ECOLOGICAL MODELLING 195 (2006) 393–401

available at www.sciencedirect.com

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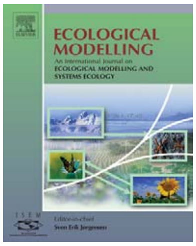

The role of dispersal in Florida Key deer metapopulation dynamics

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ARTICLE INFO

Article history:
Received 13 January 2005
Received in revised form 12 October 2005
Accepted 15 November 2005
Published on line 27 December 2005

Keywords:
Dispersal
Florida Key deer
Metapopulation
Odocoileus virginianus clavium

ABSTRACT

Metapopulation dynamics of species that occur in patchy or island subpopulations are an important consideration in the conservation of endangered species. Key deer (*Odocoileus virginianus clavium*) are endemic to the Florida Keys and occur on 11 island-complexes in the Lower Keys from Big Pine Key to Sugarloaf Key. While deer numbers have increased notably, the majority of the population occurs on two of the islands, Big Pine and No Name Keys. Deer dispersal between islands is possible due to short distances between islands and shallow water. Key deer have been documented to actively disperse between islands but at very low rates (11% males, 3% females). However, increased population densities could possibly increase dispersal rates as island populations on Big Pine and No Name Keys approach carrying capacity. We examined the probability of deer colonization of peripheral islands using a sex- and stage-structured metapopulation model. Our objectives were to (1) evaluate the effects of distance and dispersal rate on Key deer island subpopulations and (2) estimate the probability of Key deer colonizing surrounding islands with viable populations. Results suggest that over the next 20 years, the Key deer population could colonize 6 of the 11 island-complexes with viable populations. However, of the remaining five islands, three lack the resources to support a minimum viable population, and while Cudjoe and Sugarloaf Keys have the potential to support >200 deer each, they are not projected to increase to above 50 deer by 2021 regardless of dispersal rate due to distance from source population.

1. Introduction

Metapopulation theory is commonly applied in the understanding and conservation of endangered species by wildlife conservationists. A metapopulation is a collection of local populations occupying separate patches of habitat in a landscape linked by emigration and immigration (Levin, 1979; Meffe and Carroll, 1997). Though the concept of metapopulation has been studied in the past (e.g., Howe et al., 1991; Rolstad, 1991; Wootton and Bell, 1992; Akçakaya et al., 1995; Dias, 1996; Donovan et al., 1995; Hanski, 1997), few studies have evaluated the metapopulation dynamics of large and long-lived animals (Beier, 1993; Doak, 1995; Harrison and Taylor, 1997; Gaona et al., 1998; Walters, 2001), particularly in landscapes fragmented due to urban development. Landscape fragmentation and habitat deterioration typically result in the establishment of new metapopulations with varying rates of movement between subpopulations (Hanski, 1997).

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doi:10.1016/j.ecolmodel.2005.11.021

The rate of emigration and immigration between subpopulations depends on the species ability to disperse and the juxtaposition of patches. Dispersal plays an important role in the metapopulation dynamics of a species, and can be altered with dramatic landscape changes (e.g., urban development).

The Florida Keys archipelago is a collection of island habitat patches occupied by the endangered Florida Key deer. Previous researchers have described the Key deer as a metapopulation comprised of local island subpopulations in the Lower Florida Keys (Lopez, 2001). Deer dispersal between islands is possible due to short distances and shallow water; however, little is known about the role of dispersal in the Key deer population. Lopez (2001) reported that Key deer actively dispersed between Big Pine and No Name Keys but at very low rates (11% males, 3% females; Lopez, 2001). It is unknown whether Key deer disperse to other islands or at what rates. Understanding Key deer dispersal and its effects on the dynamics of the metapopulation is essential for the management of this endangered species. For example, the colonization of peripheral islands is a necessary step in the recovery of Key deer (USFWS, 1999). By modeling Key deer metapopulation dynamics, we examined the possibility of future colonizations under various dispersal scenarios.

Social animals, such as white-tailed deer, form matrilineal groups where females remain in their natal area. While previous research has shown varying degrees of male deer dispersal, female dispersal is usually rare, even during times of high population density and low reproductive fitness (Greenwood, 1980; Halls, 1984; Clutton-Brock et al., 1985; Lopez, 2001). However, Albon et al. (1992) studied an island metapopulation of red deer and found that as population density increased, family bonds began to break down and dispersal increased. Other research has suggested that Key deer lack strong philopatry (family ties) exhibited by other white-tailed deer due to the absence of predators and migration (Hardin et al., 1976) and these weaker social bonds may enhance dispersal of Key deer to other islands. Thus, we examined the effects of various dispersal scenarios on Key deer metapopulation dynamics. Specifically, we evaluated the probability of deer colonization of peripheral islands using a sex- and stage-structured metapopulation model. Our objectives were to (1) evaluate the effects of dispersal rates on Key deer island subpopulations and (2) estimate the probability of Key deer colonizing surrounding islands with viable populations.

