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FOOD HABITS OF NESTING GOLDEN EAGLES (*AQUILA CHRYSAETOS*) ON SANTA CRUZ AND SANTA ROSA ISLANDS, CALIFORNIA

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Abstract—Between 2000 and 2007, we studied food habits of golden eagles (*Aquila chrysaetos*) nesting on Santa Cruz and Santa Rosa islands by analyzing prey remains recovered from 11 nests—7 on Santa Cruz Island and 4 on Santa Rosa Island. We collected 464 prey items representing 28–30 species. Based on biomass, the most important prey for golden eagles before feral pigs (*Sus scrofa*) were eradicated from the islands were feral piglets (31.4%), mule deer (*Odocoileus hemionus*) fawns and elk (*Cervus elaphus*) calves (18.0%), common raven (*Corvus corax*; 17.4%), cormorants (*Phalacrocorax* sp.; 10.3%), and gulls (*Larus* sp. 6.7%). There were island-specific differences both in species and biomass of prey. On Santa Cruz Island, the eagles' diet consisted of feral pigs (63.2%), gulls (13.3%), and common ravens (8.9%); while on Santa Rosa Island the eagles' diet consisted of mule deer fawns (34.6%), common raven (25.8%), cormorants (14.2%), and waterfowl (8.6%). Prior to removal of feral pigs, island foxes (*Urocyon littoralis*) and feral piglets comprised 5.9% and 63.2% of the biomass found in the eagle nests on Santa Cruz Island; however after removal of feral pigs, we found a greater proportion of island foxes (45.7–57.7%), common ravens (24.7–26.7%), and gulls (18.0–19.5%) in the nest remains. The depauperate nature of the vertebrate prey on the islands has resulted in golden eagles foraging on a number of prey species not typically eaten by eagles elsewhere in North America such as island fox, western spotted skunk (*Spilogale gracilis*), feral piglets, mule deer fawns, common raven, barn owl (*Tyto alba*), gulls, and cormorants.

INTRODUCTION

Until the early 1980s, golden eagles (*Aquila chrysaetos*) were an occasional visitor to the larger islands off the coast of southern California, with the majority of records from Santa Cruz Island (SCI) (Collins and Jones, unpublished manuscript). By the late 1980s and early 1990s, sightings of golden eagles on SCI had increased, suggesting that they were becoming established as a year-round resident. They were first recorded to breed on SCI with the discovery of a nest at Coche Point in 1999 (Roemer et al. 2001; Latta et al. 2005). Since then, a total of 29 large, eagle-sized nest structures have been discovered in at least five eagle territories on SCI and four nests have been found in two eagle territories on Santa Rosa Island (SRI) (Latta et al. 2005). Multiple nests within an eagle's territory and nests with up to four distinct nest layers suggest that golden eagles have been nesting on SRI since at least the mid-1990s and on SCI since at least the early 1990s (Latta et al. 2005).

Golden eagles have been implicated in the catastrophic decline of island fox (*Urocyon littoralis*) populations on three of the northern Channel Islands between 1994 and 1999 (Roemer et al. 2001, 2002; Coonan et al. 2002; Coonan, Schwemm, et al. 2005; Roemer and Donlan 2004). To stem this population decline, the National Park Service (NPS) and The Nature Conservancy (TNC) implemented a series of emergency recovery actions including: (1) a trapping and relocation program for golden eagles; (2) establishment of on-island captive breeding programs for island foxes; (3) a reintroduction program for bald eagles (*Haliaeetus leucocephalus*) to the northern Channel Islands; and (4) an eradication program for feral pigs (*Sus scrofa*) on SCI. In 2004 the U.S. Fish and Wildlife Service (USFWS) listed four island fox subspecies as endangered, including the three found on the northern Channel Islands (USFWS 2004). As a result of these recovery actions, a total of 44 golden eagles were live-captured and translocated from the islands to the mainland (Coonan, McCurdy, et al. 2005; Latta et al. 2005; IWS 2006); a total of 61 bald eagles were released onto SCI (Dooley et al. 2005; Coonan and Dennis 2007); island fox populations on the northern Channel Islands were protected from extinction; and by mid-2006 feral pigs were eradicated from SCI (MacDonald and Walker 2008). Because of the success of each of these conservation measures, TNC began releasing island foxes back onto SCI in 2002 and 2003, and the NPS began releases of island foxes on SRI in fall 2003 and on San Miguel Island (SMI) in fall 2004 (Coonan, McCurdy, et al. 2005). Despite intensive golden eagle translocation efforts, a few eagles remain on Santa Cruz and Santa Rosa islands where they continue to prey on island foxes (IWS 2006).

There have been numerous food habit studies of golden eagles from throughout their range in North America (see summaries in Olendorff 1976 and Kochert et al. 2002) and from elsewhere in Europe and Asia (see Table 9 in Watson 1997). While food habits of golden eagles are reasonably well documented for several western states (McGahan 1968; Arnell 1971; Boag 1977; Collopy 1983; Marr and Knight 1983; Eakle and Grubb 1986; MacLaren et al. 1988), there are only a few studies that provide any data on the food habits of golden eagles in California (Dixon 1937; Carnie 1954; Bloom and Hawks 1982; Hunt et al. 1995) and only three studies that provide data on the food habits of island-inhabiting populations of golden eagles (Grubac 1987; Hogstrom and Wiss 1992; Watson 1997). Until recently there were only anecdotal observations of the eagles' diet on the Channel Islands. Collins and Latta (2006) provided the first quantitative assessment of the diet of golden eagles on Santa Cruz and Santa Rosa islands based on prey remains recovered from eight nests. The present study combines data from three new nests not previously sampled, with the original sample of eight nests analyzed by Collins and Latta (2006).

