

Implications of Fertility Control for Feral Horse Management
on Assateague Island National Seashore

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EXECUTIVE SUMMARY

The goal of this study was to explore the implications of fertility control for management of feral horses on Assateague Island National Seashore (ASIS). Objectives included the construction of a database management system for the storage and retrieval of information on ASIS horses, the analysis of the dynamics of this population of horses, and the development of a framework for evaluating the efficacy of different management scenarios through computer simulation. Assateague Island is a barrier island off the coasts of Maryland and Virginia. It is approximately 56 km long, oriented in a north-south direction. ASIS encompasses the northern, or Maryland, portion of the island and is managed by the National Park Service (NPS). The feral horses of Assateague Island have a long and illustrious legacy common to many Atlantic coastal barrier islands. This report concerns only those horses inhabiting the Maryland portion of Assateague Island. The principal source of data for this project is a database whose records (rows) consist of observations of individual horses, and whose fields (columns) represent various characters that define each horse (i.e., sex, status, coat color, etc.). Through population reconstruction, analysis of population dynamics, and simulation of feral horse life-history, an assessment of several management scenarios was made. The reconstructed population varied from a low of 35 horses in 1975 to a high of 171 in 1988 for the month of March. The observed rate of increase computed from the reconstructed March population sizes through the first 13 years of growth was estimated at nearly 15% per year and agrees with earlier estimates of >10% for this population. Two-hundred forty-seven observations of survival histories (58 uncensored) of horses were used to determine if population size affected the hazard rate. The reconstructed March population size added significant prognostic value to the prediction of hazards for ASIS horses. The analysis indicated a negative effect of population size on survival. There were no statistically detectable differences in survival between the sexes. There were no dramatic differences in the age at first foaling over time. However, analysis of the inter-birth interval revealed a strong population size influence. The estimated intercept indicated an average inter-birth interval of just over 1 year at very low population sizes, which inflates to nearly 2.5 yr at very high population sizes. The fit of Siler's model to predicted survival values for 3 different population sizes ($N = 20, 100$ and 180) showed a change in the early hazards component as population size increases. Most striking is the fact that adult survival changes very little and remains quite high over a wide range in population sizes, suggesting that the primary effect of increasing horse population size is reduced survival of immature animals, particularly foals. Because there are no natural predators of horses on the island, vitality of newborn foals seems to be the most plausible mechanism leading to greater neo-natal mortality at higher population sizes. The trajectories of the reconstructed and simulated populations of horses were comparable over the 18 year time sequence. Simulations demonstrated that for long-lived vertebrates which produce a single offspring per litter, the rate of increase is most sensitive to changes in annual adult survival rates. In the present context, it is precisely the levels of mortality due to storms, diseases and accidents that are most difficult to predict, and potentially have the most profound effect on future horse population size. Estimates of the maximum population

size achievable on ASIS were 230 and 265 horses, depending upon how density-dependence was incorporated in the simulation model. Modeled management scenarios revealed that due to the very high survival in adult horses, population change in response to fertility control will be lethargic at ASIS. In addition, modest levels of fertility control will induce the most uncertainty in realized foaling rate. At higher contraception rates, most of the uncertainty is in determining how many mares to treat. However, that uncertainty will diminish as the population size declines through repeated treatment.

INTRODUCTION

Uncertainty is inherent to the decision-making process, especially with respect to the management of natural resources (Walters 1987). Very often the manager is left on the horns of a dilemma where on one hand there is an urgent need to make a decision, and on the other, a discouraging dearth of facts on which to justify it. Moreover, the language of most land management policies is sufficiently vague to offer little guidance. It is in this context that controversies brew and inevitably erupt. The management of wild horses and burros on public lands stands as the premier example where an embarrassing lack of basic biological information has hindered progress toward finding feasible and socially acceptable population control solutions (Wagner 1983, Boyles 1986, Anonymous 1990, Garrott et al. 1991b).

Until very recently, there has been little known about the population dynamics of feral horses (Zarn et al. 1977, Keiper 1979, National Research Council 1980, 1982). Since the passage of the wild free-roaming horse and burro act, a flurry of research has been conducted and reported (Anonymous 1990), especially at an age-specific level (Eberhardt et al. 1982, Seal and Plotka 1983, Keiper and Houpt 1984, Siniff et al. 1986, Garrott 1991, Garrott et al. 1991a). As the knowledge base is expanding, so too is the need to synthesize what is known about the dynamics of feral horse populations.

One level of synthesis can be obtained through the formalized process of population modelling. Early attempts at building realistic population models for feral horses were hampered by a lack of published information on survival and reproduction (Conley 1979, Wolfe 1980). With improved understanding of the vital rates of feral

horse populations, focus has turned to evaluating the efficacy of several management programs which feature fertility control as a means of regulating population growth (Eberhardt et al. 1982, Turner and Kirkpatrick 1986, Garrott and Taylor 1990, Garrott 1991, Garrott et al. 1991b, 1992a,b, Eagle et al. 1992, 1993, Garrott and Siniff 1992).

However, all previous analyses which included modelling as a primary objective have dealt with horse populations on western ranges (see Graham 1986 for an exception). In addition, models have been constructed largely from published schedules of survival and fecundity averaged across several horse populations. Moreover, no single population has been studied long enough to examine potential changes in vital rates as horse populations grow from low numbers to high despite compelling evidence of density-dependent processes in the dynamics of large mammals (Fowler 1987, McCullough 1990). In this study I explore the implications of fertility control for management of feral horses on Assateague Island National Seashore (ASIS), an Atlantic coast barrier island. My specific objectives are to construct a database management system for the storage and retrieval of information on ASIS horses, conduct an analysis of the dynamics of this population of horses, and develop a framework for evaluating the efficacy of different management scenarios for this population through computer simulation.

STUDY AREA AND POPULATION DESCRIPTION

Assateague Island is a barrier island off the coasts of Maryland and Virginia. It is approximately 56 km long, oriented in a north-south direction. ASIS comprises the

northern, or Maryland, portion of the island and is managed by the National Park Service (NPS). Characteristic of barrier islands, the physiognomy of ASIS consists of a near shore primary sand dune and a swale area directly behind the primary dune, which grades into brackish marsh on the bay side. The principal habitats of the feral horses of ASIS are found in these basic ecotones. The horses graze in marsh habitats on the grasses Spartina alterniflora and S. patens, and in dune habitats on Ammophila breviligulata. The swale habitats are used by the horses primarily during the winter as shelter from the elements. A detailed description of the floral constituents of island habitats can be found in Higgins et al. (1971).

The feral horses of Assateague Island have a long and illustrious legacy common to many Atlantic coastal barrier islands (Keiper 1985). This report concerns only those horses inhabiting the Maryland portion of Assateague Island. Aspects of the ecology, breeding biology and socio-biology of these horses have been studied intensively since the seashore was established. These studies provide the foundation for this project.

Since 1975, an accounting of every horse that has lived and died on ASIS has been attempted. Many of the horses in this population have unique markings that allow accurate identification. This has been the primary means of tracking the fates of individual animals over time. The degree of attention paid to this difficult and time-consuming activity has waxed and waned over the years as staff and resource priorities have changed. This has led to some inconsistencies in this dataset. I have attempted to resolve as many of these inconsistencies as possible by cross-referencing published documents or by speaking with park staff and researchers.

METHODS

The principal source of data for this project is a database whose records (rows) consist of observations of individual horses, and whose fields (columns) represent various characters that define each horse (i.e., sex, status, coat color, etc.). It is solely from this database that the various analyses herein are derived. There are 4 levels of data analysis in this report: population reconstruction, analysis of population dynamics, simulation of feral horse life-history and assessment of several management scenarios. Each analysis depends heavily on the one preceding it; therefore, every attempt has been made to resolve problems at one level before proceeding to the next.

Population Reconstruction

Records for individual horses differ in the quality and quantity of available information. For example, some animals have unknown fates (e.g., death, transfer, missing) or imprecise dates associated with a particular fate. Most horses do not have precise dates of birth. Some foals are born and subsequently die or disappear before their sex can be determined. Worse are horses who, by virtue of their coat color, cannot be accurately identified and subsequently followed through time (i.e., X-horses; see below). However, very few horses have no information at all.

Both dates of birth and death are required to accurately place an individual in time using population reconstruction methods (McCullough 1979). Because feral equids exhibit fairly high annual survival (Keiper 1979), it was determined a priori that year/month precision was acceptable for reconstruction purposes. Except for a sample of foals born after 1990, no precise birth dates were recorded (i.e., only year of birth is available). The distribution of foaling by month for this population of horses is published (Keiper and Houpt 1984, Keiper 1979), however, and provides one solution to the problem of imprecise birth dates. The dates available in the database were used to update the published frequency histogram of the distribution of foaling by month.

I use the frequency histogram as an approximation to the probability density function (Lendrem 1986), and the cumulative frequency histogram as an approximation to the cumulative distribution function, which allows the calculation of the probability of certain events to occur. Each horse can be assigned a birth month (it's year of birth is automatically retained) according to the probabilities calculated from the frequency of births by month and a random draw from a uniform [0,1] distribution.

A similar Monte-Carlo method was extended to horses with imprecise or ambiguous dates of death (or other fate) as well. Sometimes, it was necessary to assign year and month, which was accomplished by a random draw in the range of the year of birth and the time extent of the database. For example, a horse that disappeared in August of one year, and whose carcass was found in May of the next year, implies that it obviously died sometime during that interval. That is, even though an exact date of death or disappearance could not be determined for some horses, an

interval of time over which the fate was exacted could usually be identified. This uncertainty was included by drawing the month of death at random within the range defined in the database. In this way, as much or as little information available for each horse could be used in reconstructing the population in a probabilistic fashion.

