Estimation of population size of the black abalone, *Haliotis cracherodii*, on San Clemente Island

Peter Raimondi
Department of Ecology and Evolutionary Biology
Long Marine Laboratory
100 Shaffer Road
Santa Cruz, CA 95060
raimondi@ucsc.edu

Dan Orr [1]
Nate Fletcher [1]
Melissa Redfield [1]
David Lohse[1]
Melissa Miner[1]
Maya George[1]
Rani Gaddam[1]
Jack Engle[2]
Steven Lee[3]
Stephen Whitaker[4]

1. University of California, Santa Cruz
2. University of California, Santa Barbara
3. University of California, Los Angeles
4. U.S. National Park Service

Estimation of population size of the black abalone, *Haliotis cracherodii*, on San Clemente Island

Background

Massive and sudden declines of *dominant* species in ecological communities can fundamentally alter the composition and structure of these natural assemblages. Disease and overharvesting are two increasingly important factors responsible for mass mortalities of species across the globe (Harvell et al. 1999; Jackson et al. 2001; Harvell et al. 2002). Predicting the recovery of these valuable species is difficult, however, because it requires a convergence of specific conditions, including high reproductive success, favorable conditions for recruitment, and availability of appropriate habitat for settling juveniles. Recovery may be inhibited by multiple factors following declines, such as shifts in habitat structure, reduced reproductive success, and the continued presence of the initial perturbation. These combined forces may act against the recovery of a species in decline, resulting in a failure not only of the species but also the ecological community that relies on the species. Often the only successful way to recover the species and ecological community is through intervention and restoration.

Recovery of a species from massive decline requires successful recruitment of new individuals into areas where local populations were impacted. Recruitment is dependent on both an available supply of new individuals and specific environmental conditions required to induce settlement. Ironically, successful recruitment is often dependent on the presence of healthy, conspecific adult populations for several reasons. First, adults may attract recruits to an area simply by their presence or by release of a chemical cue that induces settlement (e.g. Minchinton 1997). Conspecific settlement cues are particularly prevalent in marine invertebrates with larval dispersal, but conspecific attraction is also an important mechanism affecting the recruitment of many animals (e.g. reptiles, Stamps 1988; mammals, Smith & Peacock 1990; spiders, Schuck-Paim & Alonso 2001; birds, Ward & Schlossberg 2004). Second, dispersal of progeny away from adults may be limited due to geographic or hydrological barriers, or lack of motility in the dispersal stage. Finally, adults may actively maintain suitable habitat for juveniles to settle in, and thus recruits with limited dispersal are more likely to encounter appropriate habitat. Consequently, when adults decline or disappear from an area, there may no longer be an adequate supply of suitable habitat into which juveniles can recruit. This scenario unfortunately applies to the once dominant black abalone *Haliotis cracherodii,* which was once the largest and arguably most important herbivore in intertidal systems along the California coastline.

(Note, except as noted, much of the following information on life history is derived from the status review by VanBlaricom et al. 2009)

The vertical distribution of black abalone is generally from the low to mid intertidal zone (as measured by species assemblage and not by tidal height) to the very shallow subtidal. Most individuals are found in the low to mid intertidal zone. Except when populations are very dense and otters are absent, the majority of individuals live in cracks or crevices in rocks or boulder fields. Although not much is known about the requirements of newly recruited black abalone, juveniles (5-30mm) are found in habitat similar to adults and appear to have an affinity for encrusting coralline algae (Raimondi pers. obs.). There are reports of high densities of recruits found in association with adult invertebrates and under cobble and boulders, always associated

with encrusting coralline red algae (Douros, pers. obs). Black abalone have separate sexes and reproduction is by broadcast spawning. It is thought that the high density of adults residing in cracks or crevices facilitates fertilization during mass spawning events. Based on other abalone species and very limited information for black abalone it is thought that post-fertilization, zygotes and later, the planktotrophic (non-feeding) larvae are negatively buoyant and tend to sink, thus restricting dispersal. Hence, despite a potential larval period of ~10 days, effective dispersal may be very limited (typically less than 3 kilometers and often much less, VanBlaricom et al. 2009, McShane 1992). These two life history features (adult) density dependent reproduction along with limited dispersal lead to a prediction of very slow recovery following a population crash, particularly for isolated populations such as occur on islands. Recruitment is suppressed when adult density drops below 1 per meter sq. (Miner et al. 2006). This could be due to two mechanisms. First, as described above, fertilization is dependent on adult density. Second, appropriate habitat for settlement of new recruits is maintained by adults through grazing.

Sexual maturity occurs at around 40-50 mm (maximum length of shell), which is an age of between 2 and 4 years. First year growth is about 20 mm and subsequent growth rates are about 1 mm per month until individuals reach 120-140 mm , after which the rate decreases. Size may be limited and shape modified by constraints of the crack an individual is in. There is no quantitative information concerning the maximum age attained by black abalone, but based on the maximum sizes found in UCSC (University of California, Santa Cruz) coastal surveys (~200 mm) it is likely that individuals >20 years old occur commonly. Females brood unfertilized eggs until a spawning event and egg mass (and therefore number) increases volumetrically with adult size producing a non-linear increase in egg number with increasing female size. There is some evidence that egg quality may decline in older individuals (for red abalone see Rogers - Bennett et al. 2004).

The published range for black abalone suggests that it once ranged as far north as Coos Bay Oregon (Cox 1982), but it is important to note that recent surveys show populations in the United States ranging from the Mexican border to Mendocino Co., CA. Population size north of San Francisco is very small (Raimondi, unpublished data) and it unclear whether there were ever large populations in the north because there is scant historic or current information from that region. Most black abalone along the mainland coast up to Point Conception were lost via legal harvesting and poaching prior to 1980, however large populations still persisted on the Channel Islands and along the mainland north of Point Conception through 1990. Since the mid-1980s black abalone have experienced mass mortalities due to infection by a pathogen that leads to a fatal wasting disease called “withering syndrome”(WS). In animals with this disease, the foot of the abalone shrinks until it can no longer adhere to the substratum. The first massive die-offs due to withering syndrome occurred on the Channel Islands in 1986, and by 1992 the disease was observed by UCSC researchers lead by Pete Raimondi near Point Conception on the mainland. The progression of the disease up the mainland seems to be associated with El Nino events, possibly due to warming of nearshore waters (Miner et al. 2006). Prior to the disease, densities north of Point Conception on the mainland and on the Channel Islands were as high as 120 per m^2 on the Islands and 40 per m^2 on the mainland north of Point Conception (Douros 1985, Miner et al. 2006).

