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WHITE ABALONE AT SAN CLEMENTE ISLAND: POPULATION ESTIMATES AND MANAGEMENT RECOMMENDATIONS

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

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1. Abstract

White abalone (*Haliotis sorenseni*), a marine mollusk indigenous to southern California, was listed as endangered in 2001. In 2004, underwater surveys using a remotely operated vehicle (ROV) identified several remnant populations of white abalone, including one along the west and south shores of San Clemente Island (SCI). In 2012, another survey of white abalone habitats was conducted at SCI to examine potential changes in that population. White abalone are sparse at SCI; only five white abalone (mean shell length of 17.2 cm (standard deviation (SD) = 2.2 cm and 17.7 cm (SD = 1.8 cm) in 2004 and 2012, respectively) were observed in each of the two surveys. Average densities were 0-1.24 abalone per hectare (ha^{-1}) in 2004 and 0.27-1.44 abalone ha^{-1} in 2012, which resulted in a slight increase in the population from 353 (standard error (SE) = 62) to 565 (SE = 136) white abalone during that time. However, the low density and patchy distribution of white abalone at SCI resulted in high coefficients of variation (CVs) for population estimates in all years and depths (CV = 0.70-0.96). In order to slow down or halt the progression towards local extinction at SCI, NMFS recommends the following steps be taken: 1) the U.S. Navy (Navy) should continue to support research and monitoring efforts that focus on learning more about the movements, growth and spawning behavior of its small but persistent population; 2) the Navy should continue its outreach and education mission in order to discourage illegal take of all abalone species at SCI; and 3) the Navy should consider the locations of the observed animals when planning operations that may impact white abalone or its habitat at SCI. These recommendations are provided at the request of the Navy as stipulated in the funding agreement.

2. Introduction

Abalone are marine prosobranch mollusks that were historically found in rocky reef habitats in Southern California and the offshore islands and banks. Sexes are separate, and gametes are released freely into the surrounding water during reproduction. Males and females must be in close proximity for successful fertilization to occur (Shepherd & Breen 1992, Babcock & Keesing 1999, Riffell et al. 2004). Abalone are estimated to live to between 20-40 years old (Tutschulte & Connell 1988), and longevity of white abalone has been validated to a minimum of 30 years using bomb radiocarbon (Andrews et al. In review). Abalone recruitment events are likely episodic (McShane & Naylor 1996).

White abalone (*Haliotis sorenseni*) once supported a brief commercial fishery in North America. During a ten year period from 1969 to 1978, a total of 263 metric tons were landed in California (prior to 1969, the species may have been landed but not separated from the pink abalone (*H. corrugata*) landings data). By the mid-1980s, landings fell to near zero and the commercial fishery was closed in 1997 (Hobday et al. 2001). The white abalone fishery in Mexico appears to have collapsed in the 1960s (Shepherd et al. 1998). Despite fishery closures, white abalone abundance continued to decline through the 1990s and as a result, white abalone became the first marine invertebrate to be listed as endangered throughout its range under the Endangered Species Act (ESA) in 2001 (Anonymous 2001). A formal status review concluded that the population was greatly reduced due to overharvesting during the 1970s and that remnant populations showed no sign of recovery following the closure of the fishery (Hobday & Tegner 2000). Of the 263 tons of white abalone landed in the fishery, 80 percent was taken at San Clemente Island (SCI) (Hobday & Tegner 2000). Green (*H. fulgens*), pink, and threaded (*H. kamtschatkana assimilis*) abalone populations also experienced significant depletion from fishing during the 1950s, 60s and 70s and as a result, these species now number less than 1% of their pre-fishery abundance levels (Rogers-Bennett et al. 2002). As with white abalone, commercial landings of green and pink abalone reached their highest recorded levels in Southern California at San Clemente Island (460,000-2 million pounds and 5-13 million pounds, respectively). Green, pink and threaded abalone are on the National Marine Fisheries Services' (NMFS') species of concern list and are part of the state of California's Abalone Recovery and Management Plan.

Historically, SCI served as an important commercial and recreational source of white, green, pink, and black abalone. Therefore, it has been highlighted as an important area for current monitoring and future restoration efforts. SCI was surveyed with a remotely operated vehicle (ROV) in 2004 by the NOAA Southwest Fisheries Science Center with the support of the NOAA Southwest Regional Office and in cooperation with the U. S. Navy (hereafter, Navy; Butler et al. 2006). At the same time abalone habitat was mapped using multibeam sonar and relationships between white abalone presence and microhabitat characteristics were analyzed. A multivariate analysis of microhabitat data from SCI and other white abalone habitats revealed a strong positive relationship between the presence of white abalone and several factors; the strongest correlations were with depth, a faulted or folded hard substrate seabed with sand, a flat seafloor slope, moderate seafloor complexity, and the relative abundance (common or abundant) of brown algae (*Agarum fimbriatum*, *Laminaria* spp., and brown algae spp., in general).

In this study, white abalone habitats along the west shore of SCI were surveyed again, using a newly designed ROV and with the aid of existing maps of rocky habitat, to determine 1) whether abalone populations at SCI are showing signs of recovery or experiencing further declines, and 2) to prioritize habitat for future restoration activities. Here we present revised density and population estimates of white abalone at SCI from 2004, and compare those to results of the survey conducted in similar locations in 2012. Based on these results, we make recommendations regarding the management of depleted abalone populations surrounding San Clemente Island. These recommendations are provided at the request of the Navy as stipulated in the funding agreement.

