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Transoceanic Transport Mechanisms: Introduction of the Chinese Mitten Crab, *Eriocheir sinensis,* to California[1]

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ABSTRACT: Live importation of the Chinese mitten crab, (*Eriocheir sinensis* H. Milne-Edwards, 1854) was banned by both California and the United States in the late 1980s because of concerns about potential damage to levees, rice crops, and natural ecosystems, and because it harbors a human parasite. Nevertheless, mitten crabs were present in San Francisco Bay by 1992 and well established by 1994, providing the most recent example in a late-twentieth-century pulse of human-mediated transoceanic and interoceanic crab dispersals. Of 10 mechanisms available for the long-distance transport of crabs, evidence from the history of the mitten crab's global spread, data on ship traffic, the sampling of ballast water fauna, and recent patterns of introductions support the hypothesis of introduction via ballast water. Alternatively, the pattern of governmental interception of mitten crabs, their high market value, and continuing pressure to lift the import ban suggest that introduction may have been achieved via an intentional, private-party inoculation to establish a food resource. For either mechanism, the immediate source is more likely Asia than Europe. Amid a global burgeoning of potential transport mechanisms for estuarine and neritic organisms, knowledge of which mechanisms are in fact acting is essential for directing efforts to moderate the pace of such introductions.

IN THE LAST THIRD of the twentieth century, there have been numerous reports of the transport and introduction of brachyuran crabs to various parts of the globe. The northwestern Atlantic brackish-water mudcrab, *Rhithropanopeus harrisii* (Gould) (Xanthidae), and the Indo-Pacific crab *Elamenopsis kempi* (Chopra & Das) (Hymenopsomatidae) were collected from the Panama Canal in 1969 (Abele 1972, Carlton 1979). The eastern Pacific spider crab, *Pyromaia tuberculata* (Lockington) (Inachidae), appeared in Japan in 1970 (Sakai 1976*a*) and near Auckland, New Zealand, in 1978 (Webber and Wear 1981). The western Atlantic blue crab, *Callinectes sapidus* Rathbun (Portunidae), has been reported from Japan since 1975 and in Hawai'i since 1985 (Eldredge 1995). A specimen of the northeastern Pacific Dungeness crab, *Cancer magister* Dana (Cancridae), was collected in Japan in 1979 (Abe 1981). The European green crab, *Carcinus maenas* (L.) (Portunidae), introduced to northwestern Atlantic and southern Australian waters in the nineteenth century, was first collected in South Africa in 1983 and in California in 1989–1990, and is now established in both regions (Le Roux et al. 1990, Cohen et al. 1995). The Indo-Pacific crab *Charybdis helleri* (A. Milne-Edwards) (Portunidae) was collected in both the southern and northern Caribbean in 1987–1988 and in Florida in 1995 (Campos and Türkay 1989, Gómez and Martínez-Iglesias 1990, Lemaitre 1996). The Japanese shorecrab *Hemigrapsus sanguineus* (de Haan) (Grapsidae) became established in the eastern United States by 1988 (McDermott 1991).

Brachyuran crabs frequently are habitat generalists, and with the rapidly expanding volume and variety of international trade, travel, and maritime activities, multiple possible mechanisms of transoceanic and interoceanic transport have become available to them. Understanding which mechanisms are actually operating to transport these organisms is essential to developing effective control strategies.

We report here on the establishment of the

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Chinese mitten crab, *Eriocheir sinensis* H. Milne-Edwards, 1854, in San Francisco Bay, California, and analyze the suite of possible mechanisms that could have transported it to California.

MATERIALS AND METHODS

To determine the status of *E. sinensis* in the eastern Pacific, we circulated a Mitten Crab Wanted poster to and interviewed regional biologists, commercial shrimpers and bait trappers, and personnel at bait stores and marinas for possible records and specimens. All specimens were examined for epizoics and their carapace length measured. We compared San Francisco Bay specimens with *E. sinensis* specimens obtained from Germany and with Japanese specimens at the California Academy of Sciences.

