Pinto Abalone (*Haliotis kamtschatkana* Jonas 1845) Research and Monitoring Plan for Sitka Sound, Southeast Alaska, 2015–17

In partial fulfillment of Alaska Sea Grant project # R/100-03 "Coastal Resilience in Sitka Sound: Monitoring Pinto Abalone and Kelp Forests in a Changing Climate"

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Introduction

Commercial abalone fisheries worldwide (e.g., California, Washington, British Columbia, New Zealand, South Africa, Australia) are typified by a boom and bust pattern that has ultimately led to dramatic fishery reductions or closures (e.g., Karpov et al. 2000, Shepherd et al. 2001, McGarvey 2006), and near-extinction in at least one case (e.g., white abalone in California). The fate of the commercial fishery for pinto abalone (*Haliotis kamtschatkana*) in Alaska followed a similar pattern. Pinto abalone are the northernmost abalone species on the west coast of North America, and the only abalone species found in Alaska. Historically in Southeast Alaska, abalone have been found primarily in or near outer coastal environments that experience ocean swells, including Dixon Entrance and west sides of Baranof Island, Prince of Wales Island, and Dall Island (Figure 1). Within these areas, abalone live in rocky intertidal and shallow subtidal habitats, where they co-occur with kelps (Order Laminariales), a preferred food source. Pinto abalone were intensively harvested in the Alaska commercial fishery, with a peak catch between 1978 and 1981, followed by an 89% decline until the fishery was closed in 1996 due to low abundance (Woodby et al. 2000, McDougall et al. 2006). This boom and bust pattern was simultaneously mirrored in British Columbia, where all pinto abalone fisheries (commercial, recreational, subsistence) were closed in 1990. Commercial fishing was never allowed in Washington State, but a sharp decline in abundance prompted the state to close its recreational fishery in 1994.

Despite these fishery closures, pinto abalone have not recovered in any part of their geographic range, although there have been some signs of recent localized recovery in British Columbia and California (Lessard unpublished data (cited in Busch et al. 2014), Bird and Zacheri 2014). In Puget Sound and the San Juan Islands of Washington state, abalone populations have been and still are experiencing chronic recruitment failure (Bouma 2012). The recruitment failure in Washington state has been attributed to demographic Allee effects (i.e., population depensation due to low fertilization rates associated with low spawner density) (Rothaus et al. 2008). Fertilization success of greenlip abalone is reported to decrease significantly beyond a nearest-neighbor distance of 2.5 m between a spawning male and female (Babcock and Keesing 1999), and recruitment failures in multiple abalone species correlate with a critical density threshold in the range of 0.15 – 1 m^{-2} (e.g., Babcock and Keesing 1999, Miner et al. 2006). Poaching is also thought to be a contributing factor to the lack of recovery in Washington State (Rothaus et al. 2008), California, Baja California, and British Columbia (e.g., Vadopalas and Watson 2014, NOAA 2009, Zhang et al. 2007). The extent of poaching in Southeast Alaska is unknown, but is assumed to be minimal due to lack of easy access to black markets. However, this assumption may be tenuous because the coastline of Southeast Alaska is vast and largely uninhabited, enforcement resources are limited, and the southern part of the region is in close proximity to British Columbia, where poaching has been a known problem.

The most important factor thought by many to be hindering abalone recovery in Southeast Alaska is intensive predation by re-introduced sea otters (*Enhydra lutris*) (e.g., Woodby et al. 2000). Sea otter have made a spectacular comeback in Southeast Alaska (Esslinger and Bodkin 2009), growing from 402 transplanted individuals in the late 1960s (Pitcher 1989) to nearly 27,000 in 2013 (V. Gill, Wildlife Biologist, USFWS, personal communication). Sea otter recolonization can be characterized by an exponential increase in abundance coincident with geographic expansion from transplant locations to other outer coastal areas, as well as penetration into food-rich wave-protected waters, most notably Glacier Bay (Esslinger and Bodkin 2009). However, sea otter predation on pinto abalone does not directly explain why pinto abalone abundance has remained depressed in the eastern portion of the Dixon Entrance, where sea otters have not re-colonized to date (beyond anecdotal evidence for temporary forays by male "scouts"; S.Walker, Fishery Biologist, ADF&G, Ketchikan, personal communication). The Alaska Department of Fish and Game (ADF&G) permits harvest of pinto abalone in its personal use and subsistence fisheries, which are notably the only remaining open fisheries for the species in the United States and Canada, so recovery in this area may be or may have been inhibited by legal (and possibly illegal) human harvest. Until 2012, the bag limit for abalone was 50 per person per day, with no annual limit. The regulations were changed in 2012, when the bag limit was reduced by the Alaska Board of Fisheries to 5 per day. No reporting is required for these fisheries, and harvested quantities are assumed by ADF&G to be non-significant (K. Hebert, Fishery Biologist, ADF&G, Juneau, personal communication; S. Walker, Fishery Biologist, ADF&G, Ketchikan, personal communication). If human harvest and sea otter predation are indeed non-significant factors, then plausible hypotheses for lack of pinto abalone recovery in Southeast Alaska are more limited but may include demographic stochasticity at low population abundance and densities (Stephens et al. 1999), recruitment failure (e.g., Rothaus et al. 2008), biological microhabitat conversion (Miner et al. 2006), or individual- and/or population-level responses to natural environmental fluctuations (e.g., Pacific decadal oscillation) and climate change-related influences (e.g., ocean warming and acidification) (Rogers-Bennett 2007, Ben-Horin 2013).

The low population levels and lack of pinto abalone population recovery following fishing closures prompted changes in official designations by state and federal governments, as well as international non-governmental organizations. The species was listed as "Endangered" by the IUCN Red List of Endangered Species in 2006,"Endangered" in Canada since 2009, a "State Candidate Species" and "Species of Greatest Conservation Need" in Washington since 1998 (WDFW 2008), and a "Species of Concern" by the National Marine Fisheries Service since 2004 (NOAA 2004). The National Marine Fisheries Service recently conducted a status review of the pinto abalone (Busch et al. 2014) to determine if the status should be elevated to "Threatened" or "Endangered", but ultimately decided to retain the lesser "Species of Concern" designation, primarily because too little information existed to conclude that populations were at critically low levels. The State of Alaska does not have an official status designation for the species.

A major impediment to the investigation by the National Marine Fisheries Service's Status Review Team (Busch et al. 2014) of pinto abalone stock status in Alaska was a lack of baseline and current information. This problem was also noted by the International Union for the Conservation of Nature in their assessment of pinto abalone (McDougall 2006), which listed collection of fishery-independent datasets from index monitoring sites in Alaska as one of its top three recommended research priorities. Long-term monitoring programs in Washington State (Rothaus et al. 2008; M. Ulrich,WDF&W, personal communication) and British Columbia (reviewed in Busch et al. 2014), have tracked the absolute abalone density at index sites for over two decades, which has provided critical information on the magnitude of population declines, and in the case of the latter, promising new signs that poaching enforcement is working (Lessard unpublished data, cited in Busch et al. 2014). In contrast, abalone research in Alaska has been lacking, even prior to the commercial fishery closure in 1996, when the incentive to fill key information gaps in abalone biology and population dynamics for purposes of a sustainable fishery was more urgent. There have been some Alaska-specific published studies on age and growth (Paul and Paul 1981, 2000; Woodby et al. 2000) and unpublished work on population size structure (fishery-independent: Larson and Blankenbeckler, 1980, unpublished data; fishery-dependent: Alaska Department of Fish and Game,1970-1980, unpublished data), but no stock assessments or surveys of absolute density have ever been attempted. There were relative density surveys that targeted abalone over a large geographic area in Southeast Alaska from 1979 - 1981 (Larson and Blankenbeckler, 1980, unpublished data), but no dedicated efforts have been made in the 34 years since then. However, the Alaska Department of Fish and Game has conducted spatially and temporally intensive stock assessments for sea cucumbers and sea urchins since the mid-1990s, and have recorded abalone observations opportunistically during those surveys (Hebert, unpublished data). Although there is a clear trend of declining abundance that mirrors declines in other regions, the lack of a formal survey protocol raises uncertainty about the consistency with which the data were collected over time, thereby undermining the credibility of the dataset.

The question of whether abalone populations could sustain ongoing subsistence and personal use fisheries was the primary impetus for this study. Additionally, the potential listing of pinto abalone as “Threatened” or “Endangered” under the Endangered Species Act has rekindled interest in assessing the status of the species in Alaska. Limited staffing and financial resources require that this study is small in spatial and temporal scope, so the emphasis will be on quantifying key population characteristics of abalone within a small geographic area where aggregations are known to persist, and then monitoring several aggregations over time at fixed sites to assess temporal variability. Specifically, our study goals are to: 1) collect basic information about typical aggregation sizes and density within patches/localized sites, 2) determine the extent to which adult abalone aggregations exist at densities and between-neighbor distances sufficient to successfully spawn, 3) quantify how these densities and between-neighbor distances vary over a range of times scales from bi-weekly to annually, 4) examine population size structure and determine if there is evidence for successful recent reproduction, and 5) determine how key characteristics of the abalone population in Sitka Sound compare to those in British Columbia and Washington, where they are better-studied and have long histories of monitoring. We considered several other additional questions (Appendix A), but determined that the questions listed above warranted the highest priority, given limited resources. Notably, this study will be the first to formally collect data for absolute density and aggregation characteristics of abalone in Alaska. Our intent is that the results of this study will inform management about whether further action may be warranted (e.g., changing bag limits and/or size limits, initiating restoration planning, creating a management plan), as well as serve as a pilot project for scaling up to the larger geographic region.

Methods

The general approach to achieving the goals identified above, within the constraints of available resources, is to repeatedly survey 8 index sites in a small subset of the geographic range of pinto abalone in Alaska for two field seasons. Six of the index sites will be randomly chosen from a pool of 21 randomly placed reconnaissance sites within the study area, so the inference space of the study will be the entire study area instead of simply the six sites. An additional two sites with the highest known densities of abalone in the study area will be chosen non-randomly for monitoring, to ensure that high-density abalone aggregations are included in the study. At each index site we will measure a suite of metrics that were either recommended or implied as research priorities in recent reviews of pinto abalone stock status in Alaska (McDougall 2006, Busch et al. 2014), and those that we consider the most important to obtain at this early stage of investigation. Five general classes of complementary metrics will be used as measures of population dynamics for abalone at index sites: absolute density of adults (adults are defined here as > 50 mm shell length; 50 mm is the smallest size reported to be reproductive in pinto abalone (Larson and Blankenbeckler 1980;Paul and Paul 1981; Campbell et al. 1992), absolute density of juveniles (< 50 mm), nearest neighbor distances between adults, aggregation size, and abalone shell length. Detailed descriptions of the field methods that will be used to quantify each of these metrics are provided in Appendix B, and are described below in brief. Preliminary field datasheets were developed for a pilot survey during fall 2014, and these will be used as templates for field datasheets for this study (Appendix D).

Because the exact timing of abalone spawning is not known, and adult density may change as a function of spawning events or season, we will quantify variability of metrics at a range of temporal scales each year. All 8 permanent sites will be surveyed bi-annually, once in late spring/early summer, and then again in late summer/early fall. The two non-randomly selected sites will be surveyed on a biweekly basis (during spring and neap tides) to characterize higher frequency variability during the cumulative potential spawning season defined here as April 1 – September 15 (see specific date ranges in individual studies: Quayle 1971, Breen and Adkins 1979, Stekoll and Shirley 1993, Campbell et al. 2003, CDFW 2005, Seamone and Boulding 2011).

Study Area

The focal location of this study is the northeastern portion of Sitka Sound, on the west coast of Baranof Island (Figure 2). This area was chosen because it has numerous pockets of persistent abalone populations, a supportive, ocean-dependent community nearby that has historically harvested abalone, and it is logistically the most feasible to access within an otherwise remote archipelago. The Sitka area is characterized by an abundance of rocky shore habitat, diverse underwater topography, productive macroalgal communities, a shallow seafloor, and a range of wave exposures, which in sum provides a substantial amount of favorable habitat for abalone. The study area does not include coastline with very protected wave exposure, where abalone are presumably nonexistent or extremely rare (i.e., Katlian Bay, Silver Bay, and Deep Inlet). There is a long history of abalone harvest by humans in the area (Mills, 1982), and the area supported a commercial fishery before its closure, although harvest was much less than in outer coastal areas immediately south of Sitka Sound.

This study will, by necessity, be conducted in areas that remain open to legal subsistence and personal use harvest (there are no marine protected areas for abalone in Alaska), so it is not possible to control for ongoing human influence. Sea otters, the other major predator of adult abalone, have occupied the area for decades, but occur in relatively low abundance (compared to the outer portion of Sitka Sound) in the immediate vicinity of the city of Sitka (personal observation). We expect that the latter trend will continue throughout the duration of this study, based on the speculation that sea otters are scarce near Sitka because of sustained and increasing hunting pressure. In sum, there is a clear and present risk for localized sea otter predation and/or harvest by humans within the study area. pinto abalone concentrations currently occur at a small spatial scale (~5 – 30 m alongshore distance; personal observation), in general, so legal harvest by even one person or predation by one sea otter could potentially decimate any of the aggregations under study. Fishery regulations that provide some protection of abalone in the study area include prohibition of harvest by use of compressed air breathing systems, and a minimum size limit of 89 mm (3.5 inches). Consequently, depths below ~ 3 m are expected to serve as de facto harvest refugia (K. Hebert, Fishery Biologist, ADF&G, Juneau, personal communication). Karpov et al. (1988) estimated a depth refugia threshold for abalone of 8.4 m in California, where competition for abalone is probably more intense and drives deeper dives.

Survey Site Selection

Ultimately, eight “permanent” (i.e. fixed-location) sites will be chosen for monitoring. A subset of six sites will be chosen randomly to represent the full inference space of the northeastern Sitka Sound study area, and two additional sites will be chosen non-randomly to ensure inclusion of sites that have the highest known densities of abalone in the area. The latter two sites are intended to represent a “best case scenario”; e.g., if adult densities are lower than needed for successful spawning there, they would likely be lower almost everywhere else.

