

NOTES

OBSERVATIONS OF SEA OTTERS DIGGING FOR CLAMS AT MONTEREY HARBOR, CALIFORNIA

Although the feeding behavior of the sea otter, *Enhydra lutris*, is frequently observed from the surface, few underwater observations of foraging sea otters have been published. Faro (1969) and Houk and Geibel (1974) described the underwater behavior and tool use of sea otters when they removed abalone from rock substrates. Shimek (1977) observed a sea otter foraging for snails and presumably other invertebrates by patting the surface of rocks and feeling into cracks. Shimek also described a sea otter digging up the echiuroid worm, *Urechis caupo*, from a silt and cobble substrate. Further deductions about underwater foraging behavior have been made from collections of abalone shells with the characteristic "otter break" hole in the middle (Wild and Ames¹) and from observations of aluminum beverage cans bitten by otters to remove octopus (McCleneghan and Ames 1976). Some sea otters can be enticed underwater to take food offered them (pers. obs). However, these latter observations of underwater food manipulation are of limited value because the otters also take items unpalatable to them (e.g., the holothuroid *Stichopus californicus*), and because the otters were clearly interacting with the diver observer. These accounts of underwater foraging indicate that sea otters use primarily tactile sensitivity of the forelimbs to locate and capture prey, whereas all other marine mammals (pinnipeds and cetaceans) use their jaws to capture prey. Radinsky (1968) hypothesized that the sea otter evolved forelimb tactile sensitivity separately from the aonychoid otters.

The large impact of sea otters on Pismo clam, *Tivela stultorum*, populations in California has been documented (Stephenson 1977; Miller et al.²), and in Prince William Sound, Alaska, 81% of the food items taken by sea otters were bivalves, especially *Saxidomus gigantea* (Calkins 1978).

The Alaskan otters "dug out clams with their forepaws while maintaining a head downward position" in intertidal and shallow subtidal water. However, Shimek's (1977) description is the only detailed underwater observation of sea otters foraging on soft substrate. Detailed observations of sea otters taking prey from soft substrates are more difficult than those on rock, because the otter's disturbance of the bottom often results in clouds of sediment obscuring further vision. In the present account, we describe underwater observations of sea otters digging clams in a silty sand substrate and present information about the impact of this foraging on the distribution and abundance of subtidal clams at Monterey Harbor, Calif.

Observations

In 1976-77 we observed sea otters eating large numbers of the Washington clam, *Saxidomus nuttalli*, primarily in two specific areas of Monterey Harbor (A and B of Figure 1). From vantage points along the floating boat slips and elevated wharves, we observed sea otters at the surface feeding on 211 prey items: *S. nuttalli* (88.6%); the crabs *Pugettia producta* (4.2%) and *Cancer* sp. (3.3%—probably *C. antennarius* or *C. productus*, but not *C. magister*); the rock jingle bivalve *Pododesmus cepio* (1.4%); and unidentified items (2.4%). During spring 1976, as many as four sea otters were foraging at one time in the harbor vicinity, but an average of about one sea otter was observed on 38 counting trips made to the area.

The underwater path of foraging sea otters could often be observed from the surface by following the trail of air bubbles escaping from their compressed fur. The paths of foraging dives made in the inner harbor were often contorted, 50-60 m or more long, and lasted 45-80 s. These dives usually produced no prey, but the prey taken were mostly crabs and rarely clams. On those dives that resulted in the capture of kelp crabs, sea otters usually (eight out of nine dives) finished their search with a swim under 10-20 m of the floating docks in the inner area of the harbor. During scuba dives in this area, we repeatedly observed kelp crabs on the undersides of these floats and rarely elsewhere. It was difficult to observe the paths of

¹Wild, P. W., and J. A. Ames. 1974. A report on the sea otter, *Enhydra lutris* L., in California. Calif. Dep. Fish and Game Mar. Resour. Tech. Rep. 20, 93 p.

