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A New Environmental Indicator for Coastal Artificialisation and Resilience Mapping

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ABSTRACT

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Scientists and managers have developed and improved coastal protection and sustainable development measures. However, analysis and diagnostic methods are less than satisfactory when coping with the true complexity of socio economic drivers in coastal areas. Mapping of land use and its temporal variability in the coastal lands enables a first order approximation to the analysis of artificialisation although it shows a snap shot of the situation. An indicator which compares the evolution of land uses over a significant time span in the evolution of a developed coast as well as its spatial behaviour is introduced in this paper. The method, applied on the highly developed coastlines of Torremolinos in Costa del Sol, southern Spain, involves (i) mapping of a series of photo interpreted land use coverage stretching over 40 years; (ii) the implementation of a new algorithm that identifies land use change and calculates distance of change in relation to shoreline across a 1 km. buffer fringe; and (iii) transposing land use variability by qualifying via the concept of resilience onto the mapped shoreline to enable cartographic output of the analysis.

Results of the implementation of the method on the selected pilot site and timeframe illustrate a high capability to interpret resilience (beyond sole scientist’s perception). The process of artificialisation is quantified and represented on a map which helps locating areas of potential high and low resilience (as in capacity to recover) given the trends. This is illustrated by mapped results and a final resilience map that could be of use for future decision making in the context of coastal management of developed coasts.

ADDITIONAL INDEX WORDS: *Integrated Coastal Zone Management, Vulnerability, Sensibility, New Information Technologies, Coastal Land Use Change.*

INTRODUCTION

Although artificialisation is a widespread phenomenon that implies the transformation of land use towards irreversible loss or damage of coastal environments, tools to identify and measure land use change and its consequences in terms of coastal vulnerability are scarce. “Population on Europe’s coasts is continuously increasing, sometimes faster than in inland areas. Coasts are converted to manmade artificial surfaces at an even faster pace. There is a need to develop more information to better understand what is happening with built up areas and city planning in Europe and to establish some thresholds and other planning tools to avoid uncontrolled sprawl” (EEA, 2006). The same source indicates how the highest increase in artificial surfaces (20–35 %) has been observed between 1991 and 2001 in the coastal zones of Portugal, Ireland and Spain. The fastest development has taken place in Portugal (34 %), Ireland (27 %), and Spain (18 %) within the 10 km coastal zone, Urban surfaces are dominant on the first kilometre from the shoreline. In several coastal regions of Italy, France and Spain the coverage of built-up areas in the first kilometre coastal strip exceeds 45 %. In these areas further development is occurring in the coastal hinterland.

This pressure has occurred close to the shoreline and as a result coastal management has traditionally been confused with coastal protection. However, despite the evident difference between the two concepts, it is well documented that coastal protection has been the only measure in Mediterranean coastlines of Europe during most of the 20th century. The unsatisfactory results were highlighted by severe storm damage at the end of the 1980s in some of the most developed Mediterranean coasts, together with concern for the tourist industry then suffering stagnation and broader unease over the irreversible transformation of the coast through human activities. This situation coalesced to prompt the implementation of planning controls and new protective measures (MALVAREZ *et. al.*, 2000).

Despite this background, only a few attempts have been made at characterising and qualifying, through a conceptual model, how the intensification of the use of coastal lands affects shoreline stability (MORRIS and DICKINSON, 1987; POLLARD and DOMINGUEZ, 1993; 1995). It is indeed very difficult to demonstrate the exact impact of land use variability in the hinterland and its effect on coastal stability but is commonly agreed the adverse effect of the proximity of land use change in the immediacy of beach environments. Hence a method to identify the variation of land use in coastal areas could provide a sound basis for sensitivity analysis. Further, when the concept of sensitivity is questioned (and contrasted with vulnerability) a new horizon appears (CARPENTER *et al.*, 2001; TROELL *et al.*, 2005; TROSPER, 2002; VILLA and MCLEOD, 2002). A development of these ideas is found in the characterisation of coastal resilience, since the concept better reflects the inherent nature of coastal systems: resistant but vulnerable when stress thresholds are exceeded. Some authors (FONTURBEL, 2003; TROSPER, 2002; IPCC, 2001) provide good basis for the use of this concept, which is applied in the general framework of this article.

