



## Morphodynamic consequences of dredging and dumping activities along the lower Oka estuary (Urdaibai Biosphere Reserve, southeastern Bay of Biscay, Spain)

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### ABSTRACT

Dredging and dumping in the lower Oka estuary (southeastern Bay of Biscay) during 1973–2003 have modified its pattern of sedimentary transport and morphology. An analysis of these activities through time and morphodynamic response of the estuarine system is presented. The relationships between both processes have been established.

A Geographical Information System (GIS) has been used to create a temporal cartographic series of the changing patterns of estuarine sedimentary environments, identify the anthropogenic changes generated and observe the consequent responses of the estuarine system. The GIS has proven to be a very useful tool to monitor and evaluate the natural and human induced morphological evolution of the lower Oka estuary during the last 50 years. In the absence of dredging and dumping (1957–1973), the estuary had a distinct pattern of flood and ebb channels. Flood channels are deeper than ebb channels at their mouth, and progressively becomes shallower in the direction of the flooding tide. On the other hand, ebb channels form a seaward extension of the fluvial main channel. Both types of channels are prone to be evasive and braiding was common. During the period of study, the channels showed low natural variability relative to their location and spatial extension. The dredging and dumping carried out between 1973 and 2003 altered the natural flood/ebb channel distribution and modified sedimentary dynamics. Dredging caused the isolation of meanders of the ebb channel, the rapid infilling of the new dredged areas, and affected the flood channels thus producing the necessity for regular dredging, approximately every 5 years.

Observation of the natural response of the estuarine system after the dredging and dumping makes it possible to state that, at present, the lower Oka estuary is not in a state of morphodynamic equilibrium and has a tendency to lose its capacity gradually. Dredging and dumping have accelerated this process and have increasingly unbalanced sedimentary regime.

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### 1. Introduction

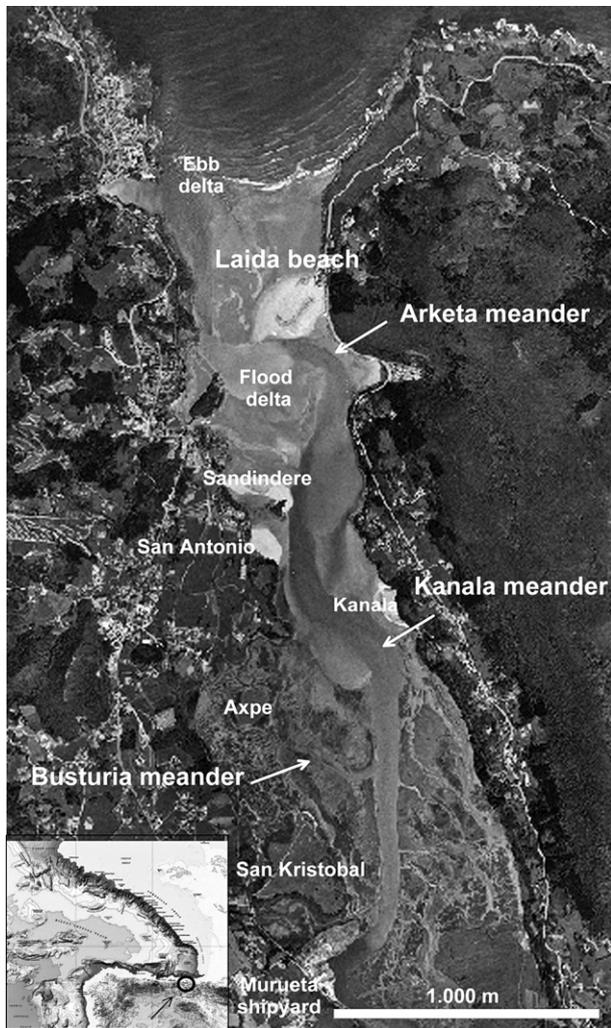
The Oka estuary is located in the southeastern Bay of Biscay and, together with its hydrographic basin, was declared by UNESCO in 1984 as a Reserve of the Biosphere. This estuary is a drowned fluvial valley type (Pritchard, 1952, 1960), meso-macrotidal (Hayes, 1975) with semidiurnal tides (tidal range 4.5 m on springs and 1.5 m on neaps), total mixed (Dyer, 1973) and tide dominated (Dalrymple et al., 1992). The maximum width is approximately 1000 m and

its length is 12 km, and it has an intertidal area of about 2 km<sup>2</sup> (Fig. 1). The local wind intensity and direction show both north and south components, reaching average daily velocities of 1–2 m/s (period May–October). Occasionally within this period isolated peaks with velocities up to 6 m/s occur. On the other hand, the period November–April is characterized by predominance of northerly winds with an average daily velocity of around 4 m/s or higher; the maximum monthly values can reach up to 10 m/s (Cearreta et al., 2004).