3. Methods

3.1 Survey design

A visual transect survey was conducted along the west and south margins of San Clemente Island from July 10-17, 2012 using a remotely operated vehicle (ROV) (**Fig. 1**). The sampling area of this survey was similar to the 2004 survey conducted by Butler et al. (2006). Fourteen patches of hard substrate between 30 m and 60 m, which is known to be preferred habitat of white abalone (Butler et al. 2006) were identified within the survey area using high resolution multibeam bathymetry maps and vector ruggedness models (see Young et al. 2010). Three 10-m depth strata were defined (30-40 m, 40-50 m, and 50-60 m) based on the depth distribution of white abalone in earlier surveys of white abalone habitat (Butler et al. 2006, Stierhoff et al. 2012). Survey effort was allocated using a stratified random design, with depth and habitat patch as the two strata types. A grid (100 m x 100 m cell size) was overlaid on each habitat patch, and grid cells were selected at random in numbers proportional to the total area of available habitat within each patch and depth stratum (**Fig. 1**). ROV transects started or ended within each randomly selected grid cell; however, due to prevailing winds and currents, the actual start or end locations were occasionally different than the intended locations. The target length of each transect was 500 m, but the actual length was occasionally shorter in smaller habitat patches.

3.2 Survey platforms

The 2004 survey was conducted aboard the NOAA Ship *David Starr Jordan* using a modified Phantom DS4 ROV (Deep Ocean Engineering, Inc.) (see Butler et al. 2006 for details). The 2012 survey was conducted aboard the commercial passenger fishing vessel (CPFV) *Outer Limits* using a custom ROV developed by engineers and fisheries biologists at the SWFSC. High-definition (1080i) video was recorded during each transect. High-resolution still images were also captured and used to verify abalone observations and identify each abalone to species. The 3-D location of the ROV above the seabed was estimated using an ultra-short baseline (USBL) acoustic tracking system (TrackLink 1500HA, LinkQuest, Inc.) and differential global positioning system (dGPS, CSI Wireless dGPS MAX). The length of each transect was estimated from the ROV speed that was measured using a Doppler velocity log (DVL, Workhorse Navigator, Teledyne RD Instruments). Water-column and near-bottom water quality parameters (e.g., temperature, salinity, dissolved oxygen (DO) concentration and DO saturation (%)) were measured during each transect using a CTD (Citadel CTD-ES, Teledyne RD Instruments) and optode

(Model 3930, Aanderaa, Inc.). All data were time-stamped and logged synchronously using WinFrog integrated navigation software (Fugro Pelagos, Inc.). Reference lasers (spaced 20 and 40 cm apart) were used to estimate abalone lengths and transect widths (see *Survey effort* below).

3.3 Data analysis

Effort analysis

Each transect was designed to sample within only one depth stratum. On occasion, however, transects would cross into the adjacent depth stratum due to the effects of prevailing wind and currents on the survey vessel and the ROV. In such cases, transects were post-stratified where they crossed the boundary of each 10-m depth stratum and considered as separate transects. To minimize differences between depth data across surveys, seabed depth for all transect data and white abalone observations was extracted from the same raster digital elevation model (DEM, 2-m resolution) developed for SCI by Butler et al. (2006; publically available from California State University, Monterey Bay, http://seafloor.csumb.edu/). Resulting transects that were shorter than 100 m were removed from the analysis to minimize artificially inflated densities.

The amount of area searched in each transect was determined by multiplying the total transect distance by the average strip width (w) during each year of the survey. Transect length (or distance, d in meters) was calculated as:

$$d = \sum_{i=2}^{n-1}(r_i * t_i) \tag{1}$$

where r is the speed of the ROV (m/s) and t is the time (s) between speed measurements, i is the measurement number, and n is the total number of measurements. This method of estimating distance was calibrated over a submerged pipeline of known distance (1,512 m) and was found to be accurate to ~1% (mean = 1,521 m; standard deviation (SD) = 12 m; n = 3 transects) (Stierhoff and Butler, unpublished data).

The average strip width of 2.0 m used to calculate area searched for the 2004 survey was taken from Butler et al. (2006). The strip width used to calculate area searched in 2012 was estimated from 10 randomly selected transects using parallel reference lasers and photogrammetric software (3Beam, Kocak et al. 2002, Pinkard et al. 2005, Stierhoff et al. 2012). Briefly, the 20-cm parallel lasers were identified in video frames every 20 s. The software then estimates the total width of the video frame using the number of pixels between the parallel lasers. Results from the automated laser identification algorithm were reviewed a second time by the analyst and manually corrected when false detections or incorrect laser positions were identified. For frames where the lasers were unable to be located (e.g., obscured by kelp or washed-out by the ROV lights) and for the distance traveled between each 20-s estimate, the strip width was calculated using linear interpolation. The total area searched (a, m^2) was calculated as:

$$a = w * d \tag{2}$$

where w is the average strip width (3.01 m) and d is the total transect distance (m).

Demographic analysis

White abalone sightings were logged at sea during each transect in 2012, and later verified by at least two analysts after reviewing video footage and high-resolution still images. Video footage and still images from the 2004 survey were also reviewed by two analysts to verify white abalone sightings. All sightings from 2012 were verified; however, one reported white abalone in the 30-40 m depth stratum during the 2004 survey was determined to be incorrect. The removal of this sighting had significant effects on revised population estimates for that survey (see *Results* section below).

White abalone density in each transect was calculated by dividing sightings by area searched, and abundance was calculated by multiplying density by total available habitat in that depth stratum. Mean density and abundance and their respective variances (standard error, *SEM*, and coefficient of variation, *CV*) of density and abundance were estimated for each depth stratum using a non-parametric bootstrap of 1,000 samples (Efron & Tibshirani 1993). Confidence intervals (90%) were estimated from the distribution of bootstrap estimates of the mean. The total population estimate in each year was calculated by summing abundances from all depth strata, and the overall *SEM* was calculated by taking the square root of the summed variances across all depth strata.