Coastal managers and policy makers have traditionally lacked the holistic scientific background that enables appropriate classification prior to policy development. For instance, the width of the buffer zone applied by the Spanish Coastal Act of 1988 (coastal legislative framework in Spain) varies between 20 and 500 metres, but is based upon planning criteria rather than any variation in local physical attributes of the coast. Policy based upon an over generalised delineation of the coastal domain will generally ignore the physical and socioeconomic variables acting on the coast, while the treatment of the coast as an undifferentiated unit is likely to lead to oversimplified management practices. Consequently, there is an urgent need to recognise variability in coastal sensitivity in order to implement policies more selectively (MALVAREZ *et. al.*, 2000). In some fields of coastal studies, namely coastal morphodynamics, it is frequent to integrate varied information affecting sensitive zones such as the surf zone, to provide some indicator of beach state. Classic methods such as the *surf scaling parameter* of GUZA and INMAN (1975) and WRIGHT and SHORT (1984) take the cross shore area identified as surf zone as a unique region and provide a single value to characterise the entire zone. In this approach the factors in consideration (i.e. sea bed morphology, wave frequency) are measured and combined as if occurring in the exact same location. The spatial integration approach is highly valuable because it provides a single value that enable surf scaling mapping of the coastline and thus a very accurate indicator of beach state.

This approach can be utilised in relation to the characterisation of coastal land use variability to provide an indicator that shows the changes, the location of these changes and enables a unique value representation on a given point or line along a coastal segment. In this paper, an indicator to characterise the state and trend of coastal artificialisation is presented.

STUDY SITE

A highly complex 10 kilometres section of a developed coastal strip in the Mediterranean coast of southern Spain, the Costa del Sol, was selected as a pilot site to implement the method (Figure 1). Costa del Sol's coastal environments are wave dominated and subjected generally to low energy levels (MCDOWELL *et al.*, 1993; MALVAREZ, 1997). Tidal range is small (<20cm average astronomical tidal range). The mean significant wave height is l m. with a mean period of 5 seconds producing a coast dominated by high frequency waves. The average directional components of the dominant wind waves are E to W and W to E that generates intense longshore drift and active cross shore sediment transport in exposed areas. The morphology of the hinterland as well as the inner shelf is steep and narrow due to the location at the border of the compressive end of the Eurasian plate; Oceanic depths are reached within two kilometres from the coast in some sections. This results in a concentration of wave action on a narrow fringe of steep coastal shelf, with predominantly intermediate to reflective beaches. Sediment supply is mainly reworked fluvial sands and supply is episodic and concentrated in time around seasonal heavy rainfall.

The Costa del Sol developed significantly during the 1950s and 1960s due to the demand for holiday makers from northern

