Prepared in cooperation with the U.S. Navy

Black Abalone Surveys at Naval Base Ventura County, San Nicolas Island, California: 2019, Annual Report

Open-File Report 2020–1047

U.S. Department of the Interior
U.S. Geological Survey

Cover Photo: A cluster of black abalone on the west end of San Nicolas Island, California. Photograph taken by M.C. Kenner, February 26, 2018.

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DAVID BERNHARDT, Secretary

U.S. Geological Survey
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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
Length		
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)
Area		
square meter (m^2)	0.0002471	acre

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F = (1.8 × °C) + 32.

Datum

Horizontal coordinate information is referenced to the World Geodetic System of 1984 (WGS 84).

Abbreviations

INRMP	Integrated Natural Resources Management Plan
NOAA	National Oceanic and Atmospheric Administration
SNI	San Nicolas Island
WS	withering syndrome
USGS	U.S. Geological Survey

Black Abalone Surveys at Naval Base Ventura County, San Nicolas Island, California: 2019, Annual Report

By Michael C. Kenner[1,2]

Abstract

The U.S. Geological Survey Western Ecological Research Center's Santa Cruz Field Station, Santa Cruz, California, has been funded by the U.S. Navy to continue monitoring a suite of intertidal black abalone sites at San Nicolas Island, California. The nine rocky intertidal sites were established in 1980 by Glenn VanBlaricom (then of the U.S. Fish and Wildlife Service) to study the potential impact of translocated sea otters on the intertidal black abalone population at the island. The sites were monitored from 1981 to 1997, usually annually or semi-annually. Monitoring resumed in 2001, and regular annual monitoring cycles have been conducted at the sites since then. The study sites became particularly important, from a management perspective, after a virulent disease decimated black abalone populations throughout southern California beginning in the mid-1980s. The disease, withering syndrome, was first observed on San Nicolas Island in 1992 and during the next few years reduced the population there by approximately 99 percent. The species was subsequently listed as endangered under the Endangered Species Act in 2009.

The subject of this report is the 2019 monitoring cycle of the sites and how the current status fits into the long-term data at San Nicolas Island. Since 2001, the monitored population has increased nearly tenfold to approximately 8.7 percent of the pre-disease level. This increase has resulted from generally higher levels of recruitment than seen in the first two decades of monitoring, punctuated by a few high recruitment events. Most of the population growth has been at two of the nine sites (sites 7 and 8). This pattern continued in 2019 with increasing numbers at sites 7 and 8 and the highest number of abalone counted and measured island-wide since 1996. However, counts declined at six of the sites during the last year and the increases in counts at sites 7 and 8 barely offset these losses. Recruitment rates have fallen since a peak in 2017 but 2019 continued to show some additional recruitment. The distance between adjacent black abalone, a metric relevant to potential reproduction, has decreased substantially since it was first consistently measured in 2005. Although sand burial can have devastating localized consequences to black abalone, the sand cover data we collected was not sufficient to suggest an obvious temporal or site-based pattern to sedimentation, and there is no indication that this was a factor in any of the declines recorded in 2019. Continued monitoring of these sites can provide island biologists with species trends to aid in adaptive management of the resource.

Introduction

Haliotis

The black abalone (*Haliotis cracherodii*) is one of seven species of *Haliotis* endemic to the west coast of North America (all of which are found in California waters). The other *Haliotis* species that are native to California are the green abalone (*H. fulgens*), the red abalone (*H. rufescens*), the pink abalone (*H. corrugata*), the white abalone (*H. sorenseni*), the pinto abalone (*H. kamtschatkana*) and the flat abalone (*H. walallensis*). World-wide, there are 55 species and several subspecies of *Haliotis* currently recognized by Integrated Taxonomic Information System (ITIS, www.ITIS.gov) and World Registry of Marine Species (WoRMS, www.marinespecies.org). The genus consists of prosobranch gastropods typified by ear shaped shells that are pierced by several small spiracle holes. The shells generally are prized for their iridescent pearly appearance and have been used in jewelry, decorations, and even tools for millennia. The flesh of the large muscular foot also is considered to be a delicacy and, historically, abalone meat has commanded high prices. Though varying considerably in size, several of the California species are large for gastropods. Of the seven species, six have been extensively fished and, though black abalone are considered inferior because of their tougher flesh, they sustained a recreational and commercial fishery until the 1990s. The commercial take for this species peaked in 1973 at a little under 2-million pounds (California Department of Fish and Game [CDFG] Marine Region, 2004).

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[2]University of California, Santa Cruz, California (former position)

The black abalone is found on rocky shores from the high intertidal to a depth of 6 meters (m), shallower than the other local species of the genus. Its range extends from Pt. Arena, California, to Isla de Cedros, Baja California Sur, Mexico, but it is most abundant from central California southward (VanBlaricom and others, 2009). Smaller black abalone feed on diatom films and coralline algae whereas larger individuals are thought to feed mainly on kelp wrack (VanBlaricom and Kenner, 2020). The species can attain a shell length of up to 20 centimeters (cm). In addition to humans, natural predators of the black abalone include octopuses (*Octopus spp*), sea stars (especially *Pisaster ochraceus*), cabezon (*Scorpaenichthys marmoratus*), and sea otters (*Enhydra lutris*; Morris and others, 1980).

Reproduction

Like many marine invertebrates, black abalone reproduce by broadcast spawning; a reproductive strategy in which mature male and female individuals release large numbers of gametes into the environment with no mutual physical contact necessary. Successful fertilization requires both temporal synchrony and spatial proximity. Although several studies have concluded that black abalone populations spawn in late summer (Boolootian and others, 1962; Leighton and Boolootian, 1963; Webber and Giese, 1969), the actual trigger for spawning is unknown. In fact, unlike several other species of *Haliotis*, *H. cracherodii* has not been successfully spawned in the laboratory. Because the concentration of gametes in sea water is inversely related to the cube of the distance from their source, the proximity of spawning individuals is important to successful fertilization. Black abalone are relatively sedentary, however, and do not aggregate to spawn. There are many confounding factors to consider when attempting to calculate critical reproductive distance in intertidal organisms such as turbulence, channeling of water through crevices, and residency time in pools. It is likely though, that inter-abalone distances greater than a few meters result in reduced reproductive success compared with shorter distances (VanBlaricom and others, 2009). Abalone produce non-feeding larvae with a relatively short larval planktonic period. For this reason, bolstered by genetic evidence, it is thought that black abalone have fairly short dispersal distances (Chambers and others, 2006).

Withering Syndrome

Withering syndrome (WS) is a disease that affects many species of *Haliotis* and results in atrophy of the “foot” and a diminished ability to cling to hard substrate. Animals showing signs of WS exhibit body shrinkage as the disease progresses due to a combination of reduced food intake and changes in the structure of the digestive gland, which eventually leads to death. The causative agent has been identified as a Rickettsiales-like prokaryotic organism, *Candidatus* Xenohaliotis californiensis (Friedman and others, 2002). The disease was first observed in black abalone on the California Channel Islands. Beginning at Santa Cruz Island in 1985, it soon spread through most of the northern Channel Islands (Lafferty and Kuris, 1993). In black abalone populations afflicted with the disease, there is typically a mortality rate of at least 90 percent. Though populations at San Nicolas Island (SNI), California, were not immediately affected by WS, it finally appeared there in 1992 (VanBlaricom and others, 1993). Most southern California black abalone populations have been devastated by the disease. It has since moved into central California populations, where it has been causing significant mortalities (Miner and others, 2006). Recent work has suggested that there is now some resistance to the WS infection in some populations on SNI, and a viral bacteria-phage could lend some protection by infecting the WS rickettsia-like organism responsible for the disease (Friedman and others, 2014), but it is too early to know how effective these factors will be in protecting wild populations.

As a result of the serial near extinction of populations in southern California and Mexico, and the continued movement of the disease northward, in addition to concerns that low population levels will lead to recruitment failures, the National Oceanic and Atmospheric Administration (NOAA) listed *H. cracherodii* as an endangered species in January 2009 (National Oceanic and Atmospheric Administration, 2009).

In their critical habitat designation for the black abalone, NOAA exempted SNI due to revisions in the Navy’s Integrated Natural Resource Management Plan (INRMP) that provide benefits to black abalone (National Oceanic and Atmospheric Administration, 2011). One of the management strategies for marine invertebrates set forth in the INRMP was to “Promote and discuss current long-term monitoring of black abalone populations established in the late 1970s (VanBlaricom, 1993) and ensure that survey information on existing populations and trends are made available to the general scientific community” (U.S. Navy, 2015).

Project History

The black abalone monitoring sites were established on SNI in 1980 and first sampled in 1981 (fig. 1). From 1981 to 1997, all sites were sampled on a cycle that took 1 or 2 years to complete. Ten cycles were completed during this time. Sampling was briefly interrupted from 1998 to 2000 but resumed in 2001. During the 1980s and 1990s, size sampling (measuring shell length) was conducted opportunistically, but several size samples of 100 or more individuals were taken between 1983 and 1993, resulting in nearly 3,400 measurements taken during 2 to 4 different cycles at each site. These size samples were taken from randomly selected transects at each site and beginning at a quadrat and direction which also were randomly chosen; all reachable abalone were measured until the sample size was reached. Since its resumption in 2001, sampling of all sites has been completed every year, and sizes were measured for all abalone possible (up to 200 per site). Consistent determination of nearest neighbor distances began in 2005. All sampling trips through 2017 were led by Glenn VanBlaricom. Monitoring cycles in 2018 and 2019 were led by the author under Navy contract, first with the University of California Santa Cruz (under Cooperative Agreement Number N62473-18-2-0001) and then with the U.S. Geological Survey (USGS; MIPR agreement N30614-19-MP-001XY). The 2019 effort represented the 29th cycle of sampling the sites since they were established. A timeline of significant events is shown in figure 2.

The original impetus for monitoring the species was the planned reintroduction of the southern sea otter (*Enhydra lutris nereis*), a top marine carnivore, which had been absent from the system for nearly a century. Sea otters, which feed almost exclusively on shellfish, have had a demonstrated impact on subtidal red abalone populations, driving them below commercially viable levels (Watson, 2000). Their potential impact on intertidal black abalone populations was uncertain, however, because of their irregular use of the intertidal zone as a foraging habitat (VanBlaricom, 1993).

Figure 1. Black abalone monitoring sites around San Nicolas Island, California.

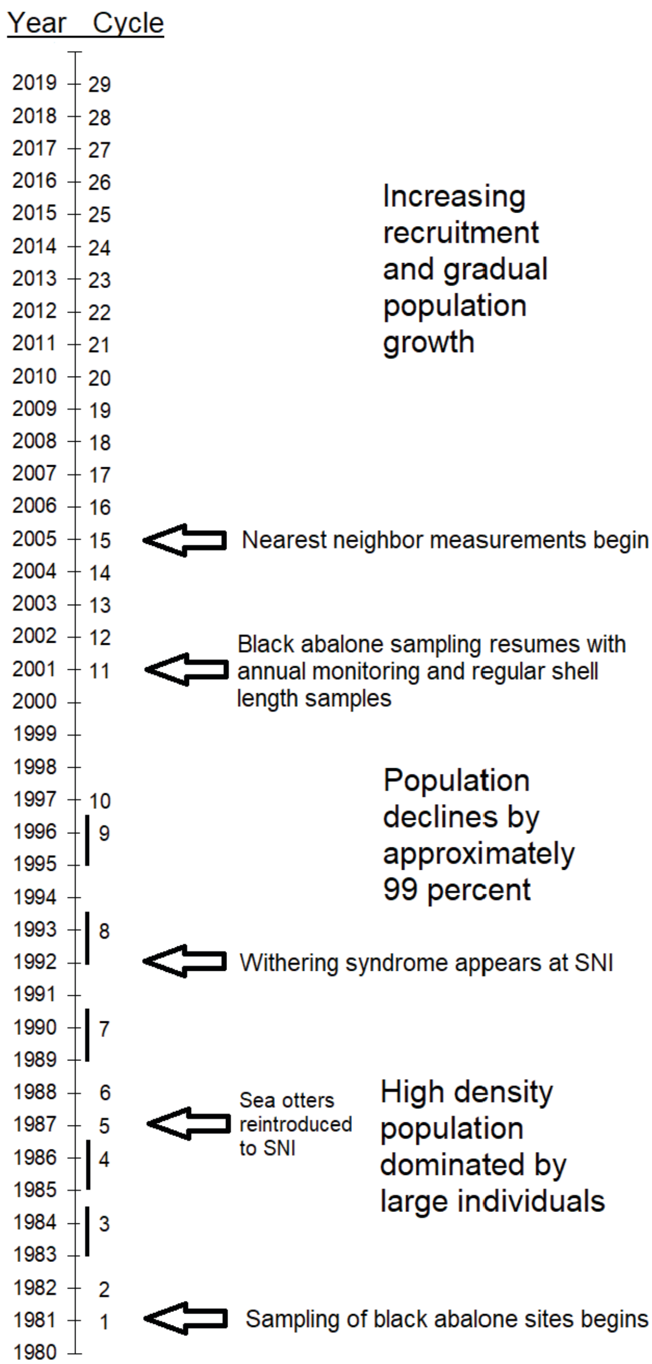

Figure 2. Timeline of major events during the black abalone sampling history, San Nicolas Island, California.

Between 1987 and 1990, 139 sea otters were translocated to SNI from the central California coast population (Rathbun and others, 2000).

During the first 10 years of monitoring, black abalone were very densely aggregated at the sites with mean densities ranging from about 4 to 24 per square meters (m^2) and with some 1-m^2 quadrats having more than 100 abalone stacked several deep. To what extent these densities were a natural or normal baseline, is arguable. Pressure from sea otter foraging was removed due to the otter population's extirpation by fur hunters in the 19th century. Even human harvest, that had been part of the system for millennia, was greatly reduced following the removal of indigenous people from SNI in 1835. The establishment of active military control of the island in 1942 likely reduced access for most commercial and sport take from then on.

Ironically, it was not sea otters that decimated the black abalone population and made these long-term sites so valuable in tracking the decline, but disease. From the time WS appeared at SNI in 1992 until 2001, when regular annual sampling resumed, the population at these nine sites was reduced by more than 99 percent. U.S. Geological Survey (USGS) intertidal monitoring sites on SNI, which use fixed quadrats not specifically targeting abalone, recorded a decline of similar magnitude during the same period (M.C. Kenner, unpub. data, 2019).

Methods

There are nine black abalone monitoring sites distributed around the island and each consists of multiple permanent transects ranging in number from two to seven (fig. 1). The transects range in length from 7 to 40 m (table 1) depending on the availability of suitable habitat. They were established in areas that supported high densities of black abalone at the time and, because they were not randomly placed, cannot be used to estimate a more general population size or density. The transects are, however, excellent for tracking trends and they provide good coverage around the island. The transect locations are marked by stainless steel eyebolts that are epoxied into holes drilled in the substrate and to which a meter tape is attached during sampling. Transects are marked by multiple eyebolts that typically are 5–10 m apart and are sampled as belt transects 2 meters wide, with the exception of two transects at site 2. The sampling unit is a 1-m^2 quadrat and these quadrats are sampled contiguously on either side of the tape so that a 30-m transect has 60 quadrats and samples 60 m^2 of area. The exceptions at site 2 (transects 3 and 4) are treated as 1 m wide because the tapes there each run along a single crevice for their entire length. The total sampled area for all nine sites is 2,054 m^2. The actual area sampled is much greater because the rocky shore is convoluted and contains many crevices, ridges, and hollows. Sampling by 1-m units yields better repeatability of effort and allows for tracking of the data at a finer scale than could be achieved with a much larger sampling unit.

