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Assessing anthropogenic impact on Mediterranean sand dunes from aerial digital photography

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Abstract. The Mediterranean region plays host to ca. 33% of the world's tourism industry. This population of visitors (ca. 147 million in 1990) inevitably exerts an enormous impact on the natural resources of this coastal zone. In May 1997, a new generation Aerial Digital Photographic System [ADPS] configured with a Kodak Digital Science 460 CIR digital camera was used to acquire colour infrared digital photographs of the sand dune systems along the Mediterranean coast of France, from Le Barcares to St-Cyprien-Plage. These have been used to assess the condition of the dunes along this coast. A series of simple analytical techniques to identify and measure features indicative of public pressure using image processing software has been devised. The dune manager with basic computer skills can analyse such indicators as path length, vegetation cover (and conversely the extent of bare sand) to enable monitoring of the performance of their dune systems under particular management regimes. These photographs have been compared with similar digital photographs of dune sites in SW France to allow a comparison of dune degradation in a region with a different population pressure and climate regime. Dune systems sampled from the Mediterranean coastal zone showed more evidence of anthropogenically induced change than those sampled in SW France.

Keywords: Dune management; Image analysis; Kodak Digital Science 460 CIR.

Introduction

This paper outlines the methodology and demonstrates simple applicable techniques for the objective assessment of dune degradation and considers whether regional differences in human impact on coastal sand dunes can be demonstrated using photographic evidence. These techniques are applicable beyond coastal dune sites and could be equally applied to overuse of National Parks and natural heritage sites.

Public pressure

Public pressure on coastal zones around the world has increased dramatically in the last 50 years. This phenomenon is particularly marked in the Mediterranean, where, since World War II, the region has been characterized by strong, often uncontrolled development and population growth in coastal areas. As a result of increasing urbanization along the 45000 km of its coastal zones, some 65% of the coastline is now developed and there are 540 coastal settlements with more than 10000 inhabitants, of which 70 have more than 100000 inhabitants and 10 with more than 800000 inhabitants. The Mediterranean coast is now home to around 400 million people, (7% of the world's population) and to 16% of the world's industry (Tabet-Aoul 1995).

Tourism is a highly dynamic industry and the coastline of France is invaded by ever increasing numbers of French and foreign visitors each year. Indeed, there has been a 240% increase in accommodation for tourists in the whole of France in the last 25 years (Anon. 1998) though as Tuppen (1983) reported, not all areas of the coast seem equally attractive to visitors. The Mediterranean region has experienced an explosion of international tourism (Tabet-Aoul 1995) whereas the SW coast of France has not shown such rapid and vigorous growth. This disparity in the extent to which visitor numbers have grown, as well as differences in the climatic regime and the management programmes has led to distinct regional differences in terms of sand dune erosion.

Impact on the dunes

Coastal sand dunes have been identified as being particularly susceptible to destabilization through visitor pressure and although changes in sand supply and loss from beaches are also serious physical threats to dunes, this paper will concentrate on human impact on coastal sand dunes particularly along the Mediterranean coast near Perpignan.

In the natural state, sand dunes are dynamic geomorphic features which are able to adjust to stress but it is well established that dune vegetation is susceptible to trampling by animals and humans and to crushing by vehicles (Liddle & Greig-Smith 1975; Williams et al. 1997). It is generally accepted that a threshold can be reached where irreversible damage can occur when recovery is unlikely and at worst impossible (Alveirinho-

Fig. 1. The ADPS - Kodak Digital Science camera mounted on shock and vibration resistant chassis, Intervalometer and Trimble Ensign XL GPS receiver.

Dias et al. 1994). One fundamental expression of human impact on dune sites is the development of access paths linking car parks to the beach and in extreme cases, the paths allow vehicle access to the dunes with parking and allied activities such as camping on the dunes themselves. The dune sites along the French Mediterranean coast between Le Barcares and St-Cyprien-Plage have been subjected to unprecedented levels of pressure by tourists and by the increase in residential populations. Mere fragments of dune now remain between the high density residential and coastal amenity structures with a consequent reduction in their coastal protection role and amenity value.