For multiple events (i.e., births, deaths, etc.) with multiple outcomes spanning many months or years in some cases, it was necessary to replicate the processes outlined above to ensure that the full range of variability was included in the final reconstruction. Toward that end, the total population was reconstructed 500 times for twelve months (January-December) and 18 years (1975-92). The population was defined as the mean of 500 reconstructions and summarized for each month of the year. The mean, minimum and maximum values were plotted over the 18 year duration for each month to represent the most probable and extreme numbers of horses on ASIS, respectively.

X-Horses

In 1992, park staff and researchers attempted to identify all horses for whom a complete time accounting was not possible. Twenty-five horses were identified as having ambiguous histories in the population, and were thus named according the convention of Keiper (1985) with the exception that their prefixes all began with "X". Since that time, every attempt has been made to follow all the X-horses to avoid losing track of them again. It is likely that the X-horses were born into the ASIS population (J. Kumer, pers. comm.) and did not immigrate from the adjacent Virginia herd. However,

there is no way to determine their exact year of birth. The only way to effectively add these horses to the population was to distribute them randomly through time during each reconstruction. The only proviso was that a mare (e.g., X16) be in the population before her first recorded offspring, which might have a precise date of birth (e.g., X16P).

Population Dynamics and Density-Dependence

The dynamics of any population are determined by its prevailing schedules of survival and reproduction, age structure and standing population size (Caughley 1977, Eberhardt 1985). Thus, robust methods for estimating survival and reproduction are paramount to a thorough population study. In the last decade, significant strides have been made in the development of methodological approaches to the analysis of populations using data commonly collected in field studies (Eberhardt 1985, Petersen 1990, White and Garrott 1990).

Unfortunately, the analysis of density-dependent changes in vital population rates has not reached a similar level of sophistication. The analysis of density-dependence can be too simplified as to be of little use to management, or complicated beyond belief with similar dubious value (Fowler 1987). I have adopted the concept of resolution as applied to the model building process (Starfield and Bleloch 1986) to guide the level of sophistication in this analysis. In general, this level must be commensurate to the quality of the data. In that spirit, I have confined the analysis in this report to several

demographic milestones commonly observed for large, herbivorous mammals as their populations grow from low numbers to high. Eberhardt and Siniff (1977) and Fowler (1980) have summarized the order of these changes as follow: 1) juvenile mortality rate increases, 2) age at first reproduction increases, 3) fecundity declines, and 4) adult mortality rate increases.

In terms of horse population dynamics, some qualification of these milestones is necessary. While data are lacking, survival rates of foals are high (>0.80 ; Keiper 1979, National Research Council 1980, 1982) relative to same-aged animals of other large mammal species; most deaths occur shortly after birth (Keiper 1979). In addition, studies have demonstrated that annual survival rates of prime-aged (5-15 yr) horses is also high, often exceeding 95% (Keiper 1979, Berger 1986, Siniff et al. 1986, Garrott and Taylor 1990). In combination, these factors indicate a relatively high potential for increase in most feral horse populations (Conley 1979, Wolfe 1980, Garrott et al. 1991b).

For many large mammal species, age at first reproduction is sensitive to changes in per-capita resources brought about by increasing density (Fowler 1980). However, the high degree of social organization in horses may mediate the sexual activity of young mares. Keiper (1985) suggests that though some young (<3 yr) mares may be sexually mature, they apparently do not make suitable mates because very few conceive and bear offspring. Furthermore, multiple-birth litters are rare in domestic and feral horses (Ginther 1979). Therefore, a decline in fecundity can only come about through an increased proportion of mares at a given age failing to breed, conceive, or

bear offspring. For prime-aged mares on western ranges, this proportion varies between 10-30% (Feist and McCullough 1975, Wolfe et al. 1989, Garrott et al. 1991a).

This kind of reproductive failure can result from a variety of mechanisms (Ginther 1979, Keiper and Houpt 1984), but on ASIS an important factor is lactational anestrus (Kirkpatrick and Turner 1991), a condition induced by a protracted weaning period. Because of the incredible energetic costs associated with lactation, mares that are unable to wean their offspring within a year are generally incapable of ovulation and consequently defer breeding in that year. For ASIS mares, weaning periods of a year or more are common (Kirkpatrick and Turner 1991).

The methods presented in the following sections were designed to explore aspects of each of these demographic milestones in detail so that an assessment of their importance to the horses of ASIS can be made.

Survival

A cohort is a group of animals born contemporaneously, and therefore are the same age (Caughley 1977). By following the fates of animals born to a particular cohort, a schedule of survival (l_x = proportion of a cohort surviving to age x) can be determined. For those horses having valid dates of birth and ultimate fate, a survival time was computed and an event history analysis (Petersen 1990) performed. In this kind of analysis, the focus is on what determines the amount of time spent in a particular state and what determines the value of the next state entered. In terms of survival, there is only one state, which is alive, and one fate, death. When the fate of

the animal is unknown, its survival time cannot be accurately determined. This circumstance is referred to as right-censoring (Cox and Oakes 1984); however, it is known that the animal survived at least as long as it was under observation (Riggs and Pollock 1992). Event history analysis uses this fact to compute the survival function (S_t) using either complete (i.e., fate observed) or incomplete (i.e., fate censored) observations.

Modeled survival is a monotonically non-increasing function of time. Its complement ($1-S_t$) describes the probability of death as a function of time. The slope of this function measures the rate at which death occurs. Because the slopes of curvilinear functions are difficult to manipulate, it is often desirable to linearize the ($1-S_t$) relationship. Kalbfleisch and Prentice (1980) have shown that $-\ln(S_t)$ provides the appropriate transformation. This form is called the cumulative hazard function and its slope, the hazard rate, is a measure of the instantaneous probability of death acting on a cohort.

Cox (1972) developed a log-linear model which expresses the hazard rate as a function of one or more covariates. The model is called the proportional hazards model. The proportional hazards model conveniently allows the analyst to explore the relationship between the duration of survival and other variables (i.e., covariates) which might affect that duration. The covariates used to model the underlying hazard rate may be discrete or continuous. As the model name implies, both kinds of covariates must satisfy the proportional hazards assumption, which means that the underlying relationship between the hazard rate and the covariate is the same across different

levels of the covariate. This is analogous the assumption of a common slope in an analysis of covariance. For continuous covariates, an additional assumption of linearity is imposed.

I used several SAS (Statistical Analysis System) macro programs (Harrell and Lee 1986) to perform the event history analysis and to verify assumptions of the proportional hazards model. Specifically, I tested the effects of sex and reconstructed March population size on subsequent survival times. The March population size was selected because very few foals are born during this month and thus it represents a convenient time index at which to start.

Reproduction

For large mammals having a single birth per litter annually, the analysis of reproduction can be characterized as a 2-part process: the age at first breeding (or birthing) and the inter-birth interval. An analysis of variance was conducted using the general linear model to determine if the age at first foaling differed between cohorts born from 1976-88. This was accomplished by tallying the recorded age at first foaling for every mare. The analysis was truncated at 1988 to exclude horses which would not have had enough time to become sexually mature before the end of the study period (i.e., 1992). All mares involved in the fertility control experiments begun in 1988 by Drs. Kirkpatrick, Liu and Turner (see Kirkpatrick et al. 1990) were also excluded from this analysis.

The mean inter-birth interval, defined as the number of years between subsequent foaling events, was regressed on the reconstructed March population size to determine if this variable exhibited density-dependence at ASIS. The inter-birth interval was recorded for each mare and summarized by calendar year from 1976-90. Because the response variable in this analysis is a mean of several observations (1 observation = 1 mare) for each year, the regression was weighted by the number of observations per mean (Freund et al. 1986). Therefore, more confidence was placed in means computed for years with a larger sample of mares.

Density-Dependence

To guard against temporal confounding of factors that might change coincidentally with population size, I conducted multiple event history analyses, each time censoring observed deaths associated with either catastrophic agents (e.g., winter storms, diseases, etc.) or accidental deaths (e.g., automobile collisions, hunter-killed through mistaken identity, etc.). By comparing the estimated coefficients of the proportional hazards model and their statistical significance, a sense of the importance of bias could be ascertained. The bias accrues in the formulation of functional relationships between variables of interest and population size or density (Walters 1985).

Simulation of Feral Horse Life-History

I used GAPPS II v1.3 (Downer 1993), which stands for Generalized Animal Population Projection System, to construct a simulation model of feral horse life-history.

GAPPS II is not a model, but a modeling language with an event-driven syntax (see Appendix III). GAPPS II operates on individuals who experience a given event according to multi-state probabilities (stored in a dBASE III+ file), and a random draw from a uniform [0,1] distribution. Therefore, no 2 runs of a particular model will produce identical results, which is the hallmark of all Monte-Carlo methods.

These kinds of models introduce the important concept of variation or uncertainty in life-history events. In general, there are 4 types of variation or uncertainty (Shaffer 1987): demographic, environmental, genetic and that owing to unpredictable catastrophic events. GAPPS II was intended to simulate demographic variation, which can be important in small (<20), isolated populations (Shaffer 1987). GAPPS II does not currently support driving variables (e.g., meteorological variables) and cannot simulate environmental variation per se. However, density-dependent changes in survival or reproduction of large herbivores are typically brought about through per-capita resource depletion, and can be thought of as environmental in origin. Population size integrates all sources of variation into a single number, and can thus be used to modify probabilities in subsequent time steps. I have adopted this framework for exploring the role that density plays in the population dynamics of ASIS horses.