Table 1. Numbers of transects and their lengths and areas at each site, San Nicolas Island, California.

[Area of 1 meter wide transects marked with * (see "Methods" section).]

Transect	Length	Area
Site 1		
1	30	60
2	30	60
3	30	60
4	30	60
5	30	60
6	30	60
Site 2		
1	30	60
2	30	60
3	17	17*
4	27	27*
5	30	60
6	25	50
Site 3		
1	31	62
2	35	70
3	36	72
4	7	14
5	8	16
6	15	30
7	18	36
Site 4		
1	12	24
2	14	28
Site 5		
1	15	30
2	12	24
3	8	16

Transect	Length	Area
Site 6		
1	26	52
2	30	60
3	30	60
4	40	80
Site 7		
1	30	60
2	30	60
3	25	50
4	25	50
5	25	50
Site 8		
1	30	60
2	30	60
3	30	60
4	25	50
5	24	48
Site 9		
1	18	36
2	7	14
3	10	20
4	20	40
5	27	54
6	17	34

Each quadrat is searched for black abalone. If one is found, its maximum shell length is measured with dividers to the nearest millimeter (fig. 3). Frequently, it is not possible to obtain a measurement since abalone often occur in crevices where they cannot be reached, and in such cases the individual is counted only. Beginning this sampling cycle (29), when possible, non-measured abalone were assigned to one of two size bins: less than 3.5 cm (recruit) or greater than or equal to 3.5 cm (non-recruit), thus giving more information on recruitment dynamics. The target sample size for shell measurements is 200 per site. If that number is reached, then individuals in remaining quadrats on the site need not be measured but are estimated into the recruit or non-recruit size bins. At the two sites where there are currently more than 200 abalone, sites 7 and 8, transects are sampled in the same order each year. All reachable abalone are measured, a quadrat at a time, until at least 200 individual abalone are measured. This approach minimizes error due to sampling different areas year to year and minimizes bias due to size selective encounter.

In addition to number and shell length, the distance to the closest conspecific found (nearest neighbor) is measured (or estimated) to the nearest centimeter. This distance measurement is taken for every abalone recorded, including non-measured ones. The nearest neighbor need not be in the same quadrat nor even within the transect. In addition, the microhabitat of each abalone recorded is classified into one of three classes: (1) open horizontal, (2) open vertical, or (3) crevice. The first two categories are characterized by open, non-cryptic habitats that are either less than or greater than a 45-degree (°) angle from a horizontal plane. Crevice habitat is defined as occurring within cracks, crevices, or pockets of any orientation. Finally, for each quadrat, the cover of exposed sand is estimated to the nearest 10 percent.

Figure 3. Shell length is measured using dividers and rule to nearest millimeter, January 2019, San Nicolas Island, California. Photographs taken by Michael C. Kenner, U.S. Geological Survey.

Figure 3. —Continued

Sites

Here follows a brief description of the nine sites around the island. Refer to figure 1 for locations. Photographs of most of the transects, taken between 2016 and 2020, also are presented in figures 4–12.

Site 1 is located in Bomber Cove on the north side of Vizcaino Point on San Nicolas Island. There are six parallel transects arranged perpendicular to the shore within about 50 meters of each other. Transect 1 follows along the base of a several meter-high rock outcropping. The other transects are on low bedrock with scattered, approximately 0.25–1 m boulders. Surfgrass (*Phyllospadix* spp.), anemones (*Anthopleura* spp.), and purple urchins (*Strongylocentrotus purpuratus*) are common in the lower areas. The site is fairly exposed to the prevailing northwest swell (see fig. 4*A*–*E*, no photograph is available for transect 4).

***A.* Transect 1**

Figure 4. Site 1 transects: *A,* transect 1; *B,* transect 2; *C,* transect 3; *D,* transect 5; and *E,* transect 6, San Nicolas Island, California, 2016–2020. Photographs taken by Glenn VanBlaricom, U.S. Geological Survey, retired (transect 4 photograph not available).

***B.* Transect 2**

Figure 4. —Continued

***C.* Transect 3**

Figure 4. —Continued

***D.* Transect 5**

Figure 4. —Continued

***E.* Transect 6**

Figure 4. —Continued

Site 2 is located in the Thousand Springs area on the northernmost point of the island. The six transects are scattered into three general areas and there is a distance of about 900 m between the westernmost and easternmost. Transects 1 and 2 parallel each other along pools on the main point near the range marker poles (fig. 5*A*, *B*). Several hundred meters east of this are transects 3, 4, and 5. Transects 3 and 4 follow along single long crevices as noted earlier, whereas transect 5 is in a bouldery area covered with the red alga *Endocladia muricata* (see fig. 5*C*–*E*). Transect 6 is several hundred meters further east and runs along a broad flat bench with parallel pools and rockweed (*Silvetia compressa*) cover (fig. 5*F*).

***A.* Transect 1**

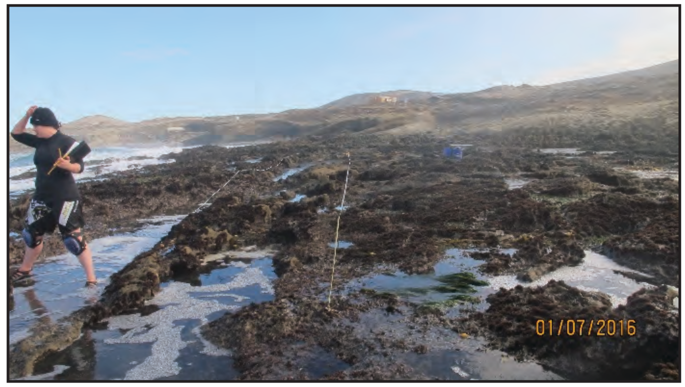

Figure 5. Site 2 transects: *A,* transect 1; *B,* transect 2; *C,* transect 3; *D,* transect 4; *E,* transect 5; and *F,* transect 6, San Nicolas Island, California, 2016–2020. Photographs taken by Glenn VanBlaricom, U.S. Geological Survey, retired.

***B.* Transect 2**

Figure 5. —Continued

***C.* Transect 3**

Figure 5. —Continued

D. **Transect 4**

Figure 5. —Continued

E. **Transect 5**

Figure 5. —Continued

F. **Transect 6**

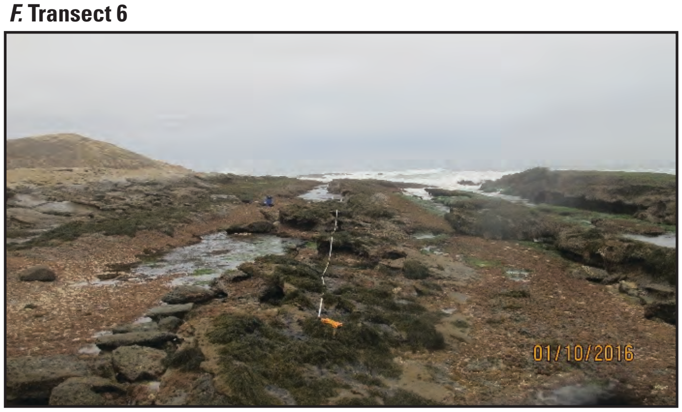

Figure 5. —Continued

Site 3 consists of seven transects in three areas along the northeast shore below the northwest end of the runway (fig. 6*A*–*G*). It is the widest spread site, spanning about 1,600 meters from transect 1, westward to transect 7. Transects 1, 2, and 3 are parallel to shore along a narrow rocky bench at the bottom of a steep bank. Transects 1 and 3 are largely covered by the coralline alga *Corallina vancouverensis* and the red alga *Mazzaella affinis,* but transect 2, having experienced a suspected sand burial event in fall 2015, is still largely bare. Figure 6*B* shows the transect covered with *Ulva* spp. soon after sand burial. This ephemeral green alga frequently colonizes disturbed areas and has since disappeared. Transects 4, 5, and 6 are clustered together on a fairly bare rock bench approximately 975 m to the west. Transect 7, another 640 m westward, is on a narrow apron of *C. vancouverensis* dominated rock between two channel-like pools.

A. **Transect 1**

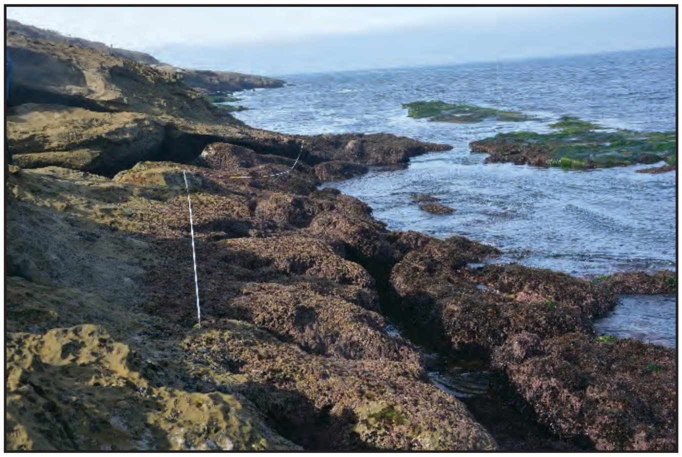

Figure 6. Site 3 transects: *A,* transect 1; *B,* transect 2; *C,* transect 3; *D,* transect 4; *E,* transect 5; *F,* transect 6; and *G,* transect 7, San Nicolas Island, California, 2016–2020. Photographs taken by Glenn VanBlaricom, U.S. Geological Survey, retired.

B. **Transect 2**

Figure 6. —Continued

C. **Transect 3**

Figure 6. —Continued

D. **Transect 4**

Figure 6. —Continued

E. **Transect 5**

Figure 6. —Continued

F. **Transect 6**

Figure 6. —Continued

***G.* Transect 7**

Figure 6. —Continued

Site 4, the smallest of the sites, consists of two parallel transects only a few meters apart on a raised mussel (*Mytilus californianus*) covered intertidal bench south of the east end sand spit (fig. 7*A*–*B*).

***A.* Transect 1**

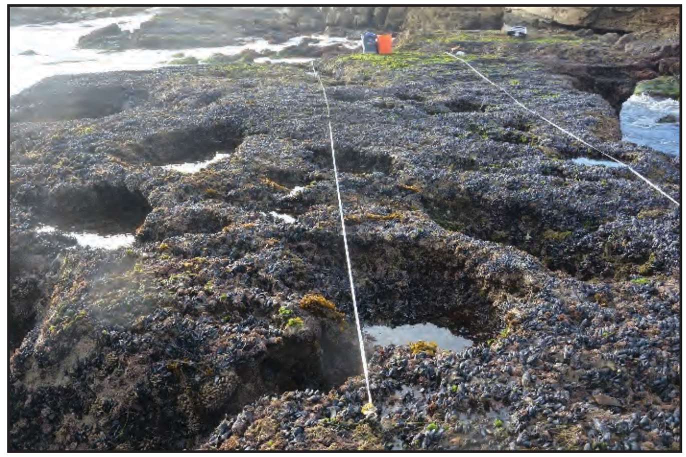

Figure 7. Site 4 transects: *A,* transect 1; and *B,* transect 2, San Nicolas Island, California, 2016–2020. Photographs taken by Glenn VanBlaricom, U.S. Geological Survey, retired.

***B.* Transect 2**

Figure 7. —Continued

Site 5 has three transects on a slightly raised *M. californianus* covered reef on the southeast shore of the island. The transects are parallel to shore and are all within about 10 meters of each other (fig. 8).

***A.* Transect 1**

Figure 8. Site 5 transects: *A,* transect 1; *B,* transect 2; and *C,* transect 3, San Nicolas Island, California, 2016–2020. Photographs taken by Michael C. Kenner, U.S. Geological Survey and Glenn VanBlaricom, U.S. Geological Survey, retired.

***B.* Transect 2**

Figure 8. —Continued

***C.* Transect 3**

Figure 8. —Continued

Site 6 consists of four transects spread out over about 300 m near the old navigation light on the southeast shore of the island. All of the transects are on fairly flat *M. californianus* beds with some large patches of *Phyllospadix* spp. (fig. 9*A–D*).

***A.* Transcect 1**

Figure 9. Site 6 transect photos: *A,* transect 1; *B,* transect 2; *C,* transect 3; and *D,* transect 4, San Nicolas Island, California, 2016–2020. Photographs taken by Glenn VanBlaricom, U.S. Geological Survey, retired.

***B.* Transect 2**

Figure 9. —Continued

***C.* Transect 3**

Figure 9. —Continued

***D.* Transect 4**

Figure 9. —Continued

Five transects near the south side range markers make up site 7. Transect 1 is along the east edge of a large raised flat reef (fig. 10*A*). Transects 2 and 3 follow channels on top of the reef and intersect each other at about a 90° angle (fig. 10*B*–*C*). Transects 4 and 5 are about 150 m west of transect 1 and traverse channels and crevices in a jumbled, high relief area of the reef (fig. 10*D*–*E*).

***A.* Transect 1**

Figure 10. Site 7 transect photos: *A,* transect 1; *B,* transect 2; *C,* transect 3; *D,* transect 4; and *E,* transect 5, San Nicolas Island, California, 2016–2020. Photographs taken by Glenn VanBlaricom, U.S. Geological Survey, retired.

***B.* Transect 2**

Figure 10. —Continued

***C.* Transect 3**

Figure 10. —Continued

***D.* Transect 4**

Figure 10. —Continued

***E.* Transect 5**

Figure 10. —Continued

Site 8, on the southwest shore, is made up of five transects spread out over about 230 m (fig. 11*A*–*E*). Transect 1 is on a low, flat ridge between two pools where a couple of boulders provide some cryptic habitat. Transects 2 and 3 are parallel to each other and follow low ridges with abundant crevice space. Somewhat to the east, transects 4 and 5 also parallel each other and traverse a more bouldery area with some sand influence.

***A.* Transect 1**

Figure 11. Site 8 transects: *A,* transect 1; *B,* transect 2; *C,* transect 3; *D,* transect 4; and *E,* transect 5, San Nicolas Island, California, 2016–2020. Photographs taken by Glenn VanBlaricom, U.S. Geological Survey, retired.

