AQUATIC CONSERVATION: MARINE AND FRESHWATER ECOSYSTEMS
Aquatic Conserv: Mar. Freshw. Ecosyst. (2015)
Published online in Wiley Online Library
(wileyonlinelibrary.com). DOI: 10.1002/aqc.2561

Historical ecology can inform restoration site selection: the case of black abalone (Haliotis cracherodii) *along California's Channel Islands*

TODD J. BRAJE[a,*], TORBEN C. RICK[b], JON M. ERLANDSON[c], LAURA ROGERS-BENNETT[d] and CYNTHIA A. CATTON[d]

[a]*San Diego State University, Department of Anthropology, San Diego, CA, USA*
[b]*Program in Human Ecology and Archaeobiology, Department of Anthropology, National Museum of Natural History, Smithsonian Institution, Washington DC, USA*
[c]*Museum of Natural and Cultural History and Department of Anthropology, University of Oregon, Eugene, OR, USA*
[d]*California Department of Fish and Wildlife, Bodega Marine Laboratory, Bodega Bay, CA, USA*

ABSTRACT

1. Identifying appropriate ecological conditions for population restoration is important for endangered species such as black abalone (*Haliotis cracherodii*) in California, but limited information exists regarding restoration locations.
2. Using a combination of ancient and historical archaeological data and modern commercial fishing records, four optimal locations for restoration based on past relative abundances of black abalone were identified: north-western, north-eastern, and south-central San Miguel Island and western San Nicolas Island.
3. These locations around California's Channel Islands have supported dense black abalone populations for at least 10 000 years and may offer optimal environmental conditions to enhance the success of black abalone restoration.
4. The strategy outlined here illustrates the promise of integrating prehistoric, historical, and modern fishery data to inform restoration of threatened and endangered abalone, oysters, and other shellfish around the world.
Copyright © 2015 John Wiley & Sons, Ltd.

Received 12 October 2014; Revised 2 February 2015; Accepted 25 February 2015

KEY WORDS: ecological history; fishery data; endangered species; enhancement; stocking; shellfish

INTRODUCTION

Black abalone (*Haliotis cracherodii*) was an important food and tool resource in southern California for more than 10 000 years, including for ancient Native Americans (Rick *et al*., 2005; Erlandson *et al*., 2009), historical Chinese (Braje *et al*., 2007a), and Euro-American fishermen (Braje

*Correspondence to: Todd J. Braje, San Diego State University, Department of Anthropology, San Diego, CA 92182–6040, USA. Email: tbraje@mail.sdsu.edu

et al., 2014). For much of the 20th century until the 1980s, rocky intertidal populations reached high densities of up to 100 individuals m^2 around the California Channel Islands (Lafferty and Kuris, 1993). The modern commercial black abalone fishery peaked in 1973 at just under two million pounds, but had declined by two-thirds 10 years later (1982; Rogers-Bennett *et al.*, 2002). All commercial and sport fisheries for black abalone closed in 1993 in response to overfishing, along with the added stressor of catastrophic Withering Syndrome (WS) disease that exacerbated population declines beginning in the 1980s (Friedman *et al.*, 2002; Butler *et al.*, 2009). In 2009 black abalone were upgraded from a 'species of concern' by the National Oceanic and Atmospheric Administration (NOAA) to 'endangered' under the US Endangered Species Act (ESA). Despite protection since 1993, their abundance was estimated at 1% of historical (between 1972 and 1981) levels at sites around the Channel Islands by the late 1990s (Rogers-Bennett *et al.*, 2002), with additional declines as WS spread northward (Raimondi *et al.*, 2002; Friedman *et al.*, 2014). Recent evidence of some recovery and recruitment has been detected on San Nicolas and Santa Cruz islands (Butler *et al.*, 2009; Neuman *et al.*, 2010; D. Richards, personal communication 2012).

Larval and juvenile seeding and active aggregation of reproductive adults have been identified as potentially effective methods for restoring abalone populations to more sustainable levels (Tegner, 2000; Abalone Recovery and Management Plan, 2005), and accelerating black abalone's path towards recovery. Seeding techniques release larval and juvenile abalone into 'optimal habitat' with the aim of creating a self-sustaining population that then can spread to adjacent areas (Tong *et al.*, 1987; Uki, 1989; Tegner, 2000). Owing to their relative isolation, lower levels of human disturbance, and nutrient-rich kelp forests, California's Channel Islands have been a focus for abalone restoration (Burton and Tegner, 2000; Abalone Recovery and Management Plan, 2005). The California Abalone Recovery and Management Plan (2005) identified 28 stretches of coastline along six of the eight California Channel Islands, in addition to 'all rocky intertidal areas' along San Nicolas Island, as key locations for black abalone outplanting (Table 1). In nearly every case, key locations constitute the vast majority of island coastline, providing little to no smaller scale recommendations for abalone outplanting. Since modern landings data are coarse-grained, site selection criteria need further refinement to help identify where restoration ecology efforts might be most fruitful.

Archaeological data from California's Channel Islands can help identify locations where black abalone were regularly harvested for 10 000 years or more (Figure 1). These types of deep historical perspectives are increasingly important in modern marine management plans, now that the 'shifting baselines' concept – the notion that modern day ecology and conservation need to be informed by past conditions – has been widely accepted (Pauly, 1995; Dayton *et al.*, 1998; Jackson *et al.*, 2001). Historical ecological case studies connecting deep temporal perspectives with modern recovery actions have made significant progress over the last two decades (Lotze *et al.*, 2011; McClenachan *et al.*, 2012; Kittinger *et al.*, 2013, 2014; Lotze and McClenachan, 2014), but historical ecology remains an emerging discipline (Braje and Rick, 2013; Rick and Lockwood, 2013; Lotze *et al.*, 2014). This case study of black abalone offers a methodological application of historical ecology by providing insights into abalone distribution and relative abundance before the extirpation of sea otters (*Enhydra lutris*), intensive commercial and recreational fishing, disease, pollution, and habitat degradation of the last two centuries, as well as during periods of fluctuating sea-surface temperature (SST). These data help identify locations along the Channel Islands that have maintained healthy black abalone populations for centuries or millennia. The combination of prehistoric and historical archaeological and modern fishery data can act as a model for planning and restoring populations of other shellfish species (e.g. *Haliotis rufescens*, *Haliotis kamtschatkana*, *Crassostrea virginica*, *Lottia gigantea*) around the world.