UCSC currently samples abalone populations (PISCO (Partnership for Interdisciplinary Study of Coastal Oceans), BOEMRE (Bureau of Ocean Energy Management, Regulation and Enforcement) and MBNMS (Monterey Bay National Marine Sanctuary), Sea Grant funding) at >40 locations from Point Conception to Bodega Bay. In 2001 UCSC reported the pattern of mass mortality of the black abalone along the west coast. The general pattern of mortality once die-offs start is that within a few months to a year the population will decrease >90%, but a few remnant individuals will remain healthy and persist. Since the early 1990's the disease has migrated sequentially northwards along the coast of California. By 2001 the documented northward spread of population crashes due to withering syndrome extended to the southern boundary of the MBNMS. The mortality was so extraordinary and the population was so reduced that the species has been listed as endangered under the Federal Endangered Species Act in 2009.

Previous black abalone monitoring on San Clemente Island (SCI)

The first records relating to black abalone abundance on SCI come from the California Department of Fish and Game (CDF&G) data on commercial landings. The total take in the decades of the 1970's, 1980's and 1990's was >500, >250 and <5 metric tons, respectively. The first quantitative fisheries independent sampling of black abalone was also done by CDF&G between 1988-1993 (CFDG 1993). During this period populations went from healthy and unaffected by WS to very depleted (<1 per meter sq.). This value <1 per meter square is a very important metric as reproduction appears not to occur at levels lower than this (Miner et al 2006). Tierra Data Inc. was contracted by the Navy to assess the population size of black abalone on SCI and in 2008 researchers surveyed 61 locations, mainly on the SE shore, and found a total of ten black abalone. It is noteworthy that all abalone found were adults (100-130 mm), because recovery of populations of black abalone throughout the range affected by WS has been impeded by the lack of recruitment of new individuals. Our lab at UCSC has determined that the lack of recruitment following loss of adults from WS is due to at least one of the following mechanisms: (1) impaired reproduction due to loss of fertilization during broadcast spawning events. This is due to low densities of local adults and the very low dispersal of abalone larvae (*note that this mechanism also provides a restoration possibility- by means of manually aggregating individuals*). (2) continued presence of the disease and (3) a change in the rest of the community (algae and invertebrates - *this mechanism also provides a restoration possibility*). This is due to the loss of large populations of grazing abalone, which fundamentally altered the biogenic substrates that formerly induced recruitment of larval black abalone. The key insight from this assessment is that restoration of stable populations of black abalone relies on an understanding of the mechanisms that currently preclude recovery. In response to this insight we developed the protocols applied at SCI.

Proposed sampling approach for UCSC surveys on SCI (note - These were the methods proposed. Methods were revised as described below in response to Navy concerns about spatial coverage of surveys)

General Methodology – consistent with previous sampling at mainland sites

At UCSC abalone sampling sites we will establish an along-shore transect centered on a focal location. We will establish sampling areas (10 meters wide) at 10, 100 and 1000 meters up and

down coast from the focal location. These areas will be in the tidal range of black abalone but will not be moved to match likely abalone habitat except that we will not place sampling areas on sandy locations (explained later). We will sample each area for black abalone, according to Multi Agency Rocky Intertidal Network (MARINe) methods (see www.marine.gov). These methods are described briefly below.

Abalone shell lengths are measured with calipers or a ruler to the nearest 5 mm for animals <40 mm and the nearest 10 mm for larger abalone. Each abalone is temporarily marked with a yellow forestry crayon to avoid duplication. This assumes permits are in place ESA section 10 research permits), which allows such marking, otherwise mark the rock near to the animal). Sometimes it is necessary to estimate lengths for abalone lodged deeply in cracks or otherwise inaccessible. Abalone are never removed from the rock. Observers must refine their search image to locate abalone in deep or narrow crevices. Use a waterproof flashlight if necessary to see into dark areas. It helps to look through the plot from different angles of view. It is good practice to have a second scorer search the plot for abalone possibly missed by the first scorer. If possible, photograph each abalone plot to document the species assemblage and appearance.

If no abalone are found in the spatial search then the Timed Search Protocol should be implemented. The purpose of timed searches is to document absence/rarity or to recognize a population increase in the future so that monitoring in replicated plots can be instituted. This method is primarily qualitative (indicating levels of abundance) because time limitations prevent a thorough search of the entire site and low tide/swell conditions affect the lower boundary accessible for searching. To survey (around the time of low tide), one person spends 30 min (or 2 persons 15 min each) searching appropriate abalone/seastar habitats (e.g., crevices and pools) along the low intertidal zone throughout the defined site (between upcoast and downcoast boundaries) for black abalone. Numbers encountered and size measurements are recorded.

Species characterization will be conducted in abalone plots at the same time as searches are conducted. Here, (following Miner et al 2006) the algal and invertebrate species attached to the rocky substrate will be sampled. Any species not identifiable in the field should be vouchered using MARINe protocols for later identification.

The UCSC protocol allows for the following:

1) The sampling uses spatial coverage as well as time as the key design attribute. Each site will be assessed for area and thoroughly searched regardless of the time needed. This allows an accurate estimate of the density of abalone per meter square.
2) Each site will be assessed for abalone (size and number) and species assemblage (invertebrates and algae). If algal or invertebrate species cannot be resolved in the field, we will voucher them for later identification in the lab. We will emphasize both adult and recruitment habitats (which may differ). Importantly, the UCSC team has considerable experience sampling very small individuals (recruits) that are often cryptic.

We will also characterize the quality of each area with respect to appropriateness for potential abalone occupation. This characterization is based on over 15 years of field sampling of black abalone. The categories are:

1) habitat very suitable for abalone occupation (Good).
2) habitat moderately suitable for abalone occupation (Moderate).
3) habitat minimally suitable for abalone occupation (Poor).