The shell length of each abalone was estimated to the nearest 0.1 cm using frames extracted from the HD video footage, the parallel reference lasers, and image analysis software (ImageJ, National Institutes of Health) (see Stierhoff et al. 2012).

In addition to counting individuals, group sizes were also recorded. ROV pilots searched the general vicinity around a sighting to determine whether a particular individual was alone or part of a larger group. A group was defined as two or more white abalone less than two meters apart. The weighted average (i.e., geometric mean) across all groups was used to calculate average group size for each year.

All statistical analyses were conducted using R (R Development Core Team 2011). All figures were produced using the R package 'ggplot2' (Wickam 2009) and maps were produced using ArcGIS Version 10.2 (ESRI, Inc.).

4. Results

4.1 Survey effort

A total of 33 and 50 ROV transects were analyzed for the 2004 and 2012 surveys, respectively. In 2004, transects were concentrated in Navy Operations Areas designated SWAT4, SHOBA, and to a lesser extent, MTR-2. In 2012, effort was distributed more evenly between each of the Navy Operations Areas (**Fig. 2**). The average transect distance and duration also varied greatly between the two surveys. In general, transects in 2012 were shorter and less variable in length and duration compared to 2004 (**Table 1**). In 2004, nearly 60% of the search effort occurred in the 40-50 m depth stratum, 25% in the in the 50-60 m stratum, and 16% in the 30-40 m stratum (**Table 2**). In 2012, 39%, 33%, and 28% of the search effort occurred in the 30-40 m, 40-50 m, and 50-60 m depth strata, respectively (**Table 2**). The percentage of available habitat distributed across the 30-40 m, 40-50 m, and 50-60 m depth strata was 41%, 31%, and 25%, respectively.

4.2 White abalone observations

Sighting frequencies for white abalone were very low in both surveys; only five white abalone were observed in each year. In 2004, two individual white abalone and one group of three white abalone were observed in the 40-50 m stratum in SHOBA (**Fig. 2**). The one white abalone sighting reported by Butler et al. (2006) in the 30-40 m stratum was determined to be incorrect after reviewing the video footage, and no white abalone were observed in the 50-60 m stratum. In 2012, one white abalone was observed in 30-40 m and one white abalone was observed at 40-50 m in SWAT4 (**Fig. 2**). Three white abalone were observed at 50-60 m in MTR-2 (**Fig. 2**). Two of the white abalone in MTR-2 were observed as a pair and were located ~50 cm apart on the same boulder. All abalone were observed on rocky substrates with some sand present in surrounding areas.

4.3 Population estimates

The density and abundance of white abalone was also very low in both surveys. The average density across depth strata ranged from 0-1.25 abalone ha^{-1} in 2004, and from 0.28-1.41 abalone ha^{-1} in 2012 (**Table 3**, **Fig. 3**). The total population estimates were slightly lower in 2004 (330, SE = 60) than in 2012 (569, SE = 90) (**Table 3**, **Fig. 4**), but precision of the estimates are too poor to assess whether abundance has truly increased or decreased.

4.4 White abalone group size and shell length

The average group size was 1.44 and 1.19 in 2004 and 2012, respectively. The average length of white abalone in 2004 and 2012 was 17.2 cm (SD = 2.2, n = 5) and 17.7

cm (SD = 1.8, n = 5), respectively. All white abalone observed in both years were greater than 14 cm and are considered to be adults.

4.5 Additional observations

Many empty abalone shells of various sizes were observed throughout the survey. The species from which these shells originated was typically not obvious. Many of these shells were heavily fouled or degraded and appeared to be quite old. Several shells appeared to be from abalone that died more recently. No attempt has been made to quantify the abundance, length, or species of empty shells.

5. Discussion

White abalone populations throughout southern CA are severely depleted. Historically, densities of white abalone were estimated to be as high as 2,300 ha^{-1} (Tutschulte 1976) and the total population was estimated to be between 700,000 and 4.2 million individuals across their entire range (Hobday et al. 2001). A more conservative density estimate, based solely on fishery-dependent information in California, is 479 ha^{-1}, which translates to a population size of 360,476 individuals for California alone (Rogers-Bennett et al. 2002). Following a status review by Hobday and Tegner (2000), the white abalone was listed as critically endangered throughout its range and it was thought that without intervention, the white abalone would become extinct by 2010. Surveys conducted since the listing in 2001 indicate that white abalone densities have declined by ~99% since the 1970s (Hobday et al. 2001), and have continued to decline at several locations in southern CA (Butler et al. 2006, Stierhoff et al. 2012). This study examined white abalone population trends at SCI, which was last surveyed in 2004, and was found to have the lowest white abalone density (0-3.1 ha^{-1}) compared to the other two sites surveyed (Cortes Bank and Tanner Bank; Butler et al. 2006), despite its historical significance.

The large variance in population estimates from this study makes conclusions about population trends difficult or impossible. The mean overall density and total population size of white abalone at SCI was slightly greater in 2012 compared to 2004 as a result of the slightly greater density in the 30-40 m and 50-60 m strata. The difference in these two population estimates is probably not significant, however, given the large standard error and coefficient of variation in each. One group of three white abalone was observed in 2004 compared to one pair observed in 2012, resulting in a small decrease in the average group size. A slight but not significant increase in shell length was also observed. There were no obvious spatial trends in the white abalone distribution. All white abalone from 2004 were observed in the 40-50 m depth stratum in SHOBA. At least one white abalone was observed in each depth stratum in 2012, and were distributed in several of the Navy Operations

Areas. Nonetheless, the density of white abalone at SCI is much lower than recent density estimates at Tanner Bank (Stierhoff et al. 2012), and far from the density of 2,000 ha^{-1} that has been suggested as the minimum density required to sustain viable white abalone populations (National Marine Fisheries Service 2008).

