Revised Population Viability Analysis for the Alabama Beach Mouse

Peromyscus polionotus ammobates

Report to the U.S. Fish and Wildlife Service

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Introduction

The Alabama beach mouse (*Peromyscus polionotus ammobates*) is one of several endangered subspecies of oldfield mice known as beach mice. Beach mice inhabit the coastal dune habitats of the southeastern U.S. and prefer sand slopes with patches of sea oats and other native coastal vegetation. They are primarily nocturnal, spending the day in burrows in the sand and emerging at night to feed on seeds and insects.

Endemic to the coastal dunes of Alabama, the Alabama beach mouse (ABM) is the most western beach mouse subspecies along the Gulf of Mexico coast. The distribution of this subspecies is restricted to the western tip of the Fort Morgan Peninsula eastward to Perdido Pass in Baldwin County. The historical range of this subspecies also included Ono Island; however no ABM are currently believed to exist there. ABM habitat consists of public lands (Fort Morgan and Perdue Units of the Bon Secour National Wildlife Refuge as well as Gulf State Park) and privately owned lands. Some level of connectivity is suspected across this range, although ABM are believed to avoid areas of human disturbance or habitation.

Coastal Baldwin County is an area of increasing recreational and residential development. Development on privately owned lands includes single family and duplex dwellings, condominiums, hotels and restaurants. Increased commercial and residential development has the potential to negatively impact beach mice populations through habitat loss and fragmentation, increased mortality, and increased vulnerability to the impacts of hurricanes.

As a step in assessing the effects of development and other factors on the viability of ABM populations, the U.S. Fish and Wildlife Service (FWS) initiated a Cumulative Impact Assessment (CIA) for this species and sought to develop a population viability analysis model. These evaluation tools will promote a better understanding of the population dynamics of the species and the expected impact of future development scenarios and management options.

PHVA Workshop and Model Results

The Conservation Breeding Specialist Group (CBSG) of the IUCN – World Conservation Union was invited to conduct a Population and Habitat Viability Assessment (PHVA) workshop for the Alabama beach mouse to assist in the development of viability projections for the species. The PHVA workshop, sponsored by FWS, was held June 8-11, 2004 in Point Clear, Alabama, and included 31 participants from 13 agencies and organizations. At the PHVA, Alabama beach mouse population data were examined and discussed in detail. A computer population simulation model (*Vortex*) was used to evaluate current and future risk of population decline or extinction with no further actions or destruction of habitat and under alternative development and management scenarios. Participants developed detailed reports outlining these discussions and justification for those values chosen for the model. The main goal of this PHVA workshop was to develop an ABM population model and use this model to assess the current status of ABM habitat and populations and projections for continued existence.

Working group and plenary discussions during and following the PHVA led to the estimation of model input values for the ABM model based on the best expert opinion available. This included estimation of population structure, habitat carrying capacity, demographic rates, hurricane effects, the impact of development, and the testing of various management scenarios. Although accurate estimates of most of these parameters are not currently available, the PHVA workshop participants used all available published and unpublished data and expertise to provide the best estimates possible for use in developing the *Vortex* model. It was agreed that the development of an ABM model is a dynamic process, and that this model is likely to be revised as new data and modeling techniques become available.

The results of the 2004 PHVA baseline model suggested that the ABM metapopulation has an 18% to 21% probability of extinction over 100 years, depending on whether fast or slow recovery of habitat following hurricanes is assumed. Sensitivity tests of alternative values for uncertain model parameters yielded probabilities of ABM extinction ranging from 13% to 36%, with the strongest impacts observed when habitat carrying capacity, juvenile survival, or adult survival was varied. The Perdue and Multi-Family model units appear to be the stabilizing portion of the overall metapopulation. These relatively large areas contain high elevation habitat that is less affected by hurricanes, and are centrally located relative to the linear array of subpopulation model units along the coast. Areas in the eastern part of ABM range (Gulf State Park and Orange Beach) suffer local extinctions, typically within 5 to 10 years. ABM subpopulations in these units have a high probability of extinction when hurricanes occur, particularly with more severe storms, and are not naturally recolonized due to isolation from other ABM populations. Subpopulations at the Fort Morgan, Single Family, and West Beach model units also frequently do not survive hurricanes (with median times to extirpation of 11 to 23 years), but they are often recolonized from adjacent units.

As expected, hurricanes are a major influence on the population dynamics of this subspecies. Additional potential threats include habitat loss due to the spread of cogongrass (an exotic invasive species) and high mortality due to predation by domestic cats, each of which have the potential to drive the ABM population to extinction (see the *Alabama Beach Mouse PHVA Final Report* for a complete description of the model results). Several future development scenarios were also modeled, both with and without management to minimize impacts upon ABM subpopulations. Some development options projected only minor impacts on the probability of overall ABM extinction (but may lead to local extinctions), while others caused significant reductions in projected metapopulation size and probability of persistence.

Revised PVA Model and Results

Several events occurred in the months following the June 2004 PHVA workshop that had implications for the ABM model results. The FWS approved several Incidental Take Permits to allow additional development in the Single Family model unit (resulting in a loss of 0.4% of ABM habitat in that model unit). A more significant event was the impact of Hurricane Ivan, a Category 3 hurricane whose eye passed over the Fort Morgan Peninsula on September 16, 2004, resulting in a major loss of primary and secondary dunes throughout ABM habitat. Finally, as work with ABM and the CIA continued, new data and ideas arose for refinement and expansion of the ABM *Vortex* model.

At the invitation of the FWS, CBSG met with FWS staff from local and regional offices in December 13-14, 2004 to discuss building upon the PHVA model. This discussion included developing a set of development scenarios that more closely match those outlined in the CIA.

One of the modifications included building the occurrence of a Category 3 hurricane into the first time step of the model to simulate the effects of Hurricane Ivan. Another significant change was the reduction in the estimated impact of hurricanes on ABM habitat, as the original values (based on storm surge estimates according to the National Hurricane Center's SLOSH model) were thought to overestimate habitat loss. Restoration efforts were modeled in what is believed to be a more realistic manner. The results of a population viability analysis using this revised model are presented in this report and are summarized below.

Given current ABM population status and habitat availability and using the revised *Vortex* model, the Alabama beach mouse is projected to have about a 14% risk of extinction over the next 100 years. Much of this extinction risk is due to the impact of hurricanes on ABM populations and habitat, which can result in relatively frequent and severe population declines. Mean size of surviving populations average about 30% of estimated carrying capacity, but tend to fluctuate widely over time. After 100 years inbreeding is predicted to accumulate to a population level equivalent to full sibling matings (77% gene diversity retained). These population projections are slightly more optimistic than those from the ABM PHVA model, which is primarily due to the revision of hurricane impact estimates.

Land development can lower ABM viability by reducing habitat, increasing mortality, and exacerbating the effects of hurricanes by reducing high elevation refugia areas. These negative effects increase with increased levels of development, but none of the development scenarios modeled result in certain ABM extinction. In the highest level of development modeled (i.e., full build-out of privately owned lands), the risk of metapopulation extinction is 34% over 100 years, with a mean population size of about 4600 mice with 74% gene diversity remaining for those populations that did not go extinct. Maximum development of the Gulf Highlands/Beach Club West parcels and maximum build-out of all private lands have substantially greater impacts than lower levels of development in these areas. Development can lead to high risk of local extinction not only in the developed area itself but in adjacent private and public lands. Fort Morgan and Single Family subpopulations are most affected by the development of private lands followed by the West Beach subpopulation, while ABM in Multi-Family and Perdue areas are least affected. ABM are projected to be extirpated from Gulf State Park in all scenarios modeled.

Habitat restoration following hurricanes may help to reduce overall extinction risk by allowing ABM populations to recover faster; however, restoration as modeled here is unlikely to substantially reduce or eliminate extinction risk. Restoration may make a small but measurable impact on ABM viability for some development scenarios.

None of the scenarios in this revised PVA include the effects of either the spread of cogongrass or predation by domestic cats. These invasive species were identified by the ABM PHVA model as having substantial impacts on ABM; therefore it should be recognized that both factors represent potential threats to ABM persistence and have the ability to significantly increase the risk of ABM extinction.

ABM populations – both in the simulation models and in nature – are subject to considerable fluctuations due to seasonal variation in breeding and survival, fluctuations in habitat quality across years, and the impacts of hurricanes. The fate of the ABM as a single, interconnected metapopulation is therefore intrinsically unpredictable, although the *probabilities* of population decimation and the long-term mean numbers of mice can be projected. These probabilities can be compared among alternative management and development scenarios to evaluate the probable effect on population trends. In addition, the accuracy of model results depends upon the accuracy of the values entered into the model. For many of the ABM model parameters, the best available data allow only approximate estimates of the true values. If these estimates are incorrect, the model results can be misleading regarding the most likely fate of the ABM population.

The ABM *Vortex* model suggests that hurricanes are a driving force for ABM populations, both directly and also indirectly as their impacts interact with other factors such as development of high elevation areas or predation by cats. These results emphasize the importance of efforts to improve the accuracy of hurricane impact estimates, including loss and recovery of habitat as well as how ABM use different habitat types before, during and following storms. Better understanding of these processes and more accurate estimation of their frequency and effects would lead to development of an even more useful and valid simulation model for ABM populations.

Revised *Vortex* Model Input Values

Vortex Simulation Model

Computer modeling is a valuable and versatile tool for assessing risk of decline and extinction of wildlife populations. Complex and interacting factors that influence population persistence and health can be explored, including natural and anthropogenic causes. Models can also be used to evaluate the effects of alternative management strategies to identify the most effective conservation actions for a population or species. Such an evaluation of population extinction risk under current and varying conditions is commonly referred to as a population viability analysis (PVA).

The *Vortex* simulation software program was used to examine the viability of the Alabama beach mouse population. *Vortex* is a Monte Carlo simulation of the effects of deterministic forces as well as demographic, environmental, and genetic stochastic events on wild populations. *Vortex* models population dynamics as discrete sequential events that occur according to defined probabilities. The program begins by creating individuals to form the starting population and stepping through life cycle events (e.g., births, deaths, dispersal, catastrophic events), typically on an annual basis. Events such as breeding success, litter size, sex at birth, and survival are determined based upon designated probabilities. Consequently, each run (iteration) of the model gives a different result. By running the model hundreds of times, it is possible to examine the probable outcome and range of possibilities (or a more detailed explanation of *Vortex* and its use in population viability analysis, see Lacy, 1993, 2000).

Development of the Revised Model

Staff from the USFWS met in Fairhope, AL on 13-14 December 2004 to discuss and revise the Alabama Beach Mouse (ABM) *Vortex* model based upon new available data and changes that had occurred to ABM habitat and populations since the model was developed in June 2004. In most cases, the input values chosen by participants at the ABM Population and Habitat Viability Assessment (PHVA) Workshop held in June 2004 were used in the revised ABM model. Listed below is a summary of changes made to the original ABM PHVA model for purposes of this revised analysis (see the ABM PHVA Workshop report for model details).

