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Habitat of endangered white abalone, *Haliotis sorenseni*

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We dedicate this manuscript to the memory of our coauthor Mia Tegner

Abstract

Surveys with a submersible at offshore islands and banks in southern California found that white abalone were most abundant at depths between 43 and 60 m. This is deeper than estimates taken when white abalone were more abundant. Densities were highest at sites far from fishing ports. Controlling for depth and site found that white abalone were significantly more abundant in areas with *Laminaria farlowii* (an alga) but abalone were not associated with areas high in the cover of other algae (*Pelagophycus porra* or *Eisenia arborea*) or the amount of sand in the habitat (except that abalone always occurred on rock). Within an area with abalone, the particular rock they occurred on was significantly larger than unoccupied neighboring rocks. Occupied rocks were not significantly different in algal cover or in sea urchin density than unoccupied neighboring rocks. The position of abalone on a rock was nearer to the rock–sand interface than would be expected based on a random distribution. More white abalone were feeding when in association with red urchins, perhaps because both grazers capture drift algae to eat. These data may aid future efforts to locate white abalone brood stock and identify locations for outplanting.

Keywords: White Abalone; Endangered; Fishing; *Haliotis sorenseni*; Channel Islands

1. Introduction

We described the depth distribution and habitat characteristics of the remaining white abalone populations in southern California, USA to obtain basic natural history information that may be useful in managing and restoring this species. The National Marine Fisheries Service listed white abalone (*Haliotis sorenseni*) as an endangered species in 2001 (Anon, 2001). In their comprehensive status review of white abalone, Hobday and Tegner (2000) concluded that, between 1969 and 1977, legal fishing reduced white abalone density in the US by several orders of magnitude; in Mexico, limited information suggests impacts occurred later and appreciable, though declining, numbers of white abalones were landed into the 1990s. Overfishing (Karpov et al., 1998) and disease (Lafferty and Kuris, 1993) has been implicated in the decline of other California abalone and other species are presently candidates for listing.

White abalone occur between Punta Abreojos in Baja California, Mexico and Point Conception, California, USA. Santa Catalina and San Clemente Islands were the reported centers of abundance (Cox, 1960; Leighton, 1972). Relatively little is known of the life history of this deep dwelling species. Historically, white abalone have been most common in areas of boulders and sand (Davis et al., 1996) at depths between 25 and 30 m, feeding on attached and drift algae (Tutschulte, 1976). Tutschulte (1976) suggested that white abalone could survive at shallower depths but that competition from other abalone species and predation from octopus (and formerly sea otters) limited this thin-shelled and emergent abalone to deeper water. However, fishermen

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report white abalone to be formerly common in relatively shallow water [10–20 m deep, Buzz Owen (abalone fisherman) personal communication].

2. Study area, materials and methods

2.1. Study area and sampling protocol

To describe spatial variability and locate potential stock for future captive breeding, we targeted a large number of sites within several locations throughout Southern California. Previous surveys (Davis et al., 1996) had found that a submersible is a good tool for surveying the deep range of white abalone. Because of the rarity of white abalone, it was not feasible to adopt a random sampling design. Instead, our efforts focused on a systematic search of appropriate habitat; therefore, optimizing search time in areas most likely to have white abalone.

We conducted survey dives from the 9th to the 25th of October, 1999, using the Research Submersible DELTA and the Research Vessel VELERO IV in waters off the coast of southern California, including the Santa Cruz, Anacapa, Santa Barbara, Santa Catalina and San Clemente islands and at the Osborn, Farnsworth, Tanner and Cortes offshore banks. As on previous dives (Davis et al., 1996, 1998), we surveyed over rocky substrate at appropriate depths where recreational and commercial divers indicated white abalone populations were once abundant.

Dives in the submersible consisted of a scientist/observer and a pilot. Most dives lasted 2 h. In areas without potential abalone habitat (e.g., sandy bottom), the submersible surfaced and moved to a new location after a 10–30 min search period. When over appropriate habitat (rocky substrate between 30 and 70 m depth), the pilot moved slowly and closely over the substrate as the observer searched for live abalone and shells of abalone. During the surveys, a Hi8 video camera and light (abalone moved away from the video light) mounted to the starboard side of the submersible recorded part of the field of view, time, date and depth. The audio portion of the videotape recorded comments about the animals, plants and habitat seen by the pilot and observer.

Large white abalone are emergent, often attached to the tops and sides of rocky substrate (Tutschulte, 1976), making them relatively easy to locate underwater. We identified each abalone or empty shell to species, recorded its location (with a sonar tracking and ranging device integrated into the support vessel's differential geographic positioning system or GPS) and then made a more thorough inspection of the immediate area for additional abalone. For this reason, search effort was higher where abalone were abundant.