An earlier version of GAPPS was modified specifically for this project to include 3 new modules: GROUP(), MOVE() and CONTRACEPT(). Only CONTRACEPT() has

been employed in this analysis as the other 2 modules are associated with spatial data, which at the time of this analysis, are not yet fully developed. Details specific to the testing and implementation of CONTRACEPT() can be found in Appendix I.

Simulating Age-Specific Survival

GAPPS II has several built-in functions for simulating functional relationships between variables created during run-time and the age-specific probabilities associated with each life-history event. The first function, CON, tells GAPPS II that the probabilities will remain constant throughout the simulation, and is the simplest age-specific representation of an individual's chance of experiencing a life-history event. The second function, SL, allows the probabilities associated with a particular event to change in a straight line fashion with some independent (i.e., predictor) variable. The structure of the files containing age-specific probabilities provides a means by which an independent variable, INDVAR, can be identified. Additional fields are available for defining the straight line parameters (i.e., slope and intercept), and for constraining the outcome to within a minimum and maximum probability. The last function, MM, is a modified version of the Michaelis-Menton equation of enzyme saturation, which in general, is useful for modelling sigmoidal functional relationships. However, the modeler need not be constrained by these 3 choices alone. Just about any non-linear functional relationship can be used to modify the age-specific probabilities using the SL function (see next section).

Because maximum survival estimates are available for only 16 year-old horses (i.e. the cohort born in 1976), another means of estimating survival for the very oldest age classes (>20) was needed for simulation purposes. I chose a data model that describes the survival function as a combination of 3 phases in the life-history of long-lived organisms (Siler 1979, Eberhardt 1985): survival to maturity, prime-age survival and demographic senescence. I used non-linear least-squares regression to estimate the parameters of Siler's model from predicted age-specific survival (l_x) values obtained from the event history analysis. The form of the equation is:

$$l_x = \exp(-\underline{a}_1(1-\exp(\underline{b}_1x))-\underline{a}_2x-\underline{a}_3(\exp(\underline{b}_3x)-1)) \text{ where,}$$

- x = age in years since birth,
- l_x = proportion of cohort surviving to age x ,
- $\underline{a}_1$ = slope of the early hazards change in survival,
- $\underline{b}_1$ = coefficient which alters the effect of $\underline{a}_1$ with increasing age,
- $\underline{a}_2$ = pertains to adult survival (i.e., $\exp[-\underline{a}_2]$ = adult survival),
- $\underline{a}_3$ = slope of the demographic senescence term,
- $\underline{b}_3$ = coefficient which alters the effect of $\underline{a}_3$ at death.

Siler's equation was fit to 3 schedules of survival corresponding to population sizes of 20, 100 and 180 horses, arbitrarily chosen to represent a low, moderate and high population numbers. Estimates of survival for the 3 life-history phases were converted to annual survival rates and plotted against population size to explore potential density-dependence.

Simulating Density-Dependent Survival

Survival to maturity and adult survival estimated from Siler's equations can be modeled as a simple linear function of population size, or by higher order polynomials in population size. The GAPPS II implementation, using the SURVIVE() module, was to first generate the expression relating survival to population size for each age group, including any higher order terms for population size, and storing each value in a uniquely named variable. Then, in the *.dbf file containing age-specific probabilities, I identified each variable in the INDVAR field, selected the function SL, and adjusted the parameter fields such that the straight line formula simply returned the value of the variable. This was accomplished by setting the slope parameter = 1, and the intercept parameter = 0. A simple example illustrating this process is presented in Table 1.

While the functions available in GAPPS II for modeling non-linear relationships work fine, the method I adopted allows for a richer set of functional relationships to be defined. A potentially severe constraint of this method, however, is that virtual memory for variable storage is quickly usurped. Therefore, there will be a tradeoff between the number of SET statements that can be executed, the size of simulated population, and the complexity of the life-history simulation.

For illustrative purposes, I constructed GAPPS II Command Files which, where appropriate, included density-dependent corrections to survival for foals (0 yrs), yearlings (1 yr), sub-adults (2 yrs), and prime-age horses (>2 yrs). In another section of this report, I describe a model which includes survival estimates for foals, yearlings, prime-age (2-10) horses, and past prime-age (11-20 yrs) horses. In other words, the

models differ in that the latter includes a demographic senescence component while the former does not. Details on how the results for these different models compare will be presented elsewhere in this report.

Simulating Density-Independent Mortality

Accidents, catastrophic storms and virulent disease represent the most important agents of density-independent mortality in the horses of ASIS. Eastern Equine Encephalitis (EEE) is the primary agent of infectious disease in the ASIS horses. This disease is not endemic to ASIS, but enzootic transmission occurs regularly in freshwater swamp habitats on the Maryland and Virginia mainlands (Moore et al. 1993).

During periods of intense transmission, the virus is probably dispersed from these foci to ASIS by infected mosquitos or viremic bird species. EEE apparently undergoes enzootic cycles which produce epizootics every 9 years or so (Moore et al. 1993).

Where appropriate, losses due to accidents, catastrophic storms and diseases were imposed on the simulation by removing animals with the HUNT() module in proportion to actual losses experienced by the horses of ASIS. For example, an outbreak of EEE was introduced into some models in years 9 and 10, producing a die-off of approximately 10% of the late summer population of horses in each year.

Simulating Age-Specific Reproduction

GAPPS II uses the WEAN() and BREED() modules to determine whether or not a given female will breed in the current year. The mare must have her reproductive

status favorably modified by these 2 modules in order to experience the remaining modules associated with adding offspring to the population. To construct a function representing the age-specific probability of breeding, I examined the frequency distribution of age at first foaling. Because these data were collected at relatively low horse population sizes, I assumed that the cumulative frequency distribution would reliably reflect the probability of foaling for the first time at or before a given age without the added effects of density.

To complete the entire schedule of age-specific reproduction, I fitted a 3-component curve (Siler 1979, Eberhardt 1985, Garrott et al. 1991a) through the cumulative frequency distribution using non-linear least squares regression. The equation is:

$$m_x = \underline{a} * (1 - \exp(-\underline{b} * (x - \underline{c}))) * \exp(-\exp(-\underline{T}/\underline{s}) * (\exp(1/\underline{s} * x) - 1)) \text{ where,}$$

- x = age in years since birth,
- m_x = probability of breeding at age x ,
- $\underline{a}$ = maximum age-specific probability of breeding,
- $\underline{b}$ = rate of change in productivity during early reproductive years,
- $\underline{c}$ = age prior to first reproduction,
- $\underline{T}$ = modal age of reproductive senescence,
- $\underline{s}$ = standard deviation around T .

In general, the age at first foaling for ASIS mares has been shown to be about 3 yr, indicating that most females are bred by the age of 2 (i.e., $\underline{c} = 1$; Keiper and Houpt 1984). Because there are no good records of reproduction in very old mares on ASIS, I

fixed $\underline{T} = 20$ years and allowed the other parameters to be estimated from the regression.

Simulating Density-Dependent Reproduction

For multi-parous mares, the probability of foaling at a given age will be overestimated using the function derived for first-time breeders due to the added density-dependent probability of failing to wean previous offspring. For simulation purposes, there are two ways in which to discount the maximum age-specific foaling rate in mares due to density-dependent weaning probabilities. The first is to multiply the entire age-specific schedule by the density-dependent weaning probability obtained after each iteration of the model. This is equivalent to changing $\underline{a}$, and flattens the age-specific curve from above. This method results in an increasingly smaller number of foals, all of which are implicitly assumed to be successfully weaned within a year of birth, as the population grows from low density to high. The second approach is to allow mares to foal at their highest age-specific rates at every population size, and to wean young according to the prevailing density-dependent probabilities. This method does not affect the age-specific reproduction curve, and produces a larger number of foals at each birth-pulse with a greater proportion failing to wean within a year as the population grows from low density to high. Deciding which method to implement is problematic.

Probabilistic elements of GAPPS II insure that some foals may be weaned despite population size using the second method, which more closely mimics nature

than does the first method. Thus, the second method will always produce higher asymptotic population sizes than the first. In addition, the second method tacitly attributes all changes in productivity to the phenomenon of lactational anestrus. While there could be other, equally plausible mechanisms operating on mares prior to conception that might inhibit fertility at a given age, this too seems to me the most realistic approach from a modeling perspective. I have permitted the implementation of both methods, but use the first for the examples presented in later sections except where otherwise noted.

The MATE() module is the male counterpart to BREED(). This module also requires a file containing the age-specific probabilities of breeding for males. While some data are available for the onset of breeding in young stallions, it is insufficient to construct a reliable productivity function for ASIS. Instead, I used data from Berger (1986) to construct a frequency histogram of the number of matings experienced by different aged stallions. By using a similar approach as for females, a crude productivity function for ASIS males was derived.

Timing of Life-History Events

I constructed a GAPPS II population file of 30 horses corresponding as closely as possible to that which might have been on ASIS in March, 1975. Because the analysis of density-dependent changes in vital rates was predicated on it, the month of March was designated as the primary period of census for the simulations. Problem horses were generally transferred to the Chincoteague National Wildlife Refuge during this

month as well, and this event was accomplished using the HUNT() module. The remaining life-history events follow in order for the rest of the annual cycle. Statements to induce low-level losses or larger catastrophic events such as EEE or mid-winter storms were included after the birth-pulse. To simulate the effects of management on a relatively large horse population, it was necessary to run the model for a number of years and then output the population file for subsequent use. This was accomplished in GAPPS II by using the WRITE() module.

