

Quantifying the Diets of Breeding Bald Eagles on the Channel Islands: A Multi-Proxy Approach

Seth D. Newsome¹
Paul W. Collins²
Peter Sharpe³

¹Biology Department, University of New Mexico, Albuquerque, NM 87131

²Santa Barbara Museum of Natural History, Santa Barbara, CA

³Institute for Wildlife Studies, Avalon, CA

PROJECT FINAL REPORT

Prepared For:

MONTROSE SETTLEMENTS RESTORATION PROGRAM

SEPTEMBER 30th, 2013

ABSTRACT

A 3-decade long restoration program has recently re-established a resident breeding bald eagle population on the Channel Islands off southern California. The population is expanding and now breeds on four of the eight islands in the archipelago. To examine the diversity of prey utilized and the proportion of biomass consumed, we identified the remains of prey collected from bald eagle nests and used stable isotope analysis to quantify the diet composition of breeding bald eagles. Over two consecutive breeding seasons (2010-11), we collected more than 6,500 prey remains from recently active bald eagle nests on Santa Rosa (2 nests), Santa Catalina (9 nests), Santa Cruz (4 nests), and West Anacapa (1 nest) islands. Over 80 percent of these prey remains were identified and contained nearly 600 individual animals from at least 60 family, genera, or species. Based on the minimum number of individuals (MNI), eagles on Santa Catalina Island consume a higher proportion of marine fish (55%) than their counterparts on the Northern Channel Islands (42%). In contrast, eagles on the Northern Channel Islands consume a higher proportion of seabirds (54%) than eagles on Santa Catalina Island (36%). Carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) stable isotope analysis of bald eagles and putative prey largely agreed with nest prey results. Stable isotope mixing models show that eagles on Santa Catalina Island consumed ~60% marine fish and 25-30% seabirds, while eagles on the Northern Channel Islands consumed equal proportions (~40-45%) of these two prey types. As expected, terrestrial resource use was generally low with the exception of the Middle Ranch nest on Santa Catalina Island, where both adults and chicks largely consume terrestrial prey in the form of ground squirrels and freshwater fish sourced from a local reservoir. We suggest that a combination of natural and anthropogenic factors are responsible for the regional differences in bald eagle diet on the Channel Islands. Specifically, bald eagle interactions with an active recreational fishery off of Santa Catalina Island may enable access to marine fish species that are not available to eagles on the Northern Channel Islands. Furthermore, the availability of seabirds is far greater on the Northern Channel Islands in comparison to Santa Catalina Island. In addition to quantifying the diet of recovering bald eagles, our study shows how human activities can influence the diet of a generalist top predator in an ecologically unique system that has been impacted by a combination of human activities over the past century.

INTRODUCTION

Bald eagles (*Haliaeetus leucocephalus*) were once a familiar apex predator and scavenger in ecosystems on and around the Channel Islands off southern California, USA. As a result of negative direct (e.g., shooting, egg collection, poisoning) and indirect (e.g., pesticides) interactions with humans, bald eagles disappeared as a resident breeder on the Channel Islands by the late 1950s to early 1960s (Kiff 1980, Kiff 2000). Over the past 30 years, a successful reintroduction program has established resident breeding bald eagles on Santa Catalina, Santa Cruz, Santa Rosa, and West Anacapa islands, which are four of the eight Channel Islands bald eagles were known to breed on historically. As this population continues to grow and expand to other islands in the Channel Islands archipelago, understanding which resources they are utilizing could benefit management of both bald eagles and their prey, some of which (e.g., seabirds) are also protected and the focus of conservation programs in the region.

Bald eagles are opportunistic dietary generalists that consume a wide variety of prey via direct capture, scavenging, and/or stealing from other consumers (Stalmaster 1987, Buehler 2000). When locally available, bald eagles generally favor freshwater or marine fish over other classes of prey. In the coastal setting of the Channel Islands, direct observation and identification of prey remains from nests of reintroduced birds show that in addition to marine fish, seabirds are also consumed (Sharpe and Garcelon 1999). Bald eagle nests examined on Santa Catalina Island (SCA) from 1991–1998 contained on average 86.0% marine fish, 9.7% seabirds, and 3.7% terrestrial mammals (Sharpe and Garcelon 1999). There are no published dietary studies available for the reintroduced bald eagles breeding on the Northern Channel Islands (NCI), but previous research on a historic bald eagle nest on San Miguel Island (SMI) (Collins et al. 2005, Erlandson et al. 2007, Newsome et al. 2010) presents a contrasting picture with dietary data available for the reintroduced bald eagle population on SCA. The identification and stable isotope analysis of bald eagle and putative prey remains from the historic nest shows that eagles breeding on SMI in the first half of the 20th century consumed a higher proportion of seabirds than their modern counterparts on SCA. Today, the NCI, and specifically SMI, are host to a greater diversity and abundance of breeding seabirds than SCA (Hunt et al. 1980, Sowls et al. 1980, Carter et al. 1992). Determining whether the reintroduced bald eagles on the NCI are using this resource, as their historic counterparts did, and which seabird species are commonly targeted by eagles is important information for both bald eagles and seabird conservation in the Channel Islands. Seabirds, whose local populations declined in the mid-20th century for some of the same reasons as bald eagle populations (e.g., pesticides, egg collection), are the focus of conservation efforts in the region. Today, over a dozen species of seabirds breed on the Channel Islands, and several of these (e.g., alcids) have smaller breeding populations relative to historic estimates and thus are of conservation concern. Furthermore, it has been proposed that seabirds, which feed at a higher trophic level than marine fish and thus likely have higher contaminant loads, could be a major vector of contaminant exposure to resident bald eagles on the Channel Islands (Garcelon et al. 1994a, 1994b, Sharpe and Garcelon 1999).

Because of their elusive behavior and large home range sizes, quantifying bald eagle diets is a difficult and time-consuming endeavor. Traditional analysis has relied a variety of techniques such as direct observation of prey items returned to the nest and adjacent perches during the breeding season (Sharpe and Garcelon 1999), examination of prey in ingested pellets collected at communal roosts, direct observation of foraging, or the identification of prey remains (e.g., bones and feathers) found in nests after the breeding season (Mersmann et al. 1992, Buehler 2000). Perhaps the most comprehensive approach is to couple these traditional methods with stable isotope analysis of bald eagle tissues and their putative prey, which provides a time-integrated estimate of ingested prey biomass. Carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) stable isotope analysis of animal tissues has rapidly become an established method for characterizing animal resource and habitat use (Kelly 2000, Koch 2007) and is especially useful for differentiating marine from terrestrial resource use in consumers because of baseline differences in the isotopic composition of primary producers in marine versus terrestrial ecosystems. In California, coastal

marine ecosystems are characterized by higher $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values than their adjacent terrestrial counterparts because terrestrial primary productivity is dominated by C_3 photosynthesis (Suits et al. 2005), resulting in food webs characterized by relatively low $\delta^{13}\text{C}$ values ranging from -22‰ to -28‰ (Craig 1953). Coastal marine ecosystems, in contrast, are dominated by a combination of micro- and macroalgae that have higher $\delta^{13}\text{C}$ values of -16‰ to -20‰ (Page et al. 2008). For nitrogen, field and laboratory-based studies have established that there is an increase in $\delta^{15}\text{N}$ values of ~3–5‰ per trophic step in marine and terrestrial ecosystems (Vanderklift and Ponsard 2003). Because coastal marine ecosystems contain a greater number of trophic levels than their terrestrial counterparts, they typically have higher $\delta^{15}\text{N}$ values. These baseline and trophic-related gradients result in apex predators in marine and terrestrial ecosystems having $\delta^{15}\text{N}$ values in the range of +15–19‰ and +7–12‰, respectively. Consumers that rely on a mixture of marine and terrestrial resources have intermediate $\delta^{15}\text{N}$ values ranging from +12–15‰, while terrestrial apex predators on the Channel Islands (e.g., island foxes) have $\delta^{15}\text{N}$ values that range from +8–10‰ (Newsome et al. 2010).

Here we use both traditional prey identification and stable isotope analysis to quantify bald eagle resource use and assess dietary patterns among areas of the Channel Island archipelago across which prey availability may vary because of both natural and anthropogenic factors. We combined the identification of prey collected directly from recently active bald eagle nests with $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ analysis of potential prey and eagle tissues. This approach allowed us to quantify the diversity of prey utilized by eagles and the relative proportions of biomass of general prey types (e.g., marine fish vs. seabirds) consumed among different nests and islands in the archipelago. Identifying the types of prey that bald eagles are currently consuming can inform management and conservation efforts regarding: 1) the prey that bald eagles may impact as they reestablish breeding populations on the Channel Islands; 2) the possible conflicts that a reestablished bald eagle population might have with other recovering wildlife (e.g., seabirds) on the islands; and 3) the impacts that contaminated prey (e.g., seabirds and marine mammals) might have on the reproductive success of a recovering bald eagle population. In addition, comparison of modern dietary patterns with that from historic and prehistoric bald eagle populations on the islands (Collins et al. 2005, Erlandson et al. 2007, Newsome et al. 2010) may identify how the prey base of this generalist predator/scavenger has changed in step with the history of human activities in the archipelago, including land use practices (e.g., ranching), commercial/recreational fishing, and successful wildlife protection (e.g., seabirds).

MATERIALS & METHODS

Field Collections from Modern Bald Eagle Nests

Nests used by the recovering bald eagle population on Santa Catalina, Santa Cruz, Santa Rosa, and West Anacapa Islands were examined in October–November of 2010 and 2011 for prey remains (e.g., bones and feathers), and bald eagle feathers and eggshell fragments. We only visited nests on Santa Rosa Island in 2010 because both nests (Lopez and Verde Canyons) failed during the 2011 breeding season. Likewise, we only visited nests on Santa Cruz Island in 2010 because of permit issues. When necessary, we used a professional climber to access eagle nests on rock pinnacles, ledges, cliff faces or in trees. All prey (bones, teeth, otoliths, fish spines/scales, and feathers) and eagle remains (eggshell fragments and feathers) visible on and within the outer stick structure of the nest, within the nest cup, in the immediate vicinity of the nest site, and under nearby perches used by eagles were collected by hand and stored in plastic bags for transport to the laboratory for identification and sampling. The lining of the nest cup was carefully examined and any accumulated sediment in the bottom of the nest cup was sifted with a 1/16-inch mesh screen to recover smaller prey remains and eagle eggshell fragments. The nest lining was returned to its original condition following the recovery of prey remains from inside of the nest cup. The stick structure of each modern, recently occupied nest was not disassembled in order to recover prey and

eagle remains from on or within the nest structure. Prey remains were initially sorted in the field by area of the nest or nest site where the remains were recovered.

Chick feathers and blood were collected during annual banding efforts on Santa Catalina, Santa Rosa, and Santa Cruz Islands in May and June 2010; adult feathers were opportunistically collected from nests and perches on Santa Catalina and Santa Rosa Islands in the fall (Oct/Nov) 2010. Three breast feathers were pulled from each ~8 week-old eaglet and placed in an envelope until analysis. A drop of non-heparinized whole blood was spread on a glass microscope slide and allowed to dry in the field. In the laboratory that same day, we scraped the dried whole blood off of the slide with a clean razor blade and stored it in a 0.6ml microcentrifuge tube until analysis.

Field Collections from Historic Bald Eagle Nests

Four historic bald eagle nests found on San Miguel (Ferrello Point nest), Santa Rosa (West Bee Rock Canyon nest) and San Nicolas (Eagle Rock nests) Islands were excavated and examined for prey remains (e.g., bones, teeth, and otoliths) and bald eagle eggshell fragments. Faunal remains observed in each historic nest were collected by hand and following removal of the remaining stick nest structure accumulated soil under and immediately down slope from each nest was sampled with the aid of a 1/16-inch (1.6 mm) mesh screen. Faunal remains were initially sorted into separate bags in the field.

Prey Identification

In the laboratory, faunal remains from each historic and modern nest were initially separated by class (fish, birds, reptiles, mammals, and invertebrates). This material was later grouped and identified to the lowest identifiable taxonomic level (e. g. class, order, family, genus, or species) by comparing diagnostic elements (bones, teeth, otoliths, invertebrate exoskeleton fragments and shells) with identified specimens in the research collections at the Santa Barbara Museum of Natural History, Santa Barbara, California, USA. For birds, seventeen elements – crania, maxilla, lower mandible, pelvic bones, sternum, sacral vertebrae, humerus, ulna, radius, carpometacarpus, phalange of wing, coracoid, scapula, clavicle, femur, tibiotarsus and tarsometatarsus – were used for species identification. Bones of some species such as Pacific and red-throated loons, Brandt's and double-crested cormorants, western and glaucous-winged gulls, and ancient and marbled murrelets were too similar to differentiate to species. For fish, twenty-three bone elements – angular, dentary, maxilla, parasphenoid, premaxilla, preopercle, vertebra, basioccipital, ceratohyla, epihyla, frontal, hyomandibular, interopercle, opercle, palatine, parietal, pharyngeal, post-temporal, radial, scapula, supracleithrum, supraoccipital, and vomers – were used for species identification; fish otoliths were also collected and identified but could not be used for isotopic analysis because they do not contain sufficient organic material. For mammals and reptiles, twenty-one elements (skull, mandible, teeth, scapula, humerus, radius, ulna, carpal/tarsal bones, metacarpal, metatarsal, phalanges, ribs, long-bone epiphyses, pelvis, femur, patella, tibia, fibula, calcaneus, astragalus, and teeth) were used for species identification. Fragmentary, non-diagnostic specimens were identified as undifferentiated mammal, reptile, bird, or fish. For invertebrates, exoskeleton fragments and shells were used for identification.

