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Beach recreation planning using video-derived coastal state indicators

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Abstract

This contribution proposes Coastal State Indicators (CSIs) for application to different aspects of recreational beach management. The beaches considered in this study are important leisure and tourism resources and of primary concern to the managers responsible is the recreational carrying capacity of the beach. Given the range of factors which potentially affect the carrying capacity this contribution is restricted to just two variables: the level of beach-use and safety. For each variable a detailed management framework is proposed together with a specific methodology to monitor appropriate CSIs. In all the cases, the proposed indicators make use of the capabilities of Argus video-cameras to record multi-purpose information in a single image. Specific algorithms are developed to deliver video-derived variables which are combined with supplementary data (e.g. wave and tide information) to yield beach management CSIs. The application of these CSIs is illustrated via two case studies.

Keywords: Beach safety; Beach hazards; Beach-use; Carrying capacity; Beach management

1. Introduction

In general terms, there are three main managerial concerns relating to beaches: protection, recreation and supporting natural values. Each of these functions refer to a specific role of the beach surface: (i) absorbing/dissipating the incident wave energy during storms reducing its impact on the hinterland, (ii) offering an environment for leisure and (iii) supplying a physical substrate for the development of coastal ecosystems.

Although these functions are usually present simultaneously, there are cases where one of them is dominant due to the characteristics of the area where they are located, or due to the type of use and/or management. Within these "beach specialisations", the most prominent is recreational (Fig. 1) and due to their worldwide exploitation for coastal tourism, beaches are extremely important economic resources.

If recreation is the main function to be preserved or enhanced on a given beach, any management or planning option has to be designed to take into account all factors controlling the recreational carrying capacity of the beach.

In general the term "*beach carrying capacity*" refers to the quantity and type of visitor that can be accommodated within a given area (the beach) without unacceptable social consequences and negative impact on resources (adapted from Manning and Lawson, 2002). Two main aspects are usually included in the assessment of the recreational carrying capacity: the integrity of the resource-base and a behavioural component. The interaction of these key components is collectively known as the "*biophysical component*" and describes the quality of the recreational experience (Sowman, 1987). In beaches subject to intensive recreational use, the recreational experience is primarily affected by physical factors. The fundamental

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Fig. 1. Example of beach managed for recreational/tourism purposes, La Cebada beach (Fuerteventura, Canary Island, Spain).

requirements of beach-users are basically limited to a clean beach (water and sand), services, access and availability of space (Pereira et al., 2003).

Taking this dependence into account, the carrying capacity can be decreased by both a degradation of the beach and/or services, or can be exceeded by the presence of an excessive number of users. Both cases are suboptimal from a recreational management standpoint.

With these antecedents, it is clear that to properly manage the beach from a recreational standpoint, the beach manager should be interested in the control of all the factors which affect the carrying capacity. Thus, when the beach is mainly used (or exploited) for recreational purposes (leisure and tourism) the interest (and need) of the beach manager can be expressed in terms of a series of questions and/or statements such as:

- Is the status of the beach good enough to satisfy users/tourists needs?
- Is it possible to sustain/increase beach tourism?
- Is it desirable to optimize beach-use and exploitation?
- Is it desirable to maintain/increase beach tourism?

These management-oriented questions can be put in terms of more “simple” and implicit question(s):

- What is the actual carrying capacity of the beach?
- What will the carrying capacity of the beach be at time *t* (temporal extrapolation) for a given management option?
- What can be done to enhance the beach carrying capacity?

All of these questions can form the basis for a managerial ‘*Frame of Reference’* (Van Koningsveld, 2003). The reader is referred to Davidson et al. (2007-this issue) for a detailed discussion of the Frame of Reference. Regarding the use of the beach for recreational purposes, the overarching management vision (or *strategic objective*) of the beach manager should be to *maintain/enhance the beach carrying capacity* (Fig. 2). The *operational objective(s)* describe what must be done to achieve this management objective. In this case the operational objectives relate to all the various parameters which affect the beach carrying capacity. Thus, the proper definition of these objectives requires thorough monitoring/measurement of all aspects that the beach (and the

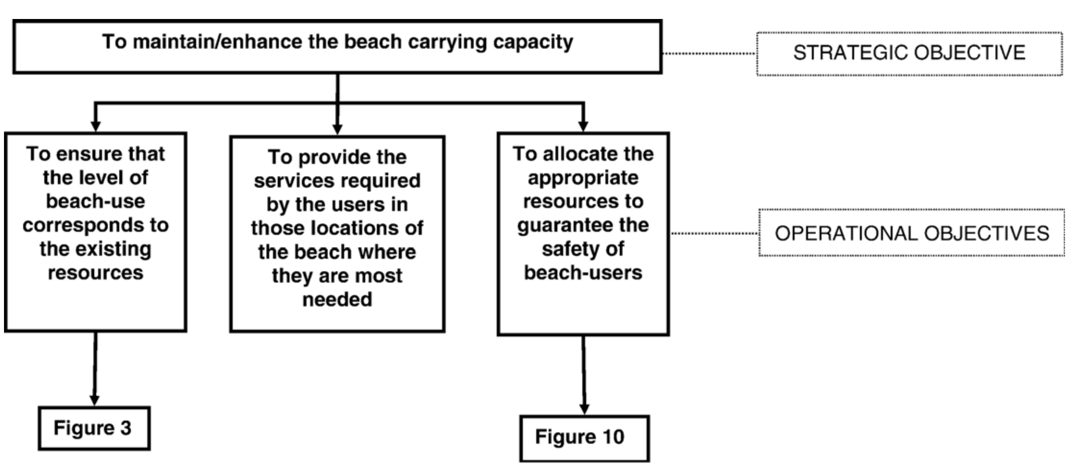

Fig. 2. Frame of Reference for recreational beach management.

manager) has to provide (and to manage) namely: *Resources, Services and Safety* (*R-S-S*).

Resources refer to the main characteristics of the resource-base to be exploited (the beach) which will control and modulate the intensity and capacity of use. In essence, they are natural parameters intrinsic to the beach such as the available beach surface, water/sediment quality and aesthetics.

Services are directly provided and controlled by beach manager and depend on the type and intensity of the use of the beach. In general terms, the larger the number of users of the beach, the larger the number of existing services will be. Thus, urban and semi-urban beaches are the ones with a highest demand on services (by the users) and consequently they should have better developed services (by the manager). They are designed to facilitate the use of the beach and to make the users' experience more comfortable and include easy access, showers, bars, sun beds and WCs amongst other things.

Safety is an aspect of the beach that is controlled by both the natural beach and the manager. The "natural part" is determined by the intrinsic hazard of the beach which depends on the bathymetric and hydrodynamic conditions (hazardous conditions) whereas the "managerial part" is related to services provided to manage such conditions (e.g. lifeguard services, public hazard warnings).

Within this framework, the *operational objectives* of the beach manager could be expressed in the following terms:

- to ensure that the level of beach-use corresponds to the existing resources;
- to provide the services required by the users in those locations of the beach where they are most needed;
- to allocate the appropriate resources to guarantee the safety of beach-users.

To achieve these operational objectives (Fig. 2), the beach manager needs detailed information on all variables affecting the management process and a way of monitoring progresses towards realising a given management objective. Due to this, it seems evident that the availability of an efficient data acquisition/monitoring system will play a key-role in this process. Video monitoring techniques provide an attractive solution to this problem and can efficiently produce part or all of the R-S-S data required by the beach manager, (Holland et al., 1997; Davidson et al., in press).

The main aim of this paper is to demonstrate the utility of coastal video systems and video-derived variables/Coastal State Indicators or CSIs, (Davidson et al., 2007-this issue) for assisting coastal managers with recreational beach management and monitoring. The derivative R-S-S status will control the recreational carrying capacity of the beach and inform the development and refinement of management strategies for better beach planning, exploitation and management.

Due to the broad scope of this topic, discussions are restricted here to the most influential aspects: density of beach-use and safety. In both cases a common format is followed: (i) a general introduction to the role of relevant variable to the management and exploitation of recreational beaches; (ii) the definition of the variables to be measured and a description of the role of video data and (iii) an application to a real case study.