In many of the dune sites in SW France there is rapid sand accumulation at the seaward edge of the dune with many prograding ridges. These new ridges are an integral part of the dune system, and because there has been insufficient time for vegetation to colonise them, they naturally support a sparse vegetation cover of pioneer species. Since succession of newly exposed land forms can take several years, and as dune systems accrete seawards there is a progressive increase in vegetation cover from the front to the rear of the dune (Begon et al. 1986). These variations in vegetation cover must be included in any analysis of the degree of vegetation loss to provide a base line from which deviation can be measured.

Whilst studies of numerous dune sites have clearly documented the features, processes and stages of dune degradation (e.g. Nordstrom & Arens 1998; Arens 1996; Nordstrom et al. 1990; Louisse & Van der Meulen 1991), the regional extent and rates of such environmental change are less well known. Aerial survey using small format digital cameras is a relatively inexpensive way of surveying long tracts of coastline in a short time (Edwards et al. 1996). Many of the features laboriously recorded in the field can be identified from digital images, including the area of the dune field, the extent (and often type) of vegetation cover, the extent of bare sand, as well as elements such as path networks, blow-outs, and breaches in the dune front. Features such as path networks can be quantified, providing a useful indicator of public pressure. Repeat surveys provide the opportunity of monitoring change through time.

The Aerial Digital Photographic System [ADPS]

The Aerial Digital Photographic System used for this research was developed at Bath Spa University College and comprises three principal components:

- Kodak Digital Science 460 CIR (colour infrared) camera;
- Aircraft mounting plate with shock and vibration resistant chassis;
- Power unit with intervalometer to manage the framing sequence.

The assembly is self contained, transportable and can be easily mounted in a light aircraft within minutes (Fig. 1). The system is easy to use since it can be operated like a film based small format camera.

Colour infrared photography allows better discrimination between types of vegetation and assessment of plant vigour than true colour photography. The spectral

sensitivity of the sensor in the CIR versions of the cameras was designed to mimic that of Kodak 2443 colour IR film (King 1997). The range is governed by the quality and sensitivity of the silicon based CCD detectors (Anderson et al. 1997) and spans the entire spectrum of visible light, extending well into the near infrared (400 nm to 1000 nm). The camera is supplied with two filters:

- CIR filter (650BP300) in the 500-800 nm spectral band, allowing wavelengths between 500 nm and 810 nm only to reach the CCD, enabling the CIR cameras to record in false colour infrared.
- VIS filter (VIS 550BP300) in the 400-700 nm spectral band enabling the CIR cameras to record natural colour.

Methodology

Research sites

10 dune fields from the Mediterranean coastline near Perpignan, were investigated for the effects of human impact on the dunes. These were compared with ten dune sites from the SW coast of France (Table 1). Although this is a small sample from both regions they are considered typical of the dunes in those areas, and provide worked examples to show how the analysis may be used to assess human impact on dunes. The areas flown are shown in Fig. 2, and for the sake of simplicity will be referred to as either SW or Mediterranean France.

Image acquisition

Two aerial photographic surveys were flown of the dune coasts of (1) the Mediterranean coast of France from Le Barcares to St-Cyprien-Plage and (2) the Atlantic coast of France from Arcachon to L'Ile de Noirmoutier, during May 1997. For both surveys a Kodak Digital Science CIR camera fitted with a 28 mm focal length lens and an Omega 650BP300 CIR filter was used to acquire colour infrared photography. The camera was mounted vertically in a light aircraft (Partanavia). Each sortie was flown at 90 knots, 4090 ft above ground level (AGL) resulting in a pixel resolution of 40 cm. Photo coverage, flight line spacings, required survey ground speed, aircraft altitude, magnetic media requirements and camera framing rates were calculated using a flight planner developed in house. Flight track waypoints and aircraft altitude from the planner were uploaded to a GPS receiver and routes were constructed, enabling the GPS to automatically compute the navigation information for use in flight. The onboard GPS was set to log the position data during the survey and since both the GPS data and the image data are tagged with a time code, a position fix was obtained for each image frame.

Fig. 2. Location of coastal sand dune sites.

Image processing and analysis

The images were acquired and enhanced using Adobe Photoshop and were then rectified in ER Mapper using ground control points derived from GPS survey and 1:25 000 IGN maps. The area of the dune field was determined in the digital image, as was the extent of the vegetation cover and the bare sand in the defined dune field.