Prior to quantifying prey remains data from historic and present-day bald eagle nests, faunal remains that were thought to be incidental and not a result of actual predation/scavenging by eagles were eliminated from all further analysis of eagle diet. Taxa considered to be incidental remains included: (1) taxa that likely were in the crop, stomach or gut of seabirds brought to the nest to feed the chicks (most of the smaller invertebrate remains), (2) small birds (Passerines) and lizards that were likely captured by other birds like peregrine falcons, American kestrels, red-tailed hawks, barn owls, and common ravens that perched on an eagle nest and fed on captured prey during the late summer and fall when eagles are not defending nest sites, and (3) small invertebrates that either crawled into the nest structure (land snails,

beetles and insect pupae) or were riders on marine plants brought to a nest to line the nest cup (coralline algae). It was difficult to know whether small mammal remains (mice and rats) and some of the small fish found in a nest were also incidental remains or were the result of actual eagle predation. Small mammal and small fish remains were kept in the prey samples for further analysis of eagle diet and were not lumped in as incidental prey. Following the removal of all incidental faunal remains from the prey remains samples, we then quantified the faunal remains in three ways by: (1) bone weight to the nearest 0.1 gram; (2) the number of individual specimens (NISP) calculated by counting the total number of elements identified to each taxon; and (3) the minimum number of individuals (MNI) determined by the greatest number of unique elements identified per taxon. NISP and MNI were the only two measures used in further quantification of the historic and present-day diet of bald eagles on the Channel Islands. To calculate MNI, we used the total of sided, non-repetitive post cranial and cranial elements from a particular taxon, or in some cases the number of fish vertebrae identified were divided by an average number of vertebrae for that taxon (Rick et al. 2001).

Prey remains were initially quantified to MNI for each nest site, identified taxonomic category and for each time period (Historic, 2010 or 2011). Remains were then lumped and quantified to MNI by island and then by island group (Northern Channel Islands, San Nicolas Island and Santa Catalina Island) to permit comparisons of the diet of eagles during each time period (historic versus modern) or between island groups (Northern versus Southern Channel Islands). Appendix 1 provides a taxonomic list of all prey identified from the faunal samples collected at historic and present-day bald eagle nests on the Channel Islands.

Stable Isotope Analysis

A small (~2mg) sub-sample of feather was removed from the tip of each chick body feather for isotopic analysis. For primary and secondary feathers from adults we removed three sub-samples for isotopic analysis: one sub-sample near the tip, the base, and the middle of each feather. We calculated the mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ value of these three sub-samples to calculate a feather value for each bald eagle adult. Feather sub-samples were treated with a 2:1 chloroform:methanol solution to remove surface contaminants. Whole blood samples from chicks were dried on glass microslides in the field and homogenized by scraping dried blood into a microcentrifuge tube. To isolate bone collagen from prey remains found in nests, a small bone fragment was demineralized in 0.5N HCl for ~36 hours at ~5°C. Both bone collagen samples were then treated with a 2:1 chloroform:methanol mixture to remove lipids, rinsed in deionized water and lyophilized.

Approximately 0.5mg of dried keratin (feathers), and blood, and bone collagen samples were sealed in tin capsules and analyzed using a Carlo Erba NC2500 or Costech 4010 elemental analyzer interfaced with a Thermo Finnigan Delta Plus XL mass spectrometer at the University of Wyoming Stable Isotope Facility (Laramie, WY). Isotopic results are expressed as δ values, $\delta^{13}\text{C}$ or $\delta^{15}\text{N} = 1000 * [(R_{\text{sample}} - R_{\text{standard}}) / R_{\text{standard}} - 1]$, where R_{sample} and R_{standard} are the $^{13}\text{C}/^{12}\text{C}$ or $^{15}\text{N}/^{14}\text{N}$ ratios of the sample and standard, respectively. The standards are Vienna-Pee Dee Belemnite limestone (V-PDB) for carbon and atmospheric N_2 for nitrogen. The units for δ values are expressed as parts per thousand, or per mil (‰). As a control for the quality of feather keratins and bone collagen, we measured the carbon-to-nitrogen concentration, reported as a [C]/[N] ratio, of each sample and compared them to the theoretical atomic [C]/[N] ratios of each tissue.

Stable Isotope Mixing Models

We used the Bayesian Stable Isotope Analysis in R (SIAR) mixing model (Parnell et al. 2010) to quantify the proportion of marine fish, seabirds, and terrestrial resources in chick and adult bald eagle diets.

Bayesian models allow for the assessment of greater than $n+1$ sources when using n isotope systems, however, the inclusion of a large number of potential prey sources often yields cumbersome results. Our goal was to quantify consumption of general prey types by bald eagles in each region and tailored our models specifically to the relative availability and isotopic composition of local prey sources. We only used bald eagle adult and chick feather values to quantify diets via mixing models; chick whole blood are presented in Table 3 but were not used in SIAR.

Because we compared different tissues between bald eagles (feather) and potential prey (bone collagen), we had to account for both tissue-specific and trophic discrimination when estimating a discrimination factor to use in the SIAR mixing models. A recent controlled feeding experiment (Rempel et al. unpublished) on captive bald eagles at the San Francisco Zoo examined trophic discrimination ($\Delta^{13}\text{C}_{\text{tissue-diet}}$ or $\Delta^{15}\text{N}_{\text{tissue-diet}}$) of feathers and whole blood for both adults and chicks. Chicks had lower $\delta^{15}\text{N}$ trophic discrimination factors, a pattern found in isotopic studies of other animals (Vanderklift and Ponsard 2003) that is caused by a decrease in isotopic discrimination during periods of high growth rates. Based on this pattern, we used a $\delta^{15}\text{N}$ discrimination factor of $3.0 \pm 0.5\text{‰}$ for adults and $2.0 \pm 0.5\text{‰}$ for chicks regardless of tissue type; $\Delta^{15}\text{N}_{\text{tissue-diet}}$ does not appear to vary among tissues. For $\delta^{13}\text{C}$, we had to account for the fact that bone collagen has higher trophic discrimination factor than feathers (Koch 2007, Caut et al. 2009), thus we used a slightly negative discrimination factor ($-1.0 \pm 0.5\text{‰}$) between prey bone collagen and consumer (feather or whole blood) in our SIAR mixing models to account for both tissue-specific and trophic discrimination.

For Santa Catalina Island (SCA), we used a mixing model with four potential prey sources: seabirds, marine fish (excluding flyingfish), flyingfish, and terrestrial resources (ungulates and rodents). Seabirds ($n=108$) had mean ($\pm\text{SD}$) $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of $-15.6 \pm 1.3\text{‰}$ and $16.3 \pm 1.5\text{‰}$ respectively; marine fish (excluding flyingfish) ($n=117$) had mean ($\pm\text{SD}$) $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of $-14.6 \pm 1.0\text{‰}$ and $15.6 \pm 1.1\text{‰}$ respectively; flyingfish ($n=32$) had mean ($\pm\text{SD}$) $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of $-17.0 \pm 0.7\text{‰}$ and $13.2 \pm 1.1\text{‰}$ respectively; terrestrial resources ($n=24$) had mean ($\pm\text{SD}$) $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of $-21.0 \pm 1.7\text{‰}$ and $6.0 \pm 2.0\text{‰}$ respectively. For the two bald eagles from the Middle Ranch nest on SCA that consumed a high proportion of terrestrial resources and had freshwater fish locally available (Thompson Reservoir), we added a fifth prey source to the model, freshwater fish ($n=11$), that had mean ($\pm\text{SD}$) $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of $-24.6 \pm 1.8\text{‰}$ and $9.5 \pm 0.8\text{‰}$ respectively.

For the Northern Channel Islands (NCI), we used a mixing model with three potential prey sources: seabirds, marine fish, and terrestrial resources (ungulates). Seabirds ($n=94$) had mean ($\pm\text{SD}$) $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of $-14.8 \pm 1.1\text{‰}$ and $16.4 \pm 1.3\text{‰}$, respectively. Marine fish ($n=47$) had mean ($\pm\text{SD}$) $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of $-12.7 \pm 1.4\text{‰}$ and $14.1 \pm 0.8\text{‰}$, respectively. Terrestrial resources ($n=34$) had mean ($\pm\text{SD}$) $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of $-21.7 \pm 1.0\text{‰}$ and $7.2 \pm 1.5\text{‰}$, respectively.

RESULTS

Identification of Prey in Modern Nests

A total of 6576 prey remains from 72 species and 38 families were recovered from 16 recently active bald eagle nests on the Channel Islands; 7 on the NCI and 9 on SCA (Table 1). Of the 575 individuals identified, 288 (50.1%) were fish, 242 (42.1%) were birds, and 45 (7.8%) were mammals (Table 1). The most important prey groups in this sample were rockfish (16.2%), gulls (13.2%), toadfishes (9.6%), cormorants (8.3%), flyingfish (7.8%), and alcids (7.0%, Table 1). The relative proportion of prey classes and diversity and abundance of species varied between the NCI the SCA bald eagle nest samples (Figure 1). The diet of eagles on the NCI was comprised of 42.1% fish (83 MNI),

53.8% birds (106 MNI) and 4.1% mammals (45 MNI) while on SCA the eagle diet was comprised of 54.2% fish (205 MNI), 36.0% birds (136 MNI) and 9.8% mammals (37 MNI, Table 1 and Figure 1).

The most important families of fish in the eagles diet on both the NCI and SCA were rockfish (Scorpaenidae), toadfish (Batrachoididae), and surf perch (Embiotocidae, Table 1). Eleven fish families were only recorded in prey remains from nests on SCA, including flyingfish, sea basses, sunfish & basses, croakers, sea chubs, tunas & mackerels, thornbacks, smoothhounds, stingrays, morays, and damselfishes while only two fish families (cat sharks and silversides) were recorded in prey remains from nests on the NCI (Table 1). A greater diversity (16 families and at least 22 species) and abundance (205 individuals) of fish were found in the prey samples recovered from SCA nests than in the prey samples from the NCI nests (7 families, 11 species, 83 individuals, Table 1). The most important families of birds represented in the eagle's recent diet on the Channel Islands were gulls (Laridae, 13.2% MNI), cormorants (Phalacrocoracidae, 8.3%), alcids (Alcidae, 7.0%), fulmars and shearwaters (Procellariidae, 6.4%), and waterfowl (Anatidae, 2.3%). The relative proportion of these five bird families varied slightly in the prey samples collected from nests on SCA and the NCI (Table 1, Figure 1). Cormorants and alcids were more abundant in the NCI nests while gulls, shearwaters, waterfowl, ravens and grebes were more abundant in nests on SCA (Figure 1, Table 1). Brown pelican and red-billed tropicbird were only found in Santa Cruz Island eagle nests while ashy storm-petrel was only found in eagle nests on SCA. Mammals comprised 4.1% and 9.8% of the diet of eagles on the NCI and SCA, respectively (Table 1 and Figure 1). Mule deer was the most abundant mammal in eagle nests on both the NCI (2.5%) and SCA (3.7%). Rodents (California ground squirrel and black rat), harbor seal and domestic cow were only found in prey samples from SCA eagle nests while western spotted skunk was only found in eagle nests on the NCI (Table 1). Island fox comprised 0.3% of the eagle's diet on SCA and 0.5% of the diet on the NCI.

