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Assessment of the effects of a port expansion on algae appearance in a costal bay through mathematical modelling. Application to San Lorenzo Bay (North Spain)

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ABSTRACT

In the last years several episodes of algae appearance affecting bathing areas have been observed in San Lorenzo Bay (north of Spain). The analysis of the collected algae revealed that they might come from near intertidal or shallow subtidal zones due to eutrophication processes or through drift algae movement by the action of marine currents. In the vicinity of this area, the expansion of the Port of Gijón (now under construction) supposes a significant modification of the coastal geometry. The magnitude of such an expansion could cause changes in the patterns of currents in the bay, with the consequent alteration of the observed algal appearance phenomena. A mathematical modelling study to evaluate the risk of generation of eutrophication processes in the San Lorenzo Bay area and the transport of drift algae from near sea bed areas was developed. This study required the use of different hydrodynamic models in order to characterize the currents caused by tides, winds and waves. The eutrophication processes in the bay were analyzed with a depth-averaged two-dimensional eutrophication model which deals with eight water quality variables. Calibration of model parameters with the observed data from a field survey was performed. A reasonable agreement with the field measurements was achieved. Model results showed that the maximum phytoplankton concentrations were below eutrophic conditions. Although, the port expansion has led to an increment of phytoplankton concentrations, chlorophyll *a* levels were not representative of eutrophic conditions. To analyse the transport of drift algae, a methodology based on the utilization of a two-dimensional model which solves the depth-averaged advection-diffusion equation considering seaweed as a conservative tracer was developed and applied. Numerical modelling allowed the identification of the coastal areas that seems to be the source of the seaweed found on the beach. It was also proven that port expansion does not significantly affect drift algae transport in the area.

1. Introduction

Increasingly, coastal bays and estuaries throughout the world tend to experience algae appearance phenomena (Justice et al., 2005). San Lorenzo Bay (SLB) in the north of Spain has suffered several of these processes in recent years. One of the region's most emblematic beaches (San Lorenzo) was particularly affected by these episodes along with other bath areas. The bay presents low flow regime and is fairly shallow, factors that could confer it the ideal conditions for the development of eutrophication processes.

In August 2002 an algae collection survey was carried out at San Lorenzo beach. The most abundant species were *Plocamium cartilagineum*, *Gelidium sesquipedale*, *Calliblepharis ciliata* and *Fucus vesiculosus*. In general, the most abundant observed species matched those living in the intertidal or subtidal shallow areas within the vicinity of this beach (Table 1). The results of this comparison indicated two possible sources of the algal blooms. They could appear as a consequence of the development of eutrophication processes at the mouth of the Piles River and the shallowest part of the bay, or they could be the result of the transport of swept away algae from rocky bed bottom areas in the vicinity of the bay.

Initially identified and studied in continental ecosystems, eutrophication is a phenomenon that also increasingly affects coastal areas as a consequence of two fundamental facts: the growing development of human activities on the coastal environment, and the intensive use of the sea as a digestor with a virtually unlimited capacity to accept wastewater discharges. There is clear evidence of an increase, not only in frequency, but also in magnitude, of algae blooms in recent years as there has been also observed

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Table 1
Algae species collected at San Lorenzo beach and during the field survey.

San Lorenzo beach	Field survey	
	More plentiful species	More frequent species
Acrosorium uncinatum	*Gelidium sesquipedale*	*Plocamium cartilagineum*
Calliblepharis ciliata	*Saccorhiza polyschides*	*Cryptopleura ramosa*
Codium tomentosum	*Laminaria hyperborea*	*Pterosiphonia complanata*
Cryptopleura ramosa	*Calliblepharis ciliata*	*Gelidium sesquipedale*
Cystoseira baccata	*Plocamium cartilagineum*	*Saccorhiza polyschides*
Dictyota dichotoma	*Chondrus crispus*	*Heterosiphonia plumosa*
Asparagopsis armata	*Halidrys siliquosa*	*Calliblepharis ciliata*
Fucus vesiculosus	*Pterosiphonia complanata*	*Dictyopteris membranacea*
Gelidium sesquipedale	*Rhodymenia holmesii*	*Perosiphonia pennata*
Plocamium cartilagineum	*Heterosiphonia plumosa*	*Rhodymenia pseudopalmata*
Pterosiphonia sp.	*Dictyopteris membranacea*	*Acrosorium uncinatum*
Ulva sp.	*Desmarestia aculeata*	*Rhodymenia holmesii*
	Rhodymenia pseudopalmata	
	Cystoseira baccata	*Gymnogongrus crenulatus*
	Cryptopleura ramosa	*Callophyllis laciniata*
	Gymnogongrus crenulatus	*Laminaria hyperborea*
	Callophyllis laciniata	*Desmarestia aculeata*
	Pterothamnion crispum	*Cystoseira baccata*
	Kalymenia reniformis	*Palmaria palmata*
	Gracilaria multipartita	*Corallina elongata*
		Chondrus crispus

a significant increase in the amounts of nutrients introduced into the sea from different sources (rivers, urban and rural runoffs, urban and industrial discharges).