Several factors make it difficult to directly compare density and population estimates between each of these surveys and also with previously published estimates at SCI. First, and perhaps most important, a review of the data used in the analysis by Butler et al. (2006) revealed that the only white abalone observed in the 30-40 m stratum was not actually an abalone. The removal of this individual from their analysis results in a density of zero in that stratum and a decrease in the total population across all depths from 1,938 (SE = 1,598) to 723 (SE = 500) prior to reanalysis. Revised estimates of survey effort and a different method of statistical analysis resulted in a further reduction in the population estimate to 330 (SE = 60) in 2004. The sampling design also varied between surveys. Transects in 2012 were more evenly distributed between depth strata and across habitat patches compared to 2004, and therefore, some areas that were surveyed in 2012 were not sampled in 2004. Different methods were used to measure transect distance between analyses. Butler et al. (2006) measured distance by calculating the Euclidian distance between adjacent navigation points and the present analysis calculates distance from the speed of the ROV and the time between speed measurements. The former method typically results in a larger estimate of transect length due to larger errors associated with USBL position data. Finally, the cameras used in each survey had different optical resolution and horizontal field of view, which can affect the detectability of white abalone and the total area searched, respectively. Differences in strip width were taken into account in the density and population estimates, but the potential differences in detectability cannot be easily quantified. Given the factors above and the low density and patchy distribution of white abalone at SCI, any temptation to infer a trend from these two surveys should be carefully considered.

White abalone, like other abalone species, are cryptic and often difficult to detect during visual surveys. They preferentially inhabit rocky substrates and are often covered in the same encrusting algae and kelp that cover their habitat, which provides effective camouflage and makes detection and positive identification challenging. The challenges associated with detection become even greater as shell size decreases, making our ability to monitor any recent recruitment or gauge recovery more difficult. White abalone can occur in deep water habitats and since the highest densities recorded by ROV surveys are between 30 and 60 m, it is difficult or impossible to survey using traditional methods such as SCUBA, which would allow for closer visual inspection and perhaps more accurate density estimates. At such low densities, the addition or deletion of one individual, or the observation of a cluster of individuals on one transect, can have dramatic effects on demographic estimates.

Despite these challenges, continuing to monitor abalone populations at SCI remains a high priority for state and federal agencies for a number of reasons including: its historic importance for multiple abalone species based on fishery landings data, the current presence of high quality intertidal and subtidal rocky reef habitat, the protection of habitat offered by the Island's remote location and limited access due to military activities, and its inclusion on the list of areas where white abalone must be restored to viable levels before NMFS will consider removing ESA protections. Generally, the state and federal recovery actions for abalone are similar and include monitoring extant populations and their habitats to examine trends in key demographic variables over time (e.g., abundance, density, amount of optimal habitat, etc.), restoring compromised habitat to habitats that can support healthy abalone populations, enhancing high quality habitat areas with animals reared in captivity and/or animals that have been transplanted from areas where abalone are abundant, enforcing abalone regulations in an effort to decrease illegal activities, and building an effective outreach and education plan. In the following paragraphs we put forward, as requested by the Navy, a list of recommended activities that should continue or begin at SCI in order to recover white abalone populations at the Island and continue the Navy's core mission without interruption or delay in activities.

6. Recommendations

6.1 Monitoring extant populations

Monitoring extant white abalone populations is a very important component to the NMFS recovery plan in that it is the only way we can detect trends in key demographic variables of populations (e.g., abundance, density, size range). These data are used to gauge the effectiveness of recovery actions, understand natural variability in populations, and ultimately justify removing species from the ESA list. Even after species are removed from the ESA list, monitoring must continue for at least five years to confirm that relisting is not warranted after ESA protections are removed.

The monitoring NMFS has been conducting at SCI could be improved by reducing methodological biases. To examine future abundance and shell length trends in this small, but stable population, we recommend that:

- A comparison of abalone detection rates between ROV and SCUBA methods be conducted in areas that: 1) are known to support abalone populations (which could be any species of abalone for this analysis, and preferably a species that is more abundant at SCI); and 2) are suitable for conducting both SCUBA and ROV surveys. With the appropriate sampling design, estimated probabilities of missing an abalone when one is present could be calculated. Understanding this error rate could improve future ROV estimates of white abalone abundance in deeper water SCI habitats that are beyond depths typically visited by SCUBA divers using compressed air (i.e., > 33 m). We recommend that this comparison be carried out as soon as possible.

- Other methodological improvements could be explored through the use of improved equipment and/or sampling design and more sophisticated analyses that account for the difficulties in sampling rare and/or elusive species. We recommend that improved methodologies be tested as soon as possible.
- Improved estimates of abundance be used to examine trends in population growth or decline at a minimum of once every 2 years.
- Examine the size distribution of extant animals and fresh shells to assess trends in recent reproduction and recruitment events at the island at a minimum of once every 2 years.