Identification of Prey in Historic Nests

A total of 12,158 prey remains from at least 70 species and 32 families were recovered from four historic bald eagle nests on the Channel Islands; n=2 on San Nicolas Island, n=1 on San Miguel Island, n=1 on Santa Rosa Island (Table 2). Of the 523 individuals identified 148 (27.8%) were fish, 330 (62.0%) were birds and 54 (10.2%) were mammals (Table 2). The most important prey groups in the historic nest prey samples were alcids (19.7%), rockfish (10.7%), cormorants (10.5%), waterfowl (9.4%), fulmars and shearwaters (7.7%), toadfish (6.8%), and surfperches (5.8%, Table 2). The proportion of prey classes and the diversity and abundance of species varied in samples collected from historic nests on the NCI and on San Nicolas Island (Figure 2). The historic eagle nests on the NCI were comprised of 21.7% fish (92 MNI), 68.8% birds (291 MNI) and 9.5% mammals (40 MNI) while on San Nicolas Island the historic eagle nest contained 51.4% fish (56 MNI), 35.8% birds (39 MNI) and 12.8% mammals (14 MNI, Table 2 and Figure 2). Eleven fish families are represented in the historic Channel Islands bald eagle nest prey samples (Table 2). The most important of these to eagles were rockfish (Scorpaenidae), toadfish (Batrachoididae), and surf perch (Embiotocidae, Figure 2). Four fish families (Scombridae, Atherinidae, Clinidae, and Stichaeidae) were only found in historic nests on the NCI (Table 2). Fish comprised a greater proportion of the eagle's diet historically on San Nicolas Island (51.4%) than on the NCI (21.7%) which matches the relative importance today of fish in the eagles diet on the NCI versus SCA. The most important families of birds in the eagle's historic diet were alcids (Alcidae, 19.7%), cormorants (Phalacrocoracidae, 10.5%), waterfowl (Anatidae, 9.4%), fulmars and shearwaters (Procellariidae, 7.7%), and gulls (Laridae, 7.3% MNI, Table 2). Most of the bird families were more abundant in historic nests on the NCI than in historic nests on San Nicolas Island (Figure 2). Albatrosses and pelicans were only recovered from historic nests on San Nicolas Island while common raven, loons, storm-petrels, herons, and egrets were only found in historic nests on the NCI (Table 2). Mammals comprised 9.5% and 12.8% of the historic diet of eagles on the NCI and San Nicolas Island, respectively (Table 2 and Figure 2). Sheep (4.5%, n=24) and rodents (3.4%, n=18) were the most abundant mammals in the historic diet of eagles on the islands. Island fox comprised 1.8% and 0.7% of the eagle's historic diet while sheep

comprised 8.3% and 3.5% of the historic diet on San Nicolas Island and on the NCI, respectively (Table 2). Finally, marine mammals (Otariidae and Phocidae) represented a small proportion (1.0%) of the prey found in historic eagle nests on the Channel Islands.

Stable Isotope Analysis

Mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of potential prey identified from nests are presented in Table 3. Given the high diversity of potential prey, we grouped prey by family or genera and subdivided them into two regions: SCA and the NCI (Santa Rosa, Santa Cruz, and West Anacapa). As expected, marine resources (fish and seabirds) in both regions had significantly higher $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values than terrestrial resources (ungulates, rodents, and freshwater fish) for both SCA ($\delta^{13}\text{C}$: $F(1,293)=630.5$ $P<0.0001$, $\delta^{15}\text{N}$: $F(1,293)=796.0$ $P<0.0001$) and the NCI ($\delta^{13}\text{C}$: $F(1,175)=721.0$ $P<0.0001$, $\delta^{15}\text{N}$: $F(1,175)=795.7$ $P<0.0001$). Within the marine realm, seabirds had significantly higher $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values than marine fish on both SCA ($\delta^{13}\text{C}$: $F(1,257)=7.2$ $P=0.008$, $\delta^{15}\text{N}$: $F(1,257)=41.4$ $P<0.0001$) and the NCI ($\delta^{13}\text{C}$: $F(1,141)=88.9$ $P<0.0001$; $\delta^{15}\text{N}$: $F(1,141)=119.6$ $P<0.0001$).

At the family and genera level, we found significant isotopic differences among potential bald eagle prey, however, the isotope system ($\delta^{13}\text{C}$ or $\delta^{15}\text{N}$) that showed significant differences was not consistent between regions. On SCA, $\delta^{15}\text{N}$ values were the most useful isotope system to discriminate among prey family or genera. The following comparisons among SCA prey are based on a one-way ($\delta^{15}\text{N}$) ANOVA ($F[1,257]=25.1$ $P<0.05$). On SCA, gulls had significantly higher values than other seabirds or marine fish. All other seabird families had similar $\delta^{15}\text{N}$ values and were not significantly different from that of rockfish, midshipman, or kelp bass. Surfperch, sheephead, flyingfish, and miscellaneous small fish had significantly lower $\delta^{15}\text{N}$ values than seabirds and other marine fish with the exception of kelp bass.

On the NCI, patterns among potential bald eagle prey families or genera were detectable with both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values. For $\delta^{13}\text{C}$ ($F[1,141]=24.3$ $P<0.05$), rockfish and surfperch had higher values than another other family or genera of marine fish or seabird. All other families and genera (seabird or marine fish) had similar $\delta^{13}\text{C}$ values. For $\delta^{15}\text{N}$ ($F[1,141]=29.1$ $P<0.05$), alcids had higher $\delta^{15}\text{N}$ values than any other family or genera of marine fish or seabird. Gulls and cormorants had significantly higher $\delta^{15}\text{N}$ values than rockfish and surfperch. The procellariiformes had similar $\delta^{15}\text{N}$ values as all other groups except for alcids and surfperch. Lastly, midshipman had similar $\delta^{15}\text{N}$ values as all other groups, except for alcids.

For bald eagle chicks (Table 4), we found no sex-related differences in feather $\delta^{13}\text{C}$ ($F[1,27]=0.45$ $P>0.10$) and $\delta^{15}\text{N}$ ($F[1,27]=0.25$ $P>0.10$) or blood $\delta^{13}\text{C}$ ($F[1,26]=0.45$ $P>0.10$) and $\delta^{15}\text{N}$ ($F[1,26]=0.65$ $P>0.10$). Likewise, we found no year-effects in $\delta^{13}\text{C}$ (feather: $F[1,27]=0.006$ $P>0.10$; blood: $F[1,26]=0.01$ $P>0.10$) or $\delta^{15}\text{N}$ (feather: $F[1,27]=1.9$ $P>0.10$; blood: $F[1,26]=2.6$ $P>0.10$) of either tissue. Chicks from SCA had lower feather ($F[1,27]=18.2$ $P<0.001$) and blood ($F[1,27]=24.6$ $P<0.001$) $\delta^{13}\text{C}$ values than their counterparts from the NCI. There were no significant differences in feather ($F[1,27]=2.3$ $P>0.10$) or blood ($F[1,26]=1.0$ $P>0.10$) $\delta^{15}\text{N}$ values between chicks from these two regions. Due to low sample sizes, we did not test for significant differences between chicks from different nests. Lastly, we found that on average chick feathers had higher $\delta^{13}\text{C}$ values than whole blood (Table 4). Mean ($\pm\text{SD}$) $\Delta^{13}\text{C}_{\text{feather-blood}}$ was $+1.7\pm 0.5$; $\Delta^{15}\text{N}_{\text{feather-blood}}$ was only $+0.6\pm 0.5$ and not different than zero.

For bald eagle adults (Table 5), after excluding the two individuals that obviously consume a high proportion of terrestrial resources, birds from SCA had significantly lower $\delta^{13}\text{C}$ ($F[1,14]=10.3$ $P<0.01$) and slightly lower $\delta^{15}\text{N}$ ($F[1,14]=3.4$ $P=0.09$) values than their counterparts from the NCI.

Stable Isotope Mixing Model Results

We did not include results for Middle Ranch bald eagles on SCA that consume a high proportion of terrestrial resources in the calculated mean proportions shown in Figure 4. In order of importance, mean (\pm SD) source proportions for the chick from Middle Ranch were $43\pm 11\%$ terrestrial resources, $30\pm 12\%$ freshwater fish, $12\pm 9\%$ flyingfish, $8\pm 6\%$ seabirds, and $8\pm 6\%$ marine fish. Mean (\pm SD) source proportions for the adult from Middle Ranch were $37\pm 9\%$ terrestrial resources, $25\pm 10\%$ freshwater fish, $17\pm 11\%$ flyingfish, $11\pm 8\%$ seabirds, and $11\pm 8\%$ marine fish.

Figure 4 presents a summary of mixing model results for all of the other bald eagle adults and chicks that we analyzed. At SCA, we combined post-hoc source proportions for marine fish and flyingfish to report a total marine fish proportion. In order of importance, mean source proportions for the chicks ($n=16$) from SCA were $57\pm 4\%$ marine fish (flyingfish: $25\pm 2\%$, other marine fish $32\pm 5\%$), $28\pm 4\%$ seabirds, and $15\pm 7\%$ terrestrial resources (ungulates and rodents). Mean source proportions for the adults ($n=9$) from SCA were $61\pm 3\%$ marine fish (flyingfish: $20\pm 3\%$, other marine fish $41\pm 4\%$), $31\pm 2\%$ seabirds, and $8\pm 2\%$ terrestrial resources. Mean source proportions for the chicks ($n=10$) from the NCI were $48\pm 4\%$ seabirds, $44\pm 3\%$ marine fish, and $8\pm 2\%$ ungulates. Mean source proportions for the adults ($n=6$) from the NCI were $47\pm 6\%$ marine fish, $41\pm 8\%$ seabirds, and $12\pm 9\%$ ungulates.

DISCUSSION

Isotopic Patterns Among Potential Prey

Isotopic patterns among potential prey generally conformed to expectations. Terrestrial resources (ungulates and rodents) and freshwater fish have lower $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values than marine resources. We found subtle but significant differences in mean (\pm SD) $\delta^{15}\text{N}$ values between ungulates on Santa Catalina ($5.7\pm 1.7\text{‰}$) and Santa Rosa islands ($7.2\pm 1.5\text{‰}$); mule deer and elk had statistically indistinguishable $\delta^{15}\text{N}$ on Santa Rosa Island. Thus, differences in ungulate $\delta^{15}\text{N}$ values between islands likely reflect variation in the composition of plant communities on which they forage. Such baseline effects are important to identify when using stable isotopes to examine consumer diets, however, this degree of variation is small relative to the large differences (8–12‰) in $\delta^{15}\text{N}$ between terrestrial and marine resources on the Channel Islands (Figure 3). We were pleased to find that isotope values could be used to discriminate between marine fish and seabirds, as these two resource types represent the most common prey found in nests (Table 1). The only exception to this pattern was midshipman (*Porichthys spp.*), which had similar isotope values as seabirds. Midshipman are a carnivorous intertidal-subtidal genus and were expected to have similar isotope values as other nearshore species that occupy similar dietary and habitat niches, such as surfperch and rockfish. Why midshipman had higher $\delta^{15}\text{N}$ and, on the NCI lower $\delta^{13}\text{C}$ values, relative to other fish species is not known. The only other fish that had significantly different isotope values than the common nearshore species found in nests on SCA were California flyingfish (*Cypselurus californicus*), an epipelagic species that can be seasonally found close to shore in the Channel Islands. Flyingfish are seasonal visitors to nearshore habitats and use offshore habitats for significant periods of the year, which are characterized by lower $\delta^{13}\text{C}$ values than the kelp-influenced nearshore marine ecosystem that is home to many of the fish found in bald eagle nests. Furthermore, flyingfish are largely zooplanktivores, which explains why they have lower $\delta^{15}\text{N}$ values relative to many piscivorous nearshore species that feed at higher trophic levels.

While midshipman sourced from the two regions had similar isotope values, rockfish and surfperch from the NCI had slightly lower $\delta^{15}\text{N}$ but significantly higher $\delta^{13}\text{C}$ values than their counterparts from SCA. Species effects could drive the observed isotopic differences, since both of these

fish families (Scorpaenidae and Embiotocidae) are difficult to identify at the species level but contain species that occupy different habitat and/or trophic niches; both families have been identified as likely examples of adaptive radiations in marine fish. Spatial isotope baseline shifts are also a possibility. In general, nearshore ecosystems that are more influenced by macroalgae (versus phytoplankton) production have higher baseline $\delta^{13}\text{C}$ values than ecosystems where kelp is less prevalent (Page et al. 2008). Isotopic analyses of sessile marine invertebrates (e.g., filter feeders) collected from the two regions are needed to further examine this explanation. Overall, the observed isotopic differences in the same prey collected from the two regions (SCA and NCI) highlight the need to collect local prey sources when using stable isotopes to quantify animal diets.

The seabirds analyzed from both SCA and the NCI had surprisingly similar mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values, and we found no significant differences at the family level between the two regions. In comparison to fish, seabirds are more mobile and forage over much larger areas of the ocean. For non-resident migratory species (e.g., shearwaters), individuals sourced from bald eagle nests on SCA and the NCI likely belong to the same population that may breed in other parts of the North Pacific or even South Pacific; the large degree of isotopic variation observed in these groups is discussed below. Even resident breeders (e.g., gulls) may use large areas of the Southern California Bight throughout the year so isotopic similarity between individuals sourced from bald eagle nests on SCA and the NCI is not surprising.