1. The Slow Logistic Recovery Baseline model from the ABM PHVA was chosen as a starting point for model development. This model uses a logistic curve to represent the recovery of habitat back to its original level following habitat loss due to hurricanes, with full recovery of K in 5, 8, 12, 25 and 40 years (for Category 1 - 5 storms, respectively).

2. The ABM PHVA model divided ABM habitat into 8 model units. In this revised model, Orange Beach and Ono Island model units were eliminated from the model, as they were estimated to contain little to no ABM habitat and few to no beach mice. The remaining model units, west to east, are: Fort Morgan, Single Family, Multi-Family, Perdue, West Beach, and Gulf State Park.

3. The carrying capacity for the Single Family model unit was reduced by 0.4% (from 6039 to 6015 mice) to account for the loss of 2.7 acres (out of 677 acres) of ABM habitat due to the issuance of 17 Incidental Take Permits and 6 additional non-permitted developments since the PHVA workshop.

4. The model was revised to always have a Category 3 hurricane occur in Year 1 to simulate the effect of Hurricane Ivan, which hit the Fort Morgan peninsula in September 2004.

5. The ABM PHVA model used data from the National Hurricane Center's SLOSH inundation model, used to predict storm surges, to estimate the loss of ABM habitat in each model unit under each category of hurricane (1 – 5). These are believed to be overestimates based upon data from the ENSR model. Given the lack of more accurate information, the estimates for habitat loss due to hurricanes were taken as 80% of the SLOSH estimates of loss.

6. Habitat restoration efforts were modeled by modifying the shape of the recovery curve for carrying capacity after a hurricane such that recovery occurs at a slightly faster rate during the early years of recovery, but the time to full recovery remains the same. This new curve was applied only to those scenarios that included restoration, only to certain model units, and only for recovery of Category 2 – 5 storms.

These changes resulted in a new model that represents no further development of ABM habitat. Additional scenarios were added to represent various levels and options for further development, as well as to assess the impact of habitat restoration following Category 2-5 hurricanes and to evaluate the effect of modifying the SLOSH hurricane impact estimates. The following 19 scenarios were modeled (see **Scenario Descriptions** section for further explanation):

1. No Further Development (with 80% of original SLOSH estimates)
2. No Further Development (with 90% of original SLOSH estimates, for sensitivity testing)
3. No Further Development (with original SLOSH estimates, for sensitivity testing)
4. No Further Development (with habitat restoration following hurricanes)
5. Gulf Highlands/Beach Club West (GH) Development – maximum development
6. GH Development – as proposed
7. GH Development – minimum development/impact
8. GH Development – as proposed (with habitat restoration following hurricanes)
9. GH Development – minimum development (w/habitat restoration after hurricanes)
10. Maximum Full Build-Out (including maximum GH)
11. Maximum Full Build-Out (including proposed GH)
12. Maximum Full Build-Out (including minimum GH)
13. Moderate Full Build-Out (including maximum GH)
14. Moderate Full Build-Out (including proposed GH)
15. Moderate Full Build-Out (including minimum GH)
16. Minimum Full Build-Out (including maximum GH)
17. Minimum Full Build-Out (including proposed GH)
18. Minimum Full Build-Out (including minimum GH)
19. Minimum Full Build-Out (with no GH development)

Model Input Values

The final values used in the baseline model are summarized below. Detailed explanations of input values and justification for their use can be found in the *Alabama Beach Mouse PHVA Final Report* (Traylor-Holzer *et al*., 2005).

Number of iterations: *1500 per scenario*

Number of years: *100 calendar years*
Due to the relatively short generation time for this species, life history events were modeled in four-week time steps rather than 365-day intervals. Therefore, iterations were run for 1300 time steps to project population trends for 100 years.

Extinction definition: *Only one sex remaining*

Number of populations: *6 (FM, SF, MF, PD, WB, GSP)*
The ABM metapopulation was modeled as six partially connected subpopulations to allow the geographical and management differences across the ABM range to be incorporated and to make it possible to test different future scenarios with respect to these areas. In most cases these areas do not describe biologically separate populations but instead reflect geographical management units, termed *model units*. Model units were defined as discrete ABM habitats having distinct geographic and/or similar threats within the historic range of ABM. Model units included in the model were Fort Morgan (FM), Single Family (SF), Multi-Family (MF), Perdue (PD), West Beach (WB), and Gulf State Park (GSP). Orange Beach and Ono Island model units were eliminated from the model due to the estimated absence of ABM and ABM habitat in these areas.

Inbreeding depression: *Yes (LE = 1.8)*
Inbreeding is thought to have major effects on reproduction and survival, especially in small populations, and so was included in the model (as reduced survival of inbred offspring through their first year). The impact of inbreeding was modeled as 1.8 lethal equivalents, which is the value reported for the Santa Rosa beach mouse (*P. p. leucocephalus*). The inbreeding effect was specified to be due entirely to recessive lethal alleles (100%).

Concordance between environmental variation in reproduction and survival: *Yes*
It was believed that there is a correlation between environmental conditions that affect survival and reproduction for beach mice (i.e., years that are good or bad for survival tend to also be good or bad for reproduction).

EV correlation among populations: *0.5*
The model includes a moderate correlation between variation in birth and death rates among all model units (populations). A correlation of 0.5 was selected as reasonable for this size species over the distance covered by ABM habitat across the Fort Morgan Peninsula.

Dispersal Among Populations: *Yes*
This parameter describes the movement of ABM from one model unit to another model unit. Values were retained from the PHVA model and represent normal dispersal by sub-adults to establish a home range outside of their natal home range and in cases in which such dispersal causes them to cross an inter-unit boundary. No additional mortality was imposed, as movement across these boundaries is assumed to be no riskier than movement within model units. Inter-unit dispersal rates range from 0 to 2.43% of sub-adult mice.

Mating system: *Long-term polygyny*
Although ABM are typically considered to be monogamous, males will also breed with unpaired females. To more accurately represent the consequences of the mating system in the model, mating was modeled as long-term polygyny so that reproduction would not be male-limited.

Age of first reproduction: *3 time steps (84 days)*
Vortex defines reproduction onset as the time at which offspring are born, not the age of sexual maturity. The model uses the mean age of first reproduction (parturition) rather than the earliest recorded age of offspring production.

Maximum age of reproduction: *19 time steps (532 days, or approx. 1.5 years)*
Vortex assumes that animals can reproduce throughout their adult life. Mice can live and breed beyond 2 years in lab conditions, but few individuals are likely to live beyond one year in the wild. Although the maximum age of reproduction was set at 1.5 years, the mortality rates used in the model result in few mice surviving past one year.

Maximum litter size/litter distribution: *8*
Values for litter size were taken from the distribution of litter sizes observed for 413 non-inbred litters of *P.p. leucocephalus*. This distribution was 3.15%, 5.08%, 20.34%, 27.85%, 28.09%, 12.35%, 2.91%, and 0.23% for 1 to 8 pups, respectively, resulting in a mean litter size of 4.23.

Sex ratio at birth: *50% male*

Density-dependent reproduction: *Yes*
Density-dependent reproduction has been observed in *Peromyscus*. Density dependence is defined by specifying parameters of a particular functional shape for the relationship between population density and breeding success. The curve that is often used to represent the functional relationship is: % breeding = $[(P_0-(P_o-P_k)*(N/K)^B)] * (N/(N+A))$. The nature of this curve was thought to differ in Fort Morgan and Multi-Family model units than in the other five units. The following parameter values were used in the model:

P_0	Specifies the % of adult females breeding in an average year when population density is very low relative to the food supply and carrying capacity of the habitat. Set at 70% based on data from *Peromyscus* populations (90% for Fort Morgan).
P_k=30	Specifies the breeding rate (% females breeding each year) when the population is at its carrying capacity. Set at 30% based on data from *Peromyscus* populations.
A=1	Defines the Allee effect (difficulty in finding mates at low densities, < 10 mice).
B	Defines the steepness with which breeding decreases as population approaches K. Set at B = 3 for most model units; set to a steeper value for Fort Morgan (B = 0.5) and Multi-Family (B = 1) units.

Environmental variation in breeding rate: *17%*
ABM populations have been observed to fluctuate seasonally, with the highest populations observed in the late winter/early spring and the lowest numbers in late summer/early fall. An oscillating sine wave was used to represent seasonal fluctuations in reproduction. In addition,

environmental variation was added to the model to account for variation in the percent of females breeding due to fluctuations in environment conditions.

Monopolization of breeding: *95%*
There is little evidence for social prevention of mating (e.g., dominance). Most males are believed to have the opportunity to breed; although only about 70% of males examined were reproductively active based on categorization of abdominal vs. scrotal males, abdominal males can quickly come into breeding condition if a female is available.

Mortality: *See below*
Sub-adult and adult mortality rates and environmental variation were calculated from data from ABM populations in Perdue and Fort Morgan units. Mortality was observed to be highest in summer. Juvenile mortality rates were taken from laboratory data and modified to include higher summer mortality, resulting in the following baseline rates used in the model:

	Fall/Winter/Spring		Summer	
Age class	% Mortality	SD (%)	% Mortality	SD (%)
0 – 1 (0-28 days)	36.2	14.4	52.5	14.4
1 – 2 (29-56 days)	21.1	14.4	30.3	14.4
2+ (>56 days)	16.1	10.6	23.7	10.6

Note: Under some of the development scenarios, these mortality rates were increased in developed areas due to projected additional sources of ABM mortality (see **Development Input Values** section).

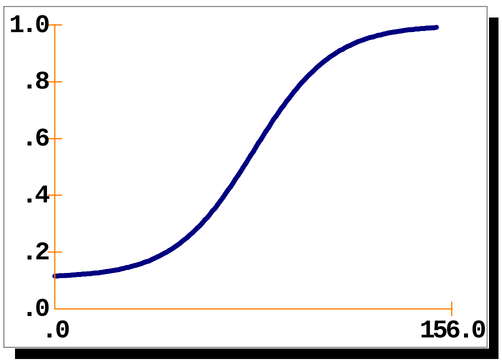
Catastrophes: *Yes (5), variable effects*
Hurricanes were the only catastrophe included in the model. Each category of storm (1-5) was modeled as a separate type of catastrophe to allow for differences in frequency of occurrence, severity of impacts, and habitat recovery time. Storms were modeled as global catastrophes (i.e., hurricanes hit all model units synchronously) occurring only in August through October. Probability of occurrence was based on site-specific estimates by the National Hurricane Center. Hurricanes affect ABM survival and carrying capacity but not reproduction in the model. These effects differ by model unit, as some units are more resilient to storm damage. Impacts on carrying capacity are constant for each storm category and model unit combination; the effect on ABM survival is variable within a specified range. Recovery of carrying capacity to pre-storm level varies based on the storm category and was modeled using a logistic curve.

