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OVERBITE CLAMS, *CORBULA AMURENSIS*, DEFECATED ALIVE BY WHITE STURGEON, *ACIPENSER TRANSMONTANUS*

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As natural systems deteriorate, invasive species are more easily established (Stachowicz et al. 1999) and can greatly threaten biodiversity (Ruiz et al. 1997; Bax et al. 2001). Mechanisms that enable the expansion and proliferation of invasive species, especially in aquatic systems, are not well understood (Carlton 1992; Johnson and Padilla 1996; Ruiz et al. 1997; Parendes and Jones 2000; Bax et al. 2001). Physical dispersal mechanisms such as ship-related activities, water delivery systems, and intentional introductions, have been described (Mills et al. 1993; Smith et al. 1996[1]; Dill and Cordone 1997; Cohen and Carlton 1998; Gollasch et al. 1998; Nicolini and Penry 2000). Biological dispersal mechanisms are not well documented, but it has been hypothesized that fish transport aquatic organisms such as clams (Voelz et al. 1998). As benthic carnivores that travel long distances, sturgeon may be substantial mechanisms of dispersal.

Sturgeon consume a wide variety of organisms and are important ecological components within their respective watersheds (Buddington and Christofferson 1985; Miller 2005). In the Sacramento River, California, the native white sturgeon, *Acipenser transmontanus*, travels at rates of up to 25 km/d upstream and 91 km/d downstream (Schaffter 1997). While little known about the frequency, timing, and rates of migration between West Coast estuaries, at least two white sturgeon have traveled from the San Francisco Bay estuary, California, to the mouth of the Columbia River, Oregon (Chadwick 1959; Miller 1972). White sturgeon tagged in the Columbia River have been recovered in Puget Sound, Washington (Galbreath 1985), the Fraser River, British Columbia (DeVore et al. 1999[2], Nelson et al. 2004[3]), and the Sacramento River (DeVore et al. 1999[2]). One white sturgeon was tracked from

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[1] Smith, L.D., M.J. Wonham, L.D. McCann, D.M. Reid, and J.T. Carlton. 1996. Shipping Study II. Biological invasions by nonindiginous species in United States Waters: quantifying the role of ballast water and sediments. U.S. Coast Guard, Report CG-D-02-97, Washington, D.C.

[2] Devore, J., B. James, and R. Beamesderfer. 1999. Lower Columbia River white sturgeon current stock status and management implications. Washington Department of Fish and Wildlife, Report SS 99-08, Olympia.

[3] Nelson, T.C., W.J. Gazey, M.L. Rosenau, and K.K. English. 2004. Status of white sturgeon in the lower Fraser River: report on the findings of the Lower Fraser River White Sturgeon Monitoring and Assessment Program 1999-2004. Prepared for the Fraser River Conservation Society, Vancouver, British Columbia, by LGL Limited, Sidney, British Columbia.

the Klamath River, California, to the Fraser River, having spent months in both the clear and turbid river systems (Welch et al. 2006). White sturgeon of unknown origin have been caught off the coast of California (Pycha 1956). A recent stomach content analysis of white sturgeon from the San Francisco Bay estuary (Kogut, unpublished data), indicates that the invasive overbite clam, *Corbula* (formerly *Potamocorbula* as per Carlton (2007)) *amurensis*, may now be a major component of the white sturgeon diet, and unopened clams were often observed throughout the alimentary canal. Similar observations were made from a white sturgeon collected in October 1996 (Peterson 1997[4]).

The overbite clam, first detected in the San Francisco Bay estuary in 1986, ranges from almost freshwater (< 1 ‰) at Rio Vista, through brackish waters of Suisun Bay and Carquinez Strait, to saline waters (32.6%) of the Central and South bays and accounts for up to 95% of the living biomass in some shallow portions of the bay (Carlton et al. 1990; Nichols et al. 1990). The overbite clam partly exposes its shell above the sediment to facilitate planktonic feeding in flowing or non-flowing water (Carlton et al. 1990) and has contributed to a decline in plankton availability in the estuary (Jassby et al. 2002). The reduced plankton availability may be a cause of fish population declines (Feyrer et al. 2003). High concentrations of overbite clams within the shallow sediments make them easily available to benthic predators (Pereira et al. 1999; Richman and Lovvorn 2004), influencing feeding behavior (Poulton et al. 2002), nutrition (Richman and Lovvorn 2004), and toxic bioaccumulation (Pereira et al. 1999; Linville et al. 2002; Richman and Lovvorn 2004). If some of the clams survive ingestion and defecation, sturgeon could serve as a dispersal mechanism, changing the trophic dynamics of other bays and estuaries. To determine whether sturgeon are potential vehicles for transporting live adult clams, I observed clams defecated by a white sturgeon caught in the San Francisco Bay estuary.