2. Background information

Endangered Key deer are endemic to the Florida Keys and occur on 11 island-complexes in the Lower Florida Keys from Big Pine Key to Sugarloaf Key (Fig. 1) (Hardin et al., 1984). An island-complex is a collection of islands in close proximity to each other separated by shallow waters. Islands within a complex are “bridged” together during low tides (i.e., sea bottom is exposed), thus, can be considered to be a functionally single island (Folk, 1992). The majority of Key deer (approximately 75%) reside on Big Pine and No Name Keys (Lopez, 2001). Over the last 30 years, Big Pine and No Name Keys have experienced a 10-fold increase in human population growth and urban development (Monroe County Growth Management Division, 1992). Urban development and its associated risks are considered the greatest threat to Key deer (Lopez et al., 2003). Key deer are also at risk to environmental catastrophes such as hurricanes (Lopez et al., 2000). While the Key deer populations on these two islands have increased, the majority of the metapopulation occupies a small geographic area. The establishment of additional deer populations on other islands is a management goal of the U.S. Fish and Wildlife Service (USFWS) and a necessary step in Key deer recovery (USFWS, 1999).

3. Model overview

The model represents the dynamics of the Key deer metapopulation in the 11 island-complexes of the Florida Keys. The model consists of 11 submodels (one for each island-complex). The model parameters are based on the estimates from the main island, Big Pine Key. Each submodel is identical to the main model except for the initial population abundance and carrying capacity. The model is driven by the dispersal rate of male and female yearling and adult deer from the main island.

Fig. 1 – Map of the Lower Florida Keys, Florida.

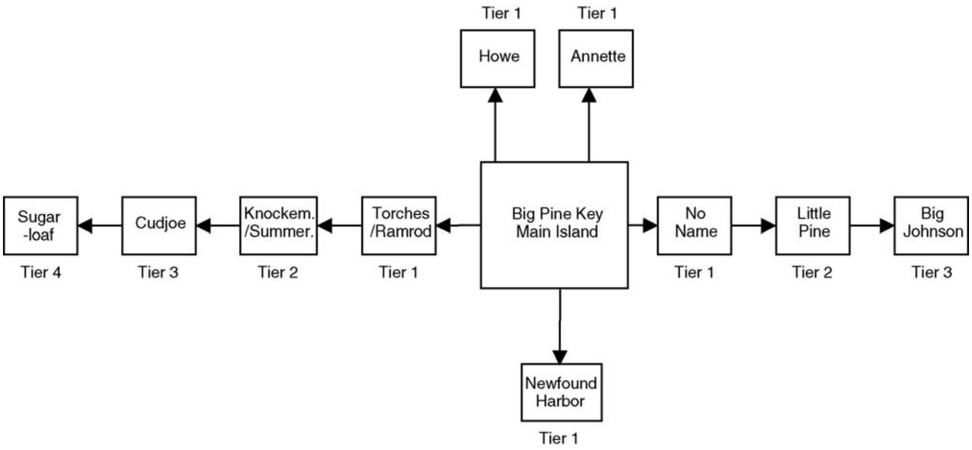

Fig. 2 – Conceptual model representing the dispersal routes of Key deer among the 11 island-complexes in the Lower Florida Keys.

Dispersal rates for each of these sex and stage classes are held constant for all 11 island-complexes. Dispersal from the main island, Big Pine Key, flows out to the five island-complexes surrounding it in a "stepping-stone" fashion following a tier-system (Fig. 2). Dispersal between tiers can only occur in successive, ascending fashion (i.e., dispersal from tier 1 would occur to tier 2 followed by tier 3, etc.).

