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The Ideal Free Distribution and Settlement History at Old Ranch Canyon, Santa Rosa Island

Christopher S. Jazwa, Douglas J. Kennett, and Bruce Winterhalder

The decisions that people make about where to settle on a landscape are influenced by climate, resource distribution, religion, cultural and economic factors, technological developments, defensive requirements, and the distribution of other human populations. These decisions are often strategic, with the goal of attaining specific economic, social, and political ends (Jochim 1976, 1981). A behavioral ecology model, the ideal free distribution (IFD), has been used to address questions about the relationships between environment, economy, and population distribution (Åström 1994; Fretwell and Lucas 1969; Fretwell 1972; Sutherland 1983, 1996; Tregenza 1995).

Potential settlement locations are ranked by their suitability based on attaining specific economic, social, or political ends. The model assumes that people are knowledgeable about their environment and predicts that they will first settle in the most suitable location. As the population grows, overcrowding, resource depression, and other effects of local competition will cause the suitability of the first-ranked location to decline. When the suitability of the settlement location falls, a portion of subsequent growth will expand into the second-ranked location. Progressively lower ranked locations are filled in order by the same mechanism. Occupancy of low-ranked areas signals lessened marginal economic returns across the full suite of occupied locations and thus, by the diet breadth model, predicts low-ranked resources in the diet. In the IFD, individuals always move if it offers any advantage, equalizing marginal suitability across all occupied settlement locations.

The IFD is scalable and can be used to predict changes in landscape use on scales both large (e.g., continental [Fitzhugh and Kennett 2010; Allen and O'Connell 2008]) and small (e.g., islands and regions [Kennett et al. 2006; Culleton 2012]). On California's northern Channel Islands, it has been used to model the establishment and persistence of 46 permanent settlements (Kennett et al. 2009; Winterhalder et al. 2010); however, these pioneering studies did not take into account details of environmental change and individual site history that allow for a more localized and environmentally sensitive refinement and appraisal of IFD predictions.

We analyzed the faunal record of two sites at Old Ranch Canyon (ORC), Santa Rosa Island, to show how environmental, economic, and cultural change influenced settlement decisions in the past. The suitability of ORC was enhanced with respect to other locations during the early Holocene and beginning of the middle Holocene because a resource-rich estuary existed at the mouth of the canyon. Sediment infilling of this small estuary started as sea level stabilized between 6,000 and 5,000 years ago, decreasing the suitability of OCR for primary human settlement. The stratigraphy and chronology of multiple sites at the mouth of Old Ranch Canyon suggests that the resident population decreased for several millennia after the estuary was largely infilled. We hypothesize that the canyon's inhabitants moved

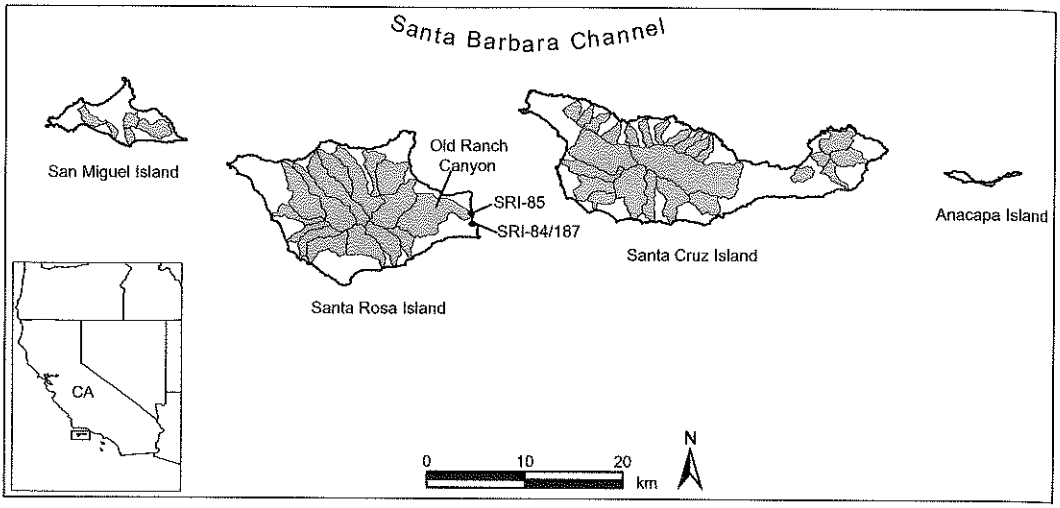

FIGURE 5.1. California's northern Channel Islands and the sites SRI-84/187 and SRI-85. Watersheds ranked by Winterhalder et al. (2010) are highlighted in gray.

to other, more suitable locations as the resource potential of the estuarine environment decreased. When ORC settlement expanded 3,000 years later, subsistence was more focused on rocky intertidal resources.

The record from ORC shows that during the late Holocene, *Olivella biplicata* shell bead production increased, paralleling the rising importance of regional trade. The long sandy beach at the mouth of the canyon would have been a good source of *Olivella* shells and provided a convenient landing place for plank canoes (*tomols*), an important technological innovation that facilitated trade with the mainland and other island communities after AD 500 (Arnold 1992a, 1995, 2001a; Gamble 2002; Fagan 2004). We argue that this increased the suitability of this location and provides an example of how localized changes in the environment or economy can impact settlement decisions and the distribution of population regionally.

California's Northern Channel Islands

The four northern Channel Islands are separated from the California mainland by the Santa Barbara Channel. From west to east they are San Miguel, Santa Rosa, Santa Cruz, and Anacapa (Figure 5.1; Jazwa and Perry, Chapter 1). These islands are an excellent test case for the IFD for several reasons. They have remained separated from the mainland, throughout the Quaternary, when sea levels were periodically lower, and therefore represent a bounded sampling universe. The earliest visible evidence of permanent settlement on the islands is approximately 8000–7000 cal BP (Kennett et al. 2009); however, people had been visiting and seasonally exploiting the resources available on the islands since at least 13,000 cal BP (Erlandson et al. 2007; Erlandson et al. 2008; Erlandson et al. 2011; Johnson et al. 2002; Kennett 2005; Kennett et al. 2008). Thus, the initial permanent occupants likely understood habitat suitability and were prepared to make informed decisions about the best settlement locations on the islands. Because islands are inherently sensitive to natural and human-induced changes (Fitzhugh and Hunt 1997:381–382), fluctuations in resource availability may be more readily documented in the archaeological record.

The terrestrial resources on islands also tend to be more limited; this is certainly the case on the northern Channel Islands (Rick et al. 2005). Because of this, the inhabitants had a strong intertidal and maritime focus from the earliest occupation (Erlandson et al. 2011). Although there is no direct evidence for boat use dating to the period of early occupation, ocean-going watercraft would have been required to reach any of the islands (Erlandson et al. 2008; Raab et al. 2009). At historic contact, island populations were primarily concentrated in large coastal villages governed by chiefs (Johnson 1982, 1993). Earlier settlements also are largely either coastally located or coastally oriented (Winterhalder et al. 2010:478), and coastal resources factor highly in the ranking of settlement locations on these islands (Kennett et al. 2009; Winterhalder et al. 2010).

Although Winterhalder et al. (2010) did not include environmental change in their regional application of the IFD, the model is well suited to address temporal dynamics in habitat suitability. At the time of earliest occupation, 13,000 years ago, sea level was ~70–75 m below its present level. The four islands were all connected to form one land mass, Santarosae. The rise in sea level through the early settlement period caused a 65 percent decrease in land area, potentially submerging evidence of early settlement (Kennett 2005; Kennett et al. 2008). There have been more than 50 nonresidential shell middens and other sites found on the islands that date to the Late Pleistocene or early Holocene, before the earliest available evidence for permanent settlement about 8,000 years ago (Erlandson et al. 2008; Erlandson et al. 2011:1181–1182; Rick et al. 2005).

