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Observations of the non-native Pacific oyster (*Crassostrea gigas*) in San Diego County, California

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California's coastline continues to accumulate species introduced from all over the world. In San Diego County's estuarine and marine waters, the number of reported non-native species now stands at around 100 (Crooks 1998, unpublished data, Preisler et al. 2009). Among the many different taxa of invaders in this region, bivalve molluscs are of particular interest given their potential ecological and economic impacts and the relatively well-documented history of changes in bivalve assemblages over time (Crooks 2001). Bivalves in general are a relatively conspicuous group, their representation in the fossil record and in archeological sites make the deeper history of these organisms accessible, and local molluscan assemblages have also been focal organisms for study by scientists for 150 years. Some of the non-native molluscs reported in the San Diego area include the bay mussel (*Mytilus galloprovincialis*), the Japanese mussel (*Musculista senhousia*), and the Manila clam (*Ruditapes philippinarum*). These are in addition to freshwater invaders of the county, including the Asian clam (*Corbicula fluminea*) and the notorious quagga mussel (*Dreissena rostriformis bugensis*). Despite repeated intentional introductions in San Diego, and California in general, one notable absence in the list of established mollusk invaders has been oysters. Herein we review isolated reports of introduced oysters into San Diego County and nearby areas in the 19th and 20th centuries, and then note what appears to be a successful establishment of the Pacific oyster (*Crassostrea gigas*) that began around the turn of the 21st century.

Movement of several species of non-native oysters into California began in the mid-1800s, driven by a desire to augment the declining fishery of the smaller native oyster, *Ostrea lurida* (Carlton 1979, Kirby 2004). Intentional introduction of Virginia oysters (*Crassostrea virginica*) from the U.S. east coast into California waters (San Francisco Bay) began in the 1860s, and by the 1880s Virginia oysters were planted on trial bases in Alamitos, Newport, and San Diego bays in southern California (Ingersoll 1881, Williamson 1894, Barrett 1963, Carlton 1979). There were some reports of what appears to be short-lived establishment of this species. In Alamitos Bay, Williamson (1894) noted an account that the Virginia oyster ground "embraces the whole of Alamitos and Anaheim Bays," and Townsend (1893)

indicated that "eastern oysters are reported as propagating in San Diego Bay." There was also interest in moving oysters from the lower Sea of Cortez into California, particularly the translocation of *Striostrea prismatica* (= *Crassostrea iridescens*) into the relatively warm waters of San Diego Bay (Gilbert 1891, Rathbun 1894, Moore 1897). As with the Virginia oyster, it appears that there were temporary populations of Mexican oysters to be found in the bay. Ingersoll (1881) highlighted a newspaper article from 1875 that stated that "the raccoon oyster, which is the native Lower California oyster, a bivalve of no mean merit, is found in great abundance in San Diego bay," and Townsend (1893) reported claims of survivors of an "accidental planting" of oysters from Guaymas, Mexico, being occasionally encountered. It is worth noting that the Mexican oyster "closely resembles the Atlantic coast species of the United States" (Rathbun 1894), so it is possible that there was confusion about the identity of the oysters being reported. Nonetheless, it does appear that non-indigenous oysters were temporarily present in San Diego in the late 1800s.

Movement of the Pacific oyster (also known as the giant or Japanese oyster, *Crassostrea gigas*) included introductions to the Pacific Northwest around the turn of the 20th century and to northern California starting in the 1920s (Carlton 1979). Intentional plantings into southern California included imports into Newport Bay in the 1930s, the inland Salton Sea in the 1950s, and San Diego Bay and Catalina in the 1960s (Barrett 1963, Carlton 1979). Small Pacific oysters were also temporarily transplanted as bioindicators in San Diego Bay and other California systems in the 1980s (Smith et al. 1987). Pacific oysters have also been introduced in Baja California, including limited introductions into Estero de Punta Banda near Ensenada (Carlton 1979), and a still-operational Pacific oyster grow-out operation in Bahia San Quintin that began in the 1970s (Islas-Olivares 1975).