The largest degree of isotopic variation observed among any prey source was that found within the bird family Procellariidae. This variation is likely driven by baseline isotopic gradients rather than differences in diet among species. The two most common species analyzed, sooty (*Puffinus griseus*) and pink-footed (*Puffinus creatopus*) shearwaters, have a similar diet and are generalist piscivores that consume fish, squid, and to a lesser extent crustaceans. These shearwater species are common within the Southern California Bight during the summer months, but breed in the South Pacific Ocean during the austral summer; sooty shearwaters breed on islands off New Zealand, pink-footed shearwaters on islands off of western South America. Northern fulmars (*Fulmarus glacialis*), the third most abundant member of the Procellariidae found in bald eagles nests, are also resident migrants that breed on islands off the Alaska Peninsula during the summer. Thus, the multi-year ecological record reflected in bone collagen represents a combination of North and South Pacific pelagic habitats in addition to that of the Southern California Bight where they forage in the non-breeding season.

Diet Composition of Breeding Bald Eagles on the Channel Islands

Each of the dietary proxies used in this study are associated with inherent biases that are important to consider when interpreting dietary patterns in bald eagle populations. When used in conjunction, however, these techniques provide as comprehensive a picture as possible of diet composition because the strengths of one particular approach supplement the weaknesses of another. For example, the identification and quantification of prey remains from nests may underestimate the contribution of small fish species in the diet of breeding eagles and their offspring because (1) bone elements of these prey species are difficult to collect without extensive disturbance and excavation of the nest structure, or (2) small fish may be completely consumed by eagles with no traces left in the nest. In addition, the quantification of prey remains at either the specimen (NISP) or individual (MNI) level does not take into account the sometimes large differences in the amount of digestible biomass provided by different prey types. For example, a seabird (on average) contains more digestible biomass than a small fish. Thus, while prey identification can provide high-resolution information on the diversity of species consumed by bald eagles, our approach did not take into account differences in consumable biomass among potential prey. Archaeologists have negotiated this problem by using meat indices to correct for differences in the digestible biomass of different foods consumed by ancient humans, however, we relied upon stable isotope analysis to provide an estimate of ingested biomass.

While stable isotope analysis does provide a time-integrated measure of ingested biomass, the method does not typically provide estimates of dietary composition at the species level. Stable isotopes measure ecological function such as difference in diet and habitat use and thus are particularly useful for determining the consumption of prey that inhabit different biomes (e.g., marine vs. terrestrial) or occupy different trophic or habitat niches in the same ecosystem (e.g., marine fish and seabirds).

Despite the different windows of insight that nest prey identification and stable isotope analysis provide, general dietary patterns provided by each of these proxies were consistent. For example, stable isotope analysis and mixing model results (Figure 4) show that NCI eagles consume a higher proportion of seabirds (~40-50%) than eagles from SCA (~25-35%). The consumption of marine fish appears to make up the difference, as mixing model results show that fish represent ~55-65% of eagle diet on SCA, where fish consumption on the NCI is similar to that of seabirds (~40-55%). This pattern generally agrees with prey remains identified from nests with a higher proportion of birds in the NCI nests (53.8%) and a smaller proportion of birds (36.0%) in the SCA nests. On SCA, the minimum number of individual (MNI) fish ($n=205$) found in eagle nests far exceeded that of seabirds ($n=136$). In contrast, the MNI of seabirds ($n=105$) exceeded that of fish ($n=83$) on the NCI. Note that on average a seabird likely contains more digestible biomass than a fish, especially many of the small fish (flyingfish, wrasses) identified from SCA nests.

Not only did SCA eagles consume a higher proportion of fish, but the diversity of fish species consumed was greater than that observed on the NCI. Based on MNI, three families accounted for >90% of the fish identified from NCI nests. On SCA, we identified at least five individuals from each of eight fish families; this number increases to nine if one includes the freshwater fish family Centrarchidae. It appears that SCA eagles not only consume more fish, but they have access to a greater diversity of fish species than their counterparts on NCI.

Our results show that three eagles consumed an appreciable proportion of their diet from terrestrial resources. An adult feather collected from the Verde Canyon on Santa Rosa Island (Figure 3) had lower $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values in comparison to other adults and chicks from the NCI. Deer and elk were the only terrestrial prey found in nests from Santa Rosa Island in 2010 (Table 1), and our mixing model results show that the adult from Verde Canyon consumed ~30% of this prey type while other adult and chicks on the NCI consumed <8% ungulates. Bald eagle primary and secondary feathers are molted in the late summer and early fall seasons, which overlapped with the fall elk and deer hunt on Santa Rosa Island during our study. Therefore, it is likely that this adult eagle from Verde Canyon was scavenging ungulate carcasses left by hunters, a common practice among trophy hunters on Santa Rosa Island. With the final transfer of Santa Rosa Island from private hands to the National Park Service in 2012, nearly all ungulates have been removed from the island and this source of prey is no longer available to bald eagles on the NCI.

The two bald eagles we sampled from the Middle Ranch nest on SCA had isotope values indicative of heavy reliance on terrestrial resources. Mixing model results show that the adult and chick consumed ~37% and 43% terrestrial mammals respectively; freshwater fish was also a major prey source accounting for ~25-30% of diet for each individual. Nest prey identifications and direct observation show that California ground squirrels (*Spermophilus beecheyi*) are the major terrestrial mammal prey source consumed by the breeding pair of eagles at Middle Ranch. The fish component of diet was not surprising as bald eagles commonly prefer a piscivorous diet when available (Stalmaster 1987), however, few published studies have documented consistent consumption of a small (300-600g) terrestrial mammal by a single individual or breeding pair of bald eagles. In addition to highlighting the diversity of prey consumed by bald eagles on the Channel Islands, this result shows that eagles are opportunistic generalists that can learn how to effectively hunt a wide variety of prey found in both marine and terrestrial habitats.

Influence of Recreational Fishing Activities on Channel Island Bald Eagle Diets

A combination of natural and anthropogenic factors may be responsible for the regional differences in bald eagle diets. First, recreational fishing could be an important factor in explaining the relatively high proportion of fish consumed by bald eagles on SCA relative to the NCI. As mentioned above, bald eagle nests on SCA contained a much more diverse assemblage of marine fish than that found in the NCI (Table 1 and Figure 1). Recreational fishermen in southern California target many of the fish species identified from SCA nests (Figure 5). For example, California sheephead (*Semicossyphus pulcher*) and kelp bass (*Paralabrax spp.*) are two nearshore fish prized by recreational fisherman but were not identified from the six bald eagle nests examined in the NCI. In addition, several species of small fish (wrasses, mackerel, sea chubs) were identified from SCA nests but not found in the NCI. Although it is possible that fish communities are more diverse and abundant in the waters off of SCA, it is likely that there is less overall recreational fishing pressure on NCI. While anecdotal and not rigorously quantified, observations by our team suggest that some eagles on SCA have learned to associate fishing boats with food and have been observed following vessels to collect discards thrown overboard. In essence, this anthropogenic resource represents a subsidy that may confer benefits for bald eagles, however, such behavior could also lead to habituation with detrimental costs, including entanglement in fishing gear and bycatch mortality.

Spatial differences in the relative availability of breeding seabirds may be another factor influencing the observed differences in bald eagle diets between SCA and the NCI. The number of breeding seabirds in the Southern California Bight has increased in recent decades (Table 6; Carter et al 1996, Newsome et al. 2010). Like other top marine consumers (e.g., California sea lions) that breed in the California Current, seabird productivity can vary significantly from one year to the next and is severely affected by El Niño Southern Oscillation events that negatively affect primary production in the region. Since state and federal protection and the ban of harmful contaminants (e.g., organochlorine pesticides), the number of breeding seabirds has steadily increased in southern California over the past four decades (Table 6). Today, the Channel Islands host 16 species of resident breeding seabirds, and at least as many seasonal migrants (e.g., loons, grebes, auklets, shearwaters, and fulmars) that breed in other parts of the North and South Pacific Ocean. Colonies of breeding seabirds are found on all of the Channel Islands, however, the largest and most productive colonies are on San Miguel (Prince Island), Santa Cruz, and Anacapa islands in the NCI (Table 6). Santa Barbara Island is also home to a diverse assemblage of breeding seabirds, however, bald eagles do not currently nest there and telemetry data show that bald eagles do *not* regularly visit this island. Estimated numbers of breeding seabirds exceed 55,000 individuals on the NCI, while a small fraction of that total (~300 seabirds) nest on SCA. Thus, higher availability of this resource could be responsible for the observed patterns in bald eagle diet between SCA and the NCI.

Comparison of Modern and Historic Diets of Bald Eagles on the Channel Islands

Our study of historic and prehistoric bald eagle diets on the Channel Islands (Newsome et al. 2010) provides an interesting contrast to the dietary patterns of modern eagles presented here. Note that $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ isotope patterns among seabirds and marine fish are similar in both historic and modern nests, and conform to expectations based on habitat preferences and differences in trophic level among these two prey types. As observed among the prey identified from recently active nests (Figure 3), marine fish sourced from historic nests on San Miguel, San Nicolas, and Santa Rosa Islands have higher $\delta^{13}\text{C}$ and lower $\delta^{15}\text{N}$ values than seabirds (Newsome et al. 2010, Newsome et al. unpublished data). For example, rockfish (-12.4 ± 1.4), surfperch (-10.8 ± 1.7), midshipman (-11.1 ± 0.3), and sheephead (-12.1 ± 1.1) have higher mean (\pm SD) $\delta^{13}\text{C}$ values by ~2–5‰ in comparison to seabirds sourced from the same historic eagle

nests. Nearly all historic and prehistoric bald eagles analyzed by Newsome et al. (2010) have trophic corrected $\delta^{13}\text{C}$ values that are lower than -14‰, but have $\delta^{15}\text{N}$ values (14–17‰) indicating that seabirds were the most important prey consumed by the population prior to local extirpation in the mid-20th century.

Prey remains from the four historic nests excavated on the Channel Islands also show a similar pattern with a much higher proportion of the diet comprised of birds (62.0%) compared to fish (27.8%). Also seabirds comprise a higher proportion of the historic diet of eagles on the NCI (68.8%) than on San Nicolas Island (35.8%) while fish were more important to eagles historically on San Nicolas Island (51.4%) than on the NCI (21.7%). Clearly, the availability of an abundant and diverse nesting seabird fauna on the NCI provides a readily available prey source for eagles to prey on during the nesting season both historically and today. The absence of an abundant nesting seabird fauna on Santa Catalina and San Nicolas islands could account for the lower abundance of birds in the eagle's diet both historically and today on these two islands.

Whether this pattern signifies a change in resource availability or a shift in dietary preferences for bald eagles on the Channel Islands is a matter of debate. Relative to today, both seabird and marine fish abundance in the archipelago are assumed to have been higher in the past, which likely supported a larger bald eagle population. Historic records support this inference. Currently, the islands support ~17 breeding pairs of bald eagles but historic (early 20th century) records suggest that at least 25 pairs nested across the archipelago in a single year, and ~50 nest sites were located by historic naturalists and egg collectors (Collins et al. unpublished data). For the historic bald eagle nest at Ferrelo Point on San Miguel Island, the diversity and numbers (MNI) of seabirds far exceeds that of marine fish (Collins et al. 2005, Erlandson et al. 2007, Newsome et al. 2010). It's possible that the regional differences in diet detected in our study of modern breeding eagles also existed in the past. Locating and excavating additional historic nests on the Channel Islands will be required to further explore regional variation in bald eagle diet. Our team has excavated historic bald eagle nests on San Miguel, Santa Rosa, and San Nicolas islands, however, given the estimated number of historic nests across the archipelago more nest sites likely exist and await discovery.

PRELIMINARY RECOMMENDATIONS

Based on our initial results, we offer the following management recommendations:

1) Periodically monitor bald eagle diets

Identifying the prey types preferred by the growing reintroduced bald eagle population is important to characterize both: (1) potential threats to their long-term viability on the Channel Islands and (2) impacts bald eagles may have on their prey, some of which is the focus of other conservation efforts. The results obtained here will provide a baseline of dietary information for the established, self-sustaining population. Bald eagles are generalists that consume prey in proportion to local availability, and dietary preferences may change as the eagle population continues to grow on Santa Catalina, Santa Rosa, and Santa Cruz islands and expand to other islands (e.g., San Clemente). Our preliminary results show that the diversity of prey changes from island to island. Some form of cost-effective annual monitoring would be ideal (e.g., stable isotope analysis or nestcam video), but intensive surveys that include nest collection and identification and perhaps stable isotope analysis of prey remains should be performed at regular intervals (3-5 years).