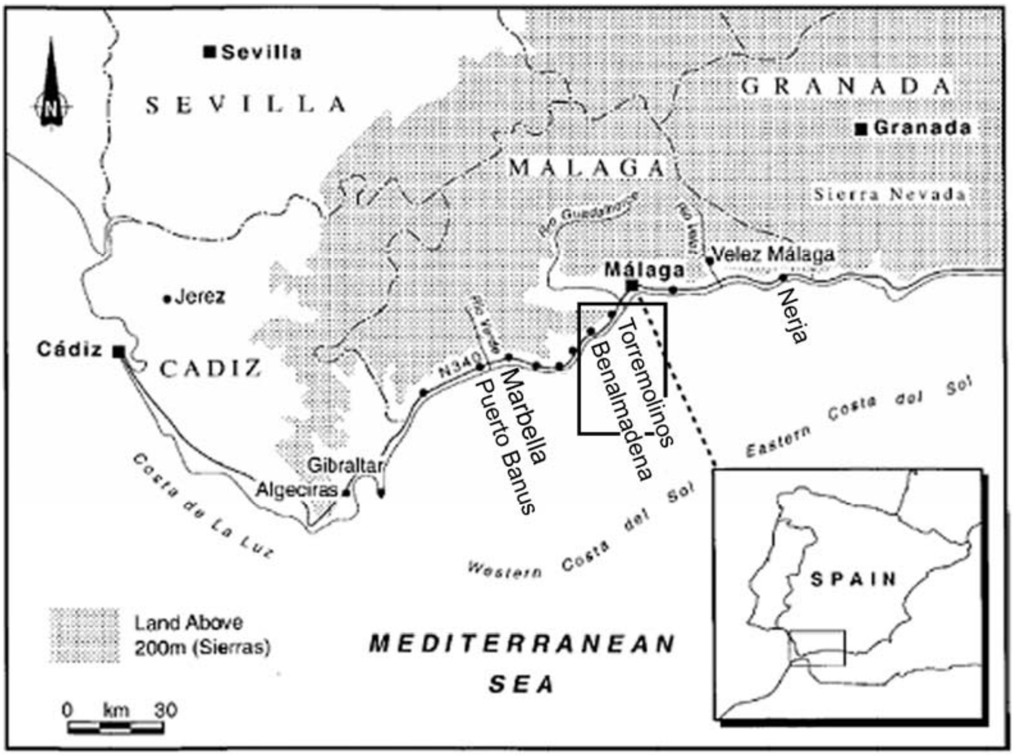

Figure 1. Costa del Sol in Spain's southern Mediterranean coastline. Thick lined box shows pilot study area.

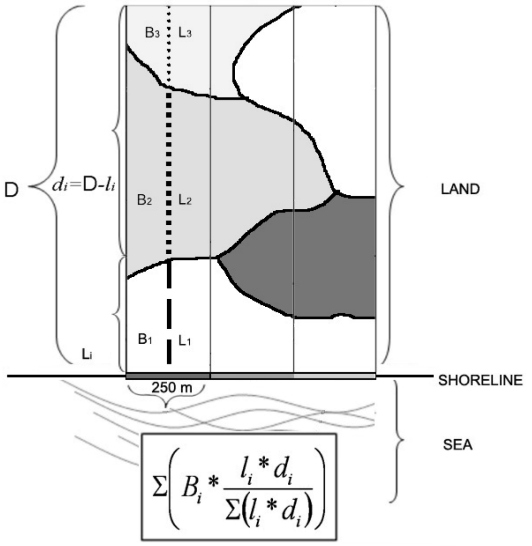

Figure 2. Sketch of land use fragmentation and resilience assessment through algorithm.

Table 1: Land use variability and valuation of vulnerability due to land use changes.

Land Use Variability		Vulnerability Valuation	
		Resilience	Susceptibility /Sensibility
External	From natural to urban or planned for urban.	1	5
	From natural to agricultural or forestry.	2	4
	From agricultural or forestry to urban.	4	2
	From agricultural/aquaculture to abandoned.	3	3
	Abandoned urban land.	3	3
	Transformed land that maintains its use.	5	1
Internal	New land as a result of shoreline accretion.	1	5
	Land loss as a result of shoreline erosion.	2	4
	Natural land with changes in vegetation maturity stage.	4	2
	Natural land with no changes.	5	1

Europe. This led to the combined development of accommodation, infrastructure and leisure facilities, such as golf courses and marinas. In general, significant development has occurred over the past 50 years. The *fashionability* of these areas and the growth of the middle class in Europe and abroad have boosted this development.

This development sprawls to the south and south-eastern Mediterranean is representative of the 'Med wall' with 'more than 50 % dominance of concrete along the coast' (EEA, 2006). In the last 10 years, the Mediterranean urban tourism model has been mirrored in many other coastal areas in Europe and beyond.

METHODS

To evaluate the potential impact of land use change and variability in the coastal fringe the view need to address a locating factor to indicate the position of variability of land uses (higher numbers are related to a fragmented urbanising territorial model) with respect to the shoreline. An indicator of the shape of this land use distribution and artificialisation needs to address how and where in the coastal fringe this process is occurring so that a mapping approach can be taken to help provide some indication to future planning.

The concept of the coastline as a limiting element has a strong relation with the approach taken. CARTER (1988) refers to the coast as an integrated fringe where land sea and atmosphere interrelate, therefore providing a fuzzy limit to natural factors. As for the Institutional framework, however, it is frequent to use administrative borders to analyse state and trends as well as implementation or design of plans (CICIN-SAIN, 1993). Technically, some authors (e.g. LAMACCHIA and BARLLET, 2003) apply methodologies to work with the coastlines as border lines.

To provide a compatible method that can generate the basis for a wider sensitivity or resilience index the indicator for coastal artificialisation needs to address the crucial issue of data integration. The overall framework for the development may be that of the multicriteria analysis (MCA) because it offers the flexibility to combine multiple units and scales. However, it is a prerequisite in MCA that segmentation is determined so that comparison of layered information is viable (CITTIB, 2003).

The method homogenises data and its presentation on cross-sectional profiles and algorithms for integration of information on the profile to illustrate results. Likewise, the information attributed to this transect or profile must then be translated to the shoreline, which has been identified as the location where land and marine data is to be integrated for further mapping of indicators. Once integrated profile information is transferred to the shoreline (as in a line -GIS item- along the shore) indicators developed for submerged processes can also be overlapped.