²Miller, D. J., J. E. Hardwick, and W. A. Dahlstrom. 1975. Pismo clams and sea otters. Calif. Dep. Fish Game Mar. Resour. Tech. Rep. 31, 49 p.

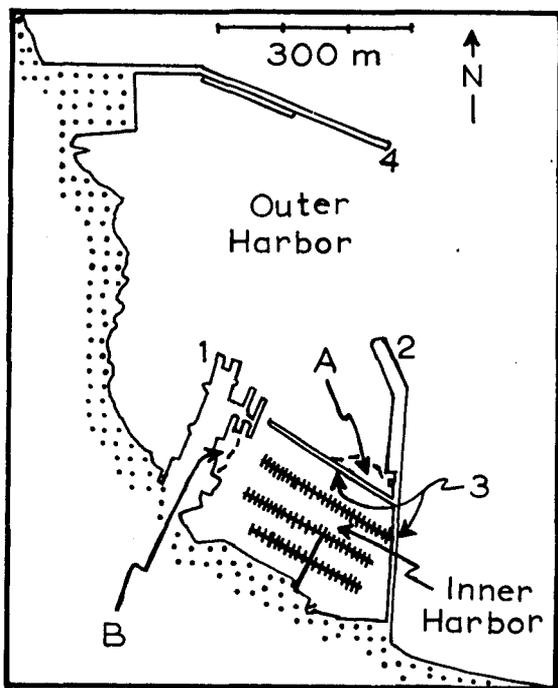


FIGURE 1.—Monterey Harbor, Calif. High densities of clams were foraged by sea otters in areas A and B. 1 = Fisherman's Wharf; 2 = Wharf No. 2; 3 = north and east sea walls of the inner harbor; 4 = breakwater for the outer harbor. (Traced from an aerial photograph in Haderlie and Donat 1978.)

dives made in the middle of the outer harbor, but sea otters usually surfaced without prey 50 m or more from the start of the dive. However, the paths of feeding dives in the two locations where clams were taken in abundance were usually quite short, only 10 m or less.

The usual sequence of dives in the harbor region began with otters making one to three 50-90 s dives that produced no prey. After about 10-20 s on the surface and a little grooming, the otters usually dove again to the same spot. A series of short (25-40 s) dives followed the initial dives, and each of these invariably resulted in a single *S. nuttalli* about 10 cm long. The otters took 30-90 s to open and eat the clams before diving to the same spot. Sometimes they pounded the clams on a rock anvil on their chest; other times they simply twisted or pried the clams open with their teeth. An average of 6 and as many as 19 clams were taken in a single series of these dives. Following such a series, otters usually spent up to 30 min grooming before they swam away, sometimes to forage in a new location.

In spring 1976, we conducted an underwater survey of most of the bottom of the inner and outer harbor, noting variations in the substrate and counting protruding clam siphons in haphazardly tossed $\frac{1}{4}$ m² quadrats. Depths in the harbor ranged from 2 to 8 m, with area A being 4.5 m and area B 2-3 m (Figure 1). The substrate in much of the enclosed inner harbor was black mud and silt, and most of the rest of the harbor (including areas A and B) was silty sand. The two areas where otters fed extensively on clams had high densities of clam siphons: for area A, \bar{x} = 13.5/m², SD = 8.9, n = 19; for area B, \bar{x} = 9.3/m², SD = 7.2, n = 16. The area under Wharf No. 2 adjacent to area A had even higher densities of siphons: \bar{x} = 17.4/m², SD = 11.9, n = 18. However, other areas of the harbor had siphon densities < 1.0/m², and the black mud of the inner harbor had densities < 0.04/m². We inserted a slender rod down siphon holes in the substrate until the rod contacted the clam shell, and, with considerable difficulty, we used a stream of freshwater from a garden hose to obtain a few 8-14 cm long clams from area A. We used these specimens to distinguish the two species present by the morphology of the protruding siphons. The species composition in areas A, B, and under Wharf No. 2 were the same: 95% were *S. nuttalli*, 5% were the gaper clam, *Tresus nuttallii*. In this way we also determined that the clams were located 10-50 cm into the substrate and that larger individuals of both species tended to occur at the deeper end of this range in the sediment. We recorded the densities of clam siphons in area A and also in the adjacent area of highest density under Wharf No. 2 at approximately bimonthly intervals from February 1976 to March 1977. The densities and proportions of the two species of clams did not change (ANOVA, $P > 0.05$).