2) Determine contaminant loads of putative prey

Preliminary studies conducted by the USFWS and NPS, in combination with published data on contaminants in marine mammals in the Santa Barbara Channel (Blasius and Goodmanlowe 2008), show that several types of putative prey (e.g., seabirds and sea lions) available to eagles on the islands, especially the northern islands, have high contaminant (e.g., PCB, DDT) loads that may be harmful to eagles if consumed in high proportion. As eagles continue to expand their breeding range on the northern Channel Islands (e.g., San Miguel Island) where seabirds and sea lion carcasses are more abundant, contaminant issues may again become important factors in bald eagle management.

3) Monitor general prey availability and diversity

Our preliminary results show that marine fish are the most important prey for bald eagles currently breeding on the Channel Islands. As the resident eagle population continues to grow, dietary preferences may expand to include a larger proportion of seabirds, especially on the northern Channel Islands where greater numbers of seabirds breed. We recommend and encourage studies to assess seabird population trends on the northern Channel Islands.

REFERENCES

- Adkins, J.Y. and D.D. Roby. 2010. A status assessment of the Double-crested Cormorant (*Phalacrocorax auritus*) in Western North America: 1998-2009. Submitted to: U. S. Army Corps of Engineers Portland district, Portland, OR. 69 pp.
- Blasius, M.E., and G.D. Goodmanlowe. 2008. Contaminants still high in top-level carnivores in the Southern California Bight: levels of DDT and PCBs in resident and transient pinnipeds. *Marine Pollution Bulletin* 56:1973–1982.
- Buehler, D.A. 2000. Bald Eagle (*Haliaeetus leucocephalus*). In: A. Poole and F. Gill, editors. *The Birds of North America*, No. 506. The Birds of North America, Inc., Philadelphia, PA. 40 pp.
- Burkett, E.E., N.A. Rojek, A.E. Henry, M.J. Fluharty, L. Comrack, P.R. Kelly, A.C. Mahaney, and K.M. Fien. 2003. Report to the California Fish and Game Commission: Status Review of Xantus's Murrelet (*Synthliboramphus hypoleucus*) in California. California Department of Fish and Game, Habitat Conservation Planning Branch Status Report 2003-01. 96 pp.
- Capitolo, P.J., J.N. Davis, L. Henkel, W.B. Tyler, H.R. Carter, and P.R. Kelly. 2006. Aerial photographic surveys of breeding colonies of Brandt's, Double-crested, and Pelagic Cormorants in Southern California in 2005. Unpublished report, University of California, Institute of Marine Sciences, Santa Cruz, California. 25 p.
- Carter, H.R., G. J. McChesney, D.L. Jaques, C.S. Strong, M.W. Parker, J.E. Takekawa, D.L. Jory, and D.L. Whitworth. 1992. Breeding populations of seabirds in California, 1989-1991. Vols. 1 and 2. Unpublished draft final report, U.S. Fish and Wildlife Service, Northern Prairie Wildlife Research Center, Dixon, California. Report prepared for Minerals Management Service, Pacific OCS Region, Los Angeles, California.
- Carter, H. R., G. J. McChesney,, J. E. Takekawa, L. K. Ochikubo, D. L. Whitworth, T. W. Keeney, W. R. McIver, and C. S. Strong. 1996. Population monitoring of seabirds in California: 1993-1995 aerial photographic surveys of breeding colonies of Common Murres, Brandt's cormorants, and Double-crested Cormorants. Unpublished final report, U. S. Geological Survey, California Science Center, Dixon, California. 213 pp.
- Carter, H.R., D. Whitworth, P. Hebert, J. Koepke, P.J. Capitolo, G. McChesney, W. McIver, L. Ochikubo Chan, M. Pierson, A. Hebshi, and P. Martin. 2008. Status of breeding seabirds in the San Miguel Island group, California. Unpublished report, Carter Biological Consulting, Victoria, British Columbia; and California Institute of Environmental Studies, Davis, California. 131 p.
- Carter, H.R., D.L. Whitworth, W.R. McIver, G.J. McChesney, L.K. Ochikubo Chan, F. Gress, and P.N. Hebert. 2009. Status of the Xantus's Murrelet, Ashy Storm-Petrel, and Black Storm-Petrel at San Clemente Island, California. Unpublished report, Carter Biological Consulting, Victoria, British Columbia, and California Institute of Environmental Studies, Davis, California. 42 p.
- Carter, H.R., P.J. Capitolo, G.L. McChesney, D.L. Whitworth, W.R. McIver, and L.K. Ochikubo Chan. 2010. Breeding status of Brandt's Cormorant, Double-crested Cormorant, Pelagic Cormorant, Western Gull, and Black Oystercatcher at San Clemente Island, California. Unpublished report, Carter Biological Consulting, Victoria, British Columbia; University of California Institute of Environmental Studies, Davis, California. 41 p.

- Caut, S., E. Angulo, and F. Courchamp. 2009. Variation in discrimination factors ($\Delta^{15}\text{N}$ and $\Delta^{13}\text{C}$): the effect of diet isotopic values and applications for diet reconstruction. *Journal of Applied Ecology* 46: 443–453.
- Collins, P.W., D.A. Guthrie, T.C. Rick, and J.M. Erlandson. 2005. Analysis of prey remains excavated from an historic Bald Eagle nest site on San Miguel Island, California, Pp. 103-120. *In*: D. K. Garcelon and C. A. Schwemm, editors. *Proceedings of the Sixth California Islands Symposium*. Institute for Wildlife Studies and National Park Service, Arcata and Ventura, California.
- Craig, H. 1953. The geochemistry of the stable carbon isotopes. *Geochimica Cosmochimica Acta* 3:53–92.
- Erlandson, J.M., T.C. Rick, P.W. Collins, and D.A. Guthrie. 2007. Archaeological implications of a bald eagle nesting site at Ferrelo Point, San Miguel Island, California. *Journal of Archaeological Science* 34:255–271.
- Garcelon, D.K., S. Tomassi, D. Kristan, and D. Delaney. 1994a. Food habits of the Bald Eagles on Santa Catalina Island, November 1991-December 1992. Prepared for U. S. Fish and Wildlife Service, Damage Assessment Office, Sacramento, CA. 24 pp.
- Garcelon, D. K., J.S. Romsos, and P. Golightly. 1994b. Food habits of Bald Eagles on Santa Catalina Island, January-July 1993. Prepared for U. S. Fish and Wildlife Service, Damage Assessment Office, Sacramento, CA. 17 pp.
- Hunt, G.L., R.L. Pitman, and H.L. Jones. 1980. Distribution and abundance of seabirds breeding on the California Channel Islands. Pp. 443-459. *In*: D. M. Power, editor. *The California Islands: proceedings of a multidisciplinary symposium*. Santa Barbara Museum of Natural History, Santa Barbara, California.
- Kelly, J.F. 2000. Stable isotopes of carbon and nitrogen in the study of avian and mammalian trophic ecology. *Canadian Journal of Zoology* 78:1–27.
- Kiff, L.F. 1980. Historical Changes in Resident Populations of California Islands Raptors. Pp. 651-671. *In*: D. M. Power, editor. *The California Islands: proceedings of a multidisciplinary symposium*. Santa Barbara Museum of Natural History, Santa Barbara, California.
- Kiff, L.F. 2000. Further notes on historical Bald Eagle and Peregrine Falcon populations on the California Channel Islands. Unpublished manuscript. 43 pp.
- Koch, P.L. 2007. *In* *Stable Isotopes in Ecology and Environmental Science*, eds Michener R, Lajtha K (Blackwell Publishing, Boston), pp. 99–154.
- Mersmann, T.J., D.A. Buehler, J.D. Fraser, and J.K.D. Seeger. 1992. Techniques used in Bald Eagle food habits studies. *Journal of Wildlife Management* 56:73–78.
- Newsome, S.D., P.W. Collins, T.C. Rick, D.A. Guthrie, J.M. Erlandson, and M.L. Fogel. 2010. Pleistocene to historic shifts in bald eagle diets on the Channel Islands, California. *Proceedings of the National Academy of Sciences* 107:9246–9251.
- Page, H.M., D.C. Reed, M.A. Brzezinski, J.M. Melack, J.E. Dugan. 2008. Assessing the importance of land and marine sources of organic matter to kelp forest food webs. *Marine Ecology Progress Series* 360:47–62.

Parnell, A.C., R. Inger, S. Bearhop, and A.L. Jackson. 2010. Source partitioning using stable isotopes: coping with too much variation. *PLoS One* 5:e9672.

Rempel, J.A., Sharpe, P.B, Garcelon D.K. A stable isotope approach to understanding bald eagle diets on the California Channel Islands. Unpublished manuscript.

Rick, T.C., J.M. Erlandson, and R. Vellanoweth. 2001. Paleocoastal marine fishing on the Pacific Coast of the Americas: perspectives from Daisy Cave, California. *American Antiquity* 66:595–614.

Sharpe, P.B., and D.K. Garcelon. 1999. Analysis of the Potential Diet of Bald Eagles Reintroduced to Santa Cruz and Anacapa Islands, California. Report prepared for the U. S. Fish and Wildlife Service, Sacramento, California. 16 pp.

Sowls, A.L., A.R. DeGange, J.W. Nelson, and G.S. Lester. 1980. Catalog of California seabird colonies. U. S. Fish and Wildlife Service, Biological Services Program, FWS/OBS 37/80.

Stalmaster, M.V. 1987. *The bald eagle*. Universe Books, New York.

Suits, N.S., A.S. Denning, J.A. Berry, C.J. Still, J. Kaduk, J.B. Miller, and I.T. Baker. 2005. Simulation of carbon isotope discrimination of the terrestrial biosphere. *Global Biogeochemical Cycles* 19:GB1017.

United States Fish and Wildlife Service. 2009. Endangered and Threatened Wildlife and Plants; 12 Month Finding on a Petition to list the Ashy Storm-Petrel as Threatened or Endangered. *Federal Register* 74(159):41832-41860.

Vanderklift, M.A., and S. Ponsard. 2003. Sources of variation in consumer-diet $\delta^{15}\text{N}$ enrichment: a meta-analysis. *Oecologia* 136:169–182.

Whitworth, D.L., H.R. Carter, R.J. Young, J.S. Koepke, F. Gress, and S. Fangman. 2005. Initial recovery of Xantus's Murrelets following rat eradication on Anacapa Island, California. *Marine Ornithology* 33:131–137.

Whitworth, D.L., H.R. Carter, T.M. Dvorak, L.S. Farley, and J.L. King. 2013. Status, distribution, and conservation of Scripps's Murrelet at Santa Catalina Island, California. *Western North American Naturalist* (In review).

Table 1. Quantification of animal remains found in bald eagle nests on the Channel Islands grouped by region: Santa Catalina Island and the Northern Channel Islands: Santa Rosa, Santa Cruz, and West Anacapa Islands. Data are presented as the minimum number of individuals (MNI) with the number of identifiable specimens (NISP) in parentheses. The percent MNI relative to other prey types in a general taxonomic group (fish, birds, mammals) is also provided.

Table 2. Quantification of animal remains found in historic bald eagle nests on the Channel Islands grouped by region: San Nicolas Island and the Northern Channel Islands: Santa Rosa and San Miguel. Data are presented as the minimum number of individuals (MNI) with the number of identifiable specimens (NISP) in parentheses. The percent MNI relative to all other prey types is also provided.

Table 3. Mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of major prey types (MNI >10) identified from bald eagle nests on the Channel Islands; numbers in parentheses adjacent to isotope values represent standard deviation (SD). When adequate sample sizes were available, prey types were grouped into two regions: Santa Catalina Island and Northern Channel Islands (Santa Cruz, Santa Rosa, and West Anacapa Islands). Archipelago columns present mean and associated SD values averaged across all islands from both regions. Numbers in parentheses adjacent to species represent sample sizes across all islands. An asterisk denotes that mean values were calculated from specimens collected on both Santa Catalina Island and the Northern Channel Islands due to low sample sizes.

Table 4. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of feather and whole blood samples collected from bald eagle chicks on Santa Rosa (2 nests), Santa Catalina (9 nests), Santa Cruz (3 nests), and West Anacapa (1 nest) in 2010 and 2011. Chick feathers were collected during annual banding efforts in the spring of each year. An asterisk denotes a significant positive mean ($\pm\text{SD}$) $\delta^{13}\text{C}$ tissue-specific discrimination between feather and blood ($\Delta^{13}\text{C}_{\text{feather-blood}}$) of $+1.7\pm 0.5$; the mean difference in $\delta^{15}\text{N}$ between these tissues is not significantly different than zero.

Table 5. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of adult bald eagle primary feathers (16) opportunistically collected from nests and adjacent perches on Santa Rosa (2 nests), Santa Catalina (9 nests) and Santa Cruz (3 nests) in 2010 and 2011. Isotope values are mean values of three separate analyses corresponding to sub-samples collected at the base, mid-shaft, and tip of a single primary feather; numbers in parentheses represent SD. Asterisks denote feathers collected from the same nest that may belong to the same individual or could derive from different individuals in the same pair assuming similarity in diet between pair members.