The methodological approach taken for the research behind this article includes (i) the development of a new algorithm to measure and locate coastal land use change, (ii) normalisation of the variable in terms of coastal resilience and (iii) translation of the calculated result to a point onto the coastline. A further step of integration within a wider index in which other indicators are also mapped is out of the scope of this contribution.

Prior to the identification of land use transects, maps of land use and change were developed from direct photo interpretation using aerial photographs from 1956 to 2002. Land use comparison was performed using the extension “Change detection” (CHANDRASEKHAR, 1999) in ArcView 3.1.

Cross sections were drawn at regular intervals of 250 m along the coastline of the selected pilot site, as shown in Figure 2. As lines cross new land use types the segmentation activates a new type of land use attribute onto the database, thus registering heterogeneity. The more the intersections the more the heterogeneity and the higher land use variability scores. This thematic information or attributes are independent from its coordinates and thus not affected by them.

The greater the variability of types along the transect the further the possibility of modification of its topology. The position where changes occur is measured from the shoreline since it is also relevant and must be registered.

Equation 1 shows the indicator for spatial analysis of the land use variable:

$$M = \Sigma\left(B_i * \frac{l_i * d_i}{\Sigma(l_i * d_i)}\right)$$

Eq. 1

where $d_i = d - l_i$ (locates the distance at which land use change occurs); d is the summation of l_i, or distance of the presence of that particular type of land use. B_i is the resilience value (see Table 1).

M is the value assigned to the profile and then moved to the shoreline for mapping (which will include value of x, y -for location- and M as attribute).

The procedure is illustrated in Figure 2. Along a hypothetical coastal area a number of transects are drawn normal to the coastline all 1 km long. Note also in the figure that resilience is the variable represented. The value for resilience is assigned following criteria derived from the assessment of susceptibility of the change in land use to be reversible or affected by change from natural to artificially urbanised; which is interpreted to be the minimum degree of resilience, as indicated in Table 1 which illustrates the conversion from land use variability to resilience nominal value in the ranking utilised for further data correlation in the MCA.

RESULTS

Photo interpretation of land use maps of various dates provided a new map of polygons with values assigned related to a land use coverage per year analysed and a total variability map. The polygons in the final map then ranked on the basis of resilience, as shown in Table 1.

During the period 1957-2002, most land use change was anthropogenic, such as crops and irrigated crops (42,4%), followed by shrub and partially cultivated land (28,7%) adding to the 1956's urban areas (10,3%).

As for nature driven change, 25% of land use change was driven by natural forces, such as beach accretion and vegetation cover change to forestry. Once procedures indicated in Table 1 are applied, the resulting map of land use changes towards artificial indicates various levels of potential resilience: lower values indicate low vulnerability or susceptibility to further change, thus high resilience.

Along the coastal segment illustrated in Figure 3 the method identified a graded scale of potential resilience. Southmost sections present a mixed landscape with an interesting diagonal polygon indicating low resilience on the face of the old quaternary fossil cliff which being transformed to a sea view opportunity for urbanisation. A central section in the area is dominated by highly resilient patch which is however fronted by the vulnerable backbeach that has been transformed towards urban land. This front line polygon extends further north. This is significant because traditionally this section was the less developed and it is only in recent times that the horticulture has been eliminated and replaced with tourism-related structures. The method seems to be resolving well the increased fragmentation and closeness of artificial uses in the vicinity of the shoreline and returns a highly vulnerable value for most of the section of *El Retiro* beach. At the *Los Alamos* beach, the northern most section of the pilot study area the values and the shape of the polygon composition shows the immaturity of the section and the gradual transformation. The very final polygon provides some hopes for recovery since values are still low given the relative stability of natural uses.