***B.* Transect 2**

Figure 11. —Continued

***C.* Transect 3**

Figure 11. —Continued

***D.* Transect 4**

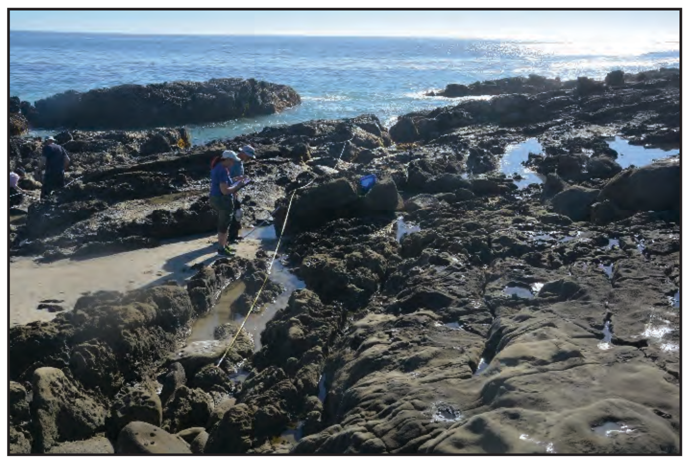

Figure 11. —Continued

***E.* Transect 5**

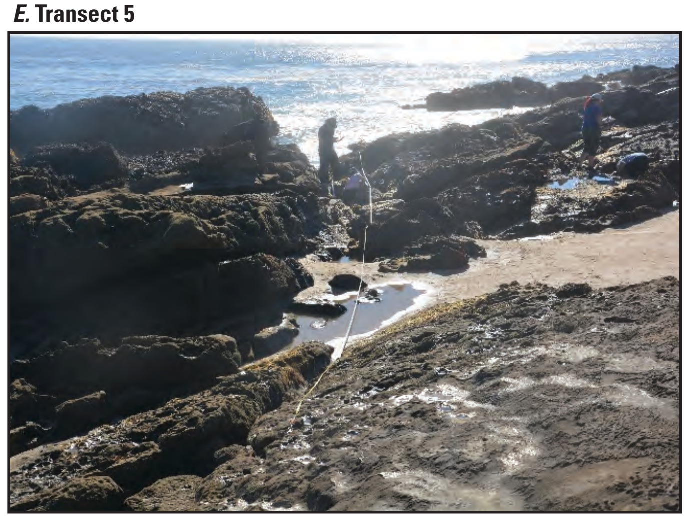

Figure 11. —Continued

Site 9 is to the south of "Rock Crusher" on the west end of the island. Six transects are spread over about 170 m on an extensive low rock reef. The transects follow ledges in an area with many boulders. *C. vancouverensis* and *Phyllospadix* spp. provide most of the cover. The site is exposed to west swell. Figure 12 shows all transects for this site.

A. **Transect 1**

Figure 12. Site 9 transects: *A,* transect 1, January 2016; *B,* transect 2, January 2020; *C,* transect 3, January 2016; *D,* transect 4, January 2019; *E,* transect 5, February 2018; and *F,* transect 6, February 2018, San Nicolas Island, California, 2016–2020. Photographs taken by Glenn VanBlaricom, U.S. Geological Survey, retired.

B. **Transect 2**

Figure 12. —Continued

C. **Transect 3**

Figure 12. —Continued

D. Transect 4

Figure 12. —Continued

E. Transect 5

Figure 12. —Continued

F. Transect 6

Figure 12. —Continued

Results

The 2019 (cycle 29) sampling of the sites took place between January 2 and March 16, 2019, and were spread out over five trips to the island. Generally good conditions prevailed during the first two trips, although only one of these had very good low tides (–0.3 m below mean lower low water, or lower). The third and fourth trips were characterized by moderate to large swells, necessitating 1 additional day of sampling during a fifth negative tide series. In addition to the sampling work, a few missing eyebolts were replaced, and Global Positioning fixes were acquired for most eyebolt locations.

Counts

A total of 2,022 abalone were counted on all nine sites in 2019 (2,054 m^2 sampled). This is the highest count since 1996 (cycle 9) when 2,192 were counted but only slightly higher than 2018's total of 2,016 abalone. There is a clear positive growth trend apparent since regular annual counts were resumed in 2001. Figure 13 shows the raw total count from each survey plotted from 2001 to 2019 and a sigmoidal nonlinear regression fitted to the population counts.

$$y = y_0 + \frac{a}{1 + e^{-\left(\frac{x - x_0}{b}\right)}}$$

R = 0.9892; R^2 = 0.9786
e is the constant 2.71828

	Coefficient	Standard error	T	P
a	1688.9531	110.8315	15.2389	<0.0001
b	1.8786	0.3257	5.7680	<0.0001
x_0	2010.9602	0.3402	5911.3998	<0.0001
y_0	267.3954	58.8916	4.5405	0.0004

The population trend over this period showed three general phases. The initial six years from 2001 to 2007 had a relatively modest growth rate followed by a higher growth period from about 2007 to 2014. During the last 5 years, growth returned to a more moderate rate. A sigmoidal population growth curve is often a sign of density dependent factors such as food or space, limiting population size after a period of rapid growth. It seems unlikely that this is the case here, however, since population densities were an order of magnitude higher a few decades ago. More likely, there has been an (as yet) unexplained fluctuation in recruitment and mortality rates.

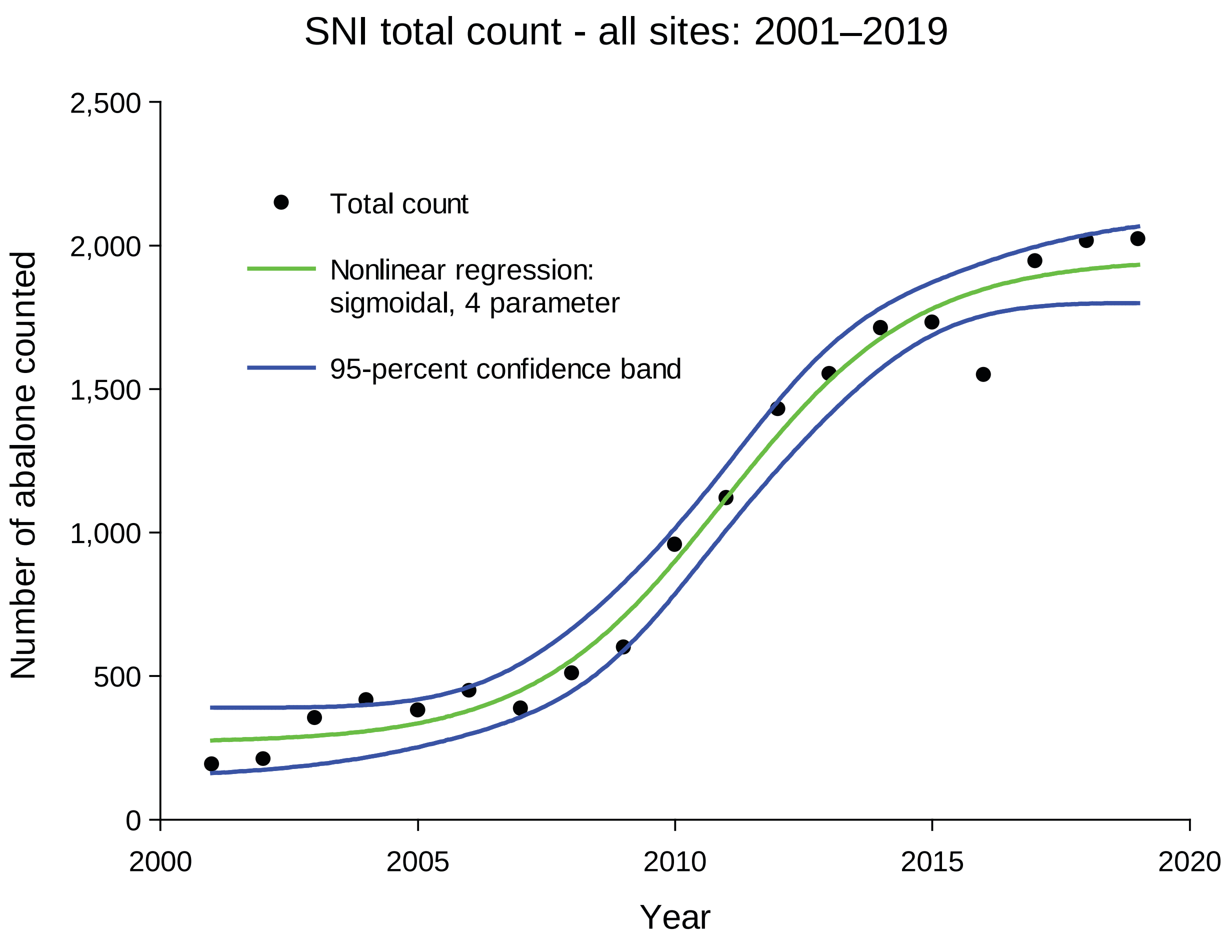

Figure 13. Total San Nicolas Island (SNI) black abalone counts, sigmoidal 4-parameter nonlinear regression, and 95-percent confidence band, San Nicolas Island, California, 2001–2019.

Figure 14 shows how the counts at the different sites contributed to the total count since 2001. During this time, site 8 always contributed the most to the overall count but site 7 became a major contributor as well during the last 10 years. Site 6 was a distant third place.

Table 2 displays counts for each site during the entire course of the sampling program. An examination of the first seven periods (1981–91) revealed that although there were some significant changes at particular sites, the total for each period was reasonably constant during the time before WS was detected at SNI. The average total count during this time was 23,339.7 individuals. Although the count fell to 0.8 percent of that total in 2001, mostly positive growth over 15 years brought the 2019 count to 8.7 percent of the pre-WS average total. Mean densities at the sites ranged from 4.18 to 24.12/m^2 (11.36/m^2 average) during the pre-WS period. At the time this report was written, site densities ranged from 0.13 to 3.66/m^2 with an average of 0.98/m^2 (bottom green row in table 2). One note of concern is that six of the nine sites showed declines in total count from 2018 to 2019, ranging from 14.3 percent to 46.0 percent (blue row in table 2). This decline of 93 abalone was just barely offset by the increase of 97 in the counts at sites 7 and 8 (the count at site 6 increased by 2).

Figures 15–23 show how the counted abalone were distributed along each transect during the 2018 and 2019 sampling period. The x-axis (quadrat number) are scaled for the longest transect at each site and the y-axis (number of abalone) for the highest count at the site. Of the 44 transects, 5 had no abalone counted on them in 2019 compared to 7 transects the previous year. There was a notable non-random aspect to their distribution, with abalone tending to cluster. Although there was some minor shuffling of quadrat densities, the distribution along the transects was fairly consistent between these 2 years.

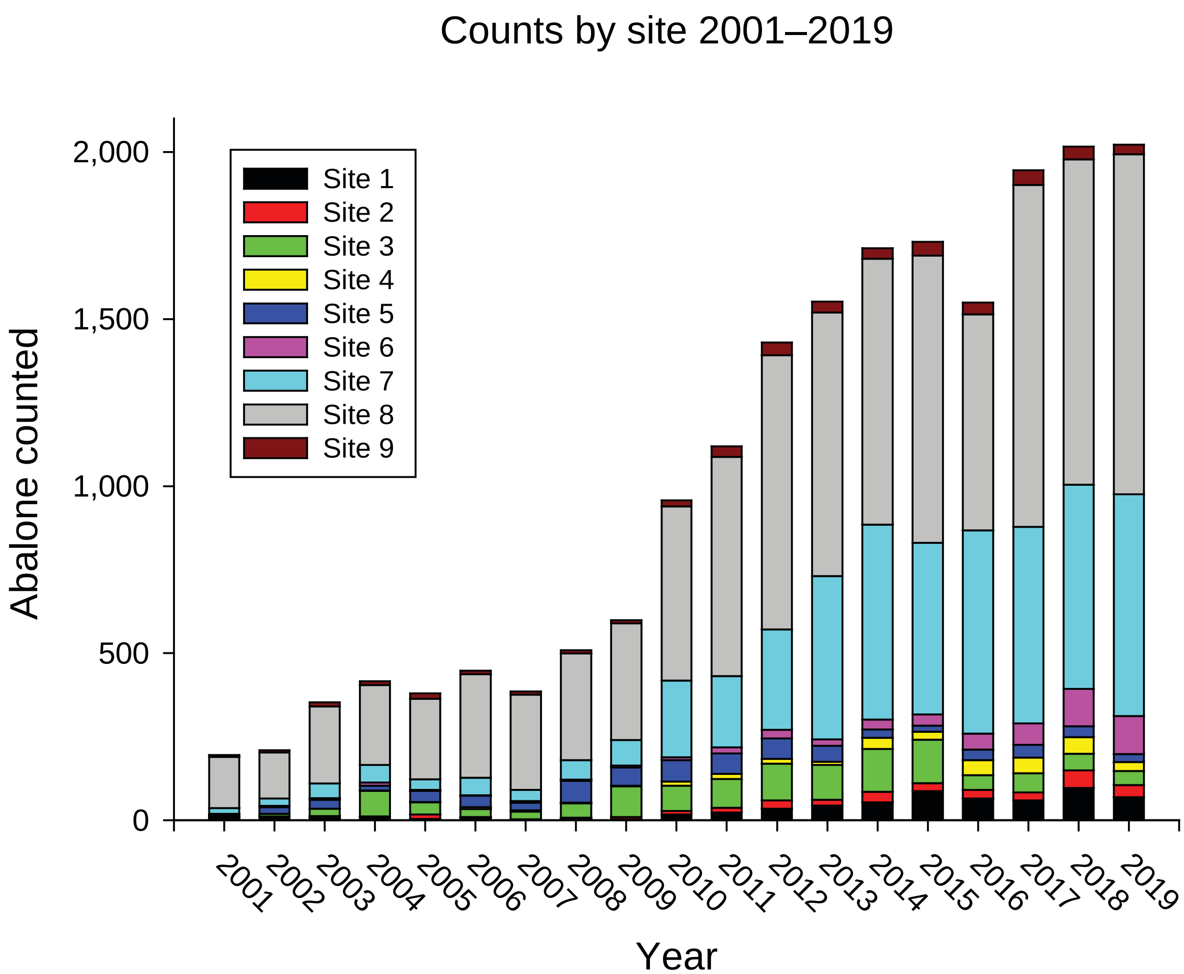

Figure 14. Black abalone counts by site for 2001–2019, San Nicolas Island, California.

The crevice microhabitat category is the most commonly observed. Between 1983 and 1993, an average 64.4 percent of sampled abalone were in this category. In surveys conducted after the WS induced population decline (2001–2019), this average jumped to 95.8 percent and in 2019 over 93 percent of abalone recorded were in the crevice microhabitat. Table 3 shows the utilization of different microhabitat categories among sites in 2019. Site 6, which had the least amount of relief and complexity, was the only location where crevice was not the dominant category. Here, 63 percent of abalone were recorded as open horizontal. Open vertical was rare throughout the sites. Perhaps the greater utilization of exposed microhabitats pre-WS was merely a result of crowding of more preferred habitats.

Table 2. Counts by site for each sampling cycle, San Nicolas Island, California.