6.2 Monitoring rocky substrate habitats

We hoped to provide better characterizations of habitat suitability for white abalone, but were unable to do so. Understanding the habitat needs of white abalone is important for prioritizing habitat protection efforts and for establishing foci areas for reestablished populations. Butler et al. (2006) reported that depth, deformed rocky substrate with sand, a relatively flat seafloor slope (0-1 degree), moderate seafloor complexity, and relatively high abundance of particular brown algae (*Laminaria farlowii* and *Agarum fimbriatum*) were all associated with the occurrence of white abalone. We were not able to improve upon this analysis because of limitations with the visual field and measurement capabilities of the ROV, the rarity of white abalone, and personnel limitations (time and expertise). One way to improve habitat characterizations would be to work collaboratively with the Navy and Geographic Information Specialists at both agencies to assemble existing information and develop data layers that incorporate the variables listed above. These data layers could be overlaid to reveal areas around SCI that could be targeted for future surveys, habitat restoration, and/or enhancement activities. In addition, it is becoming clear based on work conducted by other investigators (e.g., Glenn VanBlaricom and Peter Raimondi) that examining micro-scale characteristics of rocky substrate habitat (e.g., crevice depth, the presence/absence of certain types of encrusting algae) is important in determining abalone presence and viability. If existing finer-scale habitat information is not available for SCI presently, new methods (e.g., using SCUBA) could be developed for collecting this information in the near future.

6.3 Restoration and enhancement activities

Given our current understanding of white abalone extinction risk, captive propagation and enhancement has been identified as the only recovery action that could boost densities quickly enough to reduce the probability of extinction in the wild over the next decade. Acting on the recommendations made by the white abalone recovery team, NMFS has put a great deal of time, effort and funding behind a white abalone captive propagation and enhancement program currently housed at the University of California Davis' Bodega Marine Laboratory. This program has made slow, but encouraging progress, especially in recent years. The rate of progress has been slowed by a number of factors including (and in no particular order): disease, funding, facility limitations, inability to induce spawning in captivity, and loss of aging broodstock due to natural mortality over time. Abalone researchers have recommended that NMFS consider authorizing the collection of wild, singleton white abalone for incorporation into the captive broodstock program because: 1) singleton animals have little or no chance of contributing to future recruitment in the wild; and 2) the spawning induction success rate of animals that have recently been collected from the wild may be higher than that for animals that have been held in captivity for a long time (i.e., years). While very few animals have been observed at SCI since 2004 and 50% of those animals have been classified as singletons (i.e., greater than 2 m from its nearest neighbor), our results suggest that the SCI population is small, but stable. Thus, whether to collect singleton animals at SCI for broodstock or to leave them in place on the outside chance that these individuals may be contributing to future generations deserves further consideration. NMFS recommends that ROV and SCUBA transects be carried out concurrently in appropriate white abalone habitat, at shallower depths than previously conducted, to determine whether individuals are suitable for broodstock collection, for translocation in order to create aggregations, or should be left in place. NMFS would like to cooperate with Navy scientists and SCUBA divers on this effort. We recommend that the Navy and NMFS identify participants from both agencies to discuss this potential project. Discussions regarding the potential for SCI to serve as a future enhancement site for captively reared larvae and juveniles could also be vetted during this discussion. **Table 4** provides an initial list of the pros and cons associated with collecting or translocating white abalone from SCI and for SCI serving as a future enhancement site for captively reared larvae, juveniles, or both.

6.4 Outreach and Education

SCI's Draft Integrated Natural Resources Management Plan (INRMP) includes a commitment by the Navy to review current enforcement policies for effectiveness in combating potential illegal take. In addition to reviewing current enforcement policies, we recommend that education and outreach materials be updated to include information on white abalone and no-take restrictions for all abalone species to help prevent the illegal harvest of abalone.

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9. Tables

Table 1. A comparison of average (and standard deviation, SD) transect length, transect duration, and remotely operated vehicle speed in 2004 and 2012.

Year	Transects	Distance (m)	Duration (min)	Speed (m/s)
2004	33	776 (623)	41 (34)	0.35 (0.14)
2012	50	395 (101)	31 (10)	0.22 (0.04)

Table 2. Comparison of search effort (hectares, ha) within each U.S. Navy area (Site) and depth stratum in 2004 and 2012.

	Area searched (ha)			
Site	**30-40m**	**40-50m**	**50-60m**	**Grand Total**
2004				
MTR-2	0.00	0.13	0.35	0.47
SHOBA	0.24	1.61	0.55	2.40
SWAT4	0.22	0.82	0.41	1.45
SWAT6	0.36	0.46	0.00	0.82
All areas	**0.83**	**3.01**	**1.31**	**5.15**
2012				
MTR-1	0.09	0.00	0.00	0.09
MTR-2	0.33	0.49	0.37	1.19
SHOBA	0.59	0.51	0.62	1.72
SWAT4	0.78	0.61	0.43	1.82
SWAT6	0.61	0.35	0.24	1.20
All areas	**2.31**	**1.96**	**1.66**	**5.93**

Table 3. Summary of white abalone density and population estimates in each depth stratum at San Clemente Island in 2004 and 2012.

Year	Depth	Transects	Sightings	Distance	Area	Density		Habitat area	Abundance		90% CI		CV
				km	ha	Mean	SEM	ha	Mean	SEM	Lower	Upper	
2004	30-40 m	8	0	4.12	0.82	0	-	393	0	-	-	-	-
	40-50 m	16	5	15.03	3.01	1.25	0.23	279	330	60	0	731	0.73
	50-60 m	9	0	6.45	1.29	0	-	219	0	-	-	-	-
	All depths	33	5	25.6	5.1			892	330	60			
2012	30-40 m	21	1	7.93	2.39	0.28	0.06	393	107	22	0	326	0.96
	40-50 m	15	1	6.29	1.90	0.48	0.12	279	131	31	0	400	0.93
	50-60 m	14	3	5.52	1.66	1.41	0.37	219	331	81	0	955	0.92
	All depths	50	5	19.7	5.9			892	569	90			

Table 4. Pros and cons of collecting and/or relocating white abalone (*Haliotis sorenseni*) at San Clemente Island.