Early permanent habitation sites are associated with a diverse faunal assemblage, including fish, shellfish, and sea mammals, all present to varying degrees throughout the archaeological record on the islands. There is a general increase in the amount of fishing and a decrease in the relative contribution of shellfish through time. Fish and sea mammals became particularly important during the late Holocene (Braje et al. 2007:741; Colten 2001; Glassow 1993; Kennett 2005; Kennett and Kennett 2000; Kennett and Conlee 2002; Raab et al. 1995; Rick 2007; Rick et al. 2008:81).

There were important demographic changes on the islands over time. The earliest evidence for permanent settlement is from the mouth of Tecolote Canyon (SRI-3), a high-ranked drainage on the northern coast of Santa Rosa Island. We define *permanent settlement* by the presence of substantial residential middens, cemeteries, or houses (see Winterhalder et al. 2010). There is evidence for population expansion during the middle Holocene, particularly along the north and east coasts of Santa Rosa Island and the west and south coasts of Santa Cruz Island (Glassow et al. 1988, 2008; King 1990; Wilcoxon 1993; Winterhalder et al. 2010). It is this expansion that is addressed by Winterhalder et al. (2010). Large inland middens appeared at this time, potentially associated with seasonal exploitation of inland plant resources (Kennett 2005; Kennett and Clifford 2004; Perry 2003).

Important technological and social changes occurred during the late Holocene, many of them beginning during the Middle period (2250–800 cal BP) as occupants of the islands began to exploit fish and sea mammals more intensively (Arnold 1992a:65; Glassow 1977). This may have been related to the development of the *tomol*, which appeared after 1500 cal BP (Arnold 1992a, 1995, 2001a; Gamble 2002; Fagan 2004). Population increase and growth in the number of permanent settlements on the islands accelerated during the late Middle period (1300–800 cal BP) (Arnold 2001a; Kennett 2005; Kennett and Conlee 2002; Winterhalder et al. 2010). Also beginning at this time and continuing through the Middle to Late period transition (MLT; 800–650 cal BP) and Late period (650–168 cal BP) were institutionalized differences in social status (Arnold 2001a; Kennett et al. 2009). The MLT, in particular, has been associated with important sociocultural, economic, and technological change (Arnold 1991, 1992a, 1997, 2001b; Arnold and Tissot 1993; Arnold et al. 1997; Jazwa et al. 2012, Kennett 2005; Kennett and Conlee 2002; Raab and Larson 1997). The *Olivella biplicata* shell bead industry, which served as a medium of exchange at historic contact, also grew significantly during the MLT (Arnold 1987, 1990, 1992a, 1992b, 2001a; Arnold and Munns 1994; Munns and Arnold 2002:132–133; Kennett 2005; King 1990; Rick 2007).

Anthropogenic and climate-driven environmental changes have been well studied on the northern Channel Islands and are thought to have influenced sociopolitical developments there during the Holocene (e.g., Arnold 1992a, 2001a; Arnold and Graesch 2004; Arnold and Tissot 1993; Braje et al. 2007; Erlandson and Jones 2002; Jazwa et al. 2012; Kennett 2005; Kennett and Kennett 2000; Kennett et al. 2007; Kennett et al. 2008; Raab and Larson 1997). We demonstrate here that the IFD can contribute to such interpretations.

The Channel Islands Ideal Free Distribution Model

The IFD has its roots in population ecology (Fretwell and Lucas 1969; Fretwell 1972; Sutherland 1983, 1996; Åström 1994; Tregenza 1995). Like other human behavioral ecology models, it

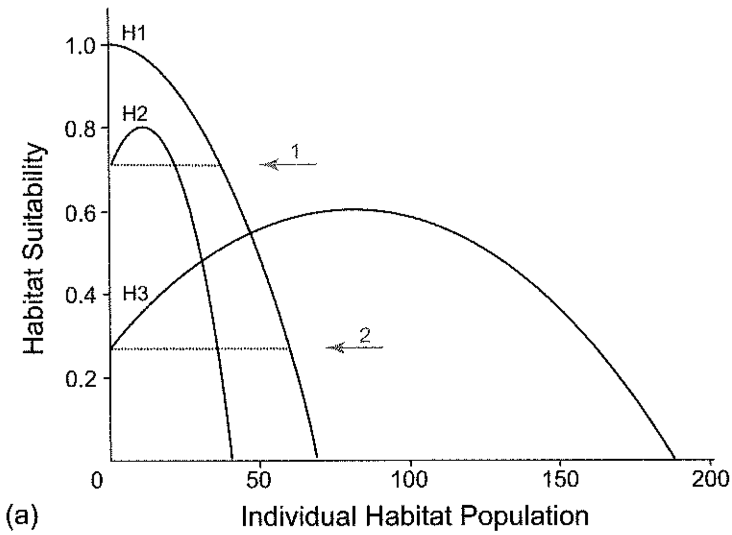

FIGURE 5.2. The ideal free distribution with Allee effects: (a) habitat suitability in three habitats as a function of habitat-specific density. H2 and H3 are characterized by Allee effects. (b) the overall population distribution as a function of total population size. We depict Allee effects causing the partial abandonment of high-suitability habitats; full abandonment is possible if the effects are sufficiently strong. Zero suitability is hypothetical. In practice, we expect in-fill to stop short of this point (after Winterhalder et al. 2010:473, Figure 3).

begins with an optimization premise: individuals elect to settle in the best available habitat; habitats differ in their basic suitability and their response to settlement and exploitation (Figure 5.2a). As population increases within a habitat, suitability decreases because of interference and exploitation competition, often in a nonlinear manner. Once suitability of the best habitat has declined to the point that it is equal to the basic suitability of the next best habitat, newcomers will divide between them (Sutherland 1983:821, 1996:5). The system reaches equilibrium when no individual has further incentive to relocate.

The IFD is built around individual choice and a simple optimization premise that integrates into its structure predictions about the relationships between environment, economy, and the population-level consequences of exploitation and competition. It is used by archaeologists to predict population distribution qualitatively (Kennett et al. 2006; Kennett et al. 2009) or quantitatively (Winterhalder et al. 2010). Habitat suitability generally will exhibit negative or declining density dependence; however, at low population density, the model can include Allee effects, or positive density dependence. Per capita opportunities for survival and reproduction may be enhanced as it becomes easier to find and defend food and mates. As such economies of scale are exhausted, suitability reaches a maximum and then decreases (Sutherland 1996:10–11; Greene and Stamps 2001).

Winterhalder et al. (2010:473) discuss in detail the primary predictions of the IFD model. Allee effects can produce a partial exodus or even complete abandonment of a high-ranked habitat (Winterhalder et al. 2010:473; Figure 5.2b). The form of the suitability curve for a given habitat is dictated by its response to human density increase and exploitation. Suitability in a habitat with many high-ranked food resources but only limited freshwater will decrease quickly with population density, as would a habitat containing only a few high-ranked resources of low yield. Conversely, suitability in habitats with abundant low-ranking but high-yield resources will decline only slowly. These habitats are less sensitive to density dependence. Allee effects also can vary. Low-density, ascending parts of the curve may be more or less steep, the peak representing a small or large increase over basic suitability. It may be placed at lower or higher human population densities.

Anthropogenic resource depression and habitat degradation from high population densities in island ecosystems is common (e.g., Hunt 2007; Hunt and Lipo 2009), the northern Channel Islands being an important example (Rick 2004, 2007; Kennett 2005; Braje 2007, 2010; Braje et al. 2007; Erlandson et al. 2008; Rick and Erlandson 2008; Erlandson and Rick 2010; Braje and Rick 2011). Empirical application of the IFD must, however, recognize that there may be lags in the linkage of human density and habitat suitability. Especially depressed habitats may not recover immediately upon release from exploitation. By incorporating lag, the IFD can be adjusted to describe realistic habitat recovery and thus a mechanism for movement back into previously depleted habitats.