Determination of randomly-chosen, permanent sites will be accomplished using a multistage process. First, the study area was subdivided into three arbitrarily designated geographic strata of similar horizontal dimensions and spanning a gradient from southeast to northwest (Figure 2). Next, several areas were eliminated from consideration for safety reasons (e.g., vessel traffic, pollution, anthropogenic debris), including Crescent Bay and the channel between Sitka and Japonski Island, from just seaward of the bridge past the breakwater, west of the Western Anchorage (Figure 2). It is unlikely abalone are present in the core of these areas because of the very protected wave exposure and fine sediments, but there are undoubtedly some that occur on the periphery, especially in the interstitial spaces of the harbors' breakwaters. Finally, NOAA's Shorezone database (NOAA 2015) was used to identify and eliminate stretches of shoreline with unsuitable or inferior abalone habitat, with the assumption that the intertidal habitat was strongly correlated with the subtidal habitat directly offshore. This assumption is certainly not true universally, especially for substrate type/mobility, but we determined that the efficiency gained from using the Shorezone dataset far outweighed the ramifications of the inaccuracies of erroneously including or excluding a presumably minor number of misclassifications. Specific criteria used to exclude shoreline from consideration were "biological wave exposure," the dominant biological structuring process, and substrate mobility. The specific steps used in GIS to execute this process are described in Appendix C.

NOAA assigned "biological wave exposure" values based on aerial observations of the presence and abundance of biota, referencing known species-specific wave energy tolerances from the literature and expert knowledge. We considered biological wave exposure to be a more realistic metric than metrics resulting from other models of wave exposure, such as fetch-based models (Schoch et al. 2013); the latter are more appropriate for enclosed waterbodies (e.g., estuaries) that are not influenced by refraction and diffraction of gravity waves. No integrated wave exposure data from refraction/diffraction models exist for the study area, to our knowledge. Five classes of biological wave exposure were present in the study area: Exposed (1.9% of shoreline), Semi-Exposed (13.4%), Semi-Protected (56.0%), Protected (26.0%), and Very Protected (2.6%) (Table 2, Figure 3). Given the known habitat preferences of abalone, they probably either do not occur, or occur at very low abundance, in areas with Very Protected wave exposure (Lessard and Campbell 2007), so shoreline in this category was eliminated from further consideration (Tables 2 and 3, Figure 4).

Several dominant structuring processes influence the biota on shoreline within the study area, according to the NOAA (2015) Shorezone database: Anthropogenic (6.0% of shoreline), Current (0.8%), Fluvial/Estuarine (2.4%), and Wave Energy (90.8%) (Table 2). Of these, all were retained except for Fluvial/Estuarine, which is not abalone habitat. Abalone are known to occur on anthropogenic substrates (e.g., coastal armoring) and may occur in current-dominated areas that are in immediate proximity to areas dominated by wave energy, therefore these categories were retained.

The mobility of intertidal substrate was an important criterion for site selection, because abalone require stable substrate for adherence. NOAA's (2015) Shorezone database defines mobility according to the interaction between sediment grain size and degree of wave exposure and mobility is determined by the type of biota (e.g., annual or perennial) present; for example, a small boulder would be considered an immobile substrate in areas with Protected or Very Protected wave exposure, but mobile when it occurs on Exposed shorelines. Several substrate mobility classes were present in the study area: Immobile (33.0%), Mobile (0.9%), Partially Mobile (56.9%), and "Not Applicable" (9.2%) (Table 2). The "Not Applicable" category was used for shoreline that did not have wave energy as the dominant structuring process (i.e., anthropogenic, current, and fluvial/estuarine). Only shoreline classified as having Mobile substrate was excluded from further consideration.

The process of elimination described above resulted in retention of 243,495 meters of shoreline (95% of the total of 256,716 m) for inclusion in the study (Table 2, Figure 4). Of this total, 25.2% was classified as having Protected wave exposure, 58.6% Semi-Protected, 14.2% Semi-Exposed, and 2.0% Exposed. In all of these combined, 34.5% was Immobile, 58.6% was Partially Mobile, and 6.8% was Not Applicable. The total amount of shoreline in each stratum was very similar in the Northwest and Southeast geographic strata (38.5% and 40.8% of the total, respectively), but the Central stratum had substantially less (20.6% of total; Table 3). The difference is largely a function of the lesser extent of island shoreline in the **C**entral stratum, because the areal coverage is approximately the same as the other two strata. We do not consider this difference problematic, because the strata were defined geographically, not by the amount of shoreline.

Seven reconnaissance sites were randomly chosen along the shoreline retained for study within each of the three geographic strata (Table 4, Figure 4). Points representing sites were placed on the shoreline using the "create random points" tool in ArcGIS 10.3, with a criterion that no points would be placed closer than 3,000 m to another along the polyline feature class representing the shoreline. This step was imposed to force greater dispersion of reconnaissance sites, given the size of the study area and low spatial replication; however, this step did not guarantee dispersion because of the vagaries of how the polyline was originally constructed in ArcGIS, most notably around islets, islands and complex shorelines; the 3000 m separation was only along a polyline, not a radius around a point. These 21 sites represent starting points for abalone reconnaissance surveys, which will be conducted over 1-2 days in late May or early June 2015 (see schedule in Table 1).

Reconnaissance Surveys and Permanent Site Selection

Reconnaissance surveys will employ timed swims to measure relative density of abalone (number of abalone per minute of search time) at each of the 21 sites (7 per geographic stratum) that are candidates for permanent site selection. There are well-known problematic issues with timed swim surveys (e.g., McGarvey 2006, McGarvey et al. 2008), most notably high among-observer variability, which may indicate apparent differences among sites when there are actually none. To address this issue, each diver will be calibrated by counting abalone in the same 30 x 1 m transect at a location with a known concentration of abalone. Count data from individual divers will be compared to the average count, and any divers with counts that are significantly different from the mean will be identified, and a correction factor (i.e. positive or negative bias) will be applied to that diver's timed swim data for all sites that they surveyed. Ideally, this calibration exercise would have a greater sample size for each diver, and would use the same comparison method (timed swim vs transect) as the method being tested (i.e. timed swim), but limited resources and the typical patch size of abalone concentrations (often small and easily missed) were more important considerations. In essence, this calibration will yield an estimate of each diver's ability to observe and count abalone, not a diver's ability to identify optimal abalone habitat, the latter of which is also an important factor in timed swims.

Specifically, the protocol for timed swims is as follows. Divers will search for abalone between 2 – 7 m depth for 20 minutes using a relatively consistent swimming speed, a general bearing from the dive starting point, alternating diagonal search pattern, mandatory flashlights, without invasive sampling or double-counting. Swimming speed will be difficult to standardize among observers, and will vary as a function of a diver's search ability, experience with abalone, and habitat complexity. Therefore, general guidance will be given to swim/search at a speed that would allow one to observe most (> 50%), but not necessarily all, adult abalone within the search path. Divers will be allowed flexibility to deviate from course in order to search promising microhabitats (e.g., crevices, interstitial spaces between boulders). Dive start and end coordinates will be recorded using Global Positioning Units with the Wide Area Augmentation System activated, which should yield horizontal precision on the order of 2-5 m.

After calibration of among-observer relative density data, abalone counts by each two-diver team will be summed and divided by the total dive time (in minutes) for each of the 21 sites. Based on inspection of the data, a threshold value will be determined post hoc to classify the sites as either "high" or "low" density; sites where no abalone were observed will not be considered for inclusion as permanent sites. If there are at least two "low density" and two "high density" site per geographic strata, one of each will be randomly chosen as a permanent site (n = 6, total). If no "high density" sites exist in a given strata, two "low density" sites will be chosen instead.

Preliminary surveys of abalone absolute and relative density were collected at eight non-randomly selected sites in the study area during August and September 2014. These sites were chosen for surveys based on anecdotal information from experienced divers about where abalone had been observed in the past, or were most likely to be found. Of these eight sites, Ellsworth Cut and the Downtown Outfall sites had the highest densities of abalone; therefore, these sites will be selected non-randomly as the two high-density permanent sites, if no sites with higher densities are encountered during reconnaissance surveys in May/June 2015.

Survey Methods for Permanent Sites

Strip transects

Strip transects, as defined here, are essentially elongated quadrats (per Krebs 2014), and have the same assumptions: 1) the area sampled is known, and 2) each target organism within the borders of the quadrat/transect is observed and enumerated (i.e., none are missed). Strip transects will be the primary method to measure the absolute density of adult abalone (# of abalone ≥ 50 mm maximum shell length per m^2) within "patches" (i.e., groups of abalone in the same general localized area). Absolute density is the single most important metric that will be measured in this study because it will directly answer the question about whether abalone occur in densities thought to be sufficient to successfully spawn, and therefore will inform a decision about whether ongoing subsistence and personal use fisheries should continue (see Introduction for further rationale).

Secondarily, strip transects will be used to collect data for absolute density of juvenile abalone (# of abalone < 50 mm maximum shell length per m^2), between-individual distances, abalone shell length, and a limited array of micro-habitat associations. The absolute density of juvenile abalone is a secondary metric because juveniles are often cryptic (i.e., under boulders and difficult to observe), and we expect that divers will miss a substantial proportion of individuals occurring within the boundaries of a transect; therefore, this metric should be considered a minimum absolute density. The density of juvenile abalone in Artificial Recruitment Modules (see methods below) will presumably be a better measure/index of recruitment to the biological population, but we chose to include the absolute density from transect counts because it may be informative, and it simplifies the transect method because divers will not have to decide underwater whether an individual should be counted or measured. Between-individual distance is also secondary because we will be using a more rigorous method to quantify this metric (see methods for distance sampling below). However, it is unclear how efficient distance sampling will be in the kelp forest habitats we expect to encounter, and minimal extra effort is needed to collect this type of information during transects, so it will be worthwhile to compare the results for the same metric between the two methods for potential elimination of redundancies. Strip transects will be the primary avenue for collection of shell length frequency data and microhabitat association data, even though these metrics are not the primary focus of the method.

Transects will be 30 m long by 2 m wide (planar area, not surface area), and oriented such that the long axis is parallel to the prevailing depth contour (Figure 5). Parallel transects were chosen to maximize sampling effort within depths less than 10 m, the optimal depth zone– for adult abalone (Abalone Recovery Team 2002; Rothaus et al. 2008); transects oriented perpendicular to the depth contour would most likely result in a small effective sample unit size because much less area where abalone actually are most of the time would be sampled. Two transects will be sampled per site, one in each of two depth strata (-3 and -6 m, relative to MLLW). Depth strata were chosen to occur within the depth zone of primary habitation by abalone, yet deep enough to allow sampling during most of the late spring, summer, and early fall months, when surf conditions and associated surge currents are relatively mild. Exact transect placement will be finalized prior to sampling, and will be based on notes from reconnaissance/timed swim surveys, and diver judgment about where an abalone aggregation exists. Once the placement has been decided, permanent markers (e.g., eyebolts, rock pitons, or anchors) will be placed at the endpoints of a 30 m transect. Each time the transect is sampled, a tape will be strung between the two endpoint markers. By eliminating any variability due to space, this “fixed-“, or “permanent-transect,” approach will allow isolation of any differences in metric values to the effect of time alone (and sampling error, which is always present).

The primary assumption of a strip transect is that all target individuals are detected and counted within the transect boundaries. On each transect, each of two divers will search intensively for abalone within 1 m on opposite sides of a transect tape, using a 1 m PVC rod as a guide. The target search speed will be slow, approximately 1m per minute, but will vary depending upon habitat complexity (e.g., substrate type, number of crevices, vertical relief, algal cover, surge currents). Divers will have a target search image for abalone > 50 mm shell length, will not invasively sample (e.g., turn over stones, remove algae), and will use flashlights and mirrors to search in poorly illuminated and/or areas hidden from casual view. Divers will record the exact position of each abalone by noting the closest meter mark on the transect tape, and the perpendicular planar distance from the transect tape to the abalone, both to the nearest centimeter. The diver will also measure the maximum shell length (to the nearest mm) for each abalone using Vernier calipers, using care to avoid cutting any tissue. If the abalone is inaccessible, the diver will estimate the length to the nearest mm and note that the length is an estimate. For each abalone, divers will also record the depth (uncorrected to tidal stage), behavior (cryptic or emergent), and the substrate type (e.g., boulder, bedrock) that the abalone is adhered to.

Each time a transect is surveyed, divers will record dominant algal taxa and algal cover by functional group (e.g., encrusting coralline, turf, foliose, understory, canopy) every 5 m. At the end of sampling a given transect, divers will record the presence of sea urchins and any important predators of adult abalone that were observed, including octopus, wolf eel, *Cancer* crabs, and large sculpins (e.g., Irish lords, Cabezon). The first time a transect is surveyed after it has been established, divers will also collect high-resolution data on the depth and primary substrate type every 1 m mark increment on the transect tape, as well as depths at the distal ends (onshore and offshore) of the 1 m swaths at the same meter mark.

Distance sampling

Because of their semi-sedentary behavior, clumped spatial distribution and broadcast spawning strategy, pinto abalone are known to succumb to Allee effects at low adult densities. Traditional measures of density estimation (e.g., quadrats, transects) do not necessarily capture the type of information required to assess the potential for Allee effects, but distance sampling methods can. Distance sampling will be the primary method to measure aggregation size (# per aggregation, defined as the count within a 4 m radius of a randomly selected individual abalone) and nearest neighbor between-individual distances of adult abalone (> 50 mm maximum shell length). Secondarily, distance sampling will be used as a plotless density estimation technique (cf. strip transects) to collect data for the absolute density of adults (# of abalone > 50 mm maximum shell length per m^2 within an aggregation), as described in Button (2008). Shell lengths will also be measured to complement lengths measured during strip transects, and in combination will be used to assess population size structure.

The Kendall-Moran protocol, as described by Button (2008) for application to pink abalone in California, will be the distance sampling method used to quantify nearest-neighbor distances within aggregations, with minor modifications (Figure 6). We anticipate that it will take 1 – 2 dives to conduct distance sampling at each permanent site, and these dives will be conducted after strip transects have been performed. Our working assumption is that abalone will not be more difficult to observe in subsequent dives after they have been disturbed, which would result in apparent method-specific bias, but this assumption will be re-evaluated after actual sampling. Divers will navigate to the 10 m mark on the transect tape deployed in the -3 m depth strata for conducting strip transects (Figure 5), and search in a concentric pattern around the 10 m mark, out to a 10 m radius if necessary, until the nearest abalone is found. If an abalone is not found within a 10 m radius, then the sampling event will be aborted. If, after the first half-day of sampling during June 2015, it is determined that searching out to 10 m is not feasible (e.g., due to entanglement with canopy-forming kelps), the maximum search radius will be revised downwards, but will not be less than 4 m. Assuming an abalone is observed within a 10 m radius, the distance and bearing to the abalone from the 10 m mark will be recorded, and then the concentric search process will be repeated using this abalone as the origin point. Divers will search out to at least a 4 m radius, which we are defining here as the boundary of the "aggregation" around the central abalone, and record the distance and bearing from the origin point to each abalone. Button (2008) used a 2.5 m radius to define aggregation sizes, but we are conservatively proposing a 4 m radius here because pinto abalone apparently exhibit greater horizontal movements than other abalone species. The 2.5 m radius Button used was based largely on laboratory work for *Haliotis laevigata* in Australia (Babcock and Keesing 1999), so the direct applicability to pinto abalone is uncertain. If no abalone are observed within the 4 m radius, the aggregation size will be equal to one (i.e., the central abalone), and the search radius will be increased incrementally until the nearest abalone is found, and the distance and bearing will be recorded. This entire process will be repeated starting at the 20 m mark on the transect in the -6 m depth strata (Figure 5), for a total sample size of two per permanent site. Ancillary data for each abalone observed will include length of maximum shell dimension, uncorrected depth, behavior (cryptic or emergent), substrate type that the abalone is adhered to, and whether the abalone is within the boundaries of the strip transect or not (so it is not over-represented in certain data summaries, e.g., length frequency).