Suitable habitats are cracks, crevices and overhangs that constitute the typical locations in which abalone are found. The overall goal of the habitat characterization is to determine the amount of suitable habitat for abalone that exists in the species' range of ecological viability. Current coastal geology maps allow discrimination between sand and rock, but not among geomorphologies within rocky shores. Hence, there is no point in sampling sandy areas since we can account for sand using coastal maps, but we have to differentiate among rocky areas based on habitat suitability. The data collected will be used together with the overall estimate of amount of habitat in each of the 3 suitability categories. For example, if 10 % of rocky habitat is in category 1 and there are 15 linear km of rocky habitat in the region of interest, then ~1.5 km of coastline has habitat considered "good" for abalone occupation. The information collected above will be georeferenced and added to the existing UCSC GIS databases.

Deviations from proposed approach in response to Navy concerns

Previous monitoring efforts have been limited in the amount of available habitat searched. In order to allow for a more complete spatial coverage of SCI, Navy biologists requested a modification to the proposed methodology. Modifications were made to allow for more rapid, spatially expansive surveys. Instead of delineating defined segment lengths we took GPS coordinates at a starting point and searched for abalone until an appropriate ending point occurred (e.g. change of exposure, rock type, a large area of habitat not suitable for black abalone). GPS coordinates were taken at the end of each segment to allow for an estimate of total linear distance sampled along the coastline. We also estimated the average width of the searched area (habitat) from onshore to offshore, which, in combination with the linear distance estimates, allowed for a rough calculation of total area sampled for each segment. Upon completion of a segment, estimates were made to determine the percent of the total area that was good, moderate and poor habitat. We also estimated the percent of the habitat where biological modifications might necessitate an adjustment to a "good" or "moderate" category (e.g. crevice filled with urchins or tube worms). Habitat estimates were based on reflection of the area just searched and agreed upon by discussion among samplers. Pan type photos were taken at the beginning and end of each segment and the time at the beginning and end of searching within each segment was noted. For each abalone found, we recorded the size, habitat (good, moderate, poor), and GPS location and a photograph was taken. We also made efforts to relocate abalone found in previous surveys.

It is very important to note that because of the departure from the standard protocols in order to sample larger areas it was not possible to utilize the extensive effort that we normally make during plot searches and for habitat characterization.

Survey Questons

1) *What is the population size of black abalone on SCI and do densities vary as a function of habitat quality?*
2) *What is the average size of black abalone on SCI and does it differ as a function of habitat quality?*

Analytical Approach - What is the population size of black abalone on SCI and do densities vary as a function of habitat quality?

We used a habitat specific approach to estimate the population size for black abalone on SCI. The basic idea was to:

1) Estimate the amount of rocky habitat on SCI (R)
2) Estimate the proportion of habitat on SCI that was considered of good, moderate or poor quality for black abalone (P_i), where i = good, moderate or poor.
3) Estimate the density of black abalone associated with each type of habitat (D_i)
4) Calculate the sum of the products of the terms above

$$\sum_{1}^{n} RP_iD_i \qquad (1)$$

5) Calculate confidence limits for the estimate of population size

Each component will be discussed separately below.

Estimation of the amount of rocky habitat on SCI (R) (Figure 1 and digital appendix). We used two GIS layers to determine the spatial extent of rocky shoreline at SCI. One was from the Environmental Sensitivity Analysis layer (ESI), the other from the US Navy layer (USN) provided to us. The ESI layer used divided the shoreline into three substrate types: rocky shores, hardened structures and beaches. The USN layer divided the shoreline into three types: rock, boulders and sand. The linear extent of each type of substrate was calculated for each data layer using ARCGIS.

Estimation of the proportion of habitat on SCI that was considered of good, moderate or poor quality for black abalone (P_i) (see digital appendix). These data were collected in the field during field surveys. Each section surveyed was divided into the proportion of substrate that had:

1) habitat very suitable for abalone occupation (Good).
2) habitat moderately suitable for abalone occupation (Moderate).
3) habitat minimally suitable for abalone occupation (Poor).

These values were estimated from UCSC field technicians, who made the assessments based on their extensive background with black abalone monitoring and the standard quantitative methodology for assessment of habitat. We intended to use the standard methodology on SCI, but based on a Navy concern that we provide greater spatial coverage of SCI surveys, we modified the protocols in the field and utilized expert estimates rather than the more time-consuming quantitative approach. *We recommend a follow-up project to do quantitative habitat*

assessment to make the monitoring on SCI consistent with previous black abalone population and habitat assessments we have conducted for National Marine Fisheries Service (NMFS). The categorization of each section was included as a layer in the UCSC GIS project.

Estimate the density of black abalone associated with each type of habitat (D_i) (Figure 1 and digital appendix). Black abalone were searched for in each sample section. When one was found, it was measured and GPS coordinates were recorded. Later, the data were incorporated into an excel table that expressed density as the number per linear meter of shoreline (by section). In addition, the location of each individual was included as a layer in the UCSC GIS project.

Calculate the sum of the products of the terms above (see equation 1). We used both estimates (ESI and Navy) for the linear extent of rocky habitat. For the estimate based on the Navy GIS layer we combined boulders and rock. This represents the maximum amount of rocky intertidal habitat on the island. *The consideration of boulders as rocky habitat suitable for black abalone should be validated in the field*. We calculated the product of the linear extent of rocky habitat and proportion of rocky habitat that was of good, moderate or poor quality to produce the linear extent of each habitat quality category. These were then multiplied by the density of abalone per linear meter for each habitat quality category yielding the number of abalone for each habitat quality category. The sum of these terms was the most likely number of black abalone on SCI at the time of sampling.

Calculate confidence limits for the estimate of population size. The term in equation 1 that had estimable error was proportion of area that was of good, moderate or poor quality. As shown below, disproportionately more abalone were found in good habitat than in moderate and none were found in poor habitat. Hence, error in estimates of the proportions of these quality categories could have profound effects on the estimate of total population size for SCI. We used resampling methodology for these habitat categories to estimate confidence limits for estimates of population size. The value for good and moderate proportion of habitat for each sample section was resampled, yielding a probability distribution for the average proportion of each habitat quality for SCI. Each value in the probability distribution was used sequentially in Equation 1, producing a probability distribution of population sizes. The covariance structure between good and moderate habitat quality indicated that they were independent and were treated as such in the resampling procedure.

