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Resource Exploitation by Island Foxes: Implications for Conservation

By

Brian L. Cypher, Alexandra Y. Madrid, Christine L. Van Horn Job, Erica Kelly, Stephen W. R. Harrison, and Tory L. Westall

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TABLE OF CONTENTS

LIST OF TABLES

List of Figures

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EXECUTIVE SUMMARY

Island foxes (*Urocyon littoralis*) occur on the 6 largest Channel Islands off the coast of southern California. This insular situation results in inherently small and therefore highly vulnerable populations, as exemplified by recent catastrophic fox declines on 4 of the islands. Thus, information that contributes to effective management of populations and habitats will facilitate long-term conservation of island foxes.

Prior investigations of island fox food habits usually have not been conducted in a manner that captures seasonal variations in use of items or permits among-island comparisons unbiased by annual variation in resource availability. Also, preferences among items have not been determined. Identifying item preferences could facilitate restoration or management of habitats in a manner that enhances the availability of preferred foods for foxes. Foraging patterns of island foxes were examined during October 2008-December 2009. Specific objectives were to: (1) examine seasonal food item use on all 6 inhabited islands, (2) compare item use among islands, (3) determine use of non-native items by foxes, and (4) use these results to develop recommendations for the management and conservation of island fox populations.

During the study, 2,928 island fox scats were collected and subsequently analyzed. Because sample sizes for Fall (October-December) 2008 were small for some islands, results for this season were excluded from the final analyses. Only results from January-December 2009 (n = 2,643 scats) were used so that a more accurate comparison of annual foraging patterns among islands could be conducted. Foxes exploited a variety of foods with over 40 different items being identified in scats. Foraging patterns of foxes varied among islands and also among seasons on each island, probably as a function of island-specific and season-specific differences in item availability. Annual diets were most similar between San Miguel and Santa Rosa, and least similar between San Nicolas and Santa Catalina.

Across all 6 islands, 14 items occurred with a frequency ≥ 10% in annual fox diets: deer mice, lizards, beetles, beetle larvae, Jerusalem crickets, silk-spinning sand crickets, grasshoppers, earwigs, terrestrial snails, and fruits of toyon, manzanita, prickly pear cactus, ice plant, and Australian saltbush (see Appendix A for scientific names). Based on use patterns, preferred items appeared to include deer mice, lizards, beetles, Jerusalem crickets, earwigs, and fruits of toyon, manzanita, and prickly pear cactus. Foxes also readily exploited non-native food items, including European earwigs, European garden snails, and fruits of ice plant, Australian saltbush, and myoporum. Use of non-native items was lowest on Santa Catalina and highest on San Nicolas where foxes may be at least partially dependent on these items.

The following recommendations are offered: (1) protect and restore natural habitats to increase the abundance and diversity of foods for foxes, which in turn will help increase fox population security by ensuring more stable food supplies during resource declines associated with cyclic and stochastic events or climate change, (2) when reducing or eliminating non-native species used as foods by foxes, do so gradually while concomitantly enhancing or restoring native food items, (3) because habitat conditions and fox populations are changing rapidly on most islands, monitor food item use periodically to identify changes in foraging patterns and adjust management strategies accordingly, and (4) consider monitoring the abundance of certain key foods to better understand the dynamics between resource availability and fox abundance.

INTRODUCTION

Island foxes (*Urocyon littoralis*) occur on the 6 largest Channel Islands off the coast of southern California. Pre-1994 population estimates on the islands ranged from 450 foxes on San Miguel to 1,465 foxes on Santa Cruz (U.S. Fish and Wildlife Service in press). Due to these relatively small population sizes and restricted distributions, the island fox was listed as Threatened by the State of California in 1987. In the mid to late 1990s, fox populations on 4 of the 6 islands declined markedly due to golden eagle (*Aquila chrysaetos*) predation (San Miguel, Santa Rosa, and Santa Cruz) and disease, probably distemper (Santa Catalina). On all 4 islands, captive breeding colonies were established using surviving animals, and for several years there were no (San Miguel, Santa Rosa) or very small (Santa Cruz, Santa Catalina) wild populations. The foxes on these 4 islands were listed as Federally Endangered in 2004 (U.S. Fish and Wildlife Service in press).

Beginning in 2004, releases of foxes from the captive colonies were initiated, and wild populations are again present on all 6 islands. The catastrophic declines of fox numbers on the 4 islands highlighted the vulnerability of these insular populations. In addition to the immediate recovery actions (e.g., captive breeding and reintroduction into the wild), additional actions are necessary for the long-term protection and security of the populations. Actions in-progress to achieve this goal include golden eagle removal, bald eagle (*Haliaeetus leucocephalus*) restoration, feral animal removal, epidemiological monitoring and prophylaxis, and habitat restoration. The purpose of restoration activities is to improve the quality of habitats degraded by feral animals, military training activities, and invasion by non-native plants (U.S. Fish and Wildlife Service in press). Habitat restoration can increase available cover and may be of even greater benefit to island foxes if such restoration also increases the abundance of preferred foods.

Typical of many canids, island foxes are considered "generalists" with regard to foraging patterns. They feed on a wide variety of food items, including rodents, birds, insects, carrion, and fruits (Moore and Collins 1995, Cypher 2003). Prior investigations of island fox food habits usually were not conducted in a manner that captured seasonal variations in use of items or permitted among-island comparisons unbiased by annual variation in resource availability. Also, preferences among items have not been determined. The recent low population levels on several of the islands provide an opportunity to evaluate item preferences. Due to these low levels, resource abundance will be high relative to fox population size and intra-specific competition for resources will be relatively low. Thus, foxes will be better able to express foraging preferences. If item preferences are identified, it may be possible to conduct habitat restoration or manage habitats in a manner that enhances the availability of preferred foods for foxes.

The goal of this project was to examine seasonal and spatial patterns of resource exploitation by island foxes. Specific objectives were to:

1. examine seasonal food item use on all 6 inhabited islands,
2. compare item use among islands,
3. determine use of non-native items by foxes, and
4. use these results to develop recommendations for the management and conservation of island fox populations.

STUDY AREA

Island foxes are restricted to the 6 largest Channel Islands located off the coast of southern California (Figure 1). The occupied islands range in size from 37-249 km^2 (Table 1). The islands are primarily volcanic in origin with sedimentary components as well (Schoenherr et al. 1999). The diversity of habitats and biota on the islands (Table 1) varies with island size, terrain complexity, and distance from the mainland. In general, diversity increases with island size and terrain complexity, and decreases with distance from the mainland (Schoenherr et al. 1999). The number of food items potentially available to island foxes also is higher on islands with greater biotic diversity. More detailed descriptions of the biotic and abiotic attributes of each island can be found in Schoenherr et al. 1999.

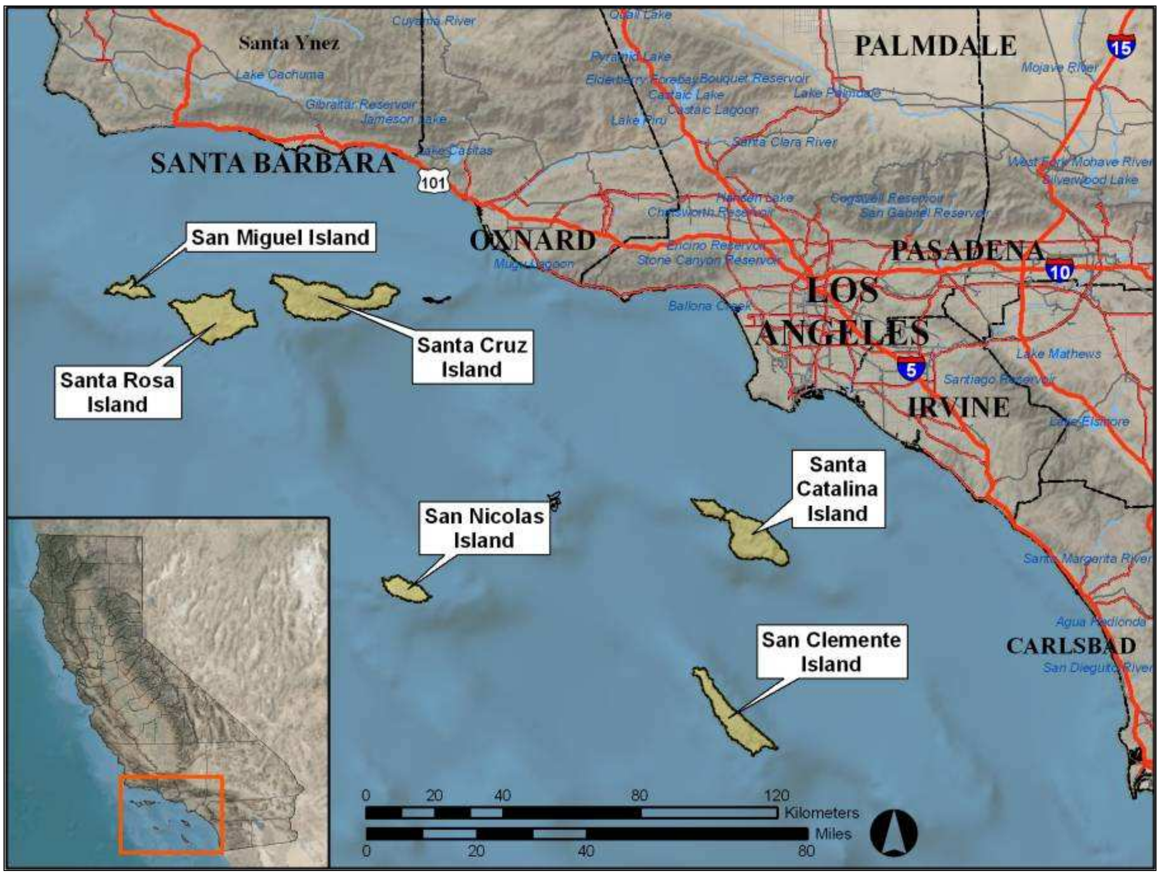

Figure 1. Channel Islands study area, Santa Barbara, Ventura, and Los Angeles counties, California.