Artificial Recruitment Modules

For at-risk populations such as pinto abalone, one of the most important pieces of evidence to determine whether the population is recovering is the presence of recently recruited individuals. However, new recruits and young juvenile abalone are notoriously difficult to quantify in natural habitats due to their cryptic nature. In this study, Artificial Recruitment Modules (ARMs) will be used to acquire standardized estimates of juvenile abalone absolute density (# of abalone < 50 mm maximum shell length per m^2), which will be used as an index of recruitment to the biological population. ARMs will be modelled on the design created by DeFreitas (2003) and also used by Bouma (2007, 2012) for pinto abalone (Figure 7). Basic ARM design includes a commercial Dungeness crab pot measuring 1m in radius by 30 cm high, with all internal fishing components removed. Stainless steel wire with a mesh size of 65 x 90 mm will be used to enclose the crab pot, and escape holes will be removed or barricaded to deter entry of predators. The latter specification is the only modification we made to the ARM design used by DeFreitas and Bouma; they used an open escape hold, but we decided to close it to reduce the potential for larger predators to enter the ARM. The ARM will be filled haphazardly with 24 equally-sized pieces of "E"-shaped cinderblock cut from 6 whole cinderblocks (i.e., cut into quarters), for a total surface area of approximately 3.5 – 3.8 m^2 per ARM. The cinderblocks will be "conditioned" in a saltwater aquarium at the Sitka Sound Science Center for approximately 3 months to encourage dilution/off-gassing of toxics in the concrete, and to allow for some biofilm or algal growth prior to being deployed. The seawater intake for this aquarium is from 18 m depth, approximately 15 m offshore. Several rocks with existing encrusting coralline algae will be collected from Sitka Sound and placed in the aquarium with the cinderblocks to expedite colonization. DeFreitas (2003) did not specify whether he conditioned cinderblocks prior to deployment, but Bouma (2007; 2012) conditioned the blocks for 10 months, and reported that the blocks were adequately conditioned within 5 months. Even so, our 3 month conditioning time is less than that, so any results within one year of deployment will be interpreted with caution.

Two ARMs will be deployed per permanent site, one at 4 m and the other at 9 m MLLW (Figure 5). Deployment of ARMs at multiple depths is planned to achieve at least some within-site replication, and because the optimal depth to deploy ARMs is unknown in the study area. Sloan and Breen (1988) reported that small (< 10 mm) juvenile pinto abalone occupy deeper habitats than adults and make an ontogenetic migration to shallower water and more exposed microhabitats as they grow older. However, it has been reported that the pattern observed in Canada by Sloan and Breen (1988) was not apparent in Southeast Alaska (R. Larson, retired, ADF&G, personal communication), hence our decision to deploy an ARM at 9 m, which is deeper than our deepest transect. The ARMs will be deployed as closely to the center of the permanent site as possible, along an imaginary line intersecting the 15m mark on each strip transect. If the site where ARMs will be deployed is determined to be susceptible to significant wave action, they will be secured to the seafloor using lagbolts or rock pitons and polyline (per Rogers-Bennett et al. 2004; Bouma 2007, 2012). The hinged lid on the top of each ARM will be secured closed with cable ties. Divers will sample ARMs during biannual sampling at all permanent sites, and two additional times per year at the two sites chosen for more intensive temporal sampling. Sampling will involve first taking several photos of the ARM for a permanent record, and then carefully removing each cinderblock piece and inspecting it closely for any abalone. Each abalone will be counted, measured, and protected from being crushed during the sampling process. All predators in the ARM will be identified to the lowest taxonomic level, counted, recorded, and removed. Once all cinderblock pieces have been inspected, divers will carefully and haphazardly replace all pieces into the ARM and secure the lid.

Statistical Analysis

The density of pinto abalone, and abalone in general, has been measured using a wide variety of sample sizes and sample unit sizes, including 1 m^2 quadrats (Breen and Adkins 1979), 30 x 2 m transects (CDFW 2005), 50 x 4 m transects (Bird 2014), and 100 x 1 m transects (McGarvey et al. 2008). This range of sizes is due, in large part, to the density of abalone being measured, which underscores the need highlighted by Krebs (2014) to obtain pilot data for empirically determining appropriate sample unit sizes and associated sample sizes. Therefore the first order of business for this study with regard to summarizing absolute density data for adult and juvenile abalone [for data collected via strip transects] is determining the optimal within-transect subsample unit size and subsample size. “Optimal” is defined here as the highest statistical precision (versus logistical or ecologically optimal, per Krebs 2014), or the narrowest confidence interval, and will be attempted using an iterative bootstrapping process. The location of each abalone recorded during sampling will be used to assign an individual into one of the thirty 1 x 2 m (L x W) contiguous subsamples that make up a given 30 x 2 m (L x W) transect. Bootstrapping will be used to generate mean values and confidence intervals for a range of subsample dimensions (e.g., 1 x 2 m, 2 x 2 m,….15 x 2 m) and sample sizes (e.g., n = 2…30). The density of abalone per square meter will be estimated as:

$$D = \frac{1}{Qkn}\sum_{i=1}^{n} c_i \qquad (1)$$

where:

D = estimated number of abalone per square meter,

i = quadrat index,

c_i = count of abalone in each quadrat i from 1 to n,

Q = quadrat length (along-transect dimension),

k = quadrat width (across-transect dimension) = 2 m,

n = number of quadrats.

Uncertainty in the density estimate will be expressed as the percent precision, which is the method used by the Alaska Department of Fish and Game to calculate uncertainty for geoduck clams (e.g., Rumble and Siddon 2009). The index is equal to the lower bound of the one-sided 90% confidence interval expressed as a percent of the average density and calculated as:

$$P_D = 100\left(1 - t_\alpha \frac{s}{D\sqrt{n}}\right) \tag{2}$$

where:

P_D = percent precision of the density estimate,

t_α = t-value from Student's distribution for a one-sided interval with significance, level α = 10%,

s = standard deviation of the mean,

D = estimated density of pinto abalone,

n = number of quadrats.

In a perfectly precise estimate, PD would equal 100%; decreasing numbers indicate increasing uncertainty. Our precision goal for this work is 70% for each transect. A decision will be made whether to adjust transect length or sample size in year 2 of the study, after the data from the first season is analyzed. The bootstrapping results will be compared across all transects to evaluate the generality of the optimal combination of sample unit size and sample size. In the event that no optimal combination is found, transects will not be divided into subsamples, and no measure of within-transect variability will be reported.

The procedure for calculating density for the KM protocol ($\widehat{N}_{KM}$) is identical to that used by Button (2008), and the following description is hers, with minor editorial modifications. The total area searched in each location (A_i), is equal to the area of the two circles searched minus the intersection of the circles (Kendall and Moran 1963; Engeman et al. 1994)

$$\widehat{N}_{KM}) = \{[\sum(p_i) - 1\}/ \sum Ai \tag{3}$$

where p_i is the number of individuals within the area A_i,

$$Ai \;=\; \pi x_i^2 + \pi z_i^2 - x_i^2\,\{\theta - \sin\theta\cos\theta\} - z_i^2\{\varphi - \sin\varphi\cos\varphi\} \tag{4}$$

and,

$$\theta = \cos^{-1}(1 - \; z_i^2\;(2x_i^2)^{-1}) \tag{5}$$

$$\varphi = \cos^{-1} z_i(2x_i)^{-1} \tag{6}$$

The 95% confidence intervals for the $\widehat{N}_{KM}$ estimate will be obtained by finding the 2.5 and 97.5 percentiles of 10,000 fixed-*xy* bootstrap samples

The error associated with the average density estimates will be calculated by subtracting the plotless density estimate from the average transect density:

$$\Delta N_{KM} = \;\widehat{N}_T - \widehat{N}_{KM} \tag{7}$$

The absolute value of these errors divided by the average transect density gives the normalized root mean squared error for each population.

To assess potential redundancy and biases of methods in which the same metric is produced, we will compare the absolute density estimates measured using strip transects against distance sampling for a single sampling event (i.e., date) via a paired t-test, with each pairing of transect and associated distance sampling as a replicate. We will make the same comparison for nearest neighbor distances measured with these methods and again use a paired t-test.

To test whether average within-site densities of adult abalone in the study area are high enough to facilitate successful fertilization, we will use the data from the sampling date with the highest average among-site density, and test whether the density at each site is lower than the threshold densities used by others (e.g., 0.2 per m^2 by the California Department of Fish and Wildlife (2005)) as an indicator of the risk of population collapse. This comparison will be made using a one-tailed one-sample t-test for each site, with a Bonferroni correction for multiple tests (n=8 total), and alpha level set at 0.1 to minimize the probability of Type II error.

The density of juvenile abalone (< 50 mm) per square meter in ARMs will be estimated for each site by:

$$D = \frac{1}{Mn}\sum_{i=1}^{n} c_i \tag{8}$$

where:

D = estimated number of abalone per square meter,

i = quadrat index,

c_i = count of abalone in each ARM i from 1 to n,

M = cumulative surface area of 24 cinderblock pieces in each ARM = 3.5 m^2,

n = number of ARMs,

Uncertainty in the density estimate will be expressed as the percent precision. The index is equal to the lower bound of the one-sided 90% confidence interval expressed as a percent of the average density and calculated as:

$$P_D = 100\left(1 - t_\alpha \frac{s}{D\sqrt{n}}\right) \tag{9}$$

where:

P_D = percent precision of the density estimate,

t_α = t-value from Student's distribution for a one-sided interval with significance, level α = 10%,

s = standard deviation of the mean,

D = estimated density of pinto abalone,

n = number of ARMs.

Our precision goal for ARMs is 70% for each site.

Descriptive statistics will be used to characterize abalone aggregation sizes and nearest neighbor distances for each combination of site and sampling event.

For each combination of method and metric, we will test whether a significant difference exists between the two depth strata across all sites using a repeated measures ANOVA, with "site" as the replicate. If there is no statistical difference between depths, the data for the two transects at each site will be pooled to increase statistical power of among-site comparisons.

The target effect size is 50% for all metrics; that is, we want to be able to detect a 50% difference in mean absolute density of both adults (> 50 mm shell length) and juveniles (< 50 mm), and in nearest-neighbor distance, among permanent sites at a given time, and within-sites over time, with 80% statistical power. The target effect size will be re-visited after analyses of data from the first sampling season in 2015, and adjustments will be made if warranted and feasible. If statistical power is adequate, we will assess whether adult densities that were measured bi-weekly for two sites vary significantly over the course of a spawning season. If significantly higher densities were observed on one or more sampling occasions, and those weeks/months are consistent in both 2015 and 2016, there will be circumstantial evidence for spawning-related aggregation behavior, and this will inform timing of future surveys.

Abalone size frequency data will be compiled and unique values (i.e., only one of the values for an individual abalone measured in both transect and distance sampling) will be retained for summary. Data from all sites will be pooled. The percentage of abalone in "intermediate" (50 – 90 mm; the larger end of the range being the minimum size allowed for retention in the personal use and subsistence fisheries) and "large" (>90 mm) size classes will be calculated and evaluated using the California Department of Fish and Wildlife's criteria of 90% and 25% within each size class, respectively. For red abalone, CDFW (2005) based their decision on a threshold size between intermediate and large size classes on the legal size permissible in their recreational fishery; no fishery is allowed for pinto abalone in California, so in that case they defined the intermediate size class to be 76 – 102 mm, and the large size class to be > 102 mm. In general, CDFW apparently considered abalone less than 100 mm to be cryptic in nature, but in the case of pinto and flat abalone, they reduced the minimum range value to 76 mm. Based on preliminary size frequency data for pinto abalone in Sitka Sound (ADF&G, 1970-1980, unpublished data), abalone between 50 and 100 mm were routinely measured, so we will include abalone between 50 – 76 mm in the "intermediate" size class, at least initially.

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Tables

Table 1.
Project schedule for 2015-16.

Year	Target Completion Date (+/- 1 week)	Task(s)	Estimated # of Days to Complete	Target # of Divers	Estimated # of Dives to Complete
2015	March 10	Begin "conditioning" cinderblocks for ARMs	2	0	0
2015	June 1	reconnaissance surveys, permanent site selection	1	8	23
2015	June 15	permanent site establishment, deploy ARMs	0.5	11	16
2015	June 15-16	biannual sampling* at 8 permanent sites	1-2	11	32
2015	July 1, 15; August 1	bi-weekly sampling** at 2 permanent sites***	1****	2****	6****
2015	August 15	biannual sampling* at 8 permanent sites	1-2	8	24
2015	September 1, 15	bi-weekly sampling** at 2 permanent sites***	1****	2****	6****
2016	April 1, 15; May 1, 15	bi-weekly sampling** at 2 permanent sites***	1****	2****	6****
2016	June 1	biannual sampling* at 8 permanent sites	1-2	8	24
2016	June 15; July 1, 15; August 1	bi-weekly sampling** at 2 permanent sites***	1****	2****	6****
2016	August 15	biannual sampling* at 8 permanent sites	1-2	8	24
2015	September 1, 15	bi-weekly sampling** at 2 permanent sites***	1****	2****	6****

* = strip transects, distance sampling, ARM monitoring
** = strip transects, distance sampling
*** = Ellsworth Cut, Bayview Pub
**** = per sampling event, not cumulative

Table 2.

Summary of the length of all shoreline types (per Shorezone database; NOAA 2015) within the study area, and the subset of shoreline retained for site selection.