Results

Spatial results – we surveyed 120 sections of rocky coastline for a linear extent of 10.8 kilometers, which represents between 13.6 and 20.7 percent of the total rocky coastline of SCI (the two values represent the difference between the ESI and Navy GIS layers). The locations of the sections are shown in Figure 2. Section length ranged from 10 – 555 meters, with an average of 118 meters. All suitable habitat was searched in each section. A total of 20 abalone were found in the 2011 survey (Figure 3).

Question 1: What is the population size of black abalone on SCI and do densities vary as a function of habitat quality (Figure 4)? The most likely point estimate of the number of black abalone on SCI is 187. Much more importantly, the 90% confidence interval for the population

size is between 91 and 344.

The relationship between habitat quality and abalone number is shown in Figure 5. Abalone numbers were disproportionately higher in good habitat than in moderate or poor. Moderate habitat had disproportionately more abalone than poor (which had no abalone).

Question 2: What is the average size of black abalone on SCI and does it differ as a function of habitat quality? The average size of the 20 black abalone found in 2011 was ~ 119.5 mm, essentially the same as for the 10 abalone found by Tierra Data in 2008 (117.4 mm). Individuals were significantly larger in moderate habitat than in good habitat (Figure 6). Importantly, no individual smaller than 80 mm was found in the 2011 UCSC surveys.

UPDATE as of May 24, 2012
Surveys at San Clemente Island and to date, as part of other tasks, we have found an additional 27 abalone (47 to date). This number coupled with the additional search effort is consistent with the predicted number of black abalone for the island.

Recommendations related to the need to understand (1) condition, extent and geography of essential habitat on SCI, and (2) restoration approaches appropriate for SCI.

1) **Condition of essential habitat**. We know from our other studies conducted by UCSC that areas having the geomorphological attributes of good black abalone habitat (e.g. deep cracks or crevices) can be compromised by "fouling" organisms such as algae, sponges, tunicates and barnacles. Extensive colonization by these organisms dramatically decreases the utility of the rock surfaces for recruitment of black abalone. We have found that the key to sustaining habitat quality is the presence of adult black abalone, as their activities lead to rock surfaces that are either bare or covered with crustose coralline red algae, which is likely to induce settlement of black abalone larvae.

   A survey should be done to assess the condition of habitat on SCI based on the information presented above. Specifically, a comparison should be made between locations with and without adult abalone to assess the condition of habitat on SCI so as to determine if habitat condition may be contributing to lack of recruitment on the island. To do this we propose to find all abalone found in the 2011 surveys and additional animals found in earlier surveys, not found in the 2011 surveys. The location of each of these individuals will be paired with a nearby location that is similar in every way (tidal height, geomorphology) except having no extant abalone. In each location (with and without black abalone) the condition of the habitat will be assessed as described in Miner et al 2006. Essentially this means a quantitative assessment of the degree of fouling of rock surfaces. The results for locations with and without abalone will be compared to determine whether differences in habitat quality currently exist on SCI. Results from the habitat survey will also be compared to data we have for areas with substantial black abalone populations to determine the degree of match (or mismatch) to locations that support healthy black abalone populations and recruitment.

2) **Extent and geography of essential habitat**. As noted, a detailed habitat characterization was not completed based on a decision to sample more area for the presence of black abalone. Because proposed protocols were modified to ensure that we would get a good estimate of population size we really do not have a good estimate of the distribution of habitats on SCI. This means that there is no ability to accurately assess the percent of area that is of "good" or "moderate" quality for black abalone. More importantly we don't have any way of doing this assessment in a spatial context, which would allow us to create a GIS layer depicting the spatial distribution of habitats for SCI. This limitation should be rectified as soon as possible as it is essential for understanding the geography of habitats critical to the recovery of the species on SCI. The sampling should follow the protocols laid out in the proposal, which have been used in other black abalone habitat assessments along the coast.

3) **Restoration approaches**. Finally, we recommend using the information collected already in conjunction with that coming from the recommendations above and previous work done on black abalone to develop a restoration proposal for black abalone on SCI. This would be a tiered approach that would have the following steps. (1) Identify those areas that are required for necessary Navy activities that would be deemed incompatible with habitat areas that are essential to black abalone. (2) Identify from the rest of the

coastal areas on SCI those areas that have substantial amounts of good and moderate habitats. (3) Propose a restoration program that would be tiered in terms of effort. All proposed actions rely on the constraints and opportunities provided by the life history of the species (see text above for more detail). These key characteristics include: (1) limited mobility of adults, which is a constraint in the sense that adult movement will not lead to population replenishment, however it is an opportunity in that transplanted individuals are unlikely to move much; (2) animals are separate sexes; (3) reproduction is by broadcast spawning; and (4) larvae likely have limited dispersal.

Tier 1: habitat restoration. Abalone need clean cracks and crevices to recruit to. One major problem with low population size is that the grazing activities of abalone are reduced, which allows for accumulation of algae and invertebrates in the prime cracks and crevices. One relatively straight forward approach is to clean these areas and determine if natural recruitment will occur and allow replenishment of the population.

Tier 2: Local aggregation of adults. Another consequence of low population size is that probability of successful reproduction is reduced dramatically. Black abalone have separate sexes and broadcast spawn (meaning they release sperm and eggs in the water column). Typically, individuals are aggregated and gamete release is cued by a hormone, so that when there is gamete release there is massive release and thus very high potential for fertilization. When individuals are not aggregated, fertilization is virtually impossible. One potential restoration approach is to aggregate existing individuals in good habitats (cracks that have had fouling organisms removed). This should yield greater reproduction and since it is likely that most dispersal of larvae is local (often within 100's of meters), the larvae are likely to settle in the local habitat and thus replenish the local population.

Tier 3: Combine Tiers 1 and 2 but bring in adults from other healthy populations that exist along the central coast of California. This approach has the advantage of (1) bringing in younger individuals that may not be as susceptible to transplant shock as adults and (2) bringing in many more individuals from the donor population than could be aggregated from existing SCI populations. There is one possible drawback to this model: mixing genetic stocks (although initial genetic analysis suggests that there is not substantial population structure in California.

Appendix 1: Experience of Raimondi Lab at UCSC with respect to black abalone monitoring.