Pros	Cons
Navy activities would proceed with lower likelihood of ESA concern if white abalone are removed from the wild or remain in the wild but are grouped together into specific locations.	Difficult to locate, collect, and/or move white abalone because they are rare and occur (at least the individuals we are currently aware of) at deep depths.
Newly collected animals or animals placed into groups in the wild may be more capable of successfully spawning and therefore achieve higher reproductive potential than if they were left in place.	Some recruitment may be occurring and collection of animals thought to be singletons may do more harm than good.
Collected animals would be protected from potential poaching or other sources of mortality, but would still have a chance to contribute to future generations.	Low success rates of existing captive breeding programs suggest that captive spawning may not be a viable enhancement and/or recovery tool.
If SCI animals are collected as broodstock and those animals reproduce, SCI could receive captive-reared larvae, juveniles, or both to jump start the recovery of white abalone populations at SCI which would highlight the Navy's capabilities as natural resource managers.	If white abalone populations as SCI are enhanced through captive propagation or aggregation, Navy activities may begin to impact the species and its habitat more, leading to increased ESA consultation activity.

10. Figures

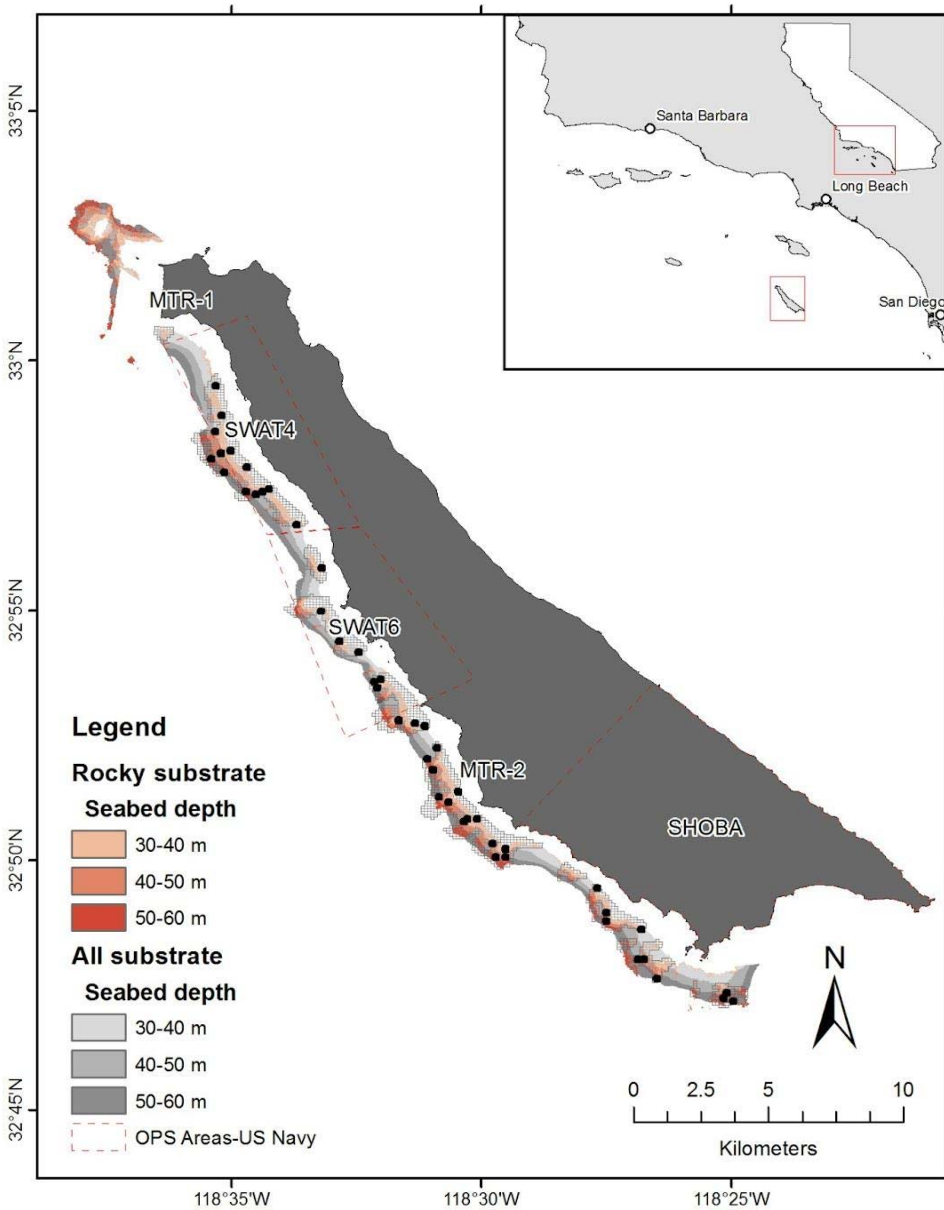

Figure 1. A map of the survey area around San Clemente Island. The extent of all substrates between 30 and 60 m (gray shaded area) and the areas identified as rocky substrates (pink shaded area, R. Kvitek, Cal State Univ. Monterey Bay, personal communication). The 100 m x 100 m sampling grid and randomly selected grid cells (bold cells) within areas with rocky substrate are also shown.