2. Measuring the level of beach-use

2.1. Introduction

The policy implemented for the management of a given beach is strongly influenced and shaped by the intensity of beach-use. This means that one of the key variables required by the manager is the number and distribution of beach-users (in both space and time), which will be used together with the estimation of the recreational beach carrying capacity to properly design a management plan.

Although the number of beach-users is one of the main data resources required for estimating the level of beach-use, time-series of this variable are seldom available. The most common situation is the existence of sparse data taken by counting in situ users (at the beach) or by analysing aerial photographs. This will allow the beach manager to establish patterns of spatial and temporal distributions of beach-users as well as an estimate of the density of beach-users, (De Ruyck et al., 1997; Yepes, 2002; Polette and Raucci, 2003 among others).

In essence, one of the first questions that the managers have to answer before launching any management plan for a recreational beach is "how many users do we have at the beach at a given time and at a given point?". These data will facilitate:

- the effective planning of services
- rearranging/optimizing beach accesses
- accurate estimation of beach-use during the season
- estimation/measurement of crowding "events"
- reliable carrying capacity forecasting (when combined with beach surface area evolution estimates).

Taking into account all the aspects listed above, the value of a technique capable of measuring the number of beach-users at proper temporal and spatial scales is self evident. In this respect, Argus video-cameras are an excellent solution to this problem as they measure several kilometres of beach continuously throughout the daylight periods. Thus, video images provide a multi-purpose data source whereby a single image will contain information relevant to several aspects of beach management in addition to those which are more routinely evaluated for physical coastal processes (Holman et al., 1993; Holman and Stanley, 2007-this issue).

Fig. 3 shows a Frame of Reference designed for recreational beach management, where the operational objective is "to ensure that the level of beach-use corresponds to the existing resource". This objective implies that the beach manager has to know the number and temporal variability of visitors as well as the associated facilities to avoid exceeding the beach carrying capacity. Knowledge of the spatial distribution of beach goers is also required in order to effectively plan the location of the services.

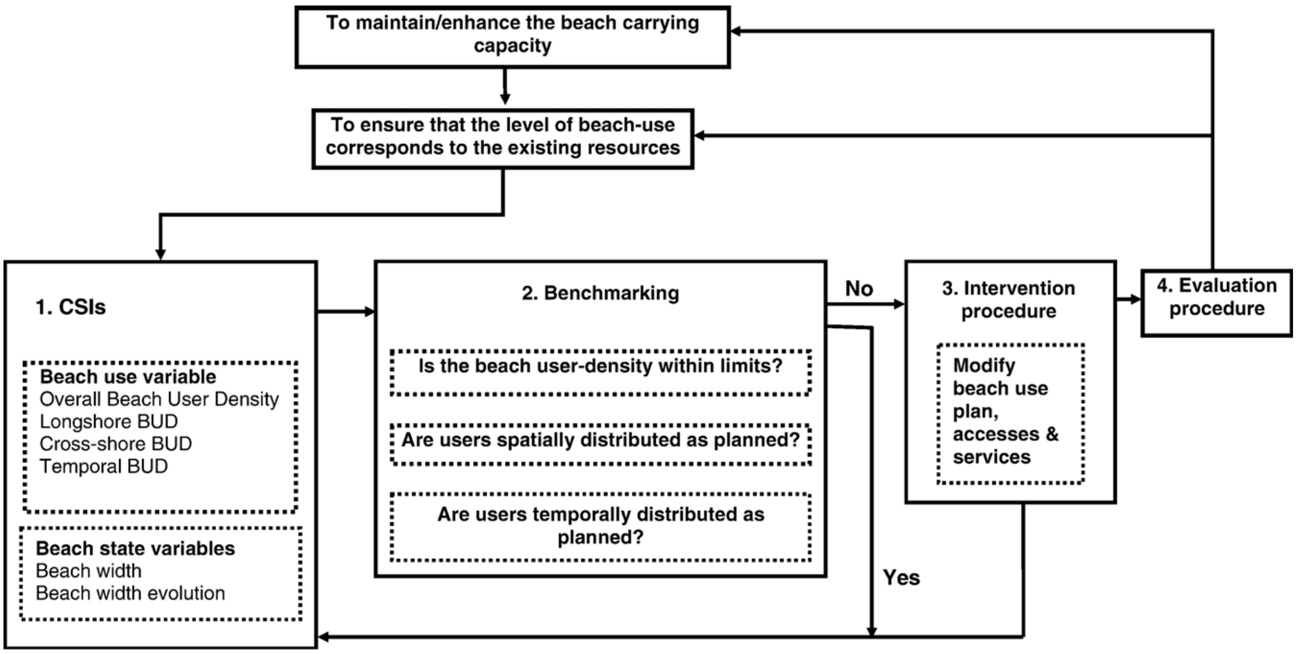

Fig. 3. Frame of Reference for analysing the level of beach-use.

This planning has to be finalised before the start of the beach exploitation season and it requires data on occupancy and use of the beach gathered during the previous season (including any expected variation in the number of visitors) and the actual physical status of the beach. These data are used to derive a key variable, the Beach-User Density (BUD), which is defined as the number of beach-users per unit area. To properly define the exploitation plan for the beach, the manager needs to know the spatial (longshore and cross-shore) and temporal distributions of the BUD. This has to be combined with variables related to coastal stability aspects such as the beach width (e.g. Kroon et al., 2007-this issue) which exert a major control on beach carrying capacity. An example of the utility of these two kinds of variables in beach recreation management can be found in Valdemoro and Jiménez (2006) who used them to forecast variations in beach carrying capacity by combining a given Beach-User Density with the long-term evolution model for beach width.

The pre-mentioned variables may be aggregated to yield Coastal State Indicators which can be monitored relative to benchmark values and used to directly to trigger management interventions (Davidson et al., 2007-this issue). For example if the spatiotemporal variability in beach-users is denoted by $P(x, y, t)$, where x and y are the cross-shore and longshore positions respectively, then an appropriate time-varying (overall) Beach-User-Density CSI is given by: $\mathrm{BUD}(t)=\iint P(x, y, t)\mathrm{d}x\mathrm{d}y$. BUD$(t)$ may be compared directly to benchmark values defined in the management plan for the beach. If the actual level of beach-use falls within the tolerances defined in beach management plan then no further adjustments are required to satisfy this operational objective. If however, the level of use differs from the target value, the beach plan must be redefined by the beach manager to cope with new conditions (Fig. 3).

In what follows, the application of video to derive indicators related to this operational objective is presented. Since the application of video to monitoring physical state of beach conditions is covered extensively elsewhere (Kroon et al., 2007-this issue), here the discussion is confined to the derivation of Beach-User Density at El Puntal (Santander, Spain) (see description of the site in Medina et al., 2007-this issue).

2.2. Methodology

The utility of video to measure the use of the beach is illustrated here by means of a procedure developed to provide the number of beach-users and their position on the beach. It

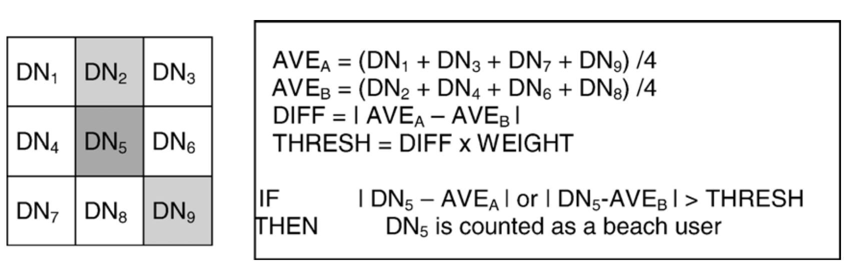

Fig. 4. Example of kernel algorithm employing a 3×3 pixel neighbourhood. (WEIGHT is an analyst-specified weighting factor).