We searched the global invasion literature for mechanisms of long-distance transport applicable to brachyuran crabs, which we compared with the circumstances pertaining to the arrival of *E. sinensis* in California, including relevant aspects of its biology and life history. Based on this initial review, the likeliest mechanisms were further investigated by (1) reviewing shipping and ballast water records, and (2) interviewing wildlife inspectors.

RESULTS

Establishment in the Northeastern Pacific

In November 1994 *E. sinensis* was identified from San Francisco Bay by Robert Van Syoc of the California Academy of Sciences. Commercial shrimp trawlers (listed in the Acknowledgments) reported catching such crabs occasionally, many with eggs, since 1992 in southern San Francisco Bay and since the summer of 1994 in northern San Francisco Bay (San Pablo Bay) (Figure 1). Of 75 mitten crabs examined that were collected in San Francisco Bay between winter 1993 and spring 1995, 52 were male, 32–76 mm in carapace length; 18 were ovigerous females, 35–70 mm in length; and five were nonovigerous females, 43–55 mm in length. Most of these were taken in shrimp nets trawled along channel bottoms at 6–15 m depth. Crabs entangled in fishing line or collected by park personnel were taken at the mouth of the Petaluma River in northwestern San Pablo Bay, at the Dumbarton Pier in the South Bay, and on the Hayward shore. In September 1995 we found smaller crabs in the drying bed of the Alameda Flood Control Channel at 9 and 12 km upstream from the bay, concentrated in small pools and in shallow burrows in damp mud under rocks, where we collected 54 crabs, 12–36 mm in length, in a 10-min search, along with the introduced crayfish *Procambarus clarkii* (Girard) (two specimens) and *Pacifastacus leniusculus* (Dana) (one specimen); in July 1996 the remains of several crabs were found in the channel 15 km from the bay. Thousands of young crabs and burrows have now been observed (1995–1996) in tidal creeks at the southern end of San Francisco Bay (K. Halat, pers. comm., 1996); two crabs, ca. 35 and 60 mm in carapace width, were collected in Suisun Marsh sloughs in February and May 1996 (S. Matern, pers. comm., 1996); and in May 1996 we observed a few crabs, 4–5 mm in length, among tubes of the introduced serpulid worm *Ficopomatus enigmaticus* (Fauvel) fouling docks in the Petaluma River in Petaluma, 20 km northwest of San Pablo Bay. In September 1996, adult mitten crabs were collected at several sites in the fresh waters of the Sacramento-San Joaquin Delta, upstream of the Bay in California's Central Valley.

Several female *E. sinensis* collected from southern San Francisco Bay in the winter of 1994–1995 were maintained in aquaria by the Marine Science Institute of Redwood City, California, and hatched active zoeae by the first week of February 1995. The number of crabs present, their persistence over several years, their broad distribution within the bay and its tributaries, and the presence of a range of size classes and of females carrying eggs and hatching larvae all indicate that the mitten crab is well established in San Francisco Bay; the lack of any prior records of this distinctive crab strongly suggests that it could not have been introduced much earlier than about 1990.

The crabs examined were generally free of epizoics; those found were the barnacle *Balanus improvisus* Darwin, the seaweed *Ulva* sp., egg cases of the snail *Ilyanassa obsoleta* (Say), and small stalks of a hydroid, cf. *Garveia franciscana* (Torrey), with an epizoic entoproct *Barentsia benedeni* (Foettinger) and ciliate *Zoothamnium* sp. All of