The extent of the vegetation cover in several undisturbed areas of each of the dunes sites was recorded, establishing a vegetation cover baseline from which a simple weighting factor was derived to compensate for naturally occurring variations in vegetation abundance and distribution. The total bare area in each dune site consisting of both naturally bare and anthropogenically devegetated areas was assessed, and the weighting factor was applied to calculate the bare area resulting solely from anthropogenic impact. Path networks were digitized to define path length and path network density establishing their relationship with the area of the dune field and the area of bare sand within the dune (see Table 1).

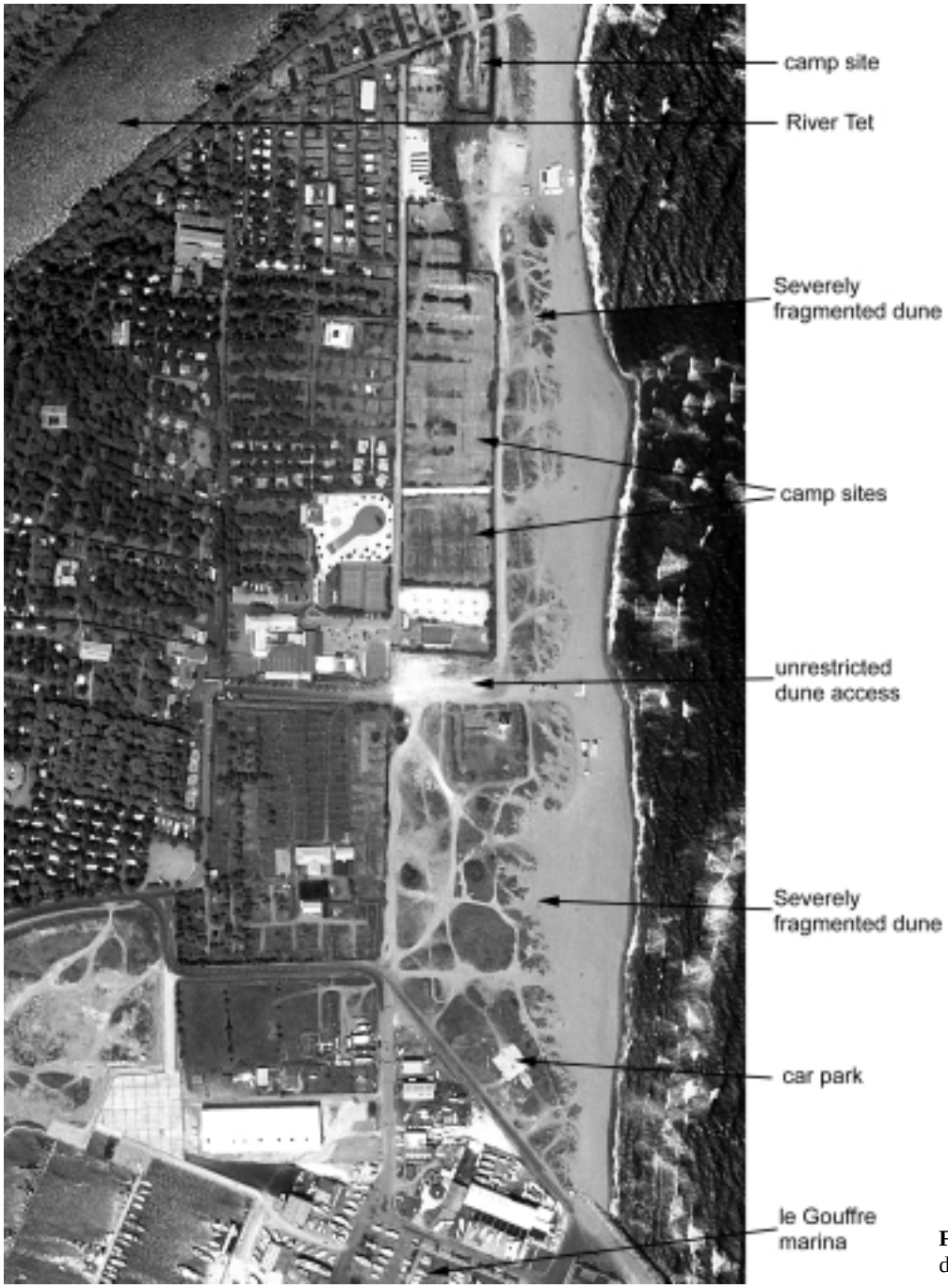

Fig. 3. Digital image of dunes at Canet Plage.