[Far right column has cycle total. Average count and average density for pre-WS years shown after cycle 7. Percent change from 2018 to 2019 and density in 2019 at each site and overall also shown. **Abbreviations**: —, not applicable; m², square meter]

Cycle	Year completed	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Cycle total
1	1981	2,946	2,146	1,247	422	1,044	1,677	5,398	6,313	2,304	23,497
2	1982	2,860	2,215	1,360	441	1,286	1,938	6,791	6,887	1,856	25,634
3	1983	3,300	2,065	1,174	408	933	1,880	6,774	5,975	1,792	24,301
4	1985	3,062	1,830	1,147	450	657	1,737	5,963	5,899	1,811	22,556
5	1987	3,187	1,933	1,391	442	495	1,517	6,377	4,523	2,303	22,168
6	1988	3,049	1,719	1,131	407	465	1,631	6,001	4,245	2,446	21,094
7	1991	3,504	1,916	1,263	405	446	2,635	7,273	4,158	2,528	24,128
Average count for cycle 1–7											
—	—	3,129.7	1,974.9	1,244.7	425	760.9	1,859.3	6,368.1	5,428.6	2,209.4	23,339.7
Average density per m² for cycle 1–7											
—	—	8.69	7.21	4.18	8.17	10.87	7.38	24.12	19.53	11.16	11.36
8	1993	3,630	1,731	581	417	151	893	1,701	3,216	2,635	14,955
9	1996	356	14	102	63	26	96	652	785	98	2,192
10	1997	183	8	21	6	17	48	297	712	78	1,370
11	2001	7	2	3	0	5	2	18	153	5	191
12	2002	11	1	7	0	21	3	22	138	7	210
13	2003	7	6	22	0	27	4	44	231	12	353
14	2004	11	1	76	1	15	9	53	239	11	416
15	2005	4	14	36	1	33	3	32	241	16	380
16	2006	8	2	24	6	34	1	52	310	11	448
17	2007	1	2	23	4	23	5	33	285	10	386
18	2008	3	5	43	2	65	4	58	319	10	509
19	2009	3	7	92	2	54	6	76	349	10	599
20	2010	18	10	76	12	64	9	229	521	18	957
21	2011	23	15	86	15	61	18	213	656	32	1,119
22	2012	35	25	109	15	61	26	300	821	38	1,430
23	2013	44	17	105	9	48	19	489	789	32	1,552
24	2014	54	31	129	33	25	30	583	795	32	1,712
25	2015	87	24	130	24	18	34	513	860	41	1,731
26	2016	65	26	44	45	32	48	607	647	35	1,549
27	2017	60	23	58	47	38	64	588	1,023	44	1,945
28	2018	97	53	49	50	32	112	611	973	39	2,016
29	2019	69	36	42	27	24	114	664	1,017	29	2,022
Percent change from 2018 to 2019											
—	—	–28.9	–32.1	–14.3	–46.0	–25.0	1.8	8.7	4.5	–25.6	0.3
Density per m² in 2019											
—	—	0.19	0.13	0.14	0.52	0.34	0.45	2.52	3.66	0.15	0.98

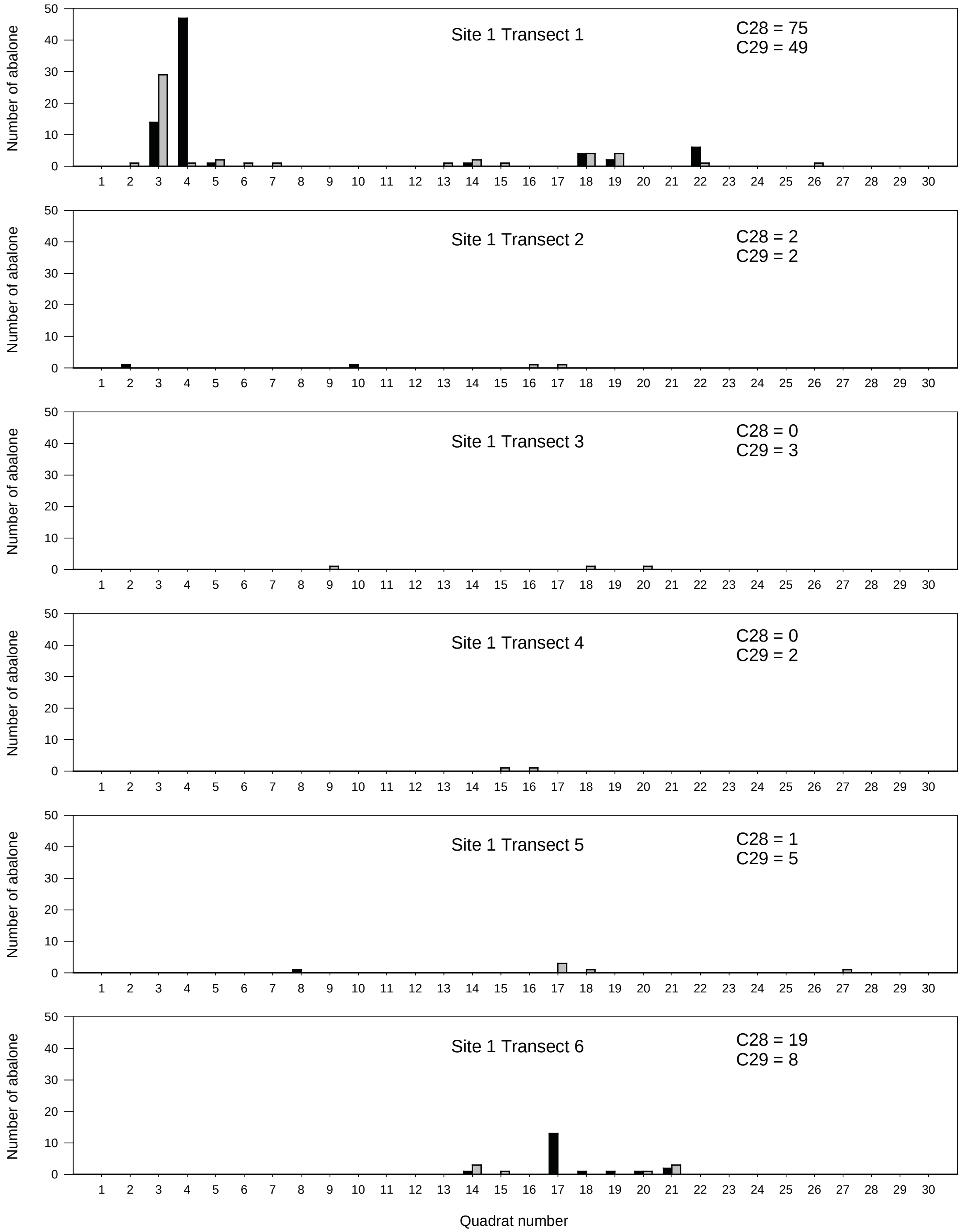

Figure 15. Cycle 28 (black bars) and Cycle 29 (gray bars) distribution of black abalone along transects at Site 1, San Nicolas Island, California, 2018–2019. Total transect count for each cycle indicated on graph.

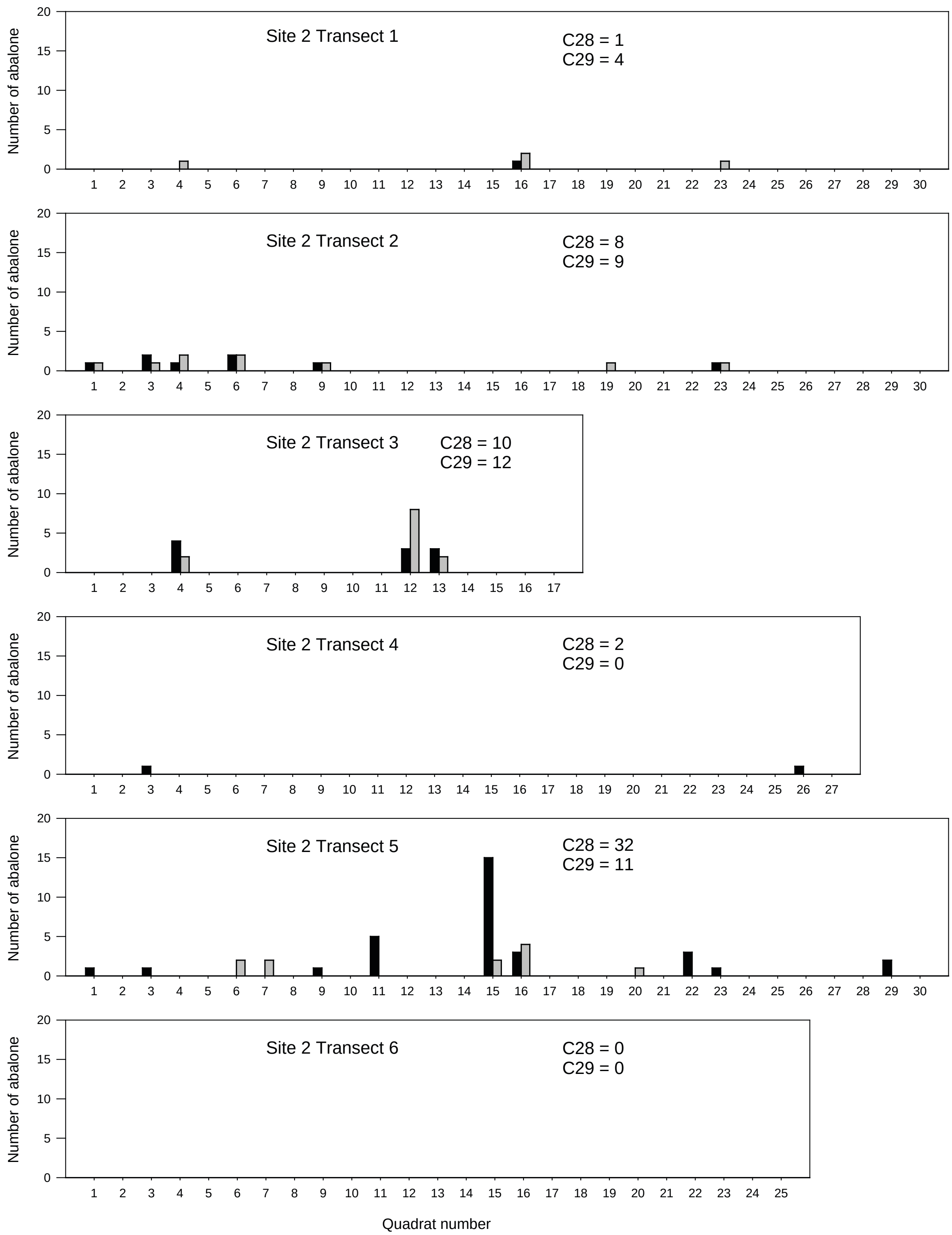

Figure 16. Cycle 28 (black bars) and Cycle 29 (gray bars) distribution of black abalone along transects at Site 2, San Nicolas Island, California, 2018–2019. Total transect count for each cycle indicated on graph.

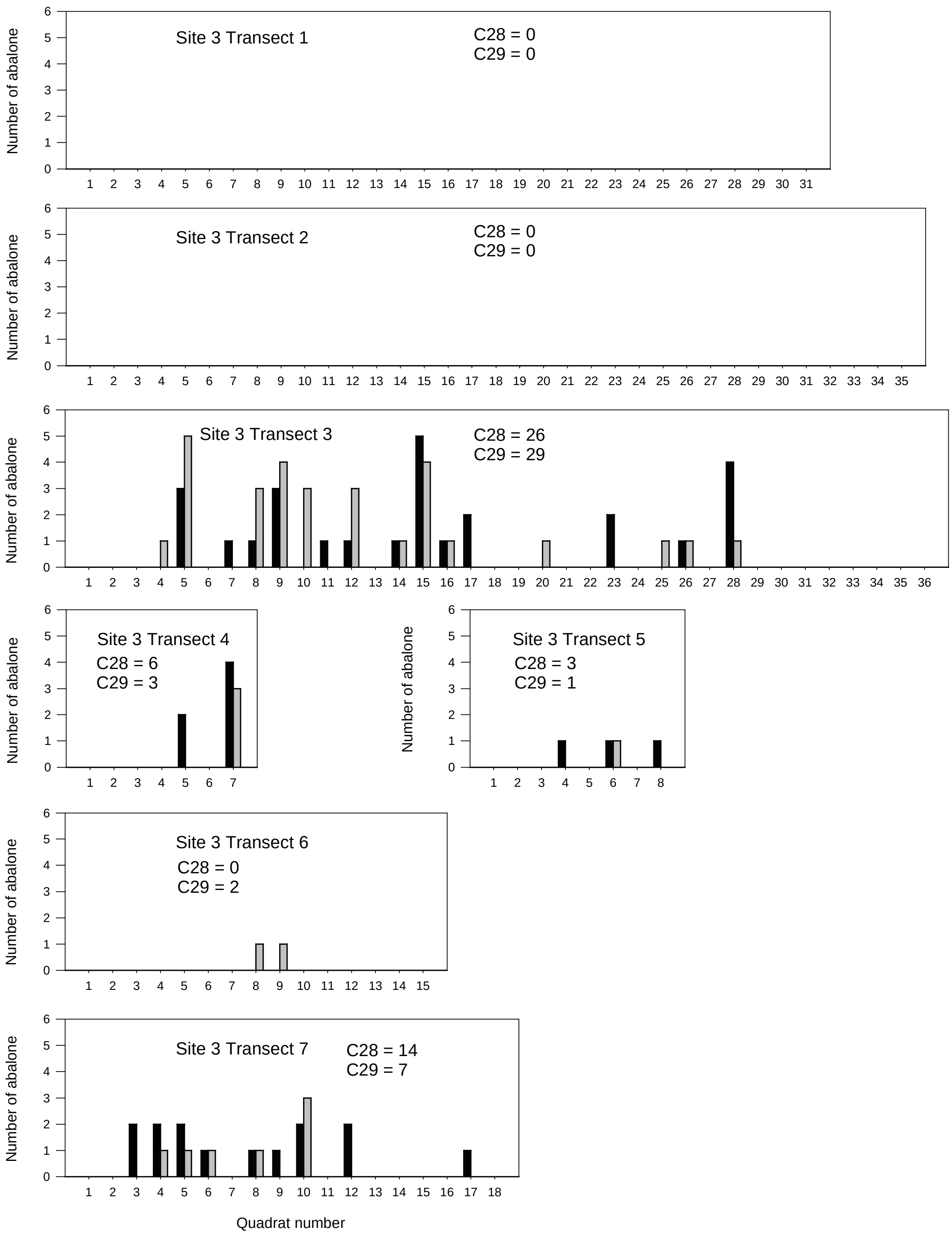

Figure 17. Cycle 28 (black bars) and Cycle 29 (gray bars) distribution of black abalone along transects at Site 3, San Nicolas Island, California, 2018–2019. Total transect count for each cycle indicated on graph.

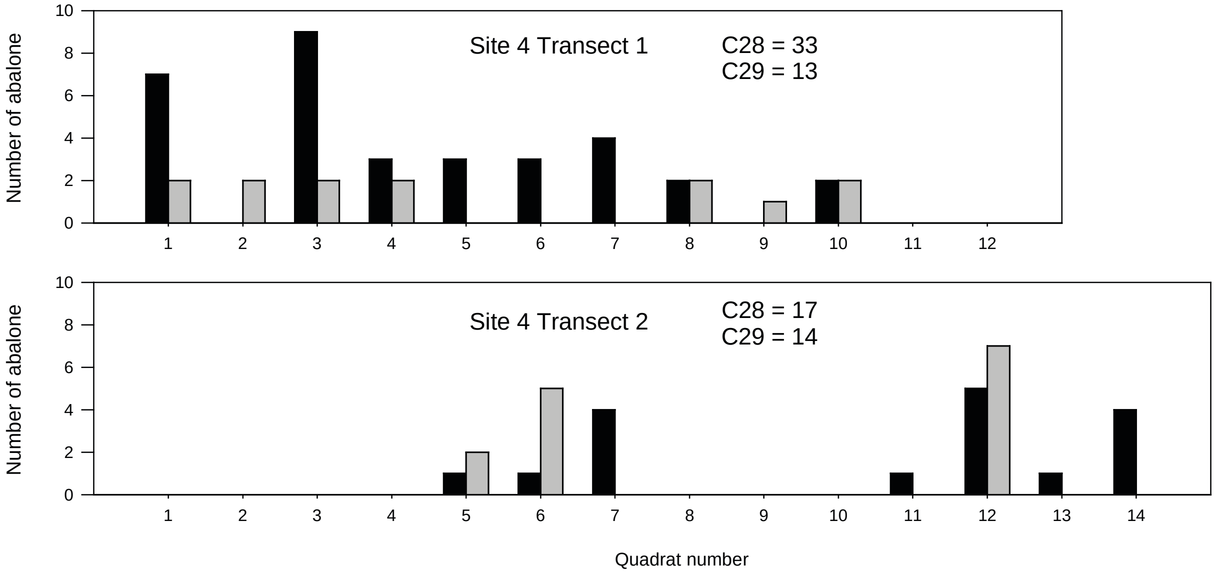

Figure 18. Cycle 28 (black bars) and Cycle 29 (gray bars) distribution of black abalone along transects at Site 4, San Nicolas Island, California, 2018–2019. Total transect count for each cycle indicated on graph.

