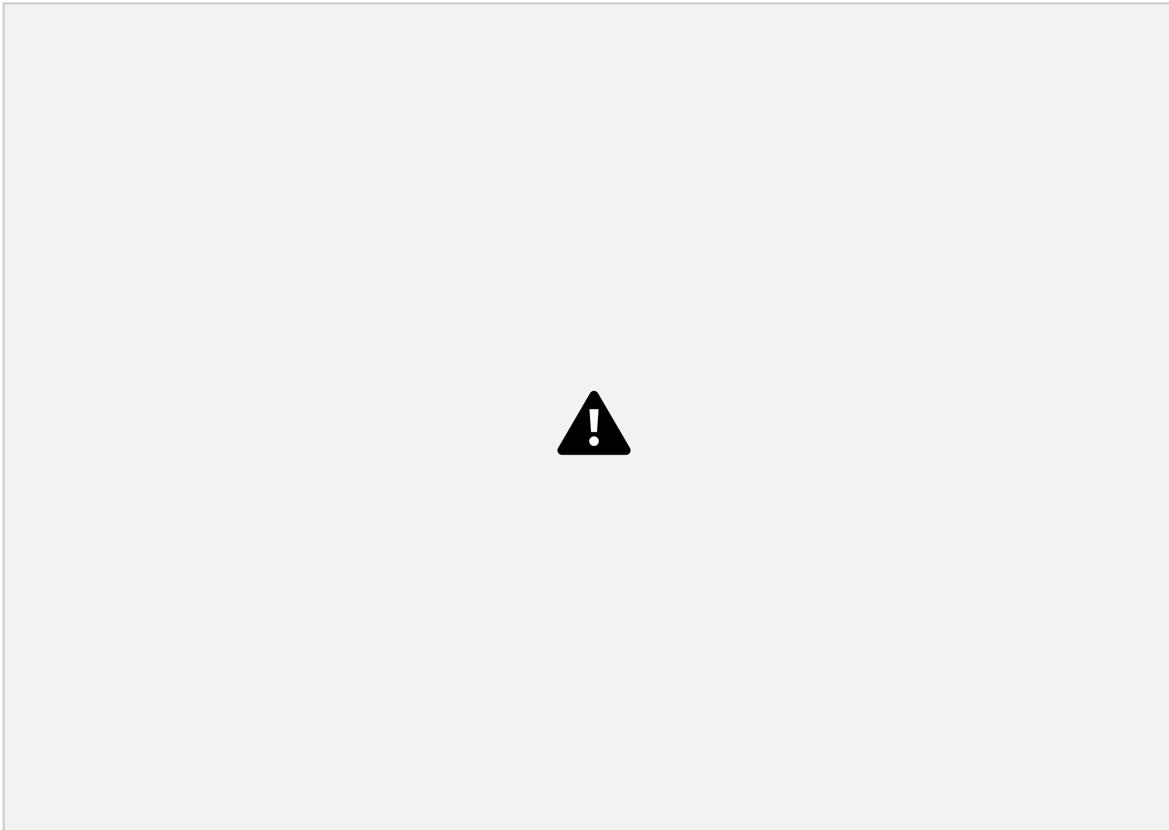

Figure 16. Number of localities and their population distribution by ranks of the Todos Santos, BCS delegation.

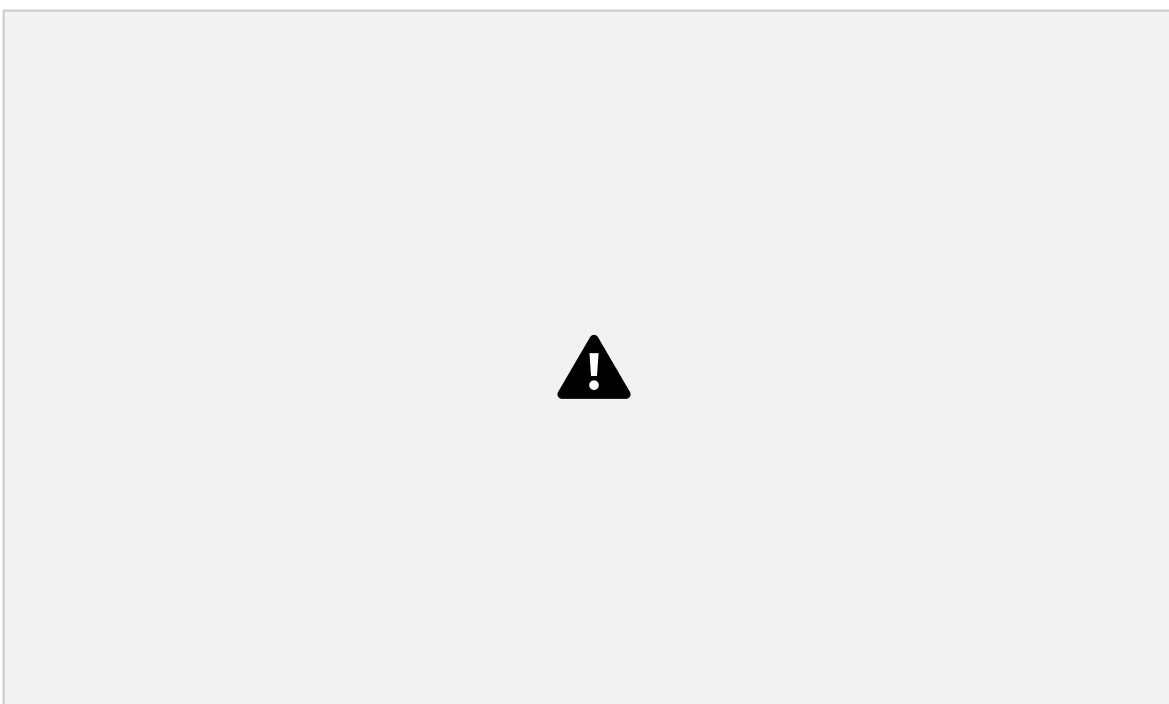

Figure 17. Distribution of the male and female population in the towns of the Todos Santos INEGI 2021 delegation

In 2006, the Ministry of Tourism recognized it as a "magic town" of Mexico. This has highlighted another attraction known as "cultural tourism"; **It is estimated that Todos Santos is visited, on average, by around 120 thousand visitors a year. However, the pristine and extensive beaches that the town has, have generated a real estate market to meet the demand for spaces for housing and the provision of services, not only for locals but for an extensive foreign market that sees Todos Santos as a retreat or business point. This real estate phenomenon is not only concentrated in the population center (which is approximately two kilometers from the coast) but has also spread to the dunes and beach area; as well as neighboring towns, belonging to the same delegation, such as El Pescadero and Cerritos. The foregoing is reflected in the population growth in the town of Todos Santos (Figure 18) and the density of houses in the limits or on the coastal dunes (Figure 19).**

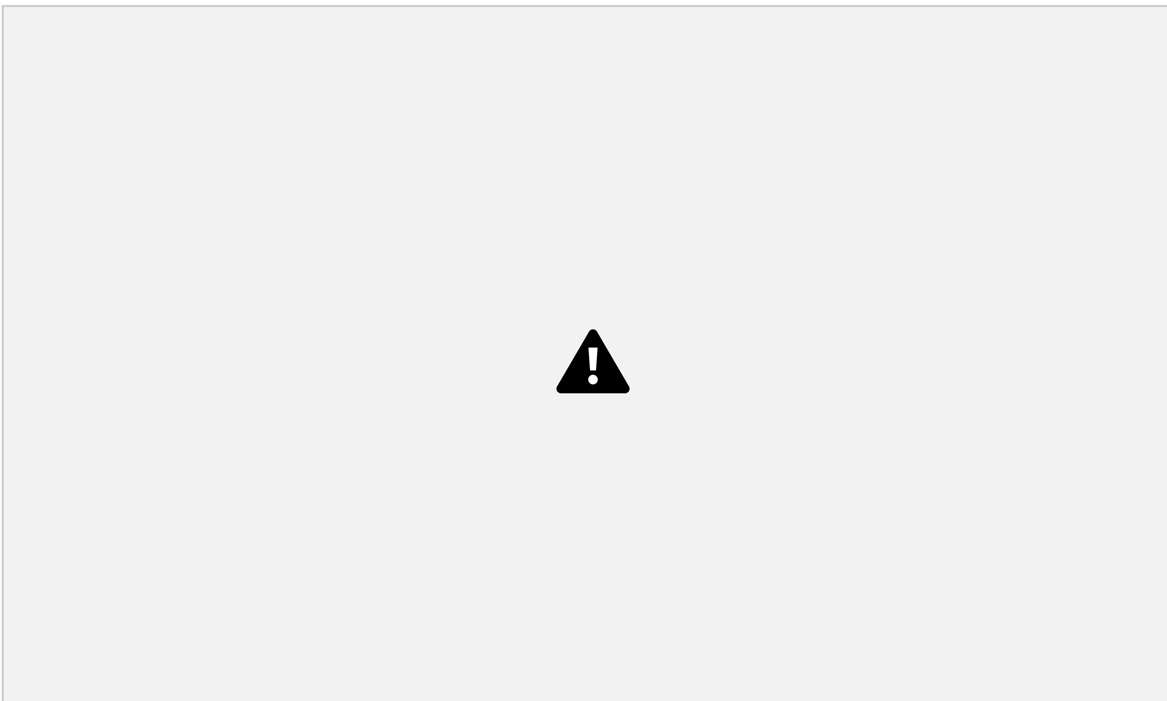

Figure 18. Population of the town of Todos Santos from 1990 to 2020.

97 infrastructures were identified, 37 of them in Cerritos, 31 in Todos Santos, 18 in El Pescadero and finally 15 in the town of Ejido Plutarco Elias Calles, most of which have distance ranges that go from 16-25 m, 26- 50 m and 51-100 m.

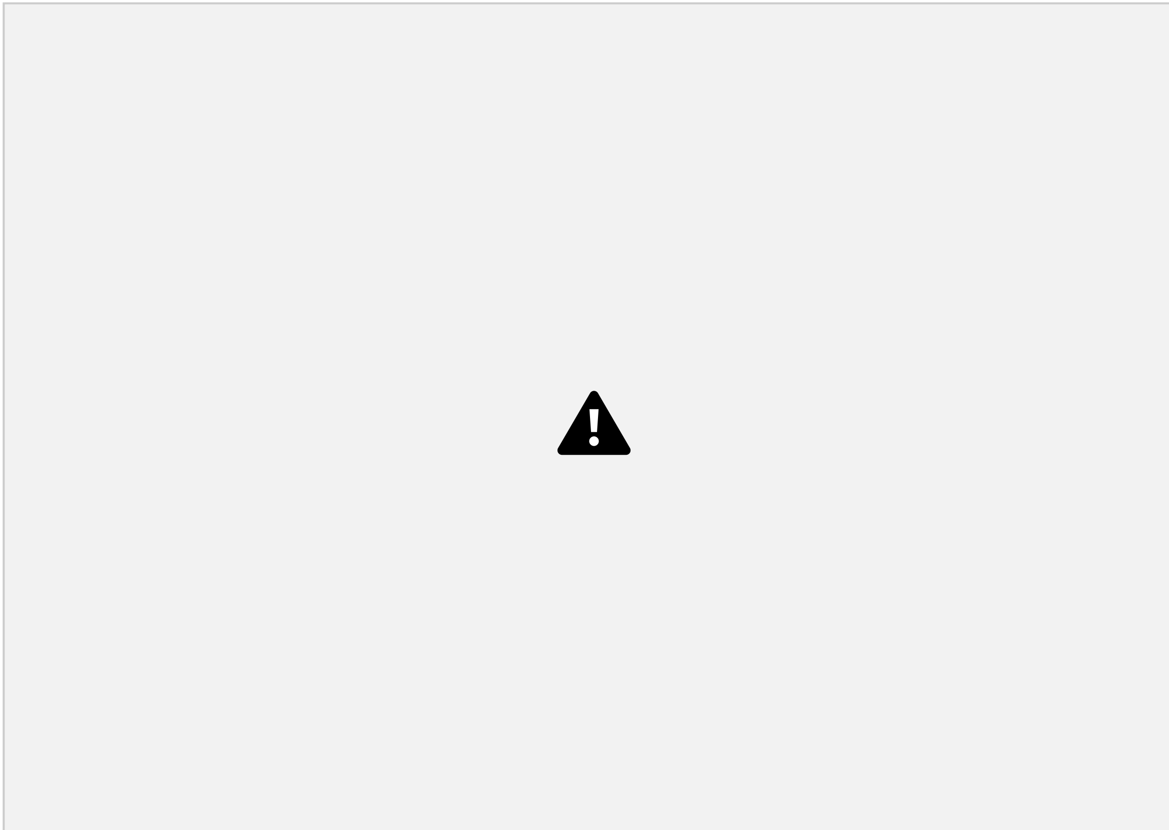

Figure 19. Infrastructure on coastal dunes and distance from the coastline.

Fauna: Photographic records were made of some species of birds (Figure 20) present during the vegetation sampling. In addition, according to the records stored in specialist platforms such as inaturalist (www.inaturalist.org) and Global biodiversity information facility (www.gbif.org) indicate the presence of a great variety of fauna in the analysis area. Next, the main records of fauna species located in the coastal zone, immediate to the coastal dunes of the study area, are listed; In Annex III you can find the complete list of identified species:

Birds: Aphelocoma california (californian chara), Callipepla californica (quail), Campylorhynchus brunneicapillus (macaw), Icterus cucullatus (calandria), Melanerpes uropygialis (woodpecker), Mimus polyglottos (cenzontle), Molothrus ateritostomaco (thrush), Toothpaste , Zenaida Asiatic (pigeon), Auriparus flaviceps (baloncillo), Calypte costae (hummingbird), Passerina amoena (bunting), Polioptila caerulea (pearlite), Sayornis nigricans (flycatcher), Cardinalis cardinalis (northern cardinal), Circus hudsonius (creeping hawk) , Caracara cheriway (face face), Geococcyx californianus (roadrunner), Haemorhous mexicanus (finch), Egretta thula (heron), Ardea alba (white heron), Ardea herodias (gray heron), Pandion haliaetus (osprey), Charadrius semipalmatus (plover), Actitis macularius (alzacolita), Larus delawarensis (ring-billed gull), Larus occidentalis (western gull).

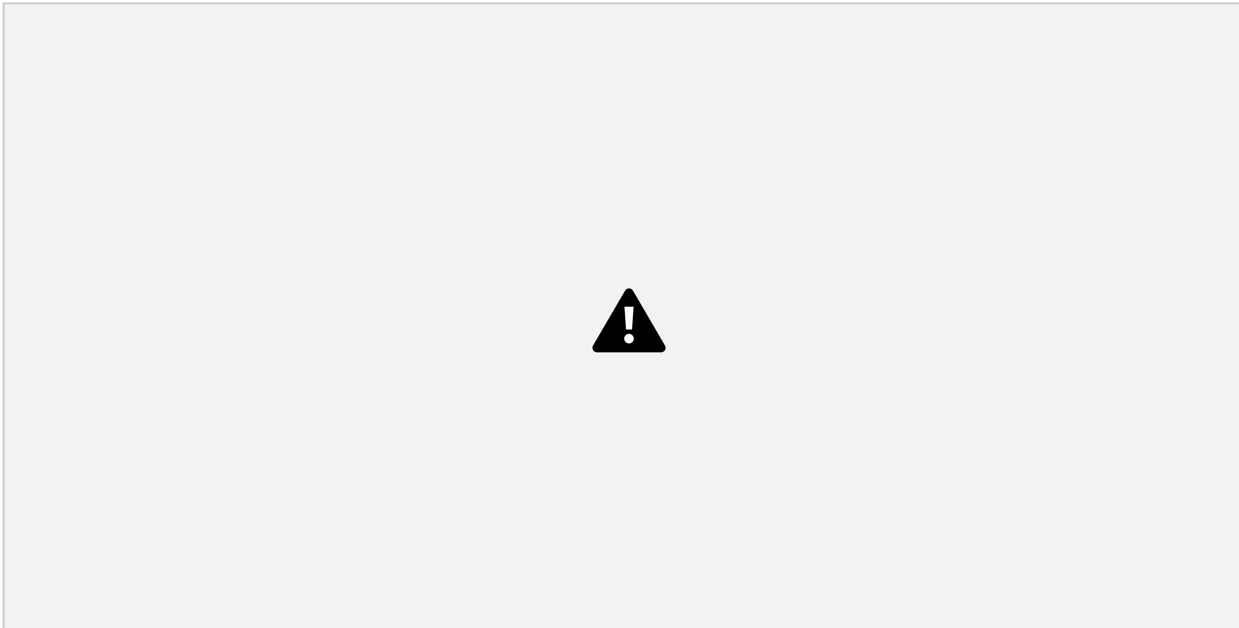

Figure 20 Some of the bird species registered in the Todos Santos delegation, Municipality of La Paz, Baja California Sur.

Reptiles and amphibians such as: Chelonia mydas (brown sea turtle), Lepidochelys olivacea (olive ridley sea turtle, Aspidoscelis hyperythrus, Dipsosaurus dorsalis, Hypsiglena ochrorhynchus, Hemidactylus frenatus, Lampropeltis californiae, Anaxyrus punctatus and Scaphiopus couchii.

Small mammals such as: Ammospermophilus leucurus, Chaetodipus spinatus (Baja California pocket mouse) and Neotoma bryanti (Coronados Island trade rat).

Insects: The coastal dunes of Todos Santos in the municipality of La Paz are the habitat of various arthropods such as bees, wasps, flies, crickets, spiders, beetles, moths and bedbugs. This dune system lends the SE of refuge to a great variety of species of beetles, to mention a few, the beetles of the genre Eusattus are specialists of sandy soils, because they need this type of sandy substrate to be able to bury themselves and take refuge from the high surface temperatures. We can also find individuals of the Scarabaeidae family such as the Tomarus gibbosus (carrot bettle) species, this species belongs to the group of rhinoceros beetles, as well as beetles of the Agriotes genus (wireworms) inhabit clay-sandy soils and generally in their state. larvae are found under leaf litter rocks (Costa et al., 2010), these beetles present a pair of luminous organs on the thorax, emitting a flash that the male uses to attract the female (Johnson, 2002). The species Apis mellifera (honeybee) is also found in large numbers in the flowering season, as well as wasps of the genus Pepsis.

IV.2. Granulometric analysis

Based on the statistical parameters of 37 sediment samples, the following was determined: 1.Frequency curve: It is obtained with the data of the percentage by individual weight (Fig. 21):

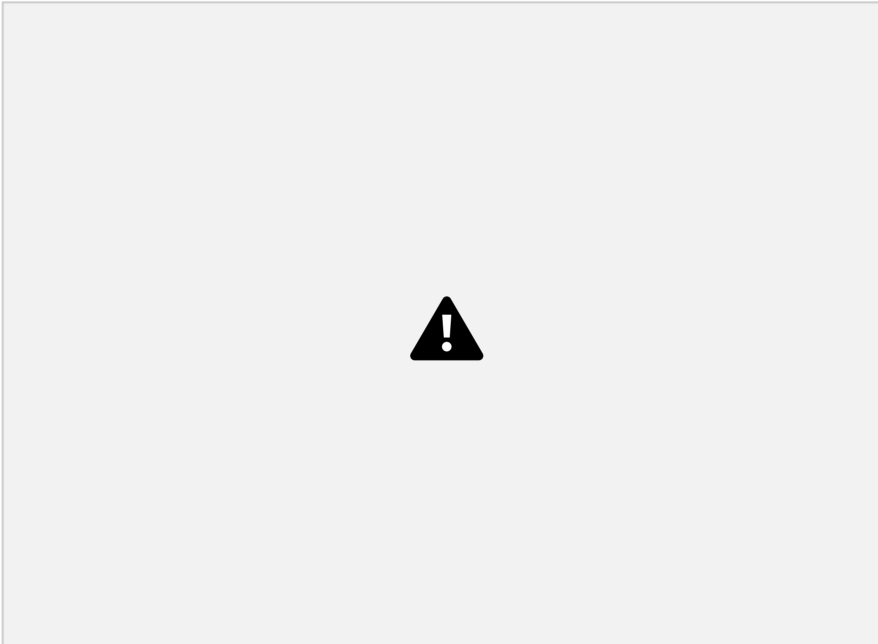

Figura 21. Individual frequency curve

In this graph you can see the shapes of the frequency curves, that is, the kurtosis. The leptocurtal forms dominate. This means that the samples have a better draw under the curve and not to the side. Two samples to the left are also observed that present platicurtic and bimodal forms, that is, they present two populations of grain size, this behavior suggests a contribution of material from another source, possibly a nearby stream, which causes a poorer sorting and a wider grain size distribution. Towards the right, two mesocurtic curves can be observed but with good sorting with a slight tendency towards fine grains, possibly those sites are more exposed to greater energy from the environment, which decreases the grain size.