This paper compiles the long-term history of black abalone fishing around California's Channel Islands, drawing from three sources: (1) the

Table 1. Key locations for black abalone outplanting along the Calfornia Channel Islands (California Fish and Game Commission 2005: Table 6–6)

	Island	Key location	Block No.	%[1]
Northern Channel Islands	Anacapa Island	Bat Ray Cove to West End	684	100
		West End to East Fish Camp	684	
	Santa Rosa Island	Tecolote Point to Sandy Point	689	60
		Sandy Point to Cluster Point	711	
		Johnson's Lee to Ford Point	711	
		Ford Point to East Point	711, 710	
	San Miguel Island	Crook Point to Cardwell Point	690, 689	100
		Bay Point to Harris Point	689, 690	
		Harris Point to Otter Harbor	690	
		Otter Harbor to Point Bennett	690	
		Judith Rock to Crook Point	690	
Southern Channel Islands	Santa Barbara Island	Arch Point to Webster Point	765	100
		Webster Point to Sutil Island	765	
		Sutil Island to Sea Lion Rookery	765	
	San Nicolas Island	All Rocky Intertidal Areas	813, 814	100
	Santa Catalina Island	Long Point to Blue Cavern Cove	761	40
		Little Harbor to Ben Weston Point	761	
		Eagle Reef to Stony Point	762	
		Stone Point to West End	762	
		West End to Ribbon Rock	762	
		Ribbon Rock to Catalina Head	762	
	San Clemente Island	Northwest Harbor to West Cove	829	100
		Little Flower to White Rock	849	
		West Cove south 3 nautical miles	849, 850	
		Eel Point north 3 nautical miles	850	
		Eel Point to Mail Point	850	
		Mail Point to Lost Point	850	
		Lost Point to Cove Point	849, 867	
		China Point to Pyramid Head	867	

[1]Calculated based on the 10' × 10', 6600-ha blocks designated by the California Fish and Game abalone recovery and management report (California Fish and Game Commission, 2005). Percentage refers to the percentage of island coastline appropriate for black abalone outplanting as determined by the California Fish and Game Commission.

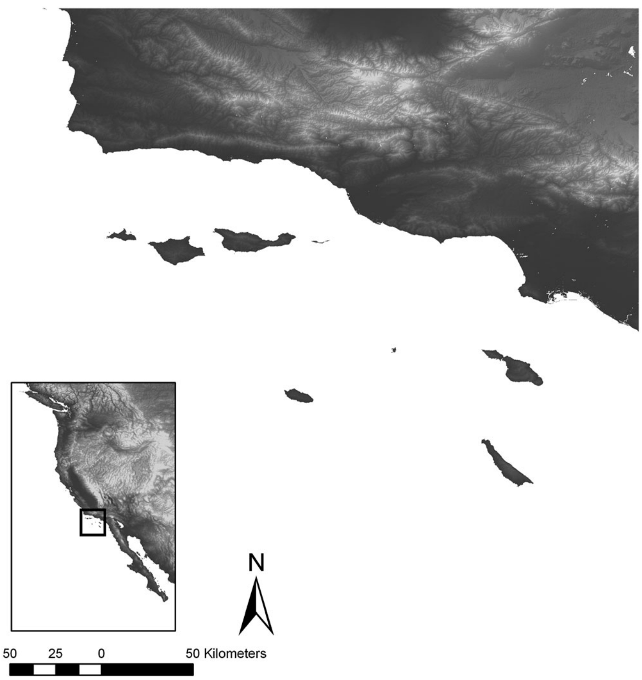

Figure 1. Map of southern California and the Southern and Northern Channel Islands.

prehistoric archaeological record of Native American black abalone fishing; (2) the mid to late 19th century historical archaeological record of commercial black abalone fishing; and (3) catch data for commercial and recreational black abalone fishing between 1950 and 1993. The integration of these datasets can help identify coastlines that have offered productive black abalone habitat for millennia and may offer optimal environmental conditions to enhance the success of black abalone restoration.

METHODS

Spatially explicit modern catch data for southern California commercial and recreational black abalone fisheries between 1950 and 1993 from Morro Bay to San Diego, including the Channel Islands were examined (Abalone Recovery and Management Plan, 2005). These data were compiled and analysed by the California Department of Fish and Wildlife as part of their 2005 Abalone Recovery and Management Plan and include commercial landing receipts and passenger recreational fishing vessel receipts, and provide a pattern of black abalone distribution and relative abundance throughout their range in California. Following reporting and templates from California Fish and Wildlife, data are divided into (10' latitude × 10' longitude) blocks and reveal the prime locations for abalone fishing when sea otters were locally extinct and an intensive commercial abalone fishery existed for a century (Braje *et al.*, 2007a).

These modern fishery data were compared with deeper time records (centuries to millennia) compiled from archaeological shell middens. Shell middens are ancient refuse piles associated with villages and camps occupied by Native Americans and more recent peoples who lived on or visited the Channel Islands. On the Channel Islands, Native Americans intensively harvested abalone and other shellfish, finfish, aquatic birds, and marine mammals for more than 12 000 years (Erlandson *et al.*, 2009, 2011). The intensity of black abalone harvest fluctuated through time, but foraging theory and ethnohistoric records suggest that abalone was a highly ranked resource for Channel Islanders throughout the Holocene (Braje *et al.*, 2007b). If and when black abalone were available, they were targeted by humans and their shells deposited in the archaeological record, making their relative abundance in shell middens an excellent proxy for prehistoric availability along adjacent coastlines. Channel Islanders probably focused their black abalone foraging on rocky intertidal areas during low tides, but may have occasionally waded or dived for prey in shallow waters. All of the Channel Islands have been surveyed for archaeological sites, but the number of shell middens that have been excavated and produced quantified shellfish data is uneven with less research on Santa Catalina, portions of San Clemente, eastern Santa Cruz, and the southern coast of Santa Rosa. Despite these gaps, the available archaeological data provide a robust measure of trans-Holocene black abalone fishing for seven of the eight Channel Islands.