4. Model description

The metapopulation model was developed as a stochastic compartment model based on difference equations ($\Delta t = 1$ year) and consists of 11, structurally identical, submodels, each representing a sex- and age-structured subpopulation for each island-complex:

$$N_{i,j,t+1} = N_{i,j,t} + (n_{j,t} - m_{i,j,t} - e_{i,j,t} - r_{i,j,t}) \times \Delta t, \quad \text{for} \quad i = 0 \qquad (1)$$

$$N_{i,j,t+1} = N_{i,j,t} + (r_{i-1,j,t} - i_{i-1,j,t} - m_{i,j,t} - e_{i,j,t} - r_{i,j,t}) \times \Delta t, \quad \text{for} \quad i > 0 \qquad (2)$$

where $N_{i,j,t}$ represents the number of females ($j = 1$) or males ($j = 2$) in age class i at the beginning of time t; $n_{j,t}$ the number of females or males born into age class 0 during time t; and $m_{i,j,t}$, $e_{i,j,t}$, $i_{i,j,t}$, and $r_{i,j,t}$ represent the number of females or males in age class i dying, emigrating from the island, immigrating to the island, and remaining on the island, respectively, during time t.

4.1. *Natality*

We initially assumed a sex ratio at birth of 41% females and 59% males (Hardin, 1974), and a mean maximum natality rate ($k1_{\max}$) of 1.05 fawns per reproductively mature female per year, including yearlings (1–2 years old) and adults ($\geq$2 years old) (Hardin, 1974); Key deer fawns (<1 year old) are not reproductively active (Hardin, 1974; Folk and Klimstra, 1991). We then represented natality as:

$$n_{j,t} = \sum_{i=1}^{i=2} (0.41 \times k1_t) \times N_{i,1,t}, \quad \text{for} \quad j = 1 \qquad (3)$$

$$n_{j,t} = \sum_{i=1}^{i=2} (0.59 \times k1_t) \times N_{i,1,t}, \quad \text{for} \quad j = 2 \qquad (4)$$

where $k1_t$ represents a stochastic, density-dependent natality rate (fawns born per reproductively mature female per year); the mean value of $k1_t$ is equal to $k1_{\max}$ until the island-complex deer population reaches K, and then decreases linearly from $k1_{\max}$ to 0 as the population increases from K to $2 \times K$ (Table 1). Each year of simulated time, the value of $k1_t$ for each island-complex is drawn randomly from a normal distribution (truncated at 0 and 1) (Akçakaya, 1991; Grant et al., 1997) generated by the density-dependent mean value of $k1_t$ and a standard deviation of mean natality rate calculated from data in Hardin (1974, p. 156). Estimates of K were obtained following the methodology used previously for No Name and Big Pine Keys (Lopez, 2001; Lopez et al., 2004b); each island-complex was classified into 6 habitat types using digital vegetation coverages, the area (ha) of each habitat type was multiplied by the corresponding Key deer habitat selection ratio (a weighting factor based on relative deer use), and carrying capacity was estimated as the sum of these values.

4.2. *Mortality*

Estimates of age- and sex-specific mortality rates were based on survival estimates (proportion of individuals surviving to the next age class, $k2_{i,j}$) obtained from Key deer studies conducted on Big Pine and No Name Keys (Hardin, 1974; Silvy, 1975; Lopez, 2001) (Table 2). Survival estimates for yearlings and adults were calculated from radiocollared animals using a known-fate model (Program MARK, White and Burnham, 1999; Lopez, 2001); fawn survival was estimated by adjusting the model-fitted estimates to compensate for

Table 1 – Carrying capacities (*K*) of the 11 island-complexes estimated following the methodology used previously for No Name and Big Pine Keys (Lopez, 2001; Lopez et al., 2004b)

Tier (island-complex)		Deer carrying	
	Area (ha)	Capacity (*K*)	Deer Density
Main			
Big Pine	2549	517	406
Tier 1			
Annette	222	26	6
Howe	373	50	16
Newfound Harbor	76	12	10
No Name	471	90	78
Torches/Ramrod	1714	287	94
Tier 2			
Knockemdown/Summerland	1019	155	8
Little Pine	382	61	16
Tier 3			
Big Johnson	154	19	0
Cudjoe	1319	217	6
Tier 4			
Sugarloaf	1399	224	6

Also presented are areas and estimates of Key deer abundance in the year 2001 (Lopez et al., 2004a; R. Lopez, unpublished data). Island-complexes are classified into tiers based on distance from Big Pine Key.

presumed overestimation due to small sample sizes (Lopez, 2001, p. 160).

Each year of simulated time, a value for each $k2_{i,j}$ is drawn randomly from the normal distribution (truncated at 0 and 1) (Akçakaya, 1991; Grant et al., 1997) generated by the mean and standard error corresponding to that age- and sex-class (Table 2).

Thus,

$$m_{i,j,t} = (1 - k2_{i,j}) \times N_{i,j,t} \tag{5}$$

4.3. *Emigration and immigration*

Estimates of age- and sex-specific emigration rates (proportion of individuals leaving the island-complex per year, $k3_{i,j}$) were based on estimates of dispersal from Big Pine to No Name Key (Lopez, 2001) (Table 2). Each year of simulated time, a value for each $k3_{i,j}$ is drawn randomly from the normal distribution (truncated at 0) generated by the mean and standard deviation corresponding to that age- and sex-class (Table 2).