In general, this graph indicates that all samples approximate an average grain size of 1.00 phi (0.5 mm), that is, medium sand, but with a clear trend towards coarse grains and low to no fine grain content.

2. Frequency curve of cumulative weight percentage that passes through each sieve: It is obtained with the cumulative weight percentages for each fraction (Fig. 22):

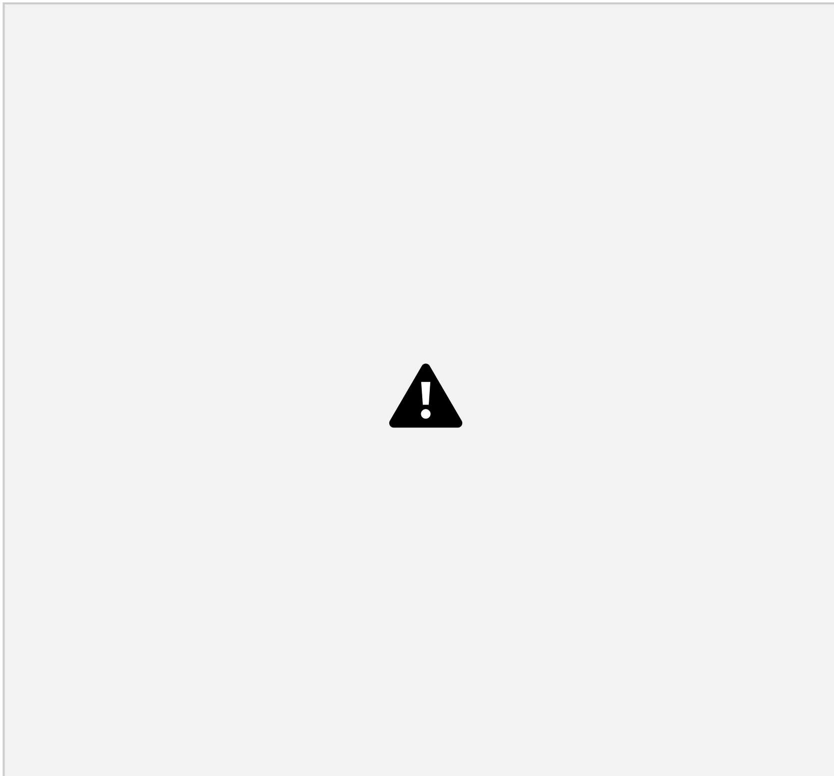

Figure 22. Curve of cumulative frequencies that pass through each sieve.

This graph clearly shows how most of the samples are sand sized with a strong tendency towards coarse grains. It can be seen how the curves widen to the left with higher percentages of coarse grain, while to the right the curves narrow, showing a much lower percentage of fine grains. It is also observed that the curves are very vertical, which indicates a reduced variability in the distribution of grain sizes, that is, they show a good sorting of particles.

From an engineering point of view, for a better definition of the granulometry, the uniformity coefficient and the curvature coefficient are used.

a. Uniformity coefficient c_u

It is defined as the ratio between the diameter corresponding to 60% of the weight of the material and the diameter through which 10% of the material passes:

$c_u=d_{60}/d_{10}$.

If the uniformity coefficient is less than five, the granulometry is uniform, (well to moderately well graded), if it is between five and 20 the soil is not very uniform (poorly graded) and if it is greater than 20 it is a well graded soil. graded (very poorly drawn).

The value of this coefficient is less than five in the 37 samples analyzed, which confirms that they have a uniform granulometry.

b. Curvature coefficient c_c

It is defined as the ratio of the diameter (D30) 2 between the product of the D30 and the D60 and measures the degree of curvature of the particle size:

$c_c = ((D_{30})^2 / (D_{10} \cdot D_{60})$

A well-graded floor will have a lower percentage of pores and therefore will have a higher density, they will be less compressible, more impermeable, and easier to work on site.

c. Fine content

As mentioned above, it is defined as the percentage that passes the sieve No. 200 ASTM or 0.008 UNE and measures the content of fines, proportion of clays and silts. It indicates the degree of water retention, the higher the value, the greater the difficulty of expelling the water under stress (undrained behavior of the materials).

3. Statistical parameters

The mean grain size indicates that, of the 37 samples analyzed, 32 falls in the range of coarse sands with a value of approximately 1.0 phi (0.5 mm), while the rest, that is, five samples are medium sands. Regarding the draw, it is observed that 36 samples present moderate draw and only one sample was poorly drawn. Regarding asymmetry, five samples presented positive asymmetry, one extremely negative and the rest were approximately symmetric. This means that most samples approximate a normal population where the kernels are in a narrow range of kernel size and an exceptionally low standard deviation, and with a tendency towards coarse kernels, but with a very uniform kernel size.

From an engineering point of view, for a better definition of the granulometry, the uniformity coefficient and the curvature coefficient are used.

a. Uniformity coefficient c_u

It is defined as the ratio between the diameter corresponding to 60% of the weight of the material and the diameter through which 10% of the material passes:

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If the uniformity coefficient is less than five, the granulometry is uniform, (well to moderately well graded), if it is between five and 20 the soil is not very uniform (poorly graded) and if it is greater than 20 it is a well graded soil. graded (very poorly drawn).

The values of the 37 samples analyzed had values lower than five, which means that the material is very uniform, that is, it presents good grain size grading.

b. Curvature coefficient c_c

It is defined as the ratio of D30 between the product of D10 and D60, and it measures the degree of curvature of the particle size:

$c_c = ((D_{30})^2 / (D_{10} \cdot D_{60})$

A well-graded soil will have a lower percentage of pores and therefore will have a higher density, they will be less compressible, more impermeable, and easier to work on site. A well-graded material will have Cc values greater than three and less than 1, that is, 1 <Cc> 3.

In this case, the Cc values for the 37 samples oscillate between 0.98 and 0.80, which indicates that the material presents a poor gradation of grain size.

c. Fine content

It is defined as the percentage that passes the 200 ASTM mesh (0.063 mm) or 0.008 UNE and measures the content of fines, proportion of clays and silts. It indicates the degree of water retention, the higher the value, the greater the difficulty of expelling the water under stress (undrained behavior of the materials).

As can be seen in the results, the 37 samples studied have an exceptionally low to zero content of fines.

4. Conclusion

Based on the results of the granulometry, these sands are characterized by an important deficiency of fine grains and a higher percentage in the content of coarse grains, falling in the range of coarse to medium sands, with good sorting and therefore little gradation of grains. This results in sands lacking in cohesion and therefore not suitable for building on them, as they represent a loose sediment in constant movement. In addition, they present high deflation, that is, they are easily removable, transported and reworked by the wind, which can generate undermining, encroachment on patios and houses, instability of pavements and installation of electrical and telephone lines.

It can also cause soil settlements due to humidity (subsidence due to compaction or mobilization of the sandy subsoil associated with seepage and irrigation); foundation failure, wall cracking and skew of structures (door and window frames).

IV.3. Flora

90 species were recorded in the 38 vegetation samplings (Table 4). Nine species are common because they are found in more than 50 percent of the sampled transects; of these, J. pilosa and E. leucophylla are found in 35 of 38 transects, J. cinerea in 33, M. marina in 28, C. cholla in 25, O. drummondii and L. brevipens in 24, M. phyllanthoides in 21, S. halimifolium and Physalis glabra in 20 transects; 27 species are found between 20 and 45% of the transects; and the remaining 64 species were found in less than 20 percent of the sampled transects. Of the latter, 32 species were only recorded once, since they are exclusive species of the scrubland.

Common species on **embryonic dunes and leeward slopes** are: J. pilosa, I. pes-caprae, E. leucophylla, M. maritima, and O. drummondii. J. pilosa forms a vegetation cover whose ecological function for fixing dunes is extremely important. Their roots are much larger than their creeping stems and they support continuous sand burial, which is why they are the sand fixers par excellence on the beaches of Todos Santos.

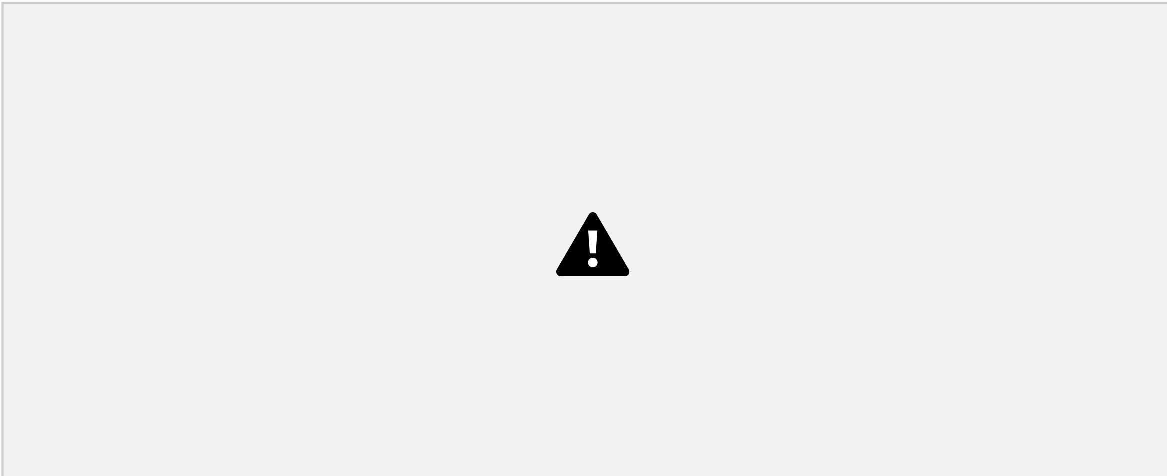
J. pilosa, M. maritima, small shrubs of J. cinerea, are found on **the ridges or tops of the dune cord**. It is natural to find fewer species on the ridges due to the force of the wind and the salinity of the breeze that it carries. However, in some of the sampled sites where the dunes are very narrow, the dune crest is stabilized by shrubs such as C. globosa and M. phyllanthoides.

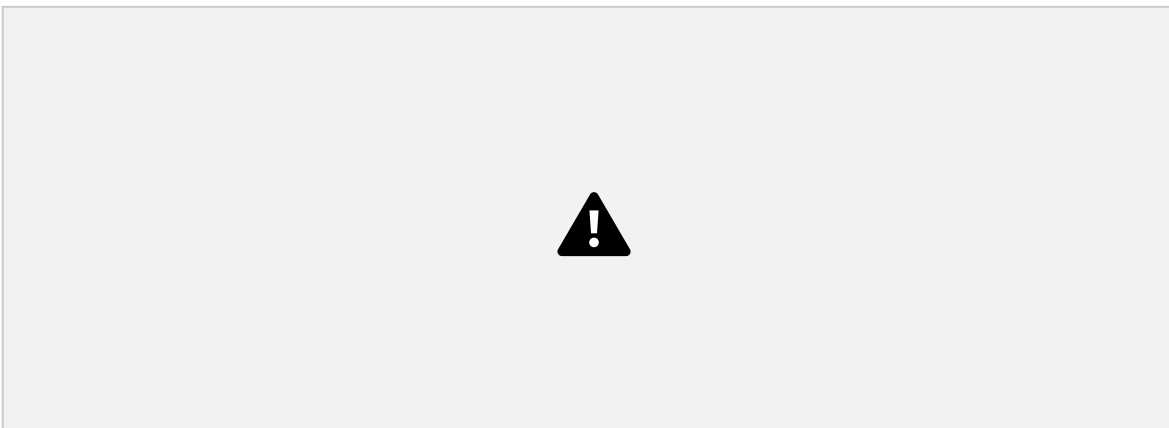
The **windward slopes** are dominated by J. cinerea, C. globosa and M. phyllanthoides and some isolated individuals of cacti. The scrub on the hillside is denser and diverse in species. Some sections of the dune cordon present an important transition zone with other ecosystems, or they are in an advanced process of ecological succession, they have a higher dune cordon and well

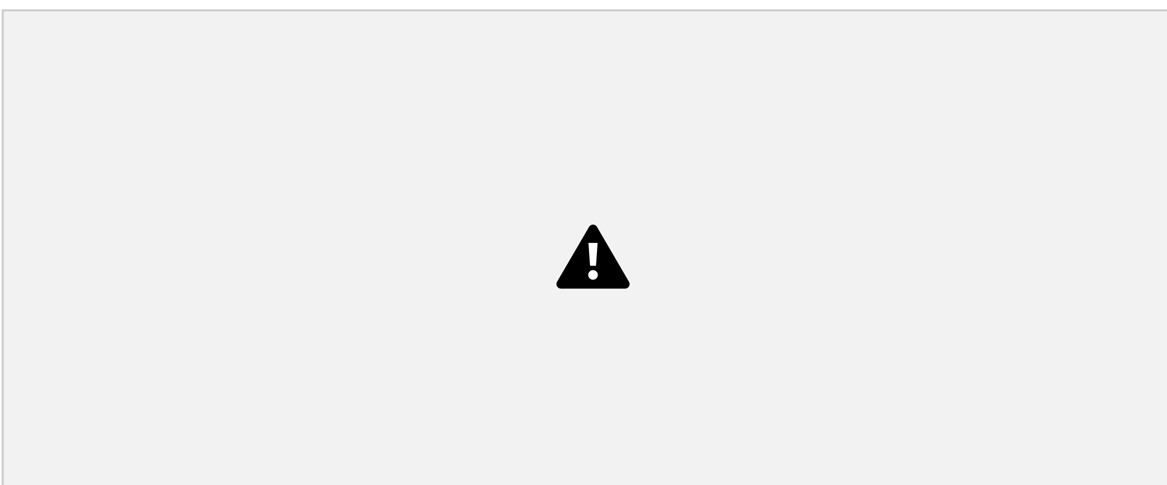
conserved scrub, so there is greater floristic richness and species of large shrubs, shrubs and cacti typical of other types of vegetation (for example, Bursera microphylla, Bursera hindsiana, Mammillaria armillata, Pachycereus pringleii, among many others).

In addition, in some cases the dune cordon borders a wetland, so the species found in the transition zone correspond to more humid habitats and there are halophyte species (for example, Salicornia pacifica, Allenrolfea occidentalis and Batis maritima of marshes and salt marshes and Conocarpus erectus typical of the mangrove). These plant associations of marshes and salt marshes are found in the extreme northwest of the Todos Santos coastline, the extreme southeast of Cerritos, and in Elías Calles where the coastal dune cordon is better preserved because there are still no massive constructions behind it.

Table 4. List of the flora of the dunes of the Todos Santos delegation, municipality of La Paz, BCS. Is highlighted.







It is interesting to note that the floristic diversity as a whole and especially of the main species of dunes on the beach and dune cord, remain the same as Johnson (1977) and Pérez Navarro (1995) described in their works. On this occasion, due to the intensity of the sampling and the number of profiles (38 instead of two), the list shows a significantly higher richness (in some cases twice as many species). **The interesting thing is that, in essence, floristically the dune cord has not changed in the almost 50 years that it was sampled for the first time (1972), neither in its topography nor in its floristic diversity. This indicates that the conservation measures that have been carried out have managed to maintain the floristic biodiversity and**

the geomorphology of the dune cord. This has been achieved, despite the hurricanes that have occurred and the constructions (houses and roads) behind the dune cordon. This is especially important because it also means that, as a whole, in the cordon of dunes, the ecosystem services that the dunes provide to the community of inhabitants of Todos Santos are not lost. However, the threat of its destruction is already evident when counting around 100 constructions on the dune cordon and gaps that fragment the vegetation of the dune cordon.

IV.4. Vegetation gradients

Figure 29 represents the most common profile found in Todos Santos, BCS. The coastal beach dune system begins with an extensive beach, which is constantly modified by the waves (strong); In the beach profile it is common to find an erosive escarpment up to one meter high, especially on beaches with stream mouths (due to the wind dynamics of the mouths). The beach may or may not have vegetation, when there is vegetation, it is I. pesca-prea, E. leucophylla (individuals scattered on the beach) and J. pilosa (Figure 23).

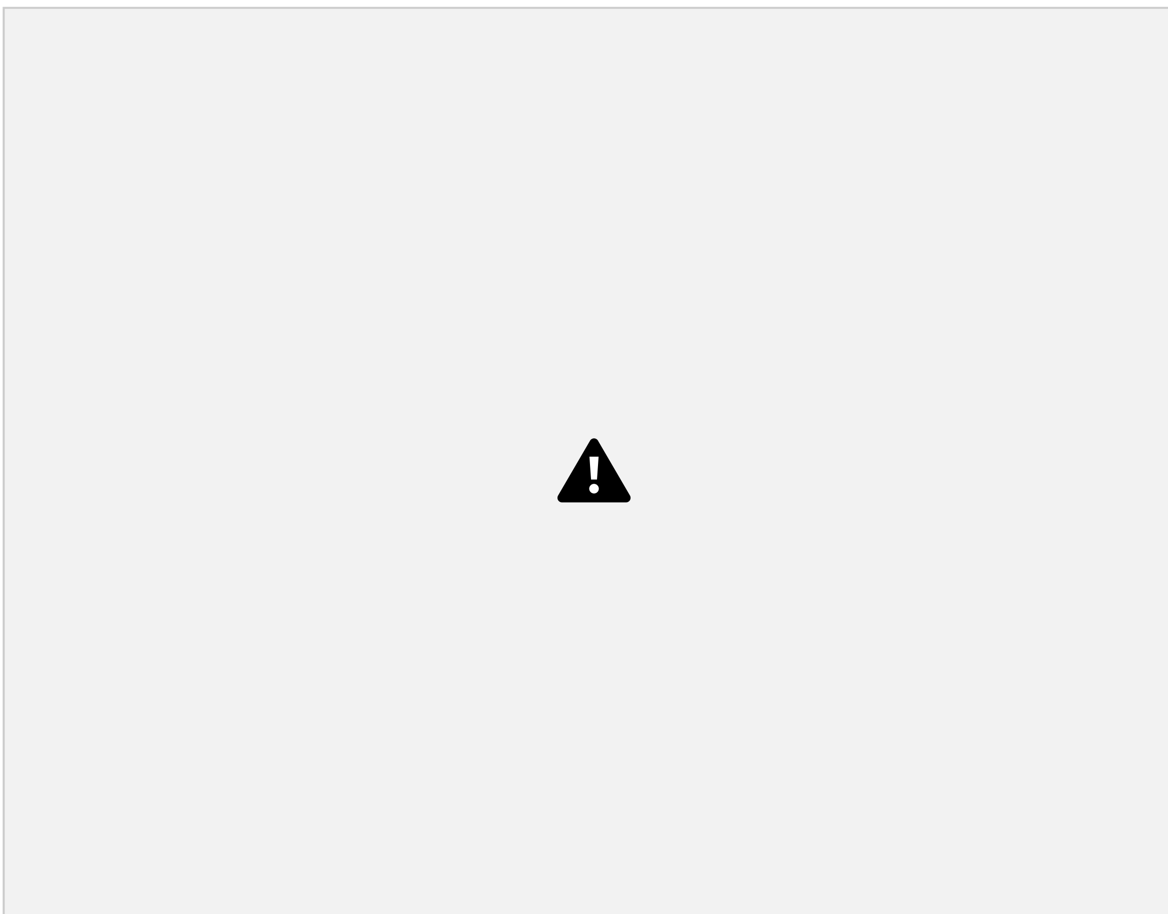


Figure 23. Location of the main plant species in the beach area of the coastal beach-dune system.

Embryonic dunes occur in two main geoforms: 1) scattered mounds on the beach, mainly built around O. drummondii; 2) as a narrow low elevation strip that merges with the frontal dune, this strip is almost always covered with J. pilosa or P. linearis (Figure 24).