Biological Wave Exposure	Dominant Structuring Process	Substrate Mobility	Total Shoreline Length (m)	Shoreline Length Retained for Study (m)
Very protected	Anthropogenic	Not Applicable	731	0
Very protected	Fluvial/Estuarine	Not Applicable	2,067	0
Very protected	Wave Energy	Immobile	531	0
Very protected	Wave Energy	Partially Mobile	3,459	0
Protected	Anthropogenic	Not Applicable	4,766	4,766
Protected	Current	Not Applicable	812	812
Protected	Fluvial/Estuarine	Not Applicable	3,810	0
Protected	Wave Energy	Immobile	10,483	10,483
Protected	Wave Energy	Mobile	1,592	0
Protected	Wave Energy	Partially Mobile	45,371	45,371
Semi-protected	Anthropogenic	Not Applicable	9,009	9,009
Semi-protected	Current	Not Applicable	1,145	1,145
Semi-protected	Fluvial/Estuarine	Not Applicable	307	0
Semi-protected	Wave Energy	Immobile	46,237	46,237
Semi-protected	Wave Energy	Mobile	689	0
Semi-protected	Wave Energy	Partially Mobile	86,259	86,259
Semi-exposed	Anthropogenic	Not Applicable	858	858
Semi-exposed	Wave Energy	Immobile	22,869	22,869
Semi-exposed	Wave Energy	Mobile	35	0
Semi-exposed	Wave Energy	Partially Mobile	10,736	10,736
Exposed	Wave Energy	Immobile	4,621	4,621
Exposed	Wave Energy	Partially Mobile	329	329
		Total	**256,716**	**243,495**

Table 3.
Summary of the length (m) of all shoreline types (per Shorezone database; NOAA 2015) within the study area, by geographic stratum.

Biological Exposure Class	Substrate Mobility Class	Study Area Geographic Strata			Grand Total
		Northwest	Central	Southeast	
Protected	Immobile	5,347	855	4,281	**10,483**
	Partially Mobile	17,752	9,475	18,144	**45,371**
	Anthropogenic	1,920	544	3,114	**5,578**
	Subtotal	*25,019*	*10,874*	*25,539*	***61,432***
Semi-protected	Immobile	14,962	5,016	26,259	**46,237**
	Partially Mobile	37,633	22,103	26,523	**86,259**
	Anthropogenic	1,405	8,192	557	**10,154**
	Subtotal	*54,000*	*35,311*	*53,339*	***142,650***
Semi-exposed	Immobile	*6,093*	*2,519*	*14,257*	**22,869**
	Partially Mobile	5,422	963	4,351	**10,736**
	Anthropogenic	858	0	0	**858**
	Subtotal	*12,373*	*3,482*	*18,608*	***34,463***
Exposed	Immobile	2,265	419	1,937	**4,621**
	Partially Mobile	329	0	0	**329**
	Subtotal	*2,594*	*419*	*1,937*	***4,950***
	Grand Total	**93,986**	**50,086**	**99,423**	**243,495**

Table 4.

Locations of reconnaissance sites under consideration for permanent site selection, and locations of two non-randomly chosen permanent sites. Latitude and longitude are in decimal degree format, and NAD 83 datum.

Geographic Stratum	Site #	Latitude	Longitude	Site Selection Method	Site Name
Central	1	57.04514	-135.35240	Random	N.A.
Central	2	57.04557	-135.37813	Random	N.A.
Central	3	57.05840	-135.40926	Random	N.A.
Central	4	57.06494	-135.43241	Random	N.A.
Central	5	57.08066	-135.41067	Random	N.A.
Central	6	57.08286	-135.41309	Random	N.A.
Central	7	57.09083	-135.44141	Random	N.A.
Northwest	1	57.09262	-135.48775	Random	N.A.
Northwest	2	57.11289	-135.47694	Random	N.A.
Northwest	3	57.11756	-135.47359	Random	N.A.
Northwest	4	57.12670	-135.38884	Random	N.A.
Northwest	5	57.13137	-135.43290	Random	N.A.
Northwest	6	57.15411	-135.52673	Random	N.A.
Northwest	7	57.15790	-135.51498	Random	N.A.
Southeast	1	56.99510	-135.30654	Random	N.A.
Southeast	2	57.00465	-135.29402	Random	N.A.
Southeast	3	57.01135	-135.31216	Random	N.A.
Southeast	4	57.01418	-135.28129	Random	N.A.
Southeast	5	57.02741	-135.32592	Random	N.A.
Southeast	6	57.03461	-135.33009	Random	N.A.
Southeast	7	57.03932	-135.32925	Random	N.A.
Southeast	8	57.03562	-135.27971	Non-random	Ellsworth Cut
Southeast	9	57.04770	-135.33441	Non-random	Downtown Outfall

Figures

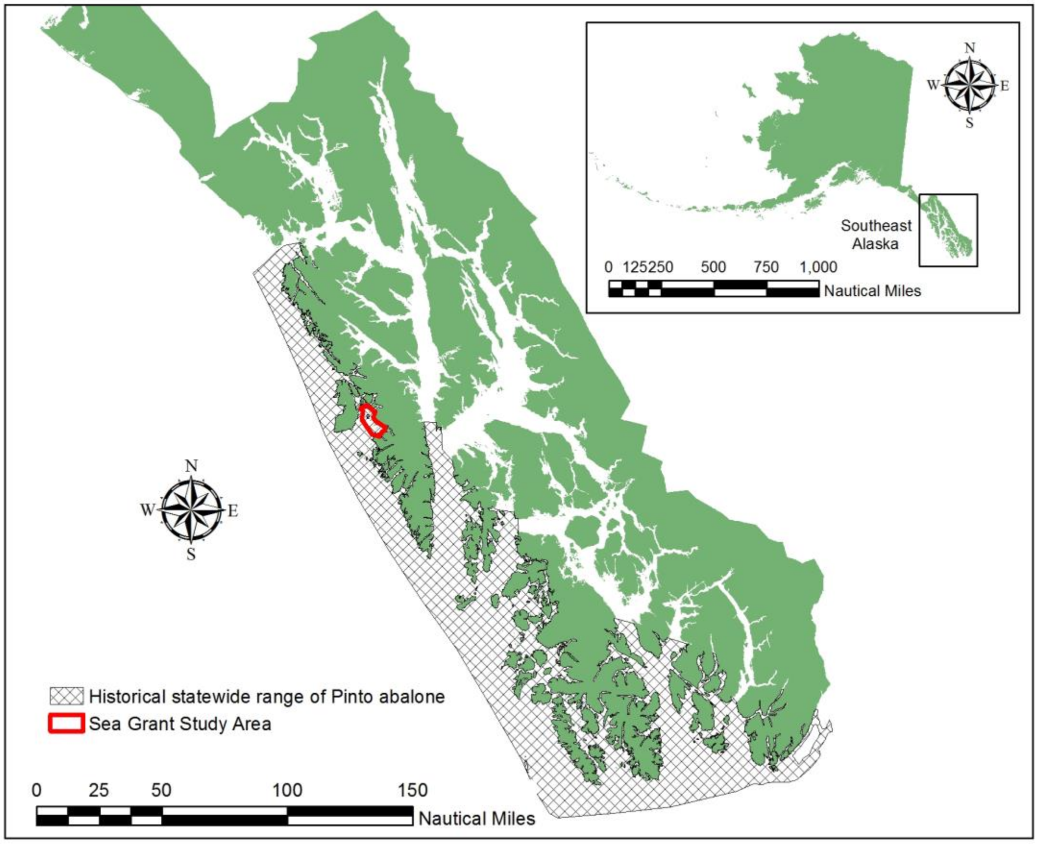


Figure 1.
Approximate historical statewide range of pinto abalone (*Haliotis kamtschatkana*). Data sources used to derive this range map included dive survey data and observations by the Alaska Department of Fish and Game (ADF&G), commercial fishery data, and expert knowledge by experienced ADF&G staff as of February 2011. The abundance of pinto abalone declined sharply from 1982 to 1996 (the period from the post-peak of commercial fishing harvests to the year commercial fishing ceased), and has apparently continued to decline from 1996 to present (2014). Pinto abalone have been disappearing from large areas of its range due, at least in part, to predation by sea otters, and to an unknown extent by humans. Subsistence and personal use fisheries remain open as of 2015, and the extent/intensity of any past and present poaching is unknown. Therefore, in sum this range depiction probably overestimates the geographic distribution of the extant population.

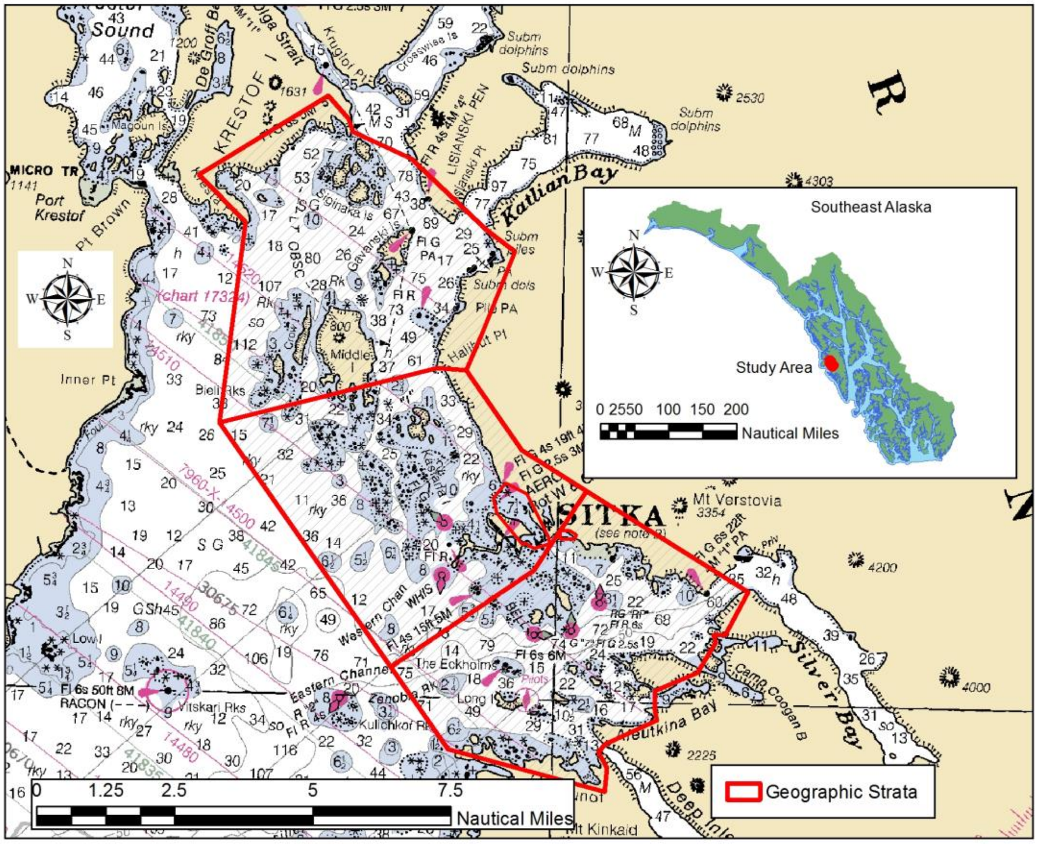


Figure 2.
Sitka Sound study area, subdivided into three geographic strata (from top left to lower right: Northwest, Central, and Southeast). Excluded from these strata were concentrated areas of heavy vessel traffic and a high degree of anthropogenic influence adjacent to Sitka, including Crescent Bay and the channel between Sitka and Japonski Island.

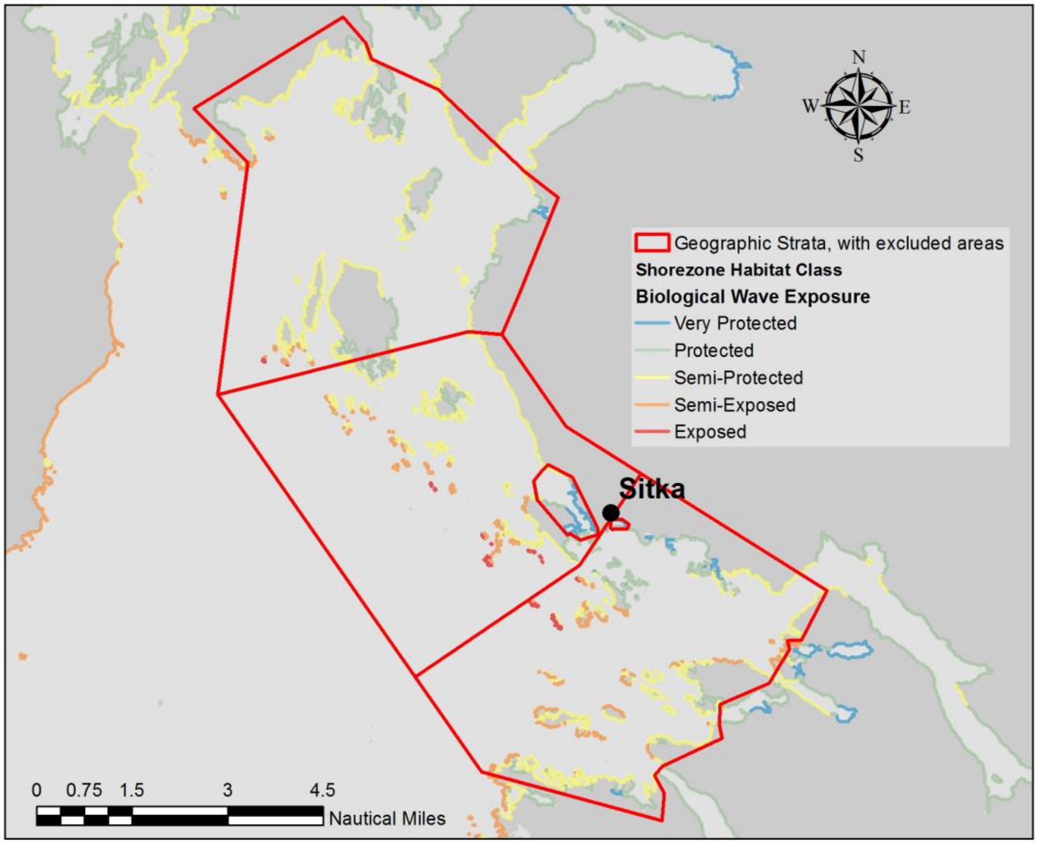


Figure 3.
Coastline within and outside of study area, color-coded according to “biological wave exposure” values from NOAA’s Shorezone database.