Thus,

$$e_{i,j,t} = k3_{i,j} \times N_{i,j,t} \tag{6}$$

Estimates of age- and sex-specific immigration ($i_{i,j,t}$) to the different island-complexes were based on geographical location and the assumption that all emigrating individuals move away from Big Pine Key. Big Pine is the main source population and is the only population that disperses to more than one other island-complex. Individuals emigrating from Big Pine are dis-

Table 2 – Estimates of age- and sex-specific survival and natality rates for Key deer on Big Pine and No Name Keys (Hardin, 1974; Silvy, 1975; Lopez, 2001), and estimates of age- and sex-specific emigration rates for Key deer moving from Big Pine to No Name Key (Lopez, 2001)

Sex (*j*) age class[a] (*i*)	Mean (S.E.) survival (prop. surviving per year)	Mean (S.D.) emigration (prop. emigrating per year)	Mean (S.D.) natality[b] (births per doe per year)
Female ($j = 1$)			
Fawn ($i = 0$)	0.470 (0.061)	0.000 (0.000)	0.000 (0.000)
Yearling ($i = 1$)	0.824 (0.071)	0.032 (0.047)	1.100 (0.300)
Adult ($i = 2$)	0.842 (0.030)	0.032 (0.047)	1.100 (0.300)
Male ($j = 2$)			
Fawn ($i = 0$)	0.470 (0.061)	0.000 (0.000)	0.000 (0.000)
Yearling ($i = 1$)	0.569 (0.089)	0.107 (0.056)	0.000 (0.000)
Adult ($i = 2$)	0.597 (0.054)	0.107 (0.056)	0.000 (0.000)

[a] Age classes defined as fawn (0–1 year), yearling (1–2 years), and adult (≥2 years).

[b] Model adjusted mean natality for female yearlings and adults based on model calibration and actual deer population growth estimates (Lopez et al., 2004a). Standard deviation based on age-specific female natality reported by Hardin (1974, p. 156).

tributed among adjoining (tier 1) island-complexes (Fig. 2); No Name, Newfound Harbor, and Howe each received 25% of the Big Pine emigrants ($i_{i,j,t} = 0.25 \times e_{i-1,j,t}$) because of their close proximity, and Torches and Annette each received 12.5% of the Big Pine emigrants ($i_{i,j,t} = 0.125 \times e_{i-1,j,t}$) because of their further distance from Big Pine. All emigrants from island-complexes other than Big Pine are immigrants ($i_{i,j,t} = e_{i-1,j,t}$) to the island-complex in the next tier to which they are connected (Fig. 2).

The number of individuals in each age- and sex-class remaining on the same island-complex (and advancing age class $i+1$) during time t is calculated as:

$$r_{i,j,t} = N_{i,j,t} - m_{i,j,t} - e_{i,j,t}. \tag{7}$$

5. Model calibration

We calibrated the model by adjusting the mean maximum natality rate ($k1_{max}$) such that simulated population growth on Big Pine Key from 1971 to 2001 compared favorably with field estimates of population size (167 individuals in 1971 and 406 individuals in 2001; Lopez et al., 2004a). We calculated mean simulated population size in 2001 based on 120 replicate stochastic (Monte Carlo) simulations, which were sufficient to detect a difference of 30 deer in the metapopulation and 2 deer in the smallest island-complex populations (Annette, Cudjoe, Sugarloaf Keys) at $\alpha = 0.05$ (Grant et al., 1997); we initialized each simulated population at 167 individuals in 1971. As initially parameterized ($k1_{max} = 1.05$), the model underestimated observed population size (a simulated mean of 331 versus the field estimate of 406 individuals). Setting $k1_{max}$ at 1.10, 1.15, and 1.20 resulted in simulated population sizes of 405, 475, and 528, respectively; thus, we set $k1_{max}$ at 1.10 for subsequent simulations.

6. Population projections

6.1. *Experimental design model parameterization*

To evaluate the effect of dispersal rates on the Florida Key deer population, we projected metapopulation dynamics over the 20-year period from 2001 to 2021 under three scenarios assuming (1) low ($f = 0$, $m = 0$), (2) medium ($f = 0.03$, $m = 0.11$), and (3) high ($f = 0.06$, $m = 0.22$) dispersal rates; the "medium" rates are those reported by Lopez (2001) and the "high" rates are double the "medium" rates. For each scenario, we ran 120 Monte Carlo simulations.