The typical IFD application (e.g., Winterhalder et al. 2010) invokes a density dependent situation. However, IFD predictions can be driven by changes of habitat suitability that are not population dependent. They may be environmental, technological, or sociocultural, and may affect all or only some habitats. Changes in sea surface temperature might affect the availability of food species in marine habitats (e.g., Arnold 1992a, 2001a; Arnold and Tissot 1993; Colten 2001; Kennett 2005; Kennett and Kennett 2000; Pletka 2001) but leave inland terrestrial resources relatively unchanged. The development of boat technology could have increased the suitability of coastal habitats with good launch and pull-out locations, but not those without them. Sociocultural change can alter the relative preference for some resources compared to others. Because these changes affect habitats independently of population, they are modeled as a displacement of the suitability curve or by a change in its shape (Figure 5.3).

In Figure 5.3, each graphic depicts suitability as a function of habitat-specific population density. For simplicity, we depict only negative density dependence—there are no Allee effects—and we have reduced the 46 watersheds of the northern Channel Islands to three hypothetical examples, habitats h_1 to h_3. Total population is a function of the number of individuals in all occupied habitats (Σp_n). Each of the four graphs represents a key stage in our hypothesized prehistory of Old Ranch Canyon: (a) as portrayed by Winterhalder et al. (2010), based solely on four habitat attributes of their analysis. ORC is highly ranked, but not so high that we predicted its early occupation at low cross-island population levels; (b) the prediction as it would be modified based on the recognition that the settlement sites rested in their early prehistory next to a rich estuary. We predict settlement much earlier, at higher suitabilities and at lower overall cross-island population levels; (c) ORC as characterized by the IFD after closure of the estuary. Although population

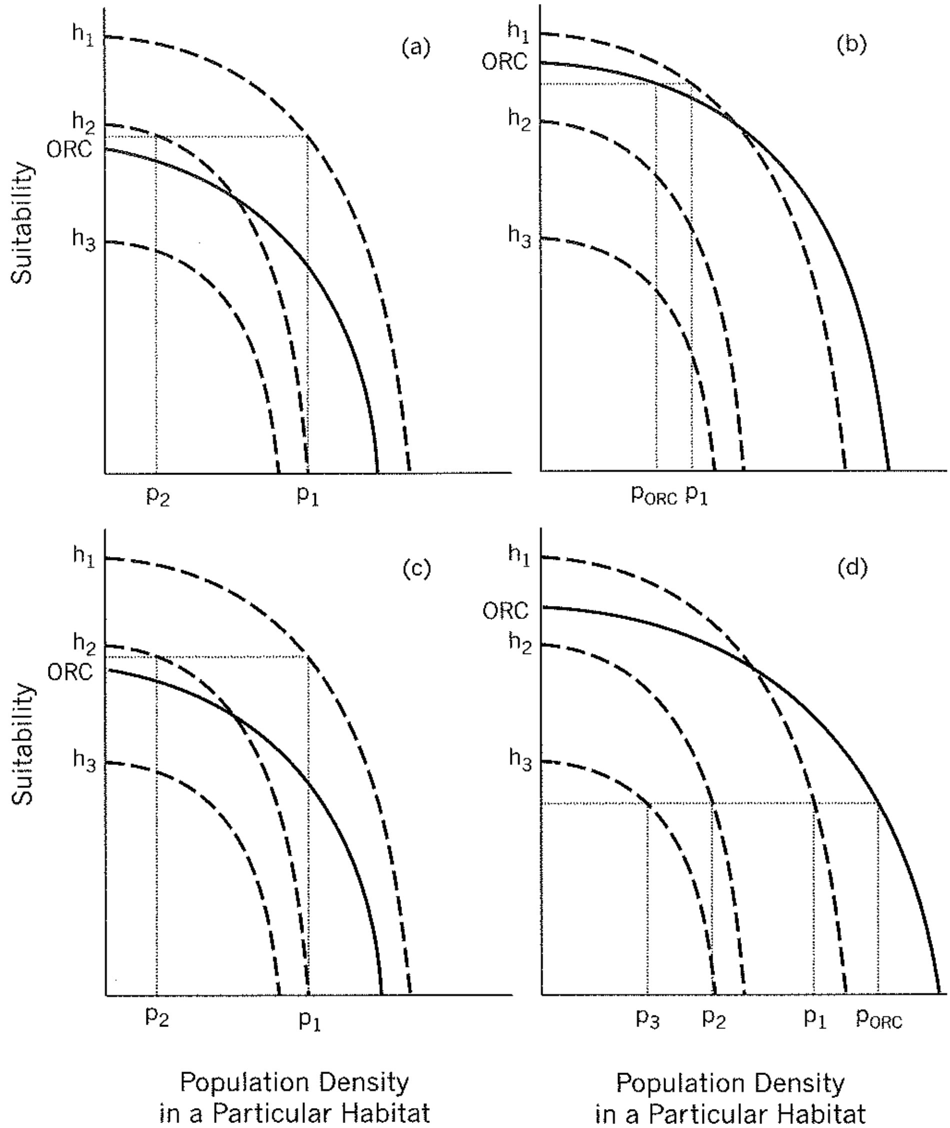

FIGURE 5.3. The ideal free distribution and Old Ranch Canyon. Each graphic depicts suitability as a function of habitat-specific population density: (a) ORC as portrayed by Winterhalder et al. (2010), based solely on the four habitat attributes of their analysis; (b) the ORC prediction as it would be modified based on the recognition that ORC rested in its early prehistory next to a rich estuary; (c) ORC as characterized by the IFD after closure of the estuary; (d) elevated suitability of ORC because of density-independent technical and socioeconomic developments.

has grown and the marginal suitability of occupied habitats has declined from that depicted in situation b, a strong density-independent decline in suitability associated with estuary closure has dropped ORC to just below a level at which the site would be occupied; (d) with further population growth, competition, and habitat exploitation, the marginal habitat suitability of occupied sites continues to decline, but density-independent technical and socioeconomic developments—the plank canoe, exploitation of the marine habitat around offshore kelp beds, and development of trade through *Olivella* bead production—significantly elevate and extend the suitability of ORC and assure its importance as a settlement up to the historic period.

Old Ranch Canyon

Old Ranch Canyon is on the eastern end of Santa Rosa Island (Figure 5.1). We assess whether or not IFD predictions are consistent with the available archaeological data from the mouth of this drainage as a means of evaluating their potential for broader applicability (see Winterhalder 2002).

Previous work established that ORC is a high-ranked drainage, sixth in rank using an intuitive environmental weighting (Kennett et al. 2009: 306, Table 20.1) and seventh based on a more statistical assessment (Winterhalder et al. 2010:483, Figure 9). The associated drainage is 18.59 km^2 in size, the second largest of the 46 drainages analyzed (range 1.28 to 34.35 km^2). The canyon has 1.46 km of rocky intertidal shoreline adjacent to its mouth (ranked twenty-sixth; range 0 to 4.30 km) and 2.98 km of sandy beach (ranked sixth; range 0 to 3.74 km). Finally, there is 0.12 km^2 of offshore kelp forest (ranked twenty-sixth; range 0 to 1.86 km^2). There is evidence for permanent village settlement at the mouth of Old Ranch Canyon during the middle Holocene and throughout the late Holocene and into the historic period (SRI-77, -81, -84, -85, -187, -191, -192 -666, -667; see Rick, Kennett, and Erlandson 2005), at which time it can be identified as the named village Qshiwqshiw (Johnson 1999).