Golden eagles are opportunistic specialists that prey on a wide variety of types and sizes of prey (Olendorff 1976; Kochert et al. 2002). In western North America they tend to feed on whatever is most readily available in a particular region, generally rabbit and squirrel-sized prey that they can overpower easily. They also feed on carrion, primarily during the winter, and occasionally kill larger prey including a variety of native ungulates and domestic animals such as sheep (*Ovis aries*), goats (*Capra hircus*), calves (*Bos tarus*), and pigs (Olendorff 1976; Kochert et al. 2002). Golden eagles generally take young ungulates but have also been known to kill adults (Deblinger and Alldredge 1996). Based on averaging the results (minimum number of individuals, MNI) from 18 food habit studies, the diet of nesting golden eagles in western North America is composed of 76.7% (MNI) terrestrial mammals, 20.5% birds, 1.6% reptiles, and 0.5% fish (see Appendix 1 in Collins and Latta 2006). During the nesting season they feed primarily on leporids (hares and rabbits) and sciurids (ground squirrels, prairie dogs, and marmots) comprising between 49 and 94% of prey items recovered in food habit studies throughout western North America (Kochert et al. 2002). They also feed less intensively on a variety of birds, with gallinaceous species (pheasants, grouse, and partridge) being the most common, and occasionally on reptiles (snakes) and fish (Olendorff 1976; Kochert et al. 2002).

Most recent studies of golden eagle food habits have relied on the identification of prey remains recovered from regurgitated food pellets and from prey remains collected at nests and perches (see references cited in Olendorff 1976; Watson 1997; Kochert et al. 2002). Recently, Caut et al. (2006) used stable isotopes coupled with bioenergetics to estimate the interspecific interactions of golden eagles, island foxes, spotted skunks, and feral pigs on SCI. Without quantified food habit data, it is impossible to fully understand the extent of interspecific interactions of golden eagles with the vertebrate fauna on the Channel Islands. Thus, obtaining accurate food habit data for golden eagles on the islands is critical to accurately assess the trophic interactions of this avian predator in the northern Channel Island ecosystem. The principal objectives of this study were to: (1) determine prey composition and abundance and dietary breadth of golden eagles nesting on the Channel Islands; (2) determine the importance of feral herbivores (piglets, sheep, mule deer fawns, and elk calves) and island foxes as prey for nesting golden eagles; and (3) document changes in the eagles' diet following the eradication of feral pigs from SCI.

STUDY AREA AND METHODS

Study Area

Santa Cruz and Santa Rosa islands, the two largest of the northern Channel Islands, are located approximately 30 km (19 mi) south and 44 km (27 mi) southwest, respectively, from the adjacent mainland. SCI lies about 9 km (5.5 mi) east of SRI and 7 km (4.5 mi) west of Anacapa Island. These two islands have a Mediterranean climate, with mild, wet winters and warm, dry summers. Most rain falls between November and April and averages about 50 cm (19.7 in) on SCI (Junak et al. 1995) and 30 cm (11.8 in) on SRI (Clark et al. 1990). Wind and fog are dominant climatic components on both islands. Strong northwest winds of 10 to 40 knots per hour drive moisture-laden marine air and summer fog across these islands. Diverse topography supports a total of 10 plant communities on SCI (Philbrick and Haller 1977) and 18 communities on SRI (Clark et al. 1990). Up to 89% of SCI is covered with grasslands, island chaparral, oak woodland, and coastal-sage and coyote-brush scrub (Minnich 1980), while 65% of SRI is covered with grasslands and 25% is covered with chaparral and six other scrub communities (Clark et al. 1990). Both of these islands contain a depauperate terrestrial bird and mammal fauna, with two medium-sized native mammals (island fox and western spotted skunk), several larger introduced herbivores (mule deer, elk, and feral pig), introduced California quail (*Callipepla californica*) and wild turkeys (*Meleagris* gallopavo; SCI only), and gopher snakes (*Pituophis catenifer*). Both islands also support large numbers of breeding and roosting cormorants, several other species of seabirds such as western gull (*Larus occidentalis*) and pigeon guillemot (*Cepphus columba*; Carter et al. 1992), and a diverse array of other migrant marine birds. Red-tailed hawks (*Buteo jamaicensis*) and common ravens (*Corvus corax*) are the largest land birds resident on the islands.