Even with this widespread import, persistent populations of Pacific oysters were not reported in California throughout the 19th and 20th centuries, although many oyster associates did successfully invade (Carlton 1979, Grosholz et al. 2012). Occasional instances of wild Pacific oysters were reported, including one specimen found in Mission Bay, San Diego (as *Ostrea laperousi*, noted as "introduced - large 4 to 5 inch specimen" [Wilson 1943]) and a small number in Newport Bay in the 1940s (Carlton 1979). Starting in the year 2000, new incidences of Pacific oysters in southern California began to be reported. Cohen et al. (2005) found Pacific oysters in Los Angeles Harbor in 2000, and LaGrange (2002) reported them from San Diego Bay soon thereafter. This was coupled with other reliable sightings from San Diego Bay and Mission Bay in the early 2000s (C. Gramlich, San Diego State University, personal communication, 2006).

In 2005, we noted the presence of Pacific oysters within Mission Bay, the Tijuana River Estuary, and Oceanside Harbor (Figure 1). Since that time, we have found non-native Pacific oysters in virtually every suitable system in San Diego County, including Oceanside Harbor; Agua Hedionda, Batiquitos, San Elijo, San Dieguito, and Los Peñasquitos lagoons; Mission Bay; the San Diego River flood control channel; San Diego Bay; and the Tijuana River Estuary (Figure 1, Figure 2). Individuals range in size from recruits to specimens reaching 300 mm in length, with instances of multiple year classes present at a given time. Although it can be difficult to distinguish similarly-sized non-native and native Olympia (*O. lurida)* oysters, Pacific oysters can rapidly attain much larger sizes than the natives. Also, limited genetic work on oyster specimens from both Mission Bay and San Pedro (near the Port of Los Angeles) indicates matches with *C. gigas* (Grosholz et al. 2012; J. Asif, California State University Los Angeles, personal communication, 2006). Similar genetic

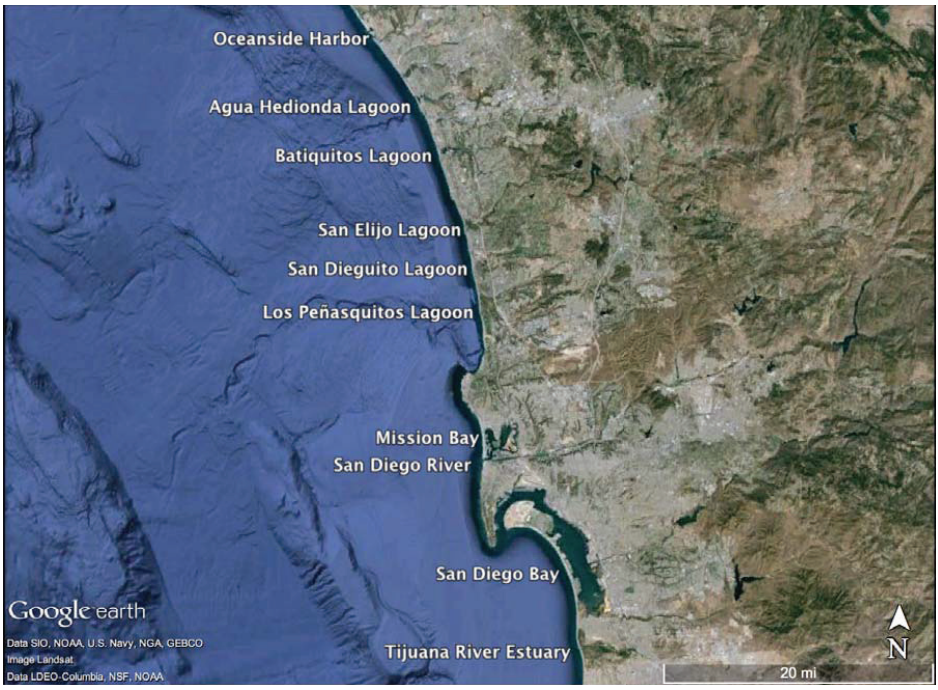

Figure 1.—Estuaries with observed occurrences of the non-native Pacific oyster (*Crassostrea gigas*) in San Diego County, California, 2005–2014.