Table 1. Abiotic and biotic attributes and island fox population size for the 6 Channel Islands occupied by foxes.[a]

Island	Area km^2 (mi^2)	Elevation m (ft)	Distance to mainland km (mi)	Native plants	Herpetiles	Birds	Mammals	Estimated 2009 fox population[b]
San Miguel	37 (14)	253 (830)	42 (26)	198	3	15	3	318
San Nicolas	58 (22)	277 (910)	98 (61)	139	3	13	2	500
San Clemente	145 (56)	599 (1965)	79 (49)	272	2	24	6	1,094
Santa Catalina	194 (76)	648 (2125)	32 (20)	421	11	33	9	947
Santa Rosa	217 (84)	484 (1589)	44 (27)	387	4	25	4	389
Santa Cruz	249 (96)	753 (2470)	30 (19)	480	9	42	12	1,000+

[a] Modified from Schoenherr et al. 1999 (Table 1, p. 7)
[b] T. Coonan, National Park Service, unpublished data

METHODS

Island fox scats (feces) were collected from all 6 islands with foxes. Scats were collected during each of 4 seasons: Fall (October-December), Winter (January-March), Spring (April-June), and Summer (July-September). Scat collections were conducted by biologists based on each island and included staff from the National Park Service (San Miguel and Santa Rosa), The Nature Conservancy (Santa Cruz), Santa Catalina (Catalina Island Conservancy), Institute for Wildlife Studies (San Nicolas), and the U.S. Navy (San Clemente). Attempts were made to collect scats from as many areas on each island as feasible. All scats were collected into paper bags and allowed to air-dry. Bags were labeled with the date and location of collection.

Analysis of scats was conducted by staff of California State University-Stanislaus, Endangered Species Recovery Program (ESRP) at their office in Bakersfield, California. Prior to analysis, scats were placed in a drying oven at 24°C for at least 24 hr to remove remaining moisture and to destroy any eggs or cysts of zoonotic parasites. Contents of each scat were then carefully separated and individual food items within the samples were identified to the lowest taxonomic level possible. Mammalian remains were identified based on bone and dental fragments and guard hair characteristics. Birds were identified based on feather and foot characteristics. Insects were identified based on exoskeleton characteristics. Fruits were identified based on seed and exocarp characteristics. Identification of items was based on comparison of remains with characteristics in established guides (e.g., mammalian guard hairs and dentition, seeds; Moore et al. 1974, Glass 1981, Roest 1986, Young and Young 1992) or by comparison with reference collections.

Frequency of occurrence of items was determined for each island and season. However, many items only occurred at low frequencies (<10%) suggesting that such items were opportunistically encountered and consumed, and were not important to the overall diet of island foxes. Thus, to facilitate statistical analysis, items were grouped into 5 broad categories: Deer mouse (*Peromyscus maniculatus*), Insect, Native fruit, Non-native fruit, and Other. Using these categories, annual use of items was compared among islands and seasonal use of items was compared for each island using contingency table analyses employing a χ^2 statistic. P-values were considered significant at $\alpha \leq 0.05$.

Shannon diversity indices (H') were calculated for annual and seasonal diets on each island using the equation:

$$H' = (N \log N - \sum n_i \log n_i)/N$$

where N is the total number of occurrences of all items and n_i is the number of occurrences of item i (Brower and Zar 1984). To further compare annual fox diets among islands, Horn's Index of Similarity (R_o) was calculated for each pair-wise comparison of islands using the Shannon diversity indices (Brower and Zar 1984).

RESULTS

ANNUAL FORAGING PATTERNS

During October 2008-December 2009, a total of 2,928 island fox scats were collected and subsequently analyzed. Sample sizes for Fall (October-December) 2008 were small for some islands due to logistical challenges on the part of the organizations conducting the collections. Thus, results for this season were excluded from the final analyses. Only results from January-December 2009 (n = 2,643 scats) were used so that a more accurate comparison of annual foraging patterns among islands could be conducted. However, results for Fall 2008 are reported in Appendix B. Over 40 different food items were identified in island fox scats collected from the 6 islands. These are listed in Appendix A along with their scientific names. Also found were a number of non-food items, many of which likely were ingested incidentally along with food items. Non-food items included grass, twigs, pieces of other vegetation, soil, pebbles, and anthropogenic items such as pieces of plastic and fibers from burlap used to cover fox traps. Island fox hairs were occasionally found in scats and were presumed to have been ingested during self- or allo-grooming.

Across all 6 islands, 14 items occurred with a frequency ≥ 10% in annual fox diets (Table 2). These items were deer mice, lizards, beetles (comprising multiple species), beetle larvae, Jerusalem crickets, silk-spinning sand crickets, grasshoppers, earwigs, terrestrial snails, and fruits of toyon, manzanita, prickly pear cactus, ice plant, and Australian saltbush. The number of items with a frequency ≥ 10% ranged from 4 on Santa Rosa to 7 on San Miguel. Concordantly, annual dietary diversity was highest on San Miguel and lowest on Santa Rosa, based on the Shannon index (Table 2). Of the 14 items above, beetles were primary foods in annual diets on all 6 islands while 5 items were a primary food on just 1 island each (lizards and grasshoppers on San Miguel; beetle larvae on San Clemente; manzanita on Santa Cruz; Australian saltbush on San Nicolas). Based on the use of items occurring with a frequency ≥ 10%, annual diets were most similar (R_o = 0.74) between San Miguel and Santa Rosa, and least similar (R_o = 0.20) between San Nicolas and Santa Catalina (Table 3).

Table 2. Food items occurring with a frequency ≥ 10% in annual island fox diets during 2009.

Food items / Frequency of occurrence (%)											
San Clemente		**San Nicolas**		**Santa Catalina**		**San Miguel**		**Santa Rosa**		**Santa Cruz**	
Beetle	62.6	Beetle	64.3	Toyon	60.1	Beetle	68.6	Deer mouse	64.0	Manzanita	48.4
Beetle larva	33.9	Snail	45.2	Prickly pear	33.5	Jerusalem cricket	60.1	Jerusalem cricket	51.5	Jerusalem cricket	35.6
Deer mouse	30.3	Ice plant	35.0	Jerusalem cricket	24.7	Deer mouse	54.2	Beetle	50.7	Beetle	30.6
Snail	20.1	Earwig	32.5	Beetle	24.5	Ice plant	41.8	Earwig	30.7	Toyon	30.6
Prickly pear	17.8	Australian saltbush	21.1	Deer mouse	18.6	Sand cricket	26.5			Earwig	25.6
		Sand cricket	18.9			Lizard	17.3			Summer holly	17.2
						Grasshopper	17.2				
H'	**0.64**		**0.73**		**0.66**		**0.79**		**0.59**		**0.69**
Scats	**433**		**560**		**388**		**577**		**505**		**180**

Table 3. Horn's index of similarity for pair-wise comparisons between islands for annual island fox diets during 2009.

	Horn's similarity indices				
	Sn. Nicolas	**Sta. Catalina**	**Sn. Miguel**	**Sta. Rosa**	**Sta. Cruz**
Sn. Clemente	0.51	0.52	0.50	0.55	0.24
Sn. Nicolas	-	0.20	0.52	0.44	0.37
Sta. Catalina	-	-	0.49	0.56	0.59
Sn. Miguel	-	-	-	0.74	0.41
Sta. Rosa	-	-	-	-	0.58

For food items grouped into 5 categories (Figure 2), annual fox diets differed significantly among islands ($\chi^2 = 2450$, 20 df, $P < 0.0001$). Insects clearly were important foods on all islands. Native fruits were important foods on Santa Catalina (toyon and prickly pear cactus) and Santa Cruz (manzanita and toyon) while non-native fruits were important foods on San Nicolas (ice plant and Australian saltbush) and San Miguel (ice plant). Deer mice were important foods on Santa Rosa and San Miguel whereas other items (e.g., terrestrial snails but other items as well) were important foods on San Nicolas and San Clemente.