Nest Sites Excavated

Prey remains were collected from 11 golden eagle nests in 7 breeding territories on Santa Cruz (*n* =5 territories) and Santa Rosa (*n*=2) islands (Fig. 1). On SRI, the Trap Canyon territory contained one

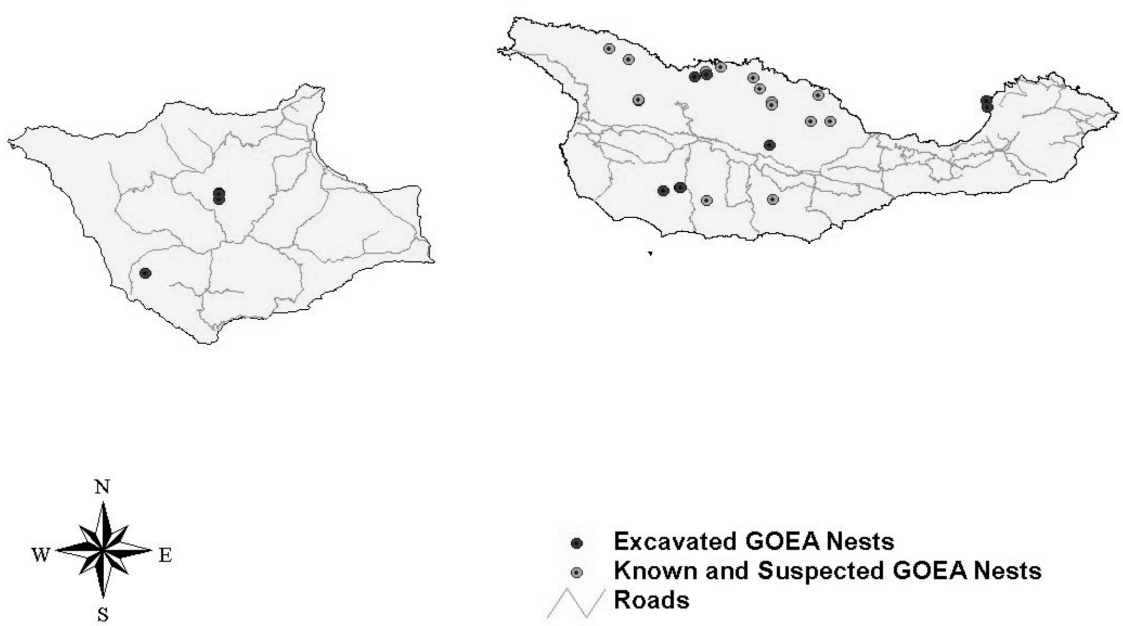

Figure 1. Golden eagle nests on Santa Cruz and Santa Rosa islands that were excavated for this study.

large nest (Big nest) and three smaller nests; while the Trancion Canyon territory contained one nest (Latta 2005). Based on the presence of multiple nest layers and/or multiple nests, the eagle territory in Trap Canyon was active from 1996 until 2004; while the Trancion Canyon territory was active from 2001 until 2003 (Latta 2005). On SCI there were at least five golden eagle nesting territories (i.e., Laguna Canyon, Cascada/Red Peaks, Coche Point, Lady's Harbor, and Christy Water Tank) with at least 29 large, eagle-sized nest structures (Fig. 1; Latta 2005). Based on the presence of multiple nest layers in the Laguna Canyon and two of the Coche Point nests, golden eagles have been nesting on SCI since at least the late 1980s or early 1990s. For this food habits study, one nest from the Trancion and three nests from the Trap Canyon territories on SRI, and two nests each from the Coche Point, Lady's Harbor, and Laguna Canyon territories and one nest from the Cascada territory on SCI were excavated. Only one (2006 nest) of the seven nests excavated on SCI for this food habits study was active following the eradication of feral pigs.

Sample Collection and Identification

Prey remains (bones and teeth) were collected from 11 golden eagle nests on Santa Cruz and Santa Rosa islands between 2002 and 2006. The surface and surrounding areas of each nest site were excavated by hand with prey remains collected and placed in bags labeled by the area within a nest site where the remains were found. After removing prey remains and loose material from the surface, successive layers of nest material were carefully excavated using trowels, shop brushes, and a 1/16-in. (1.59-mm) screen sieve. Remains recovered from each stratum were bagged according to nest layer (e.g., Layer A, B, C, etc.). Remains found outside the horizontal boundaries of the nest and not associated with a particular nest layer were placed in separate bags labeled by location found (e.g., back of nest ledge, below nest, etc.). Following excavation of each nest site, the stick nest structure was reconstructed using the original nest material (Latta et al. 2005).

Prey remains were first sorted into six taxonomic groups (bird, mammal, reptile, amphibian, fish, and invertebrates) and then identified in the lab to the highest taxonomic level possible by comparing diagnostic elements with identified specimens housed in research collections at the Santa Barbara Museum of Natural History. For mammals, a total of 16 elements (skull bones, mandible, teeth, scapula, humerus, radius, ulna, carpal/tarsal bones, metacarpals, pelvis, femur, tibia, fibula, calcaneus, astragalus, and metatarsal bones) were sufficiently diagnostic to permit identification to species. For birds, a total of 17 elements (crania, maxilla, lower mandible, pelvic bones, sternum, sacral vertebrae, humerus, ulna, radius, carpometacarpus, D4P=phalange of wing, coracoid, scapula, clavicle, femur, tibiotarsus, and tarsometatarsus) were used for species identifications. Bones not assignable to species (e.g., vertebrae, ribs, phalanges, and miscellaneous bone fragments) were listed as unidentified bird or mammal bone and were excluded from further identification or analysis. All diagnostic bird bones were identified to species except for bones from Brandt's and double-crested cormorants (*Phalacrocorax penicillatus* and *P. auritus*), and western and glaucous-winged gulls (*Larus occidentalis* and *L. glaucescens*). For these two species groups, their bones were too difficult to tell apart so they were lumped into these two species assemblages. Fish and invertebrate remains were considered to be incidental remains coming to the nest as crop or stomach contents of marine bird prey, as riders on materials used to line nest cups, or by being attracted to decomposing prey remains in nests. All incidental faunal remains were excluded from further quantitative diet analyses**.**