Estuaries are rare on the northern Channel Islands, and the presence or absence of these resource-rich habitats was not a component of earlier IFD analyses (Kennett et al. 2009; Winterhalder et al. 2010). ORC and the adjacent Old Ranch House Canyon are unique in that they were situated next to a substantial estuary during the early and middle Holocene (Cole and Liu 1994; Rick, Kennett, and Erlandson 2005; Rick et al. 2006; Wolff et al. 2007; Rick 2009). Estuaries are often extremely productive (Bickel 1978:8), and the early presence of the Abalone Rocks estuary at the mouth of Old Ranch Canyon would have enhanced its suitability for permanent settlement. Barber (1979) has argued that the lower reaches of estuaries near their marine confluence are the most productive environments on earth, supporting a rich assemblage of fish, shellfish, and waterfowl.

Although rocky intertidal shellfish species dominate the ORC assemblages, Rick, Kennett, and Erlandson (2005) have also observed evidence for the early consumption of estuarine shellfish species, namely Venus clams (*Chione* sp.), Washington clams (*Saxidomas nuttalli*), and California oysters (*Ostrea lurida*), between ~8000 and 5900 cal BP. Although estuaries were not common on the northern Channel Islands, there were many settlements on the margins of estuaries on the adjacent mainland during the early and middle Holocene (Bickel 1978; Inman 1983; Erlandson 1994). The early and extensive use of these rich habitats, when present, is one indication of their resource value.

The life cycle of the Abalone Rocks estuary followed a pattern similar to that of mainland estuaries. Estuary formation requires a freshwater input from land and an open connection to the ocean (Bickel 1978:8), a configuration more common during periods of rapid sea level rise (Inman 1983:18–20; Erlandson 1994:34). Often, embayments form in coastal canyons that were cut deeply during periods of low glacial sea level (Bickel 1978:8; Erlandson 1994:34). On the Channel Islands, sea level rise began to slow around 6,000 years ago (Inman 1983; Rick, Kennett, and Erlandson 2005). This then allowed for the formation of sand bars, which eventually close the mouth of the estuary, causing it to stagnate, fill in, and lose productivity. Estuary extinction is particularly prominent in areas where freshwater input is limited, as is the case on Santa Rosa Island (Erlandson 1994). The current Abalone Rocks Marsh is located near the mouth of the relict estuary.

By contrast, on the adjacent California mainland, estuaries persist in areas of shallower topography where the convergence of flow from multiple sources forms larger sloughs and prevents estuary senescence (Jon Erlandson, personal communication, 2011). Estuary closure and static sea level are conducive to the formation of low-productivity marshes (Bickel 1978:11).

Because estuarine shellfish are present in the Old Ranch Canyon archaeological record from the earliest known occupation (Rick, Kennett, and Erlandson 2005; Rick 2009), they cannot be used to determine when the estuary formed. However, its projected closure corresponds to a decline in estuarine shellfish use between 6,000 and 5,000 years ago at multiple sites (SRI-77, -81, -84, -191, -192 -666, -667) (Rick, Kennett, and Erlandson 2005; Rick et al. 2006; Wolff et al. 2007; Rick 2009). This timing is coincident with the closure of estuaries throughout California.

Ideal Free Distribution Predictions

(a) In their discussion, Winterhalder et al. (2010) note that incorporating site-specific conditions affecting suitability as well as previously neglected environmental history in their model should improve the fit of IFD predictions to archaeological settlement data. Because of the unique and attractive resources provided by the Abalone Rocks estuary to early inhabitants of the Islands, their predicted settlement date for this location (3428–3068 cal BP; Winterhalder et al. 2010:476, Table 1) should significantly underestimate actual settlement. (b) The eventual loss of these resources associated with the closure of the estuary should have decreased ORC's settlement suitability, leading to partial or full abandonment as populations relocated to adjacent settlements with higher relative suitability. (c) Subsequently, as human population density throughout the northern Channel Islands continues to increase and the suitability of other locations declines, ORC should, after a hiatus, again become attractive to significant settlement. (d) The development of plank canoes (Arnold 1995, 2001a; Gamble 2002; Fagan 2004) and an increased emphasis on shell bead manufacture and trade (King 1990; Arnold and Munns 1994; Arnold and Graesch 2001; Munns and Arnold 2002) are resource-enhancing activities favored by the ORC environment with its long sandy beaches and access to prime *Olivella* habitat. Based on this, the IFD model predicts progressively intensified occupation from the Middle period through the MLT and Late period (starting after ~1500 cal BP). We note that these hypotheses reflect the combined effect of shifting density-dependent and density-independent sources of adaptive pressure on settlement.

Methods

Shifts in the relative habitat suitability of ORC have been observed using midden materials excavated by Doug Kennett and Don Morris from three well-dated sites near the mouth of the drainage: SRI-85 and the site complex including SRI-84 and -187 (henceforth, SRI-187). We include in this analysis data from two column samples (25 × 25 cm) excavated at SRI-85 and -187 from existing natural exposures in arbitrary 10 cm levels, from the surface to the base of the deposit. Exceptions to this protocol occurred in the lowest levels (below 50 cm) of Unit 2 of SRI-85 and Unit 1 of SRI-187, which followed natural strata. All excavated materials were water screened, dried, and then size sorted (½", ¼", and ⅛" mesh) and identified at California State University, Long Beach. Material from each successive screen size was sorted separately. More detailed sorting and checking was later conducted at the University of Oregon.

The data include chronological and dietary information. We submitted eight marine or estuarine shell samples for radiocarbon dating: one *Haliotis cracherodii* and one *Mytilus californianus* to Beta Analytic Inc. for standard radiometric dating, and one *Saxidomus nuttalli*, two *Olivella biplicata*, one *Mytilus californianus*, one *Septifer bifurcatus*, and one unidentified marine shell to the National Ocean Sciences Accelerator Mass Spectrometry Facility at the Woods Hole Oceanographic Institution for atomic mass spectrometry (AMS) dating. These were tested in 1999–2000 (Kennett 2005). Finally, we submitted three *Mytilus californianus* samples for AMS dating to the Keck Carbon Cycle AMS facility at the University of California, Irvine, in 2011 and 2012. We calibrated all dates in OxCal 4.1 (Bronk Ramsey 2009) using the most recent marine calibration curve, Marine09 (Reimer et al. 2009) and an updated ΔR value for the Santa Barbara Channel region (261 ± 21; B. Culleton, personal communication, 2012). The revised ΔR estimate incorporates five new AMS ^{14}C dates on pre-bomb (AD 1925) *Olivella* shells collected near Santa Barbara, California, with three existing dates on *Mytilus* reported by Ingram and Southon (1996; see also Kennett et al. 1997; Culleton et al. 2006), using the Marine09 calibration curve. We used a Bayesian statistical model in OxCal to further constrain error ranges on dates based on the relative stratigraphic position of the radiocarbon samples (see below).

Shellfish, other faunal constituents, and cultural materials were separated and quantified by trained undergraduate and graduate students.

For each level, all midden material collected in the ½" mesh was sorted in its entirety, as were a 100 g subsample of ¼" material and a 15 g subsample of ⅛" material. We also sorted the residual bulk material for artifacts, *Olivella biplicata* shells, and *Mytilus californianus* hinge fragments, as well as all bone, asphaltum, charcoal, and small gastropods. All other material was bagged separately. We sorted and weighed shells from ½", ¼", and ⅛" mesh separately, but added weights for each species together by level for analysis. Meat weights were calculated for the most important dietary constituents using the multipliers compiled and summarized by Rick (2004:79). Because *Olivella biplicata* was important for bead making rather than as a dietary component (e.g., Bennyhoff and Hughes 1987; King 1990; Arnold and Munns 1994), we analyzed this species by shell weight rather than meat weight.

In order to compare all data, including those levels that differed from the 10 cm arbitrary depth, we normalized shell and meat weight data to a volume of 1 m^3. To assess long-term trends, we combined data into five time periods, the Early period prior to estuarine closure (before 5000 cal BP), the Early period after the estuary closed (5000–2550 cal BP), the Middle period (2550–800 cal BP), the Middle to Late period transition (MLT; 800–650 cal BP), and the Late period (650–168 cal BP) (King 1990; Arnold 1992a:66; Rick, Kennett, and Erlandson 2005).