Thousands of prehistoric archaeological sites are preserved on the Channel Islands, and the vast majority of island shell middens contain at least some black abalone shells. After California mussel (*Mytilus californianus*), black abalone is one of the most ubiquitous marine invertebrates found in archaeological deposits spanning the Holocene. As a methodological benchmark, data were compiled from all excavated archaeological sites that contain at least 5% black abalone shell (represented by total shell weight) following previous studies and protocols used by Braje *et al.* (2009). These archaeological locations then were compared with the recent record of modern commercial black abalone fishing locations. Although the archaeological data are based on raw weights of black abalone shells transported to terrestrial refuse piles and the modern data are catch records of living abalones (whole weight) transported to the mainland, each provides a relative estimate of black abalone abundance through time.

After Native Americans were removed from the Channel Islands to mainland towns and missions by Spanish colonialists in the early 19th century, a specialized commercial fishery for black abalone developed in southern California and along the Channel Islands by the 1850s. This industry, facilitated by intensive hunting of sea otters during the historical fur trade, was pioneered by Chinese immigrants and focused on intertidal black abalone, which could be collected without the use of hardhat diving equipment (Lundy, 1997; Braje *et al.*, 2007a). A record of this fishery can still be found along Channel Island shorelines as piles of large, mostly whole black abalone shells embedded in historical sediments near rocky intertidal coastlines and headlands. These black abalone shell piles probably represent the early phases of the commercial abalone industry, between *c.* 1850 and 1880, when abalone meat was the target and shells were discarded on shore. After a commercial abalone shell market developed, both the shell and meat were shipped to the mainland, leaving a more ephemeral archaeological signature on the islands except during times when shell prices plummeted making shell transport uneconomical (Braje *et al.*, 2007a).

Six of the eight Channel Islands, Anacapa, Santa Rosa, San Miguel, Santa Barbara, San Nicolas, and San Clemente have been completely (or nearly completely) surveyed for historical black abalone processing sites. The east and west ends of Santa Cruz Island have been extensively surveyed, but no work has been conducted on Santa Catalina Island. Since newspaper accounts document that Chinese fishermen dried and processed black abalone along island coastlines adjacent to their points of collection (Lundy 1997), these sites provide a proxy for the historical distribution of black abalone before modern commercial harvest. Some sites probably have been lost to coastal erosion and some shorelines with steep and rugged coastlines were probably harvested using small boats (sampans), with the harvest transported to island basecamps up to several kilometres distant from fishing grounds (Braje *et al.*, 2014). Site-specific data for black abalone harvest were evaluated across multiple timeframes (archaeological, historical, and modern) to help inform restoration site selection.

As with any study, methodological limitations exist with the data and interpretations that are important to confront. Both the prehistoric and historical archaeological data and modern catch data are harvest or landings data. These data do not always accurately reflect species abundance found in the wild and catch is often influenced by a number of factors (i.e. harvest effort, technological innovations, management policies, access, travel costs, resource switching, etc.; Essington *et al.*, 2006). High landings, for example, do not always signal a healthy, thriving population, but may reflect increased harvest effort of a declining population (see the example of Atlantic cod; Kurlansky, 1997; Myers *et al.*, 1997; Hutchings and Ferguson 2000). Overall, however, the methods presented here are an effective means of identifying habitats and coastlines where species persisted over thousands of years, through changing climatic conditions, varying levels of human and other animal predation, and human-induced changes. Once these locations have been identified, the assumptions and limitations can be evaluated with site-specific ecological assessments.

RESULTS

Fifty-six archaeological sites (or site components) containing at least 5% black abalone shell were identified, spanning the Early (10 500–7500 cal BP (calendar years before present)), Middle (7500–3500 cal BP), and Late (≤3500 cal BP) Holocene: 30 (53.6%) from San Miguel Island, three (5.4%) from Santa Rosa Island, two (3.6%) from Anacapa Island, 19 (33.9%) from San Nicolas Island, and two (3.6%) from Santa Barbara Island (Table 2, Figures 2 and 3). Considerable archaeological research has been conducted on San Miguel and San Nicolas islands, where the majority of archaeological sites with abundant black abalone are found. Extensive research has also been conducted on Santa Rosa Island from Sandy Point to South Point, the Carrington Point and Bechers Bay regions, and from Skunk Point to East Point, on Santa Cruz Island from West Point to Punta Arena and in the Scorpion Anchorage region as well as on all of Anacapa Island. Several sections of San Clemente and Santa Barbara islands, and on limited coastlines along Santa Catalina Island also have been surveyed. Black abalone at dozens of sites in these areas consistently comprise less than 5% of the raw shell weight, suggesting prehistoric patterning of black abalone along the Channel Islands is a reflection of their prehistoric densities rather than the history of archaeological research.

In total, 144 historical Chinese black abalone processing sites have been identified on the Channel Islands. Twenty-two (15.3%) have been identified on San Miguel Island (Braje *et al.*, 2007a), 26 (18.1%) on Santa Rosa Island (Braje and Bentz, 2015), 19 (13.2%) on Santa Cruz Island (Braje, unpublished notes), 43 (29.9%) on San Clemente Island (Berryman, 1995), and 34 (23.6%) on San Nicolas Island (Krautkramer, 2002). No historical abalone middens have been identified on Anacapa or Santa Barbara islands despite full-coverage archaeological surveys and the mention of these islands as abalone harvesting areas in 19th century newspaper accounts (Braje *et al.*, 2007a). No surveys have been conducted for historical black abalone shell middens on Santa Catalina Island. Subsurface sampling of these site

Table 2. Radiocarbon age and percentage of black abalone shell from archaeological shell middens on the Northern and Southern Channel Islands with quantified faunal data