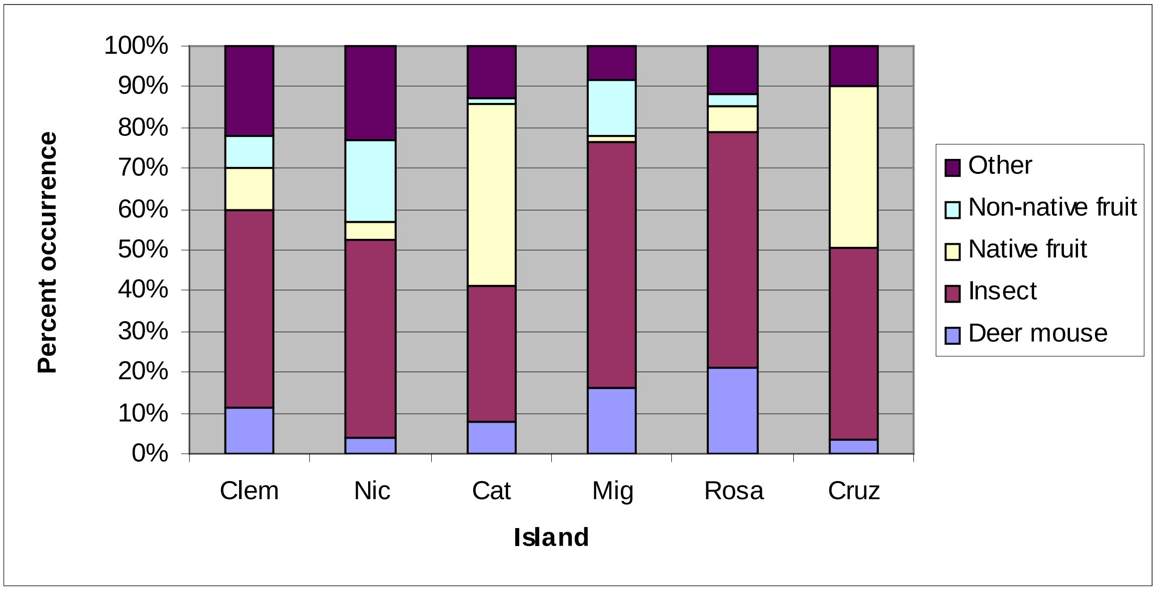

Figure 2. Use of food items (grouped into 5 categories) by island foxes during 2009.

SEASONAL FORAGING PATTERNS

San Clemente

On San Clemente, 430 scats were collected and 11 items occurred with a frequency ≥ 10% in seasonal fox diets (Table 4). These items were deer mice, lizards, beetles, beetle larvae, silk-spinning sand crickets, earwigs, terrestrial snails, marine crustaceans, and fruits of prickly pear cactus, ice plant, and Australian saltbush. The number of items with a frequency ≥ 10% ranged from 4 in winter to 8 in fall. Concordantly, dietary diversity was highest in fall and lowest in winter, based on the Shannon index (Table 4). Of the 11 items above, deer mice, beetles, and beetle larvae were primary foods in all 4 seasons while 3 items were a primary food in just 1 season each (earwigs and Australian saltbush in spring; sand crickets in fall).

Table 4. Food items occurring with a frequency ≥ 10% in seasonal island fox diets on San Clemente during 2009.

	Food items / Frequency of occurrence (%)							
	Winter		**Spring**		**Summer**		**Fall**	
	Deer mouse	54.1	Beetle	54.2	Beetle	98.8	Beetle	75.7
	Beetle	35.3	Beetle larva	38.2	Beetle larva	57.0	Snail	38.3
	Beetle larva	20.3	Deer mouse	30.4	Snail	41.9	Prickly pear	43.9
	Lizard	15.8	Lizard	22.4	Ice plant	39.5	Beetle larva	28.0
			Australian saltbush	15.9	Crustacean	19.8	Ice plant	25.2
			Earwig	15.0	Prickly pear	14.0	Crustacean	22.4
					Deer mouse	10.5	Deer mouse	15.9
							Sand cricket	12.2
H'	**0.64**		**0.73**		**0.74**		**0.82**	
Scats	**133**		**107**		**86**		**107**	

For food items grouped into 5 categories (Figure 3), fox diet on San Clemente differed significantly among seasons ($\chi^2 = 142.7$, 12 df, $P < 0.0001$). Insects, especially beetles, were clearly important foods in all seasons. Native fruits were important foods in winter and fall (prickly pear cactus) while non-native fruits (ice plant) were important foods in summer. Deer mice were important foods in winter and spring whereas other items collectively were important foods in all 4 seasons.

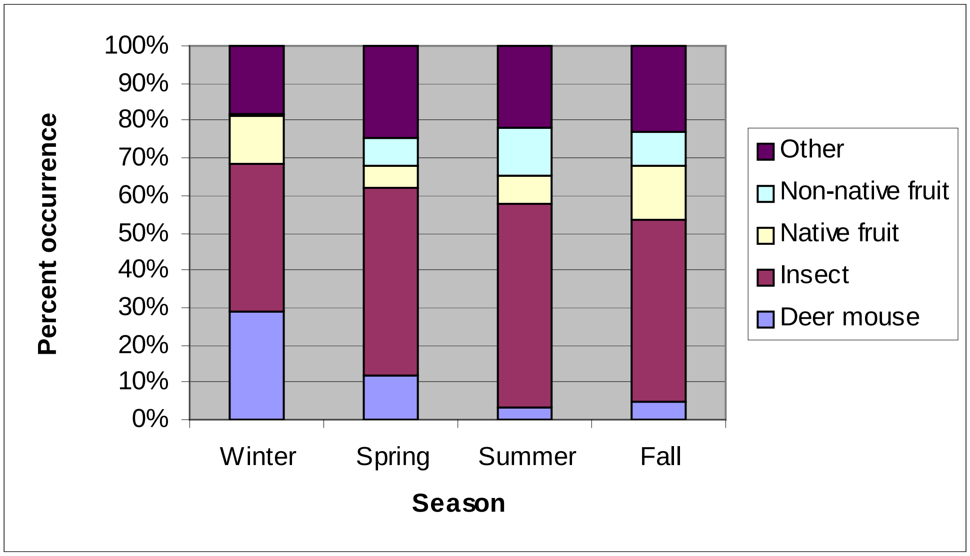

Figure 3. Seasonal use of food items (grouped into 5 categories) by island foxes on San Clemente during 2009.

San Nicolas

On San Nicolas, 560 scats were collected and 13 items occurred with a frequency ≥ 10% in seasonal fox diets (Table 5). These items were deer mice, lizards, beetles, beetle larvae, Jerusalem crickets, silk-spinning sand crickets, grasshoppers, earwigs, terrestrial snails, and fruits of prickly pear cactus, ice plant, Australian saltbush, and myoporum. The number of items with a frequency ≥ 10% ranged from 4 in winter to 9 in summer. Concordantly, dietary diversity was highest in summer and lowest in winter, based on the Shannon index (Table 5). Of the 12 items above, beetles, snails, and ice plant fruits were primary foods in all 4 seasons while 6 items were a primary food in just 1 season each (lizards in spring; beetle larvae in winter; grasshoppers and myoporum fruits in summer; Jerusalem crickets and prickly pear cactus fruits in fall).

Table 5. Food items occurring with a frequency ≥ 10% in seasonal island fox diets on San Nicolas during 2009.

	Food items / Frequency of occurrence (%)							
	Winter		**Spring**		**Summer**		**Fall**	
	Beetle	84.9	Beetle	67.4	Ice plant	56.1	Snail	57.4
	Snail	35.3	Snail	47.9	Beetle	48.0	Beetle	57.4
	Beetle larva	29.5	Earwig	47.2	Snail	41.2	Earwig	55.8
	Ice plant	10.1	Ice plant	31.9	Sand cricket	31.8	Australian saltbush	46.5
			Deer mouse	19.4	Australian saltbush	31.8	Ice plant	57.4
			Lizard	16.7	Myoporum	22.3	Sand cricket	39.5
					Earwig	21.6	Prickly pear	27.1
					Grasshopper	18.9	Jerusalem cricket	18.6
					Deer mouse	12.2		
H'	**0.46**		**0.73**		**0.91**		**0.88**	
Scats	**139**		**144**		**148**		**129**	

For food items grouped into 5 categories (Figure 4), fox diet on San Nicolas differed significantly among seasons ($\chi^2 = 155.0$, 12 df, $P < 0.0001$). Insects were important foods in all seasons. Native fruits collectively were used in low frequencies while non-native fruits, particularly ice plant and Australian saltbush, were important foods in spring, summer, and fall. Deer mice also were used in relatively low frequencies in all seasons whereas other items, particularly terrestrial snails, were important foods in all 4 seasons.

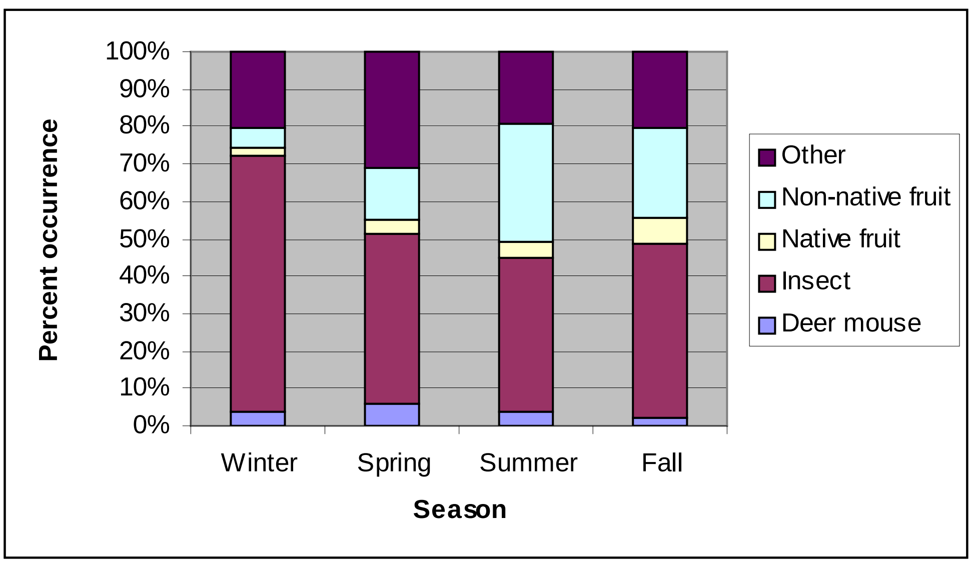

Figure 4. Seasonal use of food items (grouped into 5 categories) by island foxes on San Nicolas during 2009.