Category	Frequency	Recovery (in yrs)
C1	1 in 8 years	5
C2	1 in 16 years	8
C3	1 in 25 years	12
C4	1 in 47 years	25
C5	1 in 100 years	40

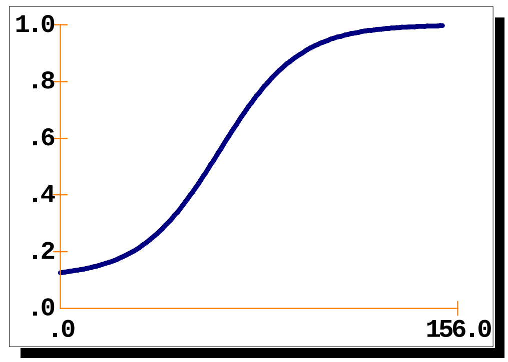
The model was revised from the PHVA model to always have a Category 3 hurricane occur in the first time-step to simulate the effects of Hurricane Ivan, which occurred in September 2004.

Habitat restoration efforts were modeled by modifying the recovery curve for K following hurricanes (Categories 2 – 5 only). This was done by changing the logistic formula value from 5.0 to 4.0 for Fort Morgan, Perdue and Gulf State Park and to 4.6 for Multi-Family to simulate restoration efforts on public lands and in the GH area of the MF model unit. Below is an example of the recovery curve for Fort Morgan model unit for a Category 3 hurricane with a recovery time of 12 years (156 *Vortex* time steps) using the following expression:

1-([.89*(1-[(EXP(Y/15.6-5))/(1+EXP(Y/15.6-5))])]
No restoration (about 50% recovery in 6 years)



1-([.89*(1-[(EXP(Y/15.6-4))/(1+EXP(Y/15.6-4))])]
With restoration (about 70% recovery in 6 years)



Carrying capacity (K): *Subpopulation specific*
The carrying capacity for each model was based upon estimates of the amount of suitable ABM habitat and ABM density for each model unit, as listed below (see ABM PHVA report for details). No environmental variation was included for carrying capacity, as year-to-year variation in K was not considered to be a factor in the absence of hurricane impacts and recovery. No future trend in K was added to the baseline model.

Initial Population Size (N): *Subpopulation specific*
There are no accurate estimates of ABM population sizes either before or after Hurricane Ivan. High population estimates in recent years suggest that ABM may have been near or at carrying capacity prior to Hurricane Ivan. For the baseline model, initial population sizes were set at carrying capacity. *Vortex* distributes the specified initial population among age-sex classes according to a stable age distribution that is characteristic of the mortality and reproductive schedule described for the model. A Category 3 Hurricane was then imposed (with variable effects) to simulate the reduction in ABM and ABM habitat following Hurricane Ivan.

Harvest: *None*
Trap mortality is negligible and does not need to be included in the model. There is no additional harvest. Predation by cats was not included in this model.

Supplementation: *None*
The addition of individuals to the population from captivity or other sources (via translocation) was not included in this model.

Scenario Descriptions

Sensitivity Testing of SLOSH Estimates

One of the changes to the ABM PHVA model was the revised estimated impacts of hurricanes on ABM habitat. The PHVA model estimated loss of ABM habitat specific to each model unit and storm category based upon inundation estimates by the SLOSH model. Further discussion and information presented at the December 2004 workshop suggested that habitat loss may be overestimated by the SLOSH model, which is designed to project maximum flooding for the development of human emergency evaluation routes. Other models, such as one developed by the ENSR corporation, may use more appropriate measures for ABM habitat effects, but data are not currently available in a form and return frequency needed for the ABM model. Therefore, the new ABM PVA began with sensitivity testing of these SLOSH estimates (100%, 90%, and 80% SLOSH estimated impacts), under no future development conditions. Impact estimates associated with 80% SLOSH were used for all other scenarios.

Development and Restoration Scenarios

The initial model represented no further development of ABM habitat. An additional 16 scenarios were added to represent various levels and options for further development, as well as to assess the impact of habitat restoration following Category 2-5. Most of these can be described by a matrix of two development strategies: 1) Gulf Highlands/Beach Club West development in the Multi-Family area (characterized as either maximum, proposed, minimum or no further development); and 2) build-out across all privately held ABM habitats (at maximum, moderate and minimum development levels). Full build-out includes development in the Single-Family, Multi-Family and West Beach model units. Three scenarios (no further development, Gulf Highlands as proposed, and Gulf Highlands with minimum development) were also modeled with habitat restoration following hurricanes. Descriptions of all 19 scenarios are given below.

1. No Further Development (NoDev)

This scenario reflects the current conditions (summer 2004, plus Hurricane Ivan impacts) in mapped ABM habitat and assumes no additional development of any ABM habitat. Reduction in K following storms is estimated as 80% of the reduction predicted by the SLOSH model.

2. No Further Development using 90% SLOSH estimates (NoDev90%)

This scenario reflects the current conditions and is the same as Scenario 1 except that the reduction in K due to storms is entered as 90% of the reduction predicted by the SLOSH model.

3. No Further Development using original SLOSH estimates (NoDevFULL)

This scenario reflects the current conditions and is the same as Scenario 1 except that the reduction in K due to storms is entered as 100% of the reduction predicted by the SLOSH model.

4. No Further Development with Restoration (NoDevRestor)

This scenario represents current conditions and is the same as Scenario 1 except that measures are implemented as soon as possible after storms to aid in the restoration of ABM habitat on public lands. These measures could include sand fencing, dune fertilization, vegetation planting, and sand translocation. Restoration efforts are modeled by increasing the rate at which K is regained during the early years of recovery (i.e., slope of recovery curve is steeper immediately following storms).

5. Gulf Highlands/Beach Club West (GH) Maximum Development (GHMax)
This scenario represents full development of the Gulf Highlands/Beach Club West parcels. Under this scenario all land in these parcels is developed or landscaped, leaving little or no ABM habitat. All remaining ABM habitat on other privately held parcels or on public lands remains.

6. GH Proposed Development (GHProp)
This scenario represents the proposed development of the Gulf Highlands/Beach Club West parcels as originally permitted as assessed in the environmental assessment. This results in the loss of 59 acres of ABM habitat in the Multi-Family model unit (as compared with Scenario 1).

7. GH Minimum Development (GHMin)
This scenario represents development of the Gulf Highlands/Beach Club West parcels with minimal impacts. Minimization would be accomplished by placing parking into parking decks and minimizing landscaping.

8. GH Proposed Development with Restoration (GHPropRestor)
This scenario represents the proposed development of the Gulf Highlands/Beach Club West parcels (same as Scenario 6), with the additional inclusion of ABM habitat restoration efforts on these two parcels and on public lands after storm events.

9. GH Minimum Development with Restoration (GHMinRestor)
This scenario represents the development of the Gulf Highlands/Beach Club West parcels with minimum impact (same as Scenario 7), with the additional inclusion of ABM habitat restoration efforts on these two parcels and on public lands after storm events.

10. Maximum Full Build-Out with Maximum GH Development (BOMaxGHMax)
This scenario represents full development of all privately held lands, including Gulf Highlands/ Beach Club West and single family zoned areas. Little to no ABM habitat remains on privately held lands. Remaining ABM habitat consists of all lands below the CCCL (Coastal Construction Control Line) and publicly held lands.

11. Maximum Full Build-Out with Proposed GH Development (BOMaxGHProp)
This scenario represents full development of all privately held lands except for the Gulf Highlands/Beach Club West parcels, which are developed as originally permitted as assessed in the environmental assessment. Little or no ABM habitat remains on privately held lands with the exception of GH, where preservation areas would remain. ABM habitat remains on all lands below the CCCL and on publicly held lands.

12. Maximum Full Build-Out with Minimum GH Development (BOMaxGHMin)
This scenario represents full development of all privately held lands except for the Gulf Highlands/Beach Club West parcels, which are developed with minimal impacts. Minimization would be accomplished by using parking decks and minimizing landscaping. Little or no ABM habitat remains on privately held lands with the exception of GH, where preservation areas would remain. ABM habitat remains on all lands below the CCCL and on publicly held lands.

13. Moderate Full Build-Out with Maximum GH Development (BOModGHMax)
This scenario represents moderate development of all single family residential lots (defined as resulting in an average loss of 0.25 acres of ABM habitat per single family residential lot). Gulf Highlands/Beach Club West is completely developed with no remaining ABM habitat. Minimal ABM habitat remains on single family residential lots, and no habitat remains at GH except for areas below the CCCL. ABM habitat remains on all publicly held lands.

14. Moderate Full Build-Out with Proposed GH Development (BOModGHProp)
This scenario represents moderate development of all single family residential lots (defined as resulting in an average loss of 0.25 acres of ABM habitat per single family residential lot). Development at Gulf Highlands/Beach Club West occurs as originally permitted as assessed in the environmental assessment. Minimal ABM habitat remains on single family residential lots, but preservation areas remain in GH. ABM habitat remains on all lands below the CCCL and on publicly held lands.

15. Moderate Full Build-Out with Minimum GH Development (BOModGHMin)
This scenario represents moderate development of all single family residential lots (defined as resulting in an average loss of 0.25 acres of ABM habitat per single family residential lot). Gulf Highlands/Beach Club West parcels are developed with minimal impacts. Minimal ABM habitat remains on single family residential lots, but preservation areas remain in GH. ABM habitat remains on all lands below the CCCL and on publicly held lands.

16. Minimum Full Build-Out with Maximum GH Development (BOMinGHMax)
This scenario represents development of all single family residential lots with minimal impacts (defined as an average loss of 0.1 acres of ABM habitat per single family residential lot). Gulf Highlands/Beach Club West is completely developed with no remaining ABM habitat except for areas below the CCCL. ABM habitat remains on public lands.

17. Minimum Full Build-Out with Proposed GH Development (BOMinGHProp)
This scenario represents development of all single family residential lots with minimal impacts (defined as an average loss of 0.1 acres of ABM habitat per single family residential lot). Development at Gulf Highlands/Beach Club West occurs as originally permitted as assessed in the environmental assessment. ABM habitat remains unaffected on public lands.

18. Minimum Full Build-Out with Minimum GH Development (BOMinGHMin)
This scenario represents development of all single family residential lots with minimal impacts (defined as an average loss of 0.1 acres of ABM habitat per single family residential lot). Gulf Highlands/Beach Club West is developed with minimal impacts. ABM habitat remains unaffected on public lands.

19. Minimum Full Build-Out with No Further GH Development (BOMinGHNo)
This scenario represents development of all single family residential lots with minimal impacts (defined as an average loss of 0.1 acres of ABM habitat per single family residential lot). There is no further development on the Gulf Highlands/Beach Club West parcels. ABM habitat remains unaffected on public lands.

Development Input Values

Gulf Highlands/Beach Club West Development

Under these scenarios, the only change in input values is a reduction in the carrying capacity of the Multi-Family model unit, from 513 acres with no development, to 483.5, 454 and 350.5 acres with minimum, proposed, and maximum development, respectively. The additional reduction in K due to Category 1 – 5 hurricanes was calculated based upon the estimated amount of ABM habitat lost using 80% of SLOSH inundation model estimates (see Table 2 for reductions in K used to model hurricanes for each scenario). No additional mortality was imposed on ABM in association with GH development.