Because of the long time span represented in Unit 2 of SRI-187, we dated all five levels of this unit. Two of the radiocarbon samples were from each of the other units. To obtain dates for each level, we calculated the weighted mean of the 2σ range for each available radiocarbon date and interpolated dates for the levels between them, assuming constant deposition rates (Braje et al. 2007). While this procedure is based on the tenuous assumption of constant deposition, we used it to assign ages to deposits that span a relatively short period of time (< 200 years).

Results

Chronology

Eleven radiocarbon dates from SRI-85 and -187 provide evidence that the mouth of Old Ranch Canyon was occupied from as early as 8,000 years ago through the middle and late Holocene (Table 5.1), consistent with previous observations by Rick (2009). The age of deposits in Unit 1 of SRI-85 are estimated to be between 440 and 590 cal BP (Late period). Deposits in Unit 2 of SRI-85 date to the Late period (0–10 cm, 600 cal BP; 10–20 cm, 630 cal BP) and the MLT (20–30 cm, 660 cal BP to 50–72 cm, 770 cal BP). Deposits in Unit 1 of SRI-187 date to the Middle period (1830 to 1880 cal BP) and predate the development of the *tomol.*

Unit 2 of SRI-187 spans a much longer time period, even though its deposits extended only 50 cm below the surface. The deepest deposits (40–50 cm) date to 8049–7835 cal BP (all radiocarbon dates are presented as 2σ cal BP), and the upper deposits (0–10 cm) date to 3305–3095 cal BP. In this case, we submitted samples from three intermediate levels to better determine when the Abalone Rocks estuary closed. The 20–30 cm (6472–6313 cal BP) and 30–40 cm (6517–6351 cal BP) levels predate closure of the estuary; the 10–20 cm (3325–3147 cal BP) level postdates it. This suggests an approximately 3,000 year gap in occupation at SRI-187.

Rick (2009) reports occupation dates for the eastern part of Santa Rosa Island for three sites that fit into this time period. SRI-191 and -192 also have a gap in occupation, however, with estuarine shell in earlier strata but not in later strata. SRI-191 has a gap between 6050–5730 and 4470–4150 cal BP, and SRI-192 has a gap between 5930–5690 and 2610–2280 cal BP. The only Old Ranch Canyon site that falls within this chronological gap is SRI-690, a shell midden that is deeply buried beneath culturally sterile sediments (~2.5 m below the surface) and has been dated to 4800–4520 cal BP. The buried midden deposit is ~50 cm thick and exposed for ~20 m in the creek bank (Rick 2009; unpublished site record). However, this site is closer to Southeast Anchorage and approximately 3 km from the mouth of Old Ranch Canyon. Therefore, these data are still consistent with the hypothesis that populations were reduced at the mouth of the canyon at this time.

Dietary Trends

Several estuarine shellfish species, including Venus clams (*Chione* sp.), Pacific littleneck clams (*Protothaca staminea*), Washington clams (*Saxidomas nuttalli*), and California oyster (*Ostrea lurida*) are present in the basal deposits of SRI-187.

TABLE 5.1. Chronology for CA- SRI-84/187 and CA-SRI-85

Site	Unit	Level	Sample	Uncalibrated Date	Uncalibrated Error	Calibrated Range (2σ)	Modeled Range (2σ)	Estimated Date (BP)	Cultural Period
SRI-85	1	0–10 cm	Beta-96870	1060	60	521–299	538–310	442	Late period
		10–20 cm						461	Late period
		20–30 cm						480	Late period
		30–40 cm						499	Late period
		40–50 cm						518	Late period
		50–60 cm						537	Late period
		60–70 cm						557	Late period
		70–80 cm	Beta-107044	1270	60	680–496	669–488	576	Late period
		80–84 cm						589	Late period
SRI-85	2	0–10 cm	OS-34576	1260	70	690–480	718–491	600	Late period
		10–20 cm						631	Late period
		20–30 cm						661	MLT
		30–40 cm						692	MLT
		40–50 cm						722	MLT
		50–72 cm	OS-34574	1500	30	885–694	875–680	771	MLT
SRI-187	1	0–10 cm						1831	Middle period
		10–20 cm	OS-32368	2500	30	1941–1730	1926–1737	1837	Middle period
		30–40 cm						1849	Middle period
		40–50 cm						1855	Middle period
		50–62 cm						1862	Middle period
		62–70 cm						1868	Middle period
		70–84 cm						1875	Middle period
		84–92 cm	OS-34474	2530	30	1983–1778	1976–1798	1881	Middle period
SRI-187	2	0–10 cm	OS-34475	3670	40	3392–3156	3305–3095	3204	Early period (no estuary)
		10–20 cm	UCIAMS-102545	3595	15	3305–3095	3325–3147	3238	Early period (no estuary)
		20–30 cm	UCIAMS-105613	6275	20	6518–6331	6472–6313	6399	Early period (estuary)
		30–40 cm	UCIAMS-105614	6260	20	6490–6313	6517–6351	6435	Early period (estuary)
		40–50 cm	OS-34564	7750	40	8054–7838	8049–7835	7945	Early period (estuary)

Notes: Radiocarbon dates are calibrated and stratigraphically modeled using OxCal 4.1.3 (Bronk Ramsey 2009) and the Marine09 calibration curve (Reimer et al. 2009). Dates for undated levels are estimated by interpolating or extrapolating from weighted mean dates of dated levels.

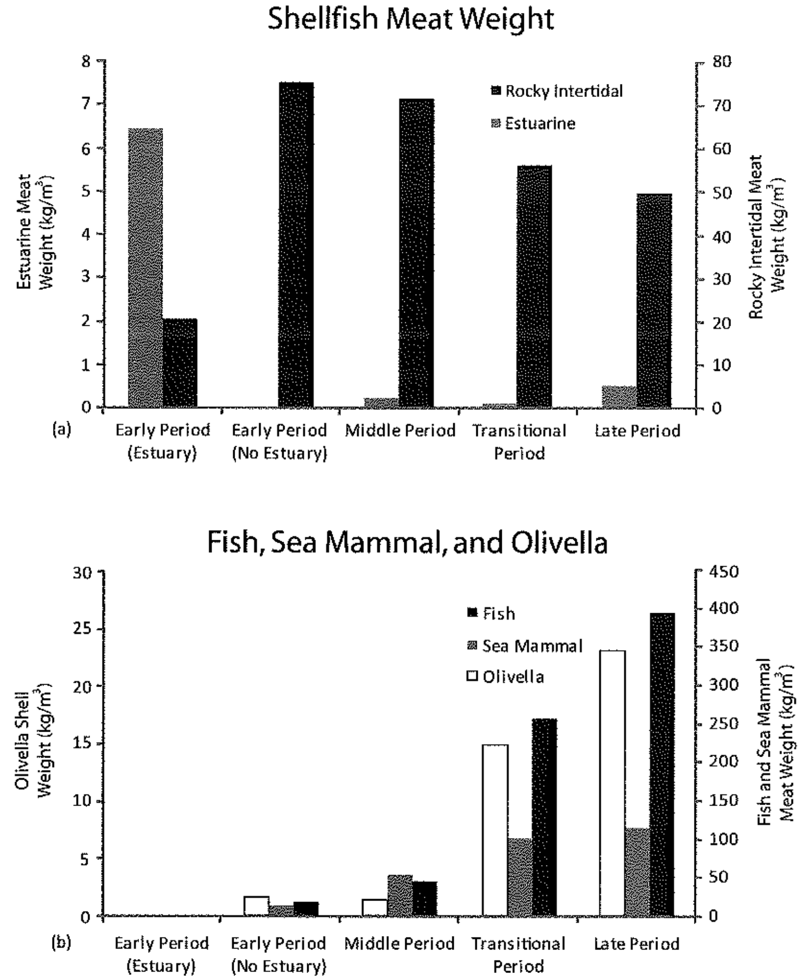

FIGURE 5.4. (a) Rocky intertidal and estuarine shellfish meat weight density, presented by cultural period. Note the different axes for the two shellfish types. (b) Fish and sea mammal meat weight density, and *Olivella* shell weight density, presented by cultural period. Again, note the two different axes.