The most significant human activity which has occurred during the last 50 years in the lower Oka estuary has been the dredging and dumping of sediment to deepen and maintain the navigation route from the Murueta shipyard, constructed in 1943, to the open sea (Monge-Ganuzas et al., 2008).

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**Fig. 1.** Location of the Oka estuary and image of study area. Localities and morphological elements mentioned in the text are shown.

The effects of dredging and dumping in the environment are variable and depend on the estuarine area and other factors such as: the magnitude and frequency of dredging, the dredging method, the form, length and depth of dredging, the grain size, the density and composition of dredged material, the intertidal area of dredging, the quality of water and sediment, the tidal range, the direction and intensity of tidal currents, the water mixing, the seasonal variability, the proximity to coastline and the presence of biological communities (IADC/CEDA, 1998).

Prediction of potential adverse effects of dredging and dumping in estuaries cannot be evaluated properly if the previously mentioned parameters are unknown. Moreover, long- and short-term effects on dredged areas must be taken in account. As well, when dredging is undertaken periodically it is possible that this provokes accumulative effects. Lindeman (1997) stated that the most devastating environmental effects are not a product of particular activities but a combination of multiple single and individual effects throughout time.

The aim of this study is to analyze the dredging and dumping which have occurred in the lower Oka estuary during the period 1957–2005, determine the consequent morphological changes in the estuary and finally to establish morphodynamic criteria for suitable management of the latter.

## 2. Materials and methods

### 2.1. Vertical aerial photographs and ortophotos

During the last 50 years various private companies and public institutions have photographed the lower Oka estuary extensively. These images have been used in this study to describe the temporal evolution of its sedimentary environments. The information sources used here were: the photo-archive of the Urdaibai Biosphere Reserve Governing board (1957 flight, scale 1:7000; author: U.S. Army), the photo-archive of the Biscay Province Council (1965 flight scale 1:20000; 1971 flight scale 1:7000; 1982 flight scale 1:18000 and 1995 flight scale 1:18000; author: Biscay Province Council) and the photo-archive of the Environment Department of Basque Government (1992 flight scale 1:5000; 1996 flight scale 1:5000; 2001 (ortophoto) 0.5 m/pixel; 2002 (ortophoto) 0.25 m/pixel and 2005 (ortophoto) 0.25 m/pixel; author: Basque Government).

Due to scale variability of the photographs and ortophotos and with the aim of homogenizing the results, a common 1:20,000 scale was chosen for this study. The images corresponding to the 1957–1996 time period were not geo-referenced so they were first scanned (300 pixel/inch) and then geo-referenced using ArcMap GIS software. During the referencing process an RMS (Root Mean Square) lower than 20 m and an error higher than 30 m for each coordinate were deemed not to be acceptable.

Later, photo interpretation and identification of different sedimentary environments throughout the temporal series was made using GIS software. Existing environmental units and their sedimentary structures were first identified in the field and compared with their air photo expression. As well, the minimum unit to map ( $100 \text{ m}^2$ ) was chosen taking into account the work-scale and image quality. The sedimentary environments chosen were: tidal channels, intertidal sandy flats, intertidal mudflats, mixed intertidal flats, salt marshes; supratidal areas and zones of human occupation.

The corresponding polygons for each sedimentary environment were delineated over each image. Later, the polygons were exported as shape files into Surfer 8 software and maps of sedimentary environments were produced for each group of historical images in order to illustrate their evolution throughout time. Also, the temporal variability of the ebb and flood channels and estuarine surface sedimentary structures (eg bedforms) were mapped and interpreted in relation to dredging and dumping operations.

### 2.2. Oblique aerial photographs

In order to complete the analysis and to obtain additional information, historical oblique aerial photos obtained by individuals, private companies and public institutions were compiled and interpreted.

### 2.3. Public archives

Likewise, historical and technical information was compiled from the local archives of the Ministry of Environment (1973–1993 period) and the Governing Board of the Urdaibai Biosphere Reserve (1994–2005 period). This information was used in order to describe the technical details of the dredging and dumping operations carried out during the last 50 years.

### 2.4. Bathymetric surveys

In order to analyze the effects of the most recent dredging and dumping carried out in the lower Oka estuary different bathymetric

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