Analysis of Management Scenarios

The first step to the analysis of population management scenarios is to have a model that is appropriate to the life-history of the organism (Ferson and Burgman 1990). Once the basic life-history model is in place, then scenarios of interest to management can be performed as computer experiments (Cooperrider and Behrend 1982). Analysis of different management scenarios was accomplished by simple comparisons of population trajectories over time. However, more complicated simulations can be analyzed using a risk assessment approach (Appendix II), which defines success and failure in terms of probability with respect to a stated population size criterion.

The first model was constructed to determine if the trend in horse numbers observed since 1975 could be verified given the event probabilities derived in the previous analyses and given data on the number of horses transferred, lost to catastrophic storms or killed by EEE. The population was projected for 18 years with 10 replications. Five additional scenarios illustrate how the model can be used in making

management decisions. Details of each scenario and how it was simulated are provided as follows:

- 1) No fertility control, nominal transfers (1 per year). This scenario represents a no-action alternative other than routine transfer of problem horses. This scenario was simulated for 10 years and 500 replications, with and without representation of significant density-independent mortality agents.
- 2) One-time reduction in horse numbers to 100 animals, no management thereafter. This scenario simulates the effects of a single, but significant removal of horses on subsequent population recovery. This scenario was simulated for 10 years and 500 replications, with and without representation of significant density-independent mortality agents.
- 3) Fifty percent fertility control, nominal transfers (1 per year). The scenario simulates a modest fertility control program in which half of all potentially reproductive females would be rendered infertile in each year. This scenario was simulated for 10 years and 500 replications, with and without representation of significant density-independent mortality agents.
- 4) Short-term (≤ 10 yr) efficacy of different levels of fertility control. This simulation was designed to determine the additional effort required to induce a significant population effect above efforts already undertaken as part of the current research program. Instead of imposing a fixed level of fertility control, I chose to model a range (50-100%) in a factorial series of

simulations. In addition to exploring the specific scenario above, statistical details around the number of mares treated and number of foals produced were derived. This set of simulations was iterated for 10 years each and 100 replications, with no density-independent mortality and with a nominal transfer rate.

- 5) One-hundred percent fertility control for 2 years, no fertility control for the next 2 years and 50% fertility control thereafter. This scenario was included to demonstrate how complexity can be incorporated into a simulation using the GAPPS II language. This scenario was iterated for 10 years and 500 replications. Mortality associated with transfers, catastrophic storms or diseases was not included in this modeled scenario.

RESULTS AND DISCUSSION

Population Reconstruction

The reconstructed population varied from a low of 35 horses in 1975 to a high of 171 in 1988 for the month of March (Fig. 1). The uncertainty in these estimates was smallest at low population sizes and greatest at high population sizes. In 1988, the interval was 156-181 horses. From 1988-92, the population experienced a rather dramatic decline due to a variety of factors including a substantial transfer of animals to the Chincoteague Wildlife Refuge, a loss of an estimated 30 animals to an epidemic of EEE, a catastrophic storm in January of 1992 which killed 11 horses on the north end of

ASIS, and finally, a decline in foaling due to experiments in fertility control (Kirkpatrick et al. 1990).

Several published reports on the ASIS horses indicate population sizes in 1975 varying between 42-45 (Keiper and Zervanos 1979 [44], Keiper and Houpt 1984 [42], Keiper 1985 [42], Rutberg and Keiper 1993 [about 45]). One unpublished piece of file correspondence indicated a population of 47 horses in 1975. However, the database I used in the reconstruction cannot account for this many horses. Similar inconsistencies that were found in the accounting of the number of foals and sexually mature mares underscore the difficulty in determining composition of the herd at any given point in time. Whether or not any of these inconsistencies greatly affects subsequent analyses and interpretation of results will be explored later.

The observed rate of increase (Caughley and Birch 1971) computed from the reconstructed March population sizes through the first 13 years of growth was nearly 15% per year (Fig. 2), which by western standards (Conley 1979, Eberhardt et al. 1982, Garrott et al. 1991b) is sub-par, but is in agreement with earlier estimates of >10% for this population (Keiper and Houpt 1984).

Survival

A graphical test based on 2 quantile groups of population size revealed that the proportional hazards assumption holds (i.e., the curves are roughly parallel and do not

cross) reasonably well for March population size (Fig. 3). In addition, estimated survival at two different time periods was linear over a range of population sizes (Fig. 4). Two hundred forty seven observations of survival histories (58 uncensored) of horses were used to determine if population size affected the hazard rate. The reconstructed March population size added significant prognostic value to the prediction of hazards for ASIS horses ($\chi^2 = 10.31$, $df = 1$, $p < 0.005$). The coefficient of the hazard rate model was positive, indicating a negative effect on survival with increasing population size, and significantly different from zero ($\beta = 0.0134$, $\chi^2 = 8.78$, 1 df , $p < 0.005$). Multiple tests of the effect of population size revealed that the catastrophic and accidental agents of death did not appreciably change the sign, magnitude or statistical significance of the coefficient of the hazard rate model. This is a good indication that changes in survival with population size reflect primarily the effects of per-capita resource depletion. There were no statistically detectable differences in survival between the sexes.

The fit of Siler's model to predicted survival values for population sizes of 20, 100 and 180 horses shows a change in the early hazards component as population size increases (Table 1, Fig. 5). This is evident when the 3 components are converted to annual survival rates and plotted against population size (Fig. 6). Most striking is the fact that adult survival changes very little and remains quite high over a wide range in population sizes, which is in full agreement with published estimates of survival rates for adult feral horses (Keiper 1979, Wolfe 1980, Berger 1986, Siniff et al. 1986, Garrott and Taylor 1990). This suggests that the primary effect of increasing horse population size is reduced survival of immature animals, particularly foals. The modal age of

demographic senescence, which is predicted from Siler's equations, is positively correlated with both survival to maturity and adult survival (Fig. 7).

In large mammals, neo-natal mortality is often linked to the vitality of the newborn, the physiological state of the mother, the mother's experience at rearing offspring or the vulnerability of the newborn to predation (Clutton-Brock 1982, McCullough 1979, Sinclair 1979). Physiological well-being apparently is not a factor for first-time breeders (see next section). However, a protracted weaning period (Kirkpatrick and Turner 1991) may very well place multi-parous females in a poorer physiological state at the onset of the next reproductive cycle and subsequent foaling period. This could lead to deficiencies in the production of prolactin, the hormone responsible for milk production and the development of a strong mother-infant bond (Schulte et al. 1981). In white-tailed deer (Odocoileus virginianus), for example, winter-induced stress has been implicated in the apparent reduction in prolactin secretion during fawning. One study documented a number of significant behavioral changes in adult females owing to low prolactin production after a severe winter. The behaviors were believed to have led directly to high neo-natal losses (Langenau and Lerg 1976). Because there are no natural predators of horses on the island, low vitality of newborn foals, perhaps through a similar hormonal mechanism, seems to be the most plausible explanation of observed greater neo-natal mortality at higher population sizes.

Reproduction

Initial tests for differences in the age at first foaling between cohorts were significant. However, a closer inspection revealed that the significance was between 2 data points (i.e., cohorts born in 1981 and 1982) and all others. The cohort of 1981 and 1982 were represented by only 2 and 4 mares, respectively. The removal of these cohorts results in no dramatic shifts in the age at first foaling over time. The weighted regression of the ln-transformed interval on population size was significant ($F = 63.061$, $df = 1, 208$, $p < 0.005$; Fig. 8). The estimated intercept indicated an average inter-birth interval of just over 1 year at very low population sizes, which inflates to nearly 2.5 yr at very high population sizes (Fig. 9). Density-dependent changes in the probability of weaning previous offspring and the potential for deferred breeding undoubtedly affect the realized foaling rate in horse populations from year-to-year. The foaling rate integrates a mare's current age-specific probability of breeding and the population-dependent probability of weaning previous offspring.

The fit of the non-linear regression through the cumulative frequency of age at first foaling (Fig. 10) produced estimates of $\underline{a} = 0.91$, $\underline{b} = 0.53$ and $\underline{s} = 2.60$ yr. The estimate of 0.91 for $\underline{a}$, the maximum probability of foaling, is close in value to the maximum probability of weaning previous offspring (computed as 1.156^{-1}). At low population density, both numbers should be relatively high and similar though not necessarily the identical. Both estimates fall within the range reported for free-ranging horse populations (Wolfe et al. 1989, Garrot et al. 1991a). The complete productivity function is given in Figure 11.

There is little evidence, other than anecdotal, that the productivity function derived for ASIS stallions is at least reasonable (Fig. 12). Most males do not have breeding opportunities until they are capable of winning and holding harems, which for ASIS males, occurs most often between the ages of 9-12 yr (Keiper 1985). The details notwithstanding, the use of this function is not likely to change the outcome of the computer experiments. The fact is that for polygynous species, most available females are bred in any given reproductive cycle except under extremely disparate sex-ratio situations (i.e., Allee effect).

Life-History Simulation

To compare modeled and reconstructed population sizes, I constructed an initial horse population of 15 sexually mature (≥ 3 yr) females, 7 foals (i.e., near yearlings: 2_, 5_), 4 harem stallions (≥ 5 yr), 3 bachelor males (ages 3, 5 and 8) and 1 sexually immature mare (age 2). This population was then projected through time using events and probabilities as described. Like the actual population of horses, the model incorporated a total of 36 transfers, a loss of 10% of the late summer population in each of 2 years (i.e., 1989 and 1990), 11 random deaths due to a catastrophic storm on 4 January, 1992, and a chronic mortality rate not due to density of 1% per year (Table 2). The timing of events in this model, relative to the monthly calendar, are provided schematically in Figure 13.