Estuarine shellfish species are relatively unique for sites of any age on the northern Channel Islands (Rick, Kennett, and Erlandson 2005). To explore habitat changes through time, we divided shellfish into the most prevalent rocky intertidal (*Mytilus californianus*, *Haliotis rufescens*, and *Haliotis cracherodii*) and estuarine (*Protothaca staminea*, *Saxidomas nuttalli*, and *Ostrea lurida*) species (Tables 5.2 and 5.3). We do not believe that changes in abundance of different shellfish species reflect differential preservation; the estuarine shells, which were only in the basal levels of SRI-187, where they would have had more time to decompose, are more fragile than rocky intertidal species. Grouped together by habitat, rocky intertidal species dominate the ORC sequence throughout, but this is less pronounced during the earliest part of the Early period (Figure 5.4a; Table 5.4). Rocky intertidal meat weight is approximately 270 percent higher after people reoccupy the site in the later part of the Early period (an increase from 20,461 g/m^3 to 75,616 g/m^3). In the absence of estuarine resources after the closure of Abalone Rocks estuary, later occupants apparently focused more heavily on rocky intertidal resources. This was followed by a decrease in rocky intertidal shellfish meat weight during the Middle period (71,739 g/m^3),

TABLE 5.2. Summary table of SRI-84/187 and SRI-85 midden constituents by shell/bone weight normalized to 1 m³

Site	Unit	Level	California Mussel wt (g/m³)	Black Abalone wt (g/m³)	Red Abalone wt (g/m³)	Abalone Total wt (g/m³)	California Oyster wt (g/m³)	Washington Clam wt (g/m³)	Pacific Littleneck Clam wt (g/m³)	Fish Bone wt (g/m³)	Sea Mammal Bone wt (g/m³)	Olivella biplicata wt (g/m³)
SRI-85	1	0–10 cm	55,630	1,361	1,496	4,352	0	0	160	6,606	2,446	31,646
		10–20 cm	167,518	0	0	506	0	0	3,242	6,699	5,075	56,843
		20–30 cm	133,149	1,778	859	4,052	0	0	2,856	27,389	11,606	23,806
		30–40 cm	150,724	1,973	1,486	3,459	0	0	1,225	11,968	6,875	43,755
		40–50 cm	385,323	272	256	528	0	0	0	14,667	16,666	31,870
		50–60 cm	284,872	795	1,182	2,330	0	0	0	35,979	6,514	21,816
		60–70 cm	102,793	0	0	432	0	0	224	16,331	2,006	14,344
		70–80 cm	189,320	0	1,128	1,128	0	0	269	20,944	1,363	6,955
		80–84 cm	8,653	0	4,760	4,760	0	0	0	2,032	716	624
	2	0–10 cm	106,465	0	191	191	0	0	0	7,520	587	2,406
		10–20 cm	78,506	0	0	948	0	0	756	3,360	3,205	3,715
		20–30 cm	139,295	0	1,827	1,915	0	0	128	2,565	3,149	6,968
		30–40 cm	252,633	0	3,120	3,546	0	0	438	11,451	11,832	30,877
		40–50 cm	215,405	970	9,912	14,407	0	0	0	15,805	1,179	15,435
		50–72 cm	46,935	0	3,214	6,376	0	0	0	7,079	581	6,500
SRI-187	1	0–10 cm	282,870	0	0	0	0	0	0	1,832	5,722	6,714
		10–20 cm	364,777	1,424	2,544	3,968	0	0	2,402	4,778	10,242	1,562
		30–40 cm	268,495	0	0	0	0	0	0	1,534	862	242
		40–50 cm	237,276	0	257	419	0	0	0	1,230	0	1,526
		50–62 cm	221,516	295	0	295	0	0	0	432	185	576
		62–70 cm	153,291	0	0	0	0	0	0	1,368	576	1,432
		70–84 cm	75,026	0	0	0	0	0	0	625	0	266
		84–92 cm	304,522	0	0	0	0	0	0	1,546	0	208
	2	0–10 cm	212,243	952	74	1,026	0	0	0	1,142	422	2,870
		10–20 cm	281,192	112	2,498	2,610	0	0	0	230	667	667
		20–30 cm	60,913	0	0	1,390	102	1,967	0	40	307	114
		30–40 cm	105,935	110	0	256	6,425	680	491	157	0	221
		40–50 cm	32,777	0	0	0	4,043	12,211	680	5	0	0

TABLE 5.3. Summary table of SRI-84/187 and SRI-85 midden constituents by raw shell/bone weight

Site	Unit	Level	California Mussel wt (g)	Black Abalone wt (g)	Red Abalone wt (g)	Abalone Total wt (g)	California Oyster wt (g)	Washington Clam wt (g)	Pacific Littleneck Clam wt (g)	Fish Bone wt (g)	Sea Mammal Bone wt (g)	Olivella biplicata wt (g)
SRI-85	1	0–10 cm	347.7	8.5	9.4	27.2	0.0	0.0	1.0	41.3	15.3	197.8
		10–20 cm	1,047.0	0.0	0.0	3.2	0.0	0.0	20.3	41.9	31.7	355.3
		20–30 cm	832.2	11.1	5.4	25.3	0.0	0.0	17.9	171.2	72.5	400.0
		30–40 cm	942.0	12.3	9.3	21.6	0.0	0.0	7.7	74.8	43.0	273.5
		40–50 cm	2,408.3	1.7	1.6	3.3	0.0	0.0	0.0	91.7	104.2	199.2
		50–60 cm	1,780.4	5.0	7.4	14.6	0.0	0.0	0.0	224.9	40.7	136.4
		60–70 cm	642.5	0.0	0.0	2.7	0.0	0.0	1.4	102.1	12.5	89.7
		70–80 cm	1,183.2	0.0	7.1	7.1	0.0	0.0	1.7	130.9	8.5	43.5
		80–84 cm	21.6	0.0	11.9	11.9	0.0	0.0	0.0	5.1	1.8	1.6
	2	0–10 cm	665.4	0.0	1.2	1.2	0.0	0.0	0.0	47.0	3.7	15.0
		10–20 cm	490.7	0.0	0.0	5.9	0.0	0.0	4.7	21.0	20.0	23.2
		20–30 cm	870.6	0.0	11.4	12.0	0.0	0.0	0.8	16.0	19.7	43.6
		30–40 cm	1,579.0	0.0	19.5	22.2	0.0	0.0	2.7	71.6	74.0	193.0
		40–50 cm	1,346.3	6.1	61.9	90.0	0.0	0.0	0.0	98.8	7.4	96.5
		50–72 cm	645.4	0.0	20.1	39.9	0.0	0.0	0.0	97.3	8.0	89.4
SRI-187	1	0–10 cm	1,767.9	0.0	0.0	0.0	0.0	0.0	0.0	11.5	35.8	42.0
		10–20 cm	2,279.9	8.9	15.9	24.8	0.0	0.0	15.0	29.9	64.0	9.8
		30–40 cm	1,678.1	0.0	0.0	0.0	0.0	0.0	0.0	9.6	5.4	1.5
		40–50 cm	1,483.0	0.0	1.6	2.6	0.0	0.0	0.0	7.7	0.0	9.5
		50–62 cm	1,661.4	2.2	0.0	2.2	0.0	0.0	0.0	3.2	1.4	4.3
		62–70 cm	766.5	0.0	0.0	0.0	0.0	0.0	0.0	6.8	2.9	7.2
		70–84 cm	656.5	0.0	0.0	0.0	0.0	0.0	0.0	5.5	0.0	2.3
		84–92 cm	1,522.6	0.0	0.0	0.0	0.0	0.0	0.0	7.7	0.0	1.0
	2	0–10 cm	1,326.5	6.0	0.5	6.4	0.0	0.0	0.0	7.1	2.6	17.9
		10–20 cm	1,757.5	0.7	15.6	16.3	0.0	0.0	0.0	1.4	4.2	4.2
		20–30 cm	380.7	0.0	0.0	8.7	0.6	12.3	0.0	0.3	1.9	0.7
		30–40 cm	662.1	0.7	0.0	1.6	40.2	4.3	3.1	1.0	0.0	1.4
		40–50 cm	204.9	0.0	0.0	0.0	25.3	76.3	4.3	0.0	0.0	0.0