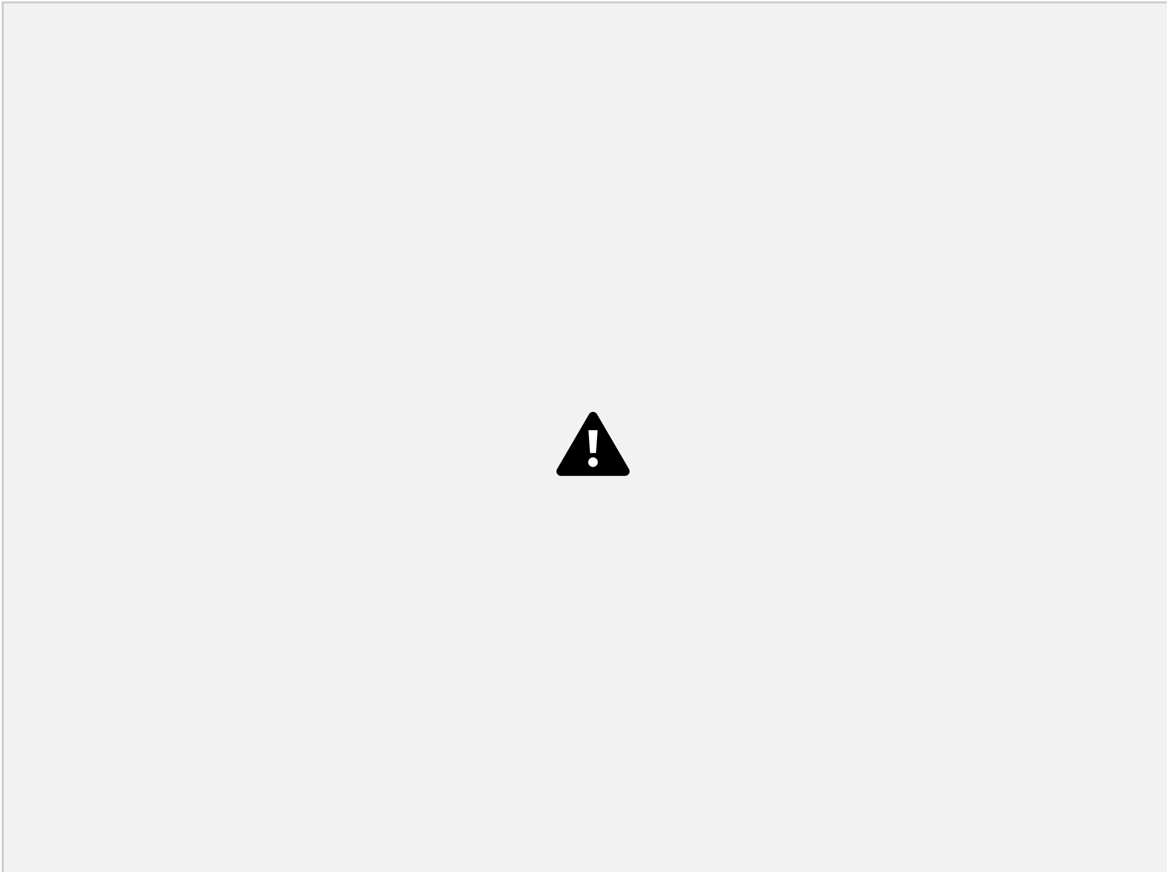


Figure 24. Location of the main plant species in the embryonic dunes.

The frontal dune cordon begins with a wind-eroded windward front; the slope of this slope is medium, and patches of J. pilosa are observed in association with M. maritima. Wind erosion forms what is known as "blowauts"(voladuras). Blasting occurs naturally from wind erosion on the frontal dune, which forms wind channels, through the windward face to the crest or where there is a reduction in vegetative cover, thus decreasing local roughness and increasing drag potential. sediment (Figure 25, 26).

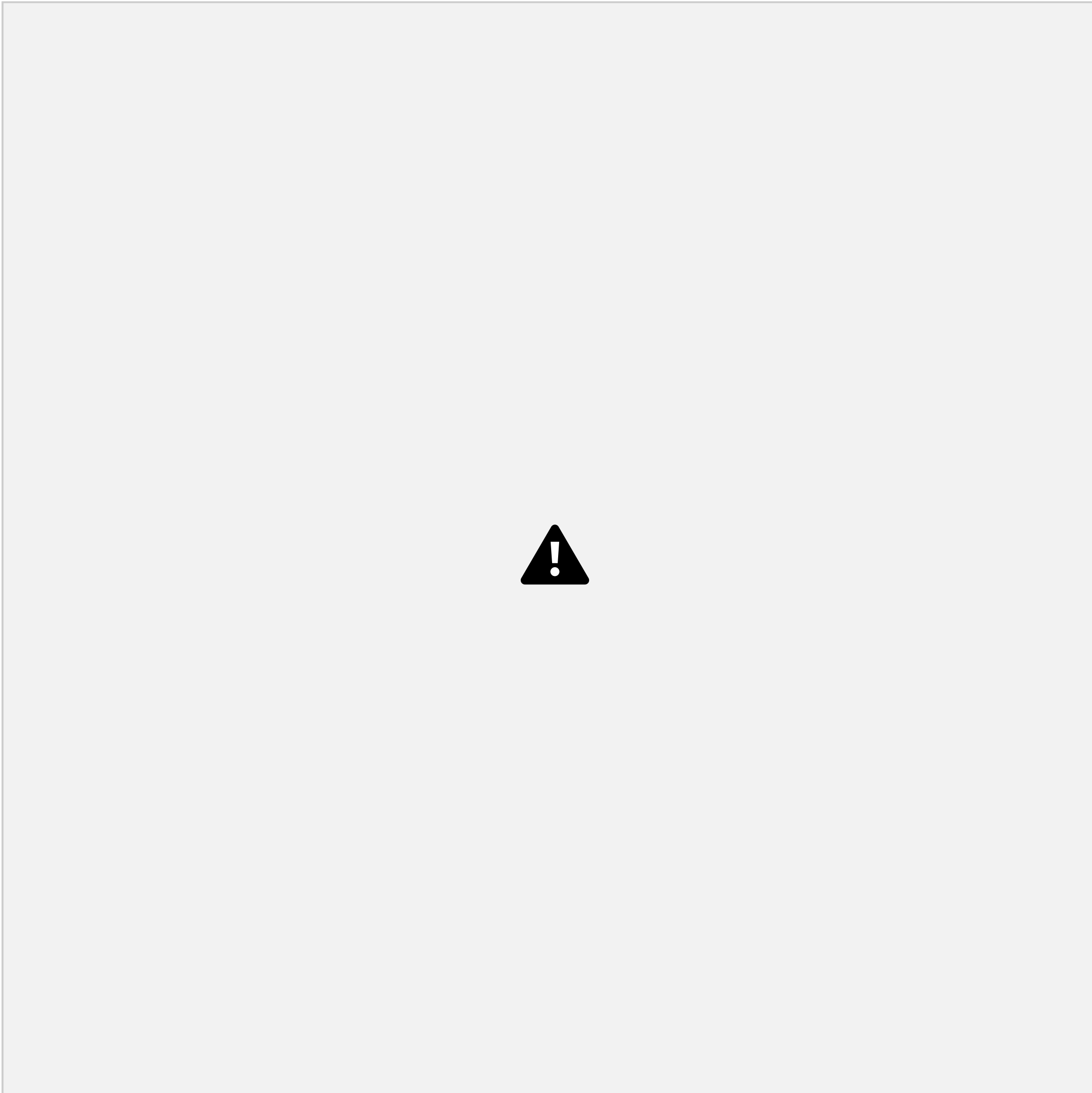


Figure 25. Characteristic profile of the coastal dune cord (a). Wind erosion occurs on the windward face of the frontal dune, causing erosion of the dune front and activating sand movement (b), which can be seen in figure 25. Taken from Hesp 2002.

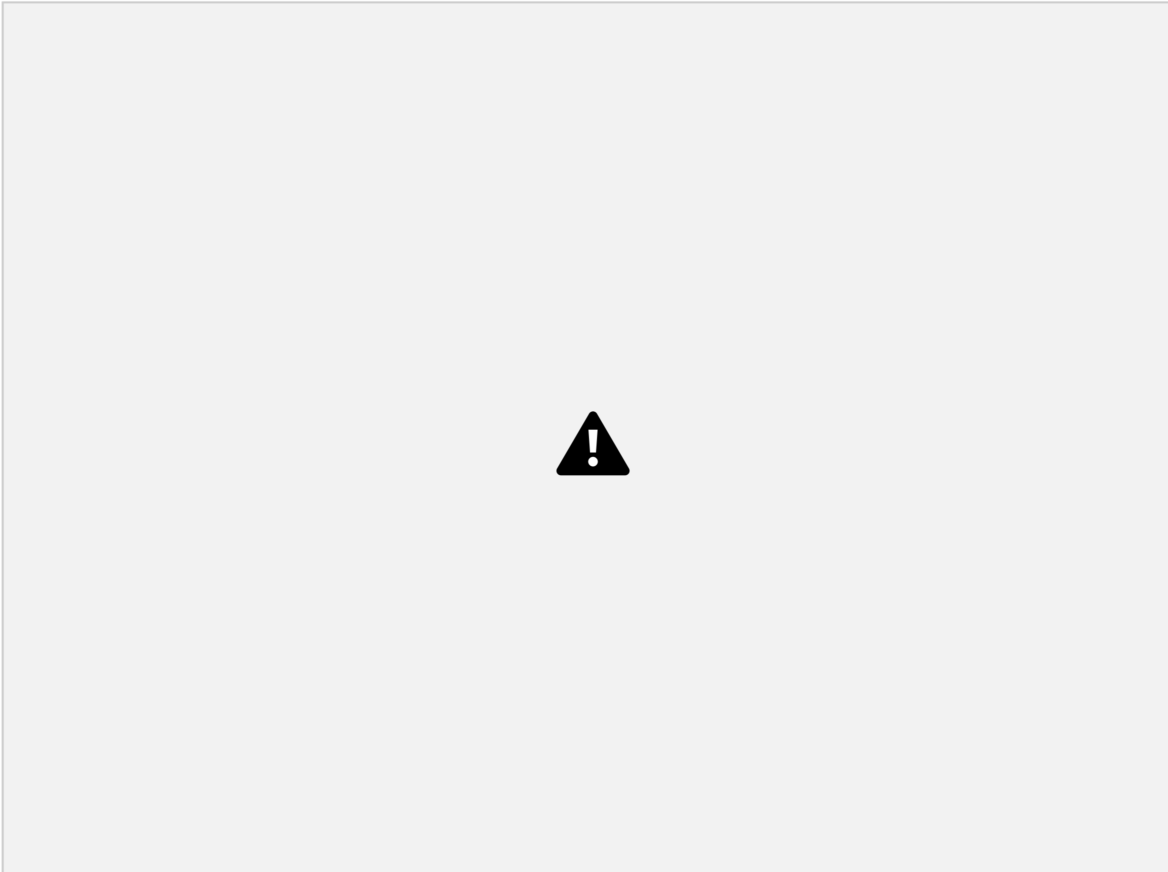


Figura 26. Location of the main plant species on the windward face (sea front) of the frontal dune.

The crest of the dune is narrow, and presents two types of geoforms, which are related to two types of plant association:

1) In the first case the crest of the dune is covered by a dense thicket, almost always of C. globosa and / or M. phylanthoides and / or L. brevipes, and is followed by a narrow leeward slope that is covered with scrub species, mainly J. cinerea, J. californica and diversity of cacti (Figure 27).

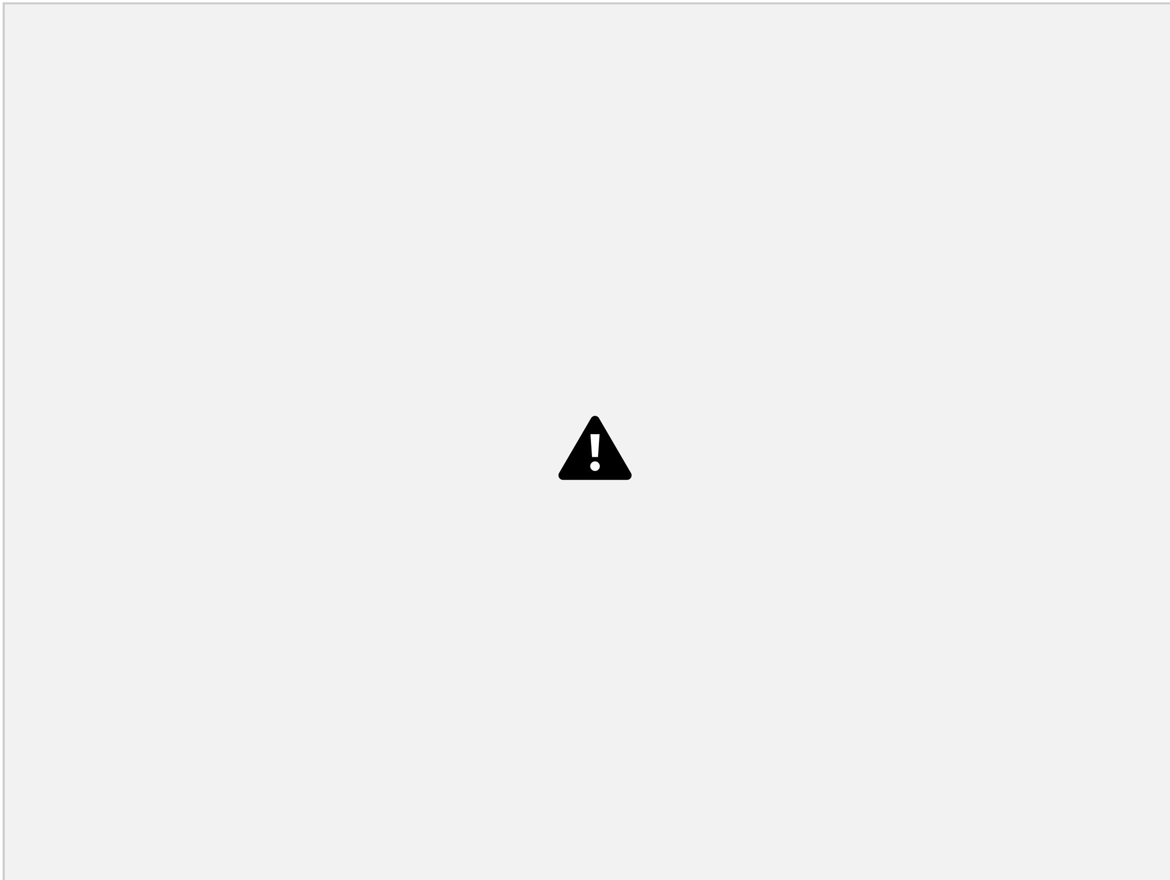


Figura 27. Location of main plant species on the ridge and lee side of very narrow frontal dunes, where scrub species have established on the dune.

2) the second characteristic case is a broad leeward slope that gently slopes down until it meets the transition zone of scrubland; On the hillside, the association of J. pilosa and M. maritima is recognized (M. maritima is mimicked with J. pilosa, and its extensive coverage is only observed directly at the site). Scattered individuals of J. cinerea, A. subulata, Bebbia atriplicifolia and C. cholla are found on this type of slope. When this type of slope ends in scrub, the most frequent species are A. leptopus, S. halimifolium, E. confinis and C. edulis (Figure 28).

1)

Figure 28. Location of the main plant species on the ridge and an extensive leeward slope in frontal dunes, where the scrub species are an indicator of the transition zone between the coastal dune and the scrub. The morphometric characteristics of these scrub species, which are found on the dunes, are very different from the characteristics that the same species present in the scrub, since different microclimatic conditions are presumed to exist.

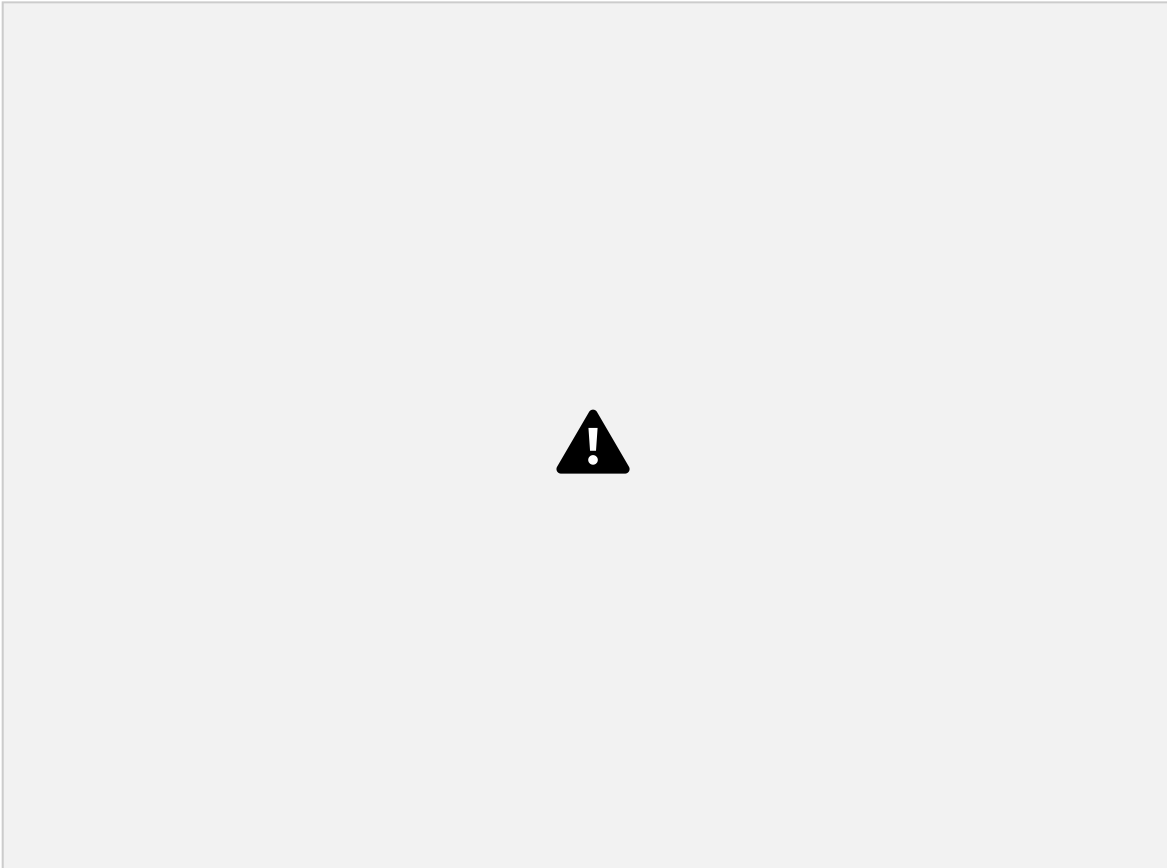


Figura 29. Average profile of the Todos Santos dunes; the frontal dune, which forms a single cordon, slopes steeply on the windward slope and gently slopes on the leeward slope.

IV.5. Todos Santos

IV.5.1. Agua Blanca-Playitas

The average width of the profile is 120 m between 9 and 10.3 m in height. The frontal dune is flanked towards the sea by a clear strip of embryonic dune, a beach and the intertidal strip and inland, the dune ends in a transition strip of dune and scrub vegetation followed by a strip of well scrub. conserved.

68 species of plants were found. The distribution of the vegetation on the dunes generally begins with I. pes-caprea on the beach, E. leucophylla dispersed together with P. glabra; in embryonic dunes it begins with scattered patches of O. drummondii followed by the dominance of J. pilosa; on the windward slope, top and leeward slope, J. pilosa is already dominant (it covers more than 90% of the dune) and is associated with M. maritima. Two well-established frontal dune cords can be seen on this dune. On the lee side of the second cordon, a strip of J. cinera is observed, which is immediately followed by C. globosa, J. californica, E. ebano and S. halimifolium. The latter indicate the end of the dune system through a transition zone with the scrub. It is important to identify this
transition zone, since the composition and arrangement and size of the species differ from their location in the scrub. Figures 30 and 35.

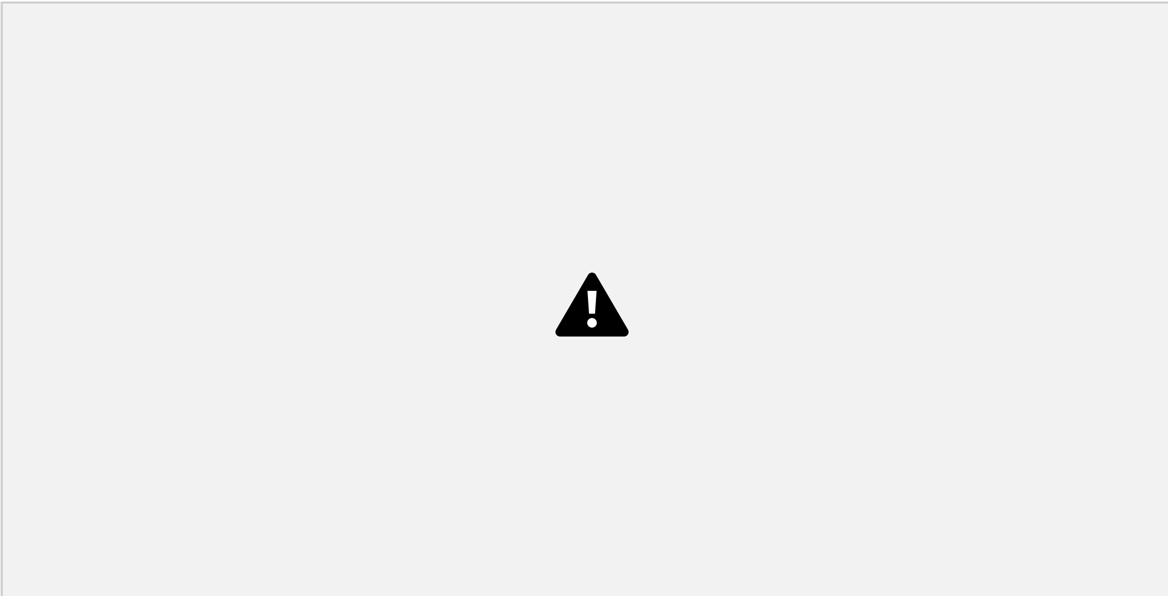


Figura 30. Dunas Agua Blanca-Playitas~~Paalyitas~~ (Todos Santos)..