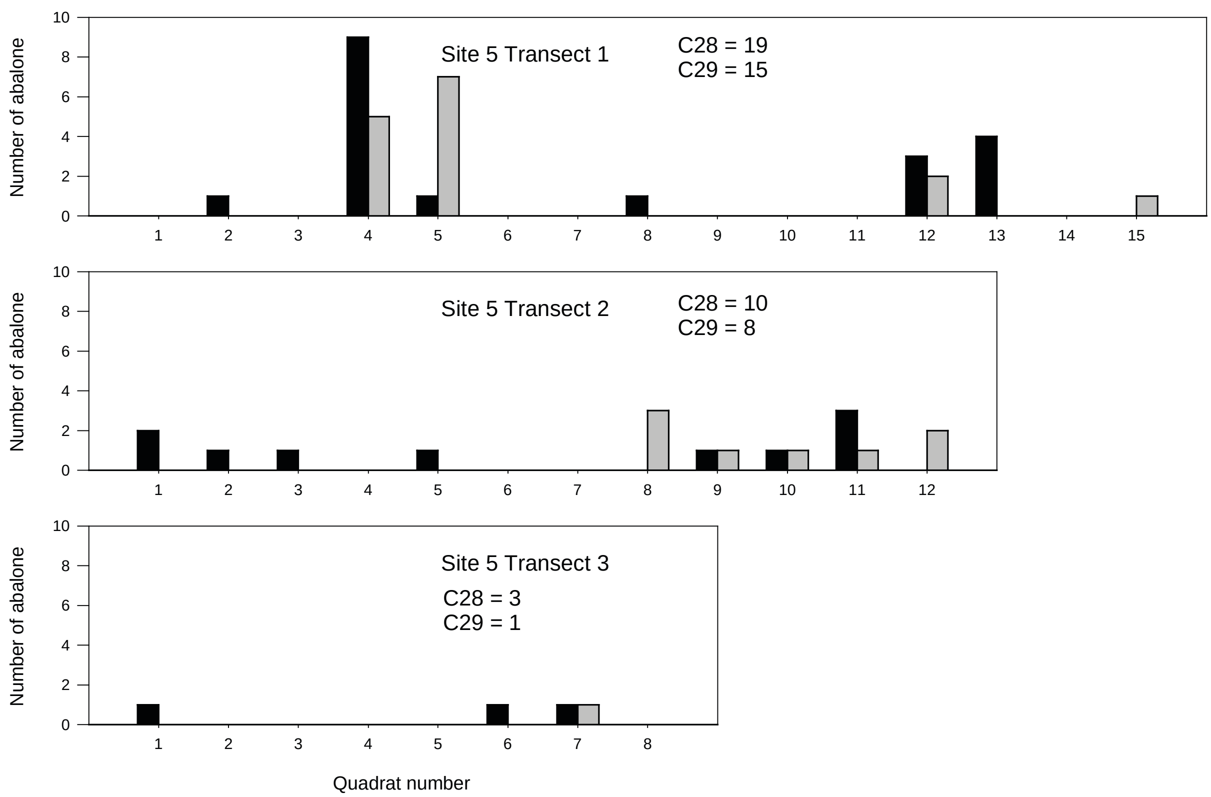

Figure 19. Cycle 28 (black bars) and Cycle 29 (gray bars) distribution of black abalone along transects at Site 5, San Nicolas Island, California, 2018–2019. Total transect count for each cycle indicated on graph.

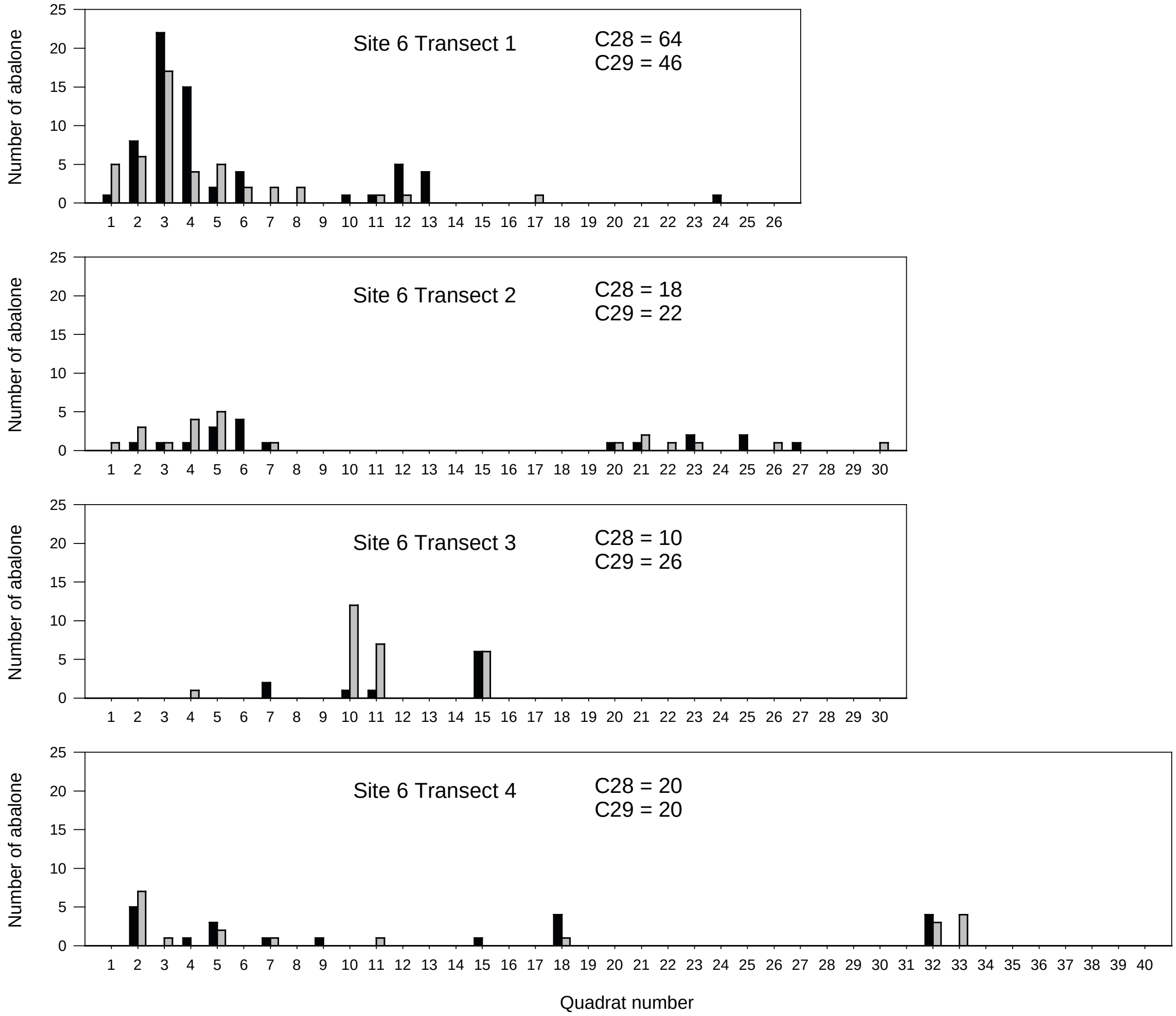

Figure 20. Cycle 28 (black bars) and Cycle 29 (gray bars) distribution of black abalone along transects at Site 6, San Nicolas Island, California, 2018–2019. Total transect count for each cycle indicated on graph.

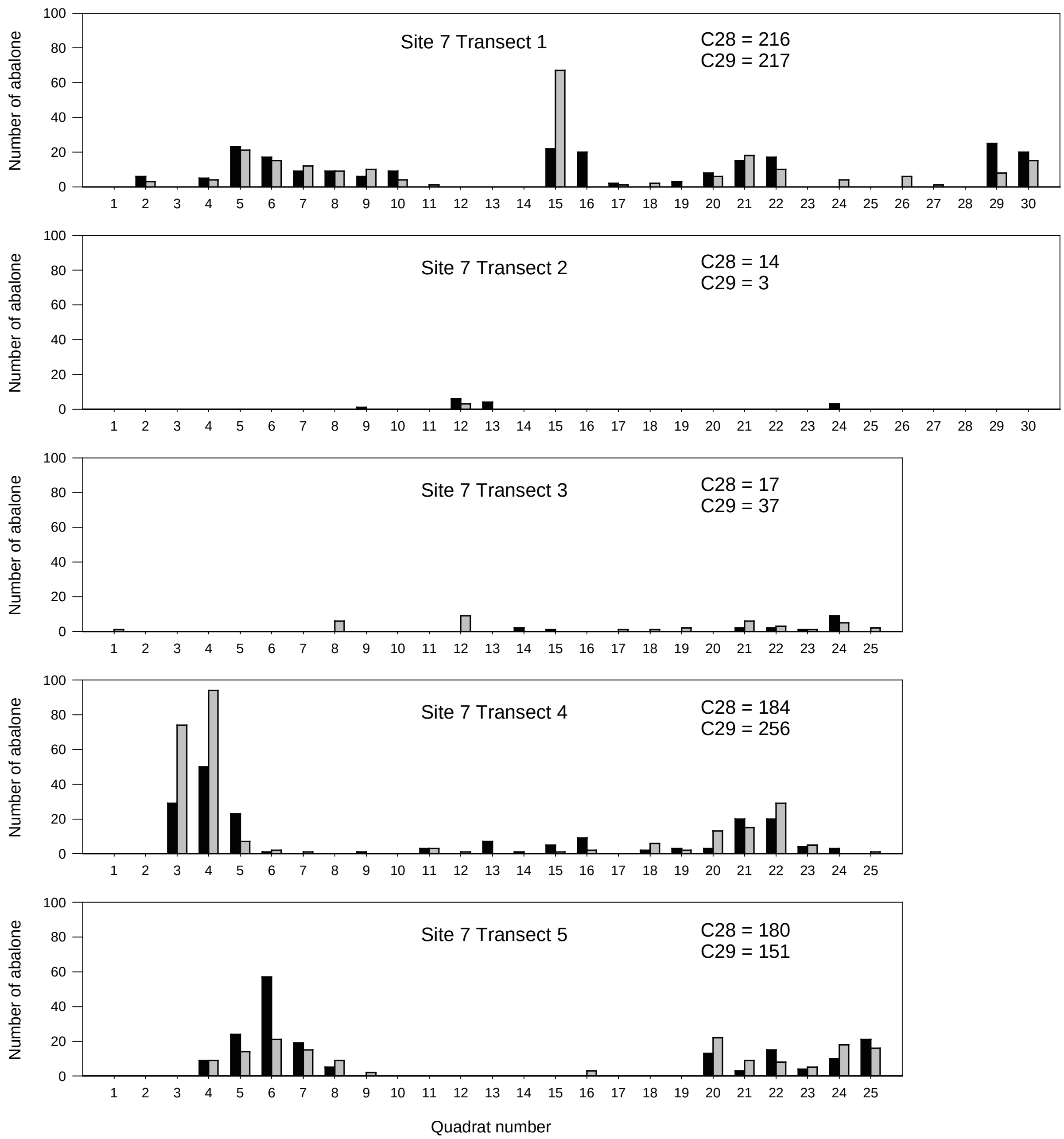

Figure 21. Cycle 28 (black bars) and Cycle 29 (gray bars) distribution of black abalone along transects at Site 7, San Nicolas Island, California, 2018–2019. Total transect count for each cycle indicated on graph.

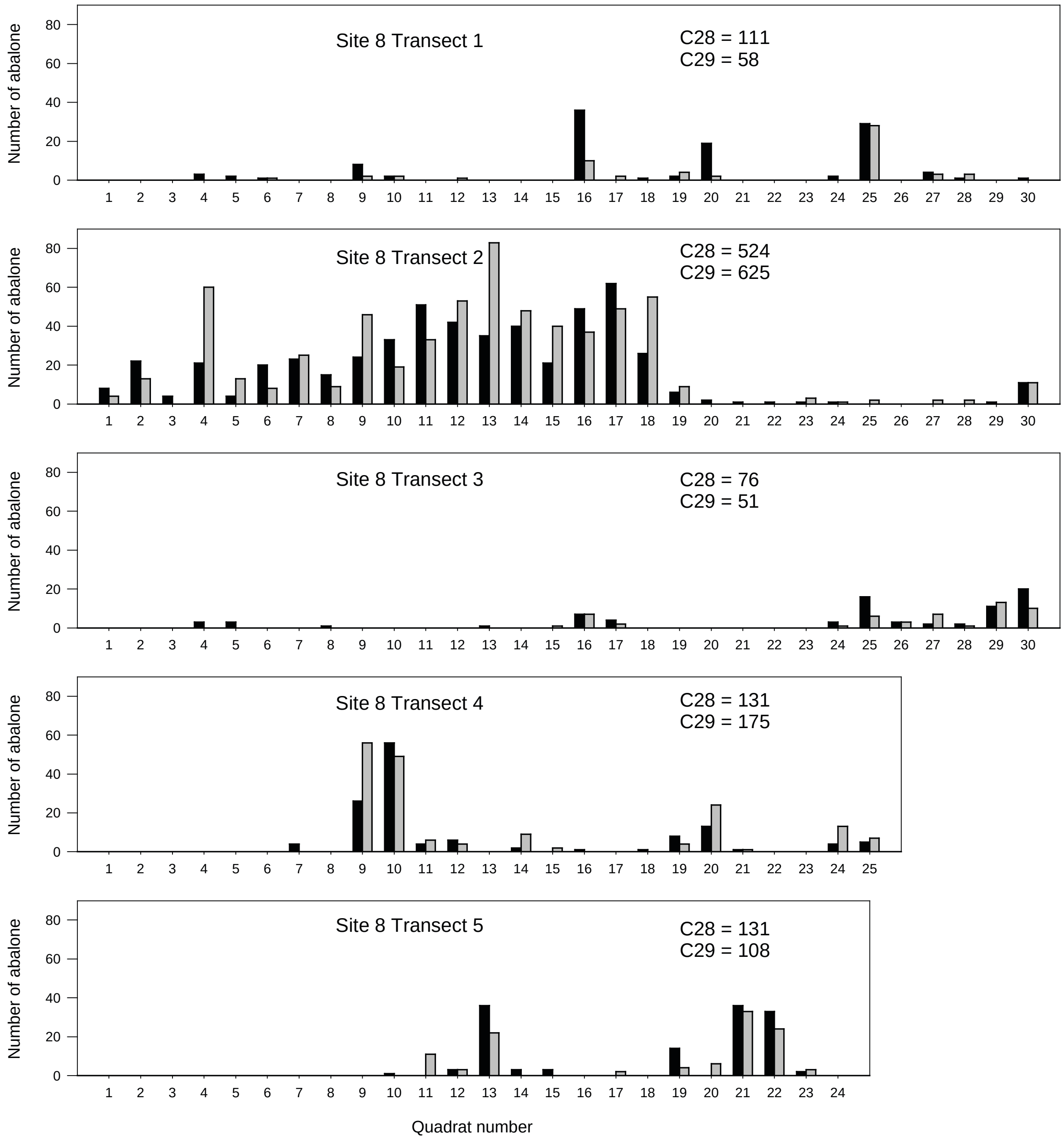

Figure 22. Cycle 28 (black bars) and Cycle 29 (gray bars) distribution of black abalone along transects at Site 8, San Nicolas Island, California, 2018–2019. Total transect count for each cycle indicated on graph.