TABLE 5.4. Meat/shell weight of each subdivision of the faunal record by time period and normalized to 1 m³

Time Period	Rocky Intertidal Meat Weight (g/m³)	Estuarine Meat Weight (g/m³)	Fish Meat Weight (g/m³)	Sea Mammal Meat Weight (g/m³)	Olivella Shell Weight (g/m³)
Late period	47,427	575	386,531	125,532	21,617
Transitional period	56,301	103	255,528	101,284	14,945
Middle period	71,739	217	46,209	53,200	1,566
Early period (no estuary)	75,616	0	19,013	13,184	1,769
Early period (estuary)	20,461	6,419	1,861	2,478	111

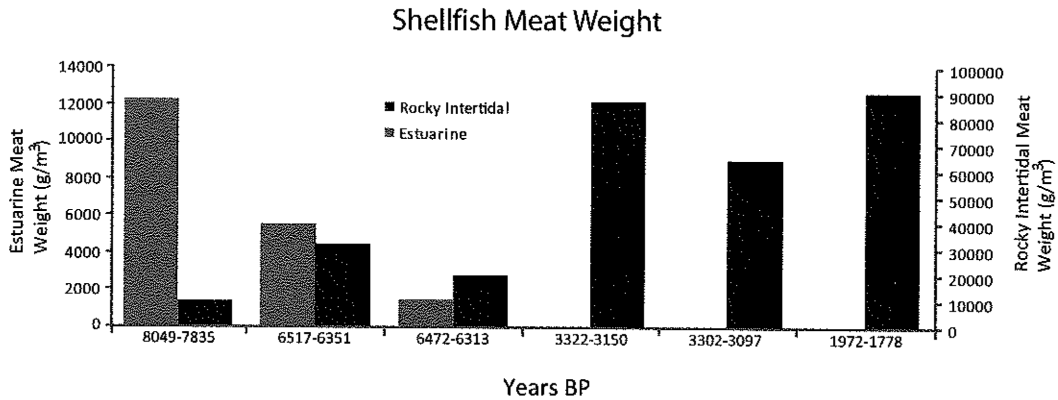

FIGURE 5.5. Shellfish meat weight density before and after the closure of Abalone Rocks Estuary.

the MLT (56,301 g/m³), and again during the Late period (47,427 g/m³), which may reflect greater focus on fish and sea mammals.

Estuarine species show a more pronounced pattern, dropping from 6,419 g/m³ in the earliest deposits to 0 g/m³ in the later part of the Early period. We suspect that small numbers of *P. staminea* later in time come from estuarine ponds at the mouth of Old Ranch Canyon or in adjacent pocket beaches that were targeted opportunistically. A stepwise decrease in estuarine meat weight is evident between 8049–7835 and 6472–6313 cal BP (Figure 5.5; Table 5.5). The abundance of rocky intertidal species does not show the reverse pattern, but fluctuates.

Variations in the meat weight of fish and sea mammal, and the shell weight of *Olivella biplicata* provide important information about environmental suitability and later occupation of ORC (Figure 5.4b; Table 5.4). All three show an increase through time. Fish meat weight increases from 1,861 g/m³ prior to closure of the estuary to 19,013 g/m³ after closure to 46,209 g/m³ during the Middle period. This was followed by a large jump during the MLT to 255,528 g/m³ and an additional increase during the Late period to 386,531 g/m³. *Olivella biplicata* shell weight follows a similar pattern. Like fish, *Olivella* jumps during the MLT to 14,945 g/m³ and then to 21,617 g/m³ during the Late period. Sea mammal

TABLE 5.5. Rocky intertidal and estuarine meat weight for each of the six oldest arbitrary excavation levels at SRI-187, normalized to 1 m³

Date (2σ cal BP)	Rocky Intertidal MW (g/m³)	Estuarine MW (g/m³)
1976–1798	90,748	0
3305–3095	64,431	0
3325–3147	86,802	0
6472–6313	19,754	1,498
6517–6351	31,863	5,499
8049–7835	9,767	12,260

meat weight increases more gradually, reaching 125,532 g/m^3 during the Late period. These resource types generally became more prevalent over time as shellfish declined in importance.

Discussion

Midden data from SRI-85 and -187 have been correlated with environmental (estuary presence, then closure), technological (advent of *tomol*), and sociopolitical (*Olivella* shell bead) changes on the northern Channel Islands, all of which are density-independent factors. Such changes are consistent with IFD predictions, but require that we engage the model dynamically. The closing of the Abalone Rocks estuary can be represented, for instance, as a downward displacement of the suitability curve for this habitat location. Depending on the severity of the shift, this could have led to partial or full abandonment as people moved to other locations with relatively higher basic suitabilities. In fact, occupation of ORC appears to have decreased following the loss of the estuary, including the potential abandonment of SRI-187. The introduction of the *tomol* and the expansion of the shell bead industry should have raised density-dependent suitability because ORC offered enhanced access to marine resources and trade, and this also appears to be the case. Each of our four hypotheses appears to be supported by the available data from ORC.

Radiocarbon dates from SRI-85 and -187 suggest human occupation from the middle Holocene to the historic period, with a gap from approximately 6,300 to 3,300 years ago. This overall span is consistent with that suggested by Rick (2009), who estimated the occupational range of ORC and the surrounding area to between 8180 to 300 cal BP based on 51 radiocarbon dates from sites throughout the canyon. He and his collaborators (Rick 2009; Rick, Kennett, and Erlandson 2005; Rick et al. 2006; Wolff et al. 2007) have focused on seven sites from the Middle Holocene. SRI-191 and -192 have dates from before and after the closure of the estuary. Like SRI-187, these sites have estuarine shell in their earlier strata but not in their later strata. Both sites, however, have gaps in their radiocarbon records, although SRI-191 (between 6050–5730 and 4470–4150 cal BP) has a shorter one than SRI-187. The only published site potentially associated with ORC that falls within the chronological gap for the canyon is SRI-690, which dates to 4800–4520 cal BP (Rick 2009) but is approximately 3 km from the mouth of the canyon and is relatively small. These dates support the hypothesis of either a short abandonment of ORC or at least an outmigration of a large part of the population as the estuary closed and became less productive.

Shellfish data from Unit 2 of SRI-187 also reflect estuarine closure. Like Rick, Kennett, and Erlandson (2005), we see clear evidence for estuarine shellfish in the midden assemblage prior to closure of the estuary (Inman 1983; Rick, Kennett, and Erlandson 2005) and for the subsequent shift away from the use of these estuarine species (Figure 5.4a). They are not found after the closure of the estuary, and, at the same time, there is a notable increase in the meat weight of rocky intertidal species. This is a significant shift but not a replacement because rocky intertidal species are always dominant in the shellfish assemblage. Even when the estuary was open, the total meat weight of estuarine shellfish species was only 31 percent of the total meat weight of rocky intertidal species.