Results

Visual analysis

Simple visual analysis of digital images as either hardcopy or screen display can yield much useful information for the dune manager without the need for sophisticated image processing. Large tracts of coastline can be assessed rapidly for overall condition and routine checks. Fig. 3 shows a colour infrared image (rendered greyscale) of a dune site between Mas Boix and Mas de la Crouste, just north of Canet Plage. This site is typical of the many isolated and fragmented dunes located between residential and holiday accommodation on this Mediterranean coast under severe pressure from human use. Some car parks have been sited within the dune but it is clear that there are no barriers preventing general vehicular access to the

Table 1. Parameters measured in the digital images.

Location	Dune site	Dune area ha	Path length m	Path density m/ha	Bare area m^2	Bare area m^2/ha
SW	Oleron 1	7.65	1916.40	250.57	15837.29	2070.74
SW	Trojan Gr Plage	4.09	1899.00	464.09	5892.01	1439.94
SW	Chardons P d'Arcay	15.28	6792.60	444.64	38139.28	2496.55
SW	Bellugas P d'Arcay	16.36	5509.50	336.80	29567.48	1807.47
SW	Hourtin	36.40	10384.40	285.25	143586.14	3944.19
SW	Oleron 2	8.25	2264.10	274.54	18250.40	2212.97
SW	La Pege St J d M	19.96	10026.30	502.28	44726.49	2240.64
SW	des Salins St J d M	2.56	979.20	382.69	6050.97	2364.85
SW	Jesus N St J d M	4.63	3647.10	787.04	11912.76	2570.76
SW	Noirmout-Frandiere	5.93	2988.60	503.81	13481.28	2272.62
Med	Barcares	16.65	6737.00	404.69	52160.48	3133.27
Med	La Crouste	6.13	5271.00	859.70	24891.52	4059.82
Med	La Ribere	25.32	9040.00	357.04	93730.24	3701.92
Med	St Cyprien	4.92	2620.00	532.98	15855.68	3225.50
Med	Capellans	8.91	4254.00	477.48	35190.40	3949.87
Med	srrignac	4.36	2802.80	642.73	25762.08	5907.67
Med	Nazaire S	23.80	10002.00	420.25	81707.52	3433.11
Med	Nazaire N	18.07	13527.20	748.44	63936.48	3537.51
Med	Pissevache	21.29	12735.20	598.04	103594.88	4864.76
Med	Toreille	18.99	7696.00	405.25	81006.56	4265.59

dune, and, although this coastline was imaged early in the vacation season, detailed examination shows some vehicles within the dune.

The dune is crossed by numerous paths of varying size, some devoted to pedestrian use, but many wide enough to allow vehicular access to the beach. Such paths fragment the dune, forming discrete vegetation units and under increasing and uncontrolled trampling pressure, paths widen with an associated progressive degeneration of the dune vegetation. Loss of vegetation in this way can render the dune system susceptible to rapid marine and aeolian erosion leading to destabilization of the dune system. All of these anthropogenically induced processes are noticeable adjacent to the harbour at le Gouffre, where the dune is severely fragmented. Further north, towards the River Tet, camp and caravan sites are located immediately behind the remaining dune vegetation.

Digital analysis

Although visual analysis provides useful general information about the dune site and surrounding area, aerial photography gives an unparalleled opportunity to assess the condition of the dune quantitatively once they are rectified. Measurement of area and distance is possible, e.g. area of the dune field, area of bare sand and vegetation units etc. Path network densities in the dune field, and their relation to public access features such as the road network, car parks and holiday facilities, including hotels and camp sites can be measured. Parameters measured from the aerial images using digital image processing software are tabulated below.

Loss of dune vegetation poses a significant threat to the survival of a dune system and the degree of vegetation loss is an important indicator of the prevailing condition of the dune system. Fig. 4 shows a comparison of the degree of devegetation at each dune site in the context of the total dune area.