Site #[1]	Provenience	Age (cal BP)[2]	Black abalone (%)	Reference
		San Miguel Island		
522	Unit 1	9700	9.5	Erlandson *et al*., 2005
608	Bulk Samples 1 & 2	9500	10.0	Braje *et al*., 2012
548	Unit 1	9500	5.8	Erlandson *et al*., 2005
261	Col. E-6, Str. E4	9100	6.2	Braje *et al*., 2012
507	Unit 1	9000	17.0	Braje *et al*., 2012
261	Col. E-6, Str. E3	9000	30.6	Erlandson *et al*., 2005
261	Col. E-6, Str. E2	8900	9.9	Erlandson *et al*., 2005
606	Units 1 & 2	8800	7.4	Braje *et al*., 2012
608 W	Unit 1	8600	5.6	Garcia, 2007
603	Bulk Sample, Str. 7	7900	12.1	Ainis *et al*., 2011
527	Bulk Sample 1	5100	7.8	Braje *et al*., 2012
396	Bulk Samples 1 & 2	4800	6.4	Braje *et al*., 2012
161	Unit 1	4500	10.7	Rick unpublished notes
603	Bulk Sample, Str. 5	4370	10.9	Ainis *et al*., 2011
603	Str. 4	4320	6.5	Braje *et al*., 2012
628	Column 1, L. 2-3	4200	6.8	Braje *et al*., 2012
603	Bulk Sample, Str. 3	4060	28.1	Ainis *et al*., 2011
503 N	Str. 2	3650	16.4	Erlandson *et al*., 2005
261	Col. E-6, Str. A	3300	6.0	Erlandson *et al*., 2005
525	Str. 3	2800	28.9	Erlandson *et al*., 2005
525D	Str. 9	1700	9.5	Erlandson *et al*., 2005
510	N Profile, Str. 6	1200	5.6	Braje *et al*., 2012
232	Col. 1 & 2	1200	10.0	Braje *et al*., 2012
468	Unit 2, Str. III	1200	11.5	Braje *et al*., 2012
481	Column Sample 1	1200	5.1	Braje *et al*., 2011
481	Unit 1a, Str. 1	1170	6.7	Braje *et al*., 2012
468	Unit 2, Str. III	1100	11.5	Braje *et al*., 2012
468	Unit 1	850	5.6	Braje *et al*., 2012
525	D Profile, Str. 3	550	9.4	Braje *et al*., 2012
470	Str. 1	350	13.3	Erlandson *et al*., 2005
		Santa Rosa Island		
6	Bulk Sample	9300	43.4	Braje *et al*., 2012
15	Unit 2, 40–50 cmbs.	590	12.1	Jazwa *et al*., 2012
2	Unit 1	130	5.5	Braje *et al*., 2012
		Anacapa Island		
2	Bulk Sample	2900	>5%	Rick unpublished notes
3	Bulk Sample	3200	6.2	Rick unpublished notes
		San Nicolas Island		
161	Component 1	5200	52.2	Vellanoweth, 2001
161	Component 2	4600	34.0	Vellanoweth, 2001
40	Index Unit	4080	51.1	Martz, 2008
157	Index Unit	3980	25.5	Martz, 2008
161	Component 3	3800	18.0	Vellanoweth, 2001
39	Index Unit	3010	20.8	Martz, 2008
161	Component 4	3000	24.3	Vellanoweth, 2001
147	Index Unit	2830	7.8	Martz, 2008
238	Index Unit	2730	13.5	Martz, 2008
106	Index Unit	2650	51.4	Martz, 2008
102	Index Unit	2540	50.0	Martz, 2008
171	Index Unit	2235	50.7	Martz, 2008
74	Index Unit	2140	14.9	Martz, 2008
163	Index Unit	2060	36.4	Martz, 2008
84	Index Unit	1410	27.4	Martz, 2008
73	Index Unit	850	12.1	Martz, 2008
328	Index Unit	650	32.9	Martz, 2008
25	Index Unit	650	9.2	Martz, 2008
76	Index Unit	305	52.5	Martz, 2008
		Santa Barbara Island		
2	Unit 1	3500	10.6	Rick *et al*., 2009
12	Unit 1	660	79.8	Rick and Erlandson, 2001

[1]Archaeologial sites are numbered using a trinomial system. Each number is proceeded by a state code 'CA-' and an island code 'SMI-' for San Miguel, 'SRI-' for Santa Rosa, 'ANI' for Anacapa, 'SNI' for San Nicolas, and 'SBI' for Santa Barbara.
[2]Site age is based on the approximate midpoint of one or more calibrated radiocarbon dates.

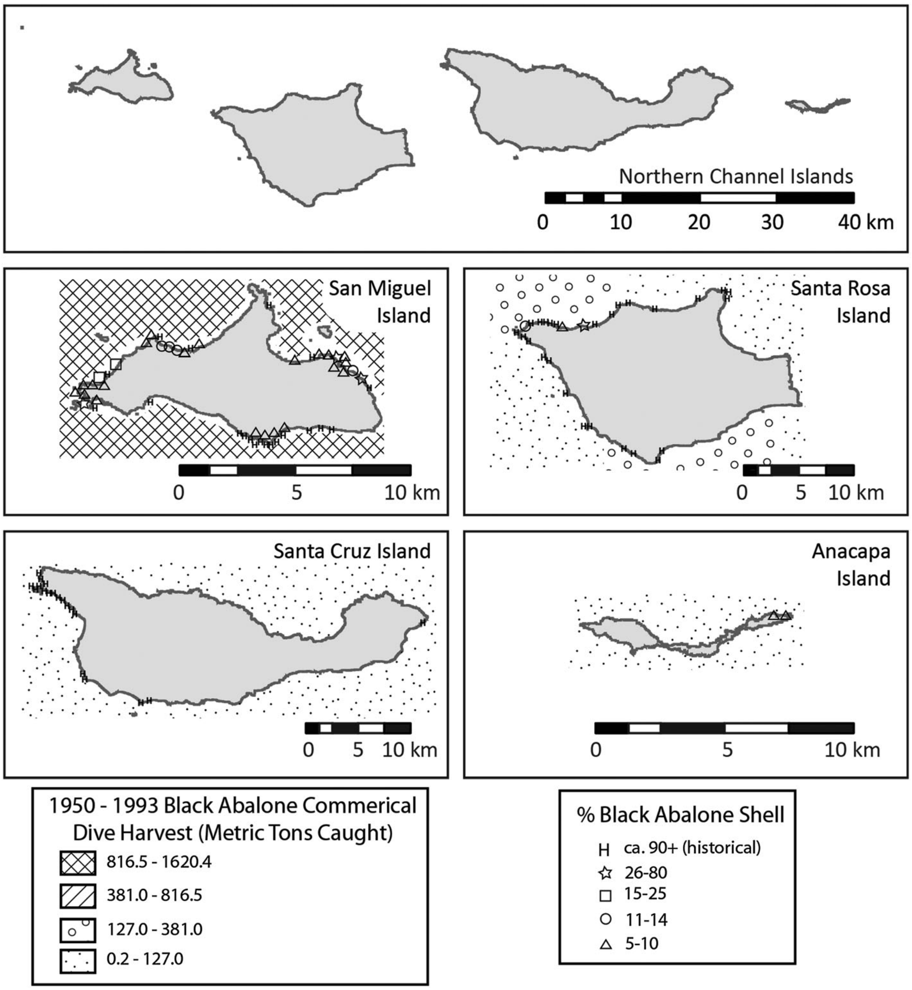

Figure 2. Map of Northern Channel Island commercial black abalone fishing areas from 1950 to 1993, prehistoric archaeological shell midden sites with >5% black abalone shell, and historical 19th century Chinese black abalone processing sites. Note: site locations are approximate to protect the location of cultural resources and to assist with readability.