Full Build-Out of Private Lands

Development was modeled as a loss in carrying capacity (due to habitat loss) in model units in which development took place and, in most instances, by a reduction in ABM survival rates as well. For the Multi-Family unit, full build-out scenarios included development of the non-GH portion of the model unit independent of GH development. Again, the reduction in K was based upon habitat loss due to development, and hurricane impacts were estimated from the SLOSH model (80%) (see Table 2). Mortality rates (for all age and sex classes over all seasons of the year) were increased for ABM in the Multi-Family model unit only under Maximum Build-Out scenarios, as follows: BOMax with maximum GH development = 25% reduction in survival; BOMax with proposed or minimum GH development = 10% reduction in survival (Table 1).

The reduction in K in the Single Family and West Beach model units under full build-out scenarios (estimated to be proportional to the reduction in acres of ABM habitat after development) was calculated to be 21%, 36% and 74% respectively, with minimum, moderate and maximum development. Hurricanes were assumed to have the same relative effect in these model units with and without development (see Table 2 for input values). This modeling strategy assumes that those areas developed in Single Family and West Beach are representative of overall ABM habitat types and densities. ABM populations are known to utilize a mosaic of habitats, some of which may act as population refugia during and following hurricanes. Heavy development of a particular habitat type might have a differential immediate or long-term impact on ABM populations than that modeled here. Survival was reduced for all ABM age and sex classes throughout the year in these two model units as follows: 10% reduction in survival with Minimum Build-Out; 25% reduction with Moderate Build-Out; and 80% reduction with Maximum Build-Out (Table 1). These reductions in overall ABM survival in developed areas were estimated based on the estimated increased mortality factors associated with areas of high human disturbance.

Table 1. Reduction in survival used in the model in association with full build-out development.

Scenario	Multi-Family	Single Family	West Beach
BOMax GHMax	80%	80%	25%
BOMax GHProp	80%	80%	10%
BOMax GHMin	80%	80%	10%
All BOMod scenarios	25%	25%	--
All BOMin scenarios	10%	10%	--

Table 2. Input values used in the ABM *Vortex* model for carrying capacity (K) and proportional reduction in K due to Category 1 – 5 storms (by model unit and scenario).

	Fort Morgan						Single Family						Multi-Family					
	K	C1	C2	C3	C4	C5	K	C1	C2	C3	C4	C5	K	C1	C2	C3	C4	C5
NoDev	2019	0.552	0.648	0.712	0.740	0.746	6015	0.288	0.656	0.746	0.777	0.786	3335	0.024	0.244	0.558	0.688	0.738
NoDev90%	2019	0.621	0.729	0.801	0.833	0.840	6015	0.324	0.738	0.839	0.874	0.884	3335	0.027	0.270	0.630	0.774	0.830
NoDevFULL	2019	0.690	0.810	0.890	0.925	0.933	6015	0.360	0.820	0.932	0.971	0.982	3335	0.030	0.300	0.700	0.860	0.922
NoDevRestor	2019	0.552	0.648	0.712	0.740	0.746	6015	0.288	0.656	0.746	0.777	0.786	3335	0.024	0.244	0.558	0.687	0.738
GHMax	2019	0.552	0.648	0.712	0.740	0.746	6015	0.288	0.656	0.746	0.777	0.786	2278	0.028	0.259	0.601	0.708	0.747
GHProp	2019	0.552	0.648	0.712	0.740	0.746	6015	0.288	0.656	0.746	0.777	0.786	2951	0.028	0.259	0.585	0.706	0.747
GHMin	2019	0.552	0.648	0.712	0.740	0.746	6015	0.288	0.656	0.746	0.777	0.786	3143	0.026	0.251	0.571	0.696	0.742
GHPropRestor	2019	0.552	0.648	0.712	0.740	0.746	6015	0.288	0.656	0.746	0.777	0.786	2951	0.028	0.259	0.585	0.706	0.747
GHMinRestor	2019	0.552	0.648	0.712	0.740	0.746	6015	0.288	0.656	0.746	0.777	0.786	3143	0.026	0.251	0.571	0.696	0.742
BOMaxGHMax	2019	0.552	0.648	0.712	0.740	0.746	1564	0.288	0.656	0.746	0.777	0.786	763	0.028	0.259	0.601	0.708	0.747
BOMaxGHProp	2019	0.552	0.648	0.712	0.740	0.746	1564	0.288	0.656	0.746	0.777	0.786	1433	0.028	0.259	0.585	0.706	0.747
BOMaxGHMin	2019	0.552	0.648	0.712	0.740	0.746	1564	0.288	0.656	0.746	0.777	0.786	1628	0.028	0.259	0.585	0.706	0.747
BOModGHMax	2019	0.552	0.648	0.712	0.740	0.746	3849	0.288	0.656	0.746	0.777	0.786	1901	0.028	0.259	0.601	0.708	0.747
BOModGHProp	2019	0.552	0.648	0.712	0.740	0.746	3849	0.288	0.656	0.746	0.777	0.786	2571	0.028	0.259	0.585	0.706	0.747
BOModGHMin	2019	0.552	0.648	0.712	0.740	0.746	3849	0.288	0.656	0.746	0.777	0.786	2766	0.028	0.259	0.585	0.706	0.747
BOMinGHMax	2019	0.552	0.648	0.712	0.740	0.746	4752	0.288	0.656	0.746	0.777	0.786	2129	0.028	0.259	0.601	0.708	0.747
BOMinGHProp	2019	0.552	0.648	0.712	0.740	0.746	4752	0.288	0.656	0.746	0.777	0.786	2799	0.028	0.259	0.585	0.706	0.747
BOMinGHMin	2019	0.552	0.648	0.712	0.740	0.746	4752	0.288	0.656	0.746	0.777	0.786	2994	0.028	0.259	0.585	0.706	0.747
BOMinGHNo	2019	0.552	0.648	0.712	0.740	0.746	4752	0.288	0.656	0.746	0.777	0.786	3185	0.028	0.259	0.585	0.706	0.747

K = carrying capacity in the absence of storm effects
C1 – C5 = proportion of reduction in K immediately following Category 1, Category 2, … Category 5 storm

NoDev = no further development
Restor = includes restoration following storms
GHMax/Prop/Min/No = maximum/proposed/minimum/no further development of Gulf Highlands project
BOMax/Mod/Min = maximum/moderate/minimum further development of privately held lands in ABM habitat

Table 2 - cont. Input values used in the ABM *Vortex* model for carrying capacity (K) and proportional reduction in K due to Category 1 – 5 storms (by model unit and scenario).

	Perdue						**West Beach**						**Gulf State Park**					
	K	C1	C2	C3	C4	C5	K	C1	C2	C3	C4	C5	K	C1	C2	C3	C4	C5
NoDev	9713	0.032	0.216	0.672	0.720	0.750	1249	0.328	0.632	0.790	0.792	0.798	496	0.544	0.600	0.766	0.790	0.797
NoDev90%	9713	0.036	0.243	0.756	0.810	0.844	1249	0.369	0.711	0.888	0.891	0.898	496	0.612	0.675	0.861	0.889	0.896
NoDevFULL	9713	0.040	0.270	0.840	0.900	0.938	1249	0.410	0.790	0.987	0.990	0.998	496	0.680	0.750	0.957	0.988	0.996
NoDevRestor	9713	0.032	0.216	0.672	0.720	0.750	1249	0.328	0.632	0.790	0.792	0.798	496	0.544	0.600	0.766	0.790	0.797
GHMax	9713	0.032	0.216	0.672	0.720	0.750	1249	0.328	0.632	0.790	0.792	0.798	496	0.544	0.600	0.766	0.790	0.797
GHProp	9713	0.032	0.216	0.672	0.720	0.750	1249	0.328	0.632	0.790	0.792	0.798	496	0.544	0.600	0.766	0.790	0.797
GHMin	9713	0.032	0.216	0.672	0.720	0.750	1249	0.328	0.632	0.790	0.792	0.798	496	0.544	0.600	0.766	0.790	0.797
GHPropRestor	9713	0.032	0.216	0.672	0.720	0.750	1249	0.328	0.632	0.790	0.792	0.798	496	0.544	0.600	0.766	0.790	0.797
GHMinRestor	9713	0.032	0.216	0.672	0.720	0.750	1249	0.328	0.632	0.790	0.792	0.798	496	0.544	0.600	0.766	0.790	0.797
BOMaxGHMax	9713	0.032	0.216	0.672	0.720	0.750	325	0.328	0.632	0.790	0.792	0.798	496	0.544	0.600	0.766	0.790	0.797
BOMaxGHProp	9713	0.032	0.216	0.672	0.720	0.750	325	0.328	0.632	0.790	0.792	0.798	496	0.544	0.600	0.766	0.790	0.797
BOMaxGHMin	9713	0.032	0.216	0.672	0.720	0.750	325	0.328	0.632	0.790	0.792	0.798	496	0.544	0.600	0.766	0.790	0.797
BOModGHMax	9713	0.032	0.216	0.672	0.720	0.750	799	0.328	0.632	0.790	0.792	0.798	496	0.544	0.600	0.766	0.790	0.797
BOModGHProp	9713	0.032	0.216	0.672	0.720	0.750	799	0.328	0.632	0.790	0.792	0.798	496	0.544	0.600	0.766	0.790	0.797
BOModGHMin	9713	0.032	0.216	0.672	0.720	0.750	799	0.328	0.632	0.790	0.792	0.798	496	0.544	0.600	0.766	0.790	0.797
BOMinGHMax	9713	0.032	0.216	0.672	0.720	0.750	986	0.328	0.632	0.790	0.792	0.798	496	0.544	0.600	0.766	0.790	0.797
BOMinGHProp	9713	0.032	0.216	0.672	0.720	0.750	986	0.328	0.632	0.790	0.792	0.798	496	0.544	0.600	0.766	0.790	0.797
BOMinGHMin	9713	0.032	0.216	0.672	0.720	0.750	986	0.328	0.632	0.790	0.792	0.798	496	0.544	0.600	0.766	0.790	0.797
BOMinGHNo	9713	0.032	0.216	0.672	0.720	0.750	986	0.328	0.632	0.790	0.792	0.798	496	0.544	0.600	0.766	0.790	0.797

K = carrying capacity in the absence of storm effects
C1 – C5 = proportion of reduction in K immediately following Category 1, Category 2, … Category 5 storm