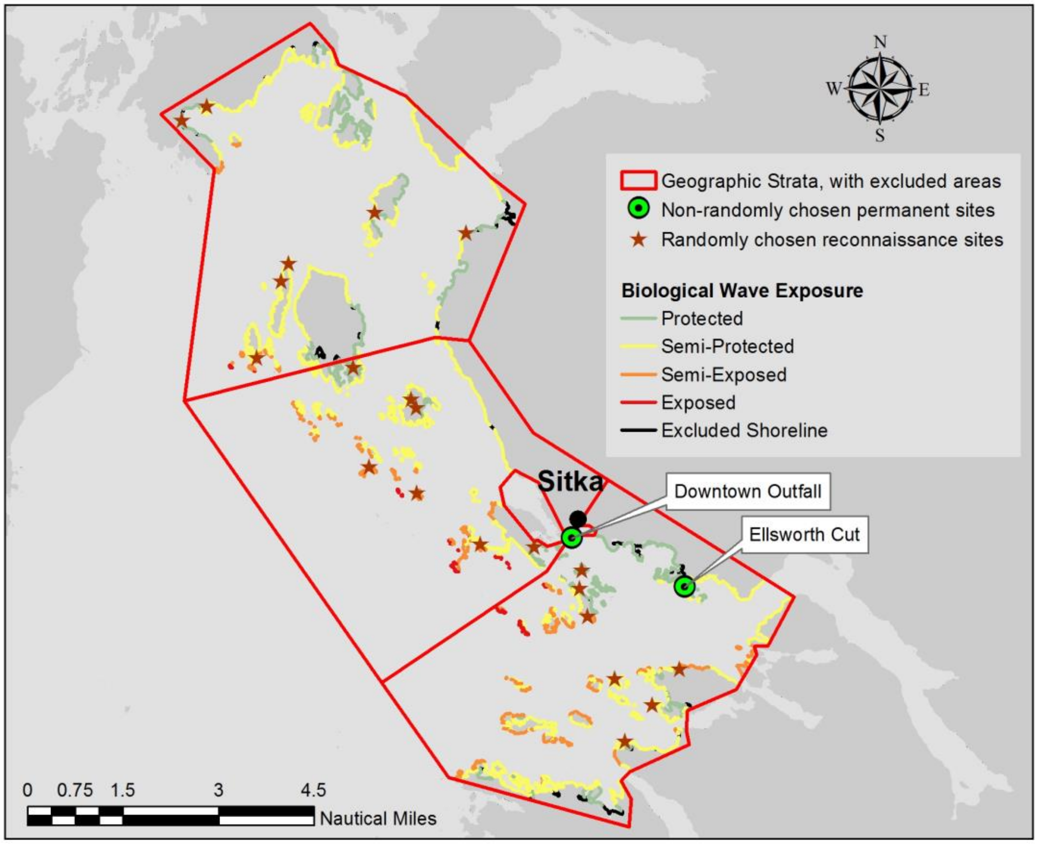


Figure 4.
Map of arbitrarily chosen permanent study sites and 21 reconnaissance sites (7 per geographic stratum) for potential selection as permanent study sites. Reconnaissance sites were chosen from shoreline in the study area classified in NOAA's Shorezone database as having biological wave exposure values of "Protected", "Semi-Protected", "Semi-Exposed", and "Exposed"; "Very Protected" shoreline was excluded from consideration of site placement, as was shoreline classified as having a dominant structuring force equal to "Fluvial/Estuarine", and sediment mobility classified as "Mobile".

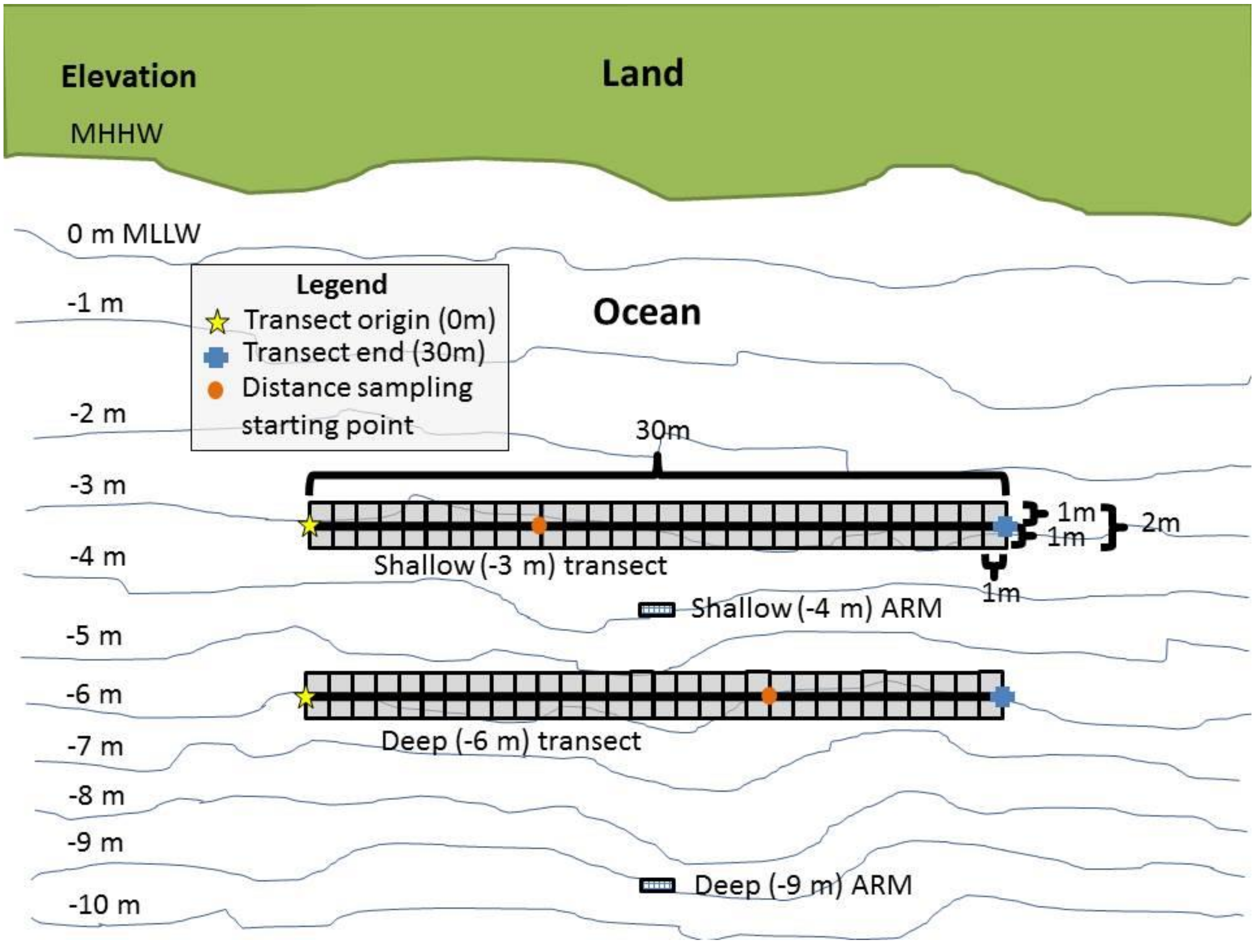


Figure 5.
Schematic of permanent site layout, including locations of depth-stratified strip transects, distance sampling starting points (the 10 m mark on the -3 m transect, and the -20 m mark on the -6 m transect), and Artificial Recruitment Modules (ARMs).

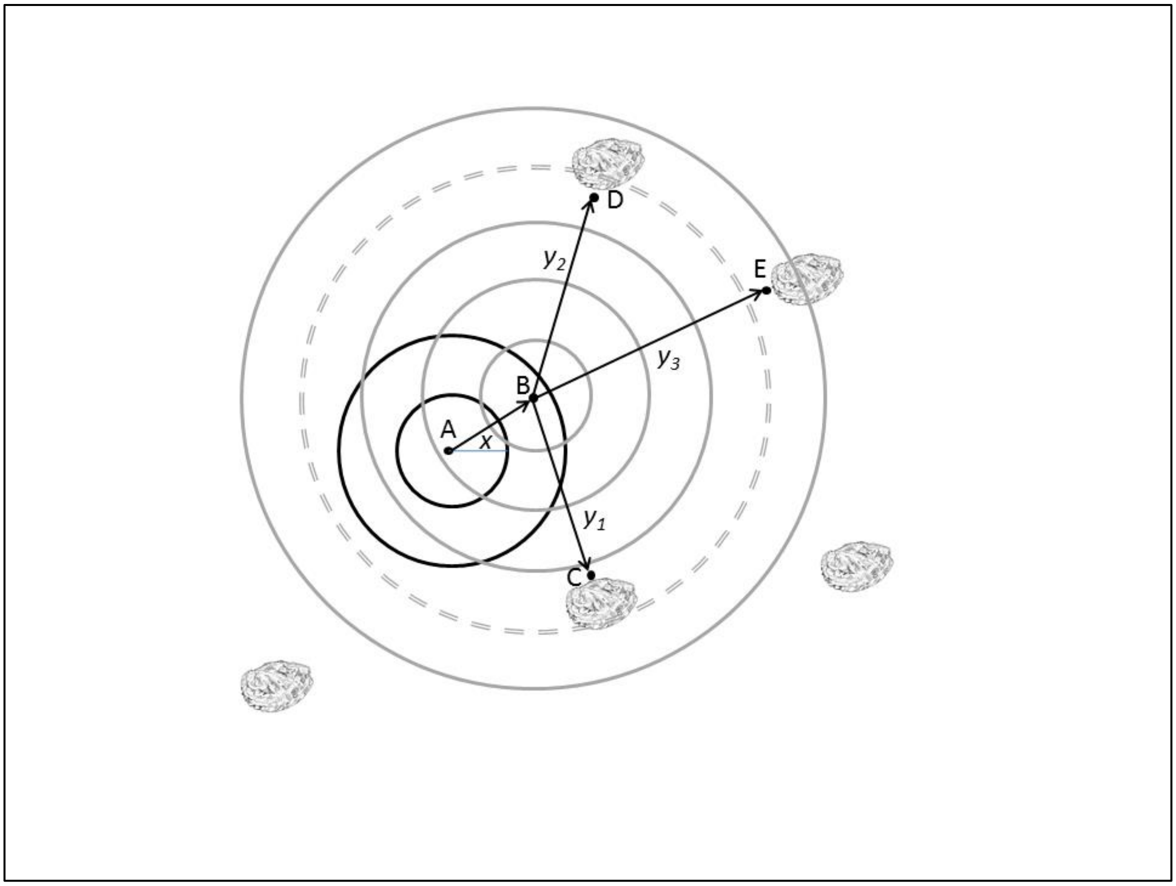


Figure 6.
Schematic of Kendall-Moran nearest neighbor sampling protocol and "aggregation" determination (adapted from Button 2008). The areas within the concentric circles represent the area searched. Each concentric circle is 1 m greater in diameter than the next smallest circle within it. A) the starting point for the search, arbitrarily chosen as the 10 m mark on the transect tape for the -3 m depth strata and the 20 m mark on the transect tape for the -6 m depth strata; B) nearest neighbor abalone to point A; x) distance from point A to point B; C) nearest neighbor to abalone at point B; y_1) distance from point B to point C; D) second nearest neighbor to abalone at point B; y_2) distance from point B to point D. The dashed double line represents the minimum search radius (4 m) around the first abalone observed (point "B"), and the summed count of abalone inside this circle is defined as the "aggregation"; the aggregation size would be 3 abalone in this example (points B, C, and D). If no abalone were observed inside the 4 m radius around the abalone at point B (which is not the case in this diagram), the divers would continue searching until they find the next nearest abalone (point E, in this example) ; y_3) distance from point B to point E. If no abalone were observed within a 10 m radius around the abalone at point B (again, which is not the case in this diagram), the divers would record a zero and abort the sampling.

Figure 7.
Photograph of planned Artificial Recruitment Module design (from Bouma et al. 2012); the open escape rings shown in this photograph will be closed in the present study.

Appendix A. Alternative Study Questions Considered

Alternative Study Questions Considered

1.
    a. Question: What is the density of abalone "patches"?
    b. Purpose of question: to test potential stock assessment methods and to put the within-patch density data collected during the 2015-16 Sea Grant study into perspective; would add significant value to the existing study, because could estimate absolute abundance, not just absolute density, and could also model total reproductive output potential
    c. Method: randomly or systematically allocate sampling sites and survey extensive sections of shoreline within the study area along the depth contour(s) of maximum density; ideally, a diver tracking/geolocation device would be used, or long transects (100 – 200 m) could be deployed
2.
    a. Question: What is the relative abundance and size frequency of abalone as a function of depth and wave exposure?
    b. Purpose of question: to refine subsequent large-scale abalone survey design
    c. Method: Perform a large number of transects perpendicular to the depth contour in different wave exposure strata (i.e., protected, semi-protected, semi-exposed, exposed), starting at 0 m MLLW and extending to 15 m, noting depth and size of each abalone encountered
3.
    a. Question: What are the microhabitat associations of abalone in Sitka Sound?
    b. Purpose of question: to identify optimal habitat for outplanting/transplanting abalone for recovery efforts
    c. Methods:
        i. Document a permanent record of microhabitat associations. Three photos will be taken of each abalone on transect, if possible: one top-down planar view with the diver's 1 m PVC rod completely in the photo (for scale), another top-down planar view close-up with 30 cm of the marked PVC rod in the photo, and one close-up oblique view of the abalone and its immediate surrounding habitat. These photos will make it possible for subsequent review by experts to identify uncommon or difficult-to-identify algal and invertebrate species associated with abalone. This photo method would also be consistent with Amanda Bird's methods for studying pinto abalone in California
        ii. During transects, note on datasheet whether abalone are inside or outside of cracks/crevices; if inside crack then measure the crack dimension and

depth in crack (refuge from otters); also record orientation (in degrees): 0, 45, 90, 135, 180

4.
   a. Question: What is the most effective ARM design, and what is the correlation of densities among different ARM designs?
   b. Purpose: To determine the most effective ARM design for future studies, and to provide a means of comparison/calibration between any potential new ARM design with the traditional ARM design that has been used in BC and WA (e.g., DeFreitas 2003, Bouma 2007).
   c. Method: Deploy 2 or more ARM designs at the same sites in different depth and wave exposure strata, and monitor at least annually.