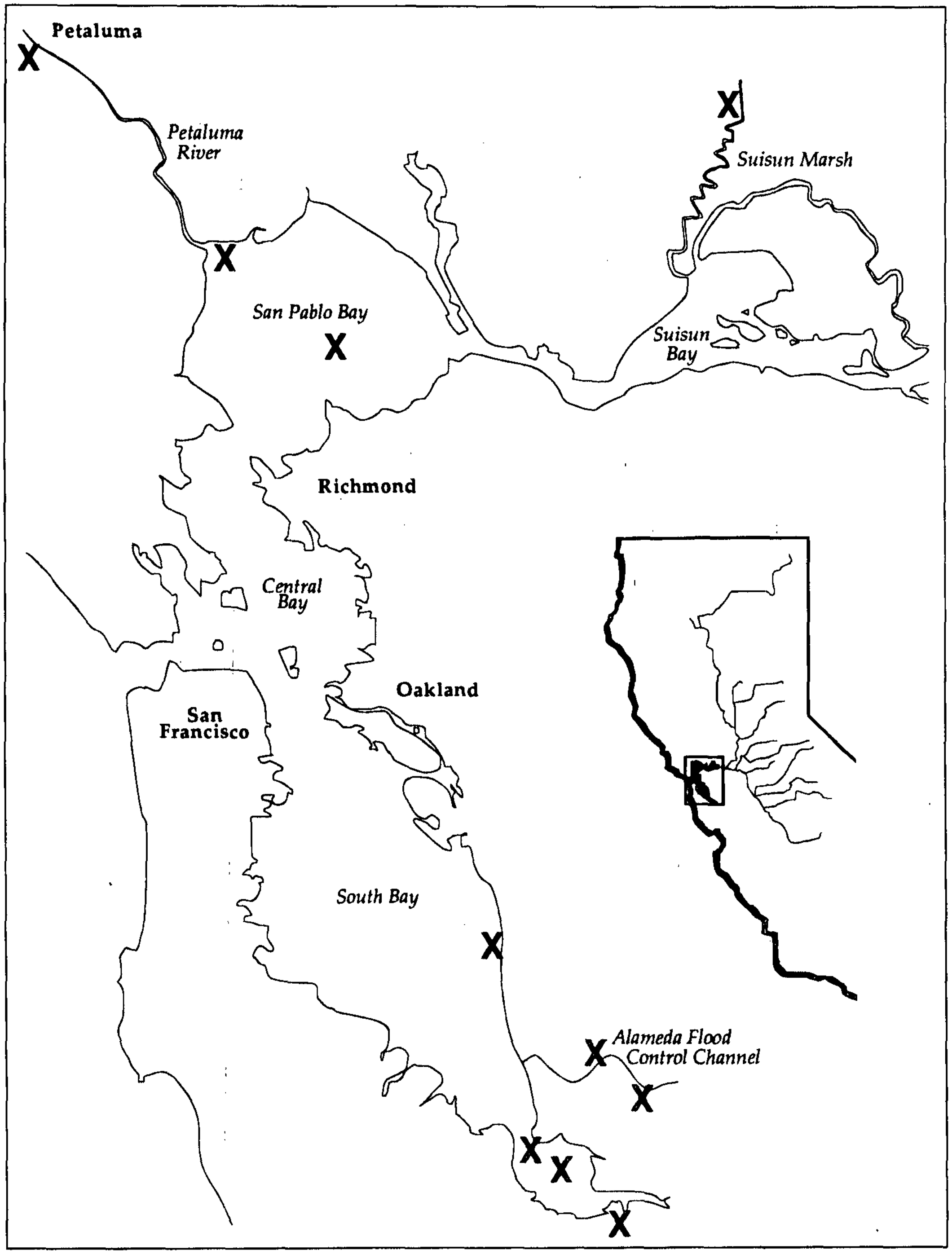

FIGURE 1. *Eriocheir sinensis* in San Francisco Bay, California. Sites at which *E. sinensis* were collected are marked by an "X."

these taxa are known or probable introductions as well (Cohen and Carlton 1995). Twenty-five crabs were dissected and examined for parasites, and none were found (A. Kuris and M. Torchin, pers. comm., 1995).

Workers have generally recognized four species of *Eriocheir,* although recent work may modify this arrangement. Dai (1993) created a subspecies under *E. japonica,* Li et al. (1993) synonymized *E. sinensis* under *E. japonica,* and Chan et al. (1995) synonymized *E. recta* under *E. japonica* and erected a new species, *E. formosa,* for crabs from Taiwan that were called *E. recta.* The first two papers, although concerning material from the same area in southern China, make no reference to each other, whereas the third describes the conclusions of the earlier two as "premature." Specimens of *E. sinensis* (from Germany) and *E. japonica* (from Japan) that we have examined are distinguished by clear and consistent morphological differences as described by Sakai (1939, 1976*a*) and Dai and Yang (1991). Li et al.'s (1993) proposed synonymy is based on their finding small genetic distance between these two forms, although they confirmed the existence of morphological distinctions. In light of the unstable taxonomy of this genus, we continue to treat *E. sinensis* as a species distinct from *E. japonica.*