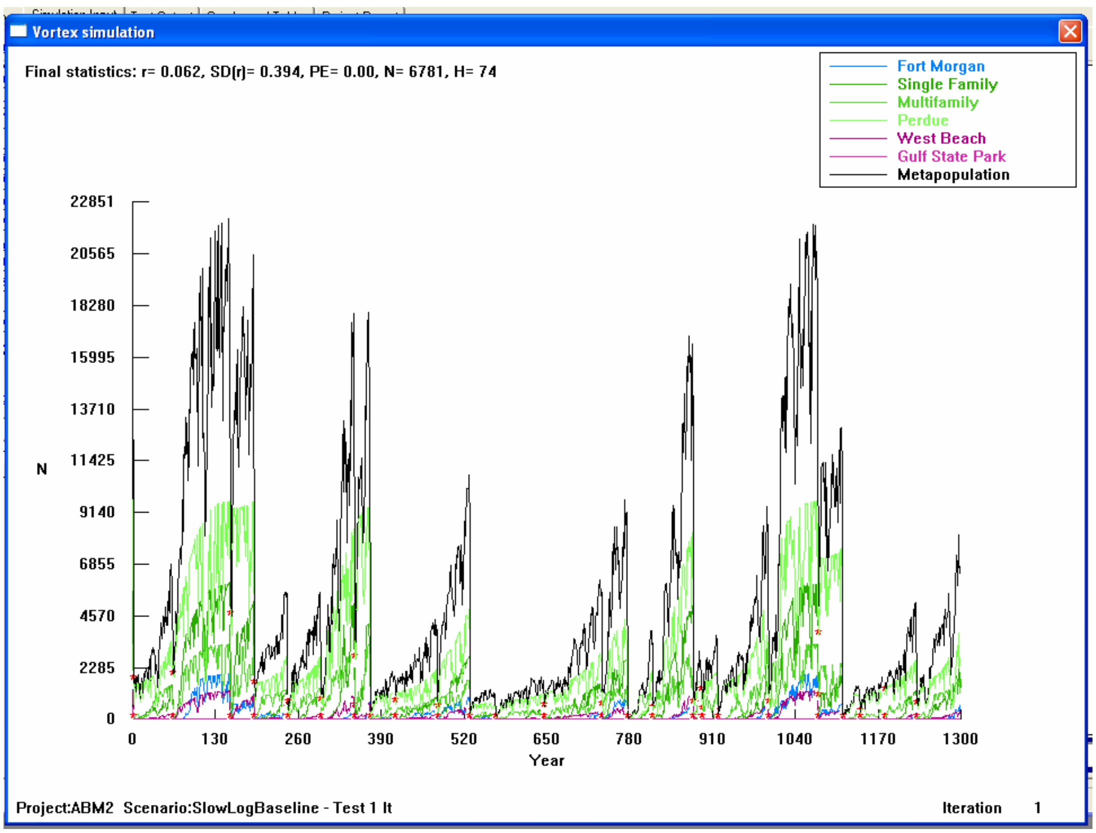
NoDev = no further development
Restor = includes restoration following storms
GHMax/Prop/Min/No = maximum/proposed/minimum/no further development of Gulf Highlands project
BOMax/Mod/Min = maximum/moderate/minimum further development of privately held lands in ABM habitat

Vortex Model Results

The 19 revised model scenarios were run with 1500 iterations per scenario to generate the following results. The results of these simulations are summarized below; complete data tables of model outputs for the metapopulation and individual model unit subpopulations can be found in Table 7 at the end of this section.

Populations of Alabama beach mice, both in nature and in the computer simulations, are subject to large, unpredictable fluctuations – due to the combination of seasonal changes in survival and breeding, large fluctuations in population performance due to random environmental variation over time, and periodic decimation of numbers of mice and habitat by hurricanes. This can be seen in the sample iteration below (Fig. 1). Note the population crash in the first time step, simulating the effects of Hurricane Ivan. Although this pattern is typical for each individual simulation, the years in which storms occur vary across simulations, resulting in a mean population size that appears much less dynamic and is intermediate between these population peaks and valleys. These results compiled across simulations project the general population trends that can be compared across alternative management and development scenarios.

Figure. 1. Single sample iteration of the revised ABM model over a 100-year period.

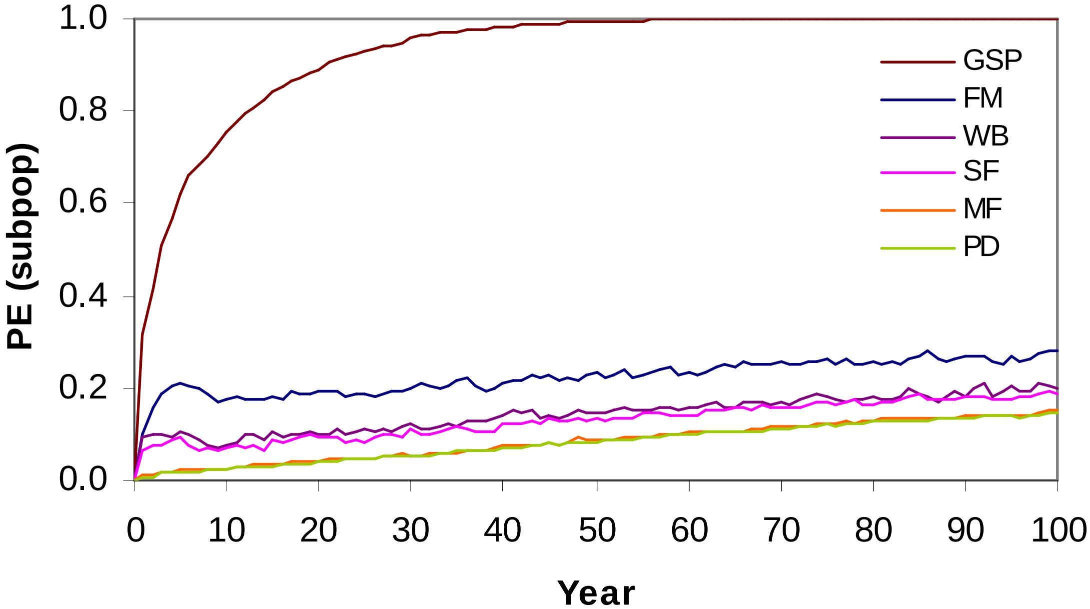


Revised ABM Population Projections

Probability of Extinction

The revised ABM model represents the best estimates available as of December 2004 regarding population and habitat status, demographic rates, and hurricanes impacts for the Alabama beach mouse. If no further development or other loss of ABM habitat occurs, the revised model gives the risk of ABM extinction over the next 100 years at 14%. The probability of local extinction in individual model units is higher; certain extinction is projected for the small, isolated subpopulation at Gulf State Park, while the risk of extinction varies from 15% to 28% for the other five model unit subpopulations (Fig. 2). The risk of extinction increases generally over time as expected, although some fluctuation in extinction risk can be observed due to the ability of some model units to be recolonized by mice from adjacent areas.

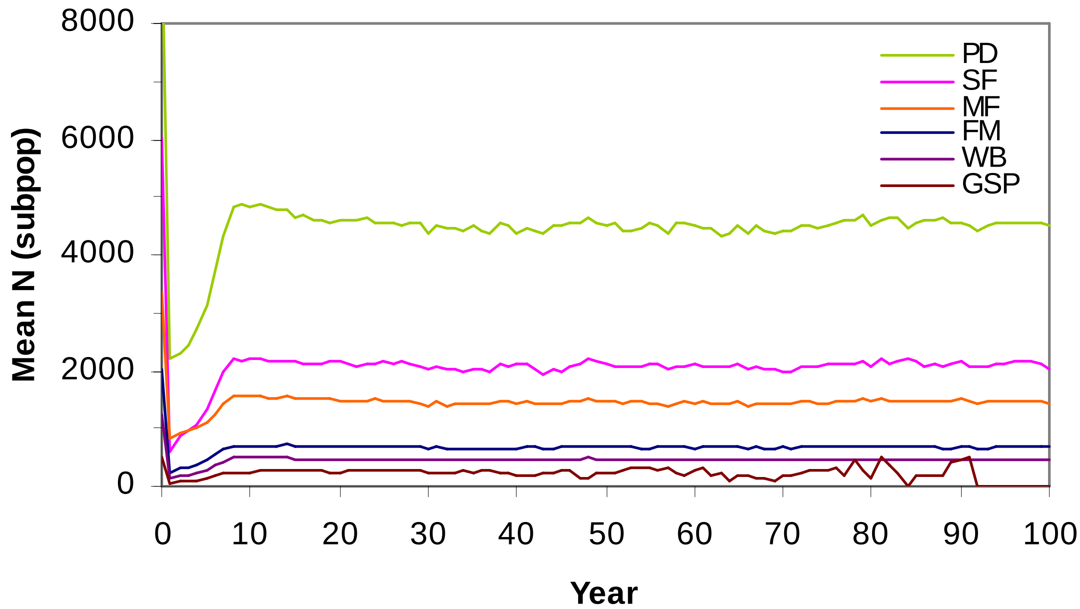
Figure 2. Probability of ABM extinction over 100 years for each model unit subpopulation (legend indicates order of lines from top to bottom).



Mean Population Size and Gene Diversity

Simulations show an immediate marked decline in population size due to the Category 3 hurricane at the onset of each simulation. On average, populations recover over the next 10 years and stabilize at approximately one-third of the carrying capacity. Mean metapopulation size falls to about 8820 ABM, with about one-half of these inhabiting the Perdue model unit (Fig. 3). Mice are quickly lost from Gulf State Park (90% probability of extirpation in 20 years), leaving only five model unit subpopulations. These results show the mean population size across a highly volatile system, and represent the average across simulations in which ABM populations can be near carrying capacity or close to extirpation (SD = 6160). Such fluctuations in population size contribute to the loss of gene diversity. About 77% of the original gene diversity is retained, approaching a level of inbreeding in the population similar to full sibling mating.

Figure 3. Mean population size (across all iterations) over 100 years for each model unit subpopulation (legend indicates order of lines from top to bottom).



Sensitivity Analysis of SLOSH Estimates

The original ABM *Vortex* model developed at the June 2004 PHVA workshop incorporated the temporary loss of ABM habitat after hurricanes based upon estimates using the SLOSH model. After observing the effects of Hurricane Ivan and other sources of information, expert opinion suggested that the SLOSH model likely overestimates the loss of ABM habitat due to storms. In the absence of a more accurate model, workshop participants chose to model the environmental impacts of hurricanes as 80% of those predicted by SLOSH. Given the uncertainty in this parameter, scenarios were run under 80%, 90% and 100% SLOSH impacts to determine the sensitivity of the model to this parameter.

As discussed earlier, in this model ABM populations appear to be driven to a large extent by the occurrence of hurricanes. Therefore it is not surprising that changes in the impact of storms on ABM carrying capacity have a relatively large effect on ABM populations (Fig. 4). Reducing the impact of hurricanes on K from 100% to 80% of the SLOSH estimates causes the probability of metapopulation extinction in 100 years to decrease from 0.21 to 0.14 (Table 3). Local extinction risks are similarly reduced except for Gulf State Park, which is predicted to go extinct under all hurricane impact estimates. In those cases in which populations persist, population size is larger and more genetic variation is retained using the 80% SLOSH estimates. The impact of hurricanes, including the temporary loss of carrying capacity, is a primary factor in this ABM model. It may therefore be important to continue refinement of estimates of hurricane effects in order to improve the accuracy of the model to project the future of ABM populations under expected and alternative management scenarios.

Figure 4. Probability of ABM metapopulation extinction over 100 years using various estimates of reduction in K following hurricanes (80%, 90%, 100% SLOSH estimates).

