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Trends in marine debris along the U.S. Pacific Coast and Hawai'i 1998–2007

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ABSTRACT

We assessed amounts, composition, and trends of marine debris for the U.S. Pacific Coast and Hawai'i using National Marine Debris Monitoring Program data. Hawai'i had the highest debris loads; the North Pacific Coast region had the lowest debris loads. The Southern California Bight region had the highest land-based debris loads. Debris loads decreased over time for all source categories in all regions except for land-based and general-source loads in the North Pacific Coast region, which were unchanged. General-source debris comprised 30–40% of the items in all regions. Larger local populations were associated with higher land-based debris loads across regions; the effect declined at higher population levels. Upwelling affected deposition of ocean-based and general-source debris loads but not land-based loads along the Pacific Coast. LNSO decreased debris loads for both land-based and ocean-based debris but not general-source debris in Hawai'i, a more complex climate-ocean effect than had previously been found.

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1. Introduction

Environmental monitoring is a valuable tool that can provide the principal record of change, a baseline for determining extreme events, and context for shorter-term studies (Lovett et al., 2007). For understanding marine debris deposition, where non-linear patterns and extreme events are common (Ribic et al., 2010), long-term monitoring is especially important. However, there are few such programs, leading the National Academy of Sciences (Criddle et al., 2009) to conclude that there was little quantitative information on amounts, sources, and trends of marine debris.

Marine debris comes from a variety of sources, land-based and ocean-based, and has multiple impacts, including aesthetic, wildlife (ingestion and entanglement), and economic (Coe and Rogers, 1997; Criddle et al., 2009). Understanding debris sources can lead to more effective mitigation strategies by targeting actions. Mitigation of debris from land-based sources is an important focus for managers. Using education is a large part of the strategy; Alkalay et al. (2007) developed an index of beach debris to assess cleanliness as a way of determining if education programs have been effective. Regulation is another tool that is starting to be used. Jung et al. (2010) discuss a comprehensive plan for Korea to manage marine debris, including regulation. Putting marine debris into a water quality framework has allowed southern California to develop regulations to reduce discharge of land-based debris (California Environmental Protection Agency Los Angeles Regional Water Quality Control Board, 2011). However, understanding the effectiveness of regulations requires a baseline of debris loads and trends.

Conducting surveys to monitor marine debris that collects along beaches is an established technique for evaluating the status of the debris, not just on those beaches, but also as an index of conditions in surrounding waters (Dixon and Dixon, 1981; Ribic et al., 1992; Rees and Pond, 1995; Alkalay et al., 2007; Cheshire et al., 2009). Where long-term data have been collected (e.g., Edyvane et al., 2004) important insights into regional issues have been gained. One large-scale program, the National Marine Debris Monitoring Program, was designed to determine quantitatively if the amount of debris on the U.S. Coastline was changing and what were its major sources (Escardó-Boomsma et al., 1995). The program recently documented variation in regional debris loads and trends over time for the U.S. Atlantic Coast (Ribic et al., 2010) and the U.S. Gulf of Mexico and Puerto Rico (Ribic et al., 2011); an important finding was that marine debris from land-based sources had different long-term patterns compared to debris from ocean-based sources. This implies that different management strategies will likely be needed to reduce debris inputs into the oceanic system.

Following the design intent of the National Marine Debris Monitoring Program and building on Ribic et al. (2010, 2011), our primary objective is to use Program data to determine whether

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there were trends in marine debris indicator items by source category found on the U.S. Pacific Coast and Hawai'i and how various processes may affect debris loads. Our secondary objective is to compare the amounts and composition of the indicator items across the defined regions in this geographic area (or "in the Pacific basin"). In all cases, we test the null hypothesis of no change or no difference among regions.

2. Methods

2.1. Study area

The U.S. Pacific Coast and Hawai'i are located in the Pacific Basin. Hawai'i is influenced by the Central Pacific Gyre and the U.S. Pacific Coast by the California Current (Fig. 1). The California Current is an upwelling system, driven by prevailing northerly winds (Mann and Lazier, 2006). The Pacific Coast can be divided oceanographically into two regions: (1) the North Pacific Coast (Washington, Oregon and California north of Point Conception) and (2) the Southern California Bight (California south of Point Conception). The Southern California Bight is where the California Current moves eastward and forms the Southern California Countercurrent, resulting in more complex circulation patterns (Oceanography of the Southern California Bight, 2011) (Fig. 1).

2.2. Survey design

The monitoring program was designed to detect change in a region with power of 0.85 and Type I error rate (i.e., alpha) of 0.10 (Escardó-Boomsma et al., 1995). The protocol was to measure the net accumulation of indicator items on a site's 500 m stretch of beach every 28 days (Escardó-Boomsma et al., 1995; Ribic and Ganio, 1996). A length of 500 m was used to ensure that an adequate number of indicator items would be collected for analysis. The survey interval reflected information that water quality measures are independent once 28 days have passed (Lettenmaier, 1978).