Transport Mechanisms

Eriocheir sinensis could have been transported to California either from its native range in the rivers and estuaries between western Korea and Fujian Province, China (Sakai 1939), or from Europe, where it became established in the twentieth century. It was first collected in Europe in Germany in 1912 and was thought to have been transported there in ballast water (Peters 1933). It spread across northern Europe to France by 1930, became phenomenally abundant in the rivers of Germany in the mid-1930s (Panning 1939, Hoestland 1948), reached the French Mediterranean via canals by 1959 (Hoestland 1959, Petit 1960), and again became abundant in Germany and the Netherlands in the 1980s (Ingle 1986; M. Türkay, pers. comm., 1995).

In England one adult *E. sinensis* and one of unreported size were collected in 1935 and 1949 and hundreds, including a few ovigerous females, have been collected since 1976 (Ingle 1986) and are apparently now established in the Thames River (P. Clark, pers. comm., 1996). Hundreds of adults have been collected in the Baltic Sea, although salinities there are below the 25 ppt reported as necessary for successful egg development (Panning 1939). Sixty-six adults but no eggs, larvae, or juveniles have been reported from Finland (Haahtela 1963), and although three out of 33 females recorded from Denmark carried eggs, "none of the eggs were healthy or able to develop" (Rasmussen 1987). One adult was taken from the North American Great Lakes in 1965 and nine or 10 adults were collected between 1973 and 1994, most from western Lake Erie (Nepszy and Leach 1973; J. Leach, pers. comm., 1994). As in the Baltic, the Great Lakes are too fresh for successful egg development. A single adult was collected from the Mississippi River delta in Louisiana in 1987 (Horwath 1989; D. Felder, pers. comm., 1995).

Ten mechanisms for long-distance transport, two involving natural means and eight based on human activities, are theoretically available to brachyurans, though most are unlikely to have operated in bringing *E. sinensis* to California. These mechanisms are as follows:

(1) DISPERSAL OF LARVAE BY CURRENTS. Thorson (1961) calculated that it would take more than 12 months to drift passively in ocean currents from Japan to California, including a minimum crossing time between "stepping stones" (islands or shallow banks) of about 10 months. That is too long a time for *E. sinensis,* whose larval development lasts at most 3–4 months (Panning 1939, Anger 1991). Larval drift from Europe is not tenable. *Eriocheir sinensis* larval behavior also promotes retention of the larvae within an estuary (Anger 1991).

(2) DISPERSAL OF ADULTS OR JUVENILES ON FLOATING MATERIAL. Certain pelagic, neustonic crabs typically are found on floating seaweeds (such as *Sargassum*) and other floating materials on slope and deep ocean waters, including species in the genera *Planes* and *Portunus* (Williams 1984). Regarding benthic crabs, Alcock (1900) noted that *Plagusia* and *Varuna* had been found on drift timber in the open sea, specifically referencing some specimens of *Plagusia depressa tuberculata* Lamarck (= *P. d. squamosa* Alcock) collected in the Bay of Bengal and Arabian Sea (though how far offshore was not stated). How-

ever, even if it were to be carried to sea on floating debris, *E. sinensis* would be unlikely to survive transit times of over a year from source areas to California.

(3) TRANSPORT OF ADULTS OR JUVENILES IN SHIP FOULING. Numerous examples exist of crabs transported across or between oceans on the hulls of ships, primarily in earlier times (e.g., Buitendijk and Holthuis 1949, Carlton and Cohen 1996), including observations of crabs on the hulls of ships on the high seas or on arrival in a foreign (to the crab) port (Stebbing 1893, Alcock 1900). Opportunities for the transport of crabs on ships' hulls have decreased dramatically because of (1) the decline of wooden ships, whose hulls were often infested with shipworms and gribbles, producing deep, bored cavities capable of hosting errant organisms such as crabs (Chilton 1910), and (2) more effective antifouling coatings, increased vessel speed, and shorter time in port, which have tended to reduce the development of extensive hull-fouling communities. We know of no recent observations of crabs on the hulls of ships in normal transoceanic operation.