Eutrophication is defined as the enrichment of water by nutrients stimulating the growth of algae and aquatic weeds to produce an undesirable disturbance to the balance of organisms present in the water as well as to the quality of the water (Chau and Jin, 1998; OSPAR, 2003). Nowadays, this point-source and non-point source enrichment with nitrogen and phosphorous is recognized as the most serious pollution problem faced by coastal waters world wide (Lapointe and Bedford, 2007).

Eutrophication in coastal marine environments may depend on hydrodynamic phenomena such as advection, diffusion, vertical stratification, frontal dynamics and the mixing of the water column (Sundarambal and Tkalich, 2003), as well as variation in light. The biomass of primary producers (macroalgae and phytoplankton) increases with high temperatures, implying the utilization of the dissolved nutrients in water, until the nutrient levels can not maintain this growing rate and a decreasing phase of the aquatic plants biomass is begun (Thomann and Mueller, 1987). In general, marine eutrophication happens with a seasonal trend (spring–summer) and, basically, in coastal zones with low renewal allowing the algae development and the sedimentation of inorganic turbidity, which, under most conditions, limits available light reducing algal growth below what normally occurs in water bodies (Berón, 1990). Among many other problems, eutrophication causes a variety of impacts such as: high levels of chlorophyll *a*, overgrowth of seaweed and epiphytes, occurrence of anoxia and hypoxia, nuisance and toxic algal blooms, and losses of submerged aquatic vegetation and benthic organisms (Gomes et al., 2007). In coastal bays with low renewal rates, the most obvious effect is the proliferation of macroalgae. The excessive growth of green algae in response to urban discharges is a phenomenon that is becoming common in many estuaries and protected bays (Reise, 1983). Parallel to the proliferation of green algae, eutrophication can also produce a change in the distribution of different species (Rueness, 1973).

Most seaweeds are attached by a holdfast to the substrate which prevents them to be swept away by waves and tide. However, under certain circumstances, algae mats could be detached from their substratum and moved via wave activity and water currents. Passive movement of drift algae implies that the hydrodynamic regime of a water body may be critical in determining the transport of algae (Biber, 2007). Bell and Hall (1997) studying the Tampa Bay area, found that algae movement is heavily dictated by waves and currents, with hydrodynamically less active environments favouring accumulations of drift algae at a greater rate than sites with high current velocity or extensive exposure to waves. The abundance of drifting algae is governed by the availability of biomass imported from its sources and physical forces such as wind, currents and wave action (Norkko et al., 2000).

Close to this area the Gijón Port Authority is carrying out an expansion of port facilities including the construction of outer docks of about 7 km perimeter and over 2 km^2 of new storage area. These works imply a significant modification of the coast line, and, consequently, of the marine currents. This change in configuration could affect the processes that determine the occurrence of algae blooms in the bay.

The great number of factors influencing the eutrophication processes or drift algae transport has led to the use of complex mathematical tools. These tools allow to compute water surface elevations and velocity fields under complex flux situations as in the case of estuarine and coastal systems. They also allow determining the transport of any diluted or suspended substance in the water column.

Despite this problem, no spatial and/or temporal studies of these phenomena have been conducted to date in SLB. Thus, it was essential to evaluate the risk of generation of eutrophication processes in the SLB area, that would favour the massive development of other species of eutrophic zones, as have been observed in some French bays with low renewal (IFREMER, 2001). The transport and accumulation of drift algae into the bay were also studied. Furthermore, an important aspect of these studies is related to the change in the development of these processes as a result of the port expansion works.

In this paper, the methodologies used to study the eutrophication conditions at SLB area and the transport of seaweed are described. An assessment of the influence of increasing hydromorphological alterations caused by port expansion is also presented. These studies were carried out applying different specific numerical hydrodynamic and water quality models which are briefly described.

2. Study area

The study area is located in the north coast of Spain, in the Bay of Biscay. SLB is a small sea entrance limited by Cervigón and Santa