Santa Catalina

On Santa Catalina, 388 scats were collected and 9 items occurred with a frequency ≥ 10% in seasonal fox diets (Table 6). These items were deer mice, lizards, beetles, Jerusalem crickets, earwigs, and fruits of toyon, prickly pear cactus, manzanita, and island redberry. The number of items with a frequency ≥ 10% ranged from 4 in spring to 7 in summer and fall. Concordantly, dietary diversity was highest in summer and lowest in spring, based on the Shannon index (Table 6). Of the 9 items above, deer mice, beetles, Jerusalem crickets, and toyon fruits were primary foods in all 4 seasons while 3 items were a primary food in just 1 season each (manzanita and island redberry fruits in summer; lizards in fall).

Table 6. Food items occurring with a frequency ≥ 10% in seasonal island fox diets on Santa Catalina during 2009.

	Food items / Frequency of occurrence (%)							
	Winter		**Spring**		**Summer**		**Fall**	
	Toyon	87.9	Toyon	92.5	Toyon	48.0	Prickly pear	88.3
	Jerusalem cricket	31.3	Jerusalem cricket	22.6	Prickly pear	29.4	Beetle	36.2
	Beetle	18.2	Beetle	21.5	Beetle	22.6	Jerusalem cricket	29.8
	Deer mouse	17.2	Deer mouse	18.3	Deer mouse	22.6	Earwig	17.0
	Earwig	16.2			Manzanita	21.6	Deer mouse	16.0
	Prickly pear	14.1			Jerusalem cricket	15.7	Lizard	15.1
					Island redberry	12.8	Toyon	11.7
H'	**0.66**		**0.48**		**0.81**		**0.73**	
Scats	**99**		**93**		**102**		**94**	

For food items grouped into 5 categories (Figure 5), differences among seasonal fox diets on Santa Catalina were marginally significant (χ^2 = 21.11, 12 df, P = 0.0501). Collectively, native fruits were important foods in all seasons, as were insects. Deer mice were most important in summer. Non-native fruits were used very infrequently, and other items collectively were important foods in all 4 seasons.

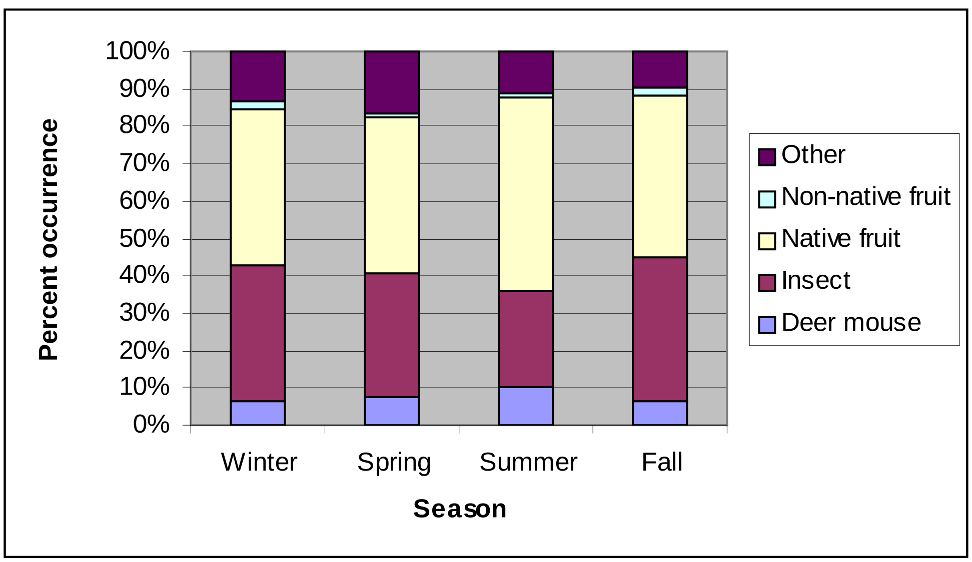

Figure 5. Seasonal use of food items (grouped into 5 categories) by island foxes on Santa Catalina during 2009.

San Miguel

On San Miguel, 577 scats were collected and 9 items occurred with a frequency ≥ 10% in seasonal fox diets (Table 7). These items were deer mice, lizards, beetles, beetle larvae, Jerusalem crickets, sand crickets, grasshoppers, earwigs, and fruits of ice plant. The number of items with a frequency ≥ 10% ranged from 5 in winter to 9 in spring. Concordantly, dietary diversity was highest in spring and lowest in winter, based on the Shannon index (Table 7). Of the 9 items above, deer mice, beetles, Jerusalem crickets, and sand crickets were primary foods in all 4 seasons while 1 item was a primary food in just 1 season (beetle larvae in spring).

Table 7. Food items occurring with a frequency ≥ 10% in seasonal island fox diets on San Miguel during 2009.

	Food items / Frequency of occurrence (%)							
	Winter		**Spring**		**Summer**		**Fall**	
	Jerusalem cricket	63.1	Beetle	67.3	Beetle	80.8	Jerusalem cricket	75.0
	Beetle	58.2	Deer mouse	58.0	Ice plant	80.8	Beetle	67.9
	Deer mouse	54.6	Jerusalem cricket	56.0	Deer mouse	47.3	Deer mouse	57.1
	Sand cricket	31.2	Ice plant	56.0	Jerusalem cricket	47.3	Sand cricket	47.9
	Earwig	14.9	Beetle larva	28.7	Lizard	26.7	Grasshopper	36.4
			Lizard	27.3	Grasshopper	20.6	Ice plant	25.0
			Sand cricket	16.0	Sand cricket	11.6	Earwig	12.1
			Earwig	12.0				
			Grasshopper	10.7				
H'	0.66		0.88		0.77		0.79	
Scats	141		150		146		140	

For food items grouped into 5 categories (Figure 6), fox diet on San Miguel differed significantly among seasons (χ^2 = 155.0, 12 df, $P < 0.0001$). Insects were important foods in all seasons, as were deer mice. Native fruits collectively were used in low frequencies while non-native fruits, particularly ice plant, were important foods in spring and summer. Other items (e.g., lizards) were important foods in spring and summer, and snails occurred in scats at a low frequency (2.1-9.9%) in all seasons.

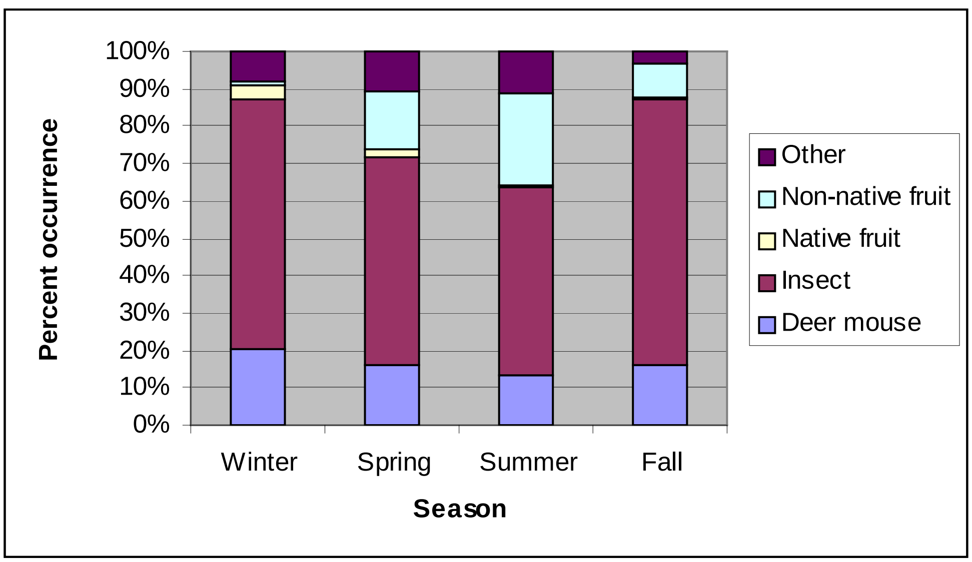

Figure 6. Seasonal use of food items (grouped into 5 categories) by island foxes on San Miguel during 2009.

Santa Rosa

On Santa Rosa, 505 scats were collected and 13 items occurred with a frequency ≥ 10% in seasonal fox diets (Table 8). These items were deer mice, ungulates, birds, lizards, beetles, beetle larvae, Jerusalem crickets, grasshoppers, earwigs, marine crustaceans, and fruits of toyon, manzanita, and Australian saltbush. The number of items with a frequency ≥ 10%

ranged from 6 in fall to 9 in summer. Dietary diversity was highest in spring and lowest in fall, based on the Shannon index (Table 8). Of the 13 items above, deer mice, beetles, Jerusalem crickets, and earwigs were primary foods in all 4 seasons while 4 items were a primary food in just 1 season each (ungulates in winter; marine crustaceans and manzanita in summer; Australian saltbush in fall).

Table 8. Food items occurring with a frequency ≥ 10% in seasonal island fox diets on Santa Rosa during 2009.