(4) TRANSPORT OF ADULTS OR JUVENILES IN CARGO. Marchand (1946) reported the transport of saber crabs, *Platychirograpsus spectabilis* (= *P. typicus* Rathbun), in a ship's cargo of cedar logs from the state of Tabasco, Mexico, to the Hillsborough River, Florida, where they became established. In Mexico the logs were floated downriver to the coast before being loaded on board ship and routinely were found to harbor crabs, snakes, and turtles on arrival in Florida. We know of no cargoes of logs or other materials arriving in San Francisco Bay in recent decades that would likely have carried live crabs.

(5) TRANSPORT OF ADULTS OR JUVENILES ON SEMISUBMERSIBLE DRILLING PLATFORMS AND OTHER LONG-DISTANCE, SLOW-MOVING VESSELS. Drilling platforms, ships serving as light stations (or in the past, as coaling stations), and the like may on occasion take slow, long-distance voyages, often under tow, after being anchored in one site for a lengthy period. Such vessels may develop and successfully transport an exuberant fouling growth, including crabs (e.g., Bertelsen and Ussing 1936, Benech 1978, Foster and Willan 1979). We found no records of drilling platforms or other such vessels arriving in the San Francisco Bay area in the 1980s or 1990s.

(6) TRANSPORT OF LARVAE OR JUVENILES IN BALLAST WATER. Ballast water—water pumped in large quantities into cargo holds or dedicated ballast tanks at the start of a voyage to achieve proper trim and buoyancy, and later discharged on arrival at a port before taking on cargo—has been implicated in the transport and introduction of numerous freshwater, estuarine, and marine species in the last several decades (Carlton 1985, Carlton and Geller 1993). Organisms introduced into San Francisco Bay via ballast water in the past two decades include two clams and numerous small crustaceans from Asia and probably many other organisms from both Asia and Europe (Cohen and Carlton 1995).

Brachyuran larvae have been collected from the ballast tanks of vessels arriving at the entrance to the St. Lawrence Seaway (Locke et al. 1991); at Australian ports (Williams et al. 1988) and Coos Bay, Oregon (Carlton and Geller 1993; J.T.C., unpubl. records), from Japan; and at Chesapeake Bay from Europe and the Mediterranean (D. Smith, M. Wonham, and G. Ruiz, pers. comm., 1995). A mitten crab was collected from the ballast tank of a ship arriving at Port Said, Egypt, from the Far East (Hoestland 1948), at least seven crab species were collected from sediments in the ballast tanks of ships arriving in Australia from Japan (Williams et al. 1988), and portunid crabs over 3 cm in carapace width were taken from the ballast tank of a European ship entering Chesapeake Bay (D. Smith, M. Wonham, and G. Ruiz, pers. comm., 1995). Although larger crabs are less likely to be taken into or discharged from ballast tanks than larvae or small juveniles because of the small size of intake screens and the damage incurred by larger organisms in passing through pumps, ships sometimes gravitate water in or out of their ballast tanks, permitting the occasional transfer of mature and even ovigerous crabs. Because cargo vessels cross from Japan to northeastern Pacific ports in 13–16 days (Carlton and Geller 1993), both larvae and adults should be capable of surviving the passage.

Estimates based on 1991 shipping data indicate that no large commercial vessels entered San Francisco Bay whose last port of call was Europe and there were about 75 whose last port of call was within the western Pacific range of *E. sinensis,* these latter carrying a total of about 400,000 metric tons of ballast water (Table 1). There are, however, no data available regarding what portion of this ballast water might have come from ports other than the last port of call and what portion of it was discharged into San Francisco Bay.

