THE INVASION OF THE PACIFIC COAST BY THE EUROPEAN GREEN CRAB *Carcinus maenas*

Andrew N. Cohen
San Francisco Estuary Institute
180 Richmond Field Station, 1325 South 46th Street
Richmond, CA 94804 U.S.A.

The common European portunid crab *Carcinus maenas* (Linnaeus 1758) has invaded many parts of the world, where its appetite for commercially valuable clams and crabs has threatened important fisheries. The crab is native to Europe and possibly also northwest Africa. It arrived in eastern North America by 1817, in southern Australia by 1900, in western North America by 1989-90, and in Tasmania in 1993 (Say 1917; Fulton & Grant; Cohen et al. 1995; Gardner et al. 1994). Recent genetic analysis has revealed the presence of genotypes of both *C. maenas* and the related Mediterranean crab *Carcinus aestuarii* (Nardo 1847) in populations of Carcinus crabs that became established in Japan by 1984 and in South Africa by 1983 (Sakai 1986; Le Roux, et al. 1990; Geller et al. 1997). These mixed genotypes mean that either hybrids or individuals of both species are present. Although specimens of *Carcinus* have been collected from Hawaii, Panama, Brazil, Madagascar, Sri Lanka and Myanmar (Burma), the crab never became established in these sites where the water is probably too warm to allow successful reproduction (Carlton and Cohen, in press).

In earlier days the crab may have travelled on ship hulls nestled among attached barnacles, mussels, seaweeds and other organisms, or been carried with rocks or mud loaded as solid ballast. More recently it may have been transported in the ballast water tanks or associated seawater systems of ocean-crossing ships; or shipped along with organisms intended for aquaculture facilities or live seafood markets; or transported to and then escaped or released from aquariums at educational or research institutions (Cohen et al. 1995; Carlton and Cohen, in press). However, we now suspect that *C. maenas* most likely reached western North America in seaweed-packed shipments of marine baitworms from Maine (Cohen, Carlton and Lau, unpublished data).

In eastern North America *C. maenas* eventually spread from the New York-New Jersey region north to Canada. Along much of this coastline it is now the most commonly encountered intertidal and nearshore crab. In the 1950s it became very abundant in northern New England, where it reportedly caused massive destruction in the soft-shell clam fishery, inspiring control efforts that included the installation of crab fences and the deployment of baits soaked in insecticides. It continues to cause problems for New England shellfish farmers today.

Carcinus maeans was first collected in western North America in an artificial lagoon in southern San Francisco Bay. Beginning in the summer of 1989 or 1990, bait trapper Joe Neider began to find his minnow traps at Redwood Shores lagoon packed with hundreds of crabs that he had never before seen in the bay. In 1991 he brought a bucketful of the crabs to the California Academy of Sciences, where they were identified by Dustin Chivers of the Invertebrate Zoology Department. Over the next few years the crab was collected at sites in San Francisco Bay progressively distant from the lagoon, and then in other bays north to Bodega Harbor in 1993, in Elkhorn Slough to the south in 1994, in Humboldt Bay in 1995, and in Coos Bay, Oregon in 1997 (Cohen et al. 1995; Grosholz and Ruiz, 1995; Miller, 1996; N. Richmond, pers. comm.) (Figure 1).

In California *C. maenas* is found in bays in intertidal and shallow subtidal waters and in nontidal lagoons, mainly on soft sediment but also on riprap and underneath rocks in the intertidal zone at low tide. In Europe

and eastern North America the crab is common in sheltered marine and estuarine waters, and present in all but the highest-energy, outer coast environments. It occupies mud, sand and rock bottoms, eelgrass beds and salt marshes. With time, *C. maenas* may occupy a similar range of habitats in western North America

Grosholz & Ruiz (1996) reported that there are marked differences in *C. maenas'* habitat usage in different regions, being common on protected hard substrate and present on exposed hard substrate in other parts of the world, but absent from all hard substrate in western North America. However, in San Francisco Bay we have found *C. maenas* to often be present and sometimes common on and within riprap and under intertidal rocks (which is about the only hard substrate present in much of the bay), and it is apparently present in such habitats in Bodega Harbor as well (J. Carlton, pers. comm.; Cohen, unpublished data). Any differences in habitat distribution as may exist between western North America and other areas with *C. maenas* populations may be due to differences in population size (related to the *C. maenas'* relatively recent arrival in the west) and the different availability of protected habitats with natural rocky substrate in these regions.

Concerns about *C. maenas'* impacts stem mainly from its broad and strong appetite. Scientists have recorded an enormous variety of food items for the crab: mussels, clams, snails, worms, barnacles, isopods, other crustaceans or seaweeds may dominate in different locations (Cohen et al. 1995) (Table 1). The green crab can open and eat mussels and soft-shell clams that are as long or longer than its carapace width, and harder shelled clams and snails that are over half its carapace width. On the Pacific coast there is concern that green crab could affect oyster farms and clam fisheries by preying on young oysters and clams and adult clams, and that it may compete with or eat young Dungeness crab, which use bays and estuaries as nursery areas (Grosholz & Ruiz 1995).

There is therefore much concern that *C. maenas* could spread further north and damage the shellfisheries and shellfish farms of Oregon, Washington and British Columbia. Unfortunately, a review of *C. maenas'* biogeography and physiology suggests that this concern is reasonably founded. Based on its distribution in other parts of the world and observations of adult mortality and breeding limitations, it appears that *C. maenas'* expansion will ultimately be limited in the north by winter surface temperatures averaging about -1 to 0° C, and in the south by average summer temperatures of about 22° C, which appear to be warm enough to inhibit reproduction. These physiological limits correspond to a potential range from north of the Aleutians in Alaska down to central Baja California (Cohen *et al.*, 1995; Carlton and Cohen, in press) (Figure 1).

However, it is difficult to predict when, or even whether, *C. maenas* will reach these apparent limits. So far, its spread on the Pacific coast has been very rapid, moving an average of about 84 km northward each year (assuming that it arrived in 1989), with an overall rate of spread—north and south—of about 100 km/yr. Overall rates of spread elsewhere in the world have been markedly less (Table 2). Moving at the fastest observed rate of spread, *C. maenas* would enter Puget Sound by the year 2005, and at the slowest rate not until 2080. And whatever rate *C. maenas* might move at naturally, human activities could speed it up or, less plausibly, slow it down.

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