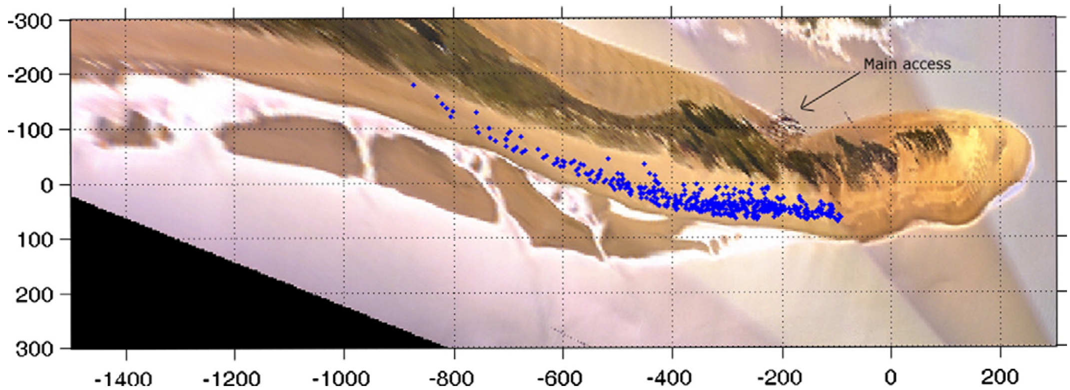

Fig. 5. Identification of individual users in El Puntal beach (Santander, Spain).

includes the utilization of an image analysis algorithm and a calibration–validation procedure.

The image analysis algorithm employed to locate beach-users is a "salt and pepper" kernel function which is adapted here to identify a person on the beach by comparing the digital value of the intensity of each pixel with its neighbours. If the difference between the digital value of the intensity of a given pixel and the mean of its surrounding pixels exceeds a specific threshold, the pixel or pixel group is identified/counted as a person (see Fig. 4). This type of algorithm has been frequently used in satellite image analysis (Lillesand and Kiefer, 1984) and it has proven its robustness for isolating single elements provided the resolution of the image is adequate. A similar methodology is implemented by Medina et al. (2007-this issue) for identifying the location of navigational marker buoys.

The method is applied in a two-step process: training and application. The first part of the process consists of a *training phase* in which a set of images are selected from the complete data base for calibration and validation purposes. In each image, the users' position are manually identified by the operator and by using the proposed image analysis algorithm. During this phase, fitting/calibration parameters such as the intensity threshold are obtained in an iterative manner. Once the calibration process is concluded, the algorithm is validated with unseen images.

To adjust the algorithm to the local conditions, the method has to be calibrated so that in practical terms proper values of the kernel size and the threshold value can be identified, thus, accurately detecting the presence of a beach-user. The selection of the first variable, kernel size, depends on both the camera resolution and the density of beach-users which will control the number of persons per pixel. The threshold value used to identify the presence of a user is related with the HSV (hue, saturation, and brightness) values of pixels including users compared to "beach" pixels (without users).

Once the optimum kernel size is determined for the local conditions, it is applied to each pixel in the study area to determine/identify the pixel coordinates (u, v) of each beach-users on the image. Once these image coordinates (u, v) have been calculated, they are converted to "real world" coordinates (x, y, z) by using the method proposed by Holland et al. (1997).

In the application of the method to El Puntal, the z-coordinate is assumed to be a mean value between the dune foot and the shoreline at low tide and the area of detection is defined as the surface of the beach limited by the shoreline and the dune

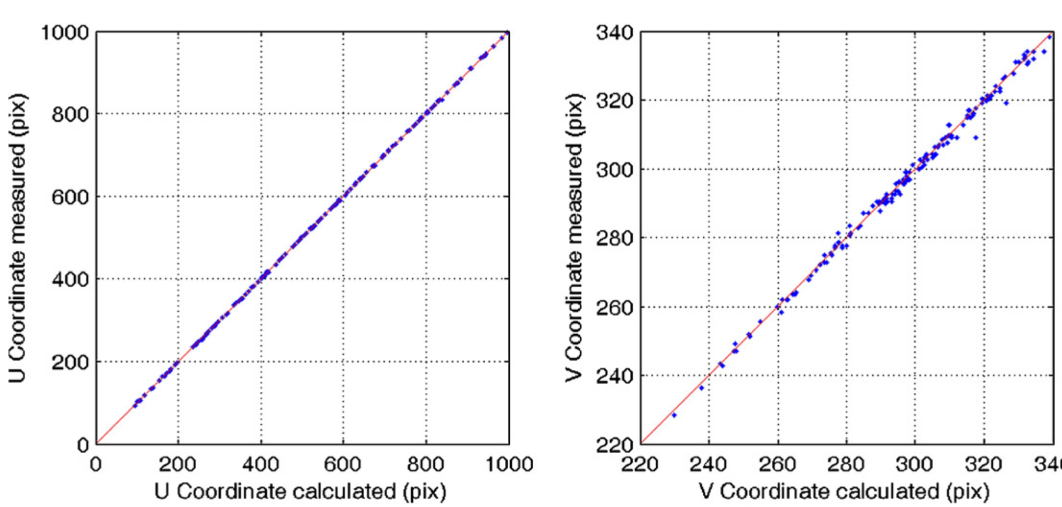

Fig. 6. Measured user position (X-, Y-coordinates) vs detected one.

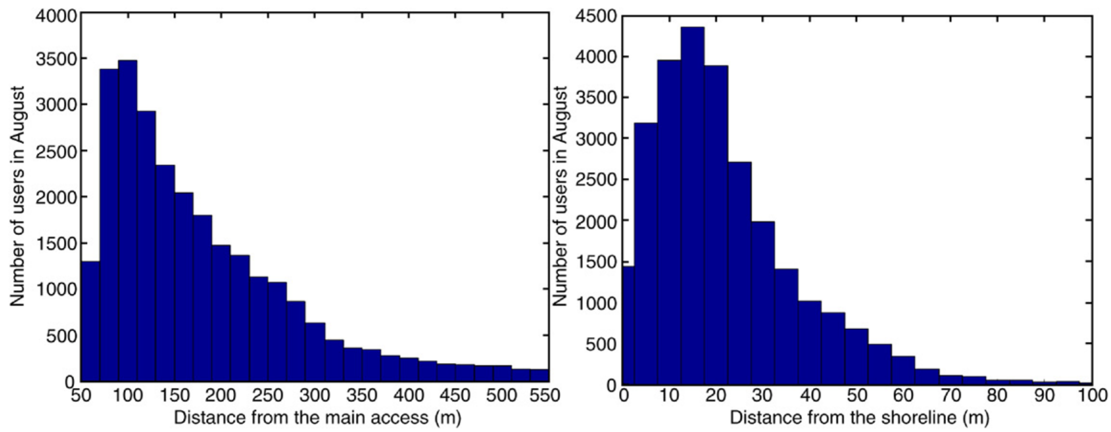

Fig. 7. Spatial distributions of beach-users in El Puntal during August 2003. (a) Histogram of the distance of users from the main access. (b) Histogram of the distance of users from the shoreline.

foot. Fig. 5 shows an example of the identification of single users in El Puntal in an image taken in the peak of the summer season, (9th August 2003). The accuracy of the automated routine was assessed by comparing the values obtained by manually clicking on the same image, (Fig. 6). A very good agreement was found in all cases.

2.3. Application

Once the algorithm has been properly calibrated and validated, it is used to estimate the beach-user position from all the images in the data set and to derive the desired variables characterising the beach-users during the season such as Beach-User Density and the spatial and temporal distribution of users.

The algorithm developed here has been used to determine the spatial distribution of beach-users ($P(x, y, t)$). This analysis reveals useful behavioural tendencies of visitors including their preferential selection of beach position in relation to other beach-users, access points and the sea. Fig. 7 shows the histogram of distances of beach-users in relation to the main beach access during August 2003 at El Puntal beach. This beach is located at the end of El Puntal spit, and it is one of the most popular beaches in the urban area of Santander (Medina et al., 2007-this issue). Although it is possible to access the area from the mainland by walking along the spit (3 km), most beach-users get there by boat using a ferry connecting Santander City with a pier located at the spit end (see arrow in Fig. 5). Consequently, it can be assumed that most beach-users at a given instant have accessed it through a single entrance; making this an ideal site to test the role of beach access points in controlling user distributions. With this constraint, most of users are located between 100 m and 250 m from the access with the peak of users being located at 150 m. Osorio (2006) found that the spatial pattern of beach-users at El Puntal follows a log-normal distribution. The longshore distribution of beach-users is clearly asymmetric reflecting the fact that users tend to prefer the beach western area which is located furthest from the busy shipping channel, (see Fig. 5).