Initial abundances in 2001 were determined from mark-resight estimates based on 247 road count surveys conducted from 1998 to 2001 on Big Pine Key (Lopez et al., 2004a). Initial densities on the other islands were estimated using trip cameras and Lincoln–Peterson mark-recapture statistics (R. Lopez, unpublished data). A stable age distribution was assumed for the Big Pine Key population and the other island populations were proportionally divided into each sex- and stage-class (0.125 for female and male fawns and yearlings and 0.25 for female and male adults) (Table 1).

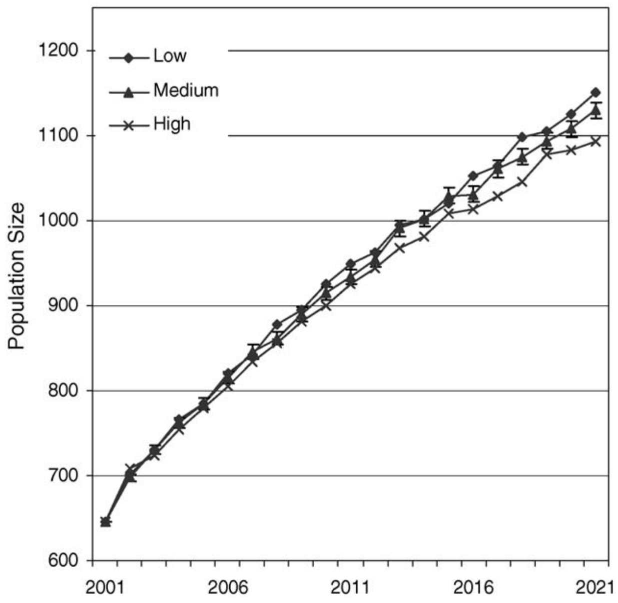

Fig. 3 – Model projected Key deer metapopulations under three dispersal scenarios (low, $f = 0$, $m = 0$; medium, $f = 0.03$, $m = 0.11$; and high, $f = 0.06$, $m = 0.22$) in the Lower Florida Keys, 2001–2021. Vertical bars represent ±1 S.E. of the mean, based on 120 replicate stochastic simulations under medium dispersal.

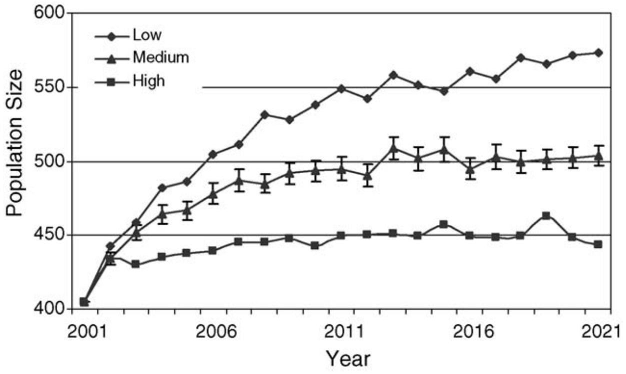

Fig. 4 – Model projected Big Pine Key deer populations under three dispersal scenarios (low, $f = 0$, $m = 0$; medium, $f = 0.03$, $m = 0.11$; and high, $f = 0.06$, $m = 0.22$) in the Lower Florida Keys, 2001–2021. Vertical bars represent ±1 S.E. of the mean, based on 120 replicate stochastic simulations under medium dispersal.

6.2. *Simulation results*

The model predicted an increase in the total metapopulation under each scenario with low dispersal producing the highest population increase and high dispersal producing the smallest increase (Fig. 3). Big Pine Key (where the majority of the Key deer population resides) also increased under each dispersal scenario (Fig. 4). Big Pine Key deer density was projected at 111% K with low dispersal, 98% K with medium dispersal, and 86% K with high dispersal.

Table 3 – Model projected Key deer populations for each island-complex under three dispersal scenarios (low, $f = 0$, $m = 0$; medium, $f = 0.03$, $m = 0.11$; and high, $f = 0.06$, $m = 0.22$) in the Lower Florida Keys, 2001–2021