Data Analysis

Two measures were used to calculate diet composition. First, the minimum number of individuals (MNI) was determined for each species or species group to be equal to the greatest number of identical bone elements per taxon. Second, a body weight value (biomass) was assigned for each species identified in the prey samples by using published weight data for each taxon (see Appendix 2 in Collins and Latta 2006). Where sex of prey could not be determined, we averaged the means of each sex for weight estimates of individual species. For larger prey species, the weights of immature animals (e.g., newborns) of appropriate subspecies were also taken from the literature if available. For elk we used the weight at birth to one week of age (Johnson 1951), and for mule deer the weight at birth (Anderson and Wallmo 1984). For sheep we used the weight recorded on SCI for lambs from birth to 6 months of age (Van Vuren and Coblentz 1984). For feral piglets, we used an estimate of 2.5 kg for the weight (e.g., birth to 1 month of age) which represents the average maximum weight of a prey item that an eagle could be expected to carry back to its nest (Huey 1962; Watson 1997). Although eagles undoubtedly fed on piglets, lambs, deer fawns, and elk calves that were older and too heavy to be carried back to their nests, it was impossible to determine an average weight for this type of prey. Thus, biomass estimates for these larger prey species are probably conservative.

Three analyses were conducted to determine diet composition. First, nests active on Santa Cruz and Santa Rosa islands were combined to examine diet composition for eagles on the islands prior to the removal of feral pigs from SCI. Second, diet composition was examined for each island separately using nests active prior to the removal of feral pigs. Finally, diet composition was examined for nests on SCI pre- and post-pig removal. Percent diet composition was examined relative to MNI and biomass. For MNI, percent diet composition was calculated as the minimum number of all prey items in a given taxonomic group, divided by the total minimum number of all prey items recovered, multiplied by 100. A similar method was used to calculate percent biomass using average body weights. Dietary breadth was calculated for both islands combined (exclusive of the 2006 Laguna Canyon nest on SCI) and separately for each island sample using Levins' (1968) formula: $B=1/\text{sum } p_i^2$ where p_i was the relative occurrence of prey i in the diet. Values of niche breadth range from 1 to n with 1 representing the narrowest value for food niche breadth.

RESULTS

Diet Composition—Combined Island Samples Pre-Pig Removal

We collected 4896 prey remains (i.e., bones, teeth, and otoliths) representing 27 prey species from 10 golden eagle nests active prior to the removal of feral pigs from the islands (6 nests on SCI and 4 nests on SRI, Table 1). Faunal remains from an 11th nest active following the removal of feral pigs on SCI were also collected but are analyzed separately and thus are not included in the following prey totals for the combined island samples. Of the 425 individuals identified, 222 (52.2% MNI) were birds, 195 (45.9%) were terrestrial mammals, and 8 (1.9%) were reptiles. Based on MNI, the three most important prey groups in this sample were introduced herbivores (26.8%), land birds (27.8%), and aquatic birds (24.5%), with all other prey classes combined accounting for 20.9% of the diet (Table 1).

The relative proportion of a prey category or species changed when prey biomass was used as the measure. The proportion of larger (heavier) species increased while smaller (lighter weight) species declined (Table 1). In terms of total biomass of prey recovered, terrestrial mammals and birds accounted for 59.5% and 40.3% of the eagles' overall nesting season diet, respectively, and reptiles comprised only 0.2% of the diet. By biomass, the most important species were feral piglets (31.4%), mule deer fawns (17.3%), common raven (17.4%), and island fox (7.2%; Table 1). While deer mice (*Peromyscus maniculatus*) comprised 9.6% of the eagles' diet based by MNI, they only comprised 0.13% of the eagles' diet based on biomass. Many other recorded prey also showed a decline when biomass was used as the measure (e.g., western spotted skunk, reptiles, land birds, and all marine birds except for cormorants).

Diet Composition—Separate Island Samples Pre-Pig Removal

There were island-specific differences in dietary breadth and composition of prey remains (Tables 2 and 3). Golden eagles on SRI had the most diverse diet (7.11 dietary breadth) with 19–20 species represented, while eagles on SCI had a less diverse diet (3.77) with 14–16 species represented. Species unique to SRI prey samples included waterfowl (mallard [*Anas platyrhynchos*] and gadwall [*Anas strepera*]), raptors (red-tailed hawk, peregrine falcon [*Falco peregrinus*], barn owl [*Tyto alba*]), loggerhead shrike (*Lanius ludovicianus*), 3 small passerine species, southern alligator lizard (*Elgaria multicarinata*), Santa Cruz gopher snake (*Pituophis catenifer pumilus*), mule deer fawns, and an elk calf (Table 2). Species unique to SCI prey

Table 1 . Diet of golden eagles nesting on Santa Cruz and Santa Rosa islands based on minimum number of individuals and on the biomass of individual prey species recovered from six nests on Santa Cruz Island and four nests on Santa Rosa Island.