In beaches with frequent and well distributed access points along their length and without any point of attraction/repulsion at either end, the spatial pattern of users should be a normal distribution for each access. Depending on the separation between access points these normal distributions can overlap; and on urban beaches the presence of numerous access points will produce a near homogeneous distribution of users along its length.

Fig. 7 shows the cross-shore distribution of beach-users ($P(x, t)$), measured relative to the shoreline (defined as the neap high-tide position), for all visitors during August 2003. The results show that most of the users are located in the first 30 m from the shoreline. This type of cross-shore distribution, whereby the beach area closest to the shoreline is the most occupied, conforms to the usual case (MOP, 1970; Yepes, 2002; Polette and Raucci, 2003) and reflects the pre-mentioned effect of the

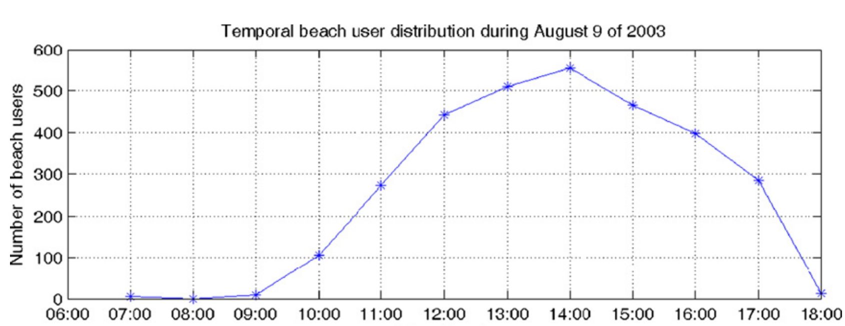

Fig. 8. Hourly distribution of users in El Puntal beach during August 2003.

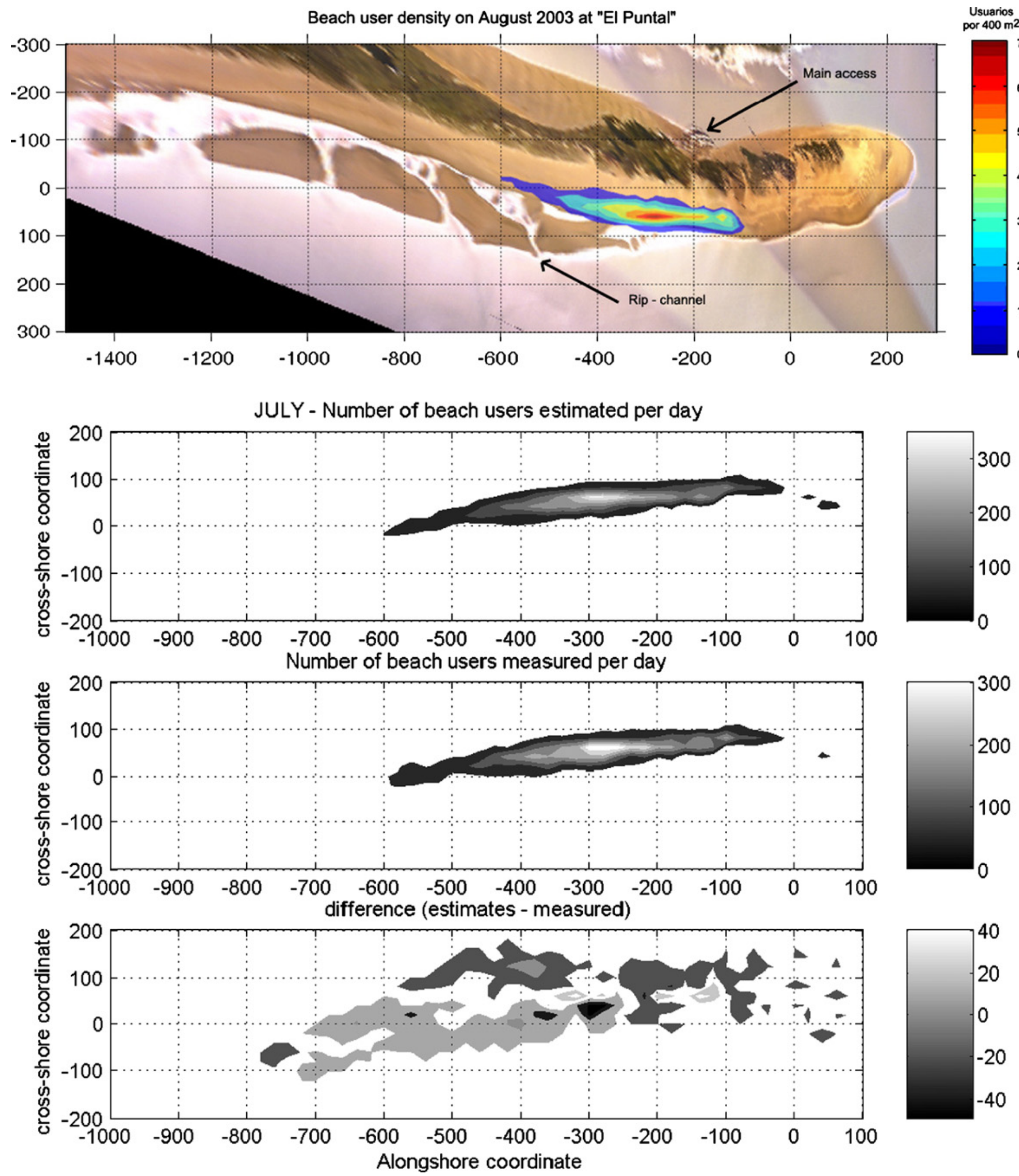

Fig. 9. Beach-User Density curves in El Puntal. (a) Curve for August 2003. (b) Daily distribution of users measured one day of July 2003. (c) Daily distribution of users derived from mean distribution. (d) Difference between measured and forecasted distributions.

existence of a spatial attraction point. Thus, for the case of a very wide beach (as is the case here), the attraction point is the sea and this produces an asymmetric distribution with values of the variable (number of users at a given distance from the attractor) decreasing as distance from the shoreline increases.

This method is also valid for evaluating the temporal distribution of beach-users which has already been established as a key parameter for beach management. Thus, although different utilization models for beaches do exist, based on standard daily variability in user distributions, (see e.g. MOP, 1970; Yepes, 2002), the seasonal and annual variability in this distribution is also an important parameter to characterise local preferences and/or constraints. Fig. 8 shows the average diurnal distribution of users at El Puntal beach during August 2003.

This distribution differs from standard curves such as those proposed for Mediterranean beaches by Yepes (2002) in which two populations of users are present with one group using the beach during the morning and the other one during the afternoon which results in a distribution with two maxima. However, in this case, the distribution shows only one maximum, located at 14:00 and a progressive decrease in users throughout the rest of the day, (Fig. 8).

Finally, Fig. 9 shows the Beach-User Density function (BUD(x, y, t)) for the entire month of August 2003 obtained by integrating all beach-user data acquired during the corresponding month. Assuming that this distribution is representative of the typical summertime beach-use at El Puntal, it could be used by beach managers to identify which parts of the beach will be used most intensively and to decide where to offer services. Assuming that there will not be a significant difference between the beach-use during July and August, Fig. 9 shows a comparison of the daily distribution of users obtained one given day of July and the daily mean distribution (obtained from the one derived for August). As it can be seen from this comparison, the mean pattern obtained during August can be considered as representative of local conditions in July and that the spatial use of the beach is strongly conditioned by spatial attractors such as beach access, the waterline with users showing a similar behaviour throughout the season.

3. Beach safety

3.1. General aspects

As previously stated, safety in terms of beach management refers to the management of hazardous conditions which subject users to the danger of drowning or injury. The importance of the risk associated with this issue, as well as the need for pro-active management can be clearly deduced from the four main characteristics related to beach usage identified by Short and Hogan (1994): (i) beaches are extremely highly frequented environments, (ii) beaches (especially surf zones) are inherently hazardous environments; (iii) as beach usage increases, the level of public risk also increases and (iv) to respond to this situation some policy must be implemented (involving the rescue authority and education).