Our lab at UCSC has been monitoring black abalone populations for nearly 20 years and has been the main group characterizing black abalone populations on the mainland of California and Mexico. Most of this work has been in response to the massive declines in the population of black abalone due mainly to WS. In addition, we have been assessing the recruitment of new individuals and the biogenic habitats required for successful recruitment (e.g. coralline algae). See:
http://www.marine.gov/IndexArticles/2009_AbHabitat.pdf
http://www.marine.gov/IndexArticles/Abalone/BlackAbalone.pdf
http://www.marine.gov/Findings.html

More recently (since 2005), we have worked extensively with the National Marine Fisheries Service (NMFS) to develop protocols to estimate population size of black abalone and assess habitat characteristics critical to black abalone populations *(Estimation of the amount of suitable habitat and population size of black abalone within their current region of ecological viability).* This work has led to the first population estimates for the central coast of CA and the first characterization of critical habitat for the species. Currently, we are carrying out a similar study for the NMFS for areas near to and north of San Francisco (*Estimation of the amount of suitable habitat and population size of black abalone in the North-Central coastal region of California (Ano Nuevo – Point Arena).* These projects (specifically related to black abalone) include the aforementioned work on population abundance and habitat characterization for NMFS along with a series of projects that assessed:

1) The temporal pattern of abundance and size structure of black abalone along the coast of California, including an assessment of recruitment (Raimondi et al. 2002, Ambrose et al. 1996)
2) The spatial and temporal pattern of the impact of withering disease on black abalone populations (George et al. 2009, Raimondi et al. 2002, Ambrose et al. 1996)
3) The genetic structure of black abalone with particular emphasis on the comparison of diseased vs non-diseased populations
4) The effect of the loss of black abalone on the other members of the community including algal and invertebrate species. (Miner et al. 2006)

In addition to the work specific to black abalone, our lab has been assessing coastal community dynamics and biodiversity for the last 20 years and is widely recognized as one of the few field teams able to perform detailed and accurate species identification in the field for rocky intertidal systems.

References

Ambrose, R.A., Altstatt J.A., Raimondi, P.T., Lafferty, K.D. and Engel, J. 1996. Recent declines in black abalone Haliotis cracherodii in the mainland coast of central California. MEPS 142: 185-192.

California Department of Fish and Game (CDFG). 1993. Field reports for San Clemente Island black abalone sites (1988-1993). Prepared by the CDFG Marine Resources

Division, Marine Invertebrates Project, Long Beach, California. Cox KW (1962) California abalones, family Haliotidae. California Fish and Game Bulletin 118:1-133

Douros WJ (1985) Density, growth, reproduction and recruitment in an intertidal abalone: effects of intraspecific competition and prehistoric predation. MA, University of California Santa Barbara

George, M., C. Bell. K. Ammann, and P Raimondi. 2009. Assessing the amount of suitable habitat and the population size of black abalone from Half Moon Bay to Point Conception. Monterey Bay National Marine Sanctuary symposium.

Harvell, C. D., K. Kim, J. M. Burkholder, R. R. Colwell, P. R. Epstein, D. J. Grimes, E. E. Hofmann, E. K. Lipp, A. Osterhaus, R. M. Overstreet, J. W. Porter, G. W. Smith, and G. R. Vasta. 1999. Review: Marine ecology - Emerging marine diseases - Climate links and anthropogenic factors. Science **285**:1505-1510.

Harvell, C. D., C. E. Mitchell, J. R. Ward, S. Altizer, A. P. Dobson, R. S. Ostfeld, and M. D. Samuel. 2002. Ecology - Climate warming and disease risks for terrestrial and marine biota. Science **296**:2158-2162.

Jackson, J. B. C., M. X. Kirby, W. H. Berger, K. A. Bjorndal, L. W. Botsford, B. J. Bourque, R. H. Bradbury, R. Cooke, J. Erlandson, J. A. Estes, T. P. Hughes, S. Kidwell, C. B. Lange, H. S. Lenihan, J. M. Pandolfi, C. H. Peterson, R. S. Steneck, M. J. Tegner, and R. R. Warner. 2001. Historical overfishing and the recent collapse of coastal ecosystems. Science **293**:629-638.

McShane PE (1992) Early life history of abalone: a review. In: Shepherd SA, Tegner MJ, Guzmán del Próo SA (eds) Abalone of the world: biology, fisheries, and culture. Proceedings of the 1st international symposium on abalone. Blackwell Scientific Publications, Inc., Cambridge, p 120-137

Minchinton, T. E. 1997. Life on the edge: Conspecific attraction and recruitment of populations to disturbed habitats. Oecologia **111**:45-52.

Miner, C. M., J. M. Altstatt, P. T. Raimondi, and T. E. Minchinton. 2006. Recruitment failure and shifts in community structure following mass mortality limit recovery prospects of black abalone. Marine Ecology-Progress Series **327**:107-117.

Miner, C.M., J.M. Altstatt, P.T. Raimondi, T.E. Minchinton. 2006. Recruitment failure and shifts in community structure following mass mortality of black abalone limit its prospects for recovery. Marine Ecology Progress Series 327:107-117.

Raimondi, P.T., Wilson, C.M., Ambrose, R.F., Engel, J.M., and Minchinton, T.E. 2002. El Niño and the continued declines of black abalone along the coast of California. Marine Ecology Progress Series 242:143-152

Rogers-Bennett, L., R. F. Dondanville, and J. Kashiwada. 2004. Size specific fecundity of red abalone (Haliotis rufescens): Evidence for reproductive senescence? Journal of Shellfish Research **23**:553-560.

Schuck-Paim, C. and W. J. Alonso. 2001. Deciding where to settle: conspecific attraction and web site selection in the orb-web spider Nephilengys cruentata. Animal Behaviour **62**:1007-1012.

Smith, A. T. and M. M. Peacock. 1990. Conspecific attraction and the determination of metapopulation colonization rates. Conservation Biology **4**:320-323.

Stamps, J. A. 1988. Conspecific attraction and aggregation in territorial species. American Naturalist **131**:329-347.

VanBlaricom, G., M Neuman, J Butler, A DeVogelaere, R Gustafson, C Mobley, D Richards, S Rumsey, and Barbara Taylor. 2009. Status Review Report for Black Abalone (*Haliotis cracherodii* Leach, 1814). NMFS Southwest Region.