Tier (island-complex)	Low dispersal			Medium dispersal			High dispersal		
	Mean	S.D.	% of K^a	Mean	S.D.	% of K^a	Mean	S.D.	% of K^a
Main									
Big Pine	573	77.6	111	504	76.1	98	443	74.9	86
Tier 1									
Annette	14	3.9	54	18	3.8	68	19	3.1	72
Howe	64	9.0	128	65	8.9	131	65	8.8	130
Newfound Harbor	20	3.8	169	21	4.2	178	22	4.2	184
No Name	110	17.3	123	108	14.2	121	103	15.8	115
Torches/Ramrod	214	52.3	74	205	43.2	72	194	37.5	68
Tier 2									
Knockemdown/Summerland	43	18.4	28	70	20.4	45	92	26.7	59
Little Pine	67	12.1	109	75	10.5	123	76	10.5	125
Tier 3									
Big Johnson	7	6.4	35	22	6.7	115	28	4.5	149
Cudjoe	19	8.1	9	21	8.1	10	30	13.4	14
Tier 4									
Sugarloaf	19	7.6	9	19	8.7	9	19	7.5	9
Metapopulation	1150	107.4	n/a	1129	105.6	n/a	1092	113.0	n/a

[a] K, island carrying capacity; percentages >100 are due to demographic stochasticity.

In analyzing model results, we defined a viable island population as ≥50 deer. We chose 50 as the minimum viable population size because, historically, it is the lowest known Key deer population size which resulted in an increase (Dickson, 1955). We defined a successful colonization as having a deer population at ≥50% K. Model results varied based on the input dispersal scenario (Table 3). Number of successful colonizations and viable populations, respectively, by dispersal scenario were as follows: low 7 and 5; medium 8 and 6; and high 9 and 6.

To evaluate the risk of quasi-extinction, we calculated the probability of each island-complex having <50 deer during each timestep (2001–2021) and under each dispersal scenario (low, medium, and high). Big Pine, No Name, and Torches/Ramrod had 0% probability of dropping below 50 deer under all dispersal scenarios from 2001 to 2021. Newfound Harbor, Annette, Big Johnson, Cudjoe, and Sugarloaf had a 100% probability of dropping below 50 deer under all dispersal scenarios. Howe, Knockemdown/Summerland, and Little Pine had variable probabilities of dropping below 50 deer depending on dispersal scenario (Figs. 5–7).

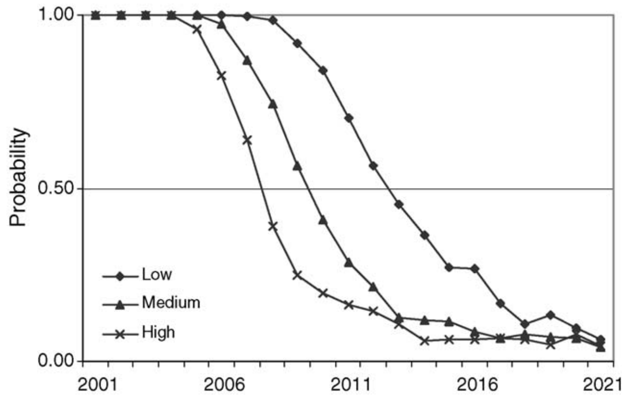

Fig. 5 – Model projected probability of Howe Key (tier 1, Fig. 2) dropping below 50 Key deer under three dispersal scenarios (low, $f = 0$, $m = 0$; medium, $f = 0.03$, $m = 0.11$; and high, $f = 0.06$, $m = 0.22$) in the Lower Florida Keys, 2001–2021.

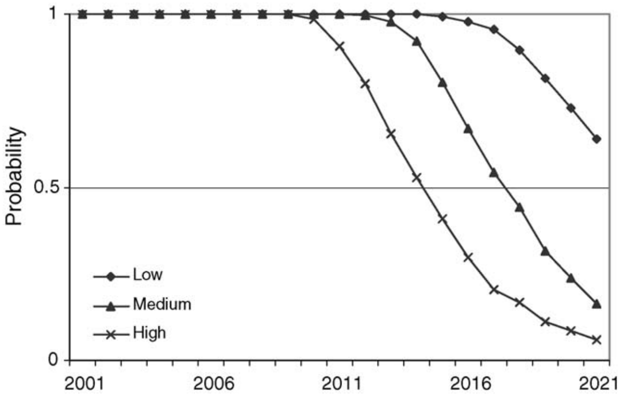

Fig. 6 – Model projected probability of Knockemdown/Summerland Complex (tier 2, Fig. 2) dropping below 50 Key deer under three dispersal scenarios (low, $f = 0$, $m = 0$; medium, $f = 0.03$, $m = 0.11$; and high, $f = 0.06$, $m = 0.22$) in the Lower Florida Keys, 2001–2021.