Table 6. Estimates of population size and diversity of seabirds breeding on the Northern Channel Islands and Santa Catalina Island; P = present and possibly breeding, E = Breeding population extinct. Estimates based on Carter et al (1992) unless otherwise noted: ^aAdkins and Roby (2010); ^bBurkett et al. (2003); ^cCapitolo et al. (2006); ^dCarter et al. (2008); ^eNorth American Birds 65:341; ^fUnpublished source; ^gUSFWS (2009); ^hWhitworth et al. (2005); ⁱWhitworth et al. (2013)

TABLE 1

| Common Name (Scientific Name) | Santa Catalina Island | | Northern Channel Islands | | All Modern Nests | |
|--------------------------------------|--------------------------|-------------|-----------------------------|-------------|-------------------|-------------|
| | MNI (NISP) | %MNI | MNI (NISP) | %MNI | MNI (NISP) | %MNI |
| FISH | | | | | | |
| Rockfish (Scorpaenidae) | 78 (827) | 38.0 | 15 (420) | 18.1 | 93 (1247) | 32.3 |
| Toadfishes (Batrachoididae) | 14 (75) | 6.8 | 41 (184) | 49.4 | 55 (259) | 19.1 |
| Flyingfish (Exocoetidae) | 45 (252) | 22.0 | | | 45 (252) | 15.6 |
| Surfperches (Embiotocidae) | 13 (54) | 6.3 | 22 (459) | 26.5 | 35 (513) | 12.2 |
| Sea Basses (Serranidae) | 17 (161) | 8.3 | | | 17 (161) | 5.9 |
| Sunfishes & Basses (Centrarchidae) | 8 (175) | 3.9 | | | 8 (175) | 2.8 |
| Wrasses (Labridae) | 7 (22) | 3.4 | 1 (1) | 1.2 | 8 (23) | 2.8 |
| Croakers (Sciaenidae) | 6 (20) | 2.9 | | | 6 (20) | 2.1 |
| Sea Chubs (Kyphosidae) | 5 (16) | 2.4 | | | 5 (16) | 1.7 |
| Tunas & Mackerels (Scombridae) | 4 (42) | 2.0 | | | 4 (42) | 1.4 |
| Flounders (Bothidae) | 3 (39) | 1.5 | 1 (75) | 1.2 | 4 (114) | 1.4 |
| Cat Sharks (Scyliorhinidae) | | | 2 (2) | 2.4 | 2 (2) | 0.7 |
| Thornbacks (Platyrrhinidae) | 1 (1) | 0.5 | | | 1 (1) | 0.3 |
| Smoothhounds (Traikididae) | 1 (65) | 0.5 | | | 1 (65) | 0.3 |
| Stingrays (Dasyatidae) | 1 (1) | 0.5 | | | 1 (1) | 0.3 |
| Morays (Meraenidae) | 1 (2) | 0.5 | | | 1 (2) | 0.3 |
| Silversides (Atherinidae) | | | 1 (25) | 1.2 | 1 (25) | 0.3 |
| Damselfishes (Pomacentridae) | 1 (2) | 0.5 | | | 1 (2) | 0.3 |
| Unidentified Fish | (905) | | (160) | | (1065) | |
| FISH TOTAL | 205 (2659) | 54.2 | 83 (1326) | 42.1 | 288 (3985) | 50.1 |
| BIRDS | | | | | | |
| Gulls (Laridae) | 45 (257) | 33.1 | 31 (326) | 29.2 | 76 (583) | 31.4 |
| Cormorants (Phalacrocoracidae) | 18 (166) | 13.2 | 30 (364) | 28.3 | 48 (530) | 19.8 |
| Alcids (Alcidae) | 19 (180) | 14.0 | 21 (268) | 19.8 | 40 (448) | 16.5 |
| Fulmars/Shearwaters (Procellariidae) | 29 (211) | 21.3 | 8 (176) | 7.5 | 37 (387) | 15.3 |
| Ducks/Geese (Anatidae) | 8 (49) | 5.9 | 5 (13) | 4.7 | 13 (62) | 5.4 |
| Corvids (Corvidae) | 6 (36) | 4.4 | 1 (21) | 0.9 | 7 (57) | 2.9 |
| Grebes (Podicipedidae) | 6 (35) | 4.4 | 2 (2) | 1.9 | 8 (37) | 3.3 |
| Loons (Gaviidae) | 3 (4) | 2.2 | 3 (15) | 2.8 | 6 (19) | 2.5 |
| Pelicans (Pelicanidae) | | | 3 (49) | 2.8 | 3 (49) | 1.2 |
| Shorebirds (Charadriidae) | 1 (1) | 0.7 | 1 (42) | 0.9 | 2 (43) | 0.8 |
| Storm-Petrel (Hydrobatidae) | 1 (1) | 0.7 | | | 1 (1) | 0.4 |
| Tropicbirds (Phaethontidae) | | | 1 (2) | 0.9 | 1 (2) | 0.4 |
| Unidentified Bird | (147) | | (99) | | (246) | |
| BIRDS TOTAL | 136 (1096) | 36.0 | 106 (1087) | 53.8 | 242 (2464) | 42.1 |
| MAMMALS | | | | | | |
| Deer & Elk (Cervidae) | 14 (19) | 37.8 | 5 (12) | 62.5 | 19 (31) | 42.2 |
| Ground Squirrels (Scuridae) | 10 (22) | 27.0 | | | 10 (22) | 22.2 |
| Eared Seals (Otariidae) | 6 (16) | 16.2 | 1 (2) | 12.5 | 7 (18) | 15.6 |
| Rats & Mice (Muridae) | 4 (6) | 10.8 | | | 4 (6) | 8.9 |
| Island Foxes (Canidae) | 1 (6) | 2.7 | 1 (4) | 12.5 | 2 (10) | 4.4 |
| True Seals (Phocidae) | 1 (3) | 2.7 | | | 1 (3) | 2.2 |
| Spotted Skunks (Mephitidae) | | | 1 (1) | 12.5 | 1 (1) | 2.2 |
| Cattle/Sheep/Goats (Bovidae) | 1 (1) | 2.7 | | | 1 (1) | 2.2 |
| Unidentified Mammal | (5) | | | | (5) | |
| MAMMAL TOTAL | 37 (78) | 9.8 | 8 (19) | 4.1 | 45 (97) | 7.8 |
| GRAND TOTAL | 378 (3835) | 100 | 198 (2741) | 100 | 576 (6546) | 100 |

TABLE 2

| Common Name (Scientific Name) | San Nicolas Island | | Northern Channel Islands | | All Historic Nests | |
|--------------------------------------|--------------------|-------------|-----------------------------|-------------|--------------------|-------------|
| | MNI (NISP) | %MNI | MNI (NISP) | %MNI | MNI (NISP) | %MNI |
| FISH | | | | | | |
| Rockfish (Scorpaenidae) | 12 (196) | 11.0 | 45 (1012) | 10.6 | 57 (1208) | 10.7 |
| Toadfishes (Batrachoididae) | 31 (57) | 28.4 | 5 (94) | 1.2 | 36 (151) | 6.8 |
| Flyingfish (Exocoetidae) | — | — | — | — | — | — |
| Surfperches (Embiotocidae) | 7 (177) | 6.4 | 24 (449) | 5.7 | 31 (626) | 5.8 |
| Sea Basses (Serranidae) | — | — | — | — | — | — |
| Sunfishes & Basses (Centrarchidae) | — | — | — | — | — | — |
| Wrasses (Labridae) | 3 (24) | 2.8 | 3 (55) | 0.7 | 6 (79) | 1.1 |
| Croakers (Sciaenidae) | — | — | — | — | — | — |
| Sea Chubs (Kyphosidae) | — | — | — | — | — | — |
| Tunas & Mackerels (Scombridae) | — | — | 1 (2) | 0.2 | 1 (2) | 0.2 |
| Flounders (Bothidae) | — | — | — | — | — | — |
| Cat Sharks (Scyliorhinidae) | — | — | — | — | — | — |
| Thornbacks (Platyrrhinidae) | — | — | — | — | — | — |
| Smoothhounds (Traikidae) | — | — | — | — | — | — |
| Stingrays (Dasyatidae) | — | — | — | — | — | — |
| Morays (Meraenidae) | — | — | — | — | — | — |
| Silversides (Atherinidae) | — | — | 1 (11) | 0.2 | 1 (11) | 0.2 |
| Damselfishes (Pomacentridae) | — | — | — | — | — | — |
| Herring (Clupeidae) | 1 (19) | 0.9 | 2 (4) | 0.5 | 3 (23) | 0.6 |
| Sculpins (Cottidae) | 1 (1) | 0.9 | 7 (101) | 1.7 | 8 (102) | 1.5 |
| Kelpfish (Clinidae) | — | — | 1 (12) | 0.2 | 1 (12) | 0.2 |
| Pricklebacks (Stichaeidae) | — | — | 1 (44) | 0.2 | 1 (44) | 0.2 |
| Hake (Merlucciidae) | 1 (13) | 0.9 | 2 (13) | 0.5 | 3 (26) | 0.6 |
| Unidentified Fish | 902 | — | 2257 | — | 3159 | — |
| FISH TOTAL | 56 (1389) | 51.4 | 92 (4054) | 21.7 | 148 (5443) | 27.8 |
| BIRDS | | | | | | |
| Gulls (Laridae) | 6 (27) | 5.5 | 33 (298) | 7.8 | 39 (325) | 7.3 |
| Cormorants (Phalacrocoracidae) | 7 (90) | 6.4 | 49 (760) | 11.6 | 56 (850) | 10.5 |
| Alcids (Alcidae) | 11 (73) | 10.1 | 94 (959) | 22.2 | 105 (1032) | 19.7 |
| Fulmars/Shearwaters (Procellariidae) | 5 (14) | 4.6 | 36 (404) | 8.5 | 41 (418) | 7.7 |
| Ducks/Geese (Anatidae) | 5 (41) | 4.6 | 45 (580) | 10.6 | 50 (621) | 9.4 |
| Corvids (Corvidae) | — | — | 3 (23) | 0.7 | 3 (24) | 0.6 |
| Grebes (Podicipedidae) | 1 (8) | 0.9 | 14 (124) | 3.3 | 15 (132) | 2.8 |
| Loons (Gavidae) | — | — | 7 (75) | 1.7 | 7 (75) | 1.3 |
| Pelicans (Pelicanidae) | 1 (2) | 0.9 | — | — | 1 (2) | 0.2 |
| Shorebirds (Charadriidae) | 2 (2) | 1.8 | 6 (15) | 1.4 | 8 (17) | 1.5 |
| Storm-Petrels (Hydrobatidae) | — | — | 3 (4) | 0.7 | 3 (4) | 0.6 |
| Tropicbirds (Phaethontidae) | — | — | — | — | — | — |
| Albatrosses (Diomedidae) | 1 (1) | 0.9 | — | — | 1 (1) | 0.2 |
| Hérons/Egrets (Ardeidae) | — | — | 1 (3) | 0.2 | 1 (3) | 0.2 |
| Unidentified Bird | 594 | — | 1969 | — | 2563 | — |
| BIRDS TOTAL | 39 (852) | 35.8 | 291 (5214) | 68.8 | 330 (6066) | 62.0 |
| MAMMALS | | | | | | |
| Deer & Elk (Cervidae) | — | — | 2 (5) | 0.5 | 2 (5) | 0.4 |
| Ground Squirrels (Scuridae) | — | — | — | — | — | — |
| Eared Seals (Otariidae) | 1 (2) | 0.9 | 3 (27) | 0.7 | 4 (29) | 0.8 |
| Rats & Mice (Muridae) | 2 (7) | 1.8 | 16 (88) | 3.8 | 18 (95) | 3.4 |
| Island Foxes (Canidae) | 2 (8) | 1.8 | 3 (11) | 0.7 | 5 (19) | 0.9 |
| True Seals (Phocidae) | — | — | 1 (5) | 0.2 | 1 (5) | 0.2 |
| Spotted Skunks (Mephitidae) | — | — | — | — | — | — |
| Cattle/Sheep/Goats (Bovidae) | 9 (155) | 8.3 | 15 (330) | 3.5 | 24 (485) | 4.5 |
| Unidentified Mammal | — | — | 11 | — | 11 | — |
| MAMMAL TOTAL | 14 (172) | 12.8 | 40 (477) | 9.5 | 54 (649) | 10.2 |
| GRAND TOTAL | 109 (2413) | 100 | 423 (9745) | 100 | 532 (12158) | 100 |