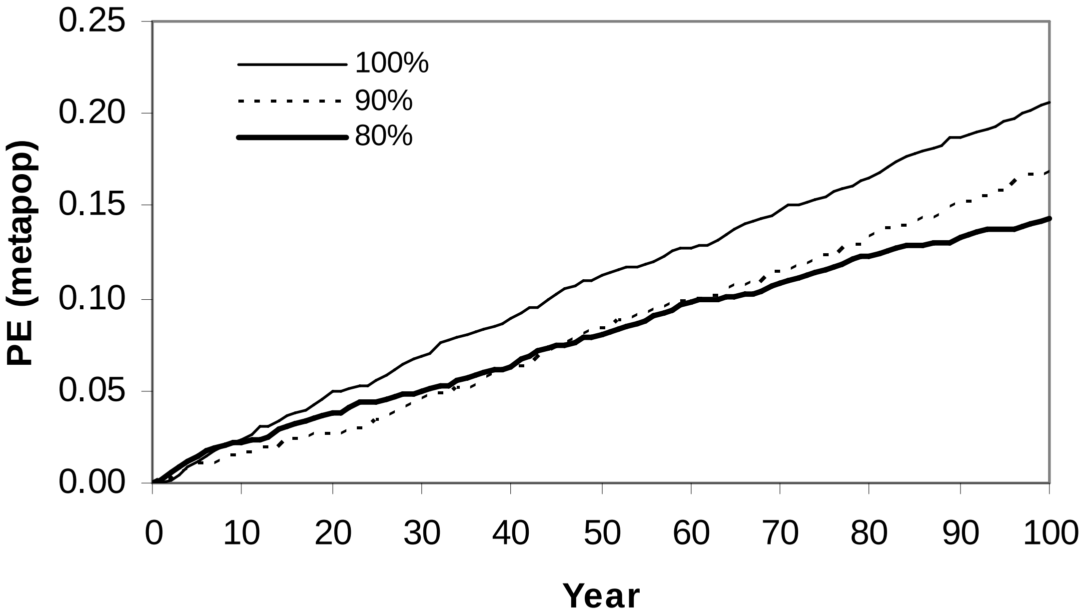


Table 3. Results for ABM subpopulations and metapopulation after 100 years using various estimates of reduction in K following hurricanes (80%, 90%, 100% SLOSH estimates).

	PE			Mean N			GD		
	80%	90%	100%	80%	90%	100%	80%	90%	100%
Fort Morgan	0.28	0.31	0.39	684	634	633	0.62	0.57	0.53
Single Family	0.19	0.22	0.28	2014	1936	1846	0.70	0.67	0.62
Multi-Family	0.15	0.17	0.22	1440	1334	1291	0.77	0.73	0.67
Perdue	0.15	0.17	0.21	4508	4194	3921	0.76	0.72	0.67
West Beach	0.20	0.23	0.29	443	412	400	0.72	0.68	0.63
Gulf State Park	1.00	1.00	1.00	0	0	0	0.00	0.00	0.00
Metapopulation	0.14	0.17	0.21	8820	8230	7683	0.77	0.73	0.68

Gulf Highlands/Beach Club West Development Scenarios

One of the areas within the ABM range being considered for further development is the Gulf Highlands/Beach Club West parcels in the Multi-Family model unit. Four options for Gulf Highlands/Beach Club West (GH) development were modeled: Maximum, Proposed, Minimum, and No Further Development (see **Scenario Descriptions** section). These scenarios differed only in the amount of ABM habitat available in these parcels; ABM habitat in the rest of the Multi-Family model unit as well as the other five model units remained constant.

Development of the Gulf Highlands/Beach Club West area leads to an increase in the probability of extinction and a decrease in mean population size and gene diversity of surviving populations.

This effect is relatively small for minimum and proposed development scenarios but is more noticeable with maximum development (Table 4). This trend holds true for both the ABM subpopulation in the Multi-Family model unit and for the entire ABM metapopulation. Standard deviations in the mean population size are quite high (see Table 7) due to the dynamic nature of the ABM population. These results suggest that minimum or proposed development of the GH parcels as modeled are likely to have little impact on the viability of the overall ABM metapopulation, while maximum development of GH is associated with a slightly greater risk of extinction. Overall, the impact of GH development is substantially lower than that observed by modifying the SLOSH estimates of hurricane impacts.

Table 4. Results for ABM Multi-Family subpopulation and metapopulation after 100 years with various levels of Gulf Highlands/Beach Club West development.

	PE		Mean N		GD	
	MF	Metapop	MF	Metapop	MF	Metapop
GH Max Dev	0.18	0.17	996	8295	0.74	0.75
GH Proposed	0.16	0.15	1265	8648	0.76	0.76
GH Min Dev	0.16	0.15	1370	8817	0.76	0.76
No GH Dev	0.15	0.14	1440	8820	0.77	0.77

Effect of Habitat Restoration

Habitat restoration efforts (e.g., sand fencing, dune fertilization, vegetation planting, and sand translocation) can lead to more rapid recovery of ABM habitat in the early years following damage from hurricanes. Restoration was modeled by modifying the recovery curve for K following hurricanes for the Fort Morgan, Perdue, Gulf State Park and a portion of the Multi-Family model units. Restoration scenarios were run with No Development, GH Proposed and GH Minimum development. Restoration as modeled shows a small effect by lowering the probability of extinction and increasing the mean population size and gene diversity of surviving populations (Table 5). This trend is true for scenarios both with and without development in GH. The ABM metapopulation fares as well or better in the restoration scenarios than in the situation of no further development but no restoration, suggesting that restoration on public lands and GH may be able to offset the negative impacts of GH development. These results reinforce the trend in model results that ABM populations are more sensitive to the effects of hurricanes than to development in the GH parcels.

Table 5. Results for ABM metapopulation after 100 years with and without restoration efforts (with various levels of Gulf Highlands/Beach Club West development).

	PE		Mean N		GD	
	No Restor	Restoration	No Restor	Restoration	No Restor	Restoration
GH Proposed	0.15	0.13	8648	9240	0.76	0.78
GH Min Dev	0.15	0.14	8817	9167	0.76	0.78
No GH Dev	0.14	0.13	8820	9350	0.77	0.77

Full Build-Out Development Scenarios

Several scenarios were run to represent various levels of development of all ABM privately-held lands (Single Family, Multi-Family and West Beach model units above the CCCL). Table 6 below presents the results for the metapopulation for the 10 Full Build-Out Scenarios compared to no Build-Out (No Development). These scenarios include various combinations of GH development (maximum, proposed, minimum, none) with three levels of Full Build-Out in other developable areas (maximum, moderate, minimum). Results for GH development only (maximum, proposed and minimum) and no development are also included.

In general, more development leads to increased risk of extinction and smaller populations with lower gene diversity. As might be expected, development across all privately-held lands (Full Build-Out) has a greater impact on the ABM metapopulation than development of the Gulf Highlands/Beach Club West parcels only. Maximum development of private lands (independent of GH development level) has the greatest impact on ABM population viability of all parameters tested by this model (Fig. 5). The risk of ABM extinction is over twice as great with full development (34%) as compared with no further development of ABM habitat (14%). While the mean population size of surviving populations is also reduced with increased development, the effect is more continuous as development increases (Fig. 6). Under both Moderate and Maximum Build-Out scenarios, the mean population size is about 31% of the carrying capacity.

Full build-out development of private lands is modeled in two ways in the *Vortex* model. First, the carrying capacity of each of the affected model units is permanently reduced to represent the permanent loss of ABM habitat due to habitat conversion. Secondly, mortality rates for all ABM sex and age classes are higher due to the estimated impacts of increased human disturbance in highly developed areas. These effects are substantially higher in the Maximum Build-Out scenario modeled here versus the minimum and moderate build-out scenarios (see **Scenario Descriptions** section). Although substantially more habitat is lost under Maximum Build-Out, population sizes are proportionately similar to K. The marked increase in extinction risk observed with maximum build-out may be associated with the high mortality rates (80% reduction in survival due to development) in these developed areas. High mortality limits the ability of ABM populations to grow quickly following hurricanes and causes these small populations to be more vulnerable to stochastic threats leading to extinction.

Table 6. Results for ABM metapopulation after 100 years under various development scenarios.

Level of Build-Out	PE				Mean N				GD			
	GH Max	**GH Prop**	**GH Min**	**GH No**	**GH Max**	**GH Prop**	**GH Min**	**GH No**	**GH Max**	**GH Prop**	**GH Min**	**GH No**
Maximum	0.34	0.30	0.32	--	4638	4951	5077	--	0.74	0.72	0.72	--
Moderate	0.19	0.17	0.16	--	5396	5522	6105	--	0.73	0.74	0.75	--
Minimum	0.17	0.16	0.17	0.16	6668	6958	7490	7212	0.74	0.74	0.76	0.75
None	0.17	0.15	0.15	0.14	8295	8648	8817	8820	0.75	0.76	0.76	0.77

Figure 5. Probability of ABM metapopulation extinction at 100 years under various development scenarios.