This coastal dune system is the most extensive, wide, and best preserved of all the coastal dune systems visited for this study. In addition, it is one of the few where you can see a second well-defined dune cordon.

In the extreme southwest, this system borders an alluvial system. The alluviums are extensive areas of intermittent river currents. This system is very important because it is the main contribution of sediments to the coastal beach-dune system of the region.

Observed impacts

● Fragmentation of the system by parcel division, indicator of future subdivision (Figure 31). ●

Overgrazing (Livestock) (Figure 32 and 33).

● Agriculture, behind the coastal dune.

● Fragmentation by accesses (sidewalks, paths) (Figure 34).

● High vehicle traffic on the beach and embryonic dunes.

● Infrastructure (houses, on and behind the dunes).

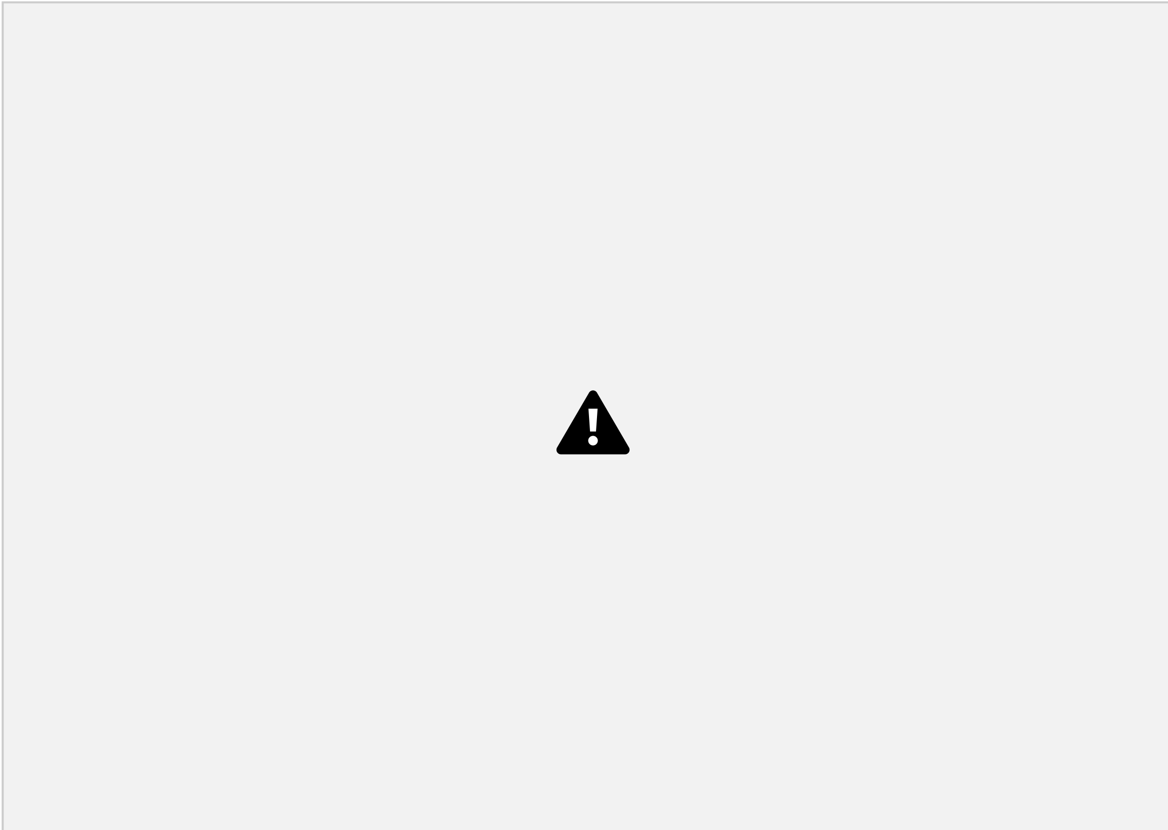


Figura 31. Fragmentation of the system by parcel divisions.

Overgrazing. The main current pressure facing the dune system is livestock (mainly cattle and goats). Cattle have contributed to the successful dispersal of the main dominant plant species, and excessive browsing of coastal dune plant species. During the tour it was possible to observe the impact of browsing on M. maritima, a species of coastal dunes that, although it supports excessive browsing, could be eliminated, in the future, by overgrazing.

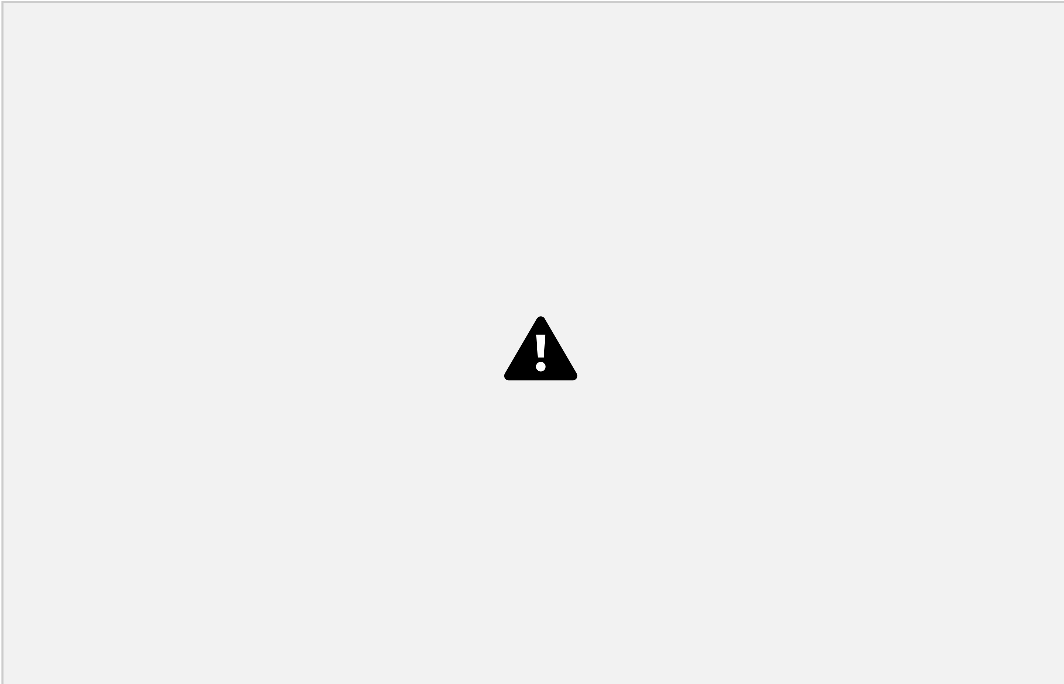


Figura 32. Cattle on coastal dunes

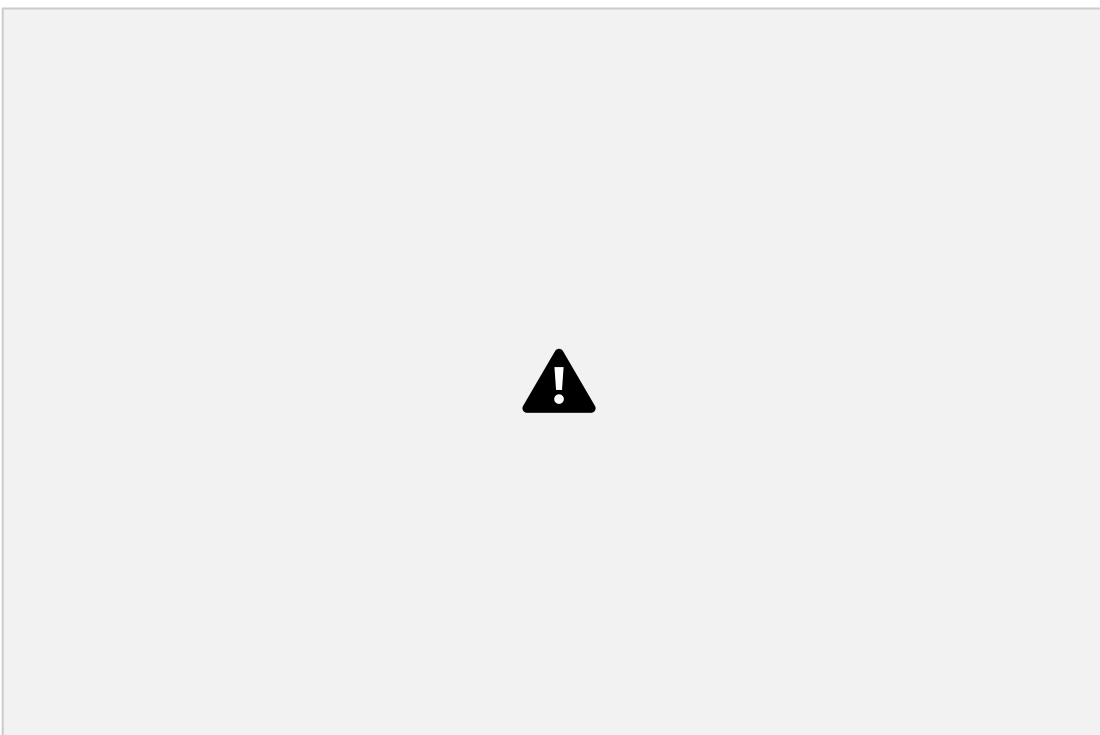


Figura 33. M. maritima damaged by browsing.

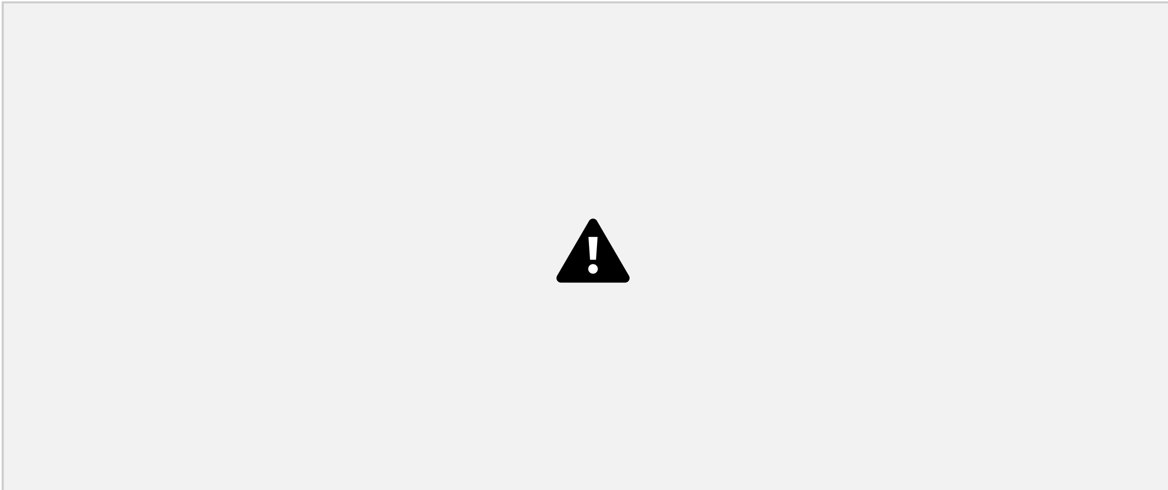


Figura 34. Gaps (erosion and / or soil compaction) generated by the passage of livestock

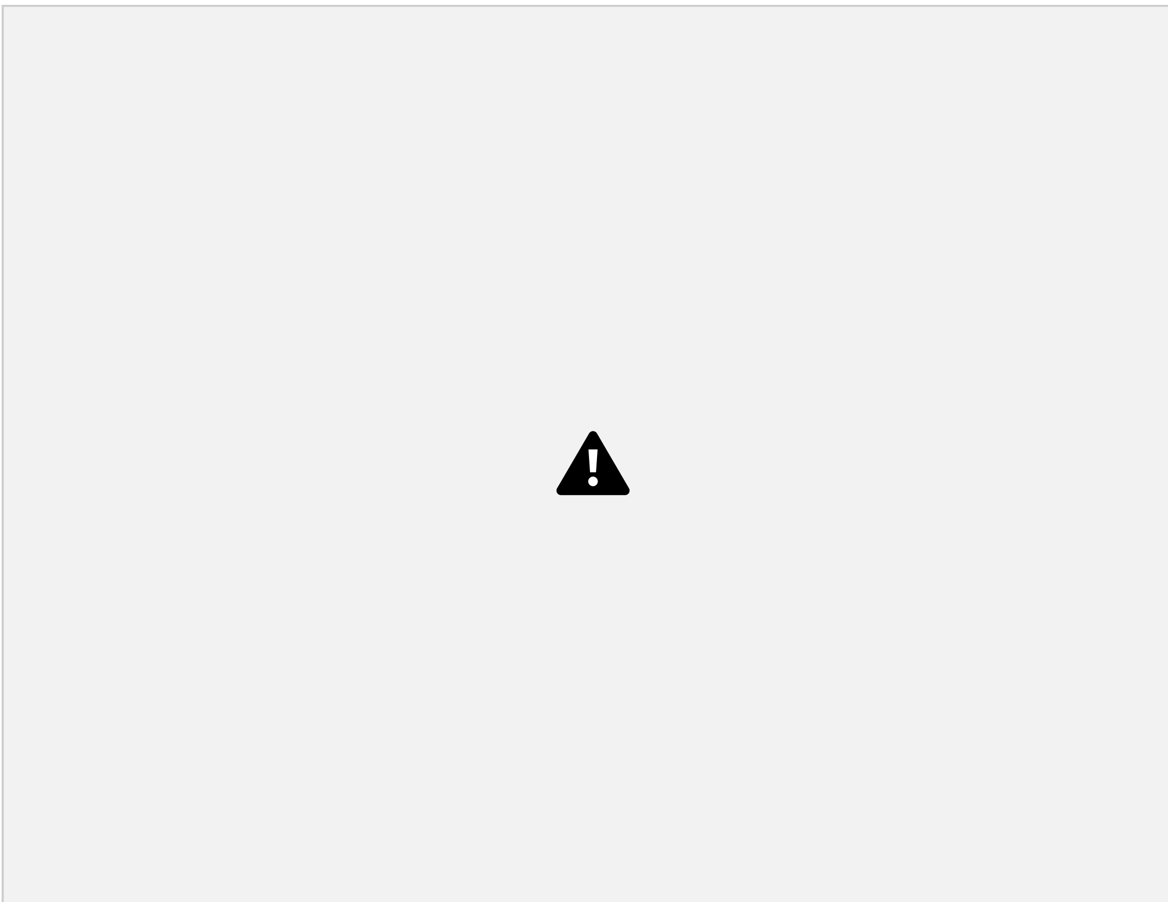
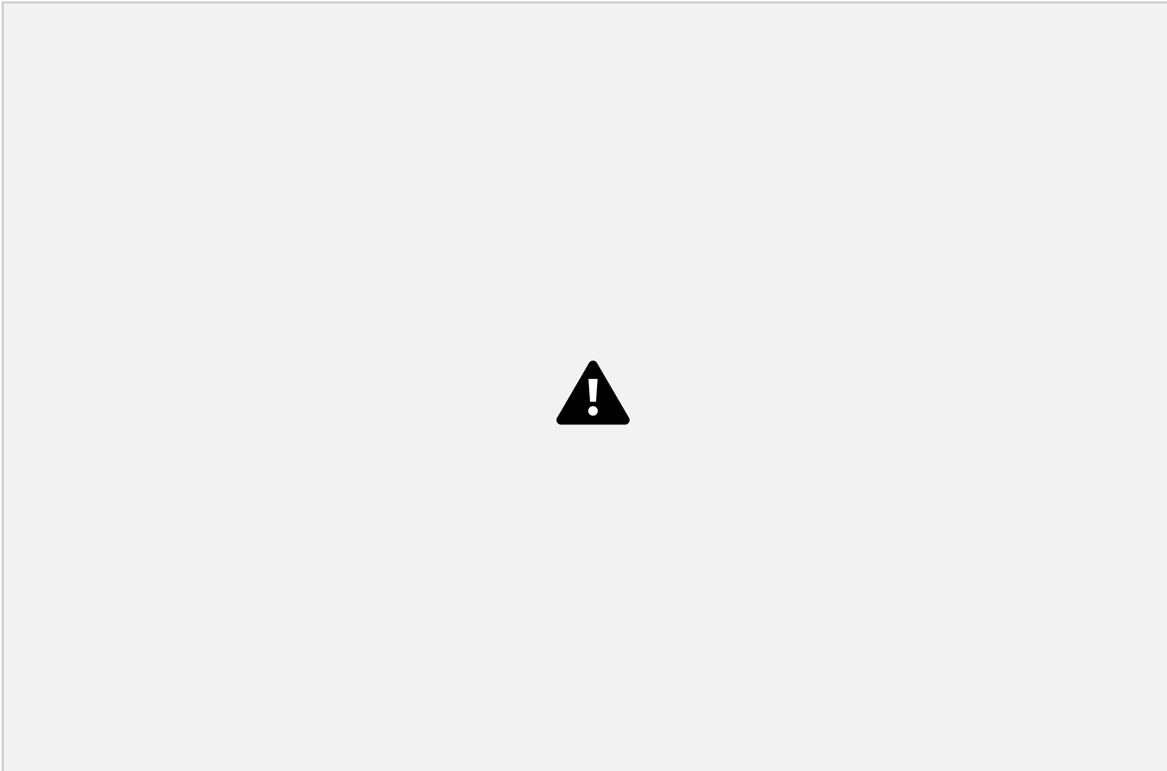
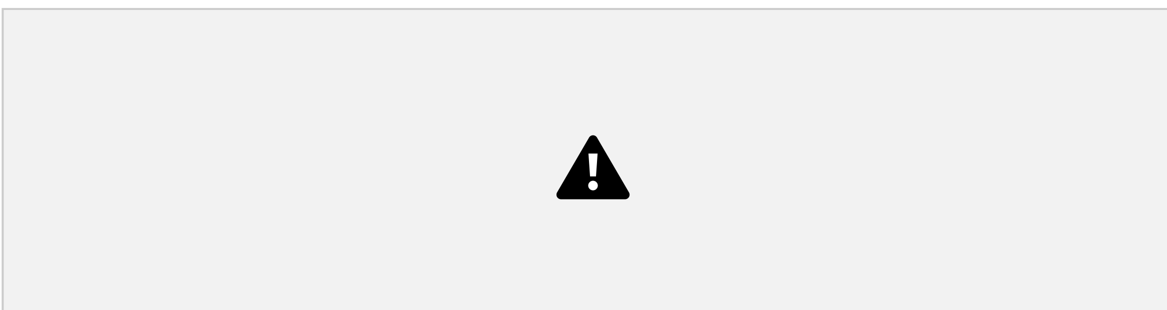


Figura 35. Zoning of the coastal dune system. It begins with an extensive beach (intertidal), followed by a strip of embryonic dunes, frontal dunes and ends in a dune-scrub transition zone, which is followed by a strip of scrub on sandy soil.

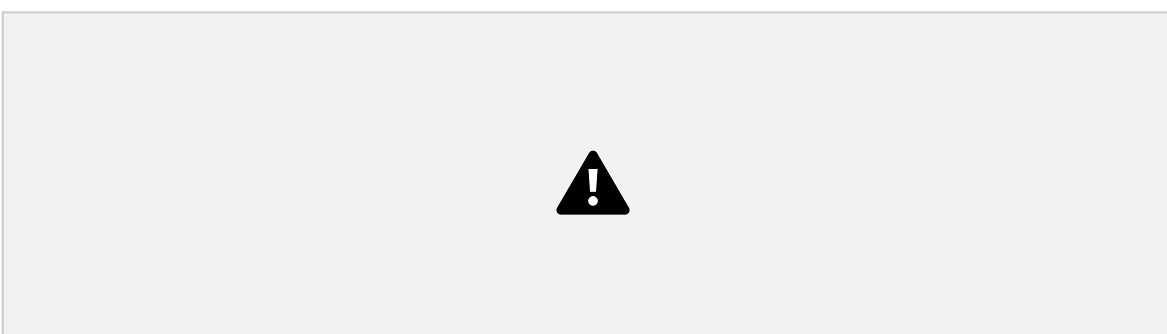
Next, the topographic profiles are presented, as well as a schematic profile of transects sampled in the coastal dunes of the dune system that is located between Agua Blanca and Playitas-Boca Muelas. In addition, the most representative plant associations of each transect are included.