7. Discussion

The ability of Key deer to swim between islands has been documented (Hardin, 1974; Silvy, 1975; Lopez, 2001). Lopez (2001) reported two translocated Key deer swam a 2.4-km channel between Little Pine and No Name Keys. Key deer dispersal

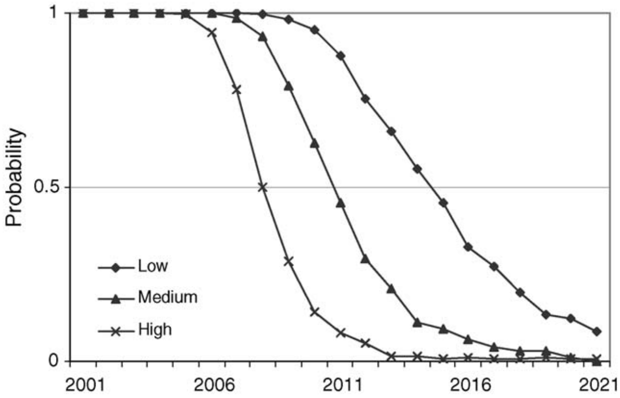

Fig. 7 – Model projected probability of Little Pine Key (tier 2, Fig. 2) dropping below 50 Key deer under three dispersal scenarios (low, $f = 0$, $m = 0$; medium, $f = 0.03$, $m = 0.11$; and high, $f = 0.06$, $m = 0.22$) in the Lower Florida Keys, 2001–2021.

rates between Big Pine and No Name Keys were reported by Lopez (2001), however, deer dispersal rates between other islands are unknown. Density dependence in white-tailed deer populations has been demonstrated in previous studies (McCullough, 1979; Halls, 1984). Current deer estimates suggest that the Big Pine Key deer population is at 78% island carrying capacity and is increasing (Lopez et al., 2004a). We included density dependence in the Key deer metapopulation model to evaluate the dynamics of the population as it approaches *K*. Deer dispersal was assumed to increase linearly as density increased toward *K*. We assumed that as deer densities increased that competition for territory and resources would increase the likelihood of dispersal to other islands (Kammermeyer and Marchington, 1976). We assumed an outward dispersal from islands of high density (the main island, Big Pine Key) to islands of lower density. As other island populations increased (due to births and immigration), they were also modeled to disperse with each island population flowing outward from the main population to peripheral islands like stepping stones (Fig. 2). We used this dispersal model to evaluate the possibility of Key deer establishing other viable populations on islands with suitable habitat within the current Key deer range in the Lower Florida Keys.

By modeling various dispersal scenarios, we were able to evaluate the effects of this unknown parameter on population projections for individual island-complexes and the metapopulation. All models predicted successful colonizations on all tier 1 islands (Table 3) suggesting that dispersal has occurred in previous years. In evaluating dispersal scenarios (low, medium, and high), we found that dispersal scenario had little effect on Key deer population growth. Both low dispersal and high dispersal projected deer populations within ±1 S.D. of the medium dispersal projections for the metapopulation and Big Pine Key (Table 3). Therefore, we will concentrate our discussion using the results from the medium dispersal scenario.

Of the 11 island-complexes we identified in the Lower Keys as possessing suitable habitat for Key deer, three would not support a deer population ≥50 deer based on our estimate of carrying capacity. Because of the low deer densities that these islands (Big Johnson, Annette, and Newfound Harbor) could support, they are considered supporting islands which can contribute habitat resources and genetic migration during times of hardship. The remaining eight islands can or do support viable deer populations according to our estimates. Big Pine, No Name, and Torches/Ramrod each had initially estimated deer populations ≥50 in 2001. Under the medium dispersal scenario, Howe, Knockemdown/Summerland, and Little Pine island-complexes were projected to increase to viable populations (≥50). Under high dispersal, no other island-complexes were projected to increase to viable populations in 20 years. Furthermore, all model simulations suggest that Cudjoe and Sugarloaf will have low deer densities (<50) despite their relatively high carrying capacities (217 and 224, respectively). Projected populations for Cudjoe (tier 3) and Sugarloaf (tier 4) were similar under all dispersal scenarios (Table 3) suggesting that dispersal rate (whether low, medium, or high) will have little effect on population size and that distance from the main island (tier level) and the size of intermediate islands will have the greatest effect on population size within the 20-year timeframe of the model.