The vegetation loss in the Mediterranean dune sites sample indicates that they are the more degraded of the

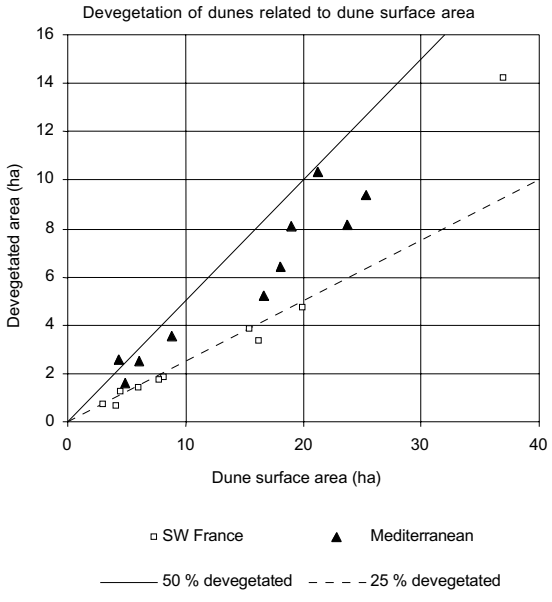

Fig. 4. Devegetation of coastal sand dunes in SW France and Mediterranean France.

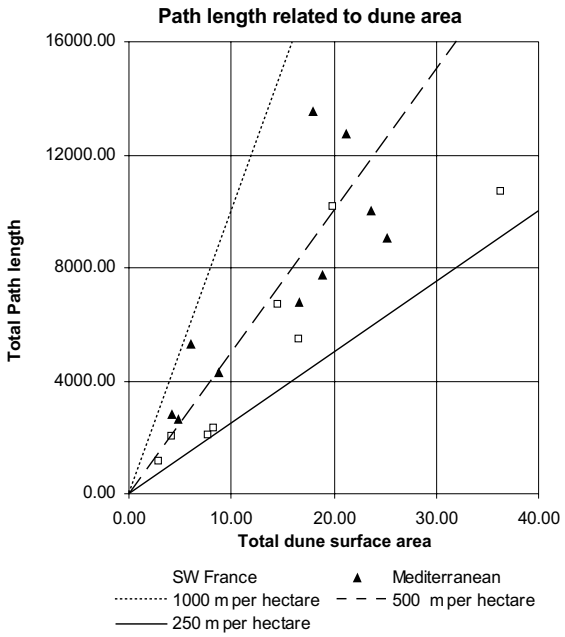

Fig. 5. Path length in relation to dune surface area in SW France and Mediterranean France.

two dune regions examined with all of these sites greater than 25% devegetated, whereas 90% of the SW dune sites fall below the 25% devegetated line. These Mediterranean dune sites are under intense pressure from the development of tourist facilities, often with small fragments of dune surrounded by hotel and campsite complexes with the concomitant human impact.

Fig. 5 shows the relationship between total path length and total dune area (average path network densities have been inserted for guidance). As might be expected the general relationship is positive, but the distribution of data points indicates that there are greater total path lengths in the Mediterranean examples than those from SW France. Of the 10 SW France sites, nine have path densities between 250 m/ha and 500 m/ha, and only one with a path density in the 500 m/ha to 1000 m/ha range. In contrast, 50% of the Mediterranean sites have path network densities in excess of 500 m/ha.

Fig. 5 should be considered in conjunction with Fig. 6, in which the devegetation of the dunes is plotted against path length.

The relationship again is positive for both series of data but the Mediterranean sites have suffered greater vegetation loss for any given path length, with one or two exceptions. This figure demonstrates that paths are generally wider in the Mediterranean dune sites than in the SW examples.