5.
   a. Question: What is the correlation between juvenile abalone densities in ARMs versus natural habitat?
   b. Purpose of question: to calibrate the recruitment index data collected in ARMs with recruitment in natural habitats
   c. Method: Base methods on DeFreitas (2003), who addressed the same question in British Columbia; ideally, study this question at the same time as testing of different ARM designs

6.
   a. Question: What is the correlation between densities derived from the Canadian "Breen method" versus the density methods that will be used during the 2015-16 Sea Grant study (i.e., strip transects and distance sampling)?
   b. Purpose: to be able to directly compare density data collected during the 2015-16 Sea Grant study with the data collected extensively in time and space in Canada, and to calibrate the method against our existing methods.
   c. Method: Use both methods and describe relationship

7.
   a. Question: What is the sex ratio of abalone in Sitka Sound, and what is the reproductive status of each individual?
   b. Purpose: to test the validity of the assumption that the sex ratio is 50:50, which will then inform and simplify modelling of reproductive output
   c. Method: Use syringe extraction method described in Button and Rogers-Bennett (2011)

8.
   a. Question: What is the viability of the pinto abalone population, and what is the risk of extinction?
   b. Purpose: To inform management policies (e.g., open/close fishery, increase/decrease size limits) and recovery efforts

c. Method: Use size structure data to develop a population viability model and risk assessment (per California Ocean Science Trust recommendation to CDFW for red abalone fishery)

9.

a. Question: What is the “best” method to inform managers and interested stakeholders about the likelihood or risk that populations have crossed specified biological triggers, e.g., critical spawning density), given the population density estimate and its associated uncertainty?
b. Purpose: To inform discussion and facilitate open and transparent discussions among policymakers and resource users about the acceptable risk of various alternative courses of action in abalone management.
c. Method: Generate Cumulative Probability Functions (CPF). While CIs help provide an assessment of whether population densities have changed over time, and whether or not they are clearly above or below a threshold level, CPFs provide a means to explicitly evaluate the likelihood that the actual population density has met or surpassed the threshold (per California Ocean Science Trust recommendation to CDFW for red abalone fishery)

Appendix B. Detailed Field Protocols

Timed Swims

Purpose

To determine the relative density of pinto abalone for identifying candidate permanent index stations.

Metrics

- # of abalone observed per diver per minute
- # of abalone observed (summed counts for 2 divers) per minute

Materials

- Dive slate + pencil (2)
- Datasheets (2),
- Flashlight (2)
- Compass (2)
- pelican floats (2/diver)
- depth/time gauge (2)

Personnel

- SCUBA equipped divers (2)
- dive/skiff tender (1)

Sample Size / Sample Unit Size

One variable-sized (~75-200 m^2) timed swim survey per site; n = 21 sites (7 per geographic strata)

Frequency

One-time only, for 1 day during late May or early June, 2015

Methods

1. Select a starting point for timed swim
    a. Navigate to pre-selected site in skiff via GPS
    b. Assess substrate type of exposed intertidal and supratidal areas immediately onshore and determine if it is conducive abalone habitat (defined as substrate grain size ≥ cobble, or if the subtidal substrate is visible and is composed of substrate ≥ cobble); this criterion is reliant on the assumption that intertidal and supratidal substrate type is highly correlated with subtidal substrate type. If it is not obvious that the habitat is conducive to abalone, samplers should also reference chart plotter and fathometer (i.e. slope and rugosity of seafloor); some subjective assessment by samplers will be required
        i. If it is uncertain whether habitat is acceptable, divers should don masks and get a visual of the substrate > 2m depth, if possible; If the habitat is acceptable, proceed to step 1.c.
        ii. If habitat is not deemed acceptable, turn skiff to the right (from perspective of looking from offshore to onshore) and transit alongshore and have divers check habitat every 100 – 200m until the substrate is determined to be acceptable
    c. Once the sampling site is determined to be acceptable, deploy a temporary mooring buoy to mark the starting point at 5 m depth as close as possible to the pre-planned GPS coordinates;

record the GPS position in decimal degrees to 4 decimal places (NAD83 datum) on each diver's datasheet

2. Prior to the dive, fill out datasheet header information, including site number, tide-corrected target depths, and the magnetic bearing of the general alongshore direction to the right of the starting point
3. Dive team will descend the mooring buoy, record dive time on their datasheets when ready to start the survey, and begin searching for abalone in the general direction of the pre-determined bearing
4. Search technique:
    a. Search depth zones from approximately 2-7 m MLLW
    b. Search in a roughly zig-zag pattern from minimum to maximum target depths in the general direction of the pre-planned bearing
    c. Divers shall position themselves far apart enough to avoid double-counting abalone, but close enough to maintain buddy protocol 2 -3 m)
    d. When in suitable abalone habitat, swim at a pace conducive to being able to observe most, but not necessarily all, abalone; the pace at any given site will be dependent upon the complexity of the physical and biological habitat (e.g., substrate type, relief, number of crevices, algal cover); in practical terms, this pace would be slow in complex habitat and fast in simple (or unsuitable habitat)
    e. If divers lose visual contact with each other, they should note a stop time [for searching] on their datasheet and attempt to relocate their buddy; if the buddy cannot be found within one minute, they should ascend to the surface and re-establish contact; once contact is re-established, divers should descend to the seafloor, note the start time when they are ready to begin searching again
    f. Divers will search for abalone > 50 mm in maximum shell dimension, but will record data for all abalone observed
    g. Intensively search within promising microhabitats (e.g., cracks, crevices, near undersides of boulders, smooth patches of encrusting red coralline algae), using flashlights when illumination is poor or view is obstructed
    h. Do not invasively sample (e.g., turn over rocks, remove algae)
5. Deploy a pelican float when two or more abalone are observed within ~5m of each other
6. For each abalone observed, record the dive time and un-corrected depth
7. Search intensively in immediate vicinity of any abalone observed
8. After 20 minutes of searching, stop, and record:
    a. the dive time from the dive computer, and deploy a pelican float to mark the endpoint of the search
    b. approximate percent (to the nearest 10%) of suitable and unsuitable abalone habitat
    c. two most dominant substrate types
    d. the estimated along-shore width (in meters)of the largest abalone aggregation observed during the dive, and the estimated distance from the edge of this aggregation to the pelican float that was initially deployed
9. Deploy a pelican float to mark the end of the search
10. Once divers are back onboard skiff, record GPS positions for each pelican float

Permanent Index Station Establishment

Purpose

To establish permanent index stations in a consistent, un-biased fashion while ensuring that the station is adequately positioned to survey pinto abalone, resistant to external forces (e.g., human interference, wave action), and can be relocated easily.

Materials

- Dive slate + pencil (2)
- Datasheet (2)
- 50 m transect tape with brass clips on handle and end of tape (1)
- Pelican float (2)
- Compass (2)
- Dive computer/depth gauge (2)
- Camera
- 40 m lead line
- Anchoring material and equipment, including but not necessarily limited to:
    - Rebar stakes (~2 ft. long), with flagging tied around one end
    - Mallet
    - Pneumatic drill (1)
    - 0.25” drill bit (3)
    - 6” stainless steel lag bolts (4)
    - Epoxy
    - Rock pitons
- Subsurface mooring
    - Small plastic buoy (3” diameter?)
    - Pre-fabricated ~1-1.5m buoy polyline, with buoy attached and loop on distal end
- Game bag(s) for all anchoring materials

Personnel

- SCUBA equipped diver (2)
- Dive/skiff tender (1)

Sample Size / Sample Unit Size

One planar perspective 30x2 m (60 m^2) transect per depth stratum (-3 and -6 m, MLLW); n = 2 transects per site

Frequency

One-time only, for one partial day, and possibly one follow-up day, during mid- June, 2015

Methods

1. Fine-tune placement of transects at each site in each depth strata
    a. Review datasheet notes from reconnaissance survey at each site, noting where the largest abalone aggregation was observed relative to recorded landmarks (i.e., start point of timed swim, end point of timed swim, start point of abalone aggregation; decide where to begin dive for permanent transect placement
    b. At each site, navigate the skiff to where it was decided the transect should begin, intentionally erring in the opposite alongshore direction of the transect (so not to drop an anchor on top of abalone), and then navigate directly on- or offshore to the 3 m depth contour; deploy a temporary mooring buoy with a ~15 lb. anchor
    c. Determine compass bearing (alongshore, to the left of the starting point) and record on datasheet
    d. Clip 0 m end of transect tape to mooring anchor and quickly navigate along -3 m depth contour in same direction as the reconnaissance transect, paying out the transect tape to the 50 m mark
    e. Once the transect tape is paid out, reverse course and slowly search for abalone on 1m to either side of the transect, recording:
        i. the meter mark where each abalone is observed
        ii. the start and endpoints of substrate unsuitable for abalone (i.e. where the dominant percent cover is “mobile” (i.e. defined here as substrate that moves at least once per year); mobility is a function of substrate grain size and wave exposure; e.g., sand can move anytime, cobble in shallow subtidal depths at exposed locations can move during moves during periods of moderate wave action, and boulders at very exposed locations can move during major wave events); if degree of substrate mobility is not obvious (e.g., sand or gravel, which is always mobile except for extremes of low wave and current exposure), evidence for mobility should be inferred by an absence of perennial algae or invertebrates on the substrate; Mobility is subjectively assessed and therefore depends on the knowledge, experience, and judgment of the observer.
    f. Once the entire 50 m transect has been surveyed, assess the datasheets *in situ* and determine precisely where the 30 m transect should be placed in order to maximize the number of abalone observed (primary consideration), while simultaneously minimizing the distance of unsuitable substrate (secondary consideration); the transect origin (0m mark) should be at the left endpoint of the transect (from the perspective of looking onshore from offshore)
    g. Re-position the transect and deploy pelican floats at the start and end points to mark the positions, while noting what the most effective anchoring strategy would be for each endpoint, then ascend to surface
2. Establish transect start and end points
    a. Clip a game bag(s) with leadline, mooring buoys, and all appropriate anchoring hardware and equipment to a temporary mooring with a ~25 lb. anchor, and drop the mooring as closely to the transect origin as possible (erring upslope)
    b. Diver team descends mooring line and re-positions mooring anchor to exact location of transect origin, and then bobs the mooring buoy to signal to the skiff operator to record the GPS coordinates of the starting point

c. Divers install optimal permanent anchor, attach subsurface mooring, and take photo of finished product, including a dive slate in the picture that includes a description of which endpoint the photo represents (e.g., Ellsworth Cut, -3 m transect, origin)
d. Repeat process for other end of transect, and then for the -6 m transect
e. After -6 m transect is installed, follow protocol for deploying ARMs

Strip Transects

Purpose

To determine the absolute density, size class, and between-individual distances of pinto abalone occurring within small-scale aggregations, and how these metrics change over time (bi-weekly to annually), in a standardized manner to facilitate comparisons to other studies.

Metrics

- # abalone per square meter
- Between-individual distance
- Shell length (long axis)

Materials

- dive slate + pencil (2)
- datasheets (2)
- 1m transect rod (2)
- Compass (2)
- Flashlight (2)
- Mirror (2)
- dive computer with depth gauge and timer (2)
- calipers (2)

Personnel

- SCUBA equipped divers (2)
- dive/skiff tender (1)

Sample Size / Sample Unit Size

One planar perspective 30x2 m (60 m^2) transect per depth stratum (-3 and -6 m, MLLW), with each transect subdivided into six 10x1 m subsamples (0-10 m, 10-20 m, 20-30 m, and onshore/offshore of transect tape); n = 2 transects per site

Frequency

- Bi-annually (once in late May mid-June and once in mid-August – mid-September) for all permanent index stations; June 2015 – September 2016; n = 4 temporal replicates (n = 2 per year)
- Bi-weekly [neap/spring tides] for a subset of two permanent index stations from April 1 – September 15 (2015: n = 7 total, n = 5 net; 2016: n = 12 total, n = 10 net)

Methods

1. Lay out transect tape, if it is not already; transect origin (0m mark) should be at the left endpoint of the transect (from the perspective of looking onshore from offshore)

2. Starting at the transect origin, search for abalone within 1m swath on each side of transect (one diver per side)
    a. Search very carefully and exhaustively
    b. Search for abalone > 50 mm in maximum shell dimension
    c. Intensively search complex microhabitats where abalone can and often do hide (e.g., cracks, crevices, near undersides of boulders, smooth patches of encrusting red coralline algae); use mirror if possible when view is obstructed
    d. Use flashlight whenever illumination is too poor to observe an abalone if it was there, especially in microhabitats described above
    e. Do not invasively sample (e.g., turn over rocks, remove algae)
3. For each abalone encountered on-transect, record:
    a. Length of longest shell dimension, to nearest mm
        i. if animal is accessible; measure with calipers; BE CAREFUL NOT TO CUT THE ABALONE WHEN MEASURING THEM – THEY ARE HEMOPHILIACS AND MAY DIE
        ii. if inaccessible, estimate length and note checkbox as estimated
    b. Location of each abalone relative to transect tape (meter mark on transect tape, and perpendicular planar distance from transect tape to abalone, both to nearest centimeter)
    c. Depth (un-corrected)
    d. Behavior (emergent or cryptic)
    e. Substrate type that it is on (i.e. bedrock, boulder [0.256 - 4.096 m], cobble [6.4 < 25.6 mm], pebble/granule [2 < 64 mm], sand [0.0625 - <2 mm], per CMECS 2012)
4. At the end of the 30 m transect, reverse course and record the following data for every 5 m increment:
    a. Dominant algal species
    b. algal cover, by functional group)
5. At end of the transect, record overall estimated horizontal visibility and surge, and the presence of any abalone predators that were encountered (e.g., octopus, wolf eel, Cancer crabs, large sculpins)
6. The first time a transect is surveyed after it is initially established, divers will record the following data for every 1 m increment of transect:
    a. Depths at transect tape, and at onshore/offshore edges of 2 m-wide transect
    b. Primary substrate type

Distance Sampling

Purpose

To determine the between-individual nearest neighbor distances, aggregation sizes, absolute density, and size frequency of pinto abalone, and how these metrics change over time (bi-weekly to annually), in a standardized manner to facilitate comparisons to other studies.