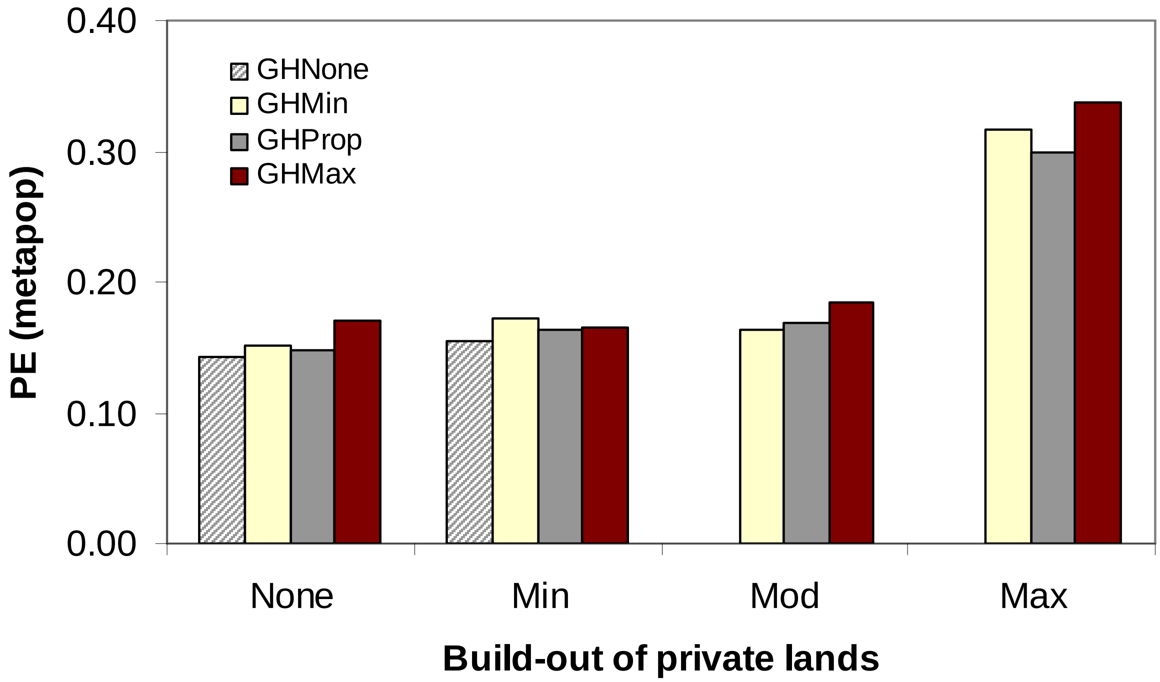
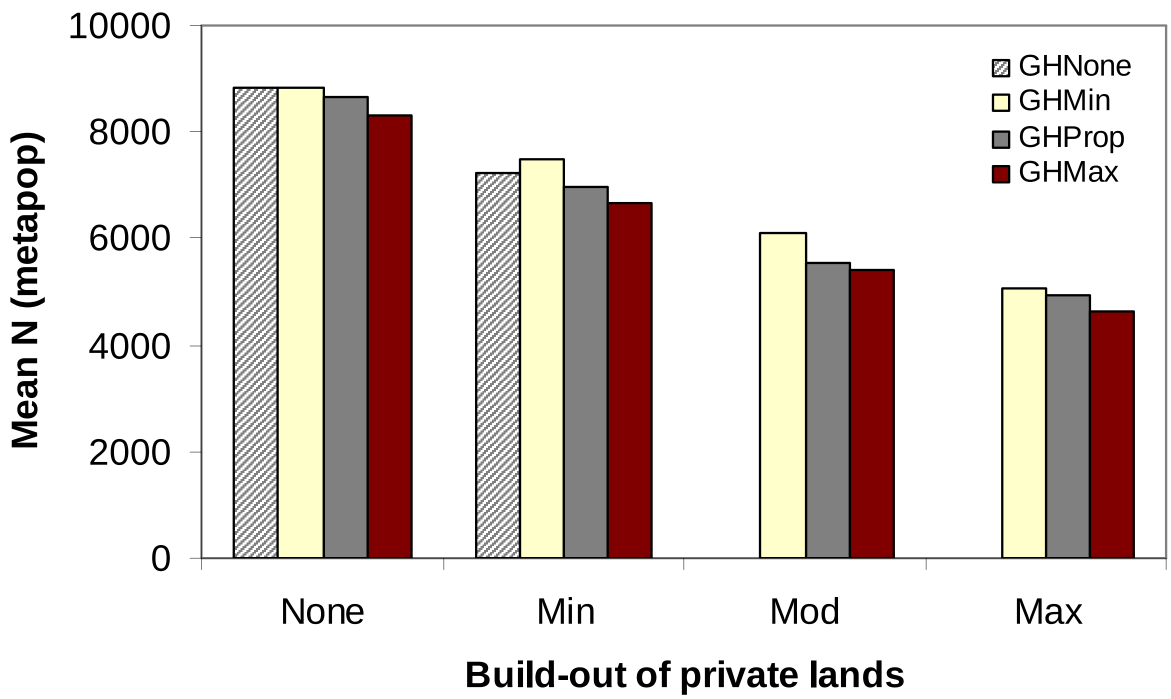


Figure 6. Mean ABM metapopulation size (of extant populations) at 100 years under various development scenarios.



Effect of Development on Local Subpopulations

Since development is only modeled in the Single Family, Multi-Family and West Beach model units (where privately held land occurs), it might be expected that local model unit subpopulations would be affected differently by development. Figure 7 illustrates the probability of extinction for each model unit subpopulation under maximum (BOMaxGHMax), moderate (BOModGHProp), minimal (BOMinGHMin) and no further (NoDev) development of ABM habitat and demonstrates differential effects among these subpopulations. The Perdue model unit, which has the largest ABM carrying capacity and consists of public land, is the least affected by development and functions as the core of the ABM metapopulation. Although the Multi-Family and West Beach model units are subject to development, they lie adjacent to the Perdue unit and are likely sustained by the movement of mice among these areas. The Single Family model unit is more susceptible to development impacts, despite the fact that ABM carrying capacity is twice that of the Multi-Family unit, possibly due to its distance from more robust ABM subpopulations. Fort Morgan is particularly vulnerable to hurricane impacts, and although no development is modeled in this public land unit, development in the adjacent Single Family unit reduces the ability of the Single Family ABM subpopulation to augment or recolonized the Fort Morgan unit. Fort Morgan is the only unit that is severely impacted by a moderate level of development; for the other model units, the risk of extinction is affected most dramatically at the maximum development level. Under all scenarios (including no further development), the Gulf State Park model unit subpopulation has a 100% probability of extinction in 100 years.

Figure 7. Probability of ABM subpopulation extinction at 100 years under various development scenarios (Max=BOMaxGHMax; Mod=BOModGHProp; Min=BOMinGHMin; No=NoDev).

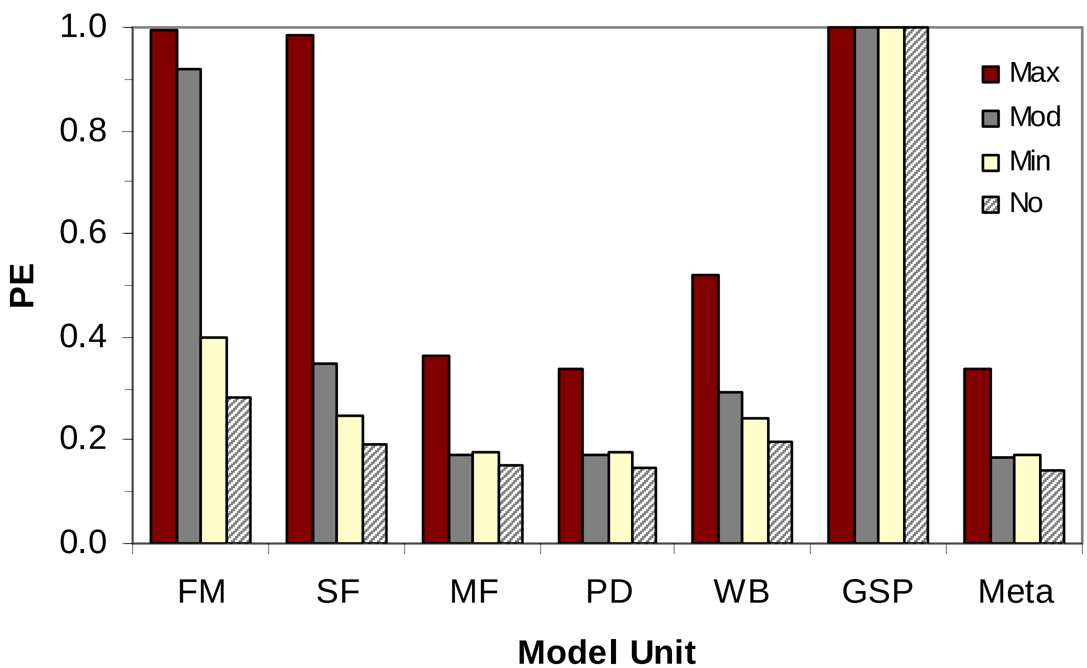


Table 7. Results for each model unit and the metapopulation after 100 years for all scenarios.

Prob. Extinct = the probability that the population is extinct after 100 years, estimated from the proportion of simulation iterations in which the population did not have mice of both sexes.

SE(PE) = standard error of probability of extinction (measure of precision)

Mean N = mean population size projected at the end of 100 years for those populations that did not go extinct

SD(N) = standard deviation of final N across iterations (measure of variability)

SE(N) = standard error of mean N (measure of precision)

Gene Diversity = mean gene diversity (expected heterozygosity) at 100 years, as a proportion of the initial diversity

Median Time to Extinction = median year at which the population first goes extinct (blank if the population goes extinct in fewer than 50% of the iterations). Note that often locally extinct populations are later recolonized.

Model Unit	Prob. Extinct	SE(PE)	Mean N	SD(N)	SE(N)	Gene Diversity	Median Time to Extinction
No Development							
Fort Morgan	0.283	0.012	684	597	15	0.62	12
Single Family	0.190	0.010	2014	1906	49	0.70	17
Multi-Family	0.149	0.009	1440	970	25	0.77	
Perdue	0.145	0.009	4508	2928	76	0.76	
West Beach	0.197	0.010	443	390	10	0.72	8
Gulf St. Park	1.000	0.000	0	0	0	0.00	4
Metapopulation	0.143	0.009	8820	6160	159	0.77	
No Development 90% SLOSH							
Fort Morgan	0.305	0.012	634	579	15	0.57	9
Single Family	0.223	0.011	1936	1914	49	0.67	13
Multi-Family	0.174	0.010	1334	981	25	0.73	79
Perdue	0.171	0.010	4194	3028	78	0.72	
West Beach	0.226	0.011	412	391	10	0.68	5
Gulf St. Park	1.000	0.000	0	0	0	0.00	3
Metapopulation	0.169	0.010	8231	6287	162	0.73	
No Development 100% SLOSH							
Fort Morgan	0.389	0.013	633	630	16	0.53	8
Single Family	0.281	0.012	1846	2002	52	0.62	11
Multi-Family	0.216	0.011	1291	1048	27	0.67	70
Perdue	0.213	0.011	3921	3203	83	0.67	
West Beach	0.291	0.012	400	419	11	0.63	3
Gulf St. Park	1.000	0.000	0	0	0	0.00	2
Metapopulation	0.207	0.010	7683	6768	175	0.68	
No Development with Restoration							
Fort Morgan	0.276	0.012	751	618	16	0.62	12
Single Family	0.184	0.010	2067	1931	50	0.71	15
Multi-Family	0.137	0.009	1480	963	25	0.77	93
Perdue	0.137	0.009	4892	2978	77	0.76	
West Beach	0.194	0.010	458	385	10	0.73	7
Gulf St. Park	1.000	0.000	0	0	0	0.00	4
Metapopulation	0.134	0.009	9350	6221	161	0.77	

Table 7. Continued.

Model Unit	Prob. Extinct	SE(PE)	Mean N	SD(N)	SE(N)	Gene Diversity	Median Time to Extinction
GH/BCW Maximum Development							
Fort Morgan	0.307	0.012	665	585	15	0.57	10
Single Family	0.226	0.011	2062	1939	50	0.66	14
Multi-Family	0.176	0.010	996	668	17	0.74	76
Perdue	0.173	0.010	4428	2958	76	0.74	
West Beach	0.227	0.011	448	396	10	0.69	6
Gulf St. Park	1.000	0.000	0	0	0	0.00	3
Metapopulation	0.170	0.010	8295	6015	155	0.75	
GH/BCW Proposed Development							
Fort Morgan	0.284	0.012	660	586	15	0.60	14
Single Family	0.198	0.010	2075	1952	50	0.69	19
Multi-Family	0.156	0.009	1265	873	23	0.76	
Perdue	0.149	0.009	4480	2983	77	0.75	
West Beach	0.210	0.011	453	396	10	0.71	8
Gulf St. Park	1.000	0.000	0	0	0	0.00	4
Metapopulation	0.147	0.009	8648	6223	161	0.76	
GH/BCW Minimum Development							
Fort Morgan	0.293	0.012	685	601	16	0.61	11
Single Family	0.200	0.010	2060	1937	50	0.70	15
Multi-Family	0.163	0.010	1370	912	24	0.76	94
Perdue	0.154	0.009	4544	2942	76	0.76	
West Beach	0.211	0.011	454	383	10	0.72	6
Gulf St. Park	1.000	0.000	0	0	0	0.00	3
Metapopulation	0.151	0.009	8817	6178	160	0.76	
GH/BCW Proposed with Restoration							
Fort Morgan	0.262	0.011	746	612	16	0.62	15
Single Family	0.185	0.010	2141	1950	50	0.71	21
Multi-Family	0.131	0.009	1312	878	23	0.77	
Perdue	0.133	0.009	4887	3029	78	0.77	
West Beach	0.184	0.010	468	396	10	0.73	8
Gulf St. Park	1.000	0.000	0	0	0	0.00	4
Metapopulation	0.128	0.009	9240	6219	161	0.78	
GH/BCW Minimum with Restoration							
Fort Morgan	0.265	0.011	725	621	16	0.62	12
Single Family	0.185	0.010	2035	1932	50	0.71	15
Multi-Family	0.149	0.009	1395	927	24	0.77	98
Perdue	0.144	0.009	4814	3009	78	0.77	
West Beach	0.199	0.010	458	391	10	0.73	7
Gulf St. Park	1.000	0.000	0	0	0	0.00	3
Metapopulation	0.142	0.009	9167	6257	162	0.78	

Table 7. Continued.