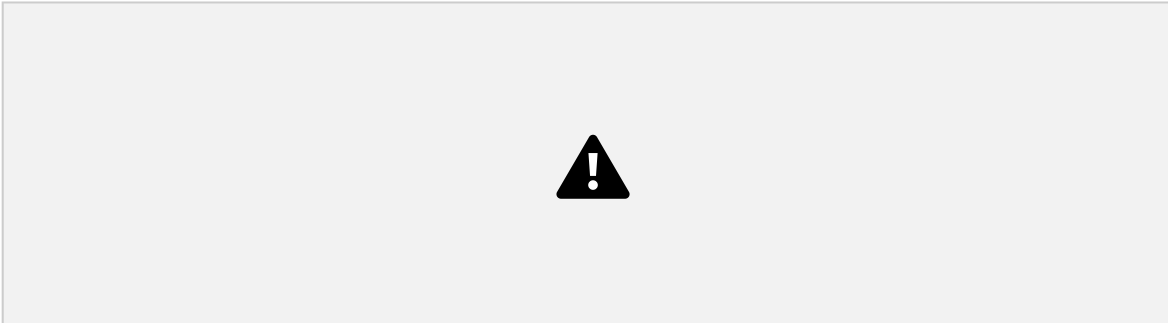
Transecto 1



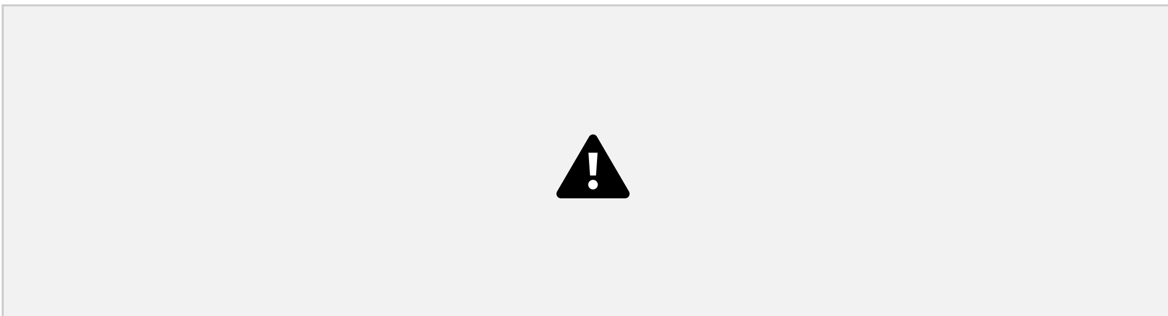
Transecto 2



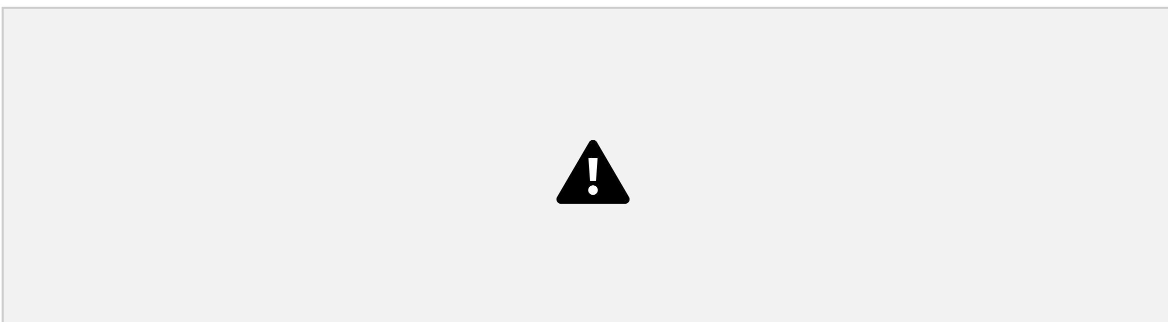
Transecto 3



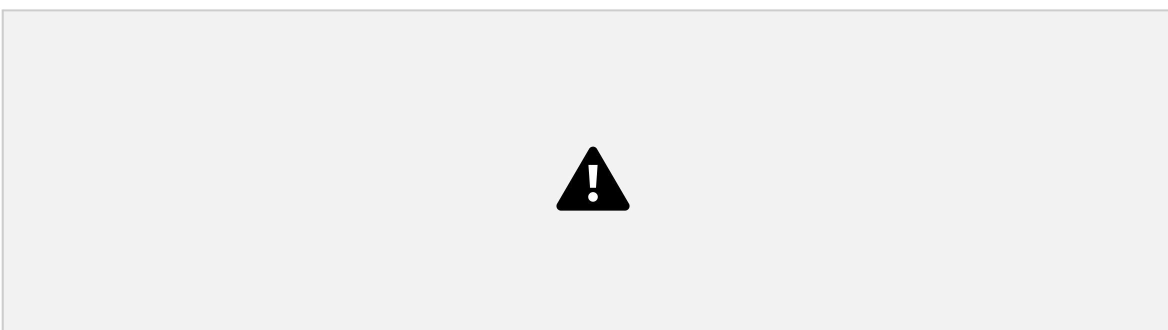
Transecto 4



Transecto 5



Transecto 6



I.1.1. Boca Muelas (Arroyo Grande)

The width of the profile is 90 m between 8 and 11 m high. The frontal dune is flanked towards the sea by a clear strip of embryonic dune, a beach, and the intertidal strip and inland, the dune ends in a transition strip of dune and scrub vegetation followed by a strip of well scrub. conserved. (Figure 36). Half of the transects sampled in this area correspond to the mouth of the Arroyo Grande, so there are no defined coastal dunes, only an extensive beach (generally with a marine erosion escarpment), a berm, followed by scattered patches of vegetation consisting mainly of L. brevipens. In addition to gallery vegetation species, such as Ambrosia ssp., As well as exotic ruderal species such as Nicotiana glauca and Tamarix ramosissima.

On the coastal dunes, J. pilosa is the constant species throughout the profile, and I. pes-caprea can be observed on the beach, in association with E. Leucophylla; here the embryonic dune is very narrow or absent, and presents the association of P. linearis, O. drummondii and M. maritma. Some shrubs such as M. phyllantoides, L. brevipens and E. farinosa are found on the left flank of the dune (when it borders the stream) or on the leeward side (when it borders the scrub).

Observed impacts

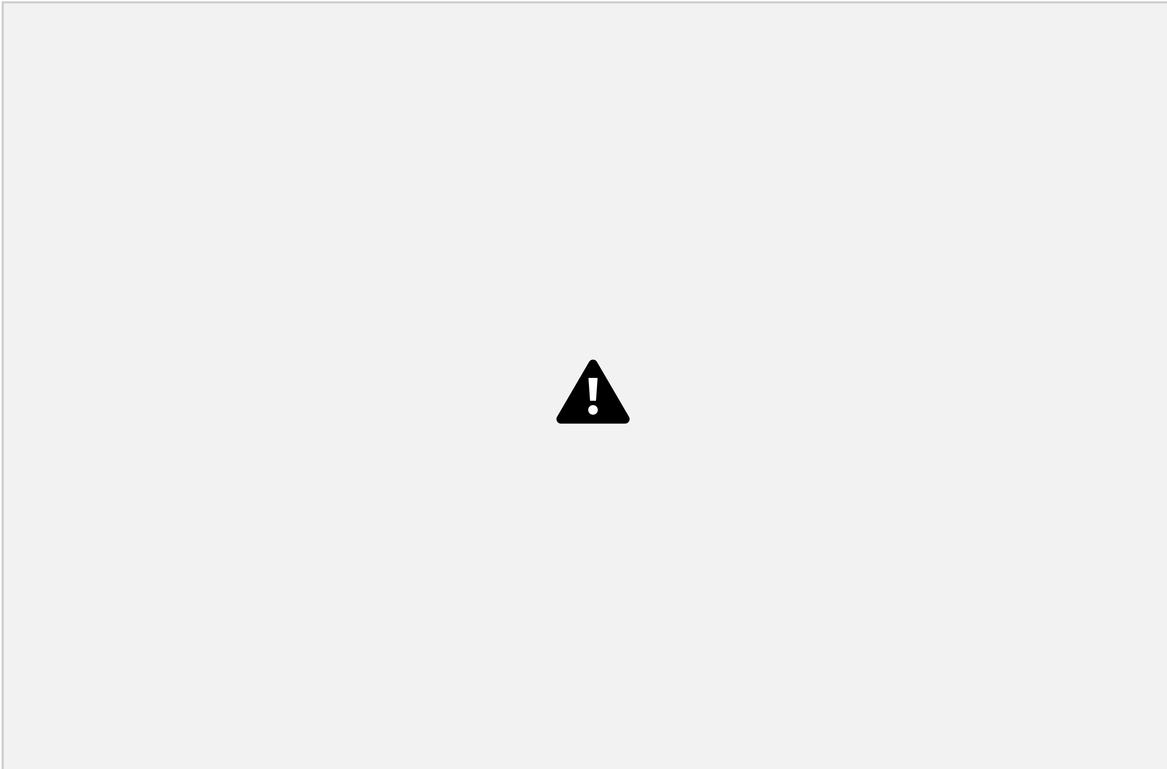
- Fragmentation of the system by parcel division, indicator of future subdivision ● Overgrazing

(Livestock)

- Agriculture, behind the coastal dune.
- Fragmentation by accesses (sidewalks, paths)
- High vehicle traffic on the beach, embryonic dunes and stream.
- Infrastructure (houses and restaurants, on and behind the dunes).

Figura 36. Dunas Boca Muelas- Todos Santos It begins with an extensive beach (intertidal), followed by a strip of embryonic dunes, frontal dunes and ends in a dune-scrub transition zone, which is followed by a

The topographic profiles are presented below, as well as a schematic profile of transects sampled in coastal dunes of the dune system located between Boca Muelas-Todos Santos. In addition, the most representative plant associations of each transect are included.



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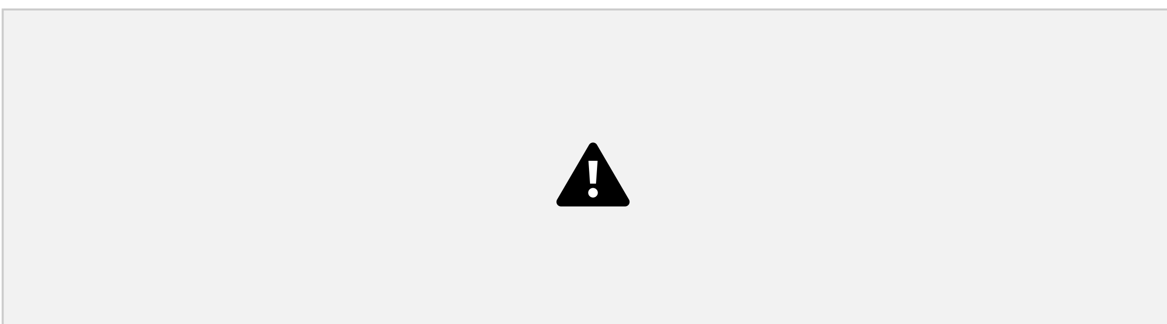
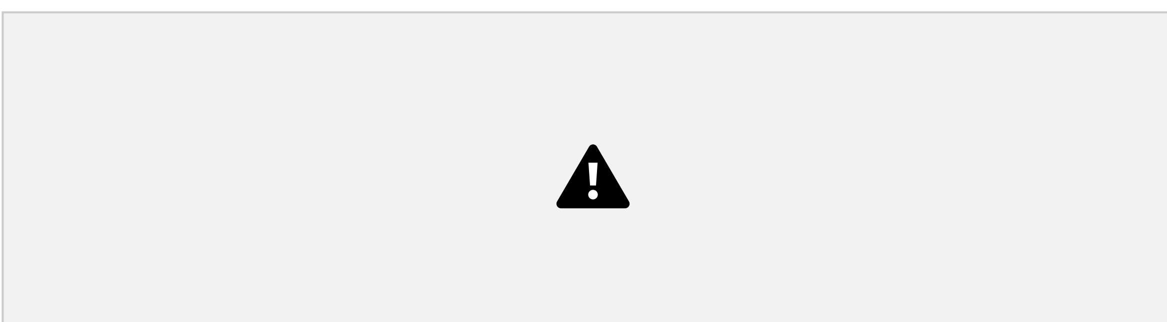
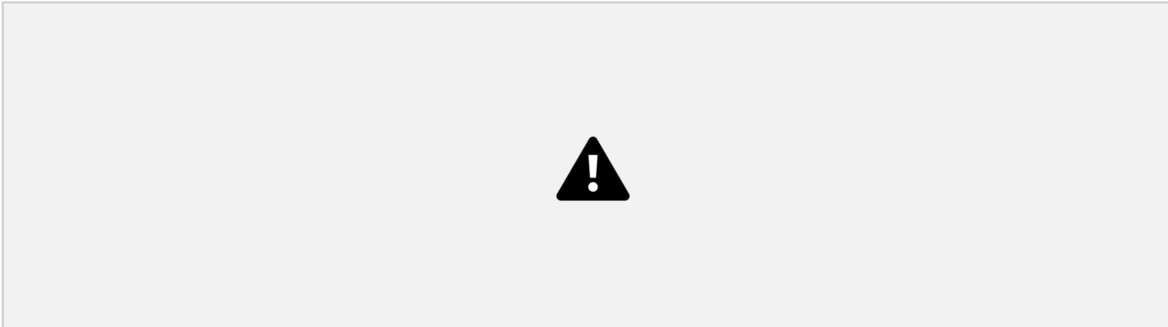


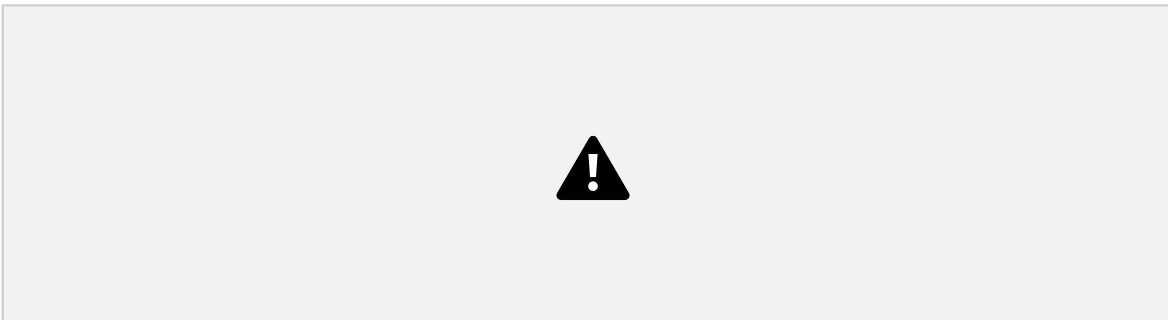
T8



T9



T10



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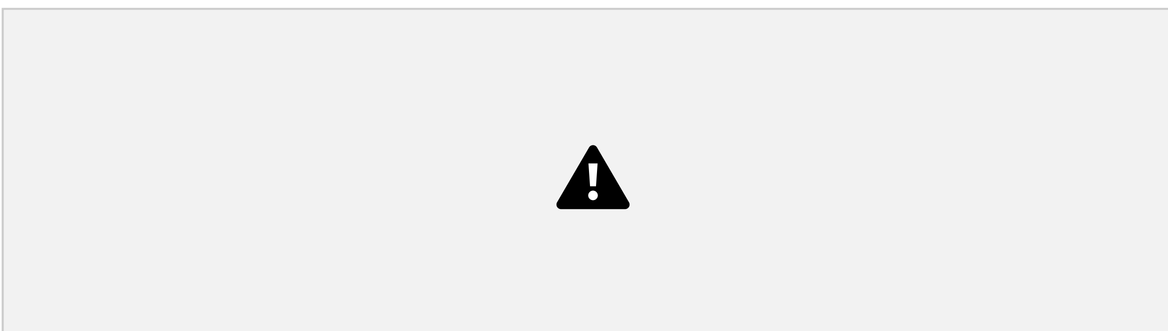


I.1.*1. Todos Santos (Las Tunas - Las Pocitas)*

The width of the profile is 90 m between 9 and 13 m high. The coastal dune system is well defined, characterized by a narrow beach, followed by the embryonic dune, also narrow, made up of sand mounds scattered around J. pilosa and / or O. drummondi. The frontal dune frontal dune presents a windward face with a steep slope, with evident wind erosion and that ends in the highest part of the dune (summit); the embryonic dune and the windward face merge and present the same characteristics of erosion and plant association. The leeward slope is generally gentle and is the most extensive part of the frontal dune, it is covered almost entirely by J. pilosa in association with M. maritma; some scattered individuals of B. atriplicifolia, J. Cinerea and C. Cholla are also observed. The dune ends in a transitional strip of dune and scrub vegetation, mainly J. califórnica, A. leptopus and S. halimifolium, almost always followed by a path that interrupts the transition zone. The constructions on the coastal dunes begin to be more frequent, while behind the dune system, in most cases there are constructions (Figure 37-40).

Observed impacts

● Fragmentation of the system due to construction on dunes

● Agriculture, behind the coastal dune.

● Fragmentation by accesses (sidewalks, paths, vehicle access)

● High vehicle traffic on the beach, embryonic dunes.

● Infrastructure (houses and restaurants, on and behind the dunes).

● Loss of landscape quality (the houses on the coastal dunes prevent the view towards the sea).

● Contamination by residues. Most things on coastal dunes have no connection to the drainage system, so they are released (filtered) by the dunes.

● Presence of exotic species, both ruderal (ornamental plants) and feral (released pets) that have an impact on the local fauna.

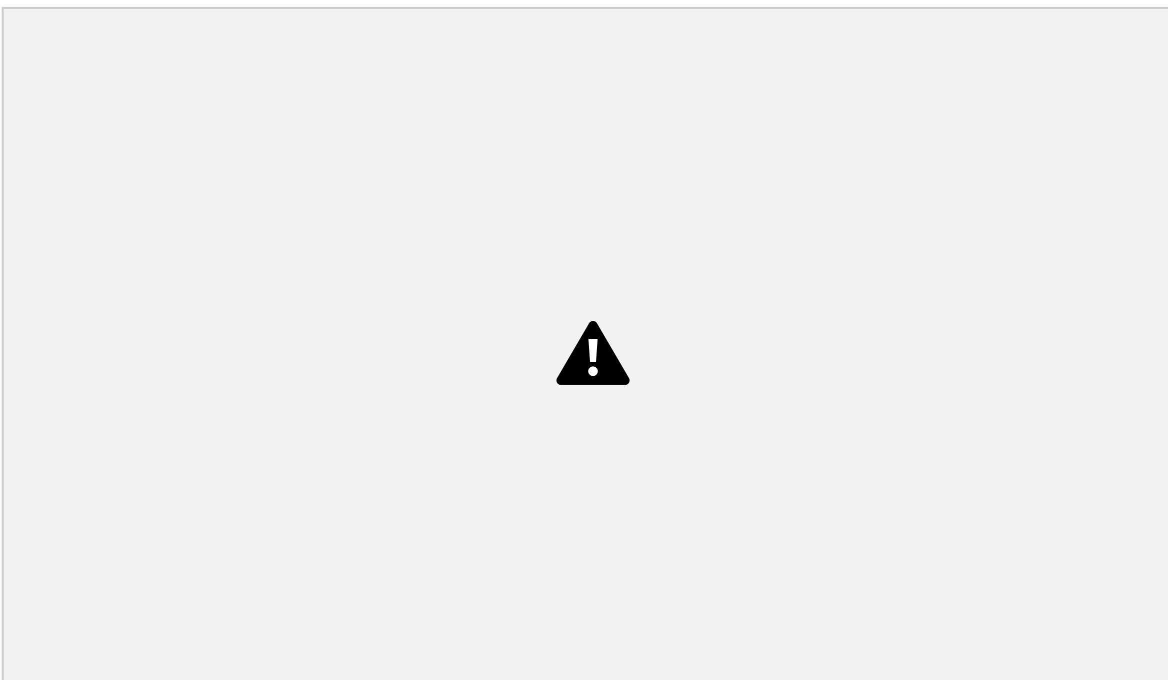


Figura 37. Typical topographic profile of the Todos Santos dune system, erosive processes are observed on the dune front, as well as fragmentation by roads. The dunes are almost always followed by construction or agriculture that are considered as an indicator of pressure on the system.