Taking into account these aspects, two main types of variables must be considered/controlled by beach managers to improve beach safety, these are variables related to both the beach and users. The first group of variables include those aspects associated with the physical characteristics of the beach such as water depth, beach and surf zone topography (beach morphodynamic state), breaking waves, surf zone currents and localised hazards such as reefs and rocks (Short and Hogan, 1994). Among them, rip-currents have been identified as the main source of risk of drowning for beach-users worldwide (Short and Hogan, 1994; Klein et al., 2003; Benedet et al., in press) because they take users away from the shoreline (theoretically a safe place) and move them seawards.

The second group of variables relate to the user-behaviour and for management purposes can be simplified by characterising the spatiotemporal distributions of users on the beach as described previously in Section 2. This is because the relative position of users in the beach with respect to the existing sources of hazard will determine the real level of risk. Thus, for instance the real risk of drowning in a beach is not the existence of rips currents per se, but the use of the part of the beach where rips do exist.

If information on both variables is available to the beach manager in due time and in an appropriated form, it is possible to detect "hazardous combinations", such as concentration of users in dangerous beach locations. Note for example there is a low density of beach-users on the left hand tail of the spatial distribution function in close proximity to a rip-current channel in Fig. 9a. On the other hand, this will also help beach manager to strategically design/plan services such as lifeguards and/or beach safety rating posters/maps.

A practical outcome of the analysis of data of the kind listed above, to *pro-actively* reduce risk levels, is the appropriate deployment of observation towers in those parts of the beach where the most hazardous conditions are identified. Here *pro-active risk management* means actions taken by the manager to reduce the damage (risk = probability × damage). This simple action would reduce the area of coast to be scanned, assuming that most of the attention will be focussed on these hazardous areas. It is known that the detection time for a distressed bather reduces proportionately with the distance between them and the lifeguard station (Brewster, 1999; Fenner et al., 1999). Moreover, the proximity of lifeguard services to the hazardous areas will reduce the time taken to reach swimmers in danger.

On the other hand, the generation of beach safety maps to inform the users of hazardous areas of the beach will also serve to *preventively* reduce such risk, provided the users are aware of and understand the maps and the information is properly updated. Here *preventable risk management* means actions taken by the manager to reduce the probability (risk = probability × damage). Practically this involves the generation of beach risk maps; one of the most commonly used beach management techniques (Short and Hogan, 1994; Short, 1999).

Fig. 10 shows a generic Frame of Reference (FoR) with the same overarching strategic objective as the previous example but this time the operational objective is "*to allocate the appropriate resources to guarantee the safety of beach-users*". In contrast to the two previous presented objectives, this one operates over a short timescale and planning has to be done on a day-to-day basis since hydrodynamic and morphodynamic changes occur very rapidly and they can change the conditions governing beach safety on such timescale.

This is a generic FoR since all the possible sources of hazards for swimmers are considered and from there, different variables are taken into account such as rip-current locations, beach morphodynamic states and nearshore circulation patterns. Contributing variables are of mixed-origin including video images, hydrodynamic data (e.g. wave and water level), expert knowledge and numerical model results. It is important to stress that to properly design an efficient risk management plan for beach safety the actual level of beach-use must be also characterised because this will permit the manager to assess the relative position of users with respect to the sources of hazard. Due to this, the previously introduced indicators to measure the level of use of the beach are also required here and must be included in the FoR.

Although Fig. 10 is designed to be a generic FoR the general idea may be illustrated by considering the example management problem of appropriately locating a patrolled bathing area. Ideally one would wish to position this in an area where most beach-users are stationed and away from environmental hazards

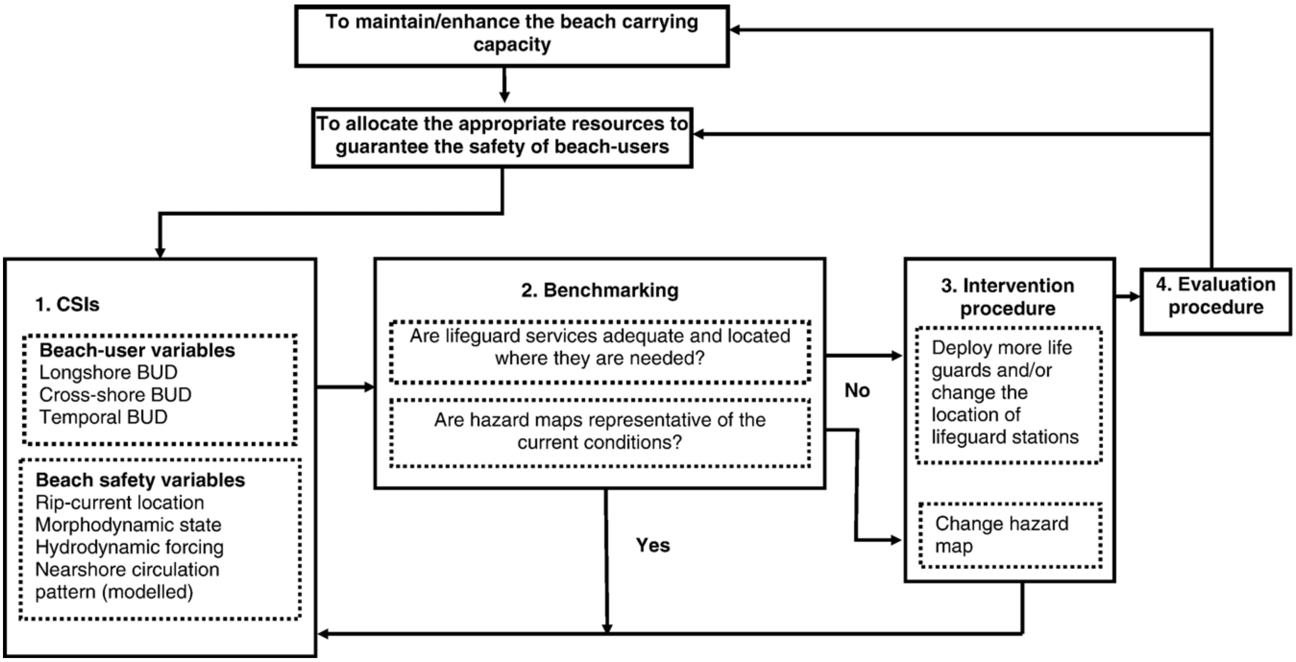

Fig. 10. Frame of Reference for beach safety management.

like rip-currents. The video-cameras can deliver data on both aspects. In terms of user density we must now preserve the longshore distribution of beach-users. Therefore an appropriate variable is: $\mathrm{BUD}(y, t)=\int P(x, y, t)\mathrm{d}x$. The y-location of rip-current channels can also be clearly seen in video images, directly at low tide in tidal environments, or in the wave dissipation patters observed in time-averaged images. The optimum position will be both a safe distance from the hazard (a rip-current in this example) and adjacent to the largest available number of beach-users given by $\mathrm{BUD}(y, t)$. If the

