Ocean & Coastal Management 116 (2015) 435–442

Contents lists available at ScienceDirect

Ocean & Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Assessing consequences of land cover changes on sediment deliveries to coastal waters at regional level over the last two decades in the northwestern Mediterranean Sea

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ARTICLE INFO

Article history:
Received 9 May 2015
Received in revised form
6 September 2015
Accepted 15 September 2015
Available online xxx

Keywords:
Land cover
Soil erosion
Sediment delivery
Coastal habitats
Mediterranean sea
Ecosystem-based management

ABSTRACT

Human-induced changes to land cover and associated strong influence such changes have on sediment delivery to coastal waters are a well-recognized threat to nearshore marine habitats worldwide. Land cover has been commonly used as a proxy to document human alterations on sediment discharges. In the present study, changes in sediment delivery to coastal waters along the coastline of the Ligurian Sea (northwestern Mediterranean Sea) were estimated on the basis of land cover data. This area includes benthic habitats-areas that are very sensitive to water turbidity and sedimentation increase -and warrant protection demonstrated by the establishment of five marine Sites of Community Importance and a Marine Protected Area (Portofino MPA). The principal objectives of the study were to identify changes in soil erosion in multiple basins and estimate the strength of the change over a defined period of time in sediment delivery at the outflow. A combination of Revised Universal Soil Loss Equation (RUSLE) model and sediment delivery ratio (SDR) was applied. The strongest changes happened individually in two different basins in the periods 1990–2000 and 2006–2012 meanwhile the period 2000–2006 showed several changes in several basins with less estimated change. This assessment can help to make better coastal-land management decisions for managing or restoring coastal marine ecosystems.

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1. Introduction

Changes in land cover can increase the runoff of sediments, pollutants and nutrients into coastal waters (Syvitski et al., 2005), having negative effects on benthic habitats due to increased water turbidity and siltation, and declines in water quality (McLaughlin et al., 2002; Restrepo and Syvitski, 2006; Wolanski et al., 2003). In particular, increased turbidity is a major threat to seagrass meadows (Erftemeijer and Lewis, 2006), while increased siltation may have dramatic effects on subtidal macroalgal assemblages (Airoldi and Virgilio, 1998; Airoldi, 1998).

In the last decades, land-cover in coastal areas of the Mediterranean Sea have been vastly altered by humans (Vallejo et al., 2001; Falcucci et al., 2006). Potential increases in soil erosion have drawn the attention of scientists and managers to study and assess current sediment delivery to coastal marine habitats. Besides the ecological effects, sediment discharges in port areas create a cost to port authorities (cleaning of sediments). The northwestern Mediterranean coastline has a steep geography and is prone to land erosion because soils are subject to long dry periods followed by heavy rainfalls (Grimm et al., 2003; Knijff et al., 1999; Panagos et al., 2015a,b). In addition, inappropriate agricultural practices, deforestation, overgrazing, fires and construction activities (Yassoglou et al., 1998) are common in the region and contribute further to the erosion problem.

The strong influence of land cover changes on the variation of

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http://dx.doi.org/10.1016/j.ocecoaman.2015.09.003
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sediment transport rates has been previously demonstrated (Pasquale Borrelli et al., 2014a,b; Cebecauer and Hofierka, 2008; Van Rompaey et al., 2007). The impacts of land cover changes on sediment discharges may be effectively assessed using soil erosion modeling, when historic land cover data is available (Jordan et al., 2005). Both soil erosion loss and sediment delivery resulting from different land cover conditions, such as agricultural areas and disturbed forest lands, have been successfully estimated using the Revised Universal Soil Loss Equation (RUSLE) model (Angima et al., 2003; Mati et al., 2000; Renard and Foster, 1997). This model, when supported by Geographic Information Systems (GIS) and geostatistical techniques, can be an important soil management tool to assess wider geographic ranges. The RUSLE model has been previously employed for the study of soil erosion loss in some Mediterranean countries (Hammad et al., 2004), and specifically in Italy (Knijff et al., 1999, 2000; Grimm et al., 2003; Terranova et al., 2009). However, special attention should be given to the spatio-temporal distribution of changes in sediment delivery and potential impact this has on coastal benthic habitats. Such knowledge is crucial for taking effective land-sea management decisions, the mitigation of land runoff processes, and achieving long-term sustainable development.

This study used a simplified RUSLE model to assess the potential change on basin's sediment delivery driven by the land cover changes during the last two decades in the Tigullio Gulf and areas surrounding Portofino MPA. The basins with increased or decreased sediment delivery were identified and the main causes for these changes were determined. A better understanding of the potential impact of land cover changes in coastal ecosystems is critical to improve marine and coastal ecosystem-based management, and current management plans.