Once the algorithm described above is implemented a single value is established for transects at 250 m intervals and this is attributed to the coast. In Figure 4 the black line, assigned to low resilience expresses the potential low resilience of the sections

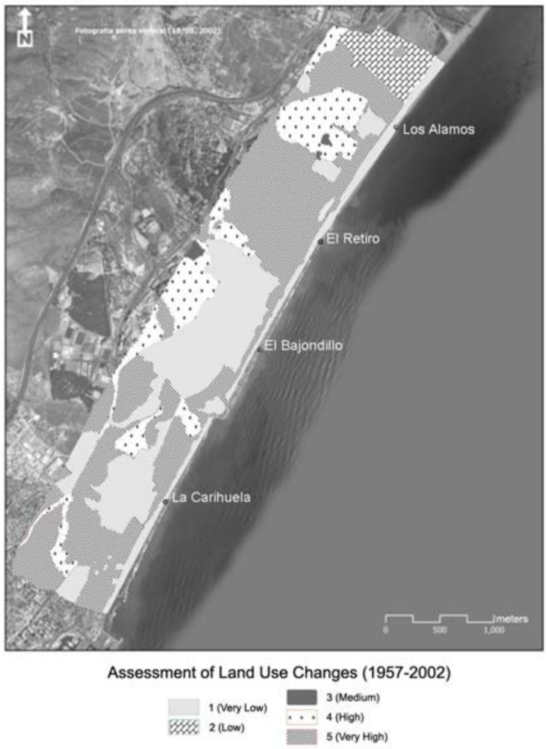

Figure 3. Land use change impact on coastal fringe. Scale in terms of resilience.

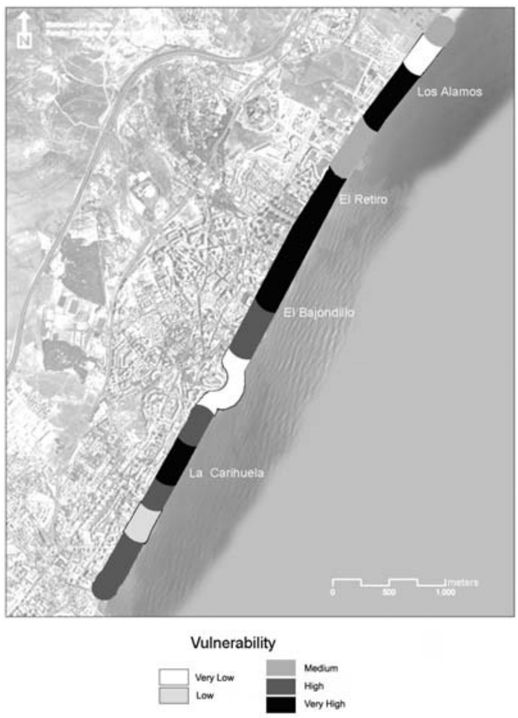

Figure 4. Interpreted resilience due to land use change towards artificialisation, transposed onto shoreline.

subjected to rapid and frequent near to the coastline changes from natural to artificial. The extra-wide line has been drawn to facilitate interpretation although it is just a segmented line which is assigned the varying attributes of the cross sections. The white line shows high resilience but the causes for both segments in this figure differ: the central stretch has been classified by the algorithm of high resilience due to the presence of extensive rock armouring whereas the north-eastern is such because of true lack of artificialisation trend in land use. Thus, at a simple glance users and managers can view the calculated resilience of the coastal stretch of Torremolinos in relation to land use change towards artificialisation.

DISCUSSION AND CONCLUSION

As World's coastlines and particularly Europe's, continue to transform from natural to highly artificial environments, coastal management faces the highly complex task of institutional integration towards Integrated Coastal Management. Scientists and managers focus on improving coastal protection and sustainable development measure while analysis and diagnostic methods are still in their infancy when coping with complexity. Artificialisation is a widespread phenomenon that implies the transformation of land use towards irreversible loss or damage of natural coastal environments, yet tools to identify and measure land use change and its consequences in terms of coastal vulnerability are scarce.

It is recognised that the trend of land use fragmentation and artificialisation is illustrated through the frequency of change, size and position of change in relation to coastline as indicated by work in the context of landscape complexity analysis PAPADIMITRIOU (2002) who argues that through topological relationships diversity and functionality can be mapped. The method presented in the current article combines both approaches to reflect the complexity of land use change at the coast. On the one hand the structural complexity given that fragmentation of transects across the coastal fringe are identified (and measured), and on the other a new attribute is provided to the new segmentation in terms of resilience (as a measure of vulnerability) The ranking of the attribute is also a relevant issue following functionality and structure principles (VENTURELLI and GALLI, 2006).

The development of sensitivity indicators is of great interest to policy making. The presence of a combination of human and physical processes applying pressure to coastal areas demands a holistic approach to any assessment of sensitivity. While decisions as to which parameters should be used in delineating risk factors are not always clear cut, an attempt has to be made to avoid too site-specific approaches, so that the procedure might have a more general applicability. This can be achieved through the use of environmental indicators as suggested by the European Environmental Agency (EEA, 2006)

The overall structure of the work presented here suggests that the use of indicators to characterise coastal land use fragmentation, state and trend could provide new value to analysis tools and help designing diagnostic and management instruments derived from commonly used spatial data bases.