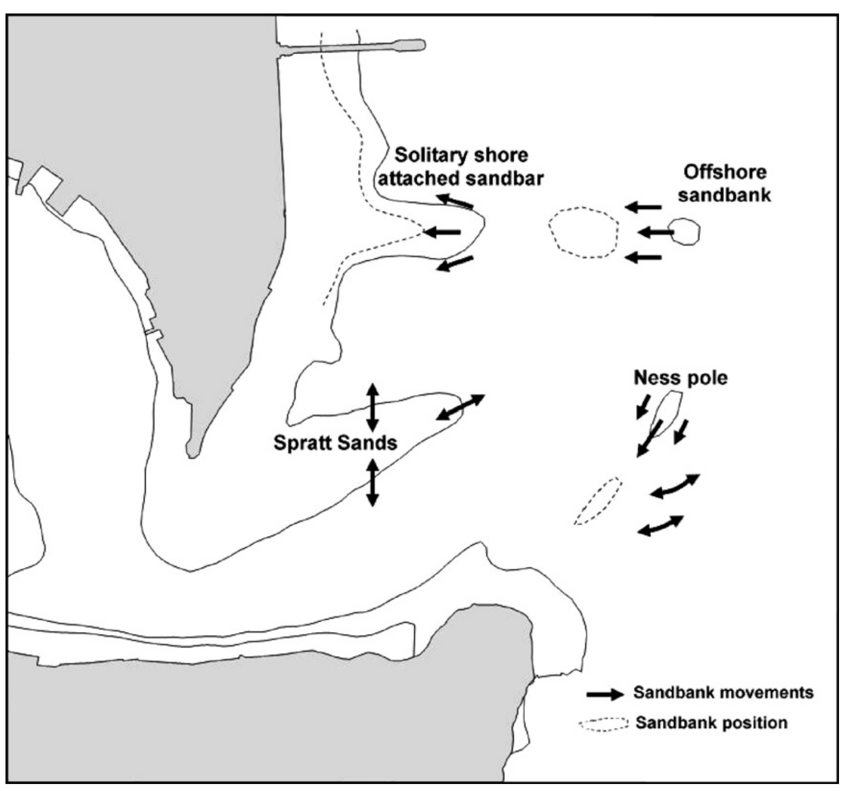

Fig. 11. Sandbanks at Teignmouth (South Devon, UK) and their dominant dynamics.

bathing area is not currently in this position then the management intervention is to move it.

In what follows, one of the possible applications of video to derive indicators related to this operational objective is presented. This consists of the derivation of beach hazard maps by combining video images, wave and water level data and numerical models.

3.2. Methodology

The methodology proposed here has been designed specifically for beaches adjacent to the Teign Estuary although it is generic enough to be adapted and applied to a wide range of natural beaches. In addition to the typical hazards that are common on many natural beaches (e.g. longshore currents, large waves, rip-currents), the Teignmouth site also has very strong tidal flows running along the navigation channel adjacent to the beach and around the numerous sandbanks. Additionally, the macrotidal regime often leads to bathers becoming cut-off on the offshore sandbanks during the flooding tide. The spatial distribution of these hazards is very dynamic and depends on the current morphodynamic state of the system, the wave conditions, tidal state and to a much lesser degree the river run-off.

In essence, the methodology involves developing beach hazard maps through careful consideration of the circulation pattern predicted by a numerical model, corresponding to frequently repeated morphodynamic states and varied wave and tide conditions. The proposed methodology can be schematised in a three-step process: (i) data acquisition, (ii) data analysis and (iii) application for management of beach safety.

The first step consists of the collection of relevant data. The role of the video is to firstly evaluate the different morphodynamic states that the system commonly and repeatedly exhibits. Later, at the application stage the video is also used to help managers to assess the current morphodynamic state of the system.

Wave, river run-off and water level data were collected to provide the necessary forcing conditions for the hydrodynamic model. These boundary conditions were statistically analysed in order to characterise hydrodynamic regime of the study site. To do that, different combinations of waves, tide and river run-off were selected to cover the full-range of potential conditions.

Finally, the circulation pattern in the estuary was obtained by applying a numerical model to each of the morphodynamic states and representative forcing conditions. In this application, the Mike-21 model (Danish Hydraulics Institute) was used. The model was rigorously calibrated and validated for the study site using in situ measurements (e.g. Siegle, 2003). The video data was also used to provide additional information for the bathymetric boundary conditions of the numerical model for each of the characteristic morphodynamic states (see Smit et al., 2007-this issue).

For each model run, the hazardous conditions can be spatially located by establishing thresholds in the wave and current intensity, above which, users could be in danger. By combining

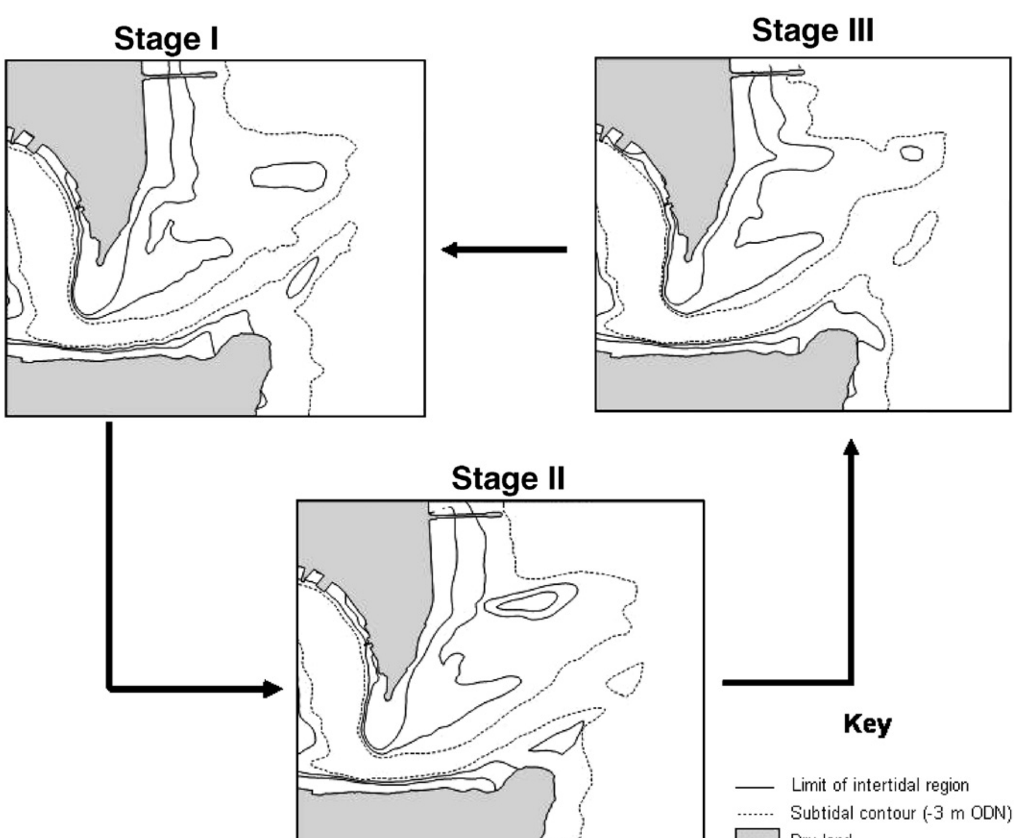

Fig. 12. Morphodynamic stages used to characterise bathymetric changes at Teignmouth.

this information with expert knowledge (e.g. from the lifeguards) a risk map can be generated for each of the morphodynamic state and corresponding forcing conditions under examination. The resulting risk maps have two main functions. Firstly, they inform the lifeguards as to the most efficient deployment of the available resources, i.e. where the man hazards will be located. Secondly, the risk maps are displayed at each beach access points, educating beach-users as to which area of the beach should be avoided.

3.3. Application

The combination of a mild wave climate and the aesthetic beauty of Teignmouth have made this site a popular tourist resort for over a century, especially amongst young families (Davidson et al., 2007-this issue). The 2 km stretch of coastline is located on the south coast of Devon, UK and faces east-south-east into the English Channel, (for a more detailed description see Davidson et al., 2007-this issue; Robinson, 1975; Kingston, 2003; Mariño Tapia et al., in press).

The sources of risk at this site include strong flood and ebb currents which flow through the adjacent navigation channel and around exposed sandbanks; morphodynamically forced rip-currents and intertidal banks where bathers become cut-off during the flooding tide. The combination of large numbers of beach-users with the physical characteristics of the site means that there is a significant risk to beach safety.

The first part of the analysis involves the characterisation of morphodynamic states (sandbank dynamics) of the area. This was done by analysing a 6 year time-series of Argus video images (1999 to 2005) and results show that the sandbank dynamics at Teignmouth are dominated by the movements of four sand bodies (Fig. 11): (i) an *Offshore sandbank*, which forms on the outer ebb delta and migrates consistently onshore until it attaches to the beach; (ii) a *Solitary shore-attached sandbank*, which is generated from the attachment of the offshore sandbank. At medium temporal scales (months) it moves shoreward, eventually dissipating and becoming part of the upper beach; (iii) *Spratt Sands* which is an omnipresent sand body which changes volume but remains approximately stationary; (iv) The *Ness Pole* which is an offshore 'ebb-shoal sandbank' which periodically migrates towards the Ness Headland especially during storms.