The bottom in the two areas where sea otters took large numbers of clams was littered with hundreds of shells, both on the surface and mixed into the sediments. About 58% of the shells did not have pairs of connected valves, and about one-third of the valves were broken. Of 89 shells sampled, 99% were *S. nuttalli* and 1% were *T. nuttallii*. The bottom topography was hummocky in these areas, and there were many craters 0.5-1.0 m across and 10-15 cm deep. The bottom under Wharf No. 2, where the density of clam siphons was highest, was mixed with debris consisting of chunks of asphalt apparently from resurfacing of the road on the wharf and of clumps of large barnacle, *Balanus nubilus*, tests which had fallen

from the massive barnacles encrusting the pilings. There were considerably fewer craters in this area compared with the adjacent area A, and our attempts to dig into the substrate under the wharf proved difficult as a result of the debris embedded in the sediment.

Sea otters were in the process of foraging on clams during several of the scuba dives in area A. Although these otters were not bothered by our presence under water, attempts to observe precisely how they were capturing clams usually failed because they stirred up large clouds of sediment that obscured all of their activity. When the otters stopped foraging and the clouds of sediment dispersed, a large hole up to 1.0-1.5 m across and 0.5 m deep had obviously resulted from their digging. The sides of these holes were initially nearly vertical, but collapsed within minutes.

Details of a sea otter digging for clams were observed by the first author on a single occasion on 30 March 1977, when a strong current rapidly dispersed the clouds of sediment. Upon observing a young male otter begin a typical sequence of foraging dives in area A, the observer moved along the bottom and approached the digging site from an upstream direction. The otter was clearly visible at a distance of 5 m and was just leaving the bottom after completing the second longer dive of the series. He returned to the bottom within 20 s but abandoned the initial digging site, leaving a small hole about 0.5 m across and 25 cm deep. Instead, on this third dive, he moved immediately to a new spot about 4 m away and began to dig rapidly with his front paws in a fashion very much like a dog, producing a large conical cloud of sediment extending downstream. Digging lasted about 45 s, followed by a 20 s surface interval. On the fourth dive the otter resumed digging in the same spot, and as during all digging periods, he faced into the current. The observer was able to approach < 1 m from the sea otter by creeping up in a prone position on the bottom while the otter substantially enlarged the hole to a short trench about 1 m long, 0.5 m across, and 25 cm deep by digging rapidly with both front paws. His back flippers were moving at a slower rate, which probably helped maintain his position and also appeared to assist in digging. Toward the end of the digging on this dive the otter began to roll repeatedly from side to side to enlarge the front end of the trench laterally, until he apparently encountered a clam and suddenly surfaced for 45 s. On the fifth dive this rapid process of rolling and

lateral digging with the front paws continued again for about 30 s until another clam was caught and the activity suddenly stopped. The hole at this time was over 0.5 m deep and the otter's body was entirely below the level of the substrate surface while digging. The otter used this process of lateral digging on three more dives lasting about 30 s each with 40-60 s surface intervals, before the observer ran out of air and surfaced. The trench at that time was over 1.5 m long and remained about 0.5 m wide and deep. The otter terminated the series of feeding dives with one additional dive while the observer was at the surface. It paid no apparent attention to the observer's close presence during the entire series. Simultaneous observations by the second author from the surface indicated that none of the first three dives (including two dives at the first spot) produced a clam, but that each of the six subsequent dives resulted in a single clam. The otter did not use a rock to open the clams.