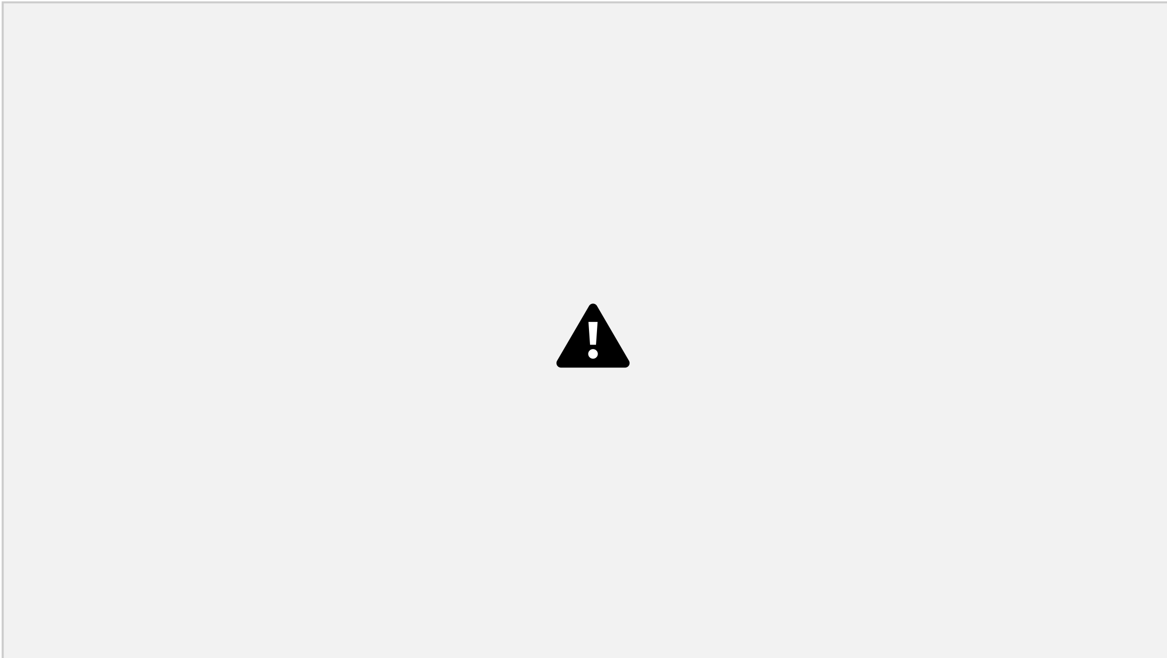


Figura 38. The erosion of the coastal dune front is a normal process in the sedimentary dynamics of the beach-dune system, however it accelerates with anthropic disturbances.

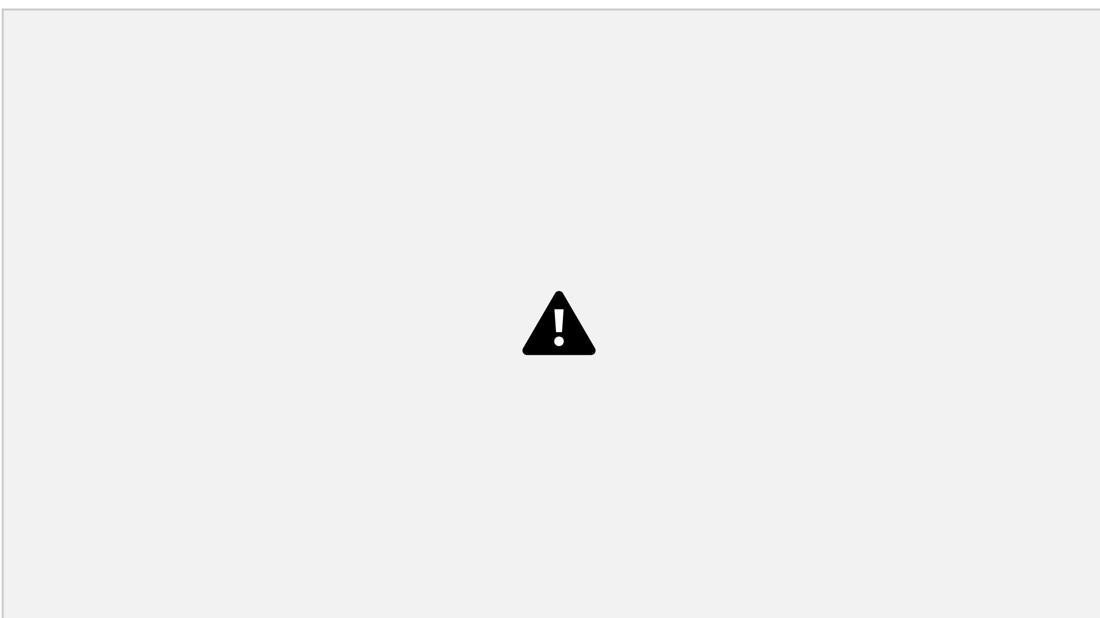


Figura 39. Fragmentation of the dune system by roads, gaps and vehicles.

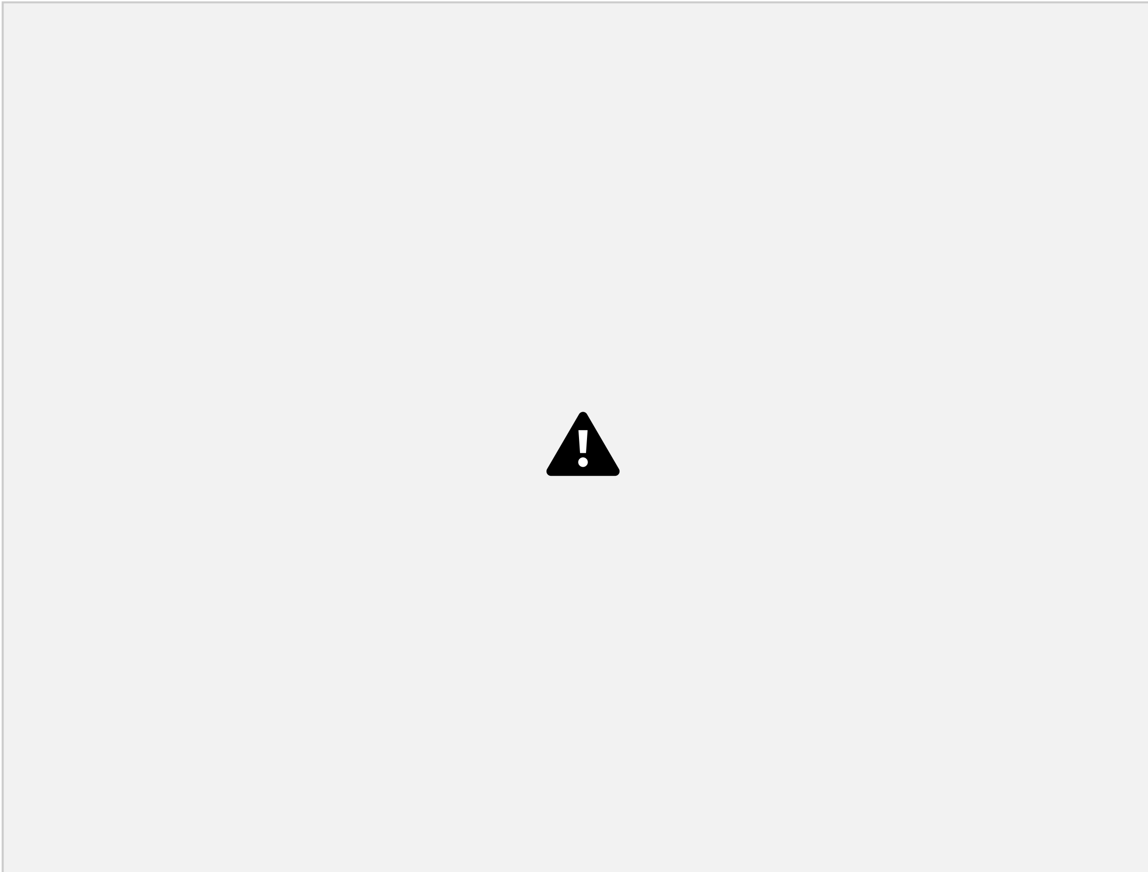
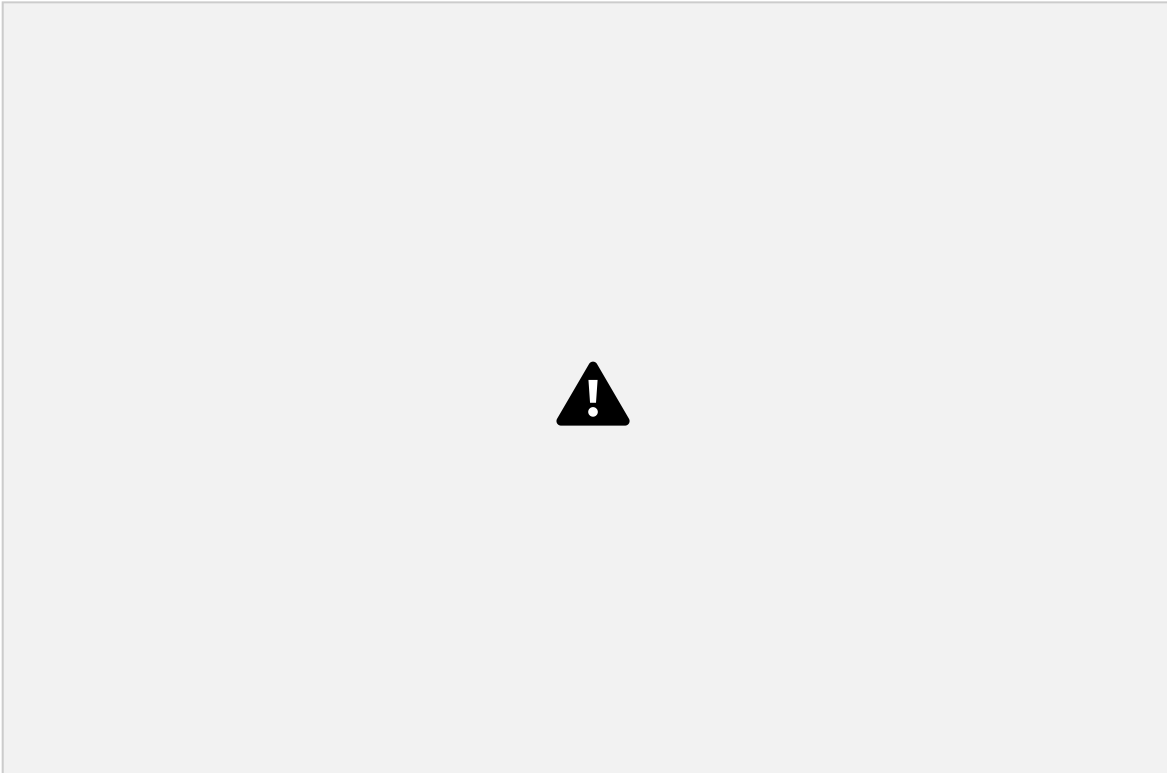


Figura 40. Zoning of the coastal dune system of Todos Santos, between Las Tunas and Las Pocitas.

The topographic profiles are presented below, as well as a schematic profile of transects sampled in dunes located between Las Tunas and Las Pocitas. In addition, the most representative plant associations of each transect are included.



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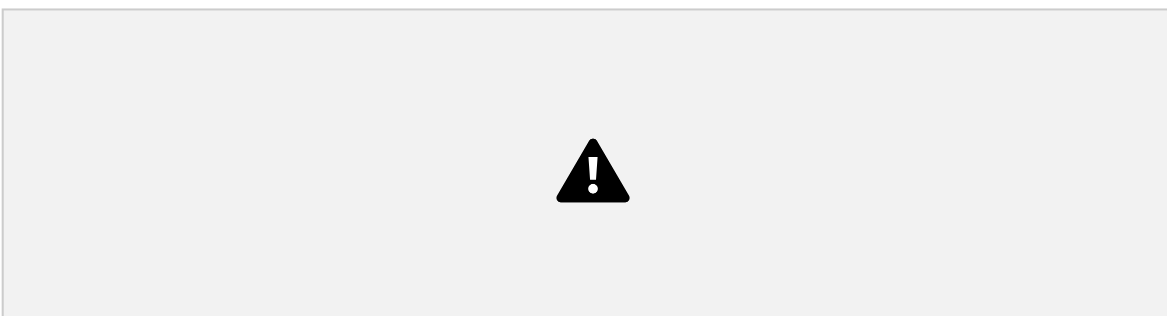

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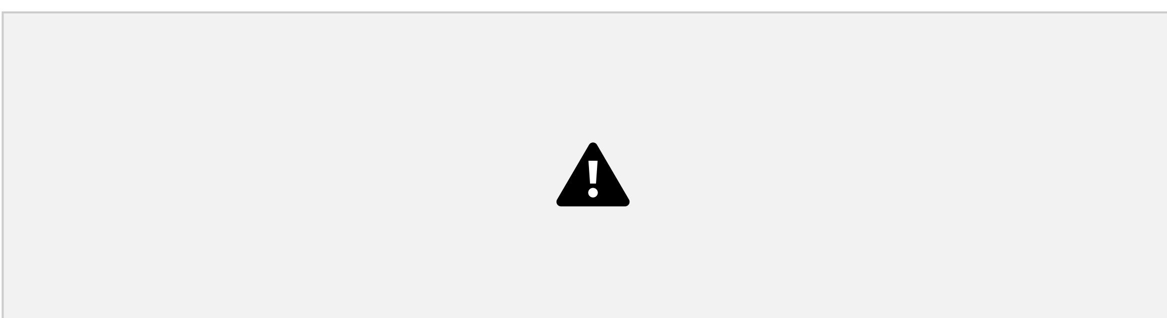
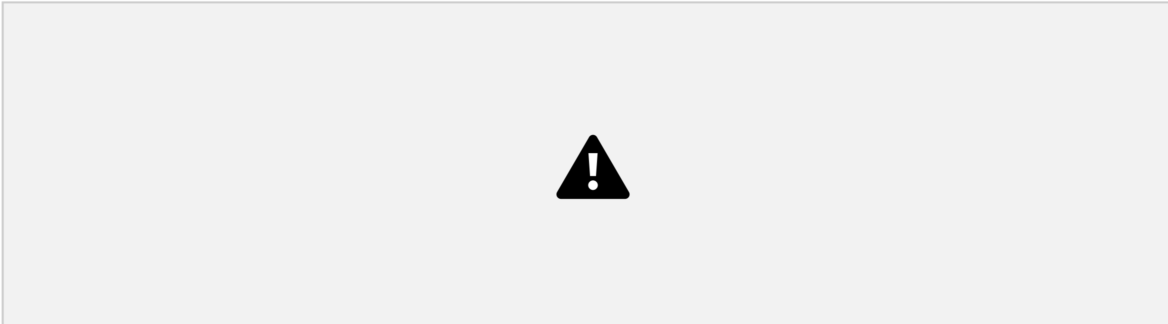
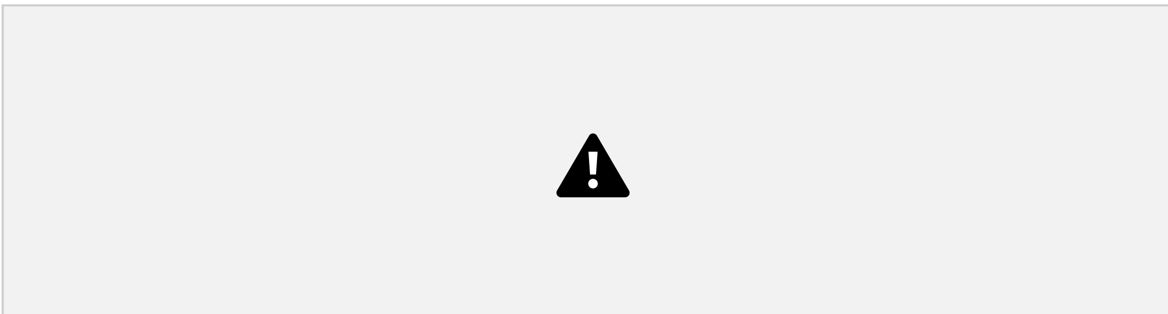


T14



T15



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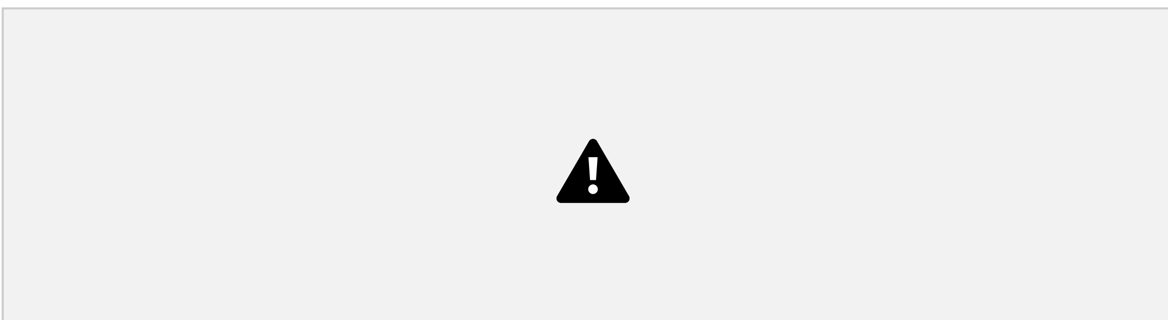


I.1.1. Todos Santos (The Lighthouse-Punta Lobos)

The width of the profile is 160 m between 9 and 9.1 m high. The frontal dune is flanked towards the sea by a broad strip of embryonic dune, and inland, the dune ends in a transitional strip of dune and scrub vegetation followed by a well-preserved strip of scrub. In this area you can see

In this area, the coastal dunes are in a good state of conservation, the frontal dune cordon is wide, and a second well-defined dune cordon is observed in the central part. The dune system is followed by coastal scrub. In the central part of this section, the coastal dune merges with the scrub, so “on foot” it is difficult to determine the end of the coastal dune and the beginning of the scrub. This is because the type and characteristics of the soil (sandy) are similar, although the species found are mainly scrubland (Transect 18) (Figures 41-42).

Although the dunes are in a good state of conservation, there is a restaurant-type infrastructure, which possibly in its services includes tours over the dunes, since gaps are observed with evidence of constant use. These gaps not only “cut through” the dune but extend throughout the system.

In the extreme southeast of the system is located an infrastructure of great importance and extension, which, according to the hemerographic research, is part of an extensive real estate development project, which if it materializes could invade the entire beach-dune system of this section of the coast.

Impacts

- Fragmentation of the system due to construction on dunes
- Fragmentation by accesses (sidewalks, paths, vehicle access)
- High vehicle traffic on the beach, embryonic dunes.
- Infrastructure (houses and restaurants and hotel, on the dunes).
- Coastal erosion, associated with infrastructure
- Presence of exotic species, ornamental plants.
- Social conflicts, due to hotel infrastructure.

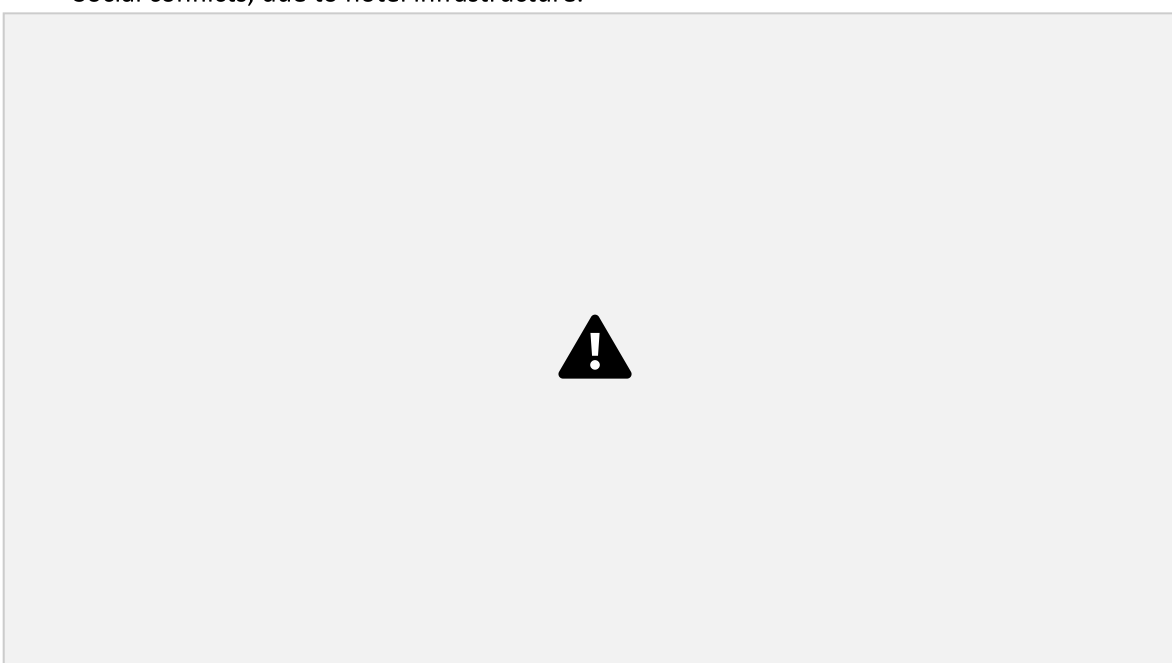


Figura 41. Identificación de impactos sobre las dunas costeras.