				Biomass		
Common name	Scientific name	MNI[a]	%MNI[b]	Body weight (grams)	Total weight (grams)	Percent of total biomass
MAMMALS	MAMMALIA					
Deer mouse	*Peromyscus maniculatus*	41	9.6	20	820	0.13
Island fox	*Urocyon littoralis*	22	5.2	2036	44792	7.2
Western spotted skunk	*Spilogale gracilis amphiala*	18	4.2	560	10080	1.6
Feral pig	*Sus scrofa*	78	18.4	2500	195000	31.4
European mouflon sheep	*Ovis aries*	3	0.7	2300	6900	1.1
Mule deer	*Odocoileus hemionus*	32	7.5	3365	107680	17.3
Elk	*Cervus canadensis*	1	0.2	4500	4500	0.7
TOTAL MAMMALS		195	45.9		369772	59.5
BIRDS	AVES					
Double-crested/ Brandt's cormorant	*Phalacrocorax auritus/penicillatus*	23	5.4	1962	45126	7.3
Pelagic cormorant	*Phalacrocorax pelagicus*	10	2.4	1868	18680	3.0
Gadwall	*Anas strepera*	3	0.7	920	2760	0.4
Mallard	*Anas platyrhynchos*	21	4.9	1139	23919	3.8
Herring gull	*Larus argentatus*	2	0.5	1135	2270	0.4
California gull	*Larus californicus*	2	0.5	607	1214	0.2
Western/glaucous-winged gull	*Larus occidentalis/ glaucescens*	43	10.1	875	37625	6.1
Subtotal aquatic birds		104	24.5		131594	21.2
Red-tailed hawk	*Buteo jamaicensis*	1	0.2	1126	1126	0.2
American kestrel	*Falco sparverius*	1	0.2	116	116	tr[c]
Peregrine falcon	*Falco peregrinus*	1	0.2	768	768	0.1
California quail	*Callipepla californica*	5	1.2	173	865	0.14
Mourning dove	*Zenaida macroura*	1	0.2	127	127	tr
Barn owl	*Tyto alba*	14	3.3	524	7336	1.2
Loggerhead shrike	*Lanius ludovicianus*	1	0.2	47.4	47.4	tr
Common raven	*Corvus corax*	90	21.2	1199	107910	17.4
White-crowned sparrow	*Zonotrichia leucophrys*	1	0.2	25.5	25.5	tr

Table 1 (continued). Diet of golden eagles nesting on Santa Cruz and Santa Rosa islands based on minimum number of individuals and on the biomass of individual prey species recovered from six nests on Santa Cruz Island and four nests on Santa Rosa Island.

				Biomass		
Common name	Scientific name	MNI[a]	%MNI[b]	Body weight (grams)	Total weight (grams)	Percent of total biomass
Western meadowlark	*Sturnella neglecta*	2	0.5	100.7	201.4	tr
Brown-headed cowbird	*Molothrus ater*	1	0.2	43.9	43.9	tr
Subtotal land birds		118	27.8		118566.2	19.1
TOTAL BIRDS		222	52.2		250287	40.3
REPTILES	REPTILIA					
Southern alligator lizard	*Elgaria multicarinata*	5	1.2	50	250	tr
Santa Cruz gopher snake	*Pituophis catenifer pumilus*	3	0.7	520	1560	0.2
TOTAL REPTILES		8	1.9		1810	0.2
TOTAL PREY		425	100		621869	

a. MNI=minimum number of individuals.

b. Percentages are rounded to the nearest 0.1 of a decimal point and are based on all prey remains recovered.

c. tr = trace amount, < 0.05 percent.

samples included gulls (herring [*Larus argentatus*], California [*L. californicus*] and western/glaucous-winged gulls), American kestrel (*Falco sparverius*), California quail, feral piglets, and sheep (lambs and at least 1 adult; Table 3).

By biomass, terrestrial mammals accounted for 71.6% and 47.8% of the eagles' diet on Santa Cruz and Santa Rosa islands, respectively, while birds made up 28.3% and 51.6% (Tables 2 and 3). Mule deer fawns were the most important prey for eagles on SRI, comprising 34.6% of the prey biomass, while feral piglets were the most important prey for eagles on SCI, comprising 63.2%. On SRI the next most important prey were common raven (25.8%), cormorants (14.2%), waterfowl (8.6%), and island fox (8.5%); while on SCI the next most important prey were gulls (13.3%), common raven (8.9%), island fox (5.9%), and double-crested/Brandt's cormorant (5.7%).