	Food items / Frequency of occurrence (%)							
	Winter		**Spring**		**Summer**		**Fall**	
	Deer mouse	66.7	Deer mouse	66.0	Deer mouse	68.2	Jerusalem cricket	72.0
	Beetle	64.8	Beetle	54.0	Jerusalem cricket	55.0	Deer mouse	56.7
	Jerusalem cricket	31.5	Jerusalem cricket	34.7	Beetle	38.4	Beetle	54.7
	Toyon	29.6	Beetle larva	34.7	Lizard	16.6	Earwig	51.3
	Ungulate	20.4	Earwig	33.3	Earwig	13.9	Grasshopper	26.0
	Bird	20.4	Toyon	26.7	Crustacean	11.9	Australian saltbush	10.7
	Earwig	13.0	Bird	12.7	Beetle larva	11.3		
			Lizard	10.0	Grasshopper	10.6		
					Manzanita	10.6		
H'	**0.78**		**0.84**		**0.83**		**0.72**	
Scats	**54**		**150**		**151**		**150**	

For food items grouped into 5 categories (Figure 7), fox diet on Santa Rosa differed significantly among seasons ($\chi^2 = 94.35$, 12 df, $P < 0.0001$). Insects were important foods in all seasons, as were deer mice. In comparison, fruits were less important and their use was greatest in winter and spring. Other items collectively were important foods in winter, spring, and summer.

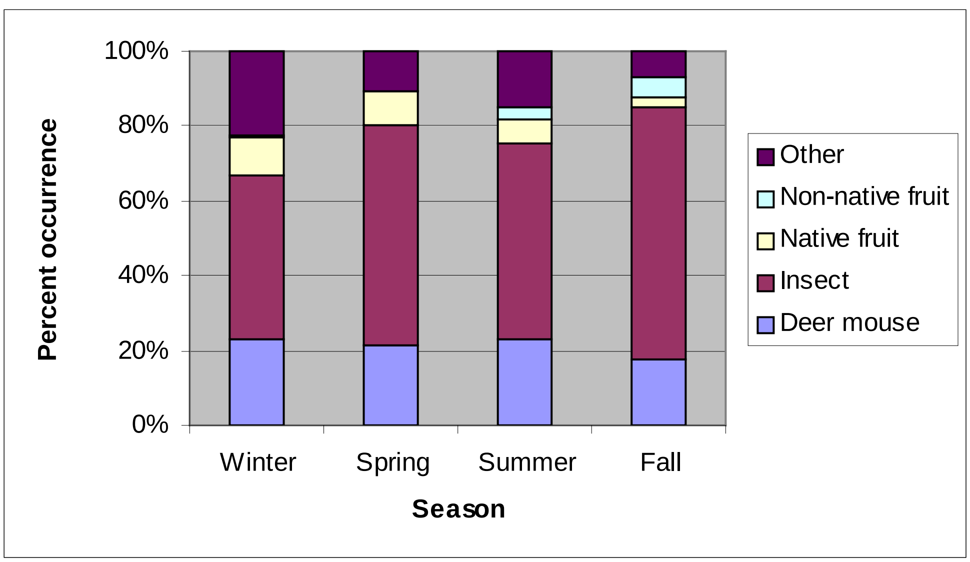

Figure 7. Seasonal use of food items (grouped into 5 categories) by island foxes on Santa Rosa during 2009.

Santa Cruz

On Santa Cruz, 180 scats were collected and 10 items occurred with a frequency ≥ 10% in seasonal fox diets (Table 9). These items were deer mice, lizards, beetles, Jerusalem crickets, grasshoppers, earwigs, and fruits of toyon, manzanita, summer holly, and oak (acorns). The number of items with a frequency ≥ 10% ranged from 5 in winter to 8 in spring. Concordantly, dietary diversity was highest in spring and lowest in winter, based on the Shannon index (Table 9). Of the 10 items above, beetles, Jerusalem crickets, toyon fruits, and manzanita fruits were primary foods in all 4 seasons while 4 items were a primary food in just 1 season each (lizards, deer mice, and acorns in spring; grasshoppers in summer).

Table 9. Food items occurring with a frequency ≥ 10% in seasonal island fox diets on Santa Cruz during 2009.

	Food items / Frequency of occurrence (%)							
	Winter		**Spring**		**Summer**		**Fall**	
	Toyon	71.4	Jerusalem cricket	51.4	Manzanita	44.2	Earwig	58.1
	Jerusalem cricket	50.0	Beetle	40.0	Jerusalem cricket	27.9	Beetle	32.3
	Earwig	42.9	Manzanita	40.0	Summer holly	27.9	Manzanita	29.0
	Beetle	35.7	Toyon	37.1	Beetle	24.4	Jerusalem cricket	25.8
	Manzanita	10.7	Earwig	31.4	Toyon	19.8	Summer holly	19.4
			Lizard	25.7	Grasshopper	11.6	Toyon	16.1
			Deer mouse	20.0				
			Acorn	14.3				
H'	**0.64**		**0.87**		**0.77**		**0.74**	
Scats	**28**		**35**		**86**		**31**	

For food items grouped into 5 categories (Figure 8), fox diet on Santa Cruz differed significantly among seasons (χ^2 = 24.9, 12 df, P = 0.0037). Insects and native fruits were important foods in all seasons. Deer mice and other items were not particularly important in any season, and both were used the most in spring.

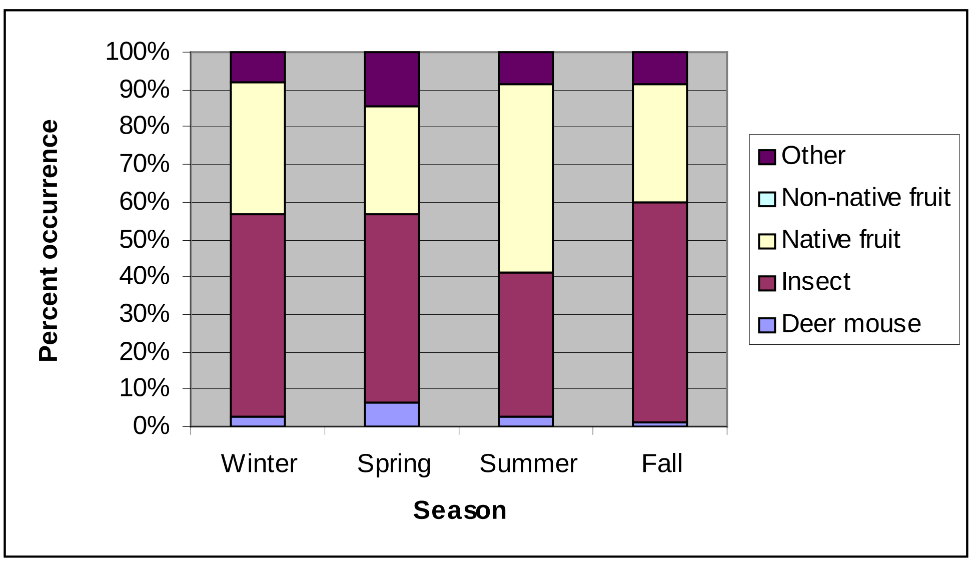

Figure 8. Seasonal use of food items (grouped into 5 categories) by island foxes on Santa Cruz during 2009.

Use of Non-Native Items

Foxes consumed non-native food items on all islands, although the contribution of these items to annual diets varied considerably among islands (Figure 9). The proportion of non-native food item occurrences ranged from 7.6% on Santa Catalina to 44.7% on San Nicolas. Non-native food items included ungulates (mule deer and elk), rats, house mice, European earwigs, European garden snails, and fruits of ice plant, Australian saltbush, myoporum, pepper tree, carob tree, and palm. Additionally, evidence of anthropogenic foods (e.g., food wrappers) was found in 2 scats from Santa Catalina and 1 scat each from San Clemente and Santa Rosa.

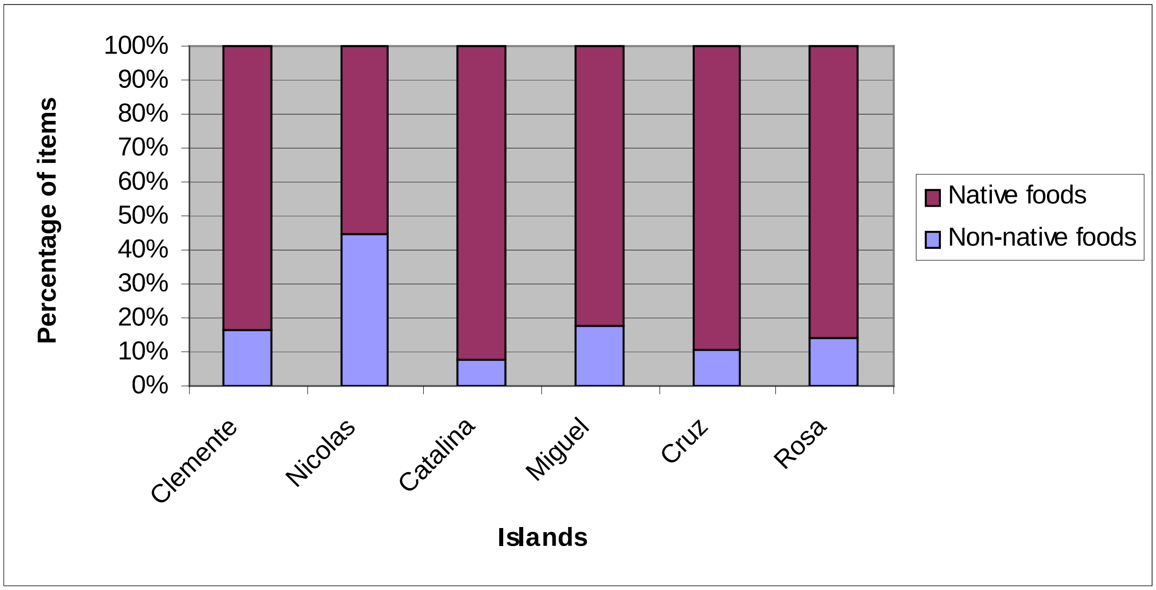

Figure 9. Proportion of non-native foods in annual diets of island foxes in 2009.