Figure 2.—Photographs of the non-native Pacific oyster (*Crassostrea gigas*) in coastal San Diego County, California. (A) approximately100-mm oysters from Mission Bay, 2006; (B) 300-mm oyster from San Diego River Channel, 2011; (C) oysters on Los Penasquitos Lagoon shoreline, 2014; (D) 230-mm oyster from Tijuana Estuary, 2007; (E) abundant oysters on rip-rap in Tuna Harbor, San Diego Bay, 2014.

confirmation was also found for putative Pacific oysters found in San Francisco Bay within the same time frame (Cohen and Weinstein 2008). From these observations and other reports (Tuskes 2012; D. Zacherl, California State University Fullerton, personal communication, 2010; H. Carson, Washington Department of Fish and Wildlife, personal communication, 2014), the Pacific oyster now appears to be established in southern California.

It is probable that the southern California invasion began in the late 1990s, given the conspicuous nature of the Pacific oyster and the fact that work on invasive bivalves in San Diego from the mid-1990s did not detect this species (Crooks 1998). Although ship ballast and fouling are possible invasion vectors, with potential source regions of its native Asia or other areas where established (e.g., the Pacific Northwest), it is likely that aquaculture played a role in this invasion. Aquaculture is an important economic activity in California's coastal waters, and the Pacific oyster is approved for propagation by registered aquaculturists (Grosholz et al. 2012). There is a report of Pacific oyster culture and harvest in San Diego in 1988 (Shaw 1997), but that appears to have been short-lived. Renewed attempts at Pacific oyster culture in Agua Hedionda Lagoon began in the 1990s, and that effort continues today (Conte and Moore 2001, Moore and Moore 2010, Grosholz et al. 2012).

In general, the Pacific oyster is one of the most widely translocated of marine organisms, and it has successfully invaded North America, Europe, South America, Africa, Australasia, and Hawaii (Ruesink et al. 2005, Carlton and Eldredge 2009). Part of what makes the Pacific oyster a successful aquaculture species (and invader) is its relatively broad environmental tolerances (Padilla 2010), including its ability to live within a broad temperature range (Rico-Vila et al. 2009). Within its native Asia, it is found where summer temperatures range from approximately 14° to 29°C and winter temperatures range from -1.9° to 20°C (Carrasco and Baron 2010). Temperatures within San Diego estuaries fall within this range, with summer highs occasionally reaching 28°C and winter lows reaching 6°C (NERRS 2014).

It remains unclear why there should be a successful invasion now, given the failure of previous attempts to deliberately introduce the species both locally and throughout California. Such lags in establishment are not uncommon, however, and invaders are known for their ability to cause "ecological surprises" (Crooks 2011). Also, it is difficult to know the invasion trajectory into the future, as this invasion is still in its early phases. It is possible that the invasion will ultimately fail, but the presence of Pacific oysters across multiple years and multiple systems makes that less likely. If populations in southern California waters do continue to expand and grow, as they have in other areas where they have invaded (e.g., Troost 2010), it will undoubtedly bring changes to the way our estuarine intertidal habitats function as well as in the way we must manage them. Oysters are ecosystem engineers that can alter systems by creating dense biogenic structure and filtering the water column (Ruesink et al. 2005, Crooks 2009, Padilla 2010). The Pacific oyster's potential ability to create "living shorelines" actually exceeds that of the smaller, native *O. lurida*, and this needs to be considered in efforts to restore native oyster habitat in San Diego Bay and elsewhere in southern California. Because Pacific oysters rapidly reach large sizes they could pose problems related to fouling of maritime equipment, infrastructure, and vessels. Finally, Pacific oysters represent an edible and sought-after species, and could be the basis of expanded harvesting activities. However, the lack of recent history of a substantial shellfish harvest in places such as upper San Diego Bay would likely necessitate management approaches that address possible public health risks, such as contamination and disease (e.g., Kaysner et al. 1987, Pauley et al. 1988).

Pacific oysters stand out as one of the most transformative invaders of marine ecosystems. Better understanding the role of the Pacific oyster, and how to manage it, will necessitate research on this species in its new setting, including studies of both the oyster population and its interaction with both biotic and abiotic elements of local ecosystems. The Pacific oyster also could advance opportunities for education and public involvement, which are important components of marine management efforts (e.g., West Coast WISE Program 2014). Because Pacific oysters are now becoming one of the most conspicuous biota in our local estuaries, they provide an opportunity to highlight often-hidden changes occurring in the sea.

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