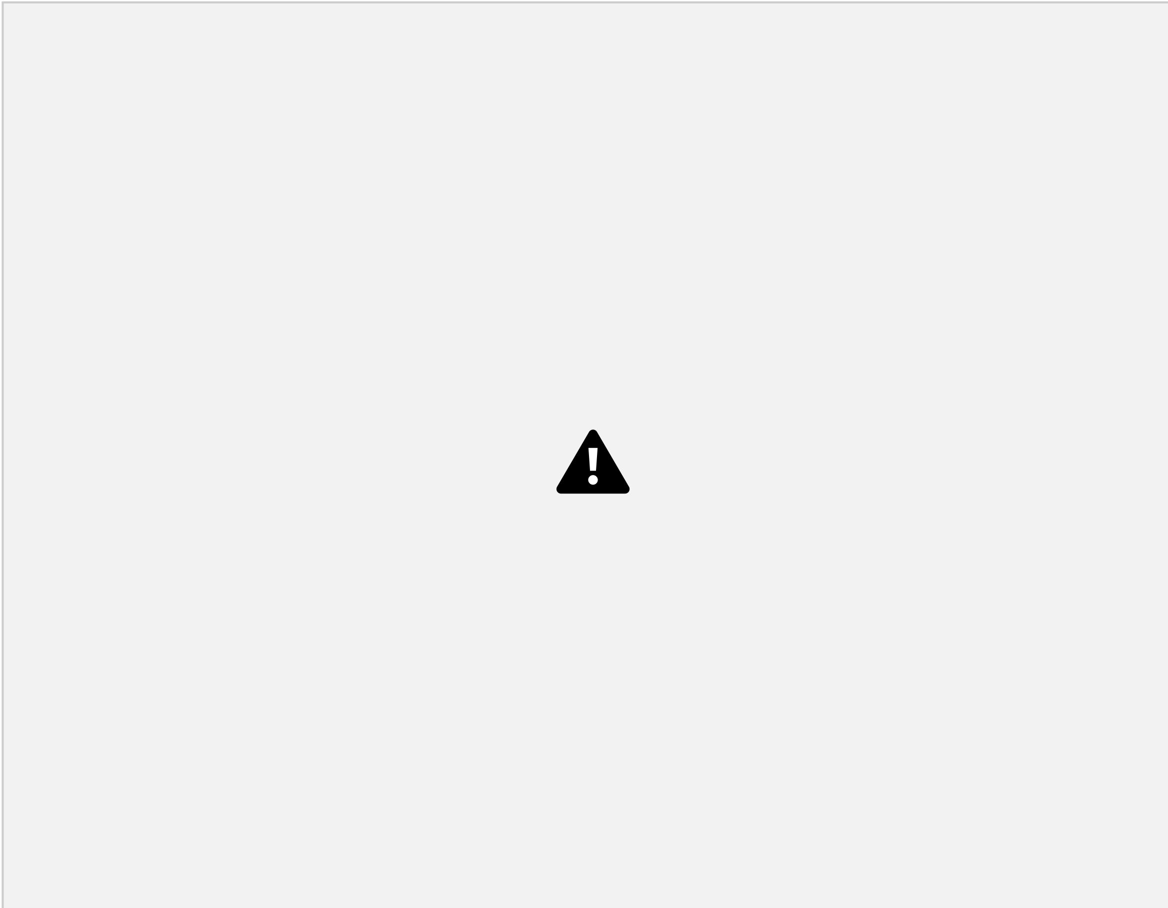
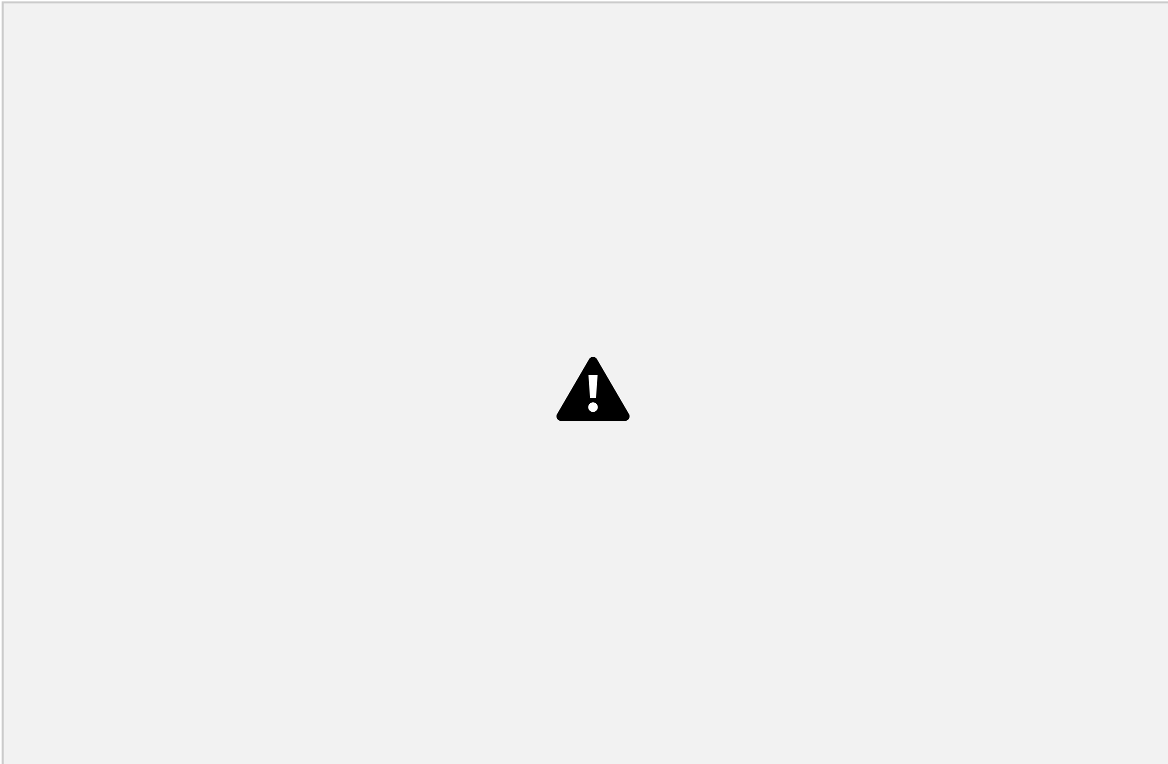


Figura 42. Zonoficación del sistema de dunas costeras de Todos Santos, entre El Faro y Punta Lobos.

The topographic profiles are presented below, as well as a schematic profile of transects sampled in the coastal dunes of the dune system between El Faro and Punta Lobos. In addition, the most representative plant associations of each transect are included.



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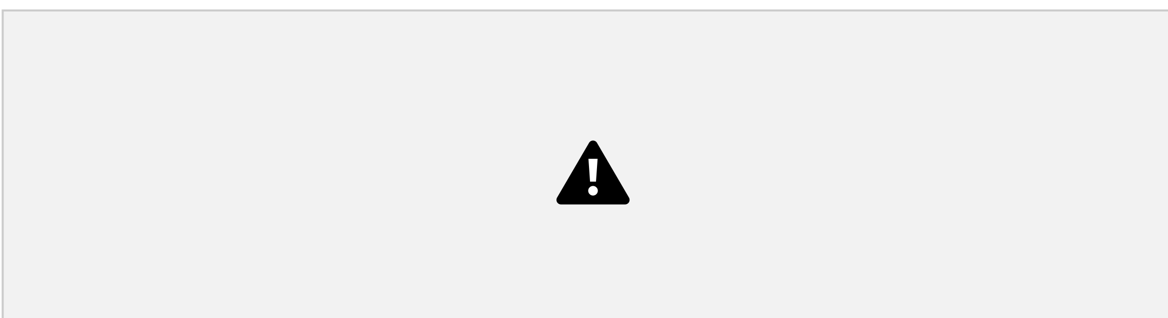

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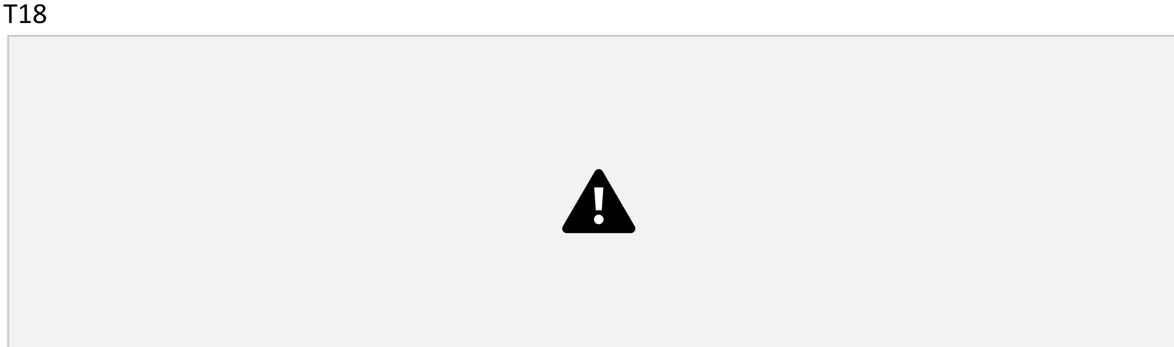


I.1.2. Pescadero

The width of the profile was 131 m. The height of the dune ranges from 6m to 12.3m at the crest. The profile consists of a strip of beach with pioneer plants, distributed in a scattered manner, mainly J. pilosa, E. leucophylla and P. glabra. The beach is followed by an isolated strip of embryonic dunes, with the same association of pioneer species on the beach, but with greater coverage. The frontal dune that corresponds to a single dune cordon, presents different plant associations according to the location of the transect, however, a typical frontal dune profile is observed with the association of J. pilosa, S. virginicus and M. marima on the windward slope; M. phylantoides in association L. bevripens and C. globosa and / or A. halimifolium on the crest of the coastal dune. The windward slope is narrow compared to the Todos Santos dunes and is generally seen covered by scrub shrubs such as J. california, J. cinera, E. farinosa and Bursera ssp. In this area, the dunes are characterized by merging with the coastal scrub, and without lack of experience, they could not be classified as coastal dunes, however, they are stabilized dunes that face high pressure due to the construction of houses on them, which which implies changes in plant associations, as well as the interruption of processes typical of the beach-dune-scrub system. In addition, in some places constructions are already observed on the bed of streams that interrupt the flow of sediments of fluvial origin. (Figures 43).

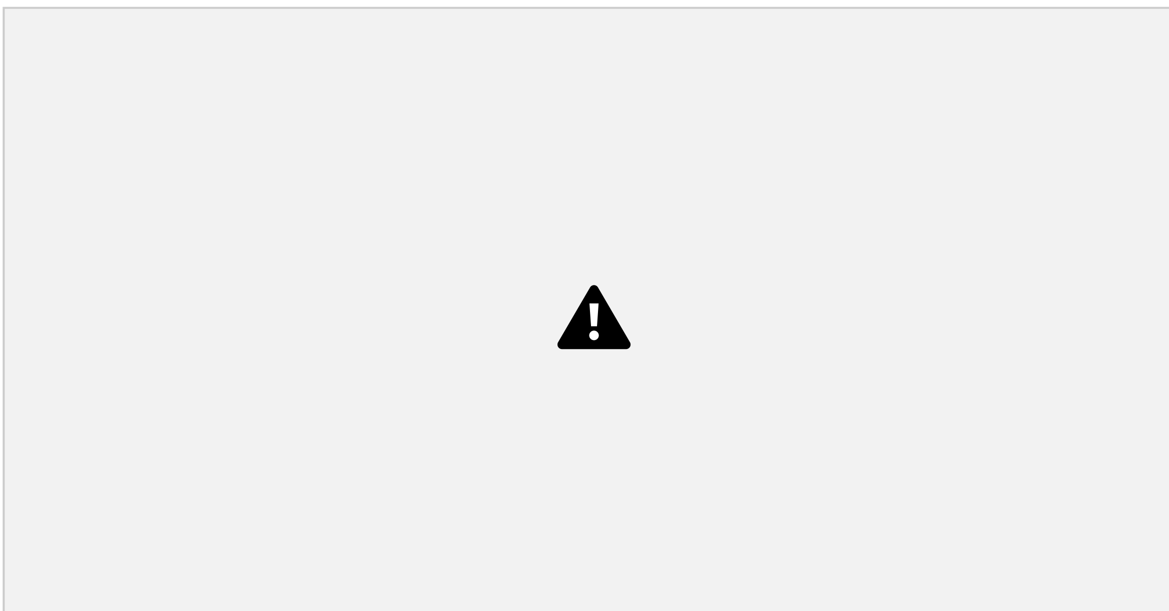


Figura 43. Construcción de casas sobre dunas costeras. En este sistema las dunas embrionarias no se desarrollan, el sistema comienza con una duna frontal baja (A), seguida de un cordón de dunas estabilizado, cubierto parcialmente por vegetación propia de matorral (B). Entre la duna frontal A y B se observa una hondonada que originalmente era parte de la salida del arroyo (al noroeste de esta ubicación) y que fue interrumpido por la construcción. Esta zona de Pescadero ha tenido un creciente desarrollo de casas en años recientes que se han construido total o parcialmente sobre las dunas costeras y cauce arroyos.

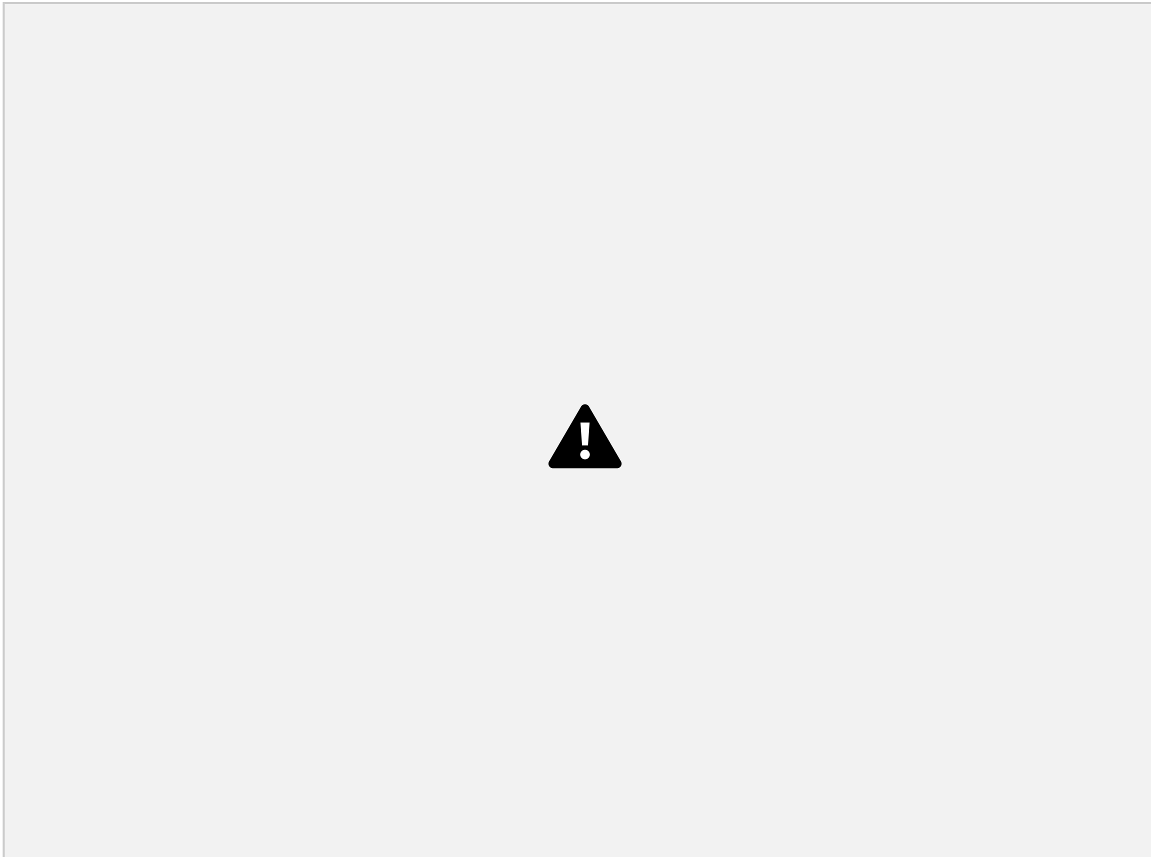


Figura 44. A lo largo de todo el litoral correspondiente a Pescadero se observa la construcción de casas sobre las dunas costeras.

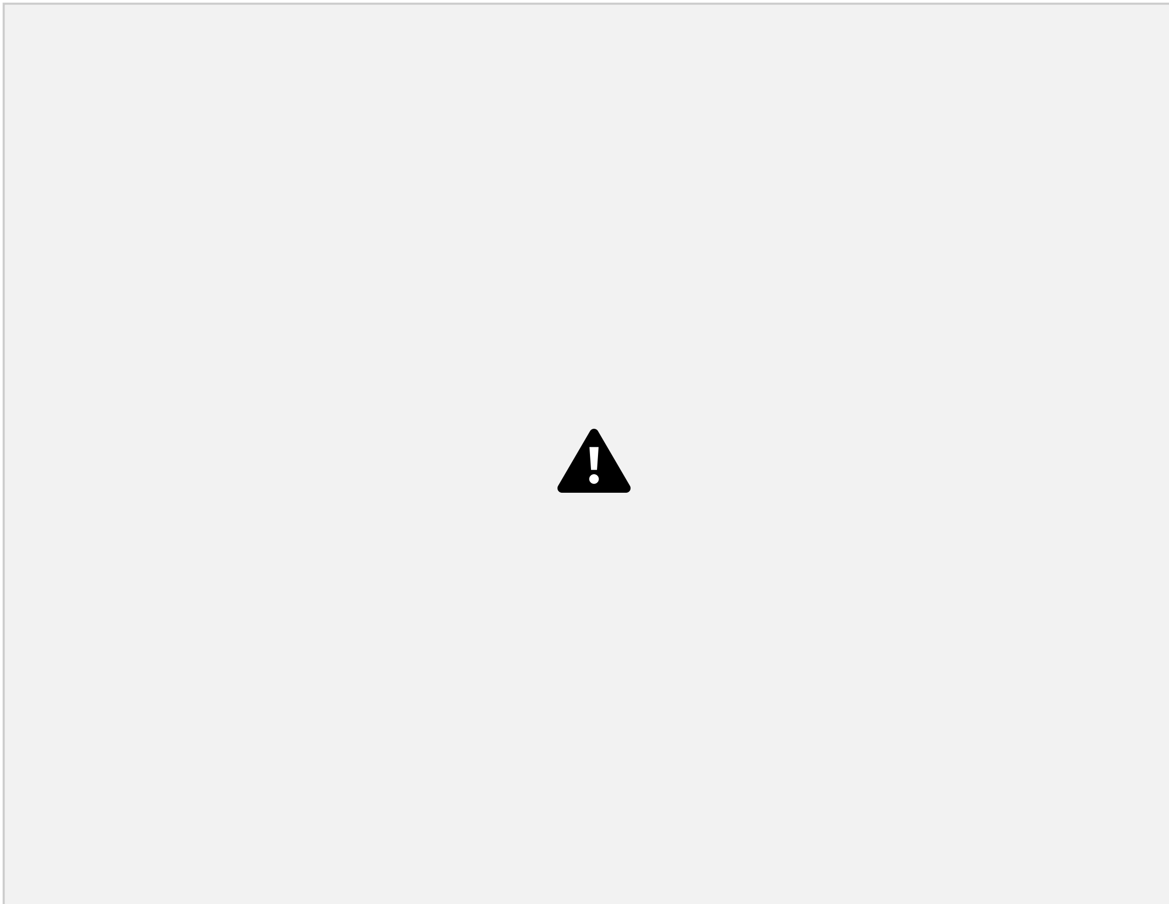


Figura 45. Mapa, perfil topográfico y gradiente de vegetación de las dunas costeras de Pescadero, La Paz, BCS.

Observed impacts

● Fragmentation of the system due to construction on dunes

● Agriculture, behind the coastal dune.

● Fragmentation by accesses (sidewalks, paths, vehicle access)

● Vehicle traffic on the beach, embryonic dunes.

● Infrastructure (houses on and behind the dunes; and in stream beds). ● Leveling

and filling of dunes.

● Loss of landscape quality (the houses on the coastal dunes prevent the view towards the sea).