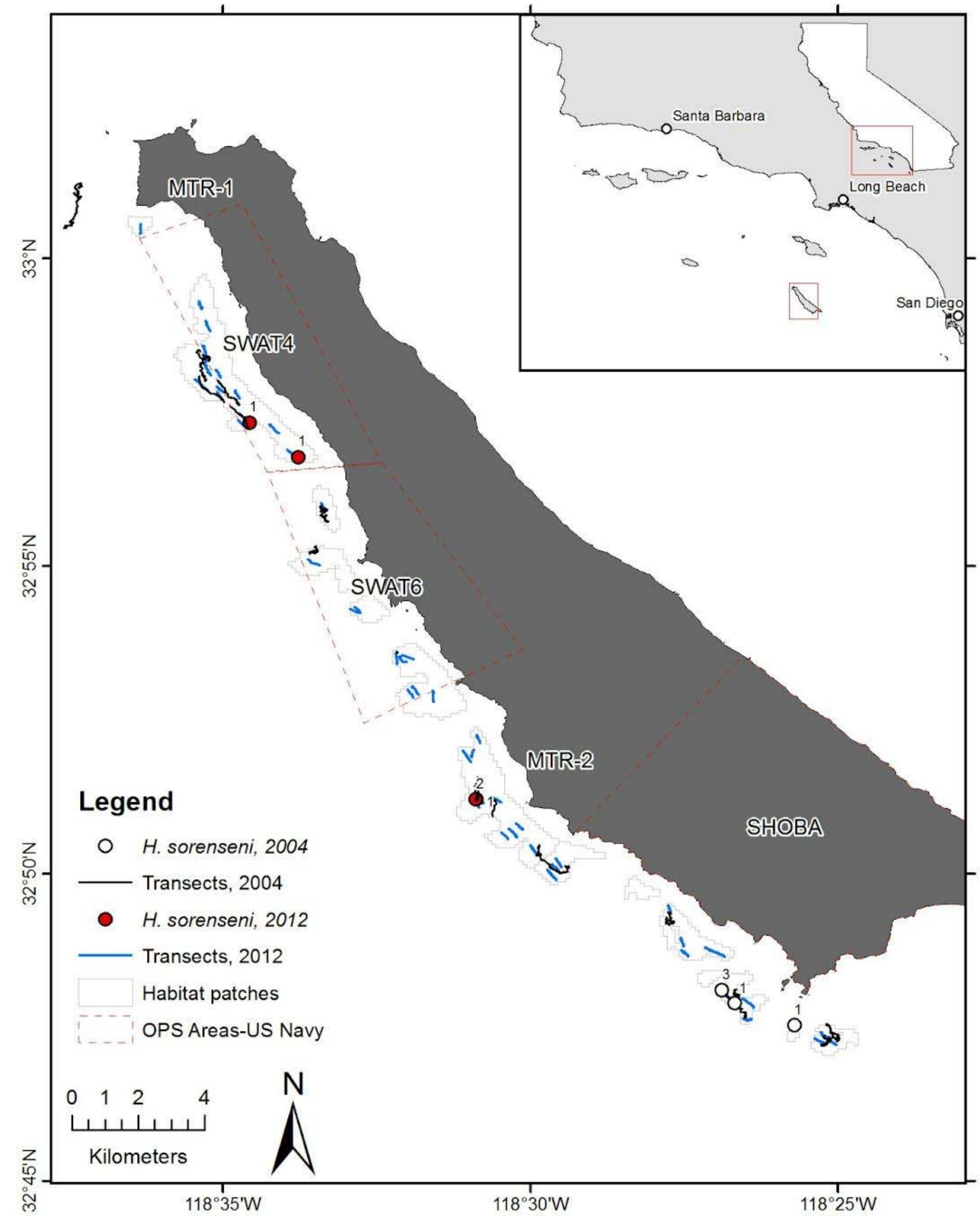

Figure 2. Remotely operated vehicle (ROV) transects in 2004 (black lines) and 2012 (blue lines). The locations of observed white abalone (*H. sorenseni*) are also shown and labeled with the number of individuals per sighting (i.e., group size). Note that two white abalone sightings occurred in close proximity in MTR-2 in 2012 and appear as one point.