Among annual diets, 4 of the 6 primary items consumed by foxes on San Nicolas were non-native (Table 2). In contrast, no primary items were non-native on Santa Catalina, and only 1 was non-native on each of the other 4 islands. Among seasonal diets, non-native foods were the most frequently occurring items in summer (ice plant fruits) and fall (snails) on San Nicolas, and in fall (earwigs) on Santa Cruz. Non-native foods were primary items (frequency ≥ 10%) in 2 seasons on Santa Catalina, 3 seasons on San Clemente and Santa Cruz, and 4 seasons on San Nicolas, San Miguel, and Santa Rosa (Tables 4-9).

DISCUSSION

Food Items

Island foxes exhibit euryphagus, omnivorous, and opportunistic foraging patterns (Moore and Collins 1995, Roemer 1999, Coonan et al. 2010). These general patterns are consistent with those of many other fox species, particularly closely related gray foxes (*Urocyon cinereoargenteus*; Cypher 2003). Island foxes exploit a wide variety of food items including vertebrates, invertebrates, and fruits. The dietary differences observed among islands and seasons reflect a functional response on the part of foxes to spatial and temporal variation in food item availability. Variation among islands and seasons also was reported by Laughrin (1977). This response is consistent with an opportunistic, generalist foraging strategy (Stephens and Krebs 1986).

Among all of the North American foxes, island foxes consume the least amount of vertebrate prey, probably due to depauperate rodent communities on the Channel Islands (Wenner and Johnson 1980). Deer mice were consumed by foxes on all islands, and were a particularly important food item on Santa Rosa, San Miguel, San Clemente, and Santa Catalina. Deer mice also were found to be important island fox foods in previous studies (Laughrin 1977, Collins 1980). Deer mice are fairly ubiquitous with regards to habitat (Schwemm 2008) and generally are available throughout each island.
Other mammals generally occurred only infrequently in fox diets. Introduced deer and elk are present on Santa Rosa while introduced deer are present on Santa Catalina. The ungulates are harvested on both islands. Ungulate remains were present in fox scats in all seasons on both islands. Remains sometimes consisted of hair and bone, and other times consisted of a black, tar-like substance, which is indicative of foxes consuming "gut piles" resulting from hunters dressing out harvested animals. Additionally, ungulates mortally wounded during harvests that are not subsequently recovered by hunters also serve as a potential food source for foxes. Consequently, ungulate remains generally occurred most frequently in the fall and winter, concomitant with harvest seasons. Ungulates even constituted a primary item in fox diets in winter on Santa Rosa (Table 8). Ungulate carcasses and organ remains constitute an energy dense food source with relatively low associated capture or handling costs, and therefore it is not surprising that foxes would readily exploit this resource. Laughrin (1973, 1977) reported use of livestock carrion by foxes when available.

Other mammals consumed by foxes included California ground squirrels, pinnipeds, island spotted skunks, rats, house mice, and a bat. Use of California ground squirrels, harvest mice (*Reithrodontomys megalotis*), California voles (*Microtus californicus*), rats, and house mice has been reported previously (von Bloeker 1967, Laughrin 1973). Ground squirrels are only present on Santa Catalina and were consumed in all seasons. This consistent use with seasonal frequencies in scats ranging from 2.0% in summer to 8.6% in spring suggests that the squirrels were more than just incidental items in the diet. Pinnipeds occur on all islands, but are particularly abundant on San Nicolas and San Miguel where large, multi-species rookeries have been established. Pinnipeds were detected in scats from San Nicolas, San Miguel, San Clemente, and Santa Catalina, although the number of occurrences in any season never exceeded 5. Predation on pinnipeds by foxes is unlikely. Instead, foxes probably scavenged dead pinnipeds or consumed pieces of molted pelts. Laughrin (1977) also reported use of marine mammals by foxes. Island spotted skunks only occur on Santa Rosa and Santa Cruz. Skunks occurred in 3 summer scats from Santa Cruz, and in 3 summer and 4 fall scats from Santa Rosa. Skunks may be consumed more as a result of competitive interactions than direct predation (Jones et al. 2008). Similarly, the low occurrences of rat, house mouse, and bat indicate that these also were opportunistically consumed items.

Birds were consistently consumed by foxes on all islands and in all seasons. It is unclear whether they were consumed opportunistically as encountered or specifically hunted. Birds were primary items in winter and spring on Santa Rosa (Table 8), and occurred in >5% of scats in at least 1 season on all islands except San Clemente suggesting that foxes may have specifically hunted birds. Bird remains commonly consisted of non-descript feathers and therefore species identification was not possible. Foxes could have preyed on ground-dwelling birds and nestlings in ground or arboreal nests (island foxes are excellent climbers; Coonan et al. 2010), or scavenged dead birds washed up on shorelines. Remains of ground nesting birds were found in scats from San Miguel, Santa Cruz, and San Nicolas and included horned larks (*Eremophila alpestris*), western meadowlarks (*Sturnella neglecta*), and chukars (*Alectoris chukar*) (Laughrin 1977, Collins 1980, Moore and Collins 1995).

Lizards occurred in fox scats from all islands and most seasons. Indeed, lizards were primary items in fox diets in 1 or more seasons on all islands, and therefore constituted an important food item for foxes. At least 2 lizard species occur on each island with 5 occurring on Santa Catalina (Schoenherr et al. 1999). Low frequency use of reptiles by island foxes has been reported previously (Moore and Collins 1995, Crowell 2001), including consumption of snakes. However, only lizard remains were detected in the current study.

Insects were extremely important food items for foxes on all islands and in all seasons. When using frequency of occurrence of items in scats, the contributions of small food items like insects can be over-estimated in canid diets if such items occur frequently but comprise a relatively small proportion of scat contents (e.g., Cypher 1991). However, that generally was not the case in the island fox scats where insect parts commonly comprised a significant proportion of each scat. Insects occur in apparent abundance on all islands, involve low foraging costs, and are highly nutritious. Thus, energetically, selective feeding on insects constitutes an optimal foraging strategy for island foxes.

Beetles and beetle larvae were very common food items. Beetles were not identified to species, but darkling beetles (Family Tenebrionidae) and ten-lined June beetles (*Polyphylla decemlineata*) were commonly detected. Doyen (1974) identified at least 9 different beetle species in fox scats collected in spring on San Clemente. Jerusalem crickets, silk-spinning sand crickets, and grasshoppers also were frequently consumed items on most islands. These Orthopterans appear to be particularly important foods, as has been reported previously (Laughrin 1977, Collins 1980, Crowell 2001). Non-native European earwigs are now ubiquitous and abundant throughout North America, including the Channel Islands (Langston and Powell 1975). This insect occurred commonly in scats from all islands and appears to be a relatively important food for island foxes. Other insects detected included cockroaches, fly larvae (i.e., maggots – probably from carrion), dragon flies, Lepidopteran larvae (i.e., caterpillars), wasps, and ants (ants likely were consumed incidentally with other foods). All of these other insects were only infrequently detected and therefore were likely consumed opportunistically as encountered.

Other invertebrates also were detected in fox diets. Crustaceans, including beach hoppers (*Orchestoidea californiana*) and mole crabs (*Emerita analoga*) as well as other unidentified crabs, were frequently consumed by foxes and indicate that foxes may commonly forage along shorelines. European garden snails are present on most islands and commonly occur in association with ice plant. Indeed, these snails were primarily found in scats from the 3 islands where ice plant fruits also were frequently consumed – San Nicolas, San Clemente, and San Miguel. The snails constituted particularly important food items on San Nicolas and San Clemente. Garcelon and Hudgens (2008) suggested that snails might be particularly important for older foxes.

Fruits from a number of plant species were consumed in abundance on all islands and in most seasons. Thus, fruit constitutes a significant component of fox diets, as has been reported previously (Laughrin 1977, Moore and Collins 1995, Crowell 2001). The species of fruit consumed varied depending upon the species present on each island, and included both native and non-native species. Among native species, prickly pear cactus, toyon, and manzanita fruits were important foods for foxes on 3 islands each. Island redberry, summer holly, and acorns each were important foods on 1 island. One or more native fruits were important foods on all islands except San Miguel, where no native fruits were detected in island fox scats. Lemonade berry was occasionally detected in scats from San Clemente, Santa Cruz, San Nicolas, and Santa Rosa.

Island foxes commonly exploited non-native fruits on all islands except Santa Cruz and Santa Catalina. Australian saltbush fruit constituted an important food on 3 islands (San Clemente, San Nicolas, and Santa Rosa). Likewise, ice plant fruit was an important food on 3 islands (San Clemente, San Nicolas, and San Miguel). Myoporum was an important seasonal food on San Nicolas. Australian saltbush was detected at low frequencies in scats on Santa Cruz while palm, carob, ice plant, and pepper tree were detected at low frequencies on Santa Catalina.