types has been limited, but research on San Miguel and Santa Rosa islands has demonstrated that they are highly specialized sites with black abalone shell always constituting more than 90% of the shell midden deposits by raw shell weight (Braje and Erlandson, 2007; Braje, unpublished field notes).

The top ranked black abalone habitat during the modern fishery period between 1950 and 1993 is along the coastline surrounding San Miguel Island. During this time at San Miguel Island, between 1620.4 and 816.4 metric tons were harvested (Abalone Recovery and Management Plan, 2005). The second ranked coastline, with harvests between 816.5 and 381.0 metric tons, is found along western San Clemente Island. Eastern San Nicolas Island and north-western and south-eastern Santa Rosa Island are ranked the third most productive black abalone coastline with harvests between 381.0 and 127.0 metric tons during the modern fishery. All other island coastlines were ranked as the least productive coastlines with harvests between 127.0 and 0.2 metric tons.

DISCUSSION

The highest densities of black abalone across the prehistoric, historical, and modern fisheries are found along north-western, north-eastern, and south-central San Miguel Island (Figures 2 and 3). The coastline stretching from the western flank of Harris Point to the Point Bennett area contains 16

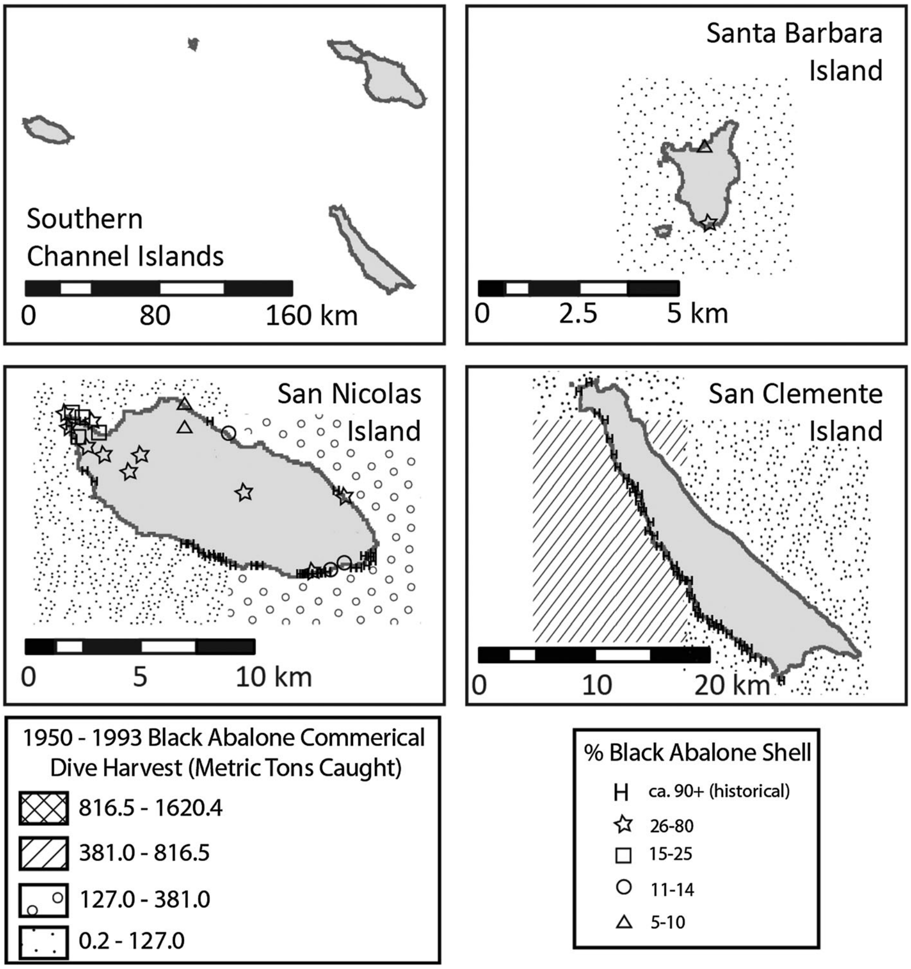

Figure 3. Map of Southern Channel Island commercial black abalone fishing areas from 1950 to 1993, prehistoric archaeological shell midden sites with >5% black abalone shell, and historical 19th century Chinese black abalone processing sites. Note: site locations are approximate to protect the location of cultural resources and to assist with readability.

prehistoric shell midden site components (CA-SMI-396, −468[3], −470, −481[2], −503 N, −507, −510, −522, −525[2], −525D, −527, and −606) ranging in age from 9700 to 350 cal BP with black abalone densities between 28.9 and 5.1%, along with four historical black abalone middens. Shorelines between the eastern flank of Harris Point and Cardwell Point produced 10 prehistoric shell midden components (CA-SMI-161, −261[4], −548, and −603[4]) ranging in age from 9500 and 3300 cal BP with black abalone densities between 30.6 and 6.1%, along with two historical black abalone middens. The Crook Point area produced four prehistoric shell midden sites (CA-SMI-232, −608, −608 W, and −628) ranging in age from 9500 to 1200 cal BP with black abalone densities between 10.0 and 5.6%, along with seven historical black abalone middens. All of these San Miguel Island areas fall within the highest ranked block for modern commercial black abalone fishing. These locations supported long-term, intensive black abalone fisheries through the Holocene, suggesting that they may contain the right mix of environmental conditions for black abalone outplanting and recovery. Although not as compelling as those areas identified on San Miguel, the far western coast of San Nicolas Island also produced long-term, viable black abalone catches during prehistoric and historical times. This coastline produced six prehistoric sites (CA-SNI-39, −40, −157, −161, −163, and −171) and nine prehistoric shell midden components ranging in age from 5200 and 2060 cal BP with black abalone densities between 52.2 and 18.0%, along with five historical black abalone middens. This coastline was among the lowest ranked during the modern commercial fishery, however, despite the dense concentration of historical black abalone fishing camps. Today, there are signs of juvenile black abalone along the San Nicolas Island coast as seen in modern survey data extending over 30 years (VanBlaricom *et al*., 1993; Friedman *et al*., 2014).