Model Unit	Prob. Extinct	SE(PE)	Mean N	SD(N)	SE(N)	Gene Diversity	Median Time to Extinction
Build-Out Maximum GH Maximum							
Fort Morgan	0.993	0.002	631	498	13	0.23	10
Single Family	0.985	0.003	4	3	0	0.48	1
Multi-Family	0.366	0.012	74	64	2	0.72	8
Perdue	0.339	0.012	4557	2956	76	0.74	
West Beach	0.522	0.013	9	7	0	0.68	1
Gulf St. Park	1.000	0.000	0	0	0	0.00	4
Metapopulation	0.338	0.012	4638	3017	78	0.74	
Build-Out Maximum GH Proposed							
Fort Morgan	0.993	0.002	886	672	17	0.22	10
Single Family	0.828	0.010	4	3	0	0.64	1
Multi-Family	0.317	0.012	389	345	9	0.71	27
Perdue	0.305	0.012	4588	3098	80	0.72	
West Beach	0.499	0.013	10	7	0	0.67	1
Gulf St. Park	1.000	0.000	0	0	0	0.00	3
Metapopulation	0.300	0.012	4951	3388	87	0.72	
Build-Out Maximum GH Minimum							
Fort Morgan	0.994	0.002	1287	662	17	0.09	11
Single Family	0.799	0.010	4	3	0	0.60	1
Multi-Family	0.326	0.012	423	368	9	0.71	29
Perdue	0.319	0.012	4652	2948	76	0.72	
West Beach	0.498	0.013	10	7	0	0.66	1
Gulf St. Park	1.000	0.000	0	0	0	0.00	3
Metapopulation	0.317	0.012	5077	3237	84	0.72	
Build-Out Moderate GH Maximum							
Fort Morgan	0.951	0.006	671	576	15	0.42	10
Single Family	0.399	0.013	17	18	0	0.66	2
Multi-Family	0.192	0.010	833	552	14	0.72	66
Perdue	0.189	0.010	4507	2925	76	0.73	
West Beach	0.295	0.012	31	28	1	0.69	1
Gulf St. Park	1.000	0.000	0	0	0	0.00	3
Metapopulation	0.185	0.010	5396	3442	89	0.73	
Build-Out Moderate GH Proposed							
Fort Morgan	0.919	0.007	600	581	15	0.37	10
Single Family	0.349	0.012	23	26	1	0.68	2
Multi-Family	0.173	0.010	1083	752	19	0.74	81
Perdue	0.169	0.010	4346	2955	76	0.74	
West Beach	0.292	0.012	30	30	1	0.70	1
Gulf St. Park	1.000	0.000	0	0	0	0.00	3
Metapopulation	0.169	0.010	5522	3672	95	0.74	

Table 7. Continued.

Model Unit	Prob. Extinct	SE(PE)	Mean N	SD(N)	SE(N)	Gene Diversity	Median Time to Extinction
Build-Out Moderate GH Minimum							
Fort Morgan	0.910	0.007	783	629	16	0.37	10
Single Family	0.313	0.012	26	34	1	0.69	3
Multi-Family	0.171	0.010	1245	813	21	0.75	87
Perdue	0.167	0.010	4753	3049	79	0.75	
West Beach	0.277	0.012	34	34	1	0.71	1
Gulf St. Park	1.000	0.000	0	0	0	0.00	3
Metapopulation	0.164	0.010	6105	3853	99	0.75	
Build-Out Minimum GH Maximum							
Fort Morgan	0.440	0.013	686	601	16	0.51	10
Single Family	0.256	0.011	742	1080	28	0.65	6
Multi-Family	0.175	0.010	915	601	16	0.73	72
Perdue	0.168	0.010	4453	2904	75	0.73	
West Beach	0.235	0.011	220	236	6	0.70	4
Gulf St. Park	0.999	0.001	124	0	0	0.00	3
Metapopulation	0.165	0.010	6668	4684	121	0.74	
Build-Out Minimum GH Proposed							
Fort Morgan	0.420	0.013	691	595	15	0.53	10
Single Family	0.245	0.011	812	1109	29	0.67	6
Multi-Family	0.169	0.010	1163	830	21	0.74	87
Perdue	0.167	0.010	4392	2967	77	0.74	
West Beach	0.251	0.011	236	251	6	0.70	4
Gulf St. Park	1.000	0.000	0	0	0	0.00	3
Metapopulation	0.164	0.010	6958	5042	130	0.74	
Build-Out Minimum GH Minimum							
Fort Morgan	0.397	0.013	695	606	16	0.55	11
Single Family	0.249	0.011	899	1175	30	0.69	7
Multi-Family	0.178	0.010	1304	872	23	0.75	
Perdue	0.177	0.010	4687	2991	77	0.75	
West Beach	0.244	0.011	239	249	6	0.71	4
Gulf St. Park	1.000	0.000	0	0	0	0.00	3
Metapopulation	0.172	0.010	7490	5172	134	0.76	
Build-Out Minimum GH None							
Fort Morgan	0.413	0.013	708	606	16	0.54	11
Single Family	0.249	0.011	847	1143	30	0.69	7
Multi-Family	0.159	0.009	1312	923	24	0.74	86
Perdue	0.159	0.009	4481	2968	77	0.74	
West Beach	0.242	0.011	230	248	6	0.71	4
Gulf St. Park	1.000	0.000	0	0	0	0.00	3
Metapopulation	0.155	0.009	7212	5182	134	0.75	

Summary of PVA Results

The best available data and expert knowledge were used to revise the ABM *Vortex* model and to project the viability of ABM populations under current and potential future development scenarios. Given current ABM population status and habitat availability, the Alabama beach mouse has about a 14% risk of extinction over the next 100 years. Mean size of surviving populations average about 32% of estimated carrying capacity, but tend to fluctuate widely over time. After 100 years inbreeding accumulates to a population level equivalent to full sibling matings.

Much of the extinction risk is due to the impact of hurricanes on ABM populations and habitat, which can result in relatively frequent and severe population declines. The habitat mosaic utilized by beach mice may help to buffer storm impacts by providing refugia for a portion of the population, and the high reproductive potential of the species makes it possible for the population to rebound as new habitat is regenerated. The connectivity of ABM habitat areas provides the opportunity for mice to recolonize heavily impacted areas following storms. The Perdue Unit of Bon Secour National Wildlife Refuge is likely to act as a core source population for ABM, providing a large, central population protected on public land that can augment ABM subpopulations to the east and west. In contract, ABM are faced with almost certain extinction in the isolated habitat of Gulf State Park; repeated translocations following severe storms will likely be necessary to maintain ABM in this area in the absence of natural corridors.

Land development can lower ABM viability by reducing habitat, increasing mortality, and exacerbating the effects of hurricanes by removing high elevation refugia areas of habitat. These negative effects increase with increased development, but none of the development scenarios modeled result in certain ABM extinction. In the highest level of Full Build-Out modeled, the risk of metapopulation extinction is 34% over 100 years, with a mean population size of about 4600 mice with 74% gene diversity remaining for those populations that did not go extinct. Maximum Gulf Highlands/Beach Club West development (vs. proposed or minimum) and maximum Full Build-Out (vs. moderate or minimum) have substantially greater impacts than lower levels of development. Development can lead to high risk of local extinction not only in the immediate developed areas but in adjacent private and public lands. Fort Morgan and Single Family subpopulations are most affected by development, followed by West Beach.

Habitat restoration following hurricanes may help to reduce overall extinction risk by allowing ABM populations to recover faster; however, restoration as modeled here is unlikely to substantially reduce or eliminate extinction risk. Restoration may make a small but measurable impact on ABM viability for some development scenarios.

The ABM PHVA model identified other factors that could potentially threat ABM viability. In particular, continual loss of habitat due to the spread of cogongrass (an exotic invasive species) and predation by domestic cats each have the ability to drive ABM populations to extinction. These threats can interact with the effects of hurricanes to keep ABM populations small and more vulnerable to stochastic threats. None of the scenarios in this revised PVA includes the effects of either cogongrass or domestic cats; however, it should be recognized that both factors represent potential significant threats to ABM persistence.

The ABM *Vortex* model suggests that hurricanes are a driving force for ABM population, both directly and also indirectly, as their impacts relate to habitat types and areas subject to development. These results support the importance of efforts to improve the accuracy of hurricane impact estimates, including loss and recovery of habitat as well as how ABM use different habitat types before, during and following storms. Better understanding of these processes and more accurate estimation of their frequency and effects would lead to development of a more useful simulation model for ABM populations.

Caveat Regarding Results of Simulation Modeling

The results presented in this report provide general indications about the expected population performance, the factors that have the greatest impact on population projections, and the development scenarios that have the greatest impact on trends. The accuracy of this result will depend on the accuracy of the values that were put into the model. For many of the model parameters, available data allow only approximate estimates of the true values. Thus, simulation results can be misleading regarding the most likely fate of a population. However, even if the mean prediction from a model is biased because of inaccurate values of some parameters describing the species biology or habitat, comparisons among models that change one or a few parameters (such as a test of the effect of a loss of some habitat) would still be expected to provide robust estimates of the relative shift in extinction probabilities or mean population size.

Even if mean results are accurate, the *mean* result of a model does not guarantee that the actual outcome in nature or in any one simulation will closely approximate that mean result. The high fluctuations in the ABM populations and the great variability among iterated simulations indicate that there is great inherent uncertainty in the future fate of the populations of beach mice. Thus, although the model estimates the probability of extinction to be, for example, 14% ± 1%, the real population either will go extinct or it will persist for the specified time period. Similarly, in many of the scenarios tested, the SD(N) among iterations was of approximately the same magnitude as the mean N, indicating that across years and across iterations the population sizes in the simulations often varied from 0 (extinction) to double the mean N or more. The boom and bust nature of ABM populations make it difficult to accurately predict the future of this subspecies.

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