Discussion

In 1966, prior to the return of sea otters to Monterey Harbor, Calif., Department of Fish and Game divers made qualitative surveys of the bottom and used a garden hose to remove several clams from the substrate for identification. The bottom topography was smooth, clams were abundant, and *T. nuttallii* was the dominant species removed from as deep as 50 cm in the substrate (Ebert³). Follow-up survey dives soon after the return of sea otters indicated that clams were less abundant and the bottom topography was hummocky (Ebert, see footnote 3). Although definitive quantitative data are not available for that period, and although construction and dredging operations in the inner marina portion of the harbor may have had important impact on clam populations, information in the present report indicates that sea otters may have limited the abundance and distribution of *S. nuttalli* and *T. nuttallii* and that *T. nuttallii* is now only a minor species. The cause of this apparent shift in dominance from *T. nuttallii* to *S. nuttalli* is unclear. Our limited measurements of the depths of these clams in the substrate indicated that larger individuals were found deeper (to about 50 cm), but that neither

³E. E. Ebert, Director, Marine Culture Laboratory, California Department of Fish and Game, Granite Canyon, Coast Route, Monterey, CA 93940, pers. commun. June 1979.

species had a depth refuge from predation by sea otters, which excavated deeper than 50 cm. *Tresus nuttallii* attains larger size than *S. nuttalli* (pers. obs.), and if sea otters prefer larger clams, they may have preyed preferentially upon *T. nuttallii*. However, clams remained abundant in small areas of the harbor in spite of heavy predation by sea otters. Densities under Wharf No. 2 averaged about 17 clams/m²; and in this area they appear to have a partial refuge from sea otters, which may have found it too difficult to dig through the debris of chunks of asphalt and clumps of barnacle tests embedded in the sediment. No such impediment to digging exists in areas A and B, where clams have persisted in somewhat lower densities of about 14 and 9/m², respectively. However, the species composition of clams was the same under Wharf No. 2 and in areas A and B, regardless of predation intensity.

By following tagged animals, Loughlin (1977) showed that certain sea otters made daily foraging trips to Monterey Harbor from rafting locations as far as 2 km away. In the present descriptions of their dive paths, sea otters feeding on items other than clams apparently located prey in a random manner similar to Shimek's (1977) description of an otter patting the surface of rocks and feeling the cracks. Observations of the bubble paths of otters taking clams in areas A and B of the harbor, however, indicated that they usually did not spend time searching for a suitable place to dig, nor did visual selection of a patch of clams appear to occur. If the density of clams in area A averaged 14/m², and if an average spot dug up by an otter was 0.5 × 1.5 m (0.75 m²) as observed in this report, then random digging in area A would produce about 10 clams. This is greater than the average number of six clams taken by otters on a series of dives. Perhaps the otters had learned the location of the clam patches, and because sediment clouds normally prevented visual cues as soon as the substrate was disturbed, they simply dug haphazardly within the patch. Indeed, Gentry and Peterson (1967) compared the underwater visual acuity of sea otters with the sea lion, *Zalophus californianus*, and harbor seal, *Phoca vitulina*, and proposed that vision in otters may be better adapted for aerial situations of predator detection rather than for underwater prey location.

The strategy of repeatedly enlarging the hole to capture clams is a good one, because it makes efficient use of the labor to start the hole on initial dives. Anyone who has dug in sand at the seashore

knows that it is relatively easy to enlarge a hole, and it would be advantageous to do this rather than dig straight down for each individual clam. The behavior of digging like a dog has also been reported by Shimek (1977) for a sea otter taking subtidal echiuroid worms and is apparently similar to the behavior of sea otters taking clams in shallow subtidal and intertidal waters in Alaska (Calkins 1978). The holes reported by these authors were only half the size of freshly dug holes at Monterey Harbor, however. The first author has observed similar (1.5 m across and 0.5 m deep) holes dug by otters in the sand channels in 12 m of water off kelp forests at Pacific Grove, Calif. In areas such as Prince William Sound and Monterey Harbor, where otters forage heavily on clams, their digging must cause a major disturbance of the infaunal community.