Black abalone populations at these prime locations span warm and cold water intervals and do not seem to be tied to natural climatic fluctuations, although the majority of high-density samples occurred during warm water periods (Figure 4). In each of the four identified areas, prehistoric sites with black abalone densities greater than 5% occur during times of both cold and warm water episodes. These data suggest that, in at least these prime locations, black abalone availability across the Holocene was not dependent on water temperature regimes.

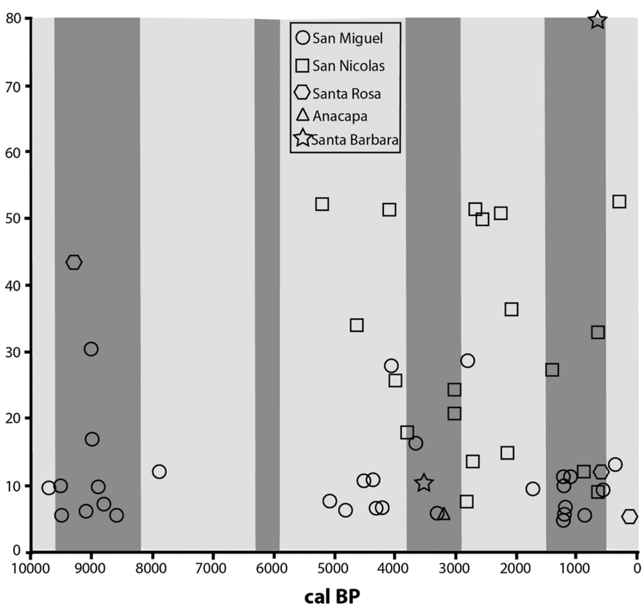

Figure 4. Percentage of black abalone (y-axis) from 56 shell midden sites or site components on the Channel Islands compared with Holocene Santa Barbara Basin sea-surface temperature (SST). Inferred SST is based on $\delta^{18}O$ of *Globigerina bulloides* (surface-dwelling species of foraminifera) from varved sediments in the Santa Barbara Basin (see Kennett, 2005: 64–69). Light grey shading along the x-axis represents warm water and dark grey represents cold water cycles through the Holocene, based on a 12.5 °C Holocene average. Discontinuities between SST and black abalone abundance suggest that black abalone abundance was not solely controlled by SST.

Frequently, chronological measures (modern, historical, or archaeological) of black abalone abundance will suggest a different location as optimal for black abalone outplanting. The western shore of San Clemente Island, for example, contains the greatest density of historical Chinese abalone fishing sites and much of the coastline ranks second in the modern commercial fishery. Despite extensive archaeological excavation along this same coastline, no prehistoric shell midden deposits of any age contain more than 5% black abalone shell. Similarly, the prehistoric site with the highest density of black abalone shell comes from southern Santa Barbara Island at CA-SBI-12, a 660 year old deposit. This same region was one of the least productive locations for modern commercial black abalone fishing, and no additional prehistoric sites, of any age, with abundant black abalone have been found in the area, along with no evidence for 19th century historical harvest. These examples illustrate that some of the challenges of combining deep historical and modern datasets, which often are reported in different ways, can represent different human behaviours under various environmental conditions, and have been influenced by diverse transformation processes (e.g. preservation inadequacies, erosion, weathering, destruction by human action). The combination of datasets, however, can offer locations where black abalone have thrived for thousands of years and areas where outplanting efforts might have the greatest potential for success.

CONCLUSIONS

Historical ecological perspectives that span centuries to millennia are increasingly important components of fisheries management and restoration (Jackson *et al*., 2011). While modern, historical, and archaeological records show patterns at different spatial scales, such long-term records provide valuable insights to aid modern restoration efforts. The archaeological and historical data provided here complement the catch data from 1950–1993 by providing 10 000 years of black abalone harvesting history. This trans-Holocene record highlights areas that were long-term 'hot spots' for black abalone fishing, recruitment, and reproduction prior to the historical extirpation of sea otters and intensive modern commercial fisheries. Hot spots for black abalone found in ancient and historical records can be used to help pinpoint specific restoration sites, while commercial fishery data are often collected over much broader spatial scales than needed for restoration.

We find using these data that the greatest concentrations of black abalone during the Holocene were found on north-western, north-eastern, and south-central San Miguel Island and, to a lesser degree, on south-eastern San Nicolas Island. During the >10 000 years of Native American black abalone fishing, marine sea-surface temperature was highly variable, including periods of warmer and colder temperatures, and higher and lower frequency of El Niño events (Kennett, 2005) than present. Prehistorically, black abalone seem to have been relatively resilient to these climatic perturbations (Figure 4). Present day black abalone resilience to climatic perturbations may now be compromised by the WS disease, which is an abalone disease that can be lethal in warmer water. Thus, these prime locations may be even more critical for black abalone restoration because high densities of black abalone were encountered during intervals of colder SSTs in archaeological sites and during the prehistoric fishery. San Miguel and San Nicolas islands have generally cooler SSTs, which may make their coastlines vital in the face of anthropogenic climate change and warming ocean waters.

Given the tremendous changes in ocean temperatures, climatic conditions, human influences, fishing pressures, and intertidal habitats over the last 150 years, we recommend that areas outside of our results should not be dismissed as they may also prove fruitful for black abalone recovery. This is evidenced by early indications of black abalone recovery on Santa Cruz Island (Butler *et al.*, 2009; D. Richards, personal communication 2012), where modern and deep historical data show few signs for a viable fishery. Much of the modern recovery, however, is being seen along San Nicolas Island, which is one of the areas the present data suggest could be optimal for recovery. Since recommendations for the best black abalone restoration locations in the Abalone Recovery and Management Plan (2005) were exceptionally broad and included the vast majority of island coastlines, the areas identified here may provide appropriate smaller-scale targets for restoration On the other hand, if black abalone are not rebounding along these prime locations, where populations thrived for millennia, resource managers and abalone biologists might consider field investigations to explore this deep historical disconnect.