Fifty-eight of the 70 dives were over suitable abalone habitat. These dives represented 76 h of bottom time over 143,778 m of submersible track and located 157 live white abalone in an estimated 57.5 ha of suitable habitat. Hobday et al. (2001) used our summary data to show that the present abundance of white abalone is orders of magnitude below previous levels.

2.2. Data collection and processing

Following each dive, the observer reviewed the video and recorded observations into a form for later inclusion into a database. The database tracked algal cover, including a list of the dominant species, the number of abalone by species, the number of abalone shells by species, the depth, substrate type, substrate relief and a subjective determination of whether the area appeared to be suitable habitat for white abalone. Subsequent study of VHS copies of the videotape allowed the extraction of additional information. For each abalone on the video, we estimated the maximum dimension of the rock it occupied and the distance to the next nearest rock according to the following five size classes: 0–40, 41–80, 81–120, 121–160, and >160 cm. To quantify the position of an abalone on a rock, the distance (to the nearest 10 cm) from the shell margin down to the sand/rock interface and up to the rock apex was estimated. We noted the presence of algae within 0.2 m of an abalone and considered an abalone to be feeding if there was fleshy algae trapped under the shell margin. The presence of neighboring red sea urchins, *Strongylocentrotus franciscanus,* was recorded if they were within 0.5 m of an abalone.

By noting the relative density of animals per search effort at a particular depth, we constructed depth–frequency histograms for comparison with known former depth ranges. In addition to noting the density of abalone across sites and depths, we characterized the locations where abalone occurred at coarse and fine spatial scales. A stepwise approach was used to construct a multivariate statistical model, independent of depth and site, that best predicted abalone abundance per 5-min observation period. We then compared the characteristics of each occupied rock with the nearest unoccupied rock to determine if abalone were selective in their use of rocks within a habitat.

3. Results

White abalone were previously recorded to be most common between the depths of 25–30 m (Tutschulte, 1976), but none occurred this shallow, and most were appreciably deeper (>40 m, average depth of white abalone was 50 m (sites pooled) or 49 m (locations averaged). The mean depth of white abalone varied moderately, but significantly among locations (Kruskal–Wallace Test, $\chi^2_{(6)} = 16.843$, $P = 0.0099$), with the white abalone on offshore banks being slightly deeper than at some island locations. Additionally, the mean depth of occurrence differed between remote (48 m) and accessible sites (45 m, Wilcoxon Test, $\chi^2_{(1)} = 8.646$, $P = 0.0033$). The mean depth of white abalone at Cortes (48 m) was slightly, but significantly, deeper than at Tanner Bank (47 m, Wilcoxon Test, $\chi^2_{(1)} = 6.061$, $P = 0.0138$). One complication associated with comparing mean depths of abalone among sites was that variation in the search effort at different depths could affect the mean reported depth of abalone. To account for this, we standardized density by search effort at a particular depth to create a distribution of density by depth. Pooling data across sites, white abalone were densest between 43 and 60 m (Fig. 1) and did not occur deeper than 66 m or shallower than 31 m. A comparison of the density by depth distribution for Tanner Bank and Cortes Bank showed that abalone were indeed deeper at Cortes Bank than at Tanner Bank. In fact, at Cortes Bank, abalone were at the deepest depths surveyed (suggesting that abalone occurred deeper than where we surveyed).

Analyses of the video provided insights into white abalone habitat, habitat choice and behavior. After controlling for depth and location using a multiple regression model, white abalone were not significantly associated with the algae *Pelagophycus porra* or *Eisenia arborea* or the amount of sand (relative to rock) in the habitat (in interpreting the lack of association with sand it is important to consider that areas without rock have no abalone but these rockless areas were excluded from the analysis). The best multiple-regression model ($R^2 = 0.23$, $F_{(3,\ 412)} = 40.887$, $P < 0.0001$) that included relief, distance from the nearest port, and *Laminaria* cover as factors found that white abalone were most dense in areas where the rock had low relief ($F = 13.508$, $P = 0.0003$) and relatively high cover of *Laminaria farlowii* ($F = 29.230$, $P < 0.0001$). It also found that density increased with distance from port ($F = 4.400$, $P = 0.0365$).