Given the level of uncertainty in the reconstructed population size, estimated event probabilities and mortality rates due to disease and accidents, the modeled and

observed population trajectories compare reasonably well (Fig. 14). However, the foaling rate computed from a simulation which included only density-dependent mortality, was consistently larger than the rate computed from the reconstructed population data when compared during the late summer (Fig. 15). One reason for this is because GAPPS II does not exert a neonatal foal mortality, so young animals are not removed from the population until later in the modeling cycle. Another cause for discrepancy may be due to the difficulty in finding newborn foals before they succumb to mortality, which would bias the observed foaling rate downward.

Using the same model, I also ran a series of simulations that differed in the level of mortality owing to factors other than density, and confirmed what any student of population ecology already knows: for long-lived vertebrates which produce a single offspring per litter, the rate of increase is most sensitive to changes in annual adult survival rates (Eberhardt 1985). In the present context, it is precisely the levels of mortality due to storms, diseases and accidents that are most difficult to predict, and potentially have the most profound effect on population size. If population control is the goal of management, a reasonable strategy to take is to assume no losses due to these agents. Results will indicate a worst case scenario. Conversely, these agents should be included if conservation is the goal. This alleviates the risk to management due to the inevitable failure of the model to predict future events.

Management Scenarios

There are essentially no meaningful differences in the results of scenarios 1-3, and scenario 5 (see pages 7-8). All produce comparable population sizes at the end of the 10 year period (Figs 16-18, 23). The most important differences are not presented. That is, the difference in effort (i.e., time, expense, etc.) required to implement any of these management alternatives is likely to be substantial depending upon the particular approach taken (Garrott 1991, Garrott et al. 1992a,b, Eagle et al. 1992, 1993). For example, a one-time removal of about 67 horses would likely be a logistical nightmare, yet at the end of 10 years, the realized difference in population size compared to scenario 1 (no action) is about 25 horses.

The results from scenario 4 really contain the most significant findings with respect to population effects (Fig. 19). To induce a meaningful population decline (>10 horse difference), an efficacy of 80% or better is required over a 10 year period. High survival in adult horses works against a rapid change in population size through fertility control. For example, contraception at the 100% efficacy level produces only about a 40 horse difference in 10 years, while at a population of 167, 70% fertility control results in essentially no population change.

On average, an 80% efficacy in fertility control translates to treating about 60 mares annually (Fig. 20). Variance in the number of treated mares increases with increasing efficacy rates. I attribute this to more rapid changes in March population sizes, and thus mare numbers, at higher efficacy rates across the time series. In other words, the higher the efficacy, the more rapid is population change, which contributes more variation in mare numbers available for treatment. The opposite trend in variance

is observed for number of foals produced (Fig. 21). For example, a 50% level of contraception efficacy allows for a larger horse population, and hence, a potentially larger range in foals produced depending upon the number of mares available for treatment. At 90% efficacy, the number of foals produced is bounded below by zero, which necessarily constrains the variance. The same reasoning can be applied to the realized foaling rate (Fig. 22).

In summary, due to the very high survival in adult horses, population change in response to fertility control alone will be lethargic. Because the rate of increase is most sensitive to changes in annual adult survival rates, it makes some sense to implement a management strategy which includes fertility control and annual removal of horses until the desired population size is attained. Recognize that by physically removing horses and effectively lowering the population size, the probability of recruiting new foals increases, which argues against a dramatic reduction in the horse population through removal methods.

Limitations and Caveats

The analysis and simulation models presented in this report represent a rudimentary understanding of feral horse population demography on ASIS. The relative merits of the approach are certainly debatable, and the biological reality depicted in regression equations and GAPPS II Command File statements is only as good as the lowest level of uncertainty in the data. In particular, there are a few areas in the analysis where due caution in interpretation is advised.

First, the event history analysis, which was based upon median groups of density, revealed at least a reasonable fit to the proportional hazards assumptions. However, predicted survival for horses >7 years of age is entirely extrapolated for populations above the median. The models clearly demonstrate that even small changes in adult survival produce large deviations in population rate of increase. In addition, the age of demographic senescence changes rapidly over small changes in adult survival. Consequently, a small change in adult survival could greatly change precisely how long individual horses remain in the population. This is particularly vexing considering that by forgoing reproduction, some mares may substantially increase their ecological longevity. Therefore, a very critical re-evaluation of survival in older horses, particularly at population sizes like those currently on ASIS, is warranted.

Second, regression curves for estimating survival and reproduction were derived from limited data. In each case, the very oldest age classes contain the highest uncertainty which could have dramatic effects on the model's utility as a management tool. For example, I fixed the senescence parameters for survival and reproduction at 20 years based on published estimates and the limited information available at ASIS. Clearly, a more desirable approach would be to actually observe when animals exhibit signs of reproductive failure in old age, and record their actual ages at death, for example. Should new data show that adjustment of the ages of demographic and reproductive senescence need to be made, I suggest that their effects on the age-specific rates (stored in GAPPS II rate files) be adjusted by eye rather than re-employing the non-linear regression approach described in the METHODS. For

example, a change in the age of reproductive senescence changes the shape of the tail in Figure 11. The effect of this change can literally be “sketched” onto the existing graph, which can then be used to modify the values in the appropriate GAPPS II rate file.

Third, I found it extremely difficult to glean from published accounts of the island's horse population precise definitions of foaling rate. It was never very clear what ages constituted the denominator in that ratio. In some cases, 2 year old mares were included even though they were, in general, considered sexually immature. In other cases, these young mares were excluded in the calculation of foaling rate. I included them in the CENSUS() of adult mares in all GAPPS II simulations. By including them, the resulting foaling rate would be lower compared to the rate computed had they been excluded. The importance of this bias was not explored, although my impression is that it probably is not significant. Still, standards for calculating such key indicator variables really need to be developed so that future work will not be similarly troubled.

Finally, the analysis of density-dependence in aspects of survival and reproduction is very compelling for ASIS horses. Yet, it is likely to be most controversial too. With the exception of the paper by Kirkpatrick and Turner (1991), there has been little evidence to date indicating density-dependent mechanisms operating against population growth rates in feral horse herds. I consider the evidence for density-dependent foal survival pretty good, but qualified as before with respect to old age survival. The evidence of density-dependent weaning is better, but highly variable due to a number of reasons. The number of mares producing foals in each year was small

from a statistical viewpoint. Additional sources of variation could include the spatial location of particular bands with respect to availability of high quality forage. Anecdotal observations tend to support this hypothesis. Moreover, some matrilineal lines appear to be disproportionately successful at recruiting offspring. Whether or not there is a genetic basis for this observation is uncertain due to the potential confounding with spatial location. In either case, additional study is warranted.

In conclusion, this analysis should really be considered a preliminary first step toward developing a knowledge-base for managing feral horses on ASIS, and represents one person's perspective on what elements of population dynamics are crucial for sound management. And there is the inevitable discovery of errors in logic, analysis and programming (though I tried my hardest to find them all), which will require re-visiting these topics in the future.

Alternative Models and Approaches

Depending upon how the density-dependent weaning rate is implemented in GAPPS II (see METHODS), asymptotic population sizes achieved were 230 and 265 horses for Method 1 and 2, respectively. These are population sizes defined primarily by the density-dependent factors (i.e., survival and weaning) operating in the model. In the milieu of feral horse management issues at ASIS, the significance of a 35 horse difference in asymptotic population sizes is uncertain. However, the difference does underscore the importance of how the implementation of certain life-history events

affects model results. I believe the models which incorporate density-dependent weaning and the senescence phase for past prime-age animals are the most realistic in terms of feral horse life-history (Appendix VI). However, the outcomes of all the models are so similar that justification for retaining the more complex ones is difficult to make.

To my knowledge, there is only one other feral horse database manager and population simulator in existence (HAREMS; Graham 1986). Like ALLPONY.prg (Appendix VI), attributes of each horse are stored in a flat file format, can be retrieved and edited, and can be manipulated to produce specific reports. The simulator, however, is a rule-based program written in LISP, an artificial intelligence dialect language. Like GAPPS II, HAREMS allows for inheritance of certain traits and can trace pedigrees. What prevents HAREMS from being general in its application, in my opinion, is the physiologic rule-base used to modify the life-history status of individual horses. GAPPS II on the other hand, is a true demographic model, requiring no inputs other than transition probabilities for each life-history event which requires them. Both simulators have features that require a very good understanding of the management purpose to make an informed selection. However, both are remarkably similar in function despite dramatic differences in form.

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TABLES

Table 1. Estimates of survival rates (*and calculations*) for feral horses of Assateague Island National Seashore derived from fits to equations proposed by Siler (1979) for modeling the life-history of large mammals.

Population Size N	Survival Rate to Maturity $\exp(-\underline{a}_1)$	Adult Survival Rate $\exp(-\underline{a}_2)$	Modal Age of Senescence, $\underline{I}$ $\text{abs}(\ln(\underline{a}_3)/\ln(\exp(\underline{b}_3)))$	Standard Deviation, $s_{\underline{I}}$ $\underline{b}_3^{-1}$
20	0.987	0.992	16.5	1.9
100	0.925	0.987	14.5	2.5
180	0.797	0.961	11.8	2.5

Table 2. Example of using non-linear functions other than those specified in GAPPS II for simulating complex relationships which determine event transitions.

SET (TMPOP0 = .9841064+MPOP*(.0000222-.0000049*MPOP))

SET (TMPOP1 = .9896559+MPOP*(.0000070-.0000023*MPOP))

SET (TMPOP2 = .9908613+MPOP*(.0000226-.0000015*MPOP))

SET (TMPOP3 = .9899687+MPOP*(.0001344-.0000016*MPOP))

where,

TMPOP0-n = Variable name holding survival probability for each age.