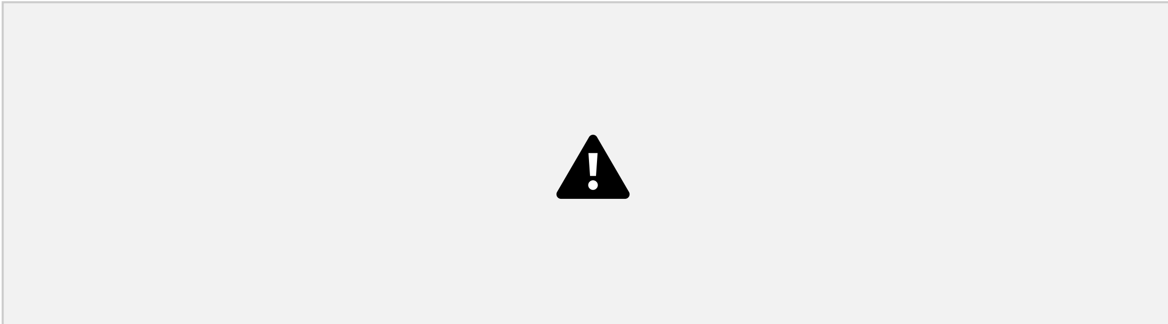
● Coastal erosion.

- Lack of accessibility to the beach (privatization of the coastal dune front)
- Environmental degradation, loss of habitat.
- Presence of exotic species, both ruderal (ornamental plants) and feral (released pets) that have an impact on the local fauna.

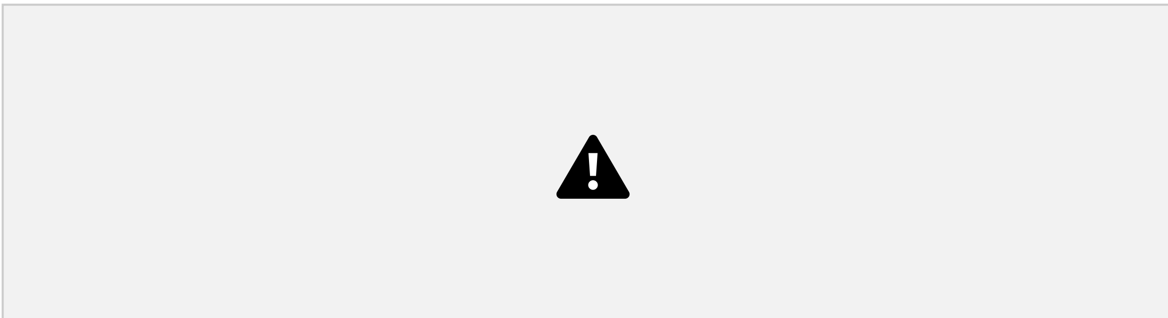
The topographic profiles are presented below, as well as a schematic profile of transects sampled in the coastal dunes of the dune system found in Pescadero. In addition, the most representative plant associations of each transect are included.

T19

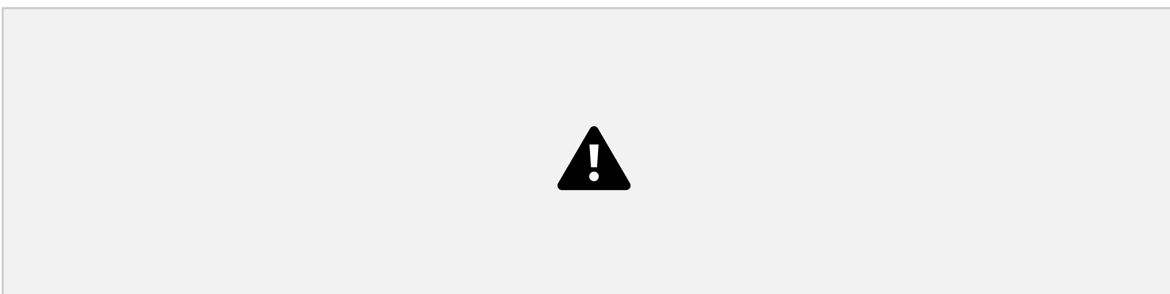
T20



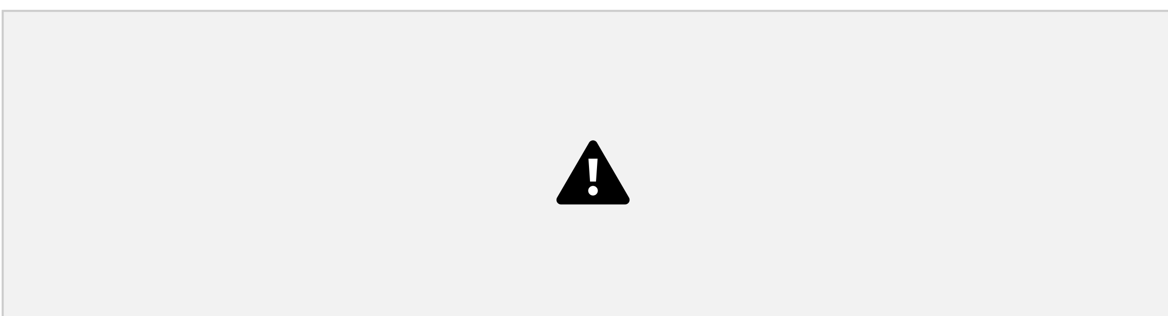
T21



T22



T23



I.1.3. Cerritos

The width of the profile is 91 m and 4.5 to 10 m high. The coastline of the Cerritos area begins to the north with an extensive beach that is interrupted by a rocky outcrop (from which it owes its name). At this end, the beach presents conditions of high disturbances because it is a beach of tourist interest (surf), so the dunes are non-existent. The only evidence of coastal dunes found is the presence of Abronia maritima, a dune-building species; however, the high concentration of tourists prevents the formation of coastal dunes. Also, at this extreme, originally the beach was followed by a wetland. Currently, the wetland has been filled in for the installation of infrastructure (Figure 46).

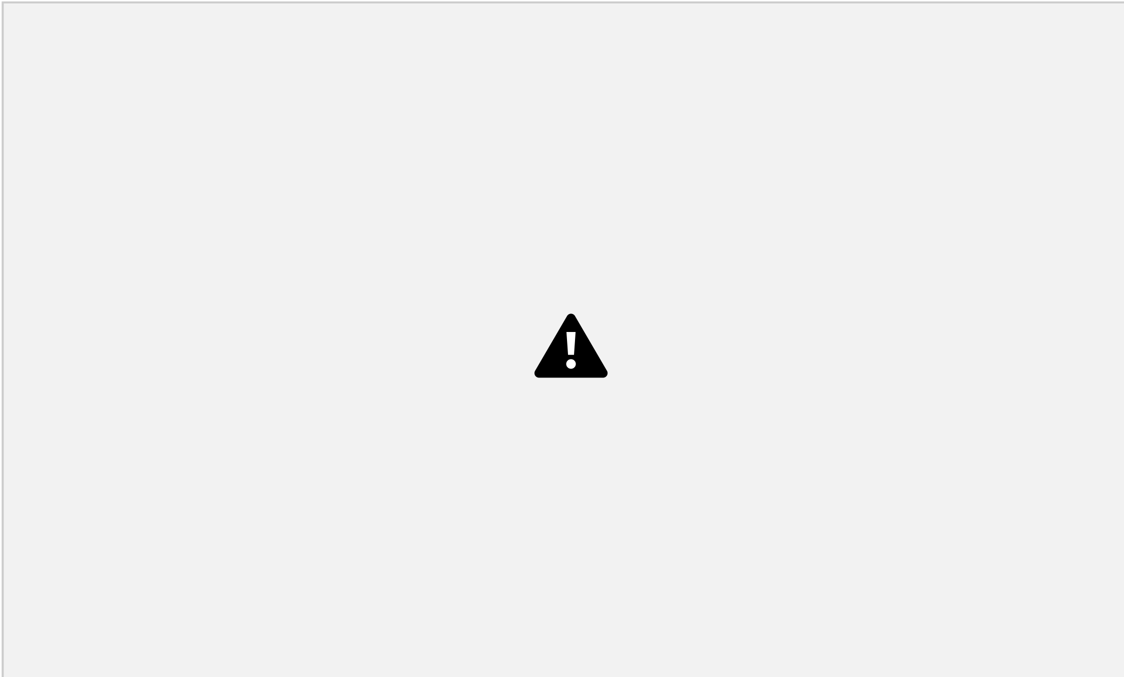


Figura 46. Imagen de satélite de Cerritos en el 2002. Se ilustra la ubicación actual de casas o desarrollos.

Heading south of this area, the dune is almost flat, without undulations. the fringe of embryonic dunes and the frontal dune forming a single dune cord. As it moves south, the coastal dunes become wider (evidence of the predominant wind direction, and the accumulation of sediments), however, the system is interrupted by: a) large constructions (more than two levels) and) low cliffs (sandstone soil, but very compacted. The impact on the

sedimentary dynamics of these two types of barrier on the coastal dunes is that, in the first case, the dunes are eliminated and the environmental service of the system is lost, while that, in the second case, when there is an excess of sediment, the dunes ramp up the cliff, forming new coastal dunes on consolidated sediment.However, among the unbuilt spaces there are still fragments of low coastal dunes covered by S. virginicus, P. linearis and Proboscidea althaeifolia, followed by an association of scrub species (Figure 47, 48).

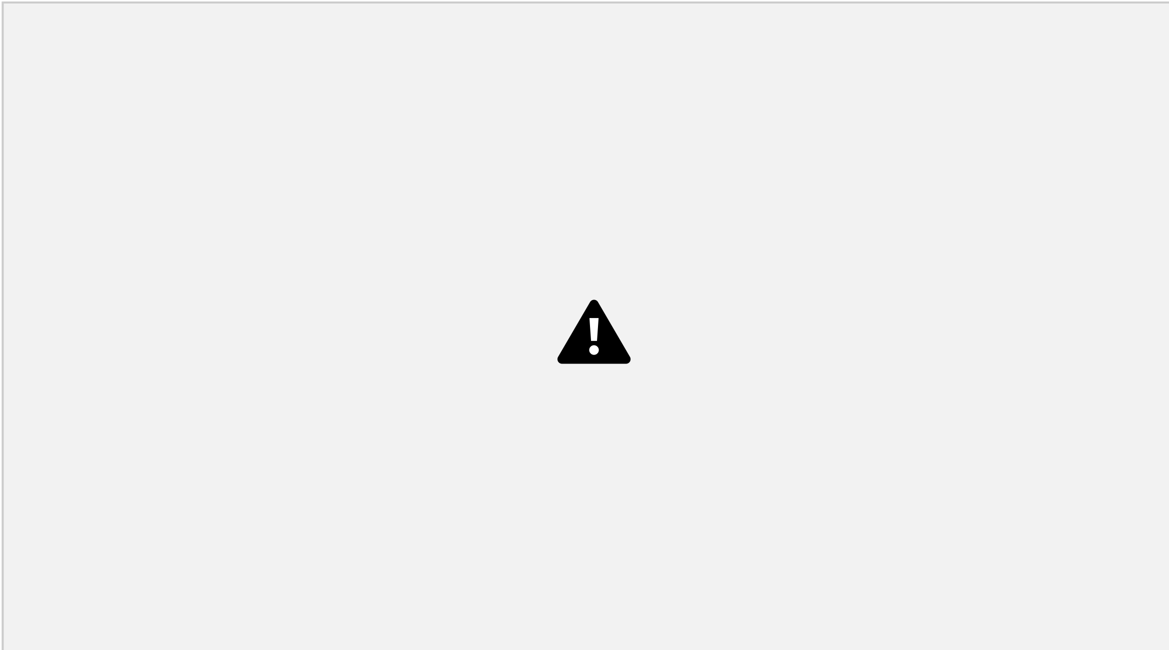


Figura 47 Ubicación de las dunas costeras en la porción norte de Playa Cerritos.

Figura 48. Zona norte de Cerritos. Debido a que la duna frontal es muy angosta, no se considera conservarla al momento de desarrollar infraestructura.

To the south of the residential and tourist development of Playa Cerritos, the coastal dunes become wider and are better preserved, with some scattered constructions. The dune profile indicates an extensive beach with the presence of pioneer species such as I. pescaprea, I. imperati, P. glabra and E. leucophylla. These species in combination of O. drummondii form small sand mounds until they form a fringe of embryonic dunes (in some places, it is not possible to identify these mounds, since the frontal dune begins immediately after the beach). The frontal dune is covered almost entirely with J. pilosa in association with M. maritima. It is recurrent to find, behind the crest of the dune, an extensive cover of C. globosa, M. phyllanthoides or L. brevipens. At the end of the dune, in the transition zone, the presence of J. cinerea, C. cholla and S. gumosus is common. In the central part of this section, the dunes are delimited by a flood plain, which in rainy seasons forms an extensive body of water that flows into the sea; here the most important species is C. erectus, as well as marsh species such as A. subterminalis, S. portulacastrum and Salicornia sp.

A total of 35 species were found, the four species from the embryonic dunes and crest area are Physalis glabra, Euphorbia leucophylla, Jouvea pilosa and Proboscidae althaeifolia. Inland front dune species are shrubs and cacti from the scrub immediately behind the dune.
It is a dune with well-preserved portions (Figure 49), but seriously threatened by constructions on dunes.

Observed impacts

● Fragmentation of the system due to construction on dunes

● Agriculture, behind the coastal dune.

● Fragmentation by accesses (sidewalks, paths, vehicle access)

● Vehicle traffic on the beach, embryonic dunes.

● Infrastructure (houses on and behind the dunes; and in stream beds). ● Leveling

and filling of dunes.

● Loss of landscape quality (the houses on the coastal dunes prevent the view towards the sea). ● Coastal

erosion.

● Environmental degradation, loss of habitat.

Housing and tourism development of high impact on the entire coastal system, not only on the dunes. It is a practice that follows a pattern from north to south begins with the filling of wetlands (temporary and intermittent streams), permanent infrastructure with a large capacity for shelter, single-family infrastructure and semi-permanent infrastructure. At the end of this section, the houses are located on land where the coastal dunes have been removed and the land is leveled or on land with some type of fill of material external to the dune system. Something that is very important to highlight in this area is the location of property boundaries (posts with wire) on the beach. This practice is very common in areas

where the properties are on the complete coastal dune system, and the backyards of the houses is the beach. In addition, this area is becoming a zone of exclusivity, where access will be privatized to the settlements that are there.

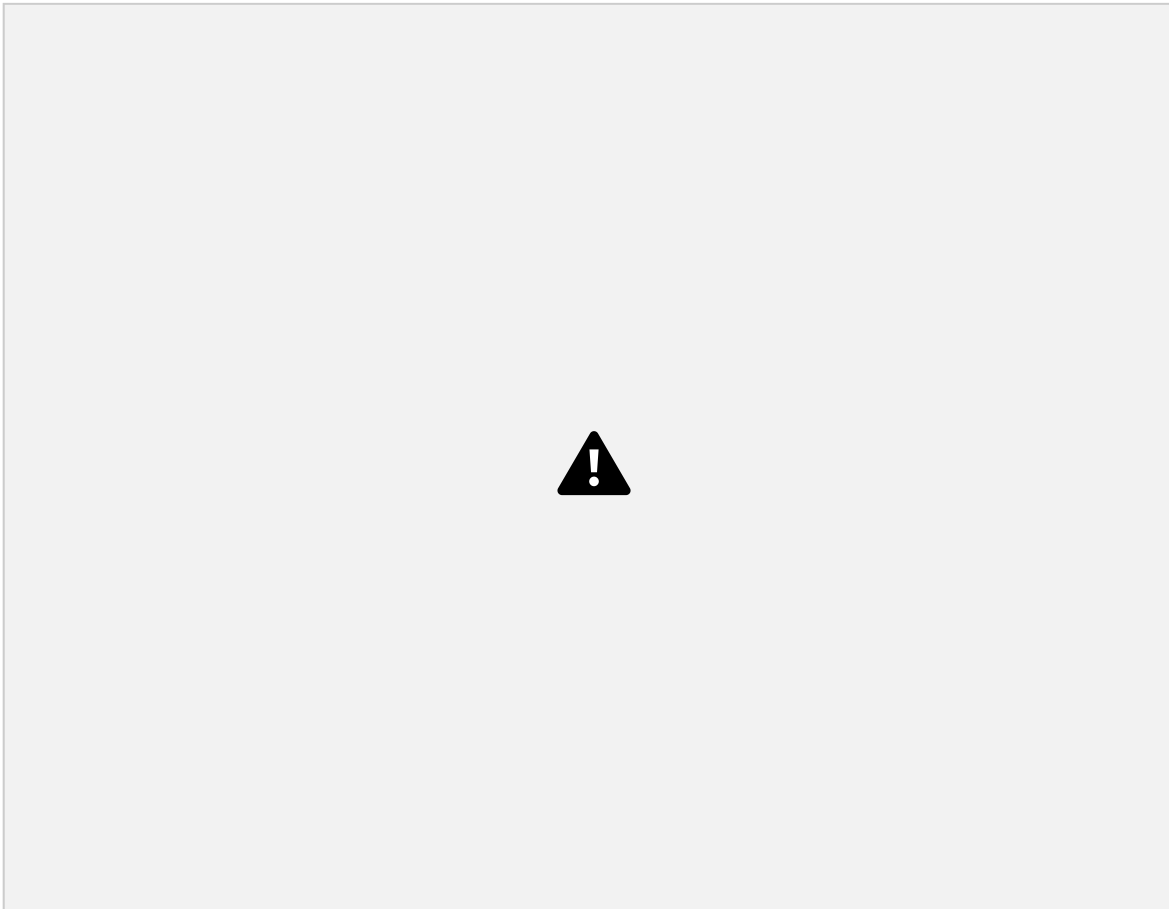


Figura 49. Distribución de dunas costeras en Playa Cerritos

The topographic profiles are presented below, as well as a schematic profile of the transects sampled in the coastal dunes of the dune system found in Cerritos. In addition, the most representative plant associations of each transect are included.

T26

T24

T25

T26

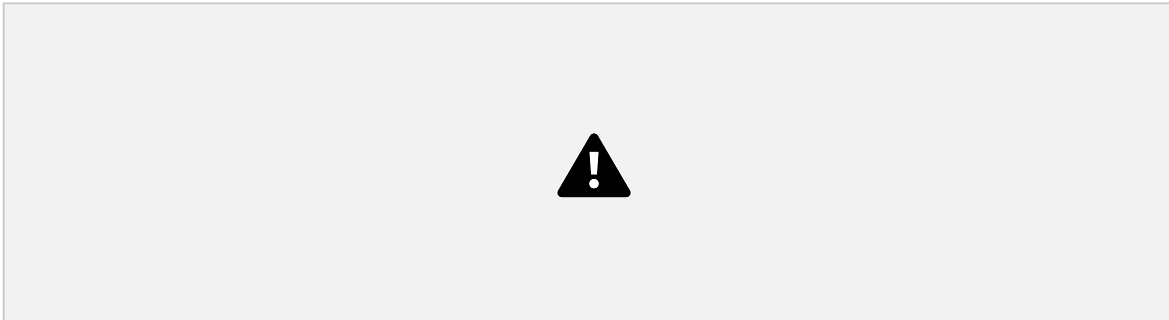
T27

T28

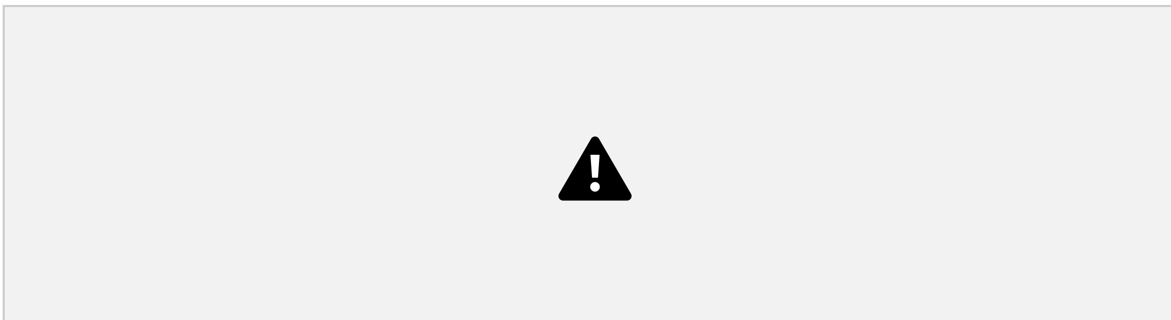
Figura 50. Distribución de dunas costeras en Cerritos-Rancho Nuevo.

T29

T30



T31



I.1.4. Ejido Plutarco Elías Calles

The coastal dune system of this section begins with a narrow strip of embryonic dunes, almost imperceptible, covered with some patches of J. pilosa; It borders on a consolidated structure (hill). To the south, the system widens, but maintains low elevation, here I. pes-caprae is observed in combination with J. pilosa, E. leucophylla and P. glabra on the beach. The embryonic dunes are dominated by O. drummondii, and J. pilosa. The slope between the embryonic dune and the frontal dune is very smooth and continuous with visible dominance of J. pilosa, M. maritima and A. subulata. At the top of the windward face is J. cinerea. At the end the dune is bounded by extensive patches of M. phyllanthoides, a common shrub in the coastal dunes in this section (Figures 46-51).