Diet Composition 2006 Nest on SCI—Post-Pig Removal

regularly clean their nests by removing uneaten prey

Prey remains were also recovered from a single golden eagle nest that was active in spring 2006 after feral pigs had been eradicated from SCI. In compiling the prey remains from this nest site, there were problems determining the exact number of island foxes that were contained at the 2006 nest site as island fox carcasses, fox collars, and passive integrated transponder (PIT) tags were removed from the nest and areas surrounding the nest by biologists from the Institute for Wildlife Studies (IWS) prior to our 2007 excavation of this nest site. As not all of the foxes represented in the nest were marked, we were unable to clarify the exact number of island foxes that were associated with the recovered carcasses, collars, and tags. As a result, we have provided in the following dietary analysis for the 2006 nest site an upper (*n*=14 foxes) and lower (*n*=12) limit for the number of island foxes that are believed to have been associated with this nest site. The actual number of island foxes eaten by the pair of eagles that used the Laguna nest in 2006 is probably more than 14 foxes since eagles (Watson 1997).

Table 2. Nesting season diet of golden eagles on Santa Rosa Island based on prey remains from four nests (two territories).

Common name	Scientific name	MNI[a]	Percent MNI[b]	Species weight (grams)	Percent of total
MAMMALS	MAMMALIA				
Deer mouse	*Peromyscus maniculatus*	36	14.9	20	0.2
Island fox	*Urocyon littoralis*	13	5.4	2036	8.5
Western spotted skunk	*Spilogale gracilis amphiala*	17	7	560	3.1
Mule deer	*Odocoileus hemionus*	32	13.2	3365	34.6
Elk	*Cervus canadensis*	1	0.4	4500	1.4
TOTAL MAMMALS		99	40.9		47.8
BIRDS	AVES				
Double-crested/Brandt's cormorant	*Phalacrocorax auritus/penicillatus*	13	5.4	1962	8.2
Pelagic cormorant	*Phalacrocorax pelagicus*	10	4.1	1868	6.0
Gadwall	*Anas strepera*	3	1.2	920	0.9
Mallard	*Anas platyrhynchos*	21	8.7	1139	7.7
Subtotal aquatic birds		47	19.4		22.8
Red-tailed hawk	*Buteo jamaicensis*	1	0.4	1126	0.4
Peregrine falcon	*Falco peregrinus*	1	0.4	768	0.2
Barn owl	*Tyto alba*	14	5.9	524	2.4
Loggerhead shrike	*Lanius ludovicianus*	1	0.4	47.4	tr[c]
Common raven	*Corvus corax*	67	27.7	1199	25.8
White-crowned sparrow	*Zonotrichia leucophrys*	1	0.4	25.5	tr
Western meadowlark	*Sturnella neglecta*	2	0.8	100.7	0.1
Brown-headed cowbird	*Molothrus ater*	1	0.4	43.9	tr
Subtotal land birds		88	36.4		28.9
TOTAL BIRDS		135	55.8		51.6
REPTILES	REPTILIA				
Southern alligator lizard	*Elgaria multicarinata*	5	2.1	50	0.1
Santa Cruz gopher snake	*Pituophis catenifer pumilus*	3	1.2	520	0.5
TOTAL REPTILES		8	3.3		0.6
TOTAL PREY		242	100		100

a. MNI=minimum number of individuals.

b. Percentages are rounded to the nearest 0.1 of a decimal point and are based on all prey remains recovered.

c. tr = trace amount, < 0.05 percent.

Table 3. Diet of golden eagles nesting on Santa Cruz Island before feral pigs were eradicated (six nests) and after pigs were eradicated (one nest).

	Nests active pre-pig eradication (n = 6)				Nests active post-pig eradication (n = 1)		
Common name	MNI[a]	Percent MNI[b]	Species weight	Percent biomass[b]	MNI[a]	Percent MNI[b]	Percent biomass[b]
MAMMALS							
Deer mouse	4	2.2	20	tr[c]			
Island fox	9	5.0	2036	5.9	12–14	30.8–37.8	45.7–57.7
Western spotted skunk	1	0.6	560	0.18			
Feral pig	78	43.1	2500	63.2			
European mouflon sheep	3	1.7	2300	2.2			
TOTAL MAMMALS	95	52.5		71.6	12–14	30.8–37.8	45.7–57.7
BIRDS							
Double-crested/Brandt's cormorant	9	5.0	1962	5.7			
Pelagic cormorant			1868		1	2.6–2.7	3.5–3.8
Herring gull	2	1.1	1135	0.74			
California gull	2	1.1	607	0.39			
Western/glaucous-winged gull	43	23.8	875	12.2	11	28.2–29.7	18.0–19.5
Subtotal aquatic birds	56	30.9	2743	19.0	12	30.8–32.4	21.5–23.3
American kestrel	1	0.6	116	0.04	1	2.6–2.7	0.22–0.23
California quail	5	2.8	173	0.28	1	2.6–2.7	0.32–0.35
Mourning dove	1	0.6	127	tr			
Common raven	23	12.7	1199	8.9	11	28.2–29.7	24.7–26.7
Subtotal land birds	30	16.6		9.3	13	33.3–35.1	25.0–27.3
TOTAL BIRDS	86	47.5		28.3	25	64.1–67.6	46.7–50.6
TOTAL PREY	181	100			37–39	100	100

a. MNI=minimum number of individuals.

b. Percentages are rounded to the nearest 0.1 of a decimal point and are based on all prey remains recovered.

c. tr = trace amount, <0.05 percent.