MPOP = Simulated March population size.

HSSURV.DBF

AGE	FUNCTION	INDVAR	MIN	MAX	INTERCEPT	SLOPE
0	SL	TMPOP0	0	1	0	1
1	SL	TMPOP1	0	1	0	1
2	SL	TMPOP2	0	1	0	1
3	SL	TMPOP3	0	1	0	1
.	.	.	.	.	.	.
.	.	.	.	.	.	.
n	SL	TMPOPn	0	1	0	1

Table 3. Typical model command file using the GAPPS II simulation language.

```

SETUP(TITLE ("GROWTH WITH TRANSFERS AND OTHER MORTALITY INCLUDED"))
BEGIN (RUN (10))
RESEED(SEED(0))

; Use CURRENT.DBF for High Density or HSGPOP.DBF for Low;
; Breeding Model 1, No Demographic Senescence Term;

READ(INPUT (HSGPOP.DBF))

; Comment: start simulation;
BEGIN (YEAR (18))

; Remove Drowned Horses: January Storm;
HUNT (NUMBER(11) RATES(CATAS.DBF) START(18) STOP(18))

; Conduct Census During March (reflected in dbf file);
CENSUS (VAR(MPOP))

; Set Density-Dependent Weaning Probability;
SET (EXPMPOP = .8654*(EXP(-.004109*MPOP)))

; Set Density-Dependent Survival Probabilities for Foals,;
; yearlings, young and prime-aged mares;

SET (TMPOP0 = .9841064+MPOP*(.0000222-.0000049*MPOP))
SET (TMPOP1 = .9896559+MPOP*(.0000070-.0000023*MPOP))
SET (TMPOP2 = .9908613+MPOP*(.0000226-.0000015*MPOP))
SET (TMPOP3 = .9899687+MPOP*(.0001344-.0000016*MPOP))

; Remove Specific Transfers;
HUNT (NUMBER(1) RATES(TRANS.DBF) START(6) STOP(6))
HUNT (NUMBER(3) RATES(TRANS.DBF) START(10) STOP(10))

; Census Adult Female Segment - note that 2 year old mares are included;
CENSUS (AGES(2-29) SEXES(FEMALES) VAR(ADFE))

; Weaning Probability as set by EXPMPOP;
WEAN (RATES (HSWN2.DBF) PAUSE(OFF))

; Age all Horses by 1 year;
AGE()

; Contracept 50% of 3 year old Mares and older - note that 2 year old mares are excluded;
CONTRACEPT (NUMBER(ADFE) VAR(CONT) RATES (HSCONT.DBF));

; Age-Specific Breeding Probabilities;
BREED (RATES (HSBR2.DBF))

```

Table 3. Continued.

```

; Male Breeding Determined from Literature;

```

MATE (RATES (HSMATE.DBF))

; Probability of Litter Size Being 1 is 1.0;

LITTER (RATES (HSLITT.DBF))

; Sex Ratio is 50:50;

BIRTH (RATES (HSGENDER.DBF) VAR (FOALS))

SET (FR = FOALS/ADFE)

; Census Population at End of Foaling Season;

CENSUS (VAR(SPOP))

SET (CATPRP = ROUND(0.10*SPOP))

SET (CHRPRP = ROUND(0.03*SPOP))

; Remove 10% In Each of 2 Years Due to Catastrophic Losses (mostly EEE);

HUNT (NUMBER(CATPRP) RATES(CATAS.DBF) START(14) STOP(15))

; Remove 3% In Each Year Due to Accidental Losses;

HUNT (NUMBER(CHRPRP) RATES(CATAS.DBF))

; Density-Dependent Annual Survival Probabilities;

SURVIVE (RATES (HSSURV.DBF) PAUSE(OFF) VAR (DEAD))

SUMMARY (REPORT (GROWTH.RPT) SYMBOLS (MPOP,ADFE,FOALS,SPOP,FR))

END ()

PURGE ()

END ()

FIGURES

Figure 1. Updated frequency histogram and cumulative frequency for age at first foaling in mares on Assateague Island National Seashore, 1975-92.

Figure 2. Relative time line for invoking life-history events in a simulation of feral horse populations on Assateague Island National Seashore.

Figure 3. Reconstructed population of feral horses on Assateague Island National Seashore, 1975-92. Reconstruction was accomplished through a probabilistic re-sampling of births and fates.

Figure 4. Observed rate of increase derived from a population reconstruction of feral horses Assateague Island National Seashore, 1975-92.

Figure 5. Graphical test of the proportional hazards assumption for modelled survival, Assateague Island National Seashore.

Figure 6. Graphical test of the linearity assumption for proportional hazards modelling of survival, Assateague Island National Seashore.

Figure 7. Estimated age at first foaling for cohort year-classes of mares on Assateague Island National Seashore.

Figure 8. Weighted regression of the inter-birth interval on reconstructed population size for feral horses on Assateague Island National Seashore.

Figure 9. Predicted inter-birth interval and associated probability of weaning current offspring at various population sizes of feral horses on Assateague Island National Seashore.

Figure 10. Foaling rate as estimated from a population reconstruction of feral horses on Assateague Island National Seashore, 1975-92.

Figure 11. Productivity function estimated for feral mares on Assateague Island National Seashore.

Figure 12. Productivity function estimated for feral stallions on Assateague Island National Seashore.

Figure 13. Siler's approximations to estimates survival of feral horses on Assateague Island National Seashore.

Figure 14. Survival rate predictions based upon Siler's approximations as a function of feral horse population size, Assateague Island National Seashore.

Figure 15. Correlation of survival rates and modal age of senescence for feral horses on Assateague Island National Seashore.

Figure 16. Comparison of reconstructed and modelled projections of a population of feral horses on Assateague Island National Seashore.

Figure 17. Estimated foaling rate derived from a simulation of feral horse life-history, Assateague Island National Seashore.

Figure 18. No action management scenario with (A) and without (B) representative levels of density-independent mortality, Assateague Island National Seashore.

Figure 19. One-time removal of 67 horses and subsequent growth trajectories for a simulated feral horse population with (A) and without (B) representative levels of density-independent mortality, Assateague Island National Seashore.

Figure 20. Fifty-percent fertility control in feral mares with (A) and without (B) representative levels of density-independent mortality, Assateague Island National Seashore.

Figure 21. Simulated population trajectories at different levels of fertility control. Only mature mares (≥ 3 years) received fertility control, Assateague Island National Seashore.

Figure 22. Necessary number of mares to treat for various levels of fertility control, Assateague Island National Seashore.

Figure 23. Number of foals produced at various levels of fertility control, Assateague Island National Seashore.

Figure 24. Realized foaling rate at various levels of fertility control, Assateague Island National Seashore.

Figure 25. Population trajectory using alternating years of fertility control in feral mares, Assateague Island National Seashore.

Figure 26. Interpretation of crossing time graphs used in a risk assessment method for evaluating management alternatives.

APPENDIX I. Testing and implementing CONTRACEPT(), a new GAPPS II module to simulate the event of delivering a contraceptive to inhibit fertility.

CONTRACEPT() is an event module of GAPPS II, a simulation language for the exploration of life-history in population dynamics. CONTRACEPT() was developed through a contract with Applied Biomathematics, Setauket, New York, who at the time was supporting the development of GAPPS II. Like all other modules of GAPPS II, CONTRACEPT() is programmed in ANSI C (Downer 1993). The CONTRACEPT() module contains switches identical to other event modules requiring a rate file (i.e., file of age-specific probabilities of participating in the event). The only argument that is passed to the module is the number of animals to render infertile. The module reads only the integer portion of a real argument via truncation of all digits to the right of the decimal point.

While testing CONTRACEPT(), I discovered that zero is not a valid argument to pass to the module. This becomes a problem when you want to contracept differing numbers of females in a time series in which some years include none. However, I developed an alternative method for specifying a no fertility control option. First, I created another rate file called HSCONT.dbf, which contains zeros everywhere except for the 0 age class (i.e., foals). Then, I passed a "1" to the CONTRACEPT() module indicating that a single female was to be affected by this event. Because the rate file filters out reproductive females, the population receives zero effective contraception. Using the de-bugging features of GAPPS II, I thoroughly tested this work-around and am convinced that it is performing satisfactorily.

In addition, because the rate file for CONTRACEPT() (i.e., HSCON2.dbf) permits only 3 year old mares and older to be eligible for contraception, some foals may still be born even when contraception efficacy has been set to 100%. This occurs because breeding probabilities are set by the product of the variable EXPMPOP, the density-dependent weaning probability, and the age-specific probability of breeding in ASIS mares as defined in HSCON2.dbf. From the listing of the rate file below, it can be seen that 2 year old mares have a small probability of breeding, especially at lower population sizes. Therefore, some foals may be born to 2 year old mares even when 100% contraception has been specified in the command file. If there is a desire to exclude 2 year old mares from breeding entirely, simply replace the age-specific probability with 0.

```
SET (EXPMPOP = .8654*(EXP(-.004109*MPOP)))
; set density-dependent weaning probability according to the March population size;
BREED (RATES (HSBR2.DBF) PAUSE(OFF))
; call the rate file which multiplies the age-specific probability of foaling by EXPMPOP;
```

HSBR2.dbf

```
0 SL EXPMPOP 0.0000 1.0000 0.0000 0.0000
1 SL EXPMPOP 0.0000 1.0000 0.0000 0.0000
2 SL EXPMPOP 0.0000 1.0000 0.0000 0.3700
3 SL EXPMPOP 0.0000 1.0000 0.0000 0.5900
4 SL EXPMPOP 0.0000 1.0000 0.0000 0.7200
```

.