(7) TRANSPORT OF ADULTS OR JUVENILES IN FISHERIES PRODUCTS. As many as 47 Atlantic and 15 Asian species of marine invertebrates may have been introduced into San Francisco Bay with shipments of oysters from the western Atlantic [*Crassostrea virginica* (Gmelin)] and Japan [*C. gigas* (Thunberg)] (Cohen and Carlton 1995). Ryan (1956) suggested that *Rhithropano-*

TABLE 1

CALCULATION OF AMOUNT OF SHIPPING AND VOLUME OF BALLAST WATER ENTERING SAN FRANCISCO BAY FROM *Eriocheir sinensis* SOURCE AREAS IN 1991

PARAMETERS	1991 DATA	
	. . . ENTERING SAN FRANCISCO BAY	
Large vessels other than naval vessels or oil tankers . . .	2,665[a]	
	. . . THE PORT OF OAKLAND	. . . THE PORT OF SAN FRANCISCO
Large vessels calling at . . .	1,283	734
Fraction whose last port of call was within the Northeast Atlantic or Mediterranean FAO Region, of a sample of large vessels calling at . . .	0 (n = 288)	0 (n = 288)
Fraction whose last port of call was within the Northwest Pacific FAO Region and that arrived in ballast, of a sample of large vessels calling at . . .	0.0139 (n = 288)	0.0174 (n = 288)
Fraction whose last port of call was within the Northwest Pacific FAO Region and that arrived in cargo, of a sample of large vessels calling at . . .	0.0868 (n = 288)	0.0451 (n = 288)
Fraction whose last port of call was within the range of *Eriocheir sinensis,* of a sample of large vessels in ballast whose last port of call was within the Northwest Pacific FAO Region and calling at . . . (fraction assumed to apply also to vessels in cargo)	0.4 (n = 10)	0.11 (n = 9)
Estimated average ballast water (in metric tons) carried by large vessels in ballast calling at . . .	5,324 (n = 12)	6,764 (n = 10)
Estimated average ballast water (in metric tons) carried by large vessels arriving from foreign ports in cargo and calling at . . .	5,394[b] (n = 205)	4,534[b] (n = 48)

CALCULATIONS

Number of large vessels other than naval vessels or oil tankers entering San Francisco Bay in 1991 whose last port of call was within the range of *Eriocheir sinensis* =

$$\frac{2,665}{1,283+734} \times \{1,283[0 + 0.4(0.0139 + 0.0868)] + 734[0 + 0.11(0.0174 + 0.0451)]\} = 74.9$$

Amount of ballast water carried by these vessels =

$$\frac{2,665}{1,283 + 734} \times \{(1,283 \times 0.4)[(0.0139 \times 5,324) + (0.0868 \times 5,394)] + (734 \times 0.11)[(0.0174 \times 6,764) + (0.0451 \times 4,534)]\} = 402,024 \text{ metric tons}$$

NOTE: Data from Carlton et al. (1995) unless otherwise indicated. Large vessels are defined as those over 250 net registered tons or 500 gross registered tons. FAO is the United Nations Food and Agriculture Organization. Vessels reported in cargo carry cargo and those reported in ballast do not; either type may carry varying amounts of ballast.

[a] Data from Chambers Group (1994). 1,006 oil tankers entered the bay in 1991, most of these arriving from domestic ports and very few if any from ports within the range of *Eriocheir sinensis* (J. Mes, pers. comm., 1996).

[b] Calculated from data on types of vessels arriving in cargo at each port from foreign ports and data on average ballast water per type of vessel in cargo estimated from a national survey of 96 large vessels.

peus harrisii and other xanthid mud crabs may have been transported along the Atlantic coast with commercial oyster shipments, and Carlton (1979) discussed the possibility that *R. harrisii* had been introduced into San Francisco Bay in a late (1930s) shipment of Atlantic oysters. Commercial shipments of Japanese oysters were planted in San Francisco Bay from 1932 to 1939, with occasional experimental plantings thereafter. In 1962 the European flat oyster, *Ostrea edulis L.*, was planted experimentally in San Francisco Bay from populations in France and Connecticut (Carlton 1979). We know of no plantings of Asian or European oysters or other shellfish in San Francisco Bay in the past 20 yr, nor has *E. sinensis* been reported in association with oyster or shellfish beds.