Ward, M. P. and S. Schlossberg. 2004. Conspecific attraction and the conservation of territorial songbirds. Conservation Biology **18**:519-525.

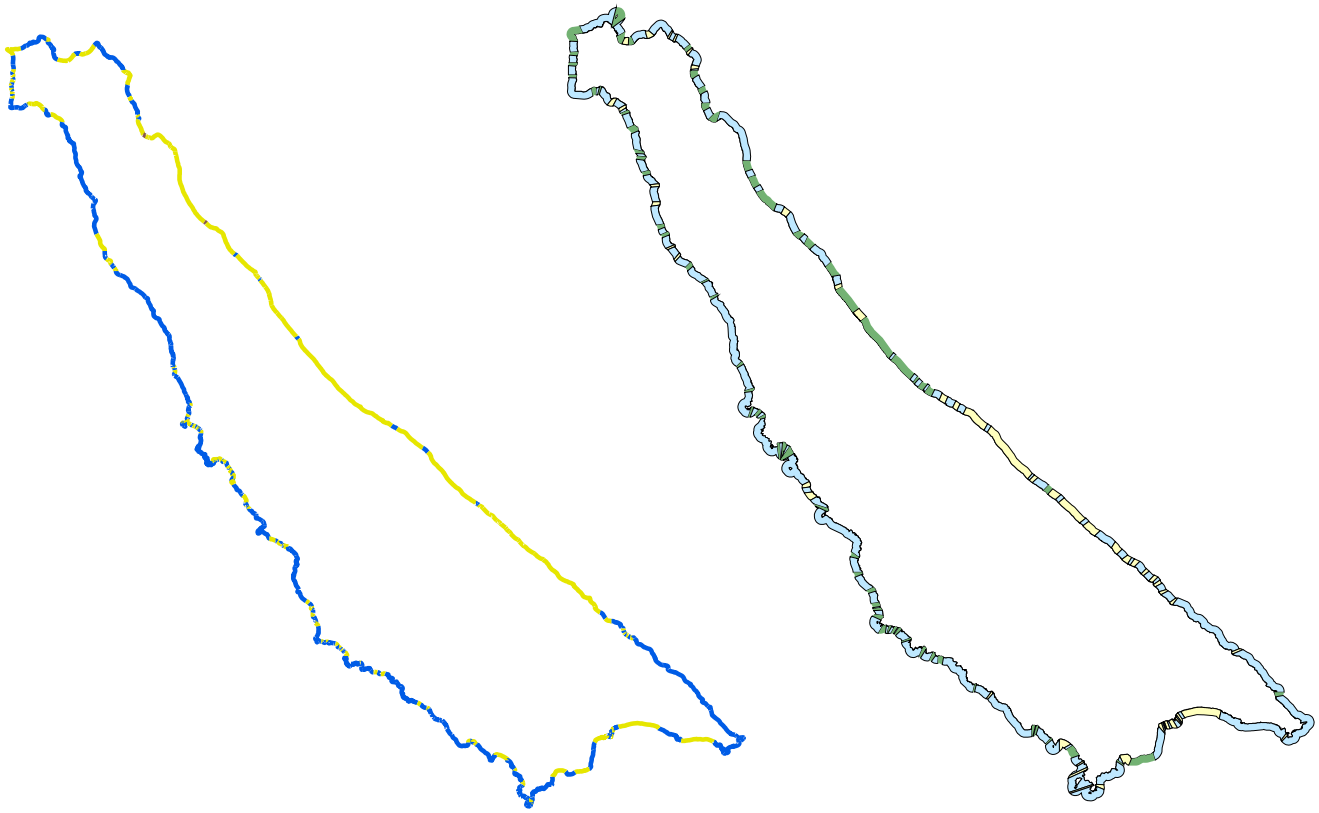


Figure 1: Left – ESI habitat layer: blue = rock, yellow = beach, hardened surfaces too rare to see. Right – Navy layer: blue = rock, green = boulders, yellow = sand.

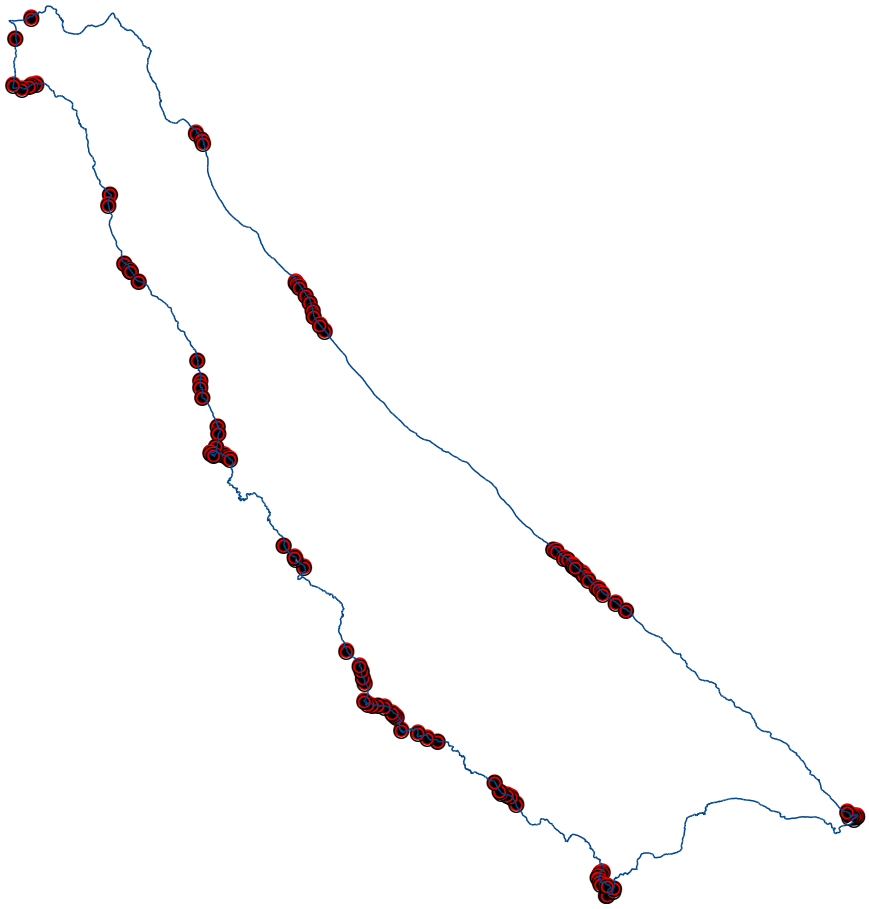


Figure 2: Locations of sections that were sampled in 2011. Only end points are shown for clarity.