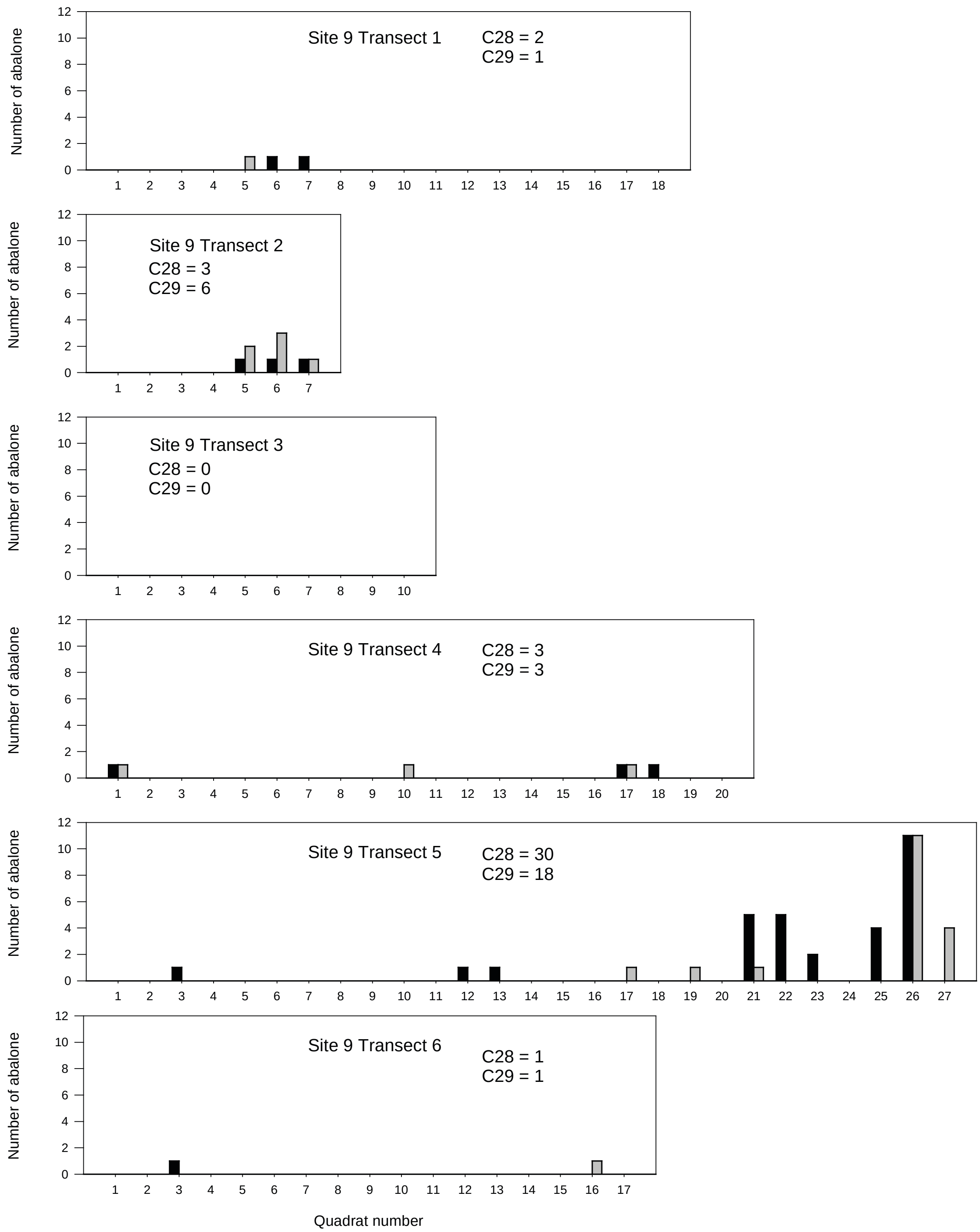

Figure 23. Cycle 28 (black bars) and Cycle 29 (gray bars) distribution of black abalone along transects at Site 9, San Nicolas Island, California, 2018–2019. Total transect count for each cycle indicated on graph.

Table 3. Distribution among microhabitats, 2019, San Nicolas Island, California.

[Percent crevice for each transect is noted and in bold if less than 90 percent. Transects with no abalone counted are not listed. **Abbreviations:** CR, Crevice; OH, Open Horizontal; OV, Open Vertical]

Transect	CR	OH	OV	Percentage CR
Site 1				
1	49	0	0	100.0
2	2	0	0	100.0
3	1	0	2	33.3
4	2	0	0	100.0
5	5	0	0	100.0
6	5	1	2	62.5
Site 2				
1	4	0	0	100.0
2	7	0	2	77.8
3	12	0	0	100.0
5	11	0	0	100.0
Site 3				
3	29	0	0	100.0
4	3	0	0	100.0
5	1	0	0	100.0
6	2	0	0	100.0
7	7	0	0	100.0
Site 4				
1	9	4	0	69.2
2	14	0	0	100.0
Site 5				
1	14	1	0	93.3
2	7	0	1	87.5
3	1	0	0	100.0
Site 6				
1	2	43	1	4.3
2	0	22	0	0.0
3	26	0	0	100.0
4	12	7	1	60.0
Site 7				
1	216	1	0	99.5
2	3	0	0	100.0
3	27	3	7	73.0
4	242	1	13	94.5
5	150	0	1	99.3
Site 8				
1	47	3	8	81.0
2	619	4	2	99.0
3	50	1	0	98.0
4	174	0	1	99.4
5	105	0	3	97.2
Site 9				
1	1	0	0	100.0
2	6	0	0	100.0
4	3	0	0	100.0
5	18	0	0	100.0
6	1	0	0	100.0

Size Distribution and Recruitment

Prior to WS reaching SNI in the early 1990s, the size distribution of black abalone on these sites was dominated by large adults (VanBlaricom, 1993). During the years 2001–2019, the period after WS dramatically reduced the population; recruits began to become more common (fig. 24). This phenomenon, in concert with the dramatic reduction of the existing population, lead to an obvious change in the overall shape of the size distribution. In 1988 (Cycle 6), a size sample was acquired from all nine sites (G.R. VanBlaricom, unpub. data, 2019), and is used in this report for comparison with the more recent size structures. Because many of the recorded abalone could not be measured, there is likely some bias in the size data from the pre-WS years. The very high densities of adults at the time could have made juveniles much more difficult to see. It also is likely that this bias changed over time as abalone became much less crowded and can vary between sites and transects due to local topography. Figure 25 (top left panel) shows that most individuals pre-WS had shell lengths of 10–13 cm.

Figure 24. Two black abalone recruits at site 5—Shell length approximately 2 centimeters (cm) in abandoned urchin cavity, San Nicolas Island, California. Photograph taken by M.C. Kenner, U.S. Geological Survey.

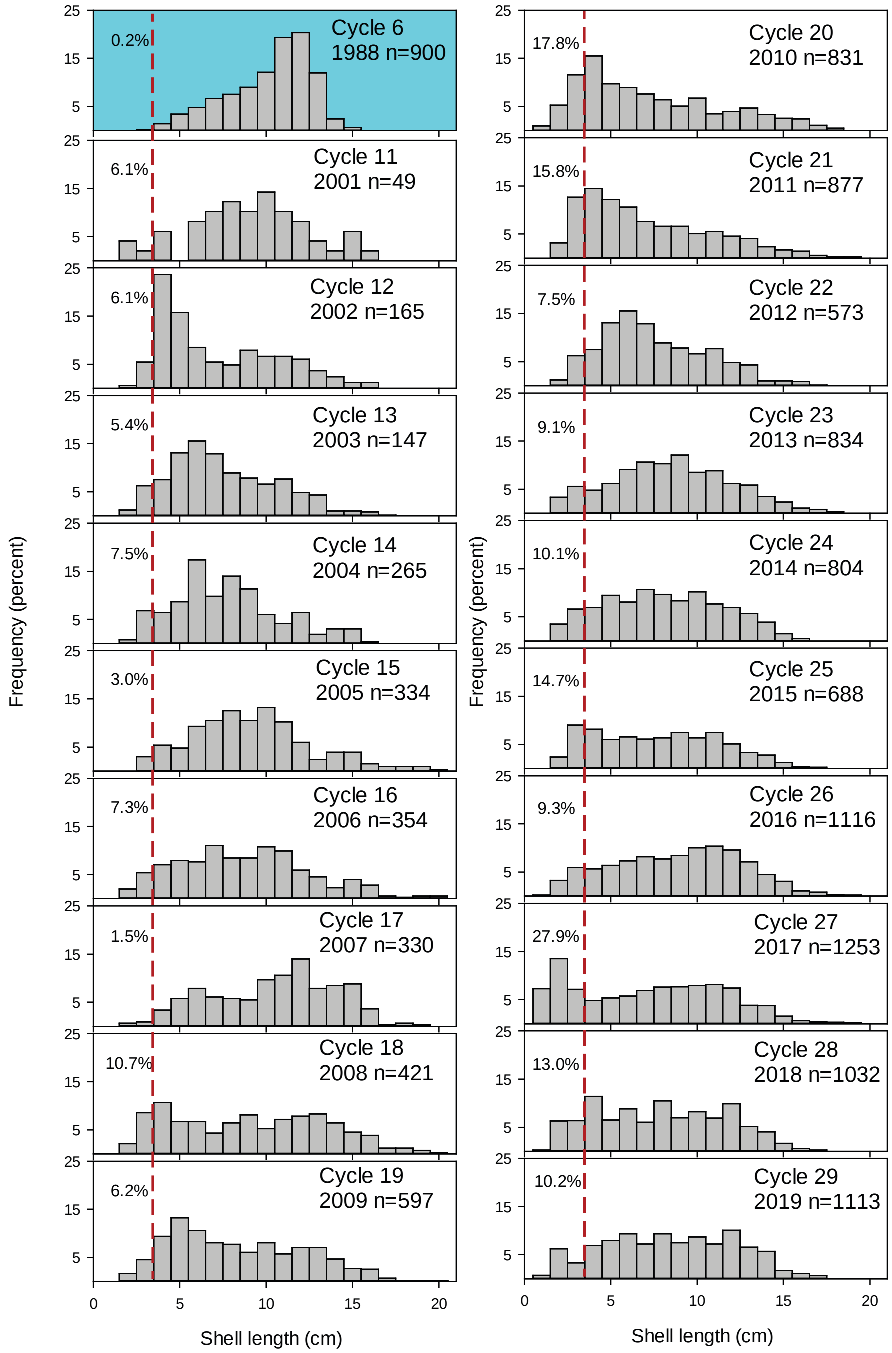

Figure 25. Whole island size distributions (total shell length in centimeters, cm) of black abalone for 1988 (colored background) and 2001–2019, San Nicolas Island, California.

Proportionately, there were very few individuals 3 cm or less in length—the size range which, for practical purposes, is considered to be composed of recruits and few small individuals in general. This lack of recruits is in contrast to the size distributions from 2001 onward (fig. 25, other panels). The size classes are much more evenly represented in these later years and, in fact, several of them show a dominance of smaller size classes. All of these samples show at least a few individuals in the recruitment size class. Recently settled abalone are thought to primarily inhabit cryptic habitat such as *Mytilus* beds or under boulders so, in the absence of destructive sampling, individuals less than 2 or 3 cm are under-represented in size samples (VanBlaricom, 1993). The percent of the sample that is made up of these less than 3.5 cm individuals is noted on each of the annual size plots. There have been several sizable recruitments in the last 10 years. A successful recruitment can shape the size distribution for several years as the mode composed of a young cohort moves across successive size plots. This can be seen in the plots from 2010 to 2013. Based on the shape of the plot from 2002 to 2005, there was likely a larger recruitment in 2001 than is apparent in the data from that year.

The size frequency for each of the nine sites in 2019 is illustrated in figure 26. Frequency is shown as percent of the sample. Six of the nine sites had some individuals in the recruitment cohort—all except sites 3, 4, and 6. Sites 7 and 8 had the most individuals in this category but as a percent of the local population, sites 8, 5, and 9 had the highest rate. Site 2 has the biggest proportion of individuals larger than 15 cm. Table 4 shows numbers of recruits by site for each year from 2001 to 2019. Sites 8 and 7 have contributed the most recruits over the years, followed by sites 5 and 3.

The size frequency data for all sites in the 1988 sample is shown in figure 27. Besides the lack of recruits then, there also is a scarcity of individuals greater than 15 cm. The size distributions of the sites appear relatively similar to each other in this sample compared to the 2019 data.

A strong recruitment event was detected at site 8, transects 1 and 2 in 2017. Figure 28 illustrates the sequence of size frequencies at these transects from 2016 to 2019. Note that the frequencies plotted here are numbers of individuals rather than percent of the sample and only represents the portion of the population on these transects that were measurable. Although the recruitment observed on transect 1 in 2017 increased total counts from 14 to 252, there was only a net gain of 44 individuals by 2019 even though there were additional recruits in 2018 and 2019. The total number of recruits measured on transect 1 from 2017 to 2019 was 239. On transect 2, on the other hand, total counts increased from 332 to 476 in 2017 and the net gain by 2019 was 293 abalone. There was a total of only 146 recruits measured on this transect over the 3 years. The discrepancy between measured recruits and increase in count can be explained by the fact that, due to the complex structure of transect 2, there were 218 unmeasurable abalone in 2019 alone. Of these, 106 were estimated to be in the recruit size bin (table 4). It is likely there were similarly high numbers of unmeasured recruits in 2017 and 2018. There was considerable attrition of the new recruits, either from mortality or movement out of the transects, between 2017 and 2019.