Cohen et al. (1995) suggested that the green crab *Carcinus maenas* could have been transported to San Francisco Bay as juveniles in the seaweed [mainly *Ascophyllum nodosum* (L.) Le Jolis] used as packing for shipments of live marine bait worms (*Nereis virens* Sars and *Glycera dibranchiata* Ehlers) to bait shops and of live lobsters (*Homarus americanus* Milne-Edwards) to restaurants and food markets. However, those shipments all originate in New England or New York, and we know of no similar shipments from China, Japan, or Europe.

(8) TRANSPORT OF LARVAE IN WATER WITH SHIPMENTS OF LIVE FISH. Snovsky and Galil (1990) suggested that blue crabs *Callinectes sapidus* were introduced as planktonic larvae into the Sea of Galilee in water carrying fish imported from the Mediterranean for stocking, and the same method of accidental transport has been proposed for other invertebrate species (e.g., Hazel 1966 [but see Cohen and Carlton 1995], Holdich and Tolba 1985). No fish have been imported and stocked into the San Francisco Bay watershed from Asia since 1959 or from Europe since 1872 (Cohen and Carlton 1995).

(9) ESCAPE OR RELEASE FROM RESEARCH, PUBLIC, OR PRIVATE AQUARIA. Cohen et al. (1995), noting that nonindigenous lobsters had escaped or been released from University research laboratories on both coasts of the United States, suggested that the green crab *Carcinus maenas* could have been introduced thereby to San Francisco Bay. Many species of living crabs from other regions are readily available to researchers: the 1994 catalog of the Woods Hole Marine Biological Laboratory listed 10 species of brachyuran crabs available for shipment by next-day air delivery service. *Eriocheir* species, however, are not available from any biological supply house in the United States, and, as discussed below, it has been illegal to import mitten crabs into California or the United States since the late 1980s. Before the discovery of their establishment in late 1994, we know of no *Eriocheir* species maintained in aquaria at research or other institutions in the San Francisco Bay area.

(10) INTENTIONAL PLANTING TO ESTABLISH A FOOD RESOURCE. Many crabs are highly valued as food items, and there have been numerous attempts, successful and unsuccessful, by government agencies and by private parties, to establish crabs as food resources in areas outside of their native ranges. In the San Francisco Bay watershed two nonnative aquatic organisms, the freshwater clam *Corbicula fluminea* (Müller) and the freshwater snail *Cipangopaludina chinensis malleata* (Reeve), are thought to have been introduced into the western United States from China or Japan in the late nineteenth century as intentional, private-party plantings to establish new food resources (Cohen and Carlton 1995). Atlantic blue crabs, *Callinectes sapidus*, occasionally are collected in San Francisco Bay and elsewhere along the central California coast, released by private individuals (Cohen and Carlton 1995; although listed in Jensen [1995], blue crabs are not believed to be established in San Francisco Bay).

In 1978 the late Dustin Chivers of the California Academy of Sciences noted live mitten crabs available for import into California through firms in Hong Kong and Macao. In early 1986 the California Department of Fish and Game found live mitten crabs offered for sale in Asian food markets in San Francisco and Los Angeles at US$27.50–32.00 per kilogram. Concerns over the potential impacts of these crabs led to the banning of live imports by California in 1987 and by the United States in 1989 (Horwath 1989), but efforts to import them continued. An aquaculturist recently lobbied the California state legislature for permission to import and raise mitten crabs in California (T. Gosliner, pers. comm., 1994; Weintraub and Lifsher

1995). U.S. government inspectors have continued to intercept mitten crabs at San Francisco (hand-carried by disembarking airplane passengers [Table 2]), Los Angeles (in shipments of aquarium animals), and Seattle (packed in "soil" intercepted by the U.S. Department of Agriculture) (H. Roche, M. Osborne, and M. Williams, pers. comm., 1995). The interceptions at the San Francisco Airport all occurred in the fall or winter, when the crabs appear in markets in China after being harvested during the adults' downstream migration (G. Li, pers. comm., 1995). The government inspectors we interviewed doubted that all mitten crab imports are intercepted.

