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Nutrient contributions to the Santa Barbara Channel, California, from the ephemeral Santa Clara River

Jonathan A. Warrick[a,*], Libe Washburn[b], Mark A. Brzezinski[c], Dave A. Siegel[b]

[a]*Coastal and Marine Geology Program, United States Geological Survey, 345 Middlefield Road, MS 999, Menlo Park, CA 94025-3591, USA*
[b]*Institute for Computational Earth System Science and Department of Geography, University of California, Santa Barbara, USA*
[c]*Marine Science Institute and the Department of Ecology, Evolution and Marine Biology, University of California, Santa Barbara, USA*

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Abstract

The Santa Clara River delivers nutrient rich runoff to the eastern Santa Barbara Channel during brief (~1–3 day) episodic events. Using both river and oceanographic measurements, we evaluate river loading and dispersal of dissolved macronutrients (silicate, inorganic N and P) and comment on the biological implications of these nutrient contributions. Both river and ocean observations suggest that river nutrient concentrations are inversely related to river flow rates. Land use is suggested to influence these concentrations, since runoff from a subwatershed with substantial agriculture and urban areas had much higher nitrate than runoff from a wooded subwatershed. During runoff events, river nutrients were observed to conservatively mix into the buoyant, surface plume immediately seaward of the Santa Clara River mouth. Dispersal of these river nutrients extended 10s of km into the channel. Growth of phytoplankton and nutrient uptake was low during our observations (1–3 days following runoff), presumably due to the very low light levels resulting from high turbidity. However, nutrient quality of runoff (Si:N:P = 16:5:1) was found to be significantly different than upwelling inputs (13:10:1), which may influence different algal responses once sediments settle. Evaluation of total river nitrate loads suggests that most of the annual river nutrient fluxes to the ocean occur during the brief winter flooding events. Wet winters (such as El Niño) contribute nutrients at rates approximately an order-of-magnitude greater than "average" winters. Although total river nitrate delivery is considerably less than that supplied by upwelling, the timing and location of these types of events are very different, with river discharge (upwelling) occurring predominantly in the winter (summer) and in the eastern (western) channel.
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1. Introduction

Eastern boundary upwelling regions are very productive coastal ecosystems due to the introduction of nutrients from depth (Summerhayes et al., 1995; Hill et al., 1998). River nutrient inputs are generally ignored in these regions since these contributions are assumed to be small compared to upwelling and other sources of vertical mixing. However, river discharge can influence coastal water biogeochemistry and primary production especially near river mouths (Drinkwater and Frank, 1994; Smith and Hitchcock, 1994). For example, the Columbia River is known to influence ocean concentrations of nutrients and chlorophyll for 100s of km from the river mouth (Stefansson and Richards, 1963; Hobson, 1966; Pruter and Alverson, 1972). Further, historic changes in river discharge quantity or qualities have forced significant changes to other coastal ecosystems (Humborg et al., 1997; Chen, 2000; NRC, 2000; Schilman et al., 2001; Scrivner et al., 2004).

* Corresponding author.
E-mail address: jwarrick@usgs.gov (J.A. Warrick).

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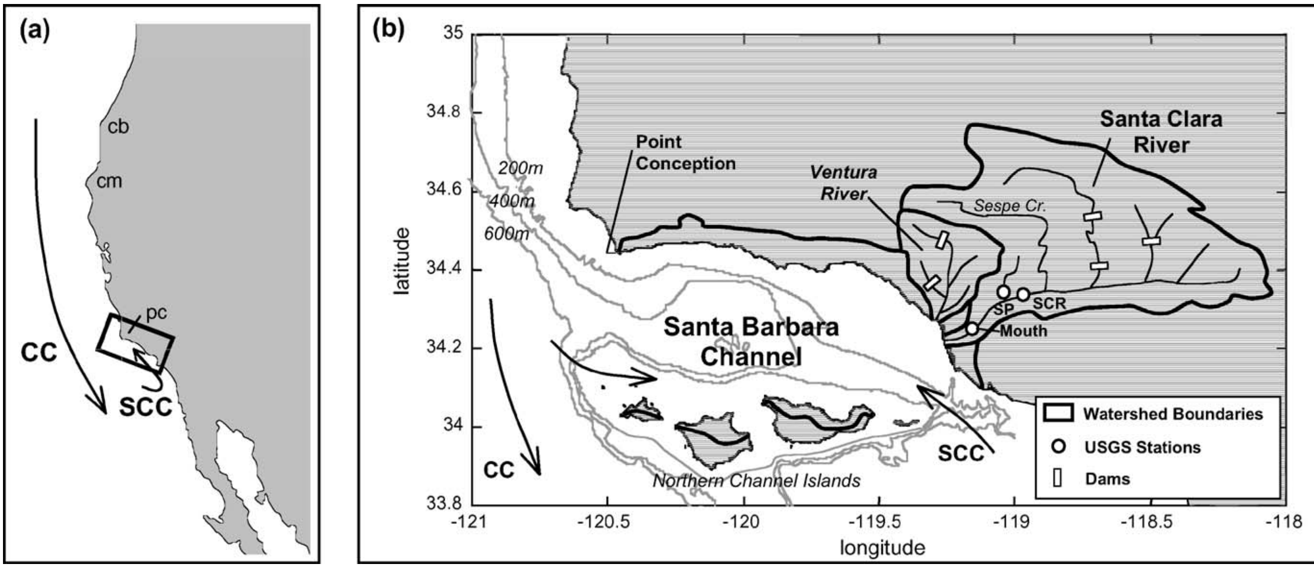