Metrics

- Between-individual nearest neighbor distances (Kendall-Moran Protocol)
- # abalone per aggregation
- # abalone per square meter
- Shell length (long axis)

Materials

- dive slate + pencil (2)
- datasheets (2)
- 30 m transect tape (1)
- Flashlight (2)
- dive computer with depth gauge and timer (2)
- calipers (2)
- 10 lb. weight, with loop (1)

Personnel

- SCUBA equipped divers (2); one sampler/data recorder and one sampler/transect tape manager
- dive/skiff tender (1)

Sample Size / Sample Unit Size

One distance sampling event per depth stratum (-3 and -6 m, MLLW) per site; sample unit size is variable

Frequency

- Bi-annually (once in late May – mid-June and once in mid-August – mid-September) for all permanent index stations; June 2015 – September 2016; n = 4 temporal replicates
- Bi-weekly [neap/spring tides] for a subset of two permanent index stations from April 1 – September 15 (2015: n = 7 total, n = 5 net; 2016: n = 12 total, n = 10 net)

Methods (see figure below for illustration of method)

1) For each abalone encountered during distance sampling, measure and record:
    a) Length of longest shell dimension, to nearest mm
        i) if animal is accessible; measure with calipers; BE CAREFUL NOT TO CUT THE ABALONE WHEN MEASURING THEM – THEY ARE HEMOPHILIACS AND MAY DIE

        ii) if inaccessible, estimate length and note checkbox as estimated
    b) Distance and magnetic bearing) to abalone from origin reference point (see below, to nearest centimeter and degree, respectively)
    c) Depth (un-corrected for tidal stage)
    d) Behavior (emergent or cryptic)
    e) Substrate type that it is on (i.e. bedrock, boulder [0.256 - 4.096 m], cobble [6.4 < 25.6 mm], pebble/granule [2 < 64 mm], sand [0.0625 - < 2 mm]) Grain sizes will be estimated in the field
    f) Note if the abalone is within the 30 x 2 m transect boundaries, so they are not double-counted in subsequent summaries and analyses (e.g., length frequencies, species – habitat analyses)
2) Navigate to 10 m mark (point "A" in figure) on transect in the -3 m depth stratum, then place weight on mark and attach end of transect tape to weight; record depth on datasheet
3) Find the nearest abalone to 10 m mark
    a) Pay out 2 m of transect tape and position divers so that the recorder is between the 0 and 1 m mark and the transect tape manager is between the 1 and 2 m mark, and holding the transect tape reel
    b) Search for abalone in incrementally increasing concentric rings around the tape origin (point "A" in figure); and record the distance and other metrics to the first abalone observed (point "B" in figure); complete a full rotation of the circle and only search for abalone that are closer to the origin than the first abalone observed; if a closer abalone is observed, update the data on the datasheet accordingly; repeat search process until a full rotation of the circle is completed;
    c) If no abalone are observed within a 10m radius circle around the 10 m mark on the transect tape (point "A" in figure), abort the sampling event and move to the next depth stratum (if applicable)
4) Find the nearest neighbor of the abalone that is closest to the 10 m mark (point "A" in figure)
    a) Move the weight from the 10m transect mark (point "A") to immediately adjacent to the abalone (point "B" in figure) that was determined to be closest to the 10 m mark, and attach the end of the transect tape to the weight
    b) Search for abalone in incrementally increasing concentric rings around the tape origin; measure and record the distance and other metrics to all abalone observed (points "C" and "D" in the figure), along with depth and bearing from origin to abalone, within a 4 m radius of the abalone at the origin (point "B" in the figure)
        i) If no abalone were observed within 4 m of the origin, repeat concentric search process in 2 m distance increments (1 m per diver) until an abalone is observed (e.g., point "E" in the figure)
5) Repeat process for transect in -6 m depth strata, but begin at 20 m mark instead

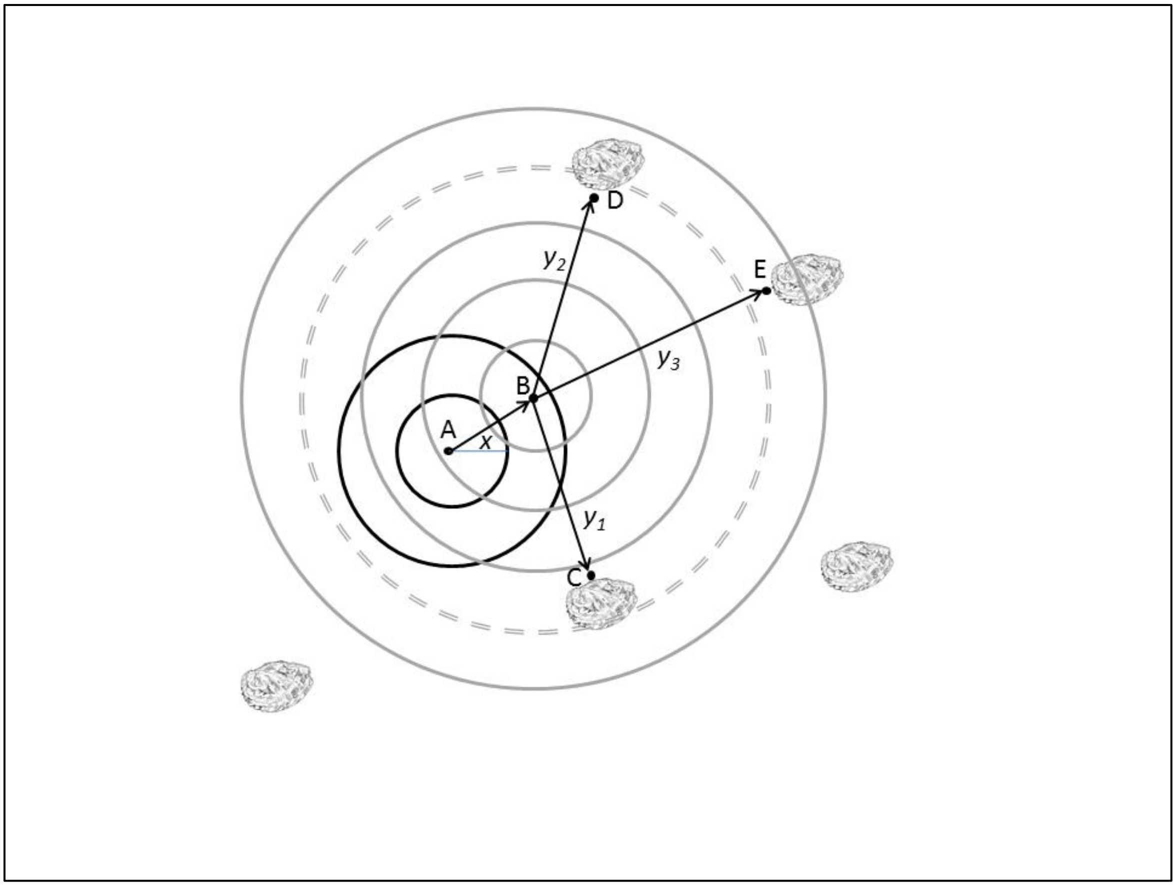


Diagram of Kendall-Moran nearest neighbor sampling protocol and “aggregation” determination (adapted from Button 2008). The areas within the concentric circles represent the area searched. Each concentric circle is 1m greater in diameter than the next smallest circle within it. A) the starting point for the search, arbitrarily chosen as the 10 m mark on the transect tape for the -3 m depth strata and the 20 m mark on the transect tape for the -6 m depth strata; B) nearest neighbor abalone to point A; x) distance from point A to point B; C) nearest neighbor to abalone at point B; y_1) distance from point B to point C; D) second nearest neighbor to abalone at point B; y_2) distance from point B to point D. The dashed double line represents the minimum search radius (4 m) around the first abalone observed (point “B”), and the summed count of abalone inside this circle is defined as the “aggregation”; the aggregation size would be 3 abalone in this example (points B, C, and D). If no abalone were observed inside the 4 m radius around the abalone at point B (which is not the case in this diagram), the divers would continue searching until they find the next nearest abalone (point E, in this example) ; y_3) distance from point B to point E.

Artificial Recruitment Modules (ARMs) – Construction and Deployment

Purpose

To construct an effective, efficient sampling tool for quantifying newly recruited and young juvenile pinto abalone, and to do so in a standardized manner to facilitate comparisons with other studies.

Materials

Construction (modelled on Bouma 2007, 2012 and DeFreitas 2003)

Figure from Bouma et al. 2012; note open escape rings shown here will not be included in the design for this study

- Enclosure type: commercial Dungeness crab pot (~1 m diameter x ~0.3 m high), including crossbars and hinged lid on top; entry tunnels removed and escape ring holes removed or blocked
- Stainless steel wire w/ diamond mesh size 65x90 mm
- Concrete cinderblocks 40x20x20 cm (L x W x H) (6/ARM); with each block cut in half and then again longitudinally, to make "E"-shaped pieces (24/ARM)
- Concrete saw

Deployment (quantities listed are per transect)

- ARM, empty (1)
- ¼ cinderblock pieces (24)
- X lb. lift bag (2)
- Cable ties (10)
- Pneumatic drill (1)
- 0.25" drill bit (3)
- 6" stainless steel lag bolts (4)
- Epoxy
- Rock pitons
- 2m lengths of polyline (4)
- Camera

Personnel

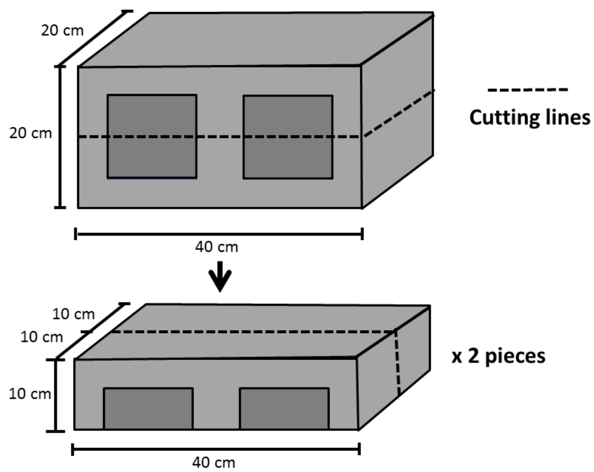
- SCUBA equipped divers (2)
- dive/skiff tender (1)

Frequency

One-time only, for 1 day during late May or early June, 2015

Methods

1. Cut 108 full-sized cinderblocks (40x20x20 cm L x W x H) into quarters; cut each block in half (to make two "E"-shaped pieces), and then again longitudinally, into four "E"-shaped pieces (= 432 total)



2. As soon as possible (February 2015, ideally), place all 432 cinderblock pieces in a rocky shallow subtidal area that is ~4-6 m deep, moderately protected, to "condition" substrate (i.e., dilute contaminants in concrete, allow colonization by encrusting coralline and other algae)
3. Deploy ARMs
   a. During the dive when the permanent transect is being placed, identify and mark the intended location of the ARM with a pelican float
      i. Place one ARM at 5 m depth, directly upslope of the 15 m mark on the transect tape for the 6 m depth strata, and at least 3 m away from the transect tape (with priority to the latter if both conditions aren't met)
      ii. Place one ARM at 9 m depth, directly downslope of the 15 m mark on the transect tape for the 6 m depth strata, and at least 3 m away from the transect tape (with priority to the latter if both conditions aren't met)
   b. Drop off each unloaded ARM from a dive skiff at the designated GPS point, and then drop the 24 cinder block pieces that will go inside of it as closely as possible to the ARM
   c. Fine-tune position of ARM, using liftbags if necessary
   d. Secure ARM to the seafloor using lag bolts or pitons (3-4 should suffice), and polyline
   e. Place the 24 cinderblock pieces haphazardly in each ARM, then secure the lid with cable ties
   f. Photograph the completed ARM, including at least a top-down planar view and a view from each side; and a photo of one of the datasheets with completed header info (to link photos to location and depth strata)

Artificial Recruitment Modules (ARMs) – Sampling

Purpose

To obtain a meaningful, repeatable, and comparable index of pinto abalone recruitment to the subset of the abalone population within the study area

Metric

- # abalone < 50 mm per m^2 [of ARM surface area]

Materials

- Dive slate + pencil (1)
- Datasheets (1),
- Flashlight (2)
- Vernier calipers (2)
- Dive knife or scissors (1)
- Cable ties (10)
- Camera (1)

Personnel

- SCUBA equipped divers (2)
- dive/skiff tender (1)

Sample Size / Sample Unit Size

One ARM (~3.5 m^2) per depth strata (-6 and -9 m, MLLW) per Index Site (n = 16)

Sampling Frequency

August 2016 and November/December 2016; n = 2

Methods

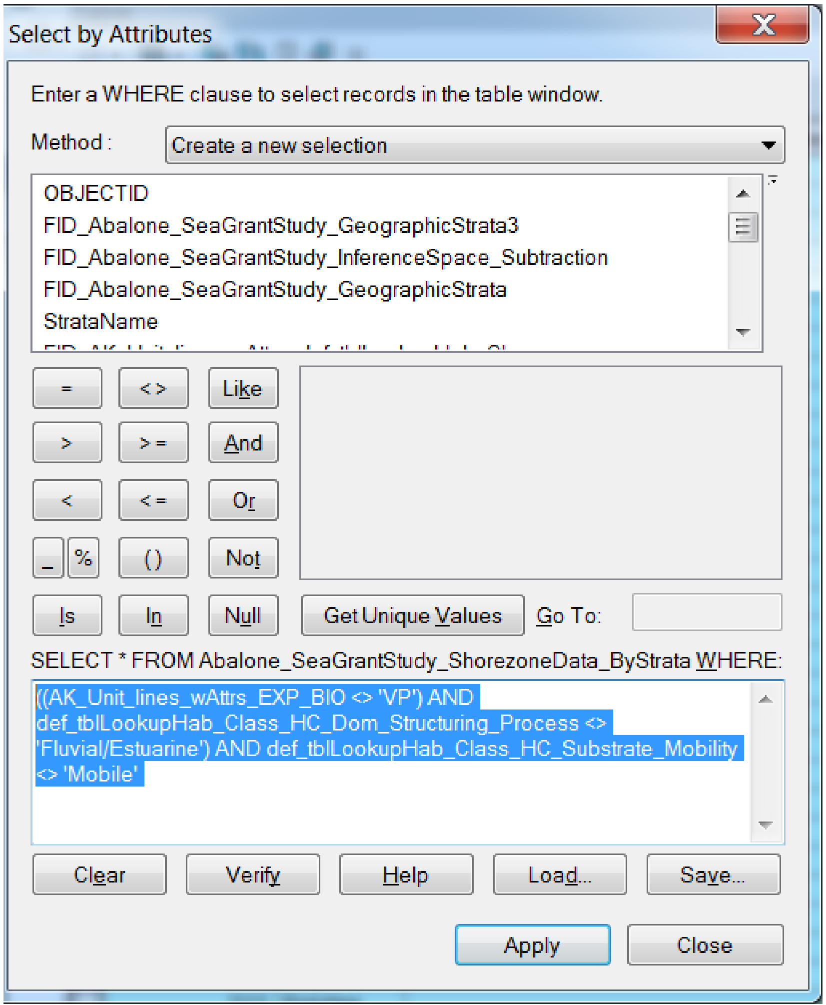
1. Take photos of the ARM for a permanent record prior to any work on the module; include at least a top-down planar view, and views from each side; take a photo of one of the datasheets with completed header info to link photos to location and depth strata
2. Cut cable ties, open lid, and carefully take out and inspect each cinderblock piece with a flashlight for abalone
3. Measure and record the maximum shell dimension of each abalone to the nearest millimeter using Vernier calipers