TABLE 3

| Prey Type | Family/Genus/Species | Santa Catalina Island | | | Northern Channel Islands | | | All Islands | | |
|-----------------------------|--|-----------------------|-----------------------|-----------------------|--------------------------|-----------------------|-----------------------|-------------|-----------------------|-----------------------|
| | | <i>n</i> | $\delta^{13}\text{C}$ | $\delta^{15}\text{N}$ | <i>n</i> | $\delta^{13}\text{C}$ | $\delta^{15}\text{N}$ | <i>n</i> | $\delta^{13}\text{C}$ | $\delta^{15}\text{N}$ |
| Ungulates | Mule Deer, <i>Odocoileus hemionus</i> (30) Elk, <i>Cervus canadensis</i> (16) | 12 | -21.4 (1.8) | 5.7 (1.7) | 34 | -21.7 (1.0) | 7.2 (1.5) | 46 | -21.6 (1.3) | 6.8 (1.7) |
| Rodents | California Ground Squirrel <i>Spermophilus beechi</i> (9) Black Rat, <i>Rattus rattus</i> (4) | 13 | -20.7 (1.6) | 6.2 (2.3) | – | – | – | – | – | – |
| Cormorants | Brandt's Cormorant, <i>Phalacrocorax penicillatus</i> (33) Pelagic Cormorant, <i>Phalacrocorax pelagicus</i> (18) Double-Crested Cormorant, <i>Phalacrocorax auritus</i> (1) | 18 | -14.5 (1.1) | 16.4 (1.0) | 34 | -14.6 (1.1) | 16.2 (1.2) | 52 | -14.6 (1.1) | 16.3 (1.1) |
| Gulls | Western Gull, <i>Larus occidentalis</i> (46) California Gull, <i>Larus californicus</i> (14) American Herring Gull, <i>Larus smithsonianus</i> (5) Heermann's Gull, <i>Larus heermanni</i> (3) Glaucous-Winged Gull, <i>Larus glaucescens</i> (2) Mew Gull, <i>Larus canus</i> (2) Black-Legged Kittiwake, <i>Rissa tridactyla</i> (1) | 39 | -15.2 (1.0) | 16.7 (1.6) | 34 | -14.9 (1.2) | 16.3 (1.2) | 73 | -15.0 (1.1) | 16.5 (1.4) |
| Shearwaters Fulmars | Sooty Shearwater, <i>Puffinus griseus</i> (17) Pink-Footed Shearwater <i>Puffinus creatopus</i> (11) Northern Fulmar, <i>Fulmarus glacialis</i> (9) Short-Tailed Shearwater, <i>Puffinus tenuirostris</i> (2) Black-Vented Shearwater, <i>Puffinus opisthomelas</i> (1) | 33 | -16.4 (1.3) | 15.6 (1.6) | 7 | -15.6 (1.5) | 15.5 (2.2) | 40 | -16.3 (1.4) | 15.6 (1.7) |
| Alcids | Common Murre, <i>Uria aalge</i> (13) Rhinoceros Auklet, <i>Cerorhinca monocerata</i> (11) Cassin's Auklet, <i>Ptychoramphus aleuticus</i> (9) Pigeon Guillemot, <i>Cepphus Columba</i> (3) Tufted Puffin, <i>Fratercula cirrhata</i> (1) | 18 | -15.9 (0.9) | 16.6 (1.0) | 19 | -14.7 (0.7) | 17.3 (0.8) | 37 | -15.3 (1.0) | 17.0 (0.9) |
| Wrasses (Large) | California Sheephead, <i>Semicossyphus pulcher</i> | 6 | -14.6 (0.8) | 14.2 (1.2) | – | – | – | – | – | – |
| Rockfish | Unidentified, <i>Sebastes</i> spp. | 66 | -14.4 (0.9) | 16.1 (0.6) | 13 | -12.3 (0.7) | 14.6 (0.7) | 79 | -14.1 (1.2) | 15.9 (0.8) |
| Sea Basses | Kelp Bass, <i>Paralabrax clathratus</i> (13) Barred Sand Bass, <i>Paralabrax nebulifer</i> (1) | 14 | -14.3 (1.2) | 15.5 (0.8) | – | – | – | – | – | – |
| Surfperch | Unidentified, Embiotocidae (25) Pile Surfperch, <i>Damalichthys vacca</i> (9) Black Surfperch, <i>Embiotoca jacksoni</i> (7) | 12 | -14.6 (1.1) | 14.3 (0.9) | 29 | -12.4 (1.3) | 13.7 (0.5) | 41 | -13.1 (1.6) | 13.9 (0.7) |
| Midshipman | Unidentified, <i>Porichthys</i> spp. (5) Specklefin Midshipman, <i>Porichthys myriaster</i> (4) Plainfin Midshipman, <i>Porichthys notatus</i> (4) | 8 | -15.8 (1.2) | 16.1 (1.2) | 5 | -15.3 (0.6) | 15.2 (0.7) | 13 | -15.6 (1.0) | 15.7 (1.1) |
| Flying Fish | California Flying Fish, <i>Cypselurus californicus</i> | 32 | -17.0 (0.7) | 13.2 (1.1) | – | – | – | – | – | – |
| Miscellaneous Small Fish | Sea Chub, Kyphosidae (5) Mackerels & Tunas, Scrombridae (4) | 11 | -15.2 (1.5) | 14.3 (1.3) | – | – | – | – | – | – |

TABLE 4

| Sample ID | Sex | Island | Nest | Year | Feather | | Blood | | Feather–Blood | |
|-----------|-----|----------------|----------------|------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| | | | | | $\delta^{13}\text{C}$ | $\delta^{15}\text{N}$ | $\delta^{13}\text{C}$ | $\delta^{15}\text{N}$ | $\Delta^{13}\text{C}$ | $\Delta^{15}\text{N}$ |
| 679-03445 | M | Santa Catalina | Middle Ranch | 2010 | -22.1 | 10.5 | -24.4 | 8.6 | 2.3 | 1.8 |
| 679-03439 | F | Santa Catalina | Pinnacle Rock | 2010 | -16.2 | 16.7 | -17.9 | 16.3 | 1.7 | 0.4 |
| 679-03437 | F | Santa Catalina | Rattlesnake | 2010 | -18.0 | 14.7 | -19.1 | 15.0 | 1.1 | -0.3 |
| 679-03438 | M | Santa Catalina | Rattlesnake | 2010 | -17.1 | 16.2 | -19.4 | 14.6 | 2.4 | 1.6 |
| 679-04105 | M | Santa Catalina | Rattlesnake | 2011 | -18.4 | 15.1 | -19.6 | 15.4 | 1.2 | -0.3 |
| 679-04104 | F | Santa Catalina | Rattlesnake | 2011 | -17.7 | 15.9 | -20.1 | 14.7 | 2.4 | 1.2 |
| 679-03431 | F | Santa Catalina | Seal Rocks | 2010 | -16.7 | 17.0 | -18.2 | 16.5 | 1.5 | 0.5 |
| 679-04103 | M | Santa Catalina | Seal Rocks | 2011 | -16.3 | 18.3 | -18.3 | 17.0 | 2.0 | 1.3 |
| 679-04102 | F | Santa Catalina | Seal Rocks | 2011 | -16.7 | 17.2 | -18.1 | 16.9 | 1.4 | 0.3 |
| 629-52435 | M | Santa Catalina | Seal Rocks | 2011 | -15.5 | 17.5 | – | – | – | – |
| 679-03434 | M | Santa Catalina | Two Harbors | 2010 | -16.9 | 16.3 | -17.9 | 16.1 | 1.0 | 0.2 |
| 679-03433 | F | Santa Catalina | Two Harbors | 2010 | -16.2 | 16.6 | – | – | – | – |
| 679-04101 | F | Santa Catalina | Two Harbors | 2011 | -16.3 | 17.3 | -17.9 | 16.9 | 1.6 | 0.4 |
| 679-03441 | M | Santa Catalina | West End | 2010 | -16.6 | 16.9 | -18.1 | 16.5 | 1.5 | 0.4 |
| 679-03442 | M | Santa Catalina | West End | 2010 | -16.3 | 16.8 | -18.1 | 16.3 | 1.7 | 0.5 |
| 679-04108 | M | Santa Catalina | West End | 2011 | -17.7 | 16.3 | -18.8 | 16.4 | 1.1 | -0.1 |
| 679-04107 | M | Santa Catalina | West End | 2011 | -17.0 | 16.9 | -18.6 | 16.8 | 1.6 | 0.1 |
| 679-04106 | F | Santa Catalina | West End | 2011 | – | – | -18.4 | 16.7 | – | – |
| 679-03444 | M | Santa Cruz | Cueva Valdez | 2010 | -15.2 | 16.8 | -17.0 | 15.8 | 1.7 | 1.0 |
| 679-04112 | F | Santa Cruz | Cueva Valdez | 2011 | -15.6 | 17.1 | -17.0 | 16.6 | 1.4 | 0.5 |
| 679-03435 | M | Santa Cruz | Pelican Harbor | 2010 | -15.8 | 16.7 | -16.9 | 16.2 | 1.1 | 0.6 |
| 679-03436 | M | Santa Cruz | Pelican Harbor | 2010 | -15.5 | 16.7 | -17.0 | 16.1 | 1.5 | 0.6 |
| 679-04110 | F | Santa Cruz | Pelican Harbor | 2011 | -14.8 | 17.3 | -16.6 | 16.8 | 1.8 | 0.5 |
| 679-03443 | F | Santa Cruz | Sauces | 2010 | -15.2 | 16.6 | -17.4 | 15.8 | 2.3 | 0.8 |
| 679-04109 | M | Santa Cruz | Sauces | 2011 | -15.0 | 17.3 | -16.7 | 16.7 | 1.7 | 0.6 |
| 679-03440 | F | Santa Rosa | Lopez Canyon | 2010 | -14.1 | 17.6 | -16.4 | 16.3 | 2.3 | 1.3 |
| 679-03432 | M | Santa Rosa | Verde Canyon | 2010 | -14.2 | 17.3 | -16.0 | 16.4 | 1.8 | 0.9 |
| 679-04111 | M | West Anacapa | Oak Canyon | 2011 | -15.3 | 17.5 | -18.3 | 16.6 | 3.0 | 0.9 |
| | | | | | | | MEAN (SD) | 1.7 (0.5)* | 0.6 (0.5) | |

TABLE 5

| Sample ID | Island | Nest | Year | $\delta^{13}\text{C}$ | $\delta^{15}\text{N}$ |
|--------------|----------------|---------------------------|------|-----------------------|-----------------------|
| SCAT-MRN | Santa Catalina | Middle Ranch (Nest) | 2010 | -20.9 (0.2) | 12.4 (0.7) |
| SCAT-NSRP | Santa Catalina | New Seal Rocks (Perch) | 2010 | -16.2 (0.8) | 16.8 (0.3) |
| SCAT-NTRN | Santa Catalina | New Twin Rocks (Nest) | 2010 | -15.2 (0.3) | 17.6 (0.2) |
| SCAT-OSRN | Santa Catalina | Old Seal Rocks (Nest) | 2010 | -15.3 (0.3) | 16.7 (0.1) |
| SCAT-PRN | Santa Catalina | Pinnacle Rocks (Nest) | 2010 | -16.0 (0.3) | 17.2 (0.4) |
| SCAT-RSP | Santa Catalina | Rattlesnake (Perch) | 2010 | -16.2 (0.2) | 17.1 (0.3) |
| SCAT-THP* | Santa Catalina | Two Harbors (Perch) | 2010 | -15.5 (0.7) | 17.6 (0.3) |
| SCAT-THN* | Santa Catalina | Two Harbors (Nest) | 2010 | -15.7 (0.2) | 17.4 (0.2) |
| SCAT-WEP* | Santa Catalina | West End (Perch) | 2010 | -15.2 (0.3) | 17.9 (0.2) |
| SCAT-WEN* | Santa Catalina | West End (Nest) | 2010 | -15.5 (0.6) | 17.7 (0.3) |
| SCI-PB (New) | Santa Cruz | New Pelican Harbor (Nest) | 2011 | -15.0 (0.8) | 18.4 (0.2) |
| SCI-PB (Old) | Santa Cruz | Old Pelican Harbor (Nest) | 2011 | -15.4 (0.1) | 18.0 (0.3) |
| SRI-LCN | Santa Rosa | Lopez Canyon (Nest) | 2010 | -15.2 (0.6) | 17.4 (0.1) |
| SRI-GCEP | Santa Rosa | Verde Canyon (East Perch) | 2010 | -17.0 (0.6) | 15.4 (0.7) |
| SRI-GCWP* | Santa Rosa | Verde Canyon (West Perch) | 2010 | -14.1 (0.5) | 17.5 (0.2) |
| SRI-GCN* | Santa Rosa | Verde Canyon (East Perch) | 2010 | -14.5 (0.5) | 17.5 (0.3) |