2. Material and methods

2.1. Study area

The study area extends 75 km of coastline, from the Paradiso Gulf to Manara Cape, along the Ligurian Sea (northwestern Mediterranean Sea), and includes 58,919 ha of water catchment area (Fig. 1). The stretch of coastline shared with the catchment area includes the Portofino national Marine Protected Area (Portofino MPA) established in 1999, and 5 marine Sites of Community Importance (SCIs, European Habitats Directive, 92/43/EEC). *Posidonia oceanica* (Linnaeus) Delile, 1813 meadows extend for about 296 ha along the coasts of the Paradiso and Tigullio Gulfs, while coralligenous habitats extend for about 51 ha in front of the Manara Cape and Portofino Promontory (Coppo et al., 2009). The whole coastal area of the study has an important role in the regional economy as it is extensively used for beach and nautical tourism, SCUBA diving, and fisheries, among others (Italian National Institute of statistics, ISTAT, 2007).

The inland area is characterized by a mountainous territory with steep seaward slopes (Rovere et al., 2011), which increases the quantity of terrigenous material draining to the Ligurian Sea shelf (Vietti et al., 2010) (Fig. 1). Liguria region has one of the highest mean annual precipitation (1000–3000 mm yr^{-1}) in Europe and it is defined as one of the most affected areas for the rainfall erosivity in Europe with extreme values higher than 2000 MJ mm ha^{-1} h^{-1} yr^{-1} (Panagos et al., 2015a). Bioclimatic conditions change from coast to inland areas and rainfall distribution shows extreme variability in time, with sporadic torrential events during autumn and spring. The diverse climatic conditions provide a wide range of natural vegetation associations and allow different human traditional activities (e.g. homegrown agriculture), which results in higher diversities of land cover. The whole catchment area considered in the study includes 14 SCIs, one Natural Reserve (Riserva Orientata Agorale di Sopra e del Mogetto), and two Regional Parks (Parco Naturale Regionale di Portofino, Parco Regionale dell'Aveto) covering more than 12,000 ha.

2.2. Basins delineation and outflows

The basin is a common unit of management for land and water authorities in many countries (Kingdom, 1998; Zalewski and Wagner-Lotkowska, 2004), since they link land areas with their outflows. The basin delineation was performed using the hydrology toolbox in Arc-View GIS 10.2 software and the Digital Elevation Model (DEM, resolution of 30 × 20 m) from US Geological Survey. From the DEM, flow direction and flow accumulation of the water were determined. The outflows of sediments to the coast were identified in high cumulative flow points, and basins were delineated using the flow direction and the outflows obtained previously.

In order to tie the land based source of sediment directly to coastal habitat, the basins delineated with the model were corroborated with Google Earth 3D images and, aerial photographs of the Italian National Geoportal were used to detect possible human alterations to the natural flow regimes of rivers at the outflows.

2.3. RUSLE and sediment delivery yield

The Revised Universal Soil Loss Equation (RUSLE) has been selected among the applicable models thanks to its very simple structure and the parsimonious input of data in relation to the available data and the investigation scale. The combined RUSLE and sediment delivery ratio (SDR) methodology was used in this study to compare the estimations of sediment delivery yield (t ha^{-1}) at the outflow of each basin over time. The SDR value was added as a multiplier to the RUSLE equation (Renard and Foster, 1997; Wischmeier and Smith, 1978).

$$A = K \times L \times S \times R \times C \times P \tag{1}$$

Where A is the mean soil loss per season (October–December); R is the rainfall–runoff erosivity factor, K is soil-erodibility factor (Panagos et al., 2014); L is the slope–length factor and S is the slope–steepness factor (dimensionless); C is the land-cover/management factor that takes into account differences in density and structure of the vegetation cover reflecting its protective function and also the methods of land management (dimensionless); and P is the support-practice factor (dimensionless), which is not considered in this model. The temporal variability of *R-factor* is not considered in this study (due to lack of seasonal erosivity) while K, L and S factor are not changing during the time; so, those factors were treated as constant over this period of time.

2.3.1. Input parameters

Rainfall-erosivity factor was calculated using daily precipitation data from 2010 to 2012 in the rainiest season (September, October and November) in the study area. Data was collected from ten stations dispersed within the study area. The factor was calculated using the regression model suggested by Jung et al. (1983), RUSLE monthly R-factor: $R = 0.0378 \times X^{1.4190}$; X is the monthly rainfall amount (mm). Using the above regression model, the R-factor value for each station was computed and R-factor distribution map was made by Kriging interpolation (Khorsandi and Mahdian, 2012).

Land Cover/management factor was obtained from the CORINE Land Cover (Coordination of Information on the Environment Land Cover, CLC). The unified CLC methodology, a legend of 44 classes

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