Sea otters have been termed "keystone predators" (Estes and Palmisano 1974; Estes et al. 1978), because they regulate populations of epibenthic invertebrates, perhaps through a process of switching between prey species. At Monterey Harbor there is circumstantial evidence that sea otters have had a major impact on two other prey items. Surveys by the California Department of Fish and Game showed *C. antennarius* and *C. productus* were taken in abundance by fishermen from the Monterey wharves prior to the return of sea otters, but they were rarely taken at Monterey in 1972-74, while still caught in abundance at piers north of the range of sea otters (California Department of Fish and Game⁴). Observations on the scuba dives reported here for 1976-77 confirm that cancer crabs are rare in the harbor. *Mytilus edulis* and *M. californianus* formed dense clumps on wharf pilings prior to the return of sea otters (Haderlie⁵), but mussels are small and uncommon there now (Haderlie and Donat 1978). Curiously, large specimens of *B. nubilus* are still abundant on the pilings and were not taken in appreciable numbers by sea otters, even though these barnacles were taken frequently by otters at other locations in the Monterey area (pers. obs.). The factors which regulate prey selection by sea otters remain poorly understood.

⁴California Department of Fish and Game. 1976. A proposal for sea otter protection and research and request for the return of management to the State of California. Calif. Dep. Fish Game, Oper. Res. Branch, Vol. 1: Text and summaries, 271 p.

⁵E. C. Haderlie, Professor, Naval Postgraduate School, Monterey, CA 93940, pers. commun. May 1976.

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EFFECT OF ZINC ON FIN REGENERATION IN THE MUMMICHOG, *FUNDULUS HETEROCLITUS*, AND ITS INTERACTION WITH METHYLMERCURY

Methylmercury has been found to retard fin regeneration in the marsh killifish, *Fundulus confluentus*, and striped mullet, *Mugil cephalus* (Weis and Weis 1978). In *F. confluentus* the retarding effect of methylmercury was masked in water of reduced salinity (9‰). Cadmium, which also retarded fin regeneration in killifish (Weis and Weis 1976), interacted antagonistically with methylmercury so that fish exposed simultaneously to the two metals exhibited growth rates comparable to controls (Weis and Weis 1978).

This paper reports on the effects of zinc on regeneration in the mummichog, *F. heteroclitus*, and the effects of combinations of methylmercury and zinc on this process.

Methods

Fish were collected by seining in the vicinity of Montauk, N.Y. The lower portion of each caudal fin was amputated with a scalpel, and approximately 15 fish were placed in each of several all-glass aquaria with 10 l of 30‰ salinity water. The temperature was 20°-22° C and the photoperiod was 14 h light/10 h darkness. Fish were fed commercial fish food and live grass shrimp, *Palaemonetes pugio*. Tanks were dosed with methylmercuric chloride (I.C.N. Pharmaceuticals, Plainview, N.Y.¹) from a 0.1 mg/ml stock solution in 0.2% NaHCO₃ to yield a final calculated concentration of 0.050 or 0.025 ppm depending on the experiment, and/or with ZnCl₂ (Reagent Grade, Fisher Scientific) from a 1.0 mg/ml stock solution to yield calculated concentrations of 1.0, 3.0, or 10.0 ppm. Aquaria were washed, refilled, and redosed after 2, 4, 7, 9, and 11 days. Regenerating fins were measured with a calibrated ocular micrometer in a stereomicroscope at 7, 9, 11, and 14 days. Experiments were terminated at 2 wk because after that time it became difficult to ascertain the point at which the amputation had been made. The amputation plane can be seen clearly in Figure 1, a control fin 1 wk after amputation.

Three experiments were performed. Experiment I involved exposure of fish 3.5-4.2 cm stan-

¹Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.