Model projections suggest that the tier of islands extending to the northeast from the main island (Big Pine Key) will reach *K* carrying capacity within the next 20 years (Fig. 8). However, the small size of these islands indicates that only two of these islands will be able to support viable deer populations. Further, we estimate that the northeast tier as a whole can support <200 deer while the southwest tier can support over five times as many deer (Table 1). The high *K* carrying capacity and geographic location of the southwest tier of island-complexes make it the most logical choice for focusing future Key deer conservation efforts (Fig. 8). While model results suggest that deer populations on the Torches/Ramrod and Knockemdown/Summerland island-complexes will increase to viable populations by 2021, deer populations on the furthest islands, Cudjoe and Sugarloaf Keys, will not (Fig. 8). The potential benefits of establishing additional Key deer populations on Cudjoe and Sugarloaf Keys, are numerous. First, the current greatest threat to Key deer is urban development and its associated risk factors (e.g., loss of habitat, habitat fragmentation, and increased deer mortality due to vehicle collisions). The majority of Key deer reside on Big Pine Key where high urban development in the south has created an ecological sink primarily due to high roadkill mortalities of Key deer (Harveson et al., 2004). While measures are underway to reduce deer roadkill mortality on Big Pine Key, the effects of future policy (e.g., the pending Habitat Conservation Plan and lifting of the building moratorium) are unknown. Second, the Florida Keys are prone to hurricanes and while impacts on Key deer during previous hurricanes have been minimal (Lopez et al., 2000), the potential exists for a hurricane to severely impact the population because of its limited geographic range. Sugarloaf and Cudjoe are the furthest islands from Big Pine making them desirable choices for increasing the populations range to minimize the potential catastrophic effects of a hurricane. Finally, additional local populations on Cudjoe and Sugarloaf Keys will provide increased population growth and genetic

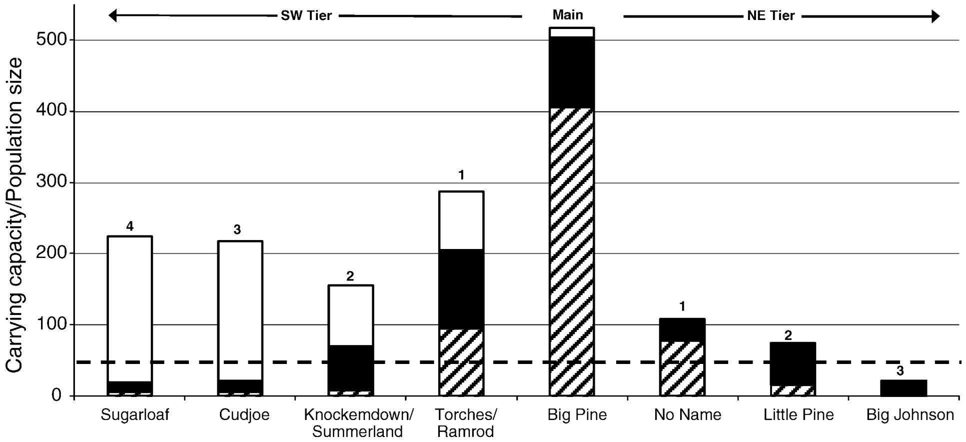

Fig. 8 – Initial Key deer population abundance (2001, hatched-fill) and projected 20 years population growth (2021, black solid-fill) on each island-complex under medium dispersal rates (*f* = 0.03, *m* = 0.11). Height of bars represents carrying capacity (*K*) and dotted line represents minimum viable population level (50 deer). The tier 1 islands of Howe, Annette, and Newfound Harbor have been excluded to simplify the figure since they do not fall in the main chain for dispersal.

heterogeneity further bolstering this endangered population towards recovery.

8. Management implications

The conservation and management of an endangered species such as Key deer requires a thorough understanding of the demographic and environmental factors influencing its population dynamics. While much is known about Key deer biology (e.g., survival, maternity, habitat use) changes in habitat conditions due to urban development will continue to prove challenging to managers. Habitat loss and fragmentation combined with increasing deer densities will have unpredictable effects on parameters such as dispersal. Through the use of simulation modeling, we examined the potential effects of changes in dispersal rates on the Key deer metapopulation. According to our results, under all modeled scenarios the establishment of viable populations on Cudjoe and Sugarloaf Keys by dispersal alone is unlikely within the next 20 years. We recommend the use of other methods (e.g., translocations) to supplement deer numbers on these islands in order to establish viable populations.

Acknowledgements

We would like to thank Texas A&M University (TAMU) graduate students and interns who assisted in the collection of field data, and L. Harveson for constructive criticism in the preparation of this manuscript. We also thank the staff of the USFWS National Key Deer Refuge. Funding was provided by the TAMU System, Hispanic Leadership Program in Agriculture and Natural Resources (USDA Forest Service), Rob and Bessie Welder Wildlife Foundation, and U.S. Fish and Wildlife Service. This manuscript is supported by the Welder Wildlife Foundation, Contribution no. 650.

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