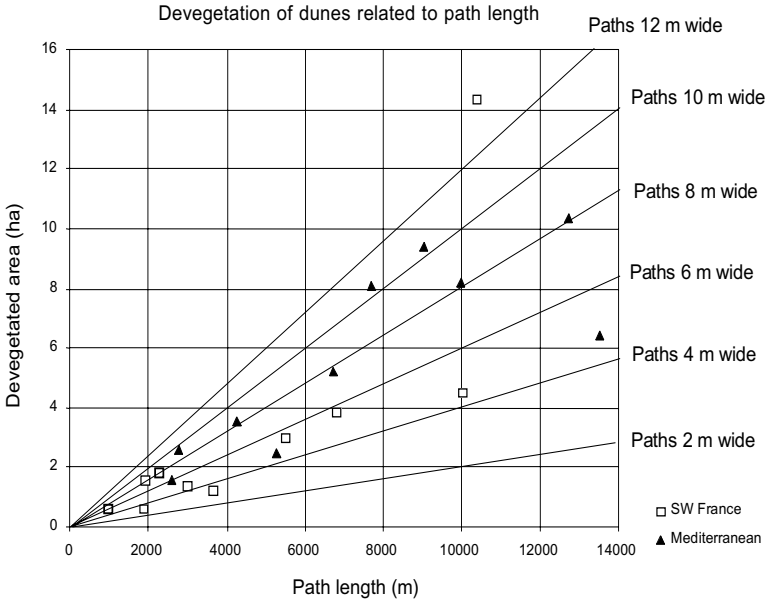

Fig. 6. Devegetation related to path development on dunes in SW and Mediterranean France.

Discussion

The character of the two data sets suggests that there is a distinct regional difference in the degree of degradation, reflecting a number of different factors. Figs. 4 and 6 show that the degree of devegetation on the dunes of the SW coast is less than that on the Mediterranean dunes. This lower value is partly the result of lower visitor pressures on this long dune dominated SW coast, which is often backed by dense forest, and where good management techniques, including careful control of access, has minimized human impact on the dunes. The lower value probably also reflects the current active and rapid accumulation of sand deposits along much of the SW Atlantic coast of France. The different climatic regimes of the two regions could also have an effect on the vulnerability of the vegetation to human impact. It is interesting to note that in both of these analyses, one dune site in particular in the SW data series has plotted well outside of the mean. This data point represents the development of an intensive recreational facility at Hourtin Plage (SW coast) which has had an atypically large impact on the coastal dune compared with the rest of the SW sample. This emphasises the need for protection of the dunes in this region, even where their extent and rate of sand accumulation suggest considerable resilience to public pressure.

There is strong evidence to suggest that footpath development on dune systems may be a useful indicator of public pressure and to indicate the degree of wear average path widths have been inserted in Fig. 6, for example, for a total path length of 10000 m with an average path width of 2 m, the devegetated area would be 2 ha. It should be stressed that these are theoretical values and there is considerable variation in path width, just as there are devegetated areas which are not described as paths such as areas adjacent to paths where camping sauvage or car parking has occurred. Using the length of the path network as a surrogate for visitor pressure and plotting the area of bare sand against path length the impact of visitor pressure can be assessed. Dunes with low visitor pressure exhibit short, narrow paths and relatively small additional areas of bare sand in relation to the undisturbed cover. High visitor pressure on the dunes results in many interlinked paths, widening and extension of the paths and enlargement of the path nodes.

Path widths are generally narrower in the dunes sampled from SW France than in the Mediterranean cases. For example, the paths on 70% of the sampled dunes from SW France average between 2 and 6 m wide, whereas the paths on 70% of the dunes sampled in the Mediterranean average between 6 and 12 m wide, indicating the greater degree of wear in the latter case. The badly degraded Hourtin Plage site on the Atlantic coast north of Arcachon stands out as extremely degraded in this analysis, warranting the current intensive management effort to recover this dune site. The narrower path widths in SW France result from the management strategies often employed in this region, where either controlled paths lead directly from the car park at the back dune to the sea front, before beach users are allowed to disperse, or where car parks are sited near the dune front, with controlled walkways to the beach before dispersal is allowed. In contrast, the higher path densities (and consequent loss of vegetation cover) in the Mediterranean examples indicate more lateral or cross linking paths.

Annual surveys can be used to monitor changes in both path length and the extent of bare sand, and the use of change detection techniques in digital image time series can quickly identify further degradation or colonization and recovery.

Conclusion

Colour infrared airborne digital photography provides an effective and efficient means of gathering data which can be used to assess the condition of coastal dunes providing objective evidence for decision making in dune management. Whilst the factors which influence the vegetation cover in dunes are complex, the devegetation impact of visitor pressure is clearly shown in the form of paths and associated features. Such phenomena can be accurately assessed and analysed using the techniques demonstrated above. Application of the techniques identified regional contrasts in dune degradation with Mediterranean systems showing greater anthropogenically induced changes than systems in SW France.

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