4. Remove any predators of abalone (e.g., octopus, seastars, crab, sculpins) from each cinderblock and set aside
5. Carefully set aside each cinderblock piece after it has been inspected, being sure not to crush any abalone
6. Record the following ancillary data after abalone sampling is complete:
   a. presence of any abalone predators in the ARM
   b. uncorrected depth of ARM
   c. algal type and percent cover on cinderblocks
   d. encrusting invertebrate type and percent cover on cinderblocks
   e. any relevant notes (e.g., if ARM moved from last known location, was found upside down, etc.)
7. Haphazardly replace all cinderblock pieces into the ARM, being careful not to crush any abalone; do not include any predators that were found in the ARM
8. Close ARM lid and secure with cable ties
9. Navigate to next ARM in other depth strata and repeat process

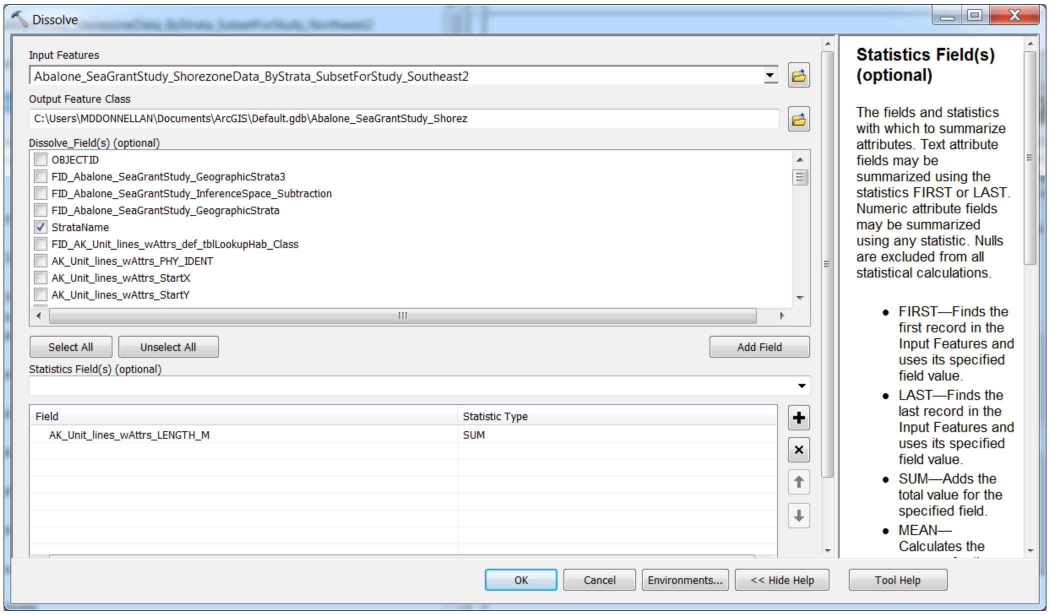
Appendix C. GIS Methods to Select Shorezone Data of Interest

GIS Methods to Select Shorezone Data of Interest

1. Draw polygon around study area
2. Create 3 geographic strata in separate feature class
3. Draw polygons around areas to be excluded from study (i.e. around harbors) in separate feature class
4. Use Union geoprocessing tool to combine the geographic strata feature class with the exclusion feature class
5. Edit resultant file and delete harbor area polygons, which results in "donut holes" in the strata feature class
6. Intersect Shorezone feature class "AK_Unit_lines_wAttrs" to the resultant file (note: apparently, ArcCatalog must first be closed before this process will run successfully; I have also had to close ArcMap and re-open before the process would run correctly)
    a. Open data table of resultant feature in Arc, and export data as a text file
    b. Import data to MS Access and summarize by study area and by strata
    c. Export data to Excel for formatting into table for report
7. In GIS, create a subset of the resultant Shorezone GIS feature class that excludes shoreline with either "very protected" wave exposure, "fluvial/estuarine" as the dominant structuring process, or substrate mobility of "mobile"
    a. Open attribute table from previous step and select by attributes using the following criteria: ((AK_Unit_lines_wAttrs_EXP_BIO <> 'VP') AND def_tblLookupHab_Class_HC_Dom_Structuring_Process <> 'Fluvial/Estuarine') AND def_tblLookupHab_Class_HC_Substrate_Mobility <> 'Mobile'

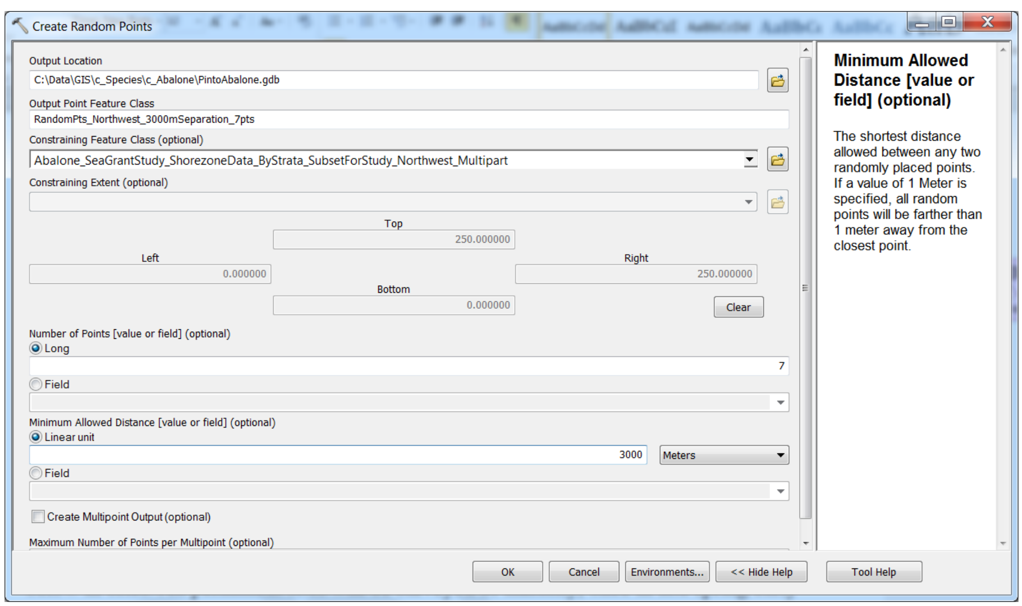
b. 

8. Create pool of potential long-term monitoring station sites in each geographic strata
    a. Create subsets of resultant polyline feature class from previous step, one feature class for each geographic strata (via opening attribute table and selecting by attributes for each Strata value)
    b. Convert each polyline subset (e.g., Northwest) into a multipart polyline feature class using the “Dissolve” tool (this step is needed because the create random points tool views each singlepart feature individually)

c. 

d. Create 7 random points in each geographic strata using the "create random points" tool (data management tools – feature class); Note: ArcInfo full version (or possibly ArcEditor – I didn't try it) is required to use this tool

    i. I arbitrarily imposed a 3000 m minimum separation distance between points (along the polyline, not a radius around a point; the latter would have been more desirable but was not an automated tool in ArcGIS; this could be done manually) to force greater dispersion of sites; note however that this did not guarantee dispersion because of the vagaries of how the polyline was constructed in Arc, most notably around islets, islands and complex shorelines.

    ii. 

Appendix D. Field Datasheet Templates

Abalone Roving Timed Swim Datasheet

Site Name: ______________________________ Date (m/d/yyyy): ____ / _____ / ________

Recorder Name: ________________________ Buddy Name: ________________________

Dive Time Start: __________ Dive Time End: __________ (hhmm, 2400 hr format)

Roving Time Start: __________ Roving Time End: __________ (minutes)

Ab #	Z (ft)	Shell length (mm)*	Ab #	Z (ft)	Shell length (mm)*	Ab #	Z (ft)	Shell length (mm)*	Ab #	Z (ft)	Shell length (mm)*	Ab #	Z (ft)	Shell length (mm)*
1			11			21			31			41		
2			12			22			32			42		
3			13			23			33			43		
4			14			24			34			44		
5			15			25			35			45		
6			16			26			36			46		
7			17			27			37			47		
8			18			28			38			48		
9			19			29			39			49		
10			20			30			40			50		

Comments:

Abalone Roving Timed Swim Datasheet

Site Name: ______________________________ Date (m/d/yyyy): ____ / _____ / ________

Recorder Name: ________________________ Buddy Name: ________________________

Dive Time Start: __________ Dive Time End: __________ (hhmm, 2400 hr format)

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5			15			25			35			45		
6			16			26			36			46		
7			17			27			37			47		
8			18			28			38			48		
9			19			29			39			49		
10			20			30			40			50		

Comments:

Abalone Survey Transect Datasheet (side 1)

Site Name: ________________________________ Date (m/d/yyyy):____/_____/________

Recorder Name:____________________________ Buddy Name:______________________________

Tide Correction (+/- ft): _____ Target Depth (un-corrected, ft):______ Bearing (° mag.):_______

Transect Side (In/Offshore):___________ Surge Index (0-3): ______ Vis. Range (ft):__________

		30-20m	20-10m	10-0m	Instructions/Notes
Habitat	Bedrock				1. Record % cover in 10% increments for each substrate
	Boulder (26cm-4m)				and vegetation class independently (range: 0-100%)
	Cobble (6-26cm)				2. Cumulative substrate % cover must be ≥ 100%
	Pebble (0.4-6cm)				3. Cumulative veg % cover has no lower limit
	Shell/Sand				4. Vegetation classes are based on height above
	Vert. Relief Index				bottom, not thallus length
	Crevice Index				5. Vertical Relief Index categories: "0" = 0-0.5m [change
Vegetation	Canopy (surface)				in depth in 1x10m area], "1"=0.5-1m, "2"=1-2m, "3"=>2m
	Sub-canopy (1-3m)				6. Crevice Index categories: "0" = no crevices, "1"=1-5,
	Foliose (0.1-1m)				"2"=6-10, "3"=>10
	Turf (<0.1m)				7. Surge Index categories: "0"= not noticeable, "1" =
	Encrust. Coralline				noticeable but doesn't or mildly affects work, "2"=
Encrusting/Turf Inverts					moderately affects work, "3"=strongly affects work

Dominant algal taxa:____

Abalone Survey Transect Datasheet (side 1)

Site Name: ________________________________ Date (m/d/yyyy):____/_____/________

Recorder Name:____________________________ Buddy Name:______________________________

Tide Correction (+/- ft): _____ Target Depth (un-corrected, ft):______ Bearing (° mag.):_______

Transect Side (In/Offshore):___________ Surge Index (0-3): ______ Vis. Range (ft):__________

		30-20m	20-10m	10-0m	Instructions/Notes
Habitat	Bedrock				1. Record % cover in 10% increments for each substrate
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Vegetation	Canopy (surface)				in depth in 1x10m area], "1"=0.5-1m, "2"=1-2m, "3"=>2m
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	Encrust. Coralline				noticeable but doesn't or mildly affects work, "2"=
Encrusting/Turf Inverts					moderately affects work, "3"=strongly affects work

Dominant algal taxa:____

Abalone Survey Transect Datasheet (side 2)

Site Name: ________________________________ **Date (m/d/yyyy):** ____ / _____ / ________

Recorder Name: ____________________________ **Buddy Name:** __________________________

Dive Time Start: ___________ **Dive Time End:** ___________ **(hhmm, 2400 hr format)**

Transect Time Start: ___________ **Transect Time End:** ___________ **(minutes)**

Ab #	Z (ft)	Meter Mark (m.##)	⊦ Dist. to tape (cm)	Shell length (mm)*	Ab #	Z (ft)	Meter Mark (m.##)	⊦ Dist. to tape (cm)	Shell length (mm)*	Ab #	Z (ft)	Meter Mark (m.##)	⊦ Dist. to tape (cm)	Shell length (mm)*
1					11					21				
2					12					22				
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4					14					24				
5					15					25				
6					16					26				
7					17					27				
8					18					28				
9					19					29				
10					20					30				

Comments:

Abalone Survey Transect Datasheet (side 2)

Site Name: ________________________________ **Date (m/d/yyyy):** ____ / _____ / ________

Recorder Name: ____________________________ **Buddy Name:** __________________________

Dive Time Start: ___________ **Dive Time End:** ___________ **(hhmm, 2400 hr format)**

Transect Time Start: ___________ **Transect Time End:** ___________ **(minutes)**

Ab #	Z (ft)	Meter Mark (m.##)	⊦ Dist. to tape (cm)	Shell length (mm)*	Ab #	Z (ft)	Meter Mark (m.##)	⊦ Dist. to tape (cm)	Shell length (mm)*	Ab #	Z (ft)	Meter Mark (m.##)	⊦ Dist. to tape (cm)	Shell length (mm)*
1					11					21				
2					12					22				
3					13					23				
4					14					24				
5					15					25				
6					16					26				
7					17					27				
8					18					28				
9					19					29				
10					20					30				

Comments:

Artificial Recruitment Module Sampling

Site: ______________ ARM(A/B): ___________ Date (m/d/yyyy): 08 / _____ /2016

Recorder Name: ___________________________________ Buddy Name: __________________________

Dive Time Start: ___________ Dive Time End: ___________ Tide Correction: ______

Sample Time Start: ___________ Sample Time End: ___________ ARM depth (uncorrected) ______ft

Substrate 1°:_____________ Substrate 2°____________ Number of bricks sampled: _________

Algae/Inverts	% Cover
Encrust. Coralline	
Art. Coralline	
Tube worms	
Brown Film	
Turf (<0.1m)	
Foliose reds (0.1 -1m)	
Sessile Inverts	

Ab #	Shell length (mm)*	Ab #	Shell length (mm)*	Ab #	Shell length (mm)*	Ab #	Shell length (mm)*
1		11		21		31	
2		12		22		32	
3		13		23		33	
4		14		24		34	
5		15		25		35	
6		16		26		36	
7		17		27		37	
8		18		28		38	
9		19		29		39	
10		20		30		40	

Other Recruits	#
Sculpins	
Sebastes	
Pisaster	
Other Stars	
Pycnopodia <50mm	
Pycnopodia >50mm	
Chlamys spp.	
Snails	
Green Urchin	
Red/Purp Urchin	
Limpets	

Comments:

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