ISLANDS

Island-specific availability of food items strongly influenced foraging patterns by foxes. Some items are ubiquitous and abundant on all or most of the islands, and these were routinely exploited by foxes. These items included deer mice, lizards, Jerusalem crickets, beetles, and earwigs. Each of these items constituted primary foods in 1 or more seasons on at least 5 islands. Other items were only present in abundance on 2 or 3 islands, but were readily exploited where available. These items mostly were fruits and included toyon and manzanita on Santa Catalina, Santa Rosa, and Santa Cruz; prickly pear cactus on San Clemente and Santa Catalina; ice plant on San Clemente, San Nicolas, and San Miguel; and Australian saltbush on San Clemente, San Nicolas, and Santa Rosa. One non-fruit exception may have been European snails, which were consumed in abundance on San Clemente and San Nicolas. Use of other foods probably was mediated by their relative abundance on each island and by their abundance relative to that of other food items, particularly the commonly exploited ones listed above.

The presence and abundance of food items on each island is a function of several factors, including island size, distance from the mainland, precipitation patterns, topographic complexity, and disturbance history. Based on the principles of island biogeography, larger islands have an inherent capacity to support more species (MacArthur and Wilson 1967), and concomitantly, a greater diversity of potential food items for foxes. Also, islands with greater topographic complexity and higher precipitation levels tend to support a greater diversity of vegetation and habitats, which again increases the number of potential food items for foxes. Finally, historic and current disturbances can reduce the number of potential food items by reducing ecosystem complexity or even completely eliminating certain habitat types and associated resources. Such disturbances include fire and introductions of invasive plants and animals, particularly larger grazing species such as goats, sheep, and pigs that can increase rapidly and significantly impact ecological communities (e.g., Donlan et al. 2002).

San Clemente is a moderately sized island with a fair amount of topographic complexity (Table 1). The island is owned and managed by the U.S. Navy. This island has been used for live-fire exercises and these activities certainly have impacted the ecosystem. However, more significant impacts have resulted from grazing by feral goats and pigs (Schoenherr et al. 1999). Intensive grazing by these non-native animals essentially defoliated large portions of the island. The ecological communities on the island were markedly impacted and reduced, and the distribution of woodlands and shrublands were severely restricted to certain deep canyons. Consequently, island foxes on San Clemente consumed few native fruits. The exception is prickly pear cactus, which apparently was less palatable to the goats and pigs, and therefore expanded considerably in abundance and distribution with the elimination of competing vegetation.

San Nicolas is a smaller island with relatively low topographic complexity (Table 1). This island also is owned and managed by the U.S. Navy, and is used for weapons testing, although most munitions are fired from the island to off-shore aerial or marine targets. In the 1800s, sheep were brought to the island and at one time exceeded 30,000 in number. The severe grazing by the sheep defoliated much of the island and caused severe erosion. The Navy attempted to control the erosion by aerial spreading of fertilizers and non-native grasses. As a result of all these disturbances, San Nicolas has the least diverse flora, about half of which is non-native (Schoenherr et al. 1999). Most trees and shrubs were eliminated by the sheep. Consequently, native fruits are generally unavailable to foxes. However, several non-native fruit-producing plants are well established on the island and were used extensively by the foxes, including ice plant, Australian saltbush, and myoporum. Also, European garden snails are common on the island, mostly in association with ice plant, and were used extensively by the foxes. Thus, fox diets on San Nicolas had the largest proportion of non-native items, and the dependence of foxes on these items may be significant.

Santa Catalina is a large and topographically complex island (Table 1). Most of the island is owned and managed by the Catalina Island Conservancy, but 2 large towns (Avalon and Twin Harbors) and several smaller settlements also are present on the island. Introduced animals include goats, pigs, bison (*Bison bison*), and mule deer (Schoenherr et al. 1999). These species have significantly impacted native flora, although these impacts were not as devastating as on other islands. Catalina retains high floristic diversity with many fruit-producing species. Consequently, use of fruits by foxes was highest on Santa Catalina, and most fruits used were from native species. Toyon was used extensively by the foxes, as was prickly pear cactus, which may have increased in abundance as a result of grazing by the introduced animals. Use of non-native resources was lowest on Santa Catalina.

San Miguel is a small island with relatively low topographic complexity (Table 1). The island is owned and managed by the National Park Service. Vegetation on the island has been significantly altered by past over-grazing and military activities. Due to these disturbances, along with small size and farther distance from the mainland, the island has low floristic diversity, including few trees or shrubs (Schoenherr et al. 1999). Consequently, the only fruit consumed in abundance was that of non-native ice plant. Foxes on San Miguel appear to rely extensively on insects.

Santa Rosa is a large and topographically complex island (Table 1). This island also is owned and managed by the National Park Service. Past grazing by cattle and sheep have altered the vegetation considerably (Schoenherr et al. 1999), and a large herd of non-native deer and elk are still present on the island. Fruit use by foxes was lowest on Santa Rosa, but toyon and manzanita still were important foods seasonally, as was non-native Australian saltbush. Also, annual harvests of deer and elk are conducted on the island, and the foxes obviously scavenged unrecovered carcasses and gut piles when available. However, all deer and elk are mandated to be removed from Santa Rosa, possibly as early as 2011 (U.S. Fish and Wildlife Service in press), after which this resource will no longer be available to foxes.

Santa Cruz is the largest of the islands, topographically complex, and floristically most diverse (Table 1). Most of the island is owned and managed by The Nature Conservancy with the remainder owned and managed by the National Park Service. Extensive grazing and disturbance by various non-native animals (e.g., goats, sheep, and pigs) has altered the vegetation (Schoenherr et al. 1999), but considerable native components of the ecosystem have remained intact. Consequently, a diversity of native fruits are available and are exploited by foxes, including toyon, manzanita, summer holly, and acorns. Fruit use by foxes on Santa Cruz was second only to that on Santa Catalina, and use of non-native fruits was limited to 1 occurrence of Australian saltbush. Indeed, use of non-native items was relatively low on Santa Cruz compared to most other islands, and consisted almost entirely of European earwigs, which were primary food items in most seasons. One caveat, fewer scat samples were available for Santa Cruz relative to other islands, and the results presented for this large island may not constitute a completely accurate representation of fox diet.

FOOD PREFERENCES, NON-NATIVE ITEMS, AND HABITAT RESTORATION

Island foxes clearly are able to exploit a diversity of food items, and diets on all islands included a number of items. Thus, identifying preferred foods can be challenging, particularly in the absence of data on the relative availability of items. However, some observed dietary patterns can provide insights on preferences. The ubiquitous use of deer mice, lizards, Jerusalem crickets, beetles, and earwigs suggests some preference for these items. Such animal foods are composed of a complex of proteins, carbohydrates, and fats, and therefore comprise highly nutritious foods (Robbins 1993). Further evidence of preference for these items might be found in the results from Santa Rosa. A diversity of food items is available on this large island. Furthermore, fox numbers were still relatively low during this study (<400; T. Coonan, NPS, unpublished data) compared to probable historic levels (>1,700; Coonan 2003). Consequently, available food resources on the island were not likely over-exploited by foxes and intra-specific competition for food would have been relatively low. Under these conditions, deer mice, Jerusalem crickets, beetles, and earwigs constituted the primary items in the annual diet. As further evidence of preference for deer mice, use of deer mice by foxes exhibited no detectable seasonality despite the fact that these rodents exhibit marked season variation in abundance (Drost and Fellers 1991, Schwemm 2008).

Certain native fruits also were used extensively by foxes on islands where available. In particular, toyon, manzanita, and prickly pear cactus fruits appeared to be preferred food items. Frequent use of prickly pear cactus and toyon fruits has been reported previously (Moore and Collins 1995, Crowell 2001). When abundant, fruits use is energetically efficient for foxes due to low foraging costs.

Non-native items were used extensively by foxes on some islands. Generally, use of non-native items was highest on the smaller islands: San Clemente, San Nicolas, and San

Miguel. These islands also are the least diverse floristically. Thus, fewer native foods may be available on these islands resulting in foxes more frequently exploiting non-native items. This is particularly true for fruits. Ice plant fruits were frequently consumed by foxes on San Clemente, San Nicolas, and San Miguel while Australian saltbush fruits were frequently consumed on San Clemente and San Nicolas. No native fruits were detected in scats from San Miguel, and the only native fruit consumed on San Clemente and San Nicolas was prickly pear cactus, which actually may have increased in abundance as a result of severe grazing on competing plants by non-native animals (Schoenherr et al. 1999). European snails inhabiting ice plant also were used extensively by foxes on San Clemente and San Nicolas.

Island fox foraging patterns, food preferences, and use of non-native items all have important implications for long-term fox conservation. Island foxes are able to exploit a variety of food items. This dietary plasticity is highly advantageous for the foxes, particularly given the inherent limitations on the number of available food items associated with living in an insular environment. Furthermore, habitat conditions on all of the islands have been degraded, in some cases extensively, primarily by past land uses (e.g., grazing by domestic and feral animals, military activities). Thus, any processes or efforts that improve ecosystem integrity and habitat quality, particularly those that expand habitat diversity and complexity, have the potential to also increase food resources available to foxes. Such actions likely would increase the abundance of preferred food items, and importantly, they also would further increase the diversity of items. Availability of specific items can vary temporally due to cyclic (e.g., precipitation) or stochastic (e.g., disease) processes. For example, many island fox foods may decrease in abundance during drought periods. Fruit crops can vary among years or even fail in non-drought years. Diseases could reduce the abundance of certain prey or fruit-producing species. On a longer time scale, climate change could alter the abundance of various food items. Thus, as the number of available items increases, so does the likelihood that some items will remain sufficiently abundant even if other foods decline in availability. In such an event, foxes would have a greater opportunity to switch and exploit alternate resources. Item diversity can help prevent or reduce food-related population declines and the extinction risks associated with smaller populations.