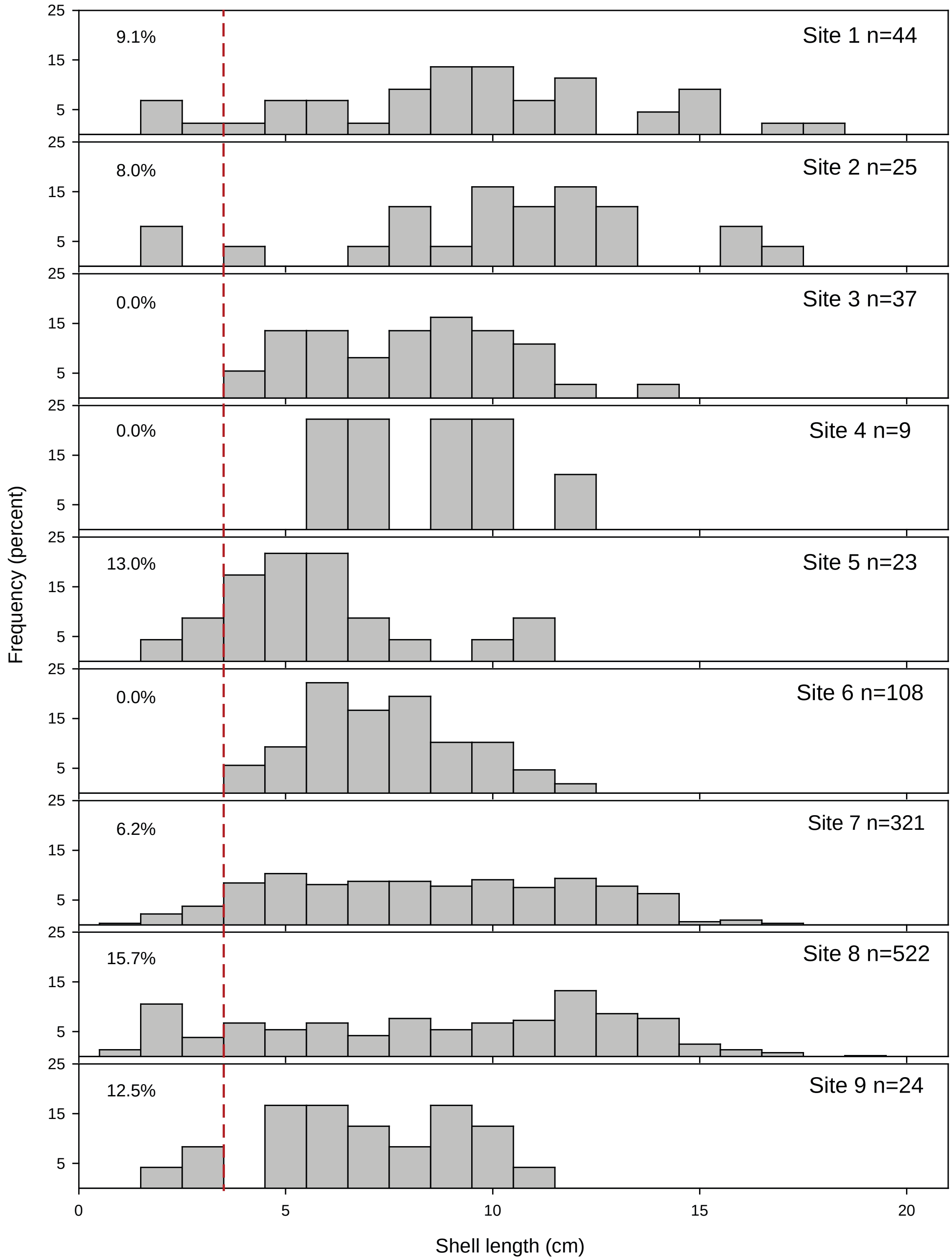

Figure 26. Size distribution (percent frequency) of each site in 2019, San Nicolas Island, California. Sizes to the left of the dashed red line may be considered recruits and the percent of each sample in that category is indicated.

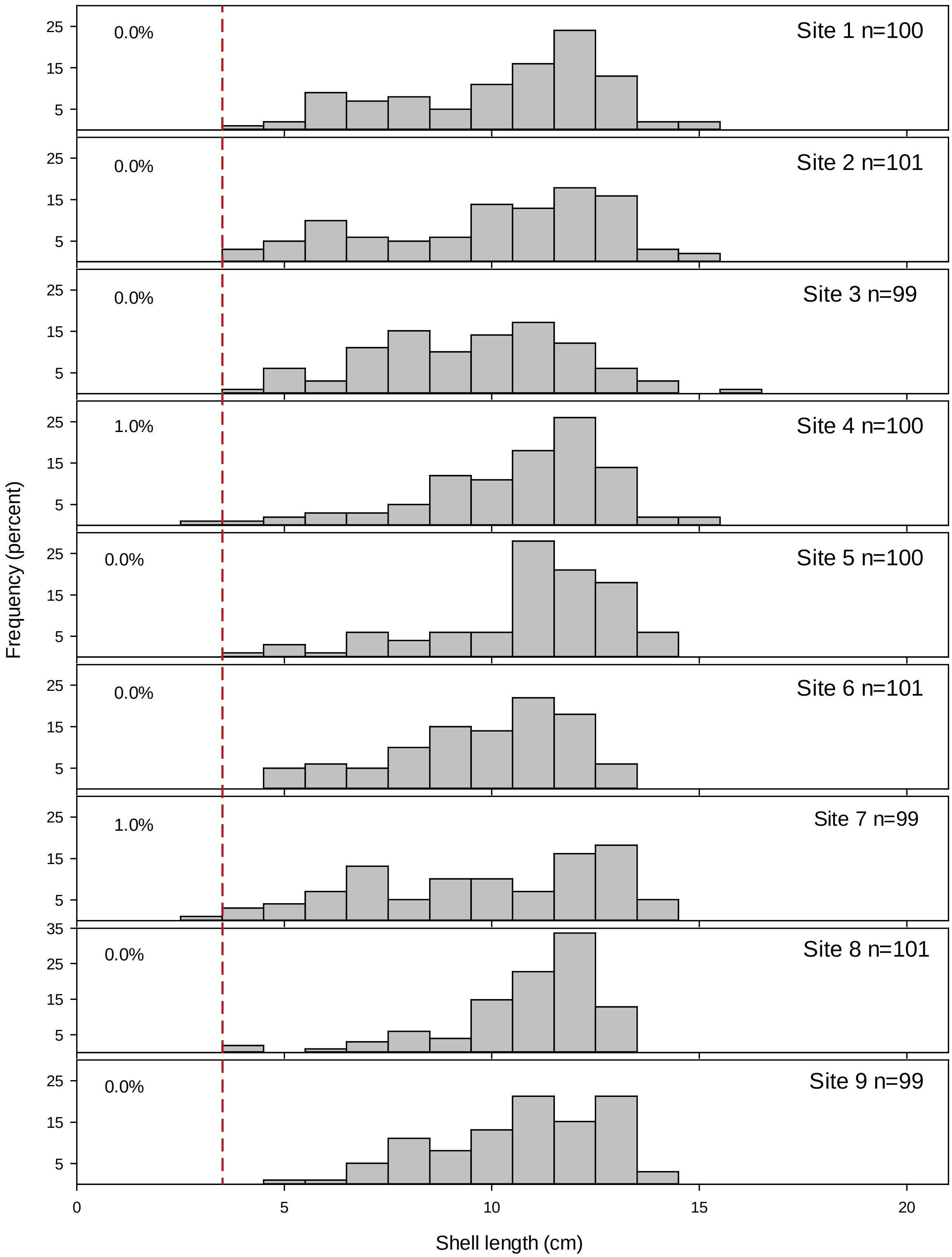

Figure 27. Size distribution (percent frequency) of each site in 1988, San Nicolas Island, California. Sizes to the left of the dashed red line may be considered recruits and the percent of each sample in that category is indicated.

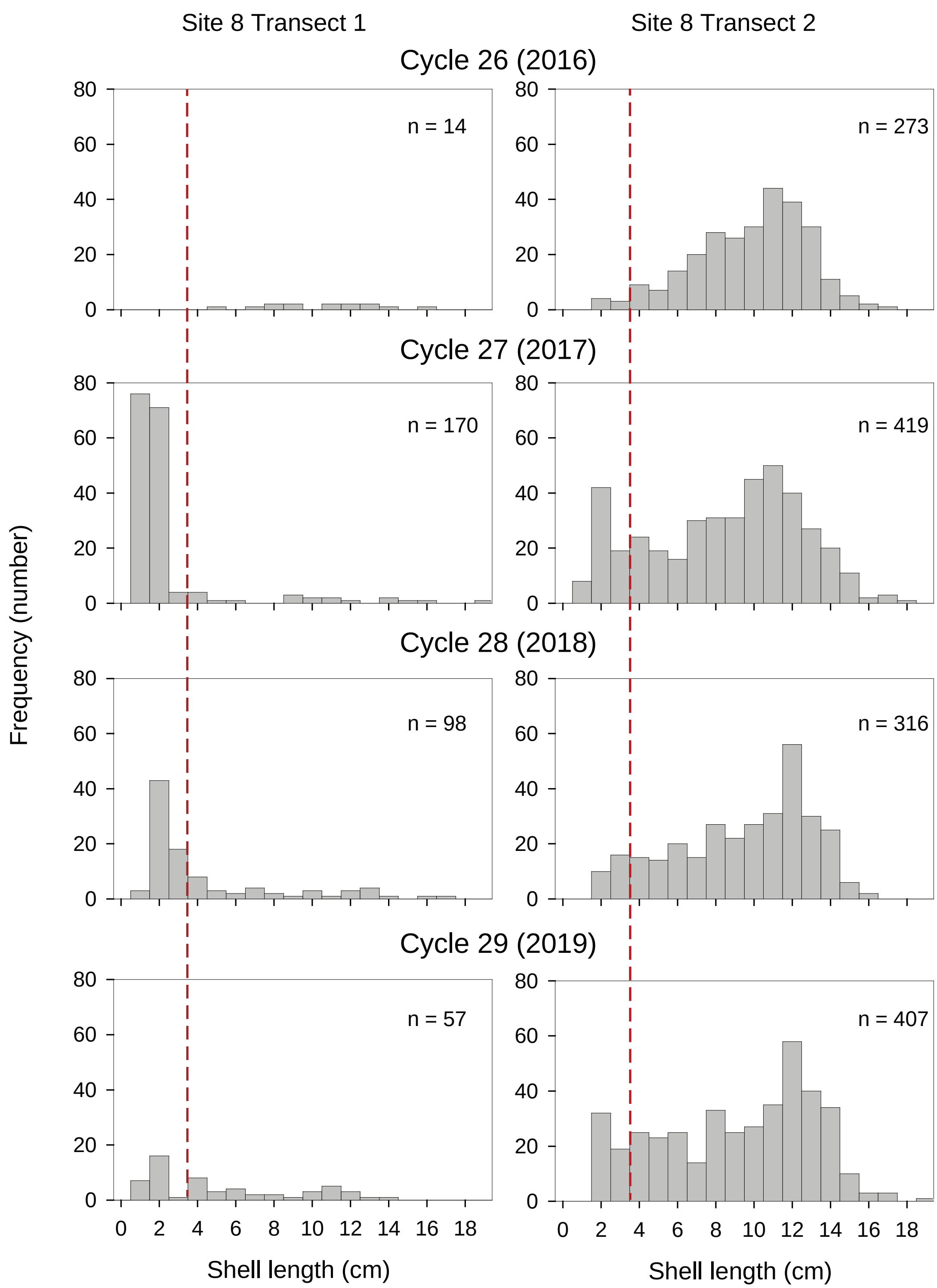

Figure 28. Recruitment pulse as observed in the size distribution measured in 2016–2019 at site 8, transects 1 (left) and 2 (right), San Nicolas Island, California. Frequencies are presented here as numbers rather than percent of sample size. Sizes to the left of the dashed red lines may be considered recruits.

Table 4. Number and percent of measured abalone that were recruits (less than 3.5 centimeters) at each site for cycles 11–29 (2001–2019) and total recruits for each cycle, San Nicolas Island, California.

[Values in parenthesis ( ) indicate percent. Bottom rows show numbers of non-measured abalone estimated to be in the recruit size bin in cycle 29 and as a percentage of sized abalone—either measured or estimated (see “Methods” section). **Abbreviations**: —, not applicable; NR, not recorded]

Cycle	Year	Site									Total count
		1	2	3	4	5	6	7	8	9	
11	2001	0	0	0	0	0	0	0	3 (10.0)	0	3 (6.1)
12	2002	1 (10.0)	0	0	0	0	0	0	9 (9.2)	0	10 (6.1)
13	2003	0	0	5 (29.4)	0	2 (8.0)	0	0	0	1 (8.3)	8 (5.4)
14	2004	0	0	4 (7.8)	0	0	1 (11.1)	4 (9.3)	11 (8.5)	0	20 (7.5)
15	2005	0	0	4 (11.8)	0	3 (10.3)	0	0	3 (1.5)	0	10 (3.0)
16	2006	0	0	2 (8.3)	0	8 (23.5)	0	1 (2.0)	15 (6.9)	0	26 (7.3)
17	2007	0	0	1 (5.3)	0	0	0	1 (3.2)	3 (1.3)	0	5 (1.5)
18	2008	0	0	14 (33.3)	0	11 (16.9)	0	2 (4.2)	18 (7.4)	0	45 (10.7)
19	2009	0	1 (12.5)	13 (14.3)	0	13 (24.1)	0	1 (1.4)	9 (2.6)	0	37 (6.2)
20	2010	3 (14.3)	2 (20.0)	10 (14.7)	2 (16.7)	17 (28.3)	1 (11.1)	42 (24.6)	70 (15.1)	1 (6.7)	148 (17.8)
21	2011	2 (8.7)	5 (33.3)	9 (11.8)	1 (6.7)	12 (21.1)	0	16 (10.6)	92 (18.6)	2 (7.4)	139 (15.8)
22	2012	2 (10.0)	6 (25.0)	3 (3.9)	0	5 (8.8)	0	15 (7.8)	11 (8.1)	1 (3.4)	43 (7.5)
23	2013	0	0	8 (8.8)	0	15 (37.5)	0	48 (13.2)	5 (2.0)	0	76 (9.1)
24	2014	5 (12.5)	3 (14.3)	8 (11.1)	2 (6.1)	6 (25.0)	0	30 (8.2)	27 (13.6)	0	81 (10.1)
25	2015	4 (6.6)	1 (4.5)	16 (17.0)	0	6 (37.5)	1 (3.2)	36 (16.7)	35 (17.2)	2 (6.3)	101 (14.7)
26	2016	3 (8.3)	6 (26.1)	0	3 (8.1)	6 (25.0)	4 (8.7)	64 (16.9)	9 (1.7)	9 (30.0)	104 (9.3)
27	2017	14 (33.3)	0	8 (14.3)	3 (6.4)	14 (43.8)	6 (10.2)	35 (17.5)	247 (32.8)	22 (50.0)	349 (27.9)
28	2018	4 (6.3)	1 (3.1)	1 (2.1)	2 (4.9)	1 (3.2)	7 (6.6)	18 98.7)	100 (21.5)	0	134 (13.0)
29	2019	4 (9.1)	2 (8.0)	0	0	3 (13.0)	0	20 (6.2)	82 (15.7)	3 (12.5)	114 (10.2)
Cycle 29 estimated											
—	—	3	3	0	0	0	0	37	125	NR	168
Cycle 29 percent including estimated sizes											
—	—	(10.1)	(13.5)	(0.0)	(0.0)	(12.5)	(0.0)	(9.1)	(20.5)	NR	(14.4)

Nearest Neighbors

The mean nearest neighbor distance has been declining over several years as the population size has increased. Figure 29 shows this trend since 2005 when consistent efforts were first made to measure this parameter. Also, plotted are the percent of each sample within 10 cm and within 100 cm of the nearest conspecific. The trend for all three metrics is toward closer proximity.

Figure 30 shows distance bins plotted by site for 2019. Sites 7 and 8, which dominate in terms of total abalone count, also drive the high numbers toward close proximity. These two sites contained 80.5 percent of the counted population, and 92.3 percent of these 1,627 abalone were within 10 cm of another black abalone. In general, the other sites are fairly evenly spread among the bins with only 41.5 (range of 29–64) percent of the counted abalone within 10 cm of another.

Table 5 shows the nearest neighbor distance bins assigned to measured abalone that were in the recruit size classes (less than 3.5 cm) for each year from 2005 to 2019. The distance bins are touching (less than 1 cm), 1 cm–10 cm, 11 cm–1 m, 1.01 m–5 m, and greater than 5 m. Most recruits, like their adult counterparts, are found in the first and second bins, between 0 and 10 cm from other abalone. Whether this is a result of settlement cues or some other phenomenon, such as migration or differential survival, is unclear, but this (apparent) intra-species fidelity, though favorable in the long-term for spawning success, may tend to limit resettlement of unoccupied areas. Perhaps resulting from this uneven distribution of recruits, a similar pattern is seen in the larger size classes, suggesting that there is not an inclination toward dispersal.