A total of 37–39 individuals were recovered from the 2006 nest with birds comprising 46.7–50.6% and land mammals comprising 45.7–57.7% of the recovered prey biomass (Table 3). In the absence of feral piglets, the Laguna pair of golden eagles preyed more intensively on island foxes (45.7–57.7%), common ravens (24.7–26.7%), and gulls (18.0–19.5%). Island foxes and common ravens went from comprising 5.9% and 8.9% of the eagle's prey biomass prior to the removal of pigs to comprising 45.7–57.7% and 24.7–26.7% of the prey biomass following the removal of feral pigs (Table 3).

DISCUSSION

Diet Composition

The nesting season diet of golden eagles on the Channel Islands differed from diets recorded from 18 other golden eagle food habit studies in North America (see Appendix 1 in Collins and Latta 2006). On the islands, golden eagles fed more intensively on birds (52.2% MNI) than the average (20.5%) recorded from published eagle food habit studies in North America. Also, land mammals comprised a smaller percentage of the eagles' diet on the islands (45.9%) than the 76.7% average recorded from 18 eagle food habit studies in North America. The absence of an abundant diurnally active native mammal or avian prey, like that found elsewhere in North America (e.g., Sciurids, Leporids, and Gallinaceous birds), contributed to golden eagles on the Channel Islands switching to other prey less frequently eaten by eagles, such as feral piglets, mule deer fawns, common raven, island fox, spotted skunk, gulls, waterfowl, cormorants, and barn owls. Golden eagles on the islands have adapted their foraging strategies to access and harvest diurnally active terrestrial and aquatic vertebrate prey found on the islands. This switch to alternative prey has had a dramatic adverse effect on the endemic island fox that had evolved in the absence of a large terrestrial avian predator like the golden eagle.

Golden eagles are adept predators of birds as evidenced by the diversity of species eaten and the relative importance of birds (3.9% to 47.6% MNI) in golden eagle diets elsewhere in North America (Arnell 1971; Olendorff 1976; Marr and Knight 1983). On the Channel Islands, birds comprised 52.2% (MNI) of the prey remains which represents the highest percentage for birds recorded in the diet of any golden eagle population in North America. While gallinaceous birds are an important secondary prey for golden eagles in some areas of North America, Scotland, and continental Europe and Asia (Watson 1997; Kochert et al. 2002), they were scarce in the eagles' diet on the Channel Islands. The only gallinaceous birds available to eagles on the islands were introduced California quail (both islands) and wild turkeys (SCI only). Both species tend to inhabit more heavily wooded habitats on the islands making them less visible and thus less accessible to foraging eagles. California quail were only taken by eagles a few times and as such were a relatively unimportant prey constituent (1.2% MNI) in the eagles' diet on the islands. Common ravens and cormorants were the most important avian prey for eagles on the Channel Islands. These two species comprised 17.4% and 10.2% of the prey biomass consumed by eagles on the islands, and both species are rare in eagle diets elsewhere in North America and Europe (Olendorff 1976; USDI 1979; Eakle and Grubb 1986; Watson 1997). Waterfowl, gulls, and barn owls were also important prey for eagles on the islands but have only occasionally been eaten by eagles elsewhere in the world (Carnie 1954; Olendorff 1976; USDI 1979; Bloom and Hawks 1982; Collopy 1983; Watson 1997). Clearly, in the absence of an abundant diurnally active terrestrial prey, golden eagles on the Channel Islands have developed foraging strategies to catch alternative avian prey that are uncommon to rare in eagle diets elsewhere in North America. While most avian bones found in eagle nests on the islands were from subadult and adult birds, there were some juvenile/nestling bones of cormorants, gulls, common ravens, and barn owls. The presence of nestling bone from these species suggests that golden eagles on the islands were occasionally capturing young birds by nest robbing.

Of 7094 prey remains identified in golden eagle nests in North America, hoofed mammals and domestic livestock remains accounted for 1.4% and 4.4% (MNI) of the remains, respectively (Olendorff 1976). In North America mule deer comprised 0.1% and 12.7% of the eagles' nesting season diet (Watson 1997). Feral herbivores were an even more important prey constituent of the eagles' diet on the islands with feral pigs comprising 43.1% MNI (63.2% biomass) on SCI and mule deer fawns comprising 13.2% MNI (34.6% biomass) on SRI. All of the feral pig and mule deer bones found in eagle nests on the islands were from very young animals (piglets and fawns) which are within the eagles' preferred, transportable prey size (0.5–4.0 kg). Feral pigs have been reported in only 6 of 24 golden eagle food habit studies from continental Europe and Asia where they comprised 0.3% to 2.7% MNI of the eagles' diet (Watson 1997). As a result of the depauperate nature of terrestrial vertebrate prey on SCI, eagles have increased their reliance on feral pigs (43.1% MNI). This is due to the abundance and seasonal availability of feral piglets during the eagles' spring breeding season, and because piglets (0–2 months of age) are within the eagles' preferred prey size. Given the number of eagle nesting territories on SCI (*n*=5), it is clear that feral pigs were probably the principal reason why eagles were able to successfully establish and maintain a breeding presence on the northern Channel Islands. Mule deer fawns probably played a similar role in helping eagles to establish a breeding presence on SRI. The ongoing occurrence of mule deer and elk on SRI will continue to attract eagles to this island and could lead to eagles attempting to nest again on this island.