On 17 May 2002, a 86-cm total length white sturgeon (75 cm fork length) was caught in a drift gill net at Broad Slough (38°02’20” N, 121°50’33” W) during a California Department of Fish and Game striped bass survey. In a tank prepared and positioned in advance for the incidental catch, the sturgeon was transported immediately to the University of California, Davis, and held it in a non-chlorinated, fresh water tank (1.7-m diameter) maintained with constant flow at 14.5°C. I observed the sturgeon continuously from 1500 hours until it defecated at 1730 hours. In the feces, I found 43 unopened overbite clams (7 to 14 mm total width), a few empty and broken overbite clam shells, one empty shell of the Asian clam, *Corbicula fluminea*, and separate muscle and viscera from clams in a matrix of detritus. I immediately placed the unopened overbite clams in a small cooler with 1 liter of water from the observation tank and a 25-mm deep substrate of washed sand, which I had collected from the estuary the same day. For the next 3 hours (1735-2035), I observed each clam and recorded whether it burrowed into the sand, extended the two siphons or the foot without burrowing, or did not indicate external signs of life.

Some clams began to burrow within a few minutes. By the end of the observation

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[4] Peterson, H. 1997. Clam-stuffed sturgeon. Interagency Ecological Program for the Sacramento-San Joaquin Estuary Newsletter 10:21.

period, 34 (79%) had actively burrowed, and 5 (12%) had extended their siphons or the foot without burrowing. The other 4 clams (9%) showed no sign of life.

Given the observations described above, white sturgeon are potential vehicles for transport of adult overbite clams. Most clams were capable of burrowing into the substrate, suggesting that some were viable. Gut residence times and digestion rates for natural prey consumed by white sturgeon are unknown. However, it is feasible that the clams could be deposited by sturgeon in new locations and become established if some remain viable. Although the clam larvae do not survive well in fresh water, spawning and fertilization can occur in a wide range of salinities, with larvae tolerating substantial changes in salinity (Nicolini and Penry 2000). Reproductive viability may also be reduced with high levels of toxicants (Brown et al. 2003). These results indicate research is needed to establish the long-term survival and reproductive viability of overbite clams defecated by white sturgeon under various environmental conditions likely to exist in habitats where dispersal might occur. This information can be coupled with white sturgeon migration patterns and bioenergetics studies to identify areas at future risk of invasion by overbite clams or to study influences on existing populations.

My observations also raise concern about the effect of this invasive clam on sturgeon nutrition and contaminant exposure. Decreased food supply and environmental contaminants have been identified as possible factors explaining reduced growth rates of white sturgeon (Kohlhorst et al. 1980). Although the apparent reduction in growth rates preceded detection of the overbite clam, this prey species may increase limitations on sturgeon growth associated with the estuary's highly altered benthos. Non-nutritive food items can be detrimental if substantial gut capacity is appropriated to them (McCauley and Bjorndal 1999). Dietary dilution may represent a threat if the digestive system is saturated with too much indigestible material, compromising the ability to increase intake to meet energetic and nutritional requirements (McCauley and Bjorndal 1999). The presence of undigested clams may indicate a significant energy drain in the form of dietary dilution (Tomas et al. 2002). When compared to the formerly dominant native clam *Macoma balthica*, overbite clams are much harder to crush (Richman and Lovvorn 2004). Possibly offsetting this dietary constraint, overbite clams have higher nitrogen and energy content per *Macoma balthica* clam of the same length (Richman and Lovvorn 2004). However, exposure to toxicants also increases with consumption of overbite clams (Brown and Luoma 1995; Lee et al. 1998; Pereira et al. 1999; Linville et al. 2002; Brown et al. 2003). These concerns could be addressed by updated studies of white sturgeon dietary composition, bioenergetics, and food web dynamics and comparison to completed diet studies (Pycha 1956; Schreiber 1962; Gannsle 1966; Ratke 1966; Semakula and Larkin 1968; McKechnie and Fenner 1971; Muir et al. 2000). Such information may have broader implications, including an increased understanding of threats to West Coast sturgeon populations (Kohlhorst et al. 1991; Birstein et al. 1997; Hildebrand et al. 1999; Klimley at al. 2007), the processes involved in degradation of Pacific North

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[5] USEPA (U.S. Environmental Protection Agency). 1997. National Water Quality Inventory 1996 Report to Congress. EPA 841-F-97-008.

American estuaries (Nichols et al. 1986; USEPA 1997[5]; Emmett et al. 2000), and biological mechanisms of dispersal in aquatic systems.

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