29 SL EXPMPOP 0.0000 1.0000 0.0000 0.0000

APPENDIX II. Analysis of GAPPS II output using a risk management framework.

I have, in this report, exploited the value of frequency distributions as approximations to probability density functions. A similar approach can be extended to the assessment of management alternatives. By specifying a population goal to be achieved through management, one can estimate the probability of growing above or falling below that goal at a given interval of time (Ginzburg et al. 1982, Ferson and Burgman 1990, Akçakaya 1992). This probability depends on the current population size, the population growth rate, the time allotted to cross the threshold abundance and the variability of population size resulting from the random elements of the simulation (Ferson and Burgman 1990).

Perhaps a more useful summary is the actual time it takes before a declining population falls below the threshold abundance. If the threshold abundance is 0, then the analysis is framed in terms of time-to-extinction. If the threshold abundance is >0 , then extinction is replaced by quasi-extinction. In this application, it may simply be referred to as the crossing time. By repetitively simulating population growth or decline, one can assess the relative risk of a certain management scenario by counting the number of times the modeled population grows above, or falls below a threshold population size. The threshold number is largely arbitrary, being set by the prevailing needs of management.

Most Monte-Carlo methods of modeling require many replications to encompass the fullest range of transient population dynamics. I recommend the use of 500 replications for this purpose. After the simulation of a given management scenario, the

output from GAPPS II must be modified in order for crossing times to be estimated. This is accomplished by adding a header to the GAPPS II output, which explains the details of the simulation (Table AII.1). Once the header has been added, the file is submitted to RISK.EXE, a risk assessment module for use with GAPPS II. RISK counts the number of individual runs where the modeled population grew above, or fell below a user-specified threshold abundance. In the crossing-time graphs produced by RISK, the vertical bars indicate the chance of increasing above or falling below the threshold during that interval of time. The probability of increasing above, or falling below the threshold before or during the interval was computed as the cumulative sum of interval probabilities (Fig. AII.1).

Presently, there are no standards for comparing crossing-time graphs in terms other than the time it takes for the population to grow above or fall below the threshold abundance. However, several interesting suggestions have been recently made (Buckley and Downer 1992). The first is to compare the time required for there to be a 50% probability of being at or below the threshold abundance. The method is useful for comparing competing scenarios, but largely ignores differences in the shape of the probability curves. Another method is to compare the maximum displacement in probability between a standard scenario and one which has been slightly modified. This method does permit a comparative analysis of curve shapes (i.e., slopes) and is useful for exploring the sensitivity of the modeled life-history to changes in 1 or more event probabilities. Finally, an analysis of changes in curve shape alone could be conducted. For example, steep-sloped cumulative probability curves indicate that the chance of

growing above or falling below the threshold abundance changes very rapidly over time, suggesting a fairly high degree of risk to management. More gradual, or S-shaped curves provide a measure of security against inducing rapid population changes. In practice, all of these methods are likely to be considered depending upon the particular questions being asked. RISK.EXE has been included to provide an alternative to the analysis of management scenarios, but has not been utilized in the presentation of results for this report.

Table All.1. Sample header to be included in front of GAPPS II output for use in the risk assessment program, RISK.EXE.

(Line descriptions bounded by semi-colons are for descriptive purposes only! Do not include these descriptions in the header used for crossing time analysis!)

```

TITLE Scenario #5
Comment 1 7 variables, 500 repetitions, 10 time steps
Comment 2 No Catastrophes, 100% FC 2 yr, 0% 2 yr
Comment 3 50% FC Thereafter
Simulation results produced by: GAPPS II
7 500 10 ; this line defined in Comment 1;
MPOP; first variable name;
ADFE ; second variable name;
CONT ; third variable name;
FOALS ; fourth variable name;
SPOP ; fifth variable name;
FR ; sixth variable name;
DENDED ; seventh variable name;
1 0 0 0 0 0 ; this line indicates which variables are to be summarized;
167 72 72 2 169 0.028 8 ; this line is the same as the first line in the
data;

1 1 167 72 72 2 169 0.028 8
1 2 161 76 76 0 161 0 7
1 3 154 82 1 24 178 0.293 4
1 4 174 83 1 27 201 0.325 12
1 5 189 83 41 7 196 0.084 7

. . . . .
500 5 180 82 40 5 195 0.028 6

```

Figure All.1. Interpretation of crossing time graphs used in a risk assessment method for evaluating simulated management alternatives.

APPENDIX III. GAPPS II language syntax summary and conventions.

Structuring a GAPPS II simulation is accomplished via a Command File. The first thing GAPPS II does when executed is to read the specified Command File. It will look for syntax errors and alert you to any it finds. It will not proceed with the simulation if any errors are detected. Many modern computer programs attempt to be "user friendly" by running via menus. Menus have been deliberately omitted in GAPPS II because the number and complexity of menus needed to allow the full flexibility in modeling would be overwhelming, and likely more confusing than editing a simple command file.

GAPPS II requires several input files at runtime (Fig. AIII.1), and has the ability to produce prodigious output in the form of text files, and in special cases, a new population file in the dBASE III+ format. While simple models are easy to construct and run, more complex models can also quickly become incomprehensible. Therefore, some time is required to become familiar with the GAPPS II language syntax.

; GAPPS II v1.2 LANGUAGE SYNTAX;

; AGE - increments animal's ages;

```
AGE (  
    AGESEX (filespec)  
    CASES (filespec)  
    PAUSE ([ON:OFF])  
    START (integer)  
    STEP (integer)  
    STOP (integer)  
    SWITCH ([ON:OFF])  
    TRACE (filespec)  
    VAR (symbol) ; stores population count;  
)
```

; ALLELES - initializes animal's alleles for MIN: MAX diversity & zygosity;

```
ALLELES (  
    AGESEX (filespec)  
    CASES (filespec)  
    DIVERSITY ([MIN:MAX])  
    HETERO ([MIN:MAX])  
    PAUSE ([IN:OFF])  
    START (integer)  
    STEP (integer)  
    STOP (integer)  
    SWITCH ([ON:OFF])  
    TRACE (filespec)  
    VAR (symbol) ; no of unique alleles in population;  
)
```

; BEGIN - marks beginning of RUNS or YEAR;

```
BEGIN (  
    PAUSE ([ON:OFF])  
    RUN (integer) ; either RUN or YEAR required;  
    TRACE (filespec)  
  
    YEAR (integer) ; either RUN or YEAR required;  
)
```

; BIRTH - creates new animal records for mothers with litters ;

```
BIRTH (  
    AGESEX (filespec) ; births by mother's age class ;  
    CASES (filespec)  
    GRIDMAP (filespec)  
    PAUSE ([ON:OFF])  
    RATES (filespec) ; required;  
    REPORT (filespec)  
    SEED (integer); reseed genetic random number generator;  
    START (integer) ; 0 = use system clock;  
    STEP (integer)  
    STOP (integer)  
    SWITCH ([ON:OFF])  
    TRACE (filespec)  
    VAR (symbol) ; stores number born;  
)
```

```
; BREED - selects females to be bred;
BREED (
    AGESEX (filespec) ; bred by age class;
    CASES (filespec)
    DEPRESS (real : symbol) ;inbreeding depression factor;
    GRIDMAP (filespec)
    PAUSE ([ON:OFF])
    RATES (filespec) ; required;
    REPORT (filespec)
    START (integer)
    STEP (integer)
    STOP (integer)
    SWITCH ([ON:OFF])
    TRACE (filespec)
    VAR (symbol)
)
```

```
; CENSUS - takes census of current population;
CENSUS(
    AGES (integer, integer..... integer)
    AGESEX (filespec) ; entire population;
    CASES (filespec)
    GRIDMAP (filespec)
    PAUSE ([ON:OFF])
    SEXES ([BOTH: FEMALES: MALES])
    START (integer)
    STEP (integer)
    STOP (integer)
    SWITCH ([ON:OFF])
    TRACE (filespec)
    VAR (symbol) ; census count - required;
)
```

```
; CONTRACEPT - renders individuals infertile;
CONTRACEPT (
    AGESEX (filespec)
    CASES (filespec)
    GRIDMAP (filespec)
    NUMBER ([symbol:number]) ; required;
    PAUSE ([ON:OFF])
    RATES (filespec) ; required;
    REPORT (filespec)
    START (integer)
    STEP (integer)
)
```

```

    STOP (integer)
    SWITCH ([ON:OFF])
    TRACE (filespec)
    VAR (symbol) ; required, stores number contracepted;
)

; END - marks end of RUN or YEAR;
END (
)

; GENETICS - determines population allelic diversity and zygosity;
GENETICS (
    AGESEX (filespec) ; entire population;
    CASES (filespec)
    GRIDMAP (filespec)
    PAUSE ([ON:OFF])
    REPORT (filespec)
    START (integer)
    STEP (integer)
    STOP (integer)
    SWITCH ([ON:OFF])
    TRACE (filespec)
    VAR (symbol) ; stores population heterozygosity;
)

; GROUP - selects and associates animals;
GROUP (
    AGESEX (filespec) ; associated animals only;
    CASES (filespec)
    GRIDMAP (filespec)
    NUMBER ([symbol:real]) ; required;
    PAUSE ([ON:OFF])
    RATES (filespec) ; required;
    REPORT (filespec)
    START (integer)
    STEP (integer)
    STOP (integer)
    SWITCH ([ON:OFF])
    TRACE (filespec)
    VAR (symbol) ; required, stores number grouped;
)

; HUNT- selects and removes animals from the population;
HUNT (