Rocks with white abalone were larger than the nearest rock without abalone (1.11 m vs. 0.74 m wide, Paired $t = 3.96$, $P = 0.0002$, df = 76). Of the abalone observed, 76.7% were within 0.2 m of foliose algae, 96.5% were within 0.2 m of coralline crust and 32.6% were within 0.2 m of articulated corallines. There was no significant difference in these biological variables between points where abalone were present and randomly selected points on adjacent rocks where abalone were not present (*G* test, $P > 0.05$, in all cases). White abalone were not randomly distributed over the vertical surface of their rock (*G* test, $\chi^2_{(171)} = 19.342$; $P < 0.0001$). They were most often closely associated with the sand/rock interface, as shown by most individuals falling below the midpoint of the available rock surface (Fig. 2). White abalone (19.8%) were within 0.5 m of a red sea urchin. This was not significantly different than randomly selected points (10.4%) on adjacent rocks where abalone were not present (*G* test, $P > 0.05$). However, individuals that were feeding were more likely to be near urchins (42%) than abalone that were not feeding (7.5%) (*G* test, $\chi^2_{(84)} = 9.718$; $P < 0.003$).

4. Discussion

The change in the depth distribution of white abalone is consistent with the prediction that today's remaining animals are those that were too deep to be fished. This has important implications for restoration because the majority of the available brood stock needed for restoration lies below safe SCUBA diving depths. We do not believe that the present depth distribution of white abalone indicates the preferred depth distribution of the species. This suggests that future outplanting efforts required for restoration of the species could occur in shallower areas than where we found white abalone. This would increase opportunities for potential outplant sites and permit monitoring of survival over time. The slightly deeper depth distribution of white abalone on the offshore banks could reflect an extension

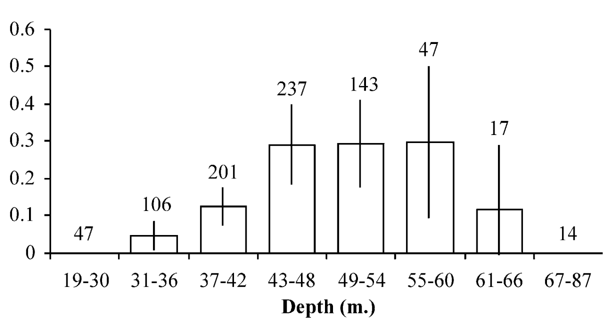

Fig. 1. Number of white abalone encountered per five minutes searched at various depths in appropriate habitat during the 1999 survey. Numbers above bars represent the number of 5 min observations. Error bars show 95% confidence intervals.

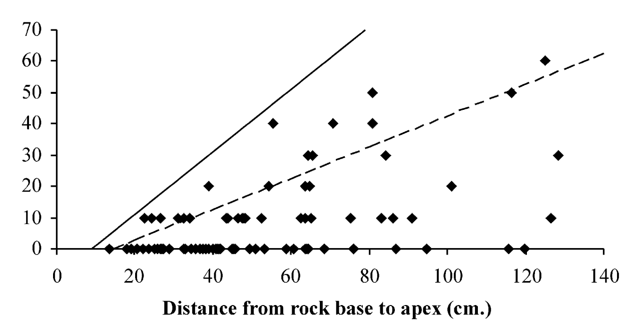

Fig. 2. Utilization of rock surface by white abalone. The solid line represents the apex of the substrate, while the dashed line represents the midpoint of the substrate. Points falling below the dashed line represent abalone located on the lower half of the substrate.

of the photic zone due to high water clarity, thereby extending the depth distribution of the algae that comprise the main source of food for white abalone.

Future outplant efforts could use the presence of *Laminaria fowlerii* and low relief rock as indications of suitable habitat for white abalone. Individual rocks within such areas could be selected without regard to algal cover. The white abalone's preference for large rocks could simply reflect the fact that large rocks present a larger proportion of the available hard substrate (a hypothesis we were unable to assess) and we cannot, therefore, suggest that rock size is an important factor to consider when outplanting white abalone. Their position close to the rock–sand interface could be an adaptation for increasing the rate of contact with negatively buoyant drift algae that may be more likely to be carried by the currents that characterize sand channels. This fine-scale habitat information may be useful for refining the search image for white abalone. Although urchins and some abalone species are potential competitors for food and space (Andrew and Underwood, 1992), there was no indication of a shortage of space and we were surprised when our results indicated white abalone fed on drift algae more in association with red urchins. This may be because both species feed where drift algae accumulate in response to physical forces and one herbivore can exploit drift algae held in place by the other. The presence of actively feeding red sea urchins may indicate to future restorationists that a particular microhabitat receives the drift algae that white abalone feed on and, therefore, could serve as an appropriate location to place outplants.

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