DISCUSSION

Eriocheir sinensis is a catadromous organism, with juveniles migrating upstream to upper estuaries or into rivers, and some crabs reported from the Changjiang (Yangtze) River over 1,250 km from the sea. In the late fall and winter maturing adults (1–2 yr old in China [G. Li, pers. comm., 1995]; 3–5 yr old in Germany [Panning 1939]) move down to coastal waters where they mate, spawn, and die. Each female produces from 250,000 to 1 million eggs, which hatch in late spring or early summer. The larvae develop through five increasingly stenohaline and euhaline zoeae and a more euryhaline and mesohaline megalopa. After the final larval molt in the summer or fall, the juvenile crab settles to the bottom and begins its migration upstream (Panning 1939, Ingle 1986, Anger 1991).

TABLE 2

Mitten Crabs, *Eriocheir sinensis*, Hand-carried by Disembarking Passengers on Flights Originating from Asian or Pacific Airports and Intercepted by U.S. Government Inspectors at San Francisco International Airport

SEASON	DATE	NO. OF CRABS
Winter 1989–1990	4 Oct. 1989	10
	6 Dec. 1989	24
Winter 1990–1991	22 Nov. 1990	10
	26 Nov. 1990	24
	31 Nov. 1990	14
	26 Dec. 1990	12
Winter 1991–1992	20 Nov. 1991	10
	21 Dec. 1991	10
	3 Jan. 1992	12
Winter 1992–1993	28 Oct. 1992	34
	30 Oct. 1992	50
	23 Nov. 1992	10
	30 Dec. 1992	28
Winter 1993–1994	18 Nov. 1993	12
Winter 1994–1995	13 Jan. 1995	10
Winter 1995–1996	8 Dec. 1995	12

Note: Data from the port log book provided by H. Roche, U.S. Fish and Wildlife Service.

Eriocheir sinensis is thus a poor candidate for crossing oceans by natural means, either as planktonic larvae or as crabs rafting on floating material carried by ocean currents. Crabs are rare or absent from hull fouling on modern ships, and some vectors that may have translocated other crabs—such as transport on drilling platforms, shipment with fishery products or live fish, or transport for research and other aquarium use—have not been available for transporting *E. sinensis* between its source areas and San Francisco Bay, at least in recent decades. *Eriocheir sinensis* was probably introduced into San Francisco Bay either in ballast water or as an intentional planting to establish a food resource.

Based upon ship traffic (northwestern Pacific ports are regularly and European ports are rarely the last port of call for foreign ships entering San Francisco Bay) and consumption patterns (mitten crabs are seasonally available in markets and commonly eaten in Asia, and not in Europe), Europe seems an unlikely immediate source for the mitten crabs that colonized San Francisco Bay. Should studies of molecular genetics, morphology, and behavior reveal characteristics capable of distinguishing the mitten crabs of Europe from those of Asia, we predict that San Francisco Bay crabs will more closely resemble populations in Asia.

In Germany in the 1930s, massive efforts to control mitten crabs stemmed from its interference with net and trap fisheries and the damage to riverbanks caused by its burrowing. *Eriocheir sinensis* is also the second intermediate host of a human parasite, the oriental lung fluke, *Paragonimus westermanii.* Although no lung flukes have been found in San Francisco Bay mitten crabs (A. Kuris, pers. comm., 1995), suitable first intermediate snail hosts are present in California or adjacent states (T. Gosliner, pers. comm., 1994), and establishment of the fluke is possible, which could conceivably lead to infections of humans (through ingestion of uncooked crab meat) or, more likely, of other mammals. The ecosystem impacts of potentially large numbers of river crabs, where none now exist, are unknown.

Eriocheir sinensis opened the twentieth century with a dispersal episode that carried it to a river in Germany, from which it spread in a few decades across northern Europe and into the Mediterranean. With its establishment on the western shore of North America, *E. sinensis* now awaits the new century with three global population centers from which to colonize suitable river systems in the Americas and elsewhere. Improved knowledge of transoceanic transport vectors can focus efforts to control such translocations. For now the potential emigration of *E. sinensis* to new areas both adds force to arguments for the regulation of ballast water discharges and suggests that airport wildlife inspectors in susceptible regions should be alert for *E. sinensis* carried by travelers arriving from source regions during the northern fall and winter.

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