TABLE 6

| Species | Northern Channel Islands | | | | Santa Catalina Island |
|---|-----------------------------------|------------|----------------------|-----------------------|-----------------------|
| | San Miguel | Santa Rosa | Santa Cruz | Anacapa | |
| Leach's Storm-Petrel (<i>Oceanodroma leucorhoa</i>) | 114 | | | | |
| Ashy Storm-Petrel (<i>Oceanodroma homochroa</i>) | 1,354 | | 323 ^g | 2 ^f | |
| Black Storm-Petrel (<i>Oceanodroma melania</i>) | P | | | | |
| Double-Crested Cormorant (<i>Phalacrocorax auritus</i>) | 552 | | 16 ^c | 764 ^a | |
| Brandt's Cormorant (<i>Phalacrocorax penicillatus</i>) | 15,700 | 4,650 | 3,140 | 485 ^c | |
| Pelagic Cormorant (<i>Phalacrocorax pelagicus</i>) | 691 | 1,162 | 460 | 328 | |
| Brown Pelican (<i>Pelecanus occidentalis</i>) | 204 ^d | | E | 10,680 | |
| Western Gull (<i>Larus occidentalis</i>) | 1,892 | 170 | 1,236 | 10,274 | 156 |
| Caspian Tern (<i>Hydroprogne caspia</i>) | | | | | 8-10 ^g |
| Common Murre (<i>Uria aalge</i>) | 70 ^e -125 ^f | | | | |
| Pigeon Guillemot (<i>Cepphus columba</i>) | 1,114 | 287 | 1,459 | 74 | |
| Scripps's Murrelet (<i>Synthliboramphus scrippsi</i>) | 100-600 | | 200-600 ^b | 400-1200 ^b | 110-160 ⁱ |
| Guadalupe Murrelet (<i>Synthliboramphus hypoleucus</i>) | | | | | |
| Cassin's Auklet (<i>Ptychoramphus aleuticus</i>) | 11,584 | | 736 | 4 ^h | |
| Rhinoceros Auklet (<i>Cerorhinca monocerata</i>) | 19 ^d | | | | |
| Tufted Puffin (<i>Fratercula cirrhata</i>) | 4-10 ^e | | | | |
| Total Number of Breeding Species | 13-14 | 4 | 8 | 9 | 3 |
| Total Number of Breeding Individuals | 33,959 | 6,269 | 7,970 | 23,811 | 274-326 |

Figure 1. Relative proportion of major prey types identified from bald eagle nests on Santa Catalina Island (A) and the Northern Channel Islands (B) based on the minimum number of individuals (MNI). MNI frequency distributions presenting the diversity of marine fish (C) and seabirds (D) identified at the family level found in Santa Catalina Island (gray bars) and Northern Channel Island (black bars) bald eagle nests. Freshwater fish (Centrarchidae) from Santa Catalina Island (MNI=8) are not shown.

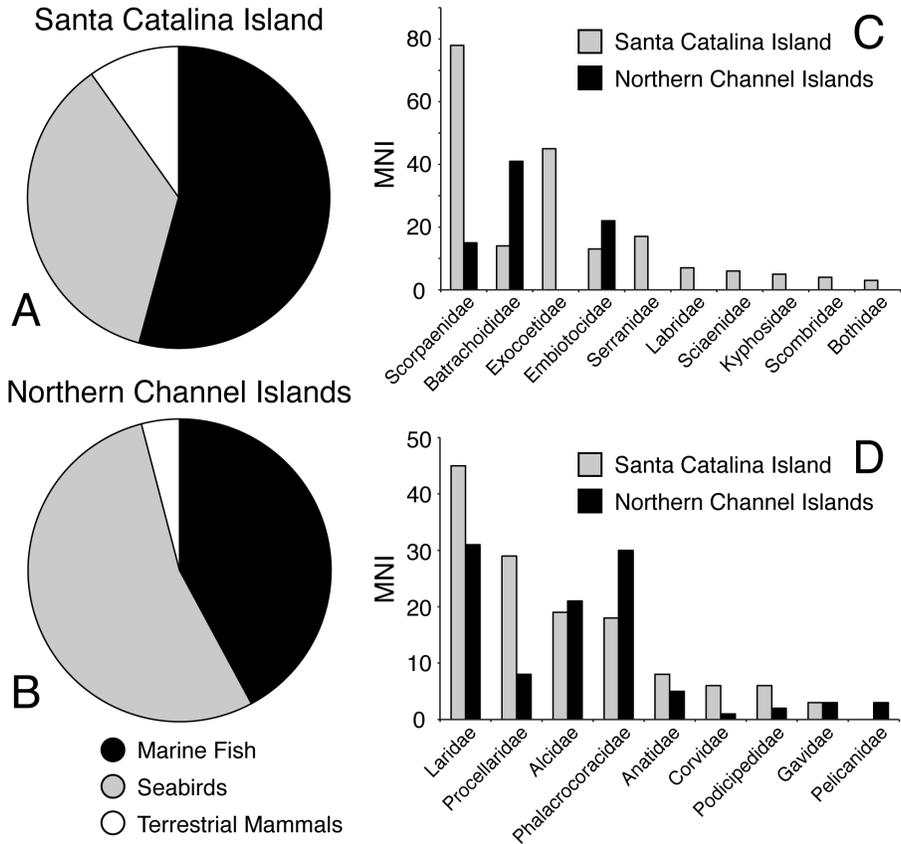


Figure 2. Relative proportion of major prey types identified from historic bald eagle nests on San Nicolas Island (A) and the Northern Channel Islands (B) based on the minimum number of individuals (MNI). MNI frequency distributions presenting the diversity of marine fish (C) and seabirds (D) identified at the family level found in San Nicolas Island (gray bars) and Northern Channel Island (black bars) bald eagle nests.

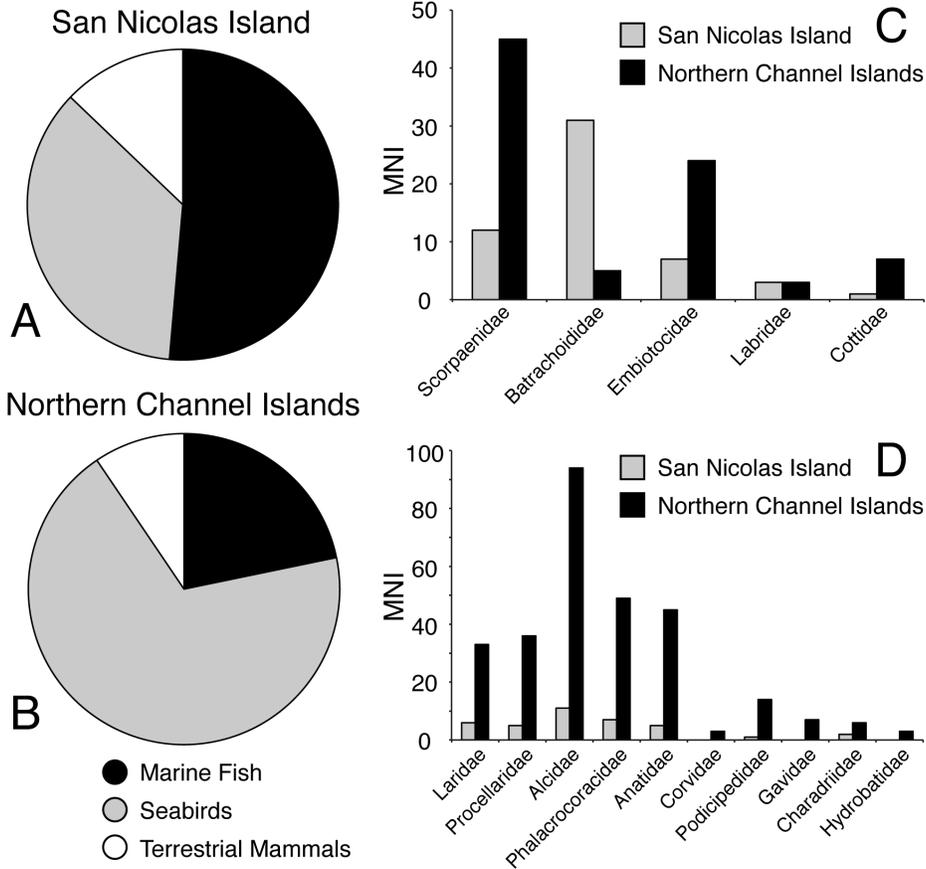


Figure 3. Carbon ($\delta^{13}\text{C}$) versus nitrogen ($\delta^{15}\text{N}$) bivariate plots of bald eagles and their potential prey collected from Santa Catalina Island (A) and the Northern Channel Islands (B). Prey ellipses represent standard deviation. Small fish include species belonging to the families Kyphosidae, Scrombridae, and Labridae (Table 4). Bald eagle adult isotope values have been corrected for trophic and tissue-specific discrimination by adding 1‰ and subtracting 3‰ to/from measured feather $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values. Bald eagle chick isotope values have been corrected for trophic and tissue-specific discrimination by adding 1‰ and subtracting 2‰ to/from measured feather $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values. See text for more details regarding isotopic discrimination. For eagles that consume a relatively high proportion of terrestrial resources, the nests of origin are labeled: Middle Ranch (MR) on Santa Catalina Island and Verde Canyone (SRI-VC) on Santa Rosa Island.

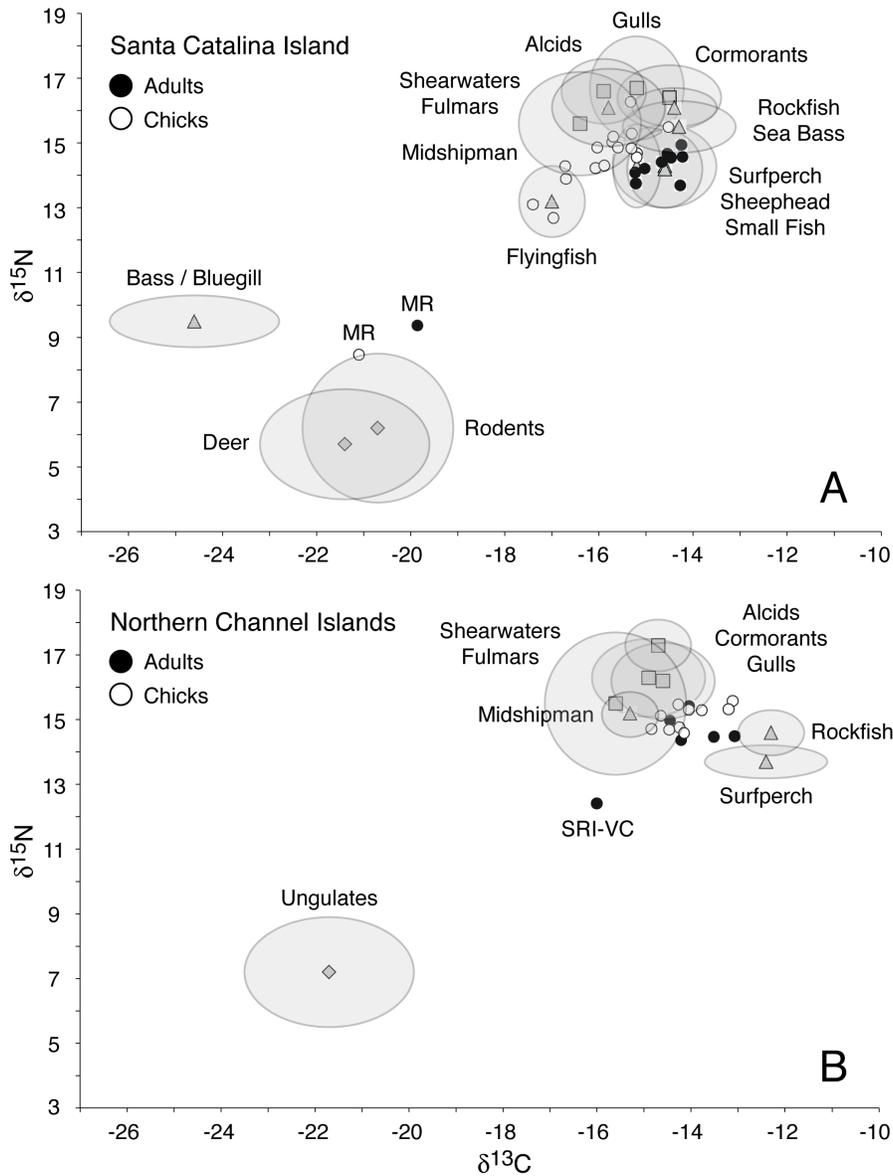


Figure 4. SIAR mixing model results reporting diet proportion of three major prey types for bald eagle adults and chick feathers collected from Santa Catalina Island (squares) and Northern Channel Islands (squares); error bars represent standard deviation. Results for the adult and chick from the Middle Ranch nest on Santa Catalina Island have been left out of this summary; see main text for a summary of mixing model results for Middle Ranch eagles. Also see main text for details about how prey species were grouped into major prey types shown here.