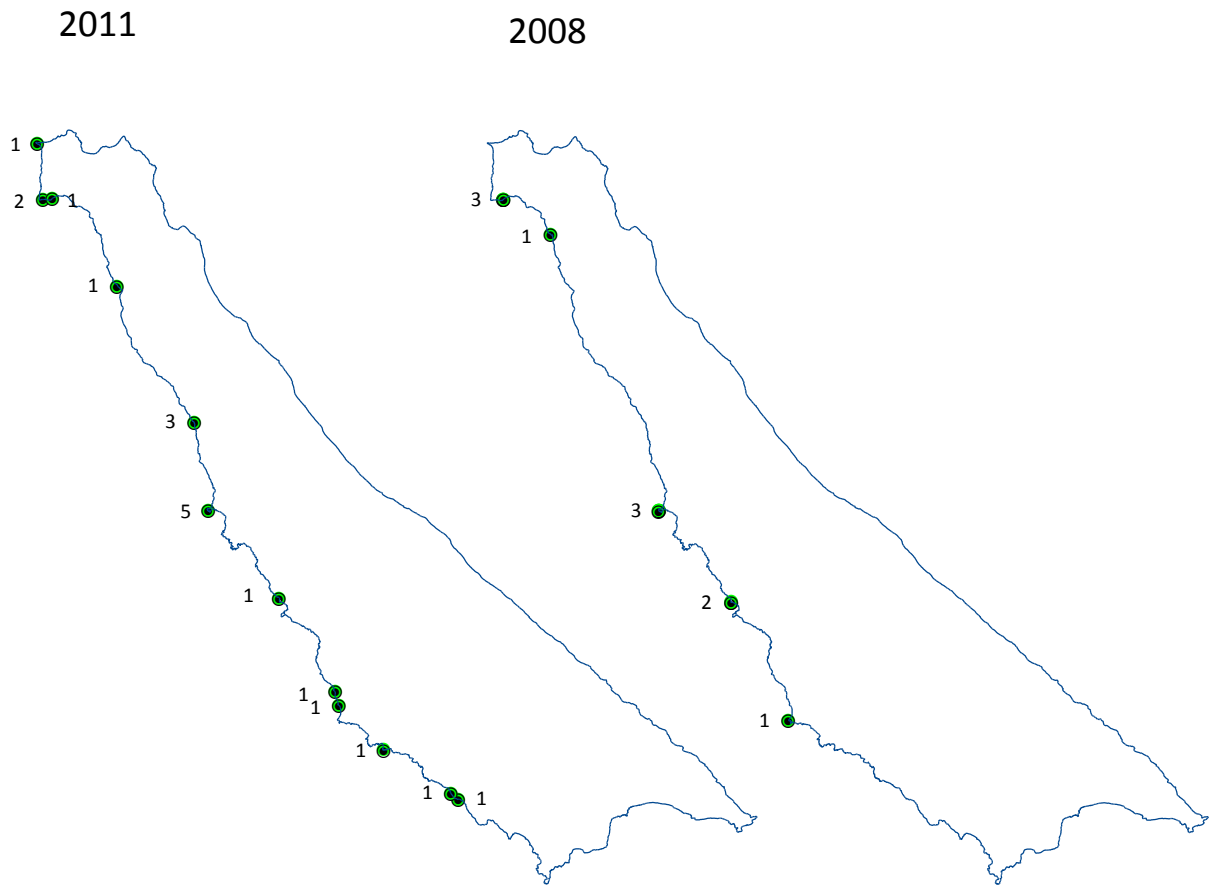


Figure 3: Locations of black abalone found in 2011 (current survey) and 2008 (Tierra Data). Numbers next to symbols indicate the number of individuals found in each location. *Note that continued surveys on the Island by UCSC have located an additional 27 black abalone (47 total).*

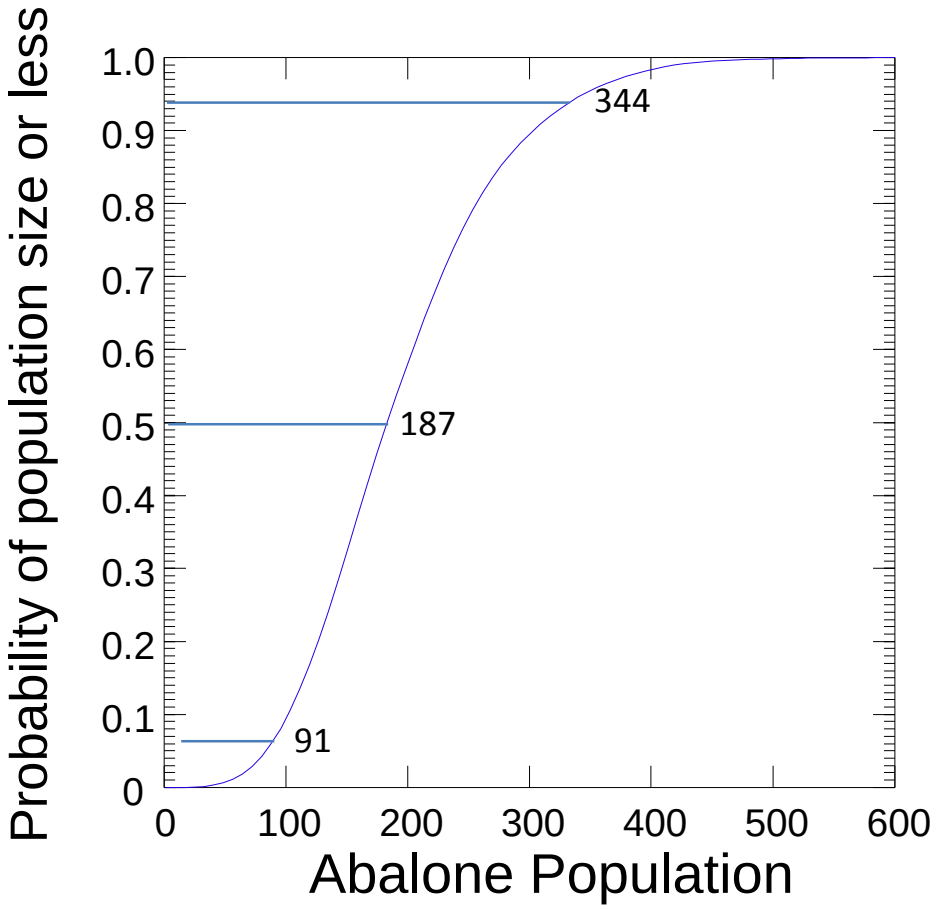


Figure 4: Cumulative probability distribution for abalone numbers on SCI at the time of the 2011 sampling. Each point on the curve shows the probability (y axis) that the actual population size is equal to or less than the number on the x axis.