Comparable studies utilizing archaeological and historical data for other affected abalone species such as the northern abalone in Washington, Canada, and Alaska, or other shellfish such as native oysters (e.g. *Crassostrea virginica*, *Ostrea lurida*), may help identify productive habitats for the restoration of these species. By consulting modern, historical, and archaeological records, restoration ecologists and managers might better understand how, where, and why shellfish species have been resilient to or victims of heavy predation, natural climate change, commercial exploitation, and disease over long time periods. Identifying locations that have provided optimal habitat for hundreds to thousands of years may be an effective starting point for modern restoration of critically endangered species.

ACKNOWLEDGEMENTS

We thank Russell Galipeau, Ann Huston, Kelly Minas, Dan Richards, Mark Senning, and Ian Williams for their support. Thanks to Leslie Reeder-Myers for graphical assistance. We are grateful to Paul Dayton, two anonymous reviewers, and the editorial staff at *Aquatic Conservation*. This is a joint contribution of San Diego State University, the Smithsonian Institute, the University of Oregon, and the UC Davis, Bodega Marine Lab. We thank the California Department of Fish and Wildlife for fishery data and support to LRB and CAC.

REFERENCES

Abalone Recovery and Management Plan. 2005. California Department of Fish and Game Marine Region, Monterey, CA.

Ainis AF, Vellanoweth RL, Davis TW, Erlandson JM, Rick TC. 2011. Changes in marine subsistence on San Miguel Island from 8500 to 2400 years ago: analysis of bulk samples from Cave of the Chimneys (CA-SMI-603). *Journal of California Great Basin Anthropology* **31**: 59–79.

Berryman JA. 1995. Archival information, abalone shell, broken pots, hearths, and windbreaks: clues to identifying nineteenth century California abalone collection and processing sites, San Clemente Island: a case study. PhD dissertation, University of California, Riverside.

Braje TJ, Bentz L. 2015. The archaeology of overseas Chinese abalone fishermen on Santa Rosa Island, Alta California. *Journal of Chinese Overseas* in press.

Braje TJ, Erlandson JM. 2007. Signatures of specialization: comparing historic and prehistoric abalone middens on San Miguel Island. *Journal of Anthropological Archaeology* **26**: 474–485.

Braje TJ, Rick TC. 2013. From forest fires to fisheries management: anthropology, conservation biology, and historical ecology. *Evolutionary Anthropology* **22**: 303–311.

Braje TJ, Erlandson JM, Rick TC. 2007a. An historic Chinese abalone fishery on California's Northern Channel Islands. *Historical Archaeology* **41**: 117–128.

Braje TJ, Kennett DJ, Erlandson JM, Culleton BJ. 2007b. Human impacts on nearshore shellfish taxa: a 7000 year record from Santa Rosa Island, California. *American Antiquity* **72**: 735–756.

Braje TJ, Erlandson JM, Rick TC, Dayton PK, Hatch MBA. 2009. Fishing from past to present: continuity and resilience of red abalone fisheries on the Channel Islands, California. *Ecological Applications* **19**: 906–919.

Braje TJ, Rick TC, Willis LM, Erlandson JM. 2011. Shellfish and the Chumash: marine invertebrates and complex hunter-gatherers on late Holocene San Miguel Island, California. *North American Archaeologist* **32**: 267–290.

Braje TJ, Rick TC, Erlandson JM. 2012. A trans-Holocene ecological record of shellfish harvesting on California's Northern Channel Islands. *Quaternary International* **264**: 109–120.

Braje TJ, Costello JG, Erlandson JM, DeLong R. 2014. Of seals, sea lions, and abalone: the archaeology of an historical multiethnic base camp on San Miguel Island, California. *Historical Archaeology* **48**: 122–142.

Burton RS, Tegner MJ. 2000. Enhancement of red abalone *Haliotis rufescens* stocks at San Miguel Island: reassessing a success story. *Marine Ecology Progress Series* **202**: 303–308.

Butler J, DeVogelaere A, Gustafson R, Mobley C, Neuman M, Richards D, Rumsey S, Taylor B, VanBlaricom G. 2009. *Status review report for black abalone*, National Marine Fisheries Service: Long Beach, CA.

Dayton PK, Tegner MJ, Edwards PB, Riser KL. 1998. Sliding baselines, ghosts, and reduced expectations in kelp forest communities. *Ecological Applications* **8**: 309–322.

Erlandson JM, Rick TC, Estes JA, Graham MH, Braje TJ, Vellanoweth RL. 2005. Sea otters, shellfish, and humans: a 10 000 year record from San Miguel Island, California. In *Proceedings of the Sixth California Islands Conference*, Garcelon DK, Schwemm CA (eds). Institute for Wildlife Studies: Arcata, CA; 9–21.

Erlandson JM, Rick TC, Braje TJ. 2009. Fishing up the food web? 12 000 years of maritime subsistence and adaptive adjustments on California's Channel Islands. *Pacific Science* **63**: 711–724.

Erlandson JM, Rick TC, Braje TJ, Casperson M, Culleton B, Fulfrost B, Garcia T, Jew N, Kennett DJ, Moss ML, *et al*. 2011. Paleoindian seafaring, maritime technologies, and coastal foraging on California's Channel Islands. *Science* **441**: 1181–1185.

Essington TE, Beaudreau AH, Wiedenmann J. 2006. Fishing through marine food webs. *Proceedings of the National Academy of Sciences of the United States of America* **103**: 3171–3175.

Friedman CS, Biggs W, Shields JD, Hedrick RP. 2002. Transmission of withering syndrome in black abalone, *Haliotis cracherodii* Leach. *Journal of Shellfish Research* **21**: 817–824.

Friedman CS, Wight N, Crosson LM, VanBlaricom GR, Lafferty KD. 2014. Reduced disease in black abalone following mass mortality: phage therapy and natural selection. *Frontiers in Microbiology* **5**: 1–10.