Indicator items provided a standardized set that all surveys would collect; each item was assigned a probable source: ocean-based, land-based, or general-source (Appendix A). The items to include in the indicator set and their source categories were developed by marine debris experts in a series of workshops held during the development of the protocol (Escardó-Boomsma et al., 1995). Probable ocean-based debris was related to activities such as recreational boating/fishing, commercial fishing and oil/gas platform activities. Probable land-based debris was related to land-based recreation and sewage systems. General-source indicators represented plastic debris items that can originate from either ocean- or land-based sources (e.g., plastic bottles).

For each region, a comprehensive list of all potential survey sites was constructed. The potential study sites met the following criteria: length of at least 500 m, low to moderate slope (15–45°), composed of sand to small gravel, direct access to the sea (not blocked by breakwaters or jetties), accessible to surveyors year round, not cleaned on a regular basis, and no impact to endangered or protected species such as sea turtles, sea/shorebirds, marine mammals or sensitive beach vegetation. The survey sites used in the program were then randomly selected from this list.

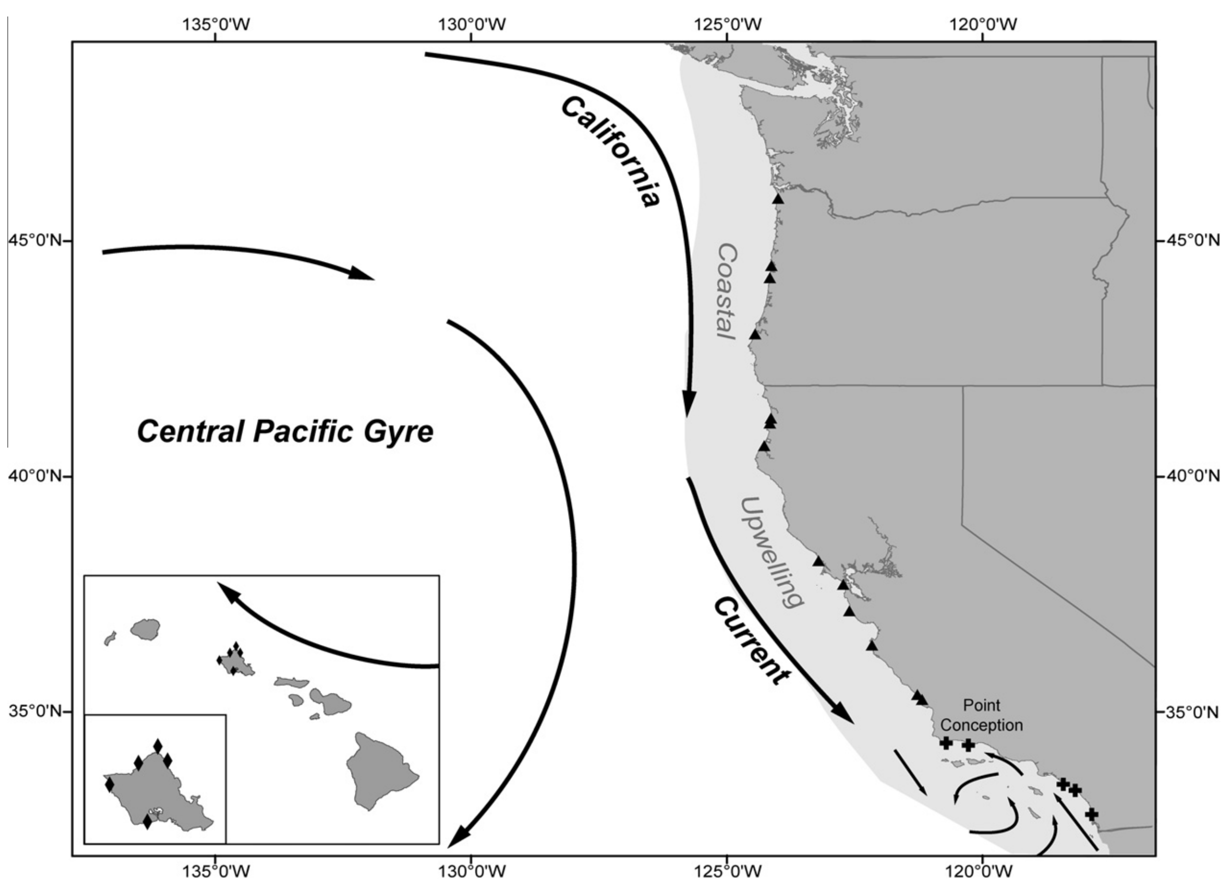

Fig. 1. Major circulation systems in the Pacific Basin and study sites from the National Marine Debris Monitoring Program along the U.S. Pacific Coast and Hawai'i. The North Pacific Coast sites are north of Point Conception (triangles), the Southern California Bight sites are south of Point Conception (+), and the Hawai'i sites are on O'ahu (diamonds).