The fact that estuarine species were consumed at all, given availability and abundance of rocky intertidal species, suggests that they were highly ranked. This is likely related to their abundance, meat yield, ease of collection, and possibly also to their resilience in the face of human predation (cf., Beaton 1991; Botkin 1980; Braje et al. 2007; Broughton 1997, 1999; Butler 2000; Cannon 2003; Hildebrandt and Jones 1992; Jones et al. 2008; Kelly 1995; Kennett 2005; Madsen 1993; Madsen and Schmitt 1998; Winterhalder 1986; Winterhalder and Smith 2000). Losing access to these species would have decreased the economic attractiveness of Old Ranch Canyon, represented by a downward shift in the suitability curve (Figure 5.3), leading to outmigration. When inhabitants again found it attractive to return to SRI-187 after a 3,000 year gap in occupation, they exploited rocky intertidal species more intensively than they did previously, with this increase more than making up for the loss of estuarine species in terms of meat weight.

The data from Unit 2 of SRI-187 show a significant decrease in estuarine shellfish dating from about 8000 to 6300 cal BP (Figure 5.5). This could be related to the stabilization of sea level and the associated closure of the estuary. There was another significant decrease in estuarine meat weight between the 30–40 cm and 20–30 cm levels of SRI-187, Unit 2, despite the fact that they are nearly contemporaneous, also suggesting that the estuary closure may have started by this time. In neither case, however, is there a clear obverse pattern in rocky intertidal meat weight that would suggest that it was exploited in higher quantities to make up for diminishing estuarine resources.

When people returned after the gap in the site's occupation, they did so to focus on rocky intertidal species. Similarly, fish and sea mammal started to become more prevalent (Figure 5.4b). The growing importance of these dietary components could have replaced meat consumption formerly satisfied by estuarine shellfish. Generally warm marine conditions and low marine productivity prevailed between 7500 to 3800 cal BP (Kennett et al. 2007), and the return to SRI-187 and an associated increase in rocky intertidal species near the end of this period may be related to an increase in marine productivity that ameliorated economic pressures on the site's inhabitants.

The development of the *tomol* after about 1500 BP would have also influenced the overall suitability of Old Ranch Canyon and other similar settlement locales. The appearance of this technology in the Santa Barbara Channel region is consistent with an increase in the consumption of fish at ORC. The quantity of fishbone for the MLT is more than 5.5 times what it was in the Middle period prior to the introduction of the *tomol*. The increase occurred largely because the *tomol* allowed more efficient exploitation of kelp forest fish species. Similarly, the meat weight of sea mammal nearly doubles from the Middle period to the MLT. These animals also were more easily hunted and transported to permanent settlements using *tomols*. Winterhalder et al. (2010:484) observe that sandy beach and kelp forests are more important predictors of settlement late in the precontact sequence, a result substantiated by our finding that fish were especially important during the MLT and Late period at ORC, along with a sandy beach to launch and land plank canoes, which could break apart on more rocky coastline.

Olivella biplicata also prefer sandy beach habitats. The increasing importance of bead manufacturing enhanced the suitability of areas like ORC with more extensive beach deposits. During the Late Middle, MLT, and Late periods there was a dramatic increase in *Olivella biplicata* shell bead production on the northern Channel Islands (Arnold 1987, 1990, 1992a, 1992b, 2001a; Arnold and Munns 1994; Munns and Arnold 2002:132–133; Kennett 2005; King 1990; Rick 2007). At ORC (SRI-85 and -187), *Olivella* bead manufacturing debris from the MLT is more than 9.5 times what it was during the preceding Middle period. Although not an important dietary species itself, *Olivella* was significant because of its use in trade that facilitated access to high-ranked resources from elsewhere. Beginning in the MLT, as many as 95-99 percent of the beads for the Santa Barbara Channel region were produced on the northern Channel Islands (Arnold 1987, 1992a:71, 2001a:18). This is consistent with the increasing importance of sandy beaches later in time.

The impact of the *tomol* and the expansion of the *Olivella* shell bead industry represent population-independent changes in the suitability of ORC. The relative suitability of areas with rich sandy beach habitat and offshore kelp forests increased with these technological and economic developments. Conversely, areas without these resources would have experienced a relative decline in suitability. These resources may also have been resilient to human exploitation, which would tend to broaden their IFD curve and sustainability at larger populations. The ORC faunal data show progressively larger amounts of fish, sea mammals, and *Olivella* from the Middle through the Late periods at the expense of rocky intertidal shellfish (Figure 5.4). Total marine meat weight increases through time, reflecting increasing human population.

Overall, the sequence of occupation at ORC was associated with at least three periods of change in population-independent suitability: the closure of the estuary (~5000–6000 cal BP), the significant reoccupation of the site with declining suitabilities elsewhere, the development of the plank canoe (~1500 cal BP), and the standardization and intensification of the *Olivella* shell bead industry (~1000 cal BP). The effects of these changes on suitability can be predicted qualitatively by changes in the IFD curves and, within the resolution of our faunal data, appear consistent with the settlement history of ORC.

Conclusion

Faunal data from Old Ranch Canyon provide an opportunity to apply the ideal free distribution model on a local scale and assess whether it facilitates a coherent explanation of the effects of environmental and cultural change on population and settlement. Radiocarbon dates from SRI-85, -187, and nearby sites (Rick 2009) indicate that the drainage was occupied from ~8,000 years ago until European contact, with at least one major gap in the record. This initial date is earlier than the prediction of the Winterhalder et al. (2010) model. This mismatch is consistent with IFD predictions, inasmuch as Winterhalder et al. (2010) purposely did not incorporate the unique and high-ranked estuarine resources of ORC into the original model.

Excavation data from SRI-85 and -187 provide evidence that major environmental, technological, and socioeconomic developments altered the conditions affecting the suitability of ORC and the settlement history, diet, and economy of its occupants. By and large, the resulting patterns are consistent with what we would predict using IFD reasoning. The rate of sea level rise slowed between 6000 and 5000 cal BP, causing closure of paleo-estuaries throughout Southern California. Abalone Rocks estuary in ORC was one of them. Prior to closure estuarine shellfish were a high-ranked resource that comprised a significant portion of the ORC diet. With estuary closure, these species were no longer available, causing a decrease in the suitability of the drainage. This decline apparently was large enough relative to the marginal suitabilities of other settlement locations on the northern Channel Islands to stimulate outmigration and perhaps site abandonment at SRI-187 and elsewhere in Old Ranch Canyon. This type of density-independent process is not visible in the regional IFD analysis of Winterhalder et al. (2010) but is fully accessible at the local level, where the specific environmental and socioeconomic changes affecting a particular site are identifiable.

During the time that ORC had a diminished population, surrounding settlement habitats presumably continued to experience population growth and gradual declines in suitability. These density-dependent declines in the suitability of alternative site locations made resettlement of SRI-187 attractive between about 3500 and 3000 cal BP. Subsequently, the development of the plank canoe enhanced cross-channel trade and increased the accessibility of kelp forest resources (fish and sea mammals), as well as the importance of sandy beaches for landing these watercraft. Island locations like ORC found their suitability enhanced independent of population as kelp forests, sea mammals, and trade became more accessible. This would be reflected in the IFD model by an upward shift in the suitability curves for locations with good canoe launch and pull-out areas. The standardization and intensification of the *Olivella* shell bead industry during the MLT augmented this effect. Consistent with these processes we find large increases in the relative quantity of faunal remains at ORC, reflecting an intensified economy and expanded population.

We believe the IFD to be an important analytical tool for understanding how human decisions, in a context of environmental and cultural change, influenced the character and pace of settlement on the northern Channel Islands. We expect the model to be similarly revealing elsewhere. We have highlighted features of its application not pursued in Winterhalder et al. (2010), especially the importance of density-independent factors in shaping IFD predictions. So far as we know, this is the first attempt to use site-specific archaeological data to assess IFD predictions. No less important, we hope to have aided understanding of human settlement on the California Channel Islands.

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