Actions that could increase food item diversity include habitat protection and restoration. Four islands are entirely or largely managed for conservation, and stringent habitat protections are being implemented on the 2 Navy-owned islands (U.S. Fish and Wildlife Service in press). Many of the past ecosystem insults, particularly over-grazing by non-native animals, have been eliminated or at least mitigated on most islands. Consequently, natural ecosystem recovery is in progress on all islands, and plant and habitat diversity is increasing. On all islands, other management actions, such as fire suppression or limiting public access and uses in natural areas, are helping to prevent further habitat degradation (Coonan 2003, U.S. Fish and Wildlife Service in press). Active restoration also is being conducted on most islands. Such restoration activities include removing remaining non-native grazers (e.g., deer and elk on Santa Rosa), removing invasive non-native plants (e.g., fennel [*Foeniculum vulgare*] on Santa Cruz), protecting native plants from further grazing/browsing (e.g., Santa Catalina), and planting native plants to increase their abundance and distribution (several islands).

On some islands, ecosystem restoration involving the reduction or elimination of non-native species may need to be conducted cautiously to avoid adverse impacts to food supplies for foxes. Fruits from non-native plants comprise significant proportions of fox diets on some islands, particularly San Nicolas, San Miguel, and San Clemente. On these islands, ice plant fruits are routinely consumed by foxes. Thus, any efforts to reduce or remove ice plant should be conducted gradually to allow time for foxes to switch to alternate foods. Preferably, plantings of native fruit-producing plants should be conducted concomitantly with the removal of non-native fruit plants to avoid any reductions in overall food availability. This cautionary note may particularly apply to San Nicolas, where foxes are frequently consuming fruits from 3 non-native plants as well as non-native snails associated with 1 of the plants. Rapid removal of these 4 food items on this island could result in a fox population decline.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The following conclusions can be drawn from this study.

1. Island foxes are exploiting a variety of food items, including both animal and plant, and including both native and non-native.
2. Fox foraging patterns varied among islands, and these variations are probably largely a result of island-specific availability of food items.
3. Fox foraging patterns varied among seasons, probably as a result of seasonal variation in the availability of food items.
4. Foxes may prefer certain food items including deer mice, lizards, Jerusalem crickets, sand crickets, beetles, earwigs, and fruits of toyon, manzanita, and prickly pear cactus.
5. Foxes readily exploited non-native food items, including European earwigs, European garden snails, and fruits of ice plant, Australian saltbush, and myoporum.
6. Foxes may be at least partially dependent on non-native food items on some islands, and therefore, foxes on these islands could be adversely impacted by the rapid reduction or removal of these items.
7. Increasing the diversity of available food items may help to increase the security of fox populations by ensuring more stable food supplies during resource declines associated with cyclic and stochastic events or climate change.

RECOMMENDATIONS

Based on the results of this project, the following recommendations are offered:

1. Protect and restore natural habitats to increase fox food supplies

Habitat protection and restoration are in progress in some fashion on all islands. Such efforts should be continued and enhanced when possible, particularly any efforts that increase native plant and habitat diversity. Such efforts will increase the abundance and diversity of foods for foxes, which in turn will help increase fox population security through the mitigation of food-related population declines.

2. Exercise caution when reducing or eliminating non-native items

Restoring ecosystem health and integrity on the islands will involve the reducing or eliminating non-native species where practicable. On islands where non-native species are being used as significant food items, removal of these species should be conducted cautiously and slowly to avoid adverse impacts to foxes. Ideally, such efforts should be conducted concomitantly with the restoration of native food items to compensate for the loss of the non-native items.

3. Periodically monitor food item use by foxes

Primarily due to recent habitat protections, particularly the removal of most non-native grazing animals, habitat conditions on most islands are changing rapidly, and in some cases, dramatically. Concomitantly, fox abundance also is changing rapidly on some islands, particularly the 4 that experienced recent marked population declines due to predation or disease. Accordingly, the diversity and abundance of foods will change with evolving habitat conditions, and food availability also could change with increasing fox numbers and the associated increase in exploitation pressure on food resources. To better understand these dynamics and gather information that may assist in fox conservation, food item use by foxes should be monitored periodically. Annual monitoring would be ideal, but if funding is limited, longer intervals would still be beneficial.

4. Monitor availability of food resources

Because island foxes use a diversity of foods, monitoring the availability of all food items would not be practical or necessary. However, it might be helpful to annually assess the abundance of certain key foods, such as deer mice, beetles, Jerusalem crickets, sand crickets, and fruits of toyon, manzanita, and prickly pear cactus. Such monitoring probably could be designed in a manner as to not be overly costly or time-consuming. Monitoring the availability of select key items could provide early warnings of food shortages associated with reductions in 1 or more items. Such monitoring concomitant with on-going fox population monitoring would provide insights into the dynamics between resource availability and fox abundance.

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Appendix A. Food items found in island fox scats by island during January-December 2009. Items in red are non-native.

			Island					
	Food item	**Scientific name**	**San Clemente**	**San Nicolas**	**Santa Catalina**	**San Miguel**	**Santa Rosa**	**Santa Cruz**
Mammals	Island fox	*Urocyon littoralis*		X	X		X	X
	Island spotted skunk	*Spilogale gracilis amphiala*					X	X
	Pinnipeds	Family Otariidae or Phocidae	X	X	X	X		
	Deer mouse	*Peromyscus maniculatus*	X	X	X	X	X	X
	Rat	*Rattus spp.*			X			
	House mouse	*Mus musculus*	X		X			X
	California ground squirrel	*Spermophilus beecheyi*			X			
	Ungulate (mule deer or elk)	*Odocoileus hemionus, Cervus elaphus*			X		X	
	Bat	*Myotis spp.*			X			
Other vertebrates	Birds	Species unknown	X	X	X	X	X	X
	Lizards	Species unknown	X	X	X	X	X	X
Insects	Jerusalem cricket	*Stenopalmatus spp.*	X	X	X	X	X	X
	Silk-spinning sand cricket	*Cnemotettix spp.*	X	X	X	X	X	X
	Grasshopper	Order Orthoptera	X	X	X	X	X	X
	Beetle and beetle larva	Order Coleoptera	X	X	X	X	X	X
	Cockroach	Family Blattidae	X	X			X	
	Fly larva	Order Diptera	X	X	X	X		
	Dragon fly	Order Odonata		X	X	X	X	X
	European earwig	*Forficula auricularia*	X	X	X	X	X	X
	Caterpillar	Order Lepidoptera				X		
	Wasp	Order Hymenoptera				X	X	
Other invertebrates	Spider	Order Araneae	X			X	X	
	Crustacean	Crustacea	X	X	X	X	X	X
	European garden snail	*Helix aspersa*	X	X	X	X	X	X
Plant fruits	Acorn (oak)	*Quercus spp.*	X		X			
	Australian saltbush	*Atriplex semibaccata*	X	X		X	X	X
	Carob tree	*Ceratonia siliqua*			X			
	Catalina cherry	*Prunus ilicifolia*			X			
	Ice plant	*Carpobrotus spp., Mesembryanthemum crystallinum*	X	X	X	X	X	
	Island redberry	*Rhamnus pirifolia*			X			X
	Lemonade berry	*Rhus integrifolia*	X	X			X	X
	Manzanita	*Actostaphylos spp.*			X		X	X
	Myoporum	*Myoporum spp.*		X				
	Palm	Family Palmaceae			X			
	Peppertree	*Schinus molle*		X	X			
	Prickly pear cactus	*Opuntia spp.*	X	X	X			X
	Summer holly	*Comarostaphylis diversifolia*			X		X	X
	Toyon	*Heteromeles arbutifolia*	X	X	X		X	X

APPENDIX B. FOOD ITEMS OCCURRING IN ISLAND FOX DIETS DURING OCTOBER-DECEMBER 2008.

Food items occurring with a frequency ≥ 10% in island fox diets during October-December 2008.

Food items / Frequency of occurrence (%)											
San Clemente (74 scats)		San Nicolas (100 scats)		Santa Catalina (118 scats)		San Miguel (36 scats)		Santa Rosa (17 scats)		Santa Cruz (12 scats)	
Deer mouse	96.0	Snail	51.0	Jerusalem cricket	36.4	Deer mouse	75.0	Jerusalem cricket	82.4	Summer holly	75.0
Prickly pear	13.5	Beetle	48.0	Prickly pear	39.8	Jerusalem cricket	66.7	Deer mouse	76.5	Jerusalem cricket	33.3
		Ice plant	36.0	Toyon	30.5	Beetle	27.8	Beetle	52.9	Toyon	33.3
		Earwig	31.0	Island redberry	23.7	Ice plant	13.9	Earwig	52.9	Manzanita	16.7
		Prickly pear	28.0	Beetle	11.0	Sand cricket	11.1	Grasshopper	29.4	Grasshopper	16.7
		Crustacean	24.0	Deer mouse	10.2	Grasshopper	11.1	Toyon	11.8		
		Australian saltbush	15.0					Summer holly	11.8		
		Beetle larva	13.0					Ungulate	11.8		
		Jerusalem cricket	10.0								
		Grasshopper	10.0								

Other food items occurring in scats:

San Clemente:	Jerusalem cricket, sand cricket, beetle, earwig, ice plant
San Nicolas:	Deer mouse, bird, sand cricket, myoporum
Santa Catalina:	Ungulate, California ground squirrel, bird, lizard, grasshopper, earwig, Dipteran
San Miguel:	Bird, earwig, Hymenopteran, Australian saltbush
Santa Rosa:	Bird, Australian saltbush
Santa Cruz:	Deer mouse, bird, beetle, crustacean