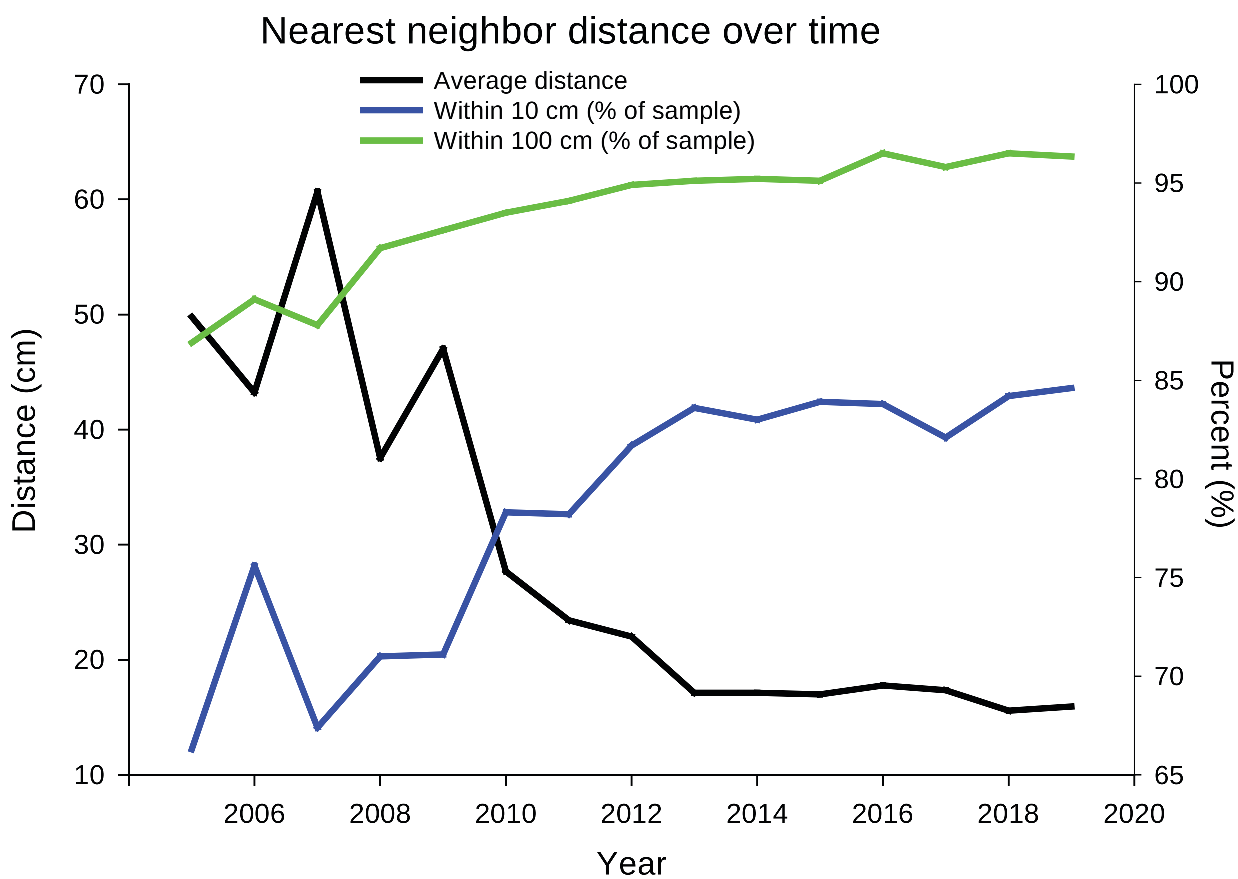

Figure 29. Mean nearest neighbor distance 2005–2019 and percent of sample within 10 centimeters (cm) and within 100 cm of neighbor, San Nicolas Island, California.

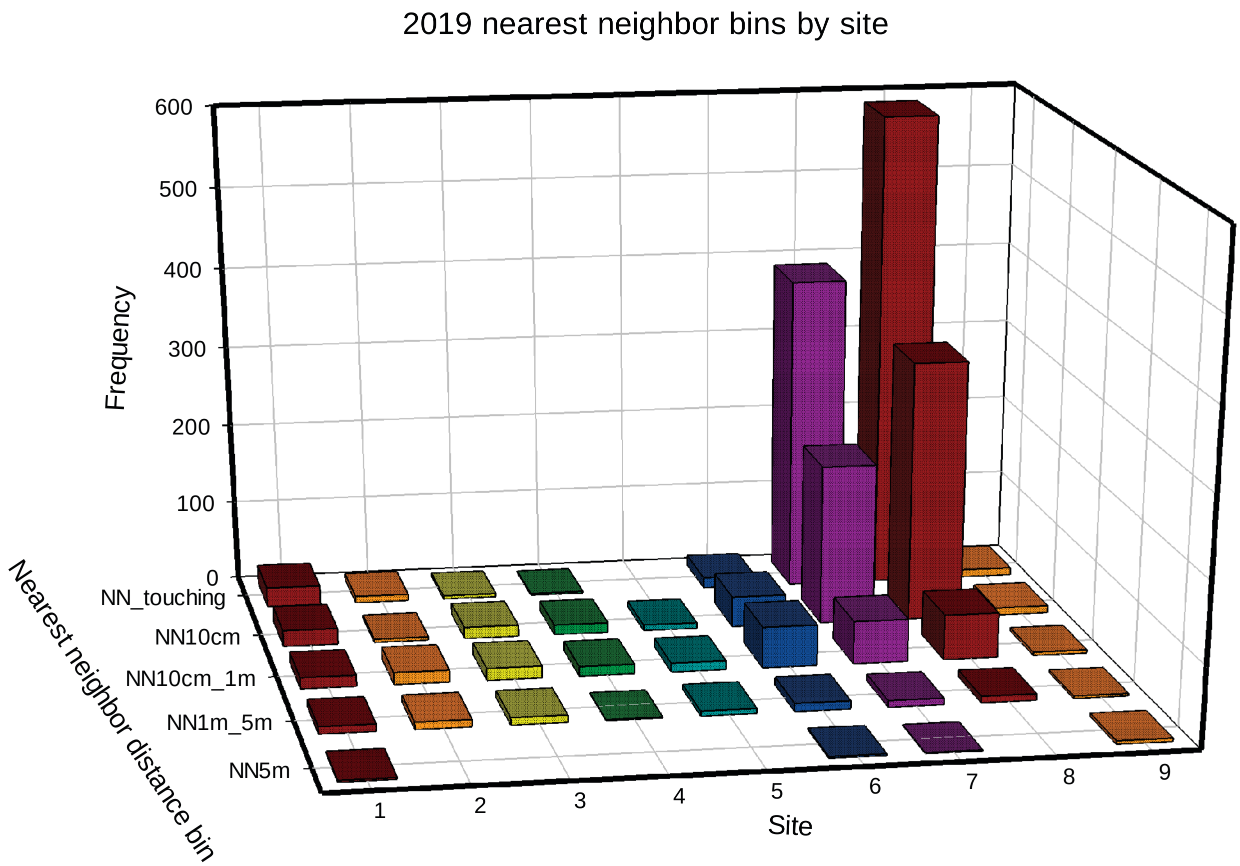

Figure 30. Nearest neighbor (NN) distance bins by site for 2019, San Nicolas Island, California. The bins are “NN touching” less than 1 centimeter (cm), “NN10cm” =1 cm–10 cm, “NN10cm_1 meter (m)” =11 cm–1 m, “NN1m_5m” =1.01 m–5 m, and “NN5m” more than 5 m.

Table 5. Total recruits for cycles 15–29 (2005–2019) by nearest neighbor distance bin, San Nicolas Island, California.

[Percent of total (NR excluded) at bottom. Recruits defined as measured individuals with a shell length less than 3.5 cm. **Abbreviations:** NR, not recorded; cm, centimeter; m, meter; >, greater than; —, not applicable]

Cycle	Year	Nearest neighbor bins					
		NR	0 cm	1–10 cm	11 cm–1 m	1–5 m	>5 m
15	2005	0	1	1	8	0	0
16	2006	7	3	13	2	1	0
17	2007	0	3	0	2	0	0
18	2008	0	11	19	12	3	0
19	2009	0	10	17	8	2	0
20	2010	1	56	66	20	5	0
21	2011	1	78	35	16	8	1
22	2012	1	14	10	13	3	2
23	2013	0	29	27	16	4	0
24	2014	0	36	26	14	4	1
25	2015	0	48	34	10	9	0
26	2016	2	51	39	8	3	1
27	2017	2	133	133	64	14	3
28	2018	0	75	39	16	4	0
29	2019	0	70	26	14	3	1
Total for all cycles							
—	—	—	618	485	223	63	9
Percent for all cycles							
—	—	—	43.8	34.3	15.8	4.5	0.6

Sedimentation

Sand cover in the quadrats does not exhibit an obvious trend temporally or by transect. Figure 31 shows mean sand cover for each transect and total mean sand cover over time from 2001 to 2019 (2009 data missing). Although there could be a weak increasing trend overall, it is clear that inter-year and inter-transect variation are more important. There appears to be only weak synchrony between the transects although, in 2016, several appeared to peak in their cover. Ironically, for the one case where it is thought that sand burial caused mass mortality of black abalone (decline recorded winter 2016, site 3, transects 1 and 2), there was no sand cover in the data. The sand cover was apparently brief and catastrophic and could have resulted from a temporary change in the size and shape of the island's east end sand spit that was observed in October 2015. The sites more typically influenced by sand are 1, 7, and 8.

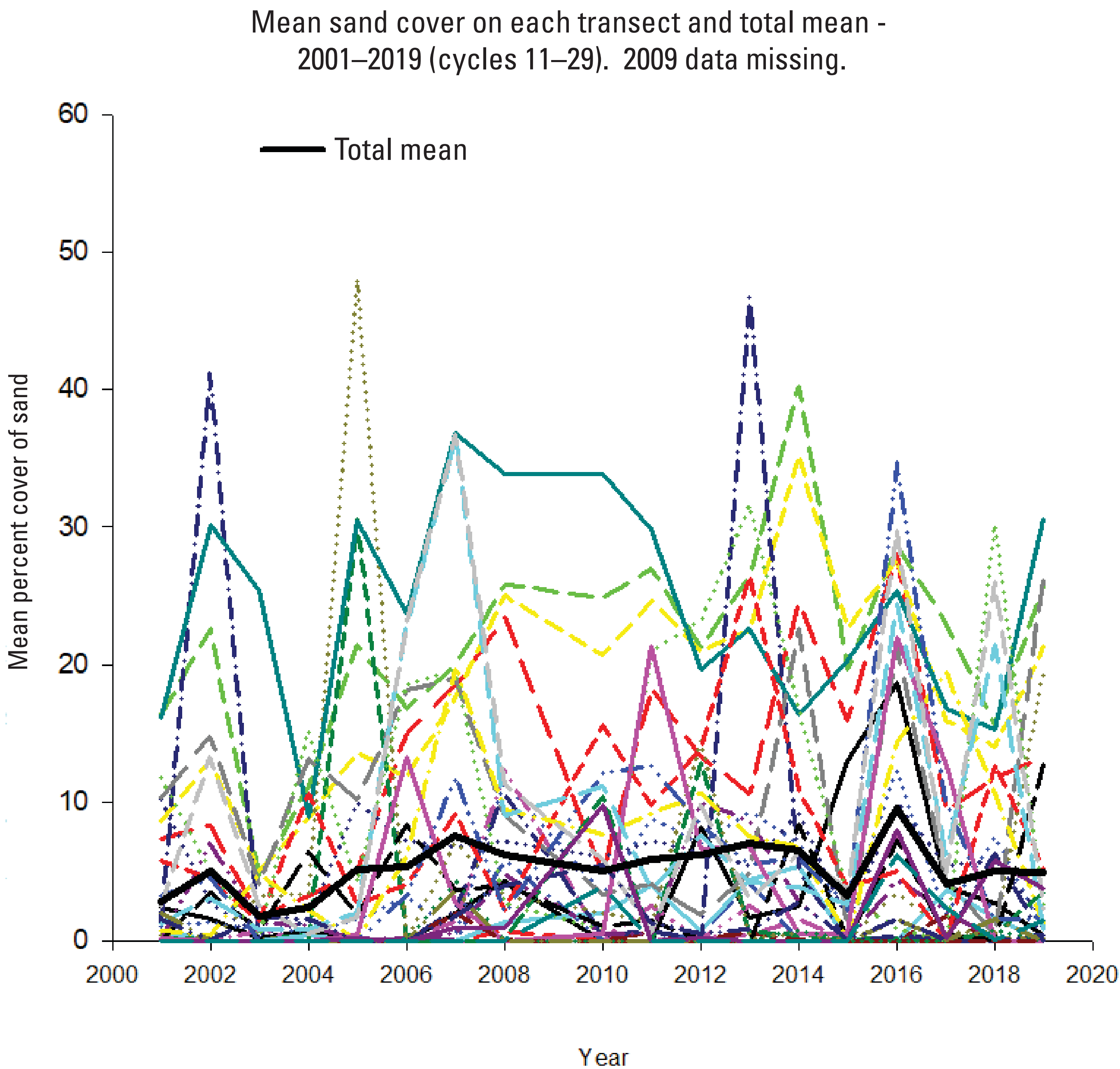

Figure 31. Sand cover by transect for 2001–2019, San Nicolas Island, California. Heavy black line shows total mean cover over time.

Discussion and Conclusions

This monitoring program brings to light several positive signs for the black abalone population at SNI. After several years of fairly regular growth, the monitored population size is at about 8.6 percent of the pre-WS average. This is a significant improvement from 2001 when the population was less than 1 percent of historic levels. Some detectable recruitment has occurred every year since then and the counts at all sites have increased. Finally, nearest neighbor distances have continued to decline, presumably improving the odds for successful spawning events.

There are several negative signs that should be kept in mind, however. In 2019, six of the nine sites showed declines of 14 to 46 percent in counted abalone. In addition, more than half the sampled population of the 2,022 individuals resides at site 8 and 30 percent of them are on an 18-m stretch of one transect there. Most of the population growth has been the result of recruitment at two of the sites (7 and 8) which are the only sites with a mean density above 1/m^2. If the increase in recruitment frequency during the last two decades is related to the current cold water Interdecadal Pacific Oscillation (IPO; see Henley and others, 2015 for definitions, scope and background) as has been postulated by VanBlaricom (2017), then this could reverse within a few years. Although there has been little sign of new outbreaks of WS on the island, and it appears that some SNI abalone might have gained resistance to the effects of WS (Friedman and others, 2014), there is no guarantee that a return of the disease would not be a catastrophic event. Finally, the mass mortality of about 50 black abalone (because of a random sand incursion at site 3 in 2015) is a reminder that stochastic disturbance events beyond human control can take a toll on small populations.

Aside from this unusual sand burial event, the sites with the most sand influence were sites 1, 7, and 8. These sites had large deposits of loose sand shoreward, in addition to offshore sources. They all had large sea lion haul-outs in common as well. Site 1, in particular, has undergone noticeable coastal degradation over the last few decades, apparently as a direct result of the increasing California Sea Lion population using the area. Sea lion use of the west end of SNI, including site 1, increased dramatically in the mid-1990s and substantial seaside terrestrial erosion has occurred since that time. It is difficult to imagine what management can do to prevent this process from continuing, nor is it clear to what extent it is a detriment to the abalone population.

Our results apprise managers of the status of the population at SNI and provide information to assist in decision making. In addition, continuing to promote awareness of the black abalone's protected status could help avoid unnecessary trampling or take of the species by island visitors.

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