```

AGESEX (filespec) ; of animals killed or removed;
 CASES (filespec)
 GRIDMAP (filespec)
 NUMBER ([symbol:real]) ; required;
 PAUSE ([ON:OFF])
 RATES (filespec) ; required;
 REPORT (filespec)
 START (integer)
 STEP (integer)
 STOP (integer)
 SWITCH ([ON:OFF])
 TRACE (filespec)
 VAR (symbol) ; required, stores number killed or removed;
)

; IMMIGRATE - creates and adds immigrants to population;

IMMIGRATE(
 AGESEX (filespec) ; immigrants only;
 BASE ([symbol:real]) ; allele base;
 CASES (filespec)
 DIVERSITY ([MIN:MAX])
 HETERO ([MIN:MAX])
 GRIDMAP (filespec)
 NUMBER ([symbol:real]) ; required;
 PAUSE ([ON:OFF])
 RATES (filespec) ; required;
 REPORT (filespec)
 START (integer)
 STEP (integer)
 STOP (integer)
 SWITCH ([ON:OFF])
 TAG (integer)
 TRACE (filespec)
 VAR (symbol) ; stores number of immigrants created;
)

; INBREED - determines animals inbreeding coefficient F;

INBREED(
 AGESEX (filespec)
 CASES (filespec)
 GRIDMAP (filespec)
 PAUSE ([ON:OFF])
 REPORT (filespec)
 START (integer)

```

    STEP (integer)
    STOP (integer)
    SWITCH ([ON:OFF])
    TRACE (filespec)
    VAR (symbol) ; mean population F;
)

; LITTER - determines litter size for bred females;
LITTER (
    AGESEX (filespec); females in age class with litters;
    CASES (filespec)
    GRIDMAP (filespec)
    PAUSE ([ON:OFF])
    RATES (filespec[filespec...,filespec]) ; required;
    REPORT (filespec)
    START (integer)
    STEP (integer)
    STOP (integer)
    SWITCH ([ON:OFF])
    TRACE (filespec)
    VAR (symbol) ; stores number of litters;
)

; MATE - selects mates for bred females and stores mate's alleles;
MATE (
    AGESEX (filespec)
    CASES (filespec)
    DEPRESS (real:symbol) ; inbreeding depression factor;
    GRIDMAP (filespec)
    PAUSE ([ON:OFF])
    RATES (filespec) ; required;
    REPORT (filespec)
    START (integer)
    STEP (integer)
    STOP (integer)
    SWITCH ([ON:OFF])
    TRACE (filespec)
    VAR (symbol) ; stores number of unique mates;
)

; MOVE - selects and moves animals;
MOVE (
    AGESEX (filespec) ; moved animals only;
    CASES (filespec)

```

```

    GRIDMAP (filespec)
    NUMBER ([symbol:real]) ; required;
    PAUSE ([ON:OFF])
    RATES (filespec) ; required;
    REPORT (filespec)
    START (integer)
    STEP (integer)
    STOP (integer)
    SWITCH ([ON:OFF])
    TRACE (filespec)
    VAR (symbol) ; stores number moved;
)

; PACK - condenses animal id's into sequential list;
PACK (
    AGESEX (filespec)
    CASES (filespec)
    PAUSE ([ON:OFF])
    START (integer)
    STEP (integer)
    STOP (integer)
    SWITCH ([ON:OFF])
    TRACE (filespec)
    VAR (symbol) ; stores population count;
)

; PURGE - removes population from memory;
PURGE (
    AGESEX (filespec) ; purged animals only;
    CASES (filespec)
    PAUSE ([ON:OFF])
    START (integer)
    STEP (integer)
    STOP (integer)
    SWITCH ([ON:OFF])
    TAG (number) ; if not 0, removes only tagged pop;
    TRACE (filespec)
    VAR (symbol) ; stores population count;
)

; READ - reads population file and adds animals to population;
READ (
    AGESEX (filespec)
    CASES (filespec)
    GRIDMAP (filespec)

```

```

INPUT (filespec) ; required;
PAUSE ([ON:OFF])
START (integer)
STEP (integer)
STOP (integer)
SWITCH ([ON:OFF])
TAG (number) ; if non-zero, is new population tag;
TRACE (filespec)
VAR (symbol) ; stores number of animals added;
)

; RESEED - reseeds random number generator using system clock;
RESEED (
    PAUSE ([ON:OFF])
    SEED (integer); 0 = use system clock;
    START (integer)
    STEP (integer)
    STOP (integer)
    SWITCH ([ON:OFF])
    TRACE (filespec)
    VAR (symbol) ; stores new seed ;
)

SET - GAPPS mathematical expression analyzer;
- Note that all function arguments may themselves be expressions.
SET (symbol = expression)
Legal operators:
ABS (expression) ; absolute value;
CEIL (expression) ; round up;
EXP (expression) ; exponent base e;
FLOOR (expression; round down;
LN (expression) ; log base e;
LOG (expression ; log base 10;
MIN (expression,expression) ; minimum of two expressions;
MAX (expression,expression); maximum of two expressions;
MM (indvar, min, max, p50, p95)
NRAND (mean, cv) ; normally distributed random number;
ROUND (expression) ; round to nearest whole number;
SQRT (expression) ; square root;
URAND (a,b) ; uniform random number  $a \leq n \leq b$ ;

; SETUP - initializes GAPPS II run-time parameters;
SETUP (
    TEST ([ON:OFF]) ; if ON, no run-time performed;

```

```

        TITLE ("literal string") ; title;
    )

; SUMMARY - displays requested variable values;
SUMMARY (
    GRIDMAP (filespec)
    PAUSE ([ON:OFF])
    QUIET ([ON:OFF])
    REPORT (filespec)
    START (integer)
    STEP (integer)
    STOP (integer)
    SWITCH ([ON:OFF])
    TRACE (filespec)
    SYMBOLS (symbol [,symbol...,symbol]) ; up to 13 variables;
)

; SURVIVE - selects and removes animals due to natural mortality;
SURVIVE (
    AGESEX (filespec) ; number died;
    CASES (filespec)
    GRIDMAP (filespec)
    DEPRESS (real:symbol) ; inbreeding depression factor;
    PAUSE ([ON:OFF])
    RATES (filespec) ; required;
    REPORT (filespec)
    START (integer)
    STEP (integer)
    STOP (integer)
    SWITCH ([ON:OFF])
    TRACE (filespec)
    VAR (symbol) ; stores number of deceased animals;
)

; WEAN - determines which young are weaned from their mother;
WEAN (
    AGESEX (filespec)
    CASES (filespec)
    GRIDMAP (filespec)
    PAUSE ([ON:OFF])
    RATES (filespec) ; required;

```

```

REPORT (filespec)
START (integer)
STEP (integer)
STOP (integer)
SWITCH ([ON:OFF])
TRACE (filespec)
VAR (symbol) ; stores number of weaned young, required;
)

; WRITE - writes current population to a *.DBF file;
WRITE (
  AGESEX (filespec)
  CASES (filespec)
  MODE ([APPEND:CREATE]); CREATE deletes existing file;
  OUTPUT (filespec) ; required ;
  PAUSE ([ON:OFF])
  START (integer)
  STEP (integer)
  STOP (integer)
  SWITCH ([ON:OFF])
  TAG (number) ; if not 0, write only if this tag;
  TRACE (filespec)
  VAR (symbol) ; number of animal records written;
)

```

Command file concepts

A command file consists of Root Modules, Event Modules, Commands, Subcommands and specifications (Fig. All.2). Specifications may be numbers, strings, or file names, depending on the circumstance. Commands and subcommands are key words; GAPPS II knows to look for them and knows what they mean. You are not allowed to use these keywords elsewhere in your model (to name a variable, for example). Most commands have associated Subcommands; most Subcommands have associated specifications.

Commands occur in blocks. At the head of each block must be the name of a module, such as ALLELES() or MATE(). Most Commands have at least one Subcommand that is required. In the case of modules that depend on a rate file, the RATES Subcommand will always be required. In a few cases, Subcommands are entirely optional. These will always be modules that do not require rate files.

Subcommands cannot be repeated within a command. Doing so will result in only the last of the identical Subcommands being invoked. Subcommands that are available within almost all of the modules include:

AGESEX [] - Specify the name for an AGESEX output file. The contents of the entries will vary with the particular module, but all will be in the same sex by age matrix format.

CASES [] - Specify the name for a CASE output file. CASE files will contain different entries, depending on the particular module, but will always be in the same format.

TRACE [] - Specify the name for a TRACE output file. TRACE files will contain summary information on the number of individuals affected by that particular module.

RATES [] - Specify the name of an appropriate RATE file. RATE files are required for modules that use them. This is especially useful for de-bugging purposes.

VAR [] - Specify the name for the variable containing the results of the module. This variable can then be displayed in the SUMMARY() module, or used as an independent variable in other modules.

START [] - Specify the year or replicate simulation to begin using this module. The default is 1. This can be used to delay the execution of a particular module until a specified year within the simulation, or until a specified run. If omitted, the module will be executed beginning with year 1 and/or replication 1.

STEP [] - Specify the interval of years or runs for executing the module. The default is 1. This can be used to execute the module only every 2, 3, etc. years or runs. If omitted, the module will be executed during each model year and/or each replication.

STOP [] - Specify the year or replication to stop using this module. The default is the appropriate value of YEAR or RUN. This can be used to discontinue execution of the module at a particular year or run. If omitted, the module will continue in use until the simulation ends.

PAUSE [ON:OFF] - When ON, Subcommand PAUSE instructs GAPPS II to display detailed information on each individual being processed, and to pause between each individual processed until the space-bar key is pressed. This way, screen information about that individual may be frozen for inspection, and the