Garcia T. 2007. The smallest island with the oldest history: an archaeological investigation of CA-SMI-608 West, an Early Holocene site on San Miguel Island, California. Senior thesis, Yale University, New Haven, CT.

Hutchings JA, Ferguson M. 2000. Temporal changes in harvesting dynamics of Canadian inshore fisheries for northern Atlantic cod, *Gadus morhua*. *Canadian Journal of Fisheries and Aquatic Sciences* **57**: 805–814.

Jackson JBC, Kirby MX, Berger W, Bjorndal K, Botsford L, Bourque B, Bradbury R, Cooke R, Erlandson J, Estes J, *et al*. 2001. Historical overfishing and the recent collapse of coastal ecosystems. *Science* **293**: 629–638.

Jackson JBC, Alexander KE, Sala E (eds). 2011. *Shifting Baselines: the Past and the Future of Ocean Fisheries*. Island Press: Washington DC.

Jazwa CS, Kennett DJ, Hanson D. 2012. Late Holocene subsistence change and marine productivity on Western Santa Rosa Island, Alta California. *California Archaeology* **4**: 69–98.

Kennett DJ. 2005. *The Island Chumash: Behavioral Ecology of a Maritime Society*, University of California Press: Berkeley, CA.

Kittinger JN, Van Houtan KS, McClenachan L, Lawrence AL. 2013. Using historical data to access the biogeography of population recovery. *Ecography* **36**: 868–872.

Kittinger JN, McClenachan L, Gedan KB, Blight LK. 2014. *Marine Historical Ecology in Conservation: Applying the Past to Manage for the Future*, University of California Press: Berkeley, CA.

Krautkramer RA. 2002. Historical archaeology of the Chinese abalone industry on San Nicolas Island, California. Masters thesis, University of California, Los Angeles, CA.

Kurlansky M. 1997. *Cod: A Biography of the Fish that Changed the World*, Penguin Books: New York.

Lafferty KD, Kuris AM. 1993. Mass mortality of abalone *Haliotis cracherodii* on the California Channel Islands: test of epidemiological hypotheses. *Marine Ecology Progress Series* **96**: 239–248.

Lotze HK, McClenachan L. 2014. Marine historical ecology: informing the future by learning from the past. In *Marine*

Community Ecology and Conservation, Bertness MD, Silliman BR, Bruno JF, Stachowicz JJ (eds). Sinauer Associates, Inc.: Sunderland, MA; 165–200.

Lotze HK, Coll M, Magera AM, Ward-Paige C, Airoldi L. 2011. Recovery of marine animal populations and ecosystems. *Trends in Ecology & Evolution* **26**: 595–605.

Lotze, HK, Hoffmann, RC, Erlandson, JM. 2014. Lessons from historical ecology and management. In *The Sea, Volume 16: Marine Ecosystem-Based Management*, Fogarty MJ, McCarthy JJ (eds). Harvard University Press, Cambridge, MA; 17–55.

Lundy AL. 1997. *The California Abalone Industry: A Pictorial History*, Best Publishing Co.: Flagstaff, AZ.

Martz P. 2008. 4000 years on *Ghalas-At*: part one of the San Nicolas Island index unit analysis program. Unpublished report submitted to the Naval Air Weapons Station China Lake, CA.

McClenachan L, Cooper AB, Carpenter KE, Dulvy NK. 2012. Extinction risk and bottlenecks in the conservation of charismatic marine species. *Conservation Letters* **5**: 73–80.

Myers RA, Hutchings JA, Barrowman NJ. 1997. Why do fish stocks collapse? The example of cod in Atlantic Canada. *Ecological Applications* **7**: 91–106.

Neuman M, Tissot B, VanBlaricom G. 2010. Overall status and threats assessment of black abalone (*Haliotis cracherodii* Lech, 1814) populations in California. *Journal of Shellfish Research* **29**: 577–586.

Pauly D. 1995. Anecdotes and the shifting baseline syndrome of fisheries. *Trends in Ecology and Evolution* **10**: 430.

Raimondi PT, Wilson CM, Ambrose RF, Engle JM, Minchinton TE. 2002. Continued declines of black abalone along the coast of California: are mass mortalities related to El Niño events? *Marine Ecology Progress Series* **242**: 143–152.

Rick TC, Erlandson JM. 2001. Late Holocene subsistence strategies on the south coast of Santa Barbara Island, California. *Journal of California and Great Basin Anthropology* **23**: 297–307.

Rick TC, Lockwood R. 2013. Integrating paleobiology, archaeology, and history to inform biological conservation. *Conservation Biology* **27**: 45–54.

Rick TC, Erlandson JM, Vellanoweth RL, Braje TJ. 2005. From Pleistocene mariners to complex hunter-gatherers: the archaeology of the California Channel Islands. *Journal of World Prehistory* **19**: 169–228.

Rick TC, Erlandson JM, Horton KE. 2009. Marine shellfish harvest on Middle and Late Holocene Santa Barbara Island, Alta California. *California Archaeology* **1**: 109–124.

Rogers-Bennett L, Haaker PL, Huff TO, Dayton PK. 2002. Estimating baseline abundances of abalone in California for restoration. *CalCOFI* **43**: 97–111.

Tegner MJ. 2000. Abalone (*Haliotis* spp.) enhancement in California: what we've learned and where we go from here. *Canadian Special Publications of Fisheries and Aquatic Sciences* **130**: 61–71.

Tong LJ, Moss GA, Illingworth J. 1987. Enhancement of a natural population of the abalone, *Haliotis iris*, using cultured larvae. *Aquaculture* **62**: 67–72.

Uki N. 1989. Abalone seeding production and its theory, Parts 1–3. *An International Journal on Fisheries Science, Fishing Technology and Fisheries Management* **1**: 3–15, 125–132, 224–231.

VanBlaricom GR, Ruediger JL, Friedman CS, Woodard DD, Hedrick RP. 1993. Discovery of withering syndrome among black abalone *Haliotis cracherodii*, Lech, 1814, populations at San Nicolas Island, California. *Journal of Shellfish Research* **12**: 185–188.

Vellanoweth R. 2001. Coastal archaeology of Southern California: accounts from the Holocene. PhD thesis, University of Oregon, Eugene.