Fig. 1. (a) A generalized map of the California Current (CC) and the Southern California Countercurrent (SCC) of the northeastern Pacific Ocean. Also identified are Cape Blanco (cb), Cape Mendocino (cm) and Point Conception (pc). The rectangle shows the area shown in (b). (b) The Santa Barbara Channel and rivers discharging directly into the channel. Three USGS river gauging sites utilized in this work are identified with circles and include 'SCR' (USGS 11113300, Santa Clara River near Santa Paula), 'SP' (USGS 11113500, Santa Paula Creek near Santa Paula), 'Mouth' (USGS 11114000, Santa Clara River at Montalvo).

The Santa Barbara Channel (Fig. 1) has a unique eastern boundary coastal setting, because it receives inputs from both nutrient-rich and nutrient-depleted circulation sources and ephemeral terrestrial runoff. Upwelled California Current waters can enter the western Santa Barbara Channel along the Northern Channel Islands (Fig. 1b), which promotes primary productivity in the western portion of the channel (Dugdale and Wilkerson, 1989). The eastern Santa Barbara Channel generally receives water from the Southern California Countercurrent (Fig. 1), which transports warmer waters poleward through the Southern California Bight (Hickey, 1998). These warmer countercurrent waters have low concentrations of macronutrients and are therefore less productive than the recently upwelled waters of the western channel. Hence, the average circulation patterns suggest that the Santa Barbara Channel should have greater productivity in the western, upwelling-dominated section than in the eastern, countercurrent dominated section.

Satellite ocean color observations of Santa Barbara Channel reveal that chlorophyll pigments are greatest in the western and central sections of the channel especially following upwelling conditions (Otero and Siegel, in press), which is consistent with the inferred productivity patterns described above. These SeaWiFS remote sensing observations, however, also reveal consistently high chlorophyll in the eastern channel extending 5–10 km from the shoreline throughout the year. If these ocean color observations are accurately portraying chlorophyll patterns, nutrient sources in the eastern channel are required to support this algal biomass.

Here we evaluate the influence of river discharge, which occurs dominantly in the eastern channel (Fig. 1b), on the spatial and temporal distribution of macronutrients (silicate and inorganic N and P) and chlorophyll pigments in the Santa Barbara Channel. This work focuses on the Santa Clara River, since it the dominant source of discharge to the Channel. Our data show that the Santa Clara River does introduce a significant source of nutrients to the channel, especially during the winter season. Although these contributions are significantly less than upwelling inputs to the channel, they are highly pulsed and supply nutrients in significantly different proportions and at different times of the year compared to upwelling.

1.1. Study area

The Santa Barbara Channel is the northernmost ocean basin of the Southern California Bight and generally receives inputs from the California Current (CC) on its western boundary and the Southern California Countercurrent (SCC) on its eastern boundary. Circulation through and within the Santa Barbara Channel, however, is complex and dynamic, as it responds to both regional alongshore pressure gradients and local wind stresses (Harms and Winant, 1998; Chen and Wang, 2000; Oey et al., 2001). Surface currents are commonly cyclonic within the channel, especially during the spring and summer. During periods of intense upwelling wind stresses, circulation can be equatorward in both the western and eastern ends of the channel, and

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