Further details on the dynamics of these sandbanks can be found in Siegle et al. (2003), Aird et al. (2004), Mariño Tapia et al. (in press). These four sandbanks can co-exist and interact, with drastic morphological changes occurring in as little as six to eight months. However, the cyclic behaviour of sandbank migration allows the identification of three basic morphodynamic stages (Fig. 12):

- Stage I: consists of two sandbanks growing at each side of the access channel, these are the offshore sandbank and the Ness pole. When the sandbanks grow enough to be exposed at low tide, they migrate rapidly and consistently in the onshore direction.
- Stage II: is simply an intermediate stage that shows the offshore sandbank and the Ness pole closer to shore.

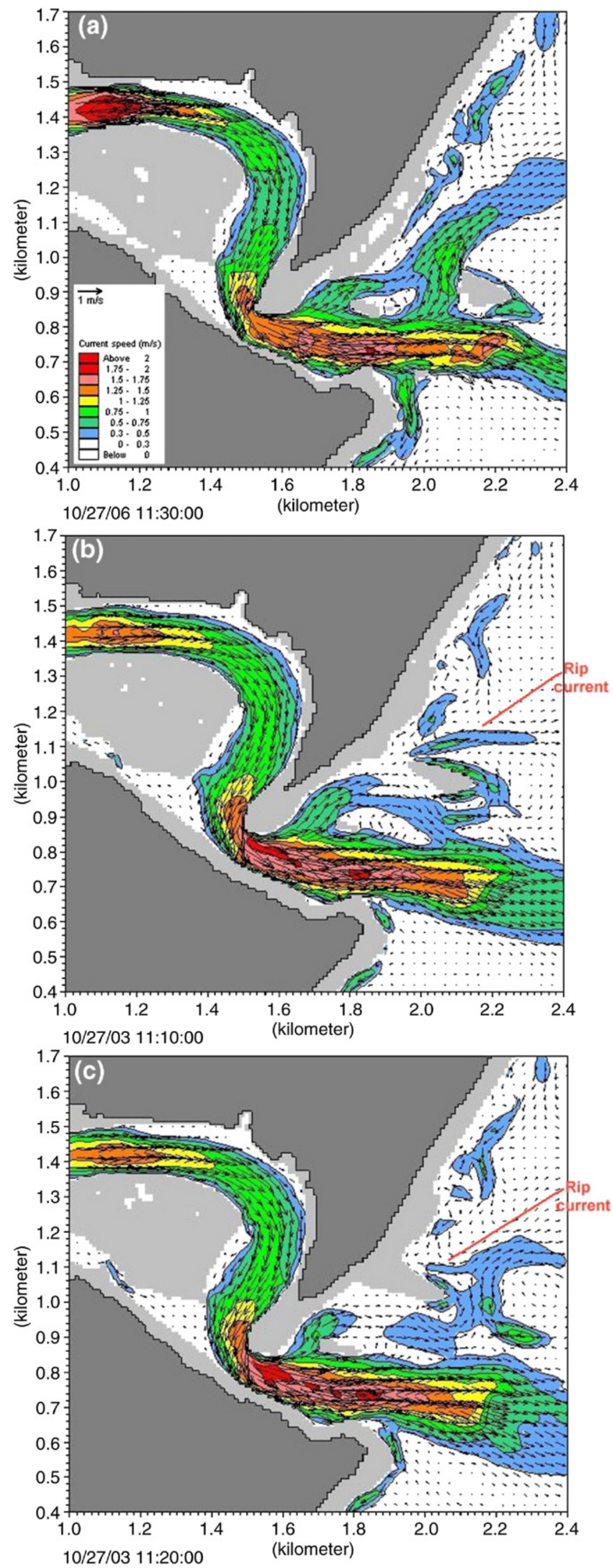

Fig. 13. Spatial distribution of hazardous currents for high wave activity and spring tides (Hs ~ 0.95 m) for Stages I (a), II (b) and III (c).

- Stage III: the morphology is dominated by the presence of an elongated, shore-normal orientated sandbank attached to the beach between the pier and the estuary mouth. The Ness pole can also be shore-attached. This sandbank is persistently moving onshore and dissipating on the beach in the medium term (months).

These changes in the morphodynamic state strongly affect beach safety and the spatial distribution of hazards. The circulation patterns associated with each of the three basic morphodynamic states are using the Mike 21 numerical model (DHI, 2000) and different combinations of characteristic wave and tidal conditions which typify the summer bathing season. The bathymetries used for representing the three morphodynamic stages were measured during the COAST3D (October 1999 for Stage II) and the CoastView projects (November 2002 for Stage III, and May 2003 for Stage I). A comprehensive series of 30 numerical model runs were used to evaluate the distribution of bathing hazards for each characteristics morphodynamic state and forcing conditions spanning the measured parameter space.

An example of the numerical model results is given in Fig. 13, showing the circulation pattern associated with each beach stage for the case of high wave action and spring tides. For these conditions, results show strong tidal flows in between sandbanks and along the navigation channel. Wave driven flows also contribute significantly to the flow field when wave heights exceed half a meter and often result in strong rip-currents. Rip-currents are particularly strong in the Stage III morphodynamic state where strong seaward directed flows occur on the northern flank of the shore-attached bar. Strong longshore currents occur flowing in a SW direction towards the navigation channel for Stages I and II. These model results compare very well to the observed circulation in the field and the hazard distribution observed by lifeguards. The good performance of the model relates to the fact that the major flow patterns are strongly topographically controlled.

Integrating the results obtained by using the numerical model for all the selected conditions, the main location of bathing hazards for the area has been scientifically derived. Nevertheless, to directly use these results for life saving activities, the complex information derived from the numerical model was simplified and presented in a way the beach-user could easily assimilate. For this purpose, three simplified risk maps were generated, one for each morphodynamic stage (Fig. 14).

Stage I (Fig. 14a) is characterised by the presence of a prominent sandbank located well offshore accessible only at low tide by swimming or wading. At this stage, the shore-attached sandbank is absent or protrudes seaward less than 200 m from the seawall at the top of the beach. Bathing hazards include the deep navigation channel (shaded in diagonal lines) and strong flows on the flanks of the sandbanks and from the sandbank to the North (blue arrows), which occur only when waves are present. Other hazards include the possibility of being cut-off on the sandbanks as the tide rises (red circled shading). In this morphodynamic state the Ness pole might be absent, or exist only as a sub-tidal feature, but if present, strong currents on the flanks and cut-off hazards should be considered.