Carnivores are typically only incidental prey for golden eagles, with most occurrences resulting from eagles scavenging on carcasses rather than actively preying on live animals. Carnivores comprised less than 1.0% of golden eagles' overall diet in North American food habit studies (Olendorff 1976). However, in several studies carnivores comprised a higher percentage of an eagles' diet, such as 5.4% of the overall diet in one study in California (Carnie 1954) and 13.2% of the eagles' diet in another study in Arizona (Eakle and Grubb 1986). Until the present study, the highest representation of carnivores in a golden eagle diet was in Mongolia, where carnivores comprised 41% MNI of the total prey remains recovered from an excavated nest (Ellis et al. 1999). On the Channel Islands, carnivores (island fox and western spotted skunk) comprised 9.4% MNI of the eagles' overall diet on both islands and 5.6% of the eagles' diet on SCI prior to the eradication of feral pigs. Following the removal of pigs from SCI, island fox increased to 30.6–37.8% MNI (45.7–57.7% biomass) at the only active eagle nest on the island. This represents one of the highest percentages ever recorded for carnivores in the diet of a golden eagle population. Spotted skunks made up 7.0% MNI and 0.6% MNI of the eagles' diet on Santa Rosa and Santa Cruz islands, respectively, and represent the first time that this species has been documented being eaten by golden eagles. On the Channel Islands eagles are feeding more intensively on terrestrial carnivores due in part to (1) the depauperate nature of diurnally active terrestrial vertebrate prey on the islands, (2) the fact that both species are within the eagles' preferred prey size, and (3) both carnivores exhibiting some diurnal activity which makes them accessible to foraging eagles. Predation from golden eagles clearly has had a significant adverse effect on island fox populations on three of the northern Channel Islands (Roemer et al. 2001, 2002; Coonan et al. 2002) and will continue to impact these populations into the future if any eagles remain as year-round residents on Santa Cruz or Santa Rosa islands.

Diet Composition—Post-Pig Eradication

Based on prey remains recovered from the only golden eagle nest which was active after feral pigs were eradicated from SCI (Laguna 2006 nest), this pair of eagles was able to switch from preying intensively on feral piglets to preying more intensively on island foxes, western gulls, and common ravens. Between July 2005 and June 2006, the Laguna pair of eagles is believed to have been responsible for more than 20 island fox mortalities (Schmidt et al. 2007). The implications of these results are that if golden eagles remain as residents on the northern Channel Islands, they will continue to adversely impact island fox populations through selective predation of this species, a fact which seems to be supported by ongoing eagle-fox related mortalities on SCI following the removal of the Laguna Canyon pair of eagles (Morrison 2007) and by recent eagle-fox mortalities on SRI (T. Coonan, personal communication). Without feral piglets to feed on, eagles are preying on the next similar-sized terrestrial prey, the island fox. The impact of this predation to fox populations on the islands will depend on the number of eagles that remain on the islands and on whether these eagles attempt to breed and rear young on the islands.

Dietary Breadth

Dietary breadth is the best measure of how specialized an eagle's diet is. In North America, eagles show a dependence on just one or two prey families (Leporidae or Sciuridae), which has led to an average dietary breadth measured from 13 food habits studies of 2.74 (range 1.36–5.36; Watson 1997). In Europe and Asia, the average dietary breadth measured from 24 golden eagle food habit studies was 4.03 (range 2.01–11.2) and from 9 food habit studies in Scotland was 5.38 (2.44–7.25; Watson 1997). Dietary breadth in Scotland, Europe, and Asia was higher than that recorded in North America because golden eagles preferred prey from two, three, or four of the principal prey families (Leporidae, Sciuridae, Tetraonidae, and Phasianidae; Watson 1997).

Golden eagles usually exhibit a more diverse diet when their preferred prey is scarce or absent. On the Channel Islands, where rabbits, squirrels, and larger-sized Gallinaceous birds are absent, golden eagles have developed a more diverse diet (average dietary breadth 8.63) than elsewhere in North America (average dietary breadth 2.74). Eagles on the islands have broadened their diet to include a wider diversity of prey, including a number of species that eagles are not known to feed on intensively, such as feral pigs, common raven, island fox, western spotted skunk, cormorants, gulls, waterfowl, and barn owls. Because of their heavier reliance on feral piglets (63.2% of prey biomass), eagles on SCI exhibit a more specialized diet (3.77 dietary breadth) than eagles on SRI (7.11). Following the removal of pigs from SCI, eagles shifted to feeding more intensively on three species (island fox, common raven, and gulls) which resulted in a slightly higher dietary breadth of 3.86. Golden eagle populations on islands off Scotland exhibited moderately diverse diets (3.47–5.14) comprised of three or four dominant prey families (Watson 1997). Eagles on two islands in Europe have exhibited very narrow diets comprised of unusual prey species. On the island of Gotland in Sweden, where rabbits are rare, eagles have shifted to preying more intensively on hedgehogs (Hogstrom and Wiss 1992); while on the island of Macedonia their principal prey is tortoises (Grubac 1987). Eagles on these two islands shifted to utilizing unusual prey species because both species fall within golden eagles' preferred size range for prey and both species were available in sufficient quantity (Watson 1997). This is probably also the same reason why golden eagles on the Channel Islands have shifted to preying on species that are not normally eaten by eagles elsewhere in North America.

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