LITERATURE CITED

CARPENTER, S., WALKER, B., ANDERIES, J. M. and ABEL, N., 2001. From metaphor to measurement: Resilience of what to what?. *Ecosystems*, 4, 765-781.

CARTER, R. W. G., 1988. *Coastal Environments*. Academic Press, New York, 617 p.

CHANDRASEKHAR, T., 1999. http://arcscripts.esri.com.

CICIN-SAIN, B., 1993. Introduction to the special issue on integrated coastal management: Concepts, issues and methods. *Ocean & Coastal Management*, 21, 1-9.

CENTRE D'INVESTIGACIO I TECNOLOGIES TURISTIQUES DE LES ILLES BALEARS (CITTIB), 2003. Análisis multicriterio de la sostenibilidad de Les Illes Balears (1989-2000). 27 + anejos.

EUROPEAN ENVIRONMENTAL AGENCY (EEA), 2006. The changing faces of Europe's coastal areas. EEA Report No 6/2006. Copenhagen, 107 p.

FONTURBEL, F., 2003. Conservación de ecosistemas: un nuevo paradigma en la conservación de la biodiversidad. *Ciencia Abierta Internacional*, 17, 1-11.

GUZA, R. and INMAN, D., 1975. Edge waves and beach cusps. *Journal of Geophysical Research*, 80**,** 2997-3012.

INTER GOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC), 2001. Climate Change 2001: Impacts, Adaptation and Vulnerability. Geneva, Switzerland, 57 p.

LAMACCHIA, M. R. and BARTLETT, D., 2003. Potential of GIS in coastal boundaries detection and pitfalls in representing the coast as boundary. *Proceedings of CoastGIS´03* (Genoa, Italy).

MALVAREZ, G. C., POLLARD, J. H. and DOMINGUEZ R. R., 2000. Origins, management, and -234.

MALVAREZ, G. C., 1997. Coastal measurement of stress on the coast of southern Spain. *Coastal Management*, 28**,** 215morphodynamics and anthropogenic impacts on sediment supply and dispersal in the Costa del Sol, Spain: an analysis using numerical modeling and GIS. Northern Ireland. United Kingdom: University of Ulster, Ph. D. thesis, 186 p.

MCDOWELL, A. J., CARTER, R.W.G. and POLLARD, J. H., 1993. The impact of man on the shoreline environment of the Costa del Sol, southern Spain. *In*: P.P. Wong (ed.), *Tourism vs Environment: the Case for Coastal Areas*. The Netherlands: Klowert Academic, the GeoJournal library, pp. 189-210.

MORRIS, A. and DICKINSON, G., 1987. Tourist development in Spain: growth versus conservation on the Costa Brava. *Geography*. 72, 16-25.

PAPADIMITRIOU, F., 2002. Modelling indicators and indices of landscape complexity: an approach using GIS. *Ecological indicators,* 2**,** 17-25.

POLLARD, J. H. and DOMINGUEZ, R., 1993. Tourism and Torremolinos: Recession or reaction to environment? Tou*rism Management*, 14 (4), 247-258.

POLLARD, J. H. and DOMINGUEZ, R., 1995. Unconstrained growth: the development of Spanish resort. *Geography*. 80 (1), 33-44.

TROELL, M., PIHL, L., RÖMMBÄCK, WENNHAGE, H., SÖDERQVIST, T., and KAUSTSKY, N., 2005. Regime shifts and ecosystem service generation in Swedish coastal soft bottom habitats: When resilience is undesirable. *Ecology and Society*, 10(1), 30.

TROSPER, R. L., 2002. Northwest coast indigenous institutions that supported resilience and sustainability. *Ecological Economics*, 41, 329-344.

VENTURELLI, R. C. and GALLI, A., 2006. Integrated indicators in environmental planning: Methodological considerations and applications. *Ecological indicators*, 6, 228-237.

VILLA, F. and MCLEOD, H., 2002. Environmental vulnerability indicators for environmental planning and decision-making: guidelines and applications. *Environmental Management*, 29, 335-348.

WRIGHT, L. D. and SHORT. A. D., 1984. Morphodynamics of reflective and dissipative beach and inshore systems: Southeastern Australia. *Marine Geology*, 56**,** 96-118.