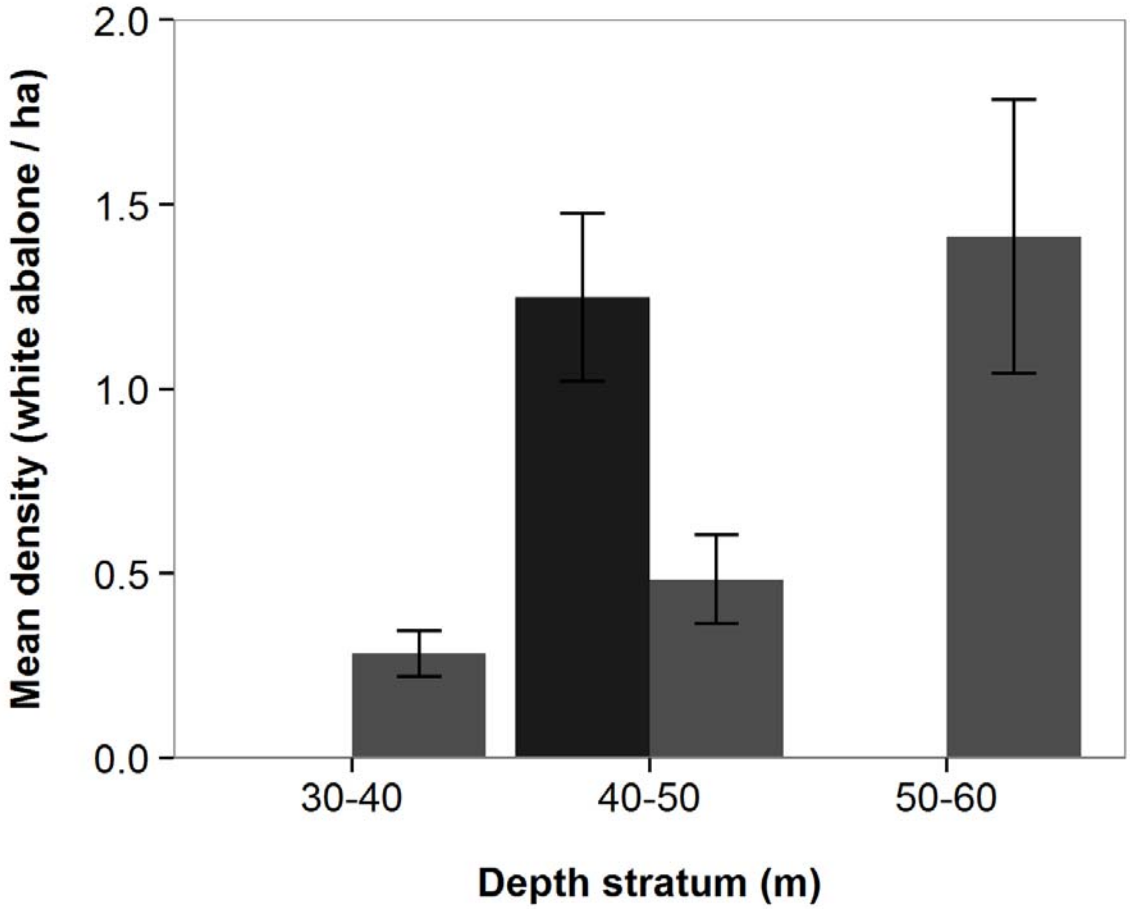

Figure 3. Average density (± standard error of the mean, SE) of white abalone (*Haliotis sorenseni*) across three depth strata at San Clemente Island in 2004 (black bars) and 2012 (grey bars).

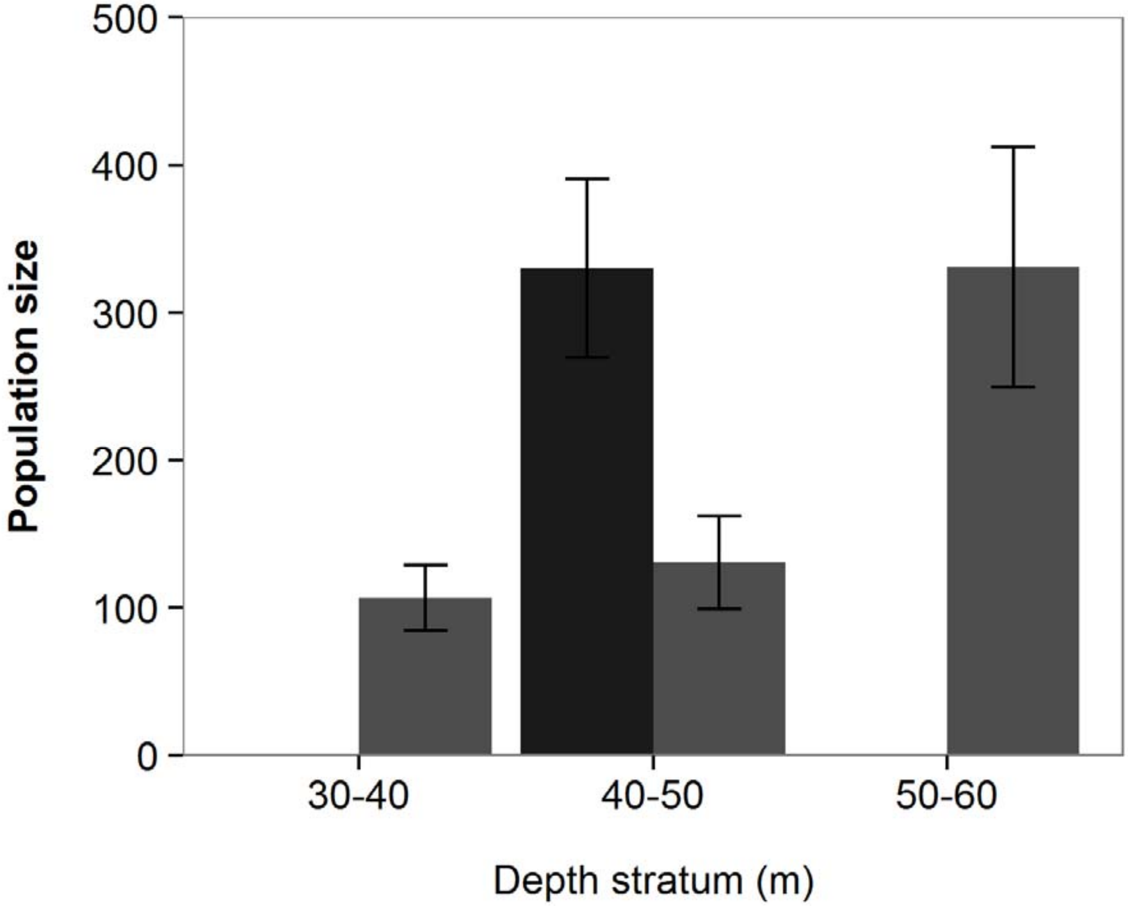

Figure 4. Average population size (± standard error of the mean, SE) of white abalone (*Haliotis sorenseni*) across three depth strata at San Clemente Island in 2004 (black bars) and 2012 (grey bars).

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