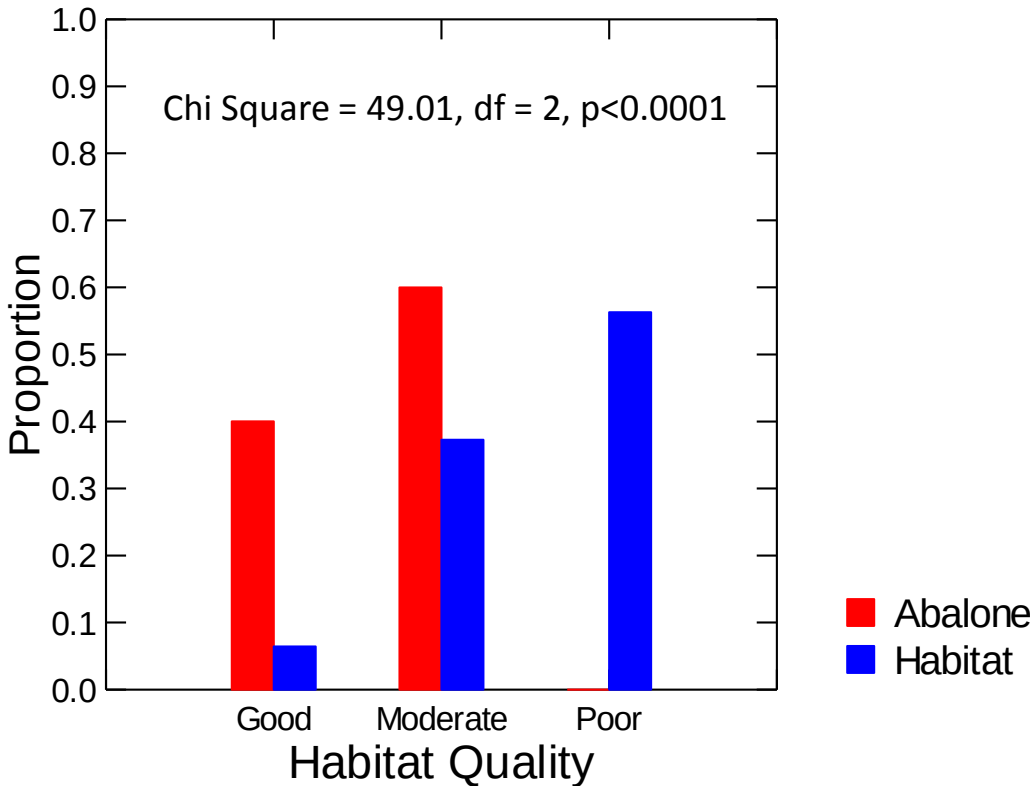


Figure 5: Results of a chi goodness of fit test comparing abalone number per habitat quality category and the proportion of that habitat at SCI. Abalone were 6.2 and 1.6 times more likely to occur in good or moderate quality habitats than would be expected based on the proportion of that habitat on the island.

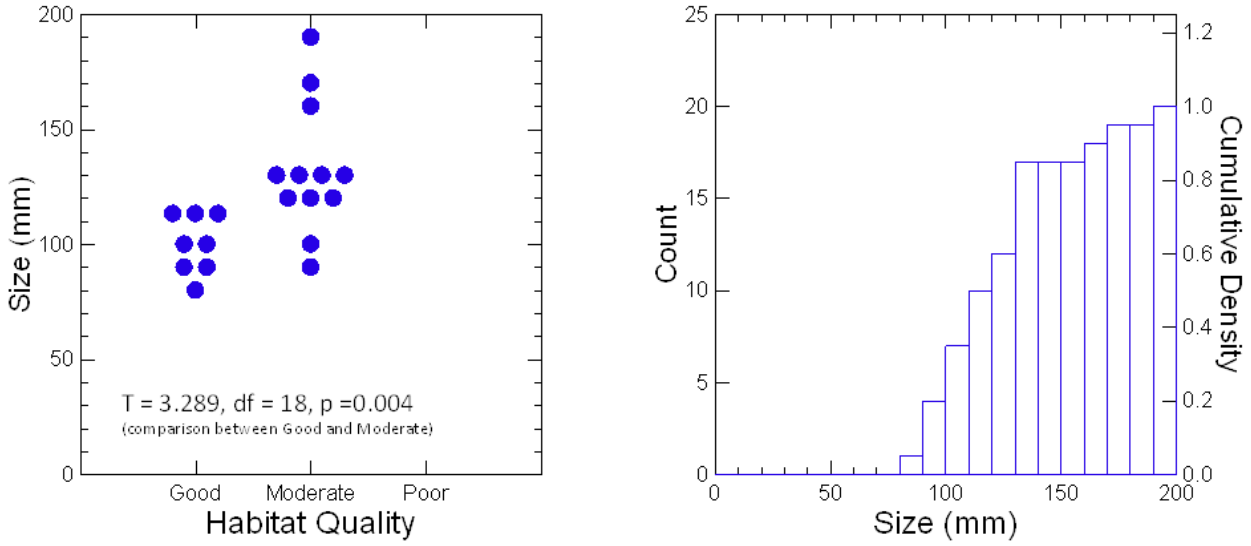


Figure 6: Left: dot histogram for size vs habitat quality. Mean size in good habitat was significantly smaller (98.7 mm) than in moderate habitat (133.3 mm). Right: cumulative frequency histogram for abalone size. Note that no individual smaller than 80 mm was found.