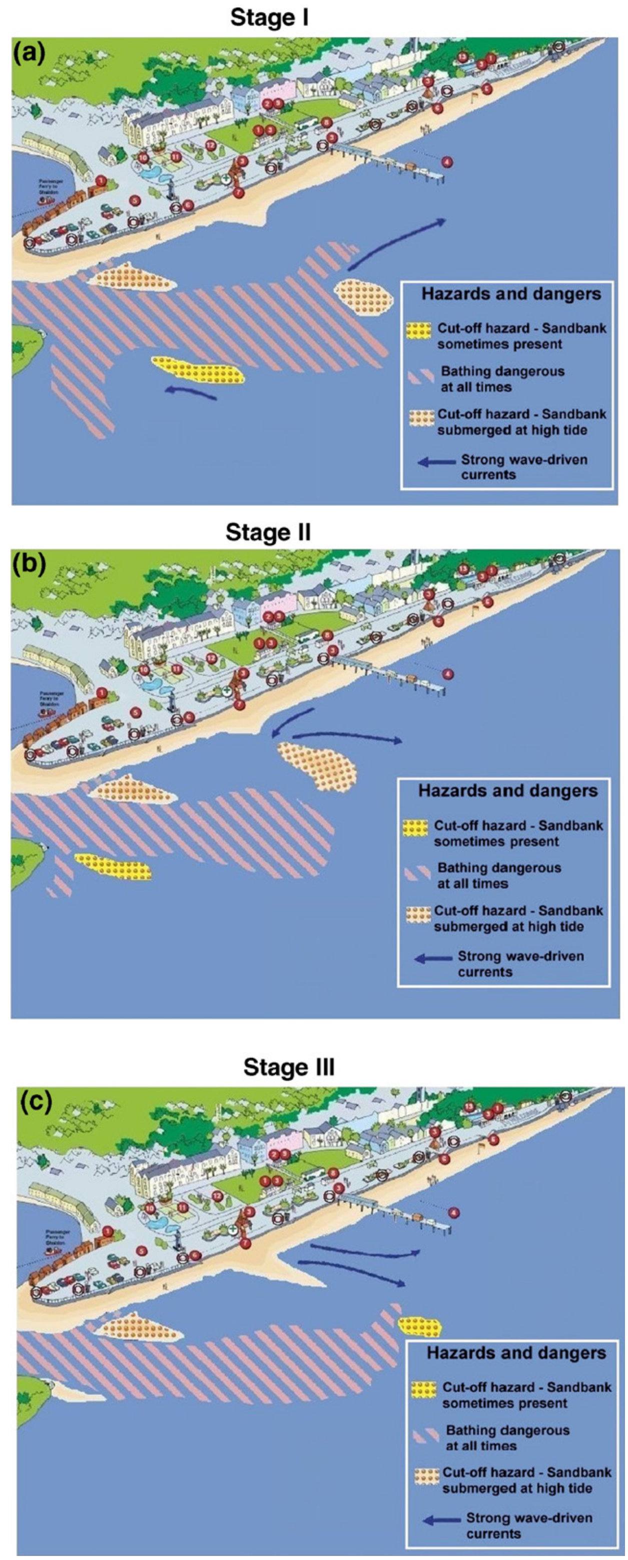

Fig. 14. Schematic representations (risk map) of every stage and their associated hazards.

Fig. 14b shows the risk map for Stage II, with a morphodynamic state very similar to Stage I, although the offshore sandbank is much closer to shore (shoreward flank at 200 m from the sea wall and can be easily accessed by walking during the spring low tide. Similarly, the bathing risks are

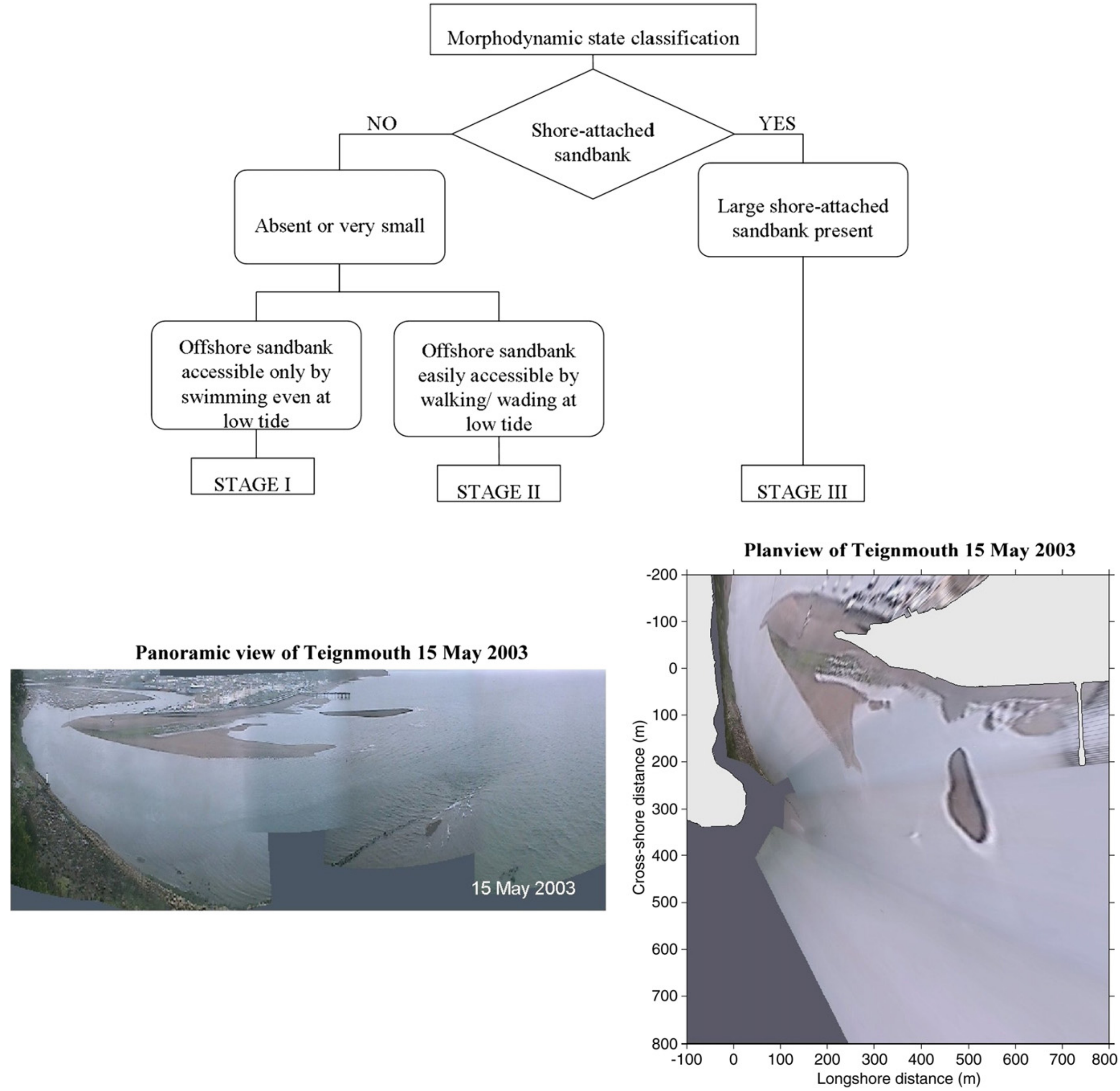

Fig. 15. Flow diagram for the selection of the appropriate hazard map for Teignmouth.

restricted to the navigation channel, but in the event of waves (Hs > 0.7 m), there is potential for dangerous rip-currents to develop on the northern flank of the feature (blue arrows). Cut-off hazards for Stage II are the same as for Stage I.

Finally, the risk map for Stage III is shown in Fig. 14c. The shore-attached sandbank is very prominent (generally extends to 200 m from the seawall) and cut-off hazards are less common as most sandbanks are attached to the coast. Nonetheless, it is possible that a newly forming offshore sandbank is sometimes present far from the shore in this morphological state. Bathing hazards are still present in the channel region, and for waves with Hs > 0.7 m dangerous morphologically driven rip-currents might also develop on the northern flank of the sandbank.

These three risk maps are displayed clearly at all beach access points to promote public awareness of beach hazards. It is the role of the manager to choose which of the three risk maps best represents the current state at Teignmouth. The tool that will help the manager to arrive at this decision is presented in Fig. 15. This flow chart provides unambiguous guidance to the coastal manager for defining each morphodynamic stage and hence the appropriate risk map to be displayed (see also Fig. 10). The decision is further supported by the most recent rectified panoramic and plan view images taken by the Argus station (Fig. 15) and the lifeguard's experience in the field. The images shown in Fig. 15 are representative of the morphodynamic Stage II.

4. Concluding remarks

In this paper the utility of video images to help managers with different aspects of recreational beach management. Amongst all the possible aspects to be covered this contribution focuses on two main topics: optimising beach-use and beach safety. For each of these, a specific Frame of Reference has been designed in which coastal state indicators have been proposed to achieve the corresponding strategic and operational management objectives.

Thus, the supporting information on the level of beach-use has been integrated into the Beach-User Density indicator (or BUD), including its temporal and spatial variations. In the other example, beach safety is addressed by generating beach hazard maps helping the managers to reduce the risk of drowning.

The proposed indicators make use of the unique capabilities of Argus video-cameras to record multi-purpose information in a single image. Thus, different methods of analysing video images have been here presented in such a way that, in addition to the usual information on coastal processes, data relevant to recreational beach management can also be obtained.

In some cases, the combined CSI-FoR system also makes use of additional data (e.g. those characterising forcing conditions such as waves and tides) and combine them with results of other techniques, such as numerical models. The FoR is a useful tool for aggregating different information sources to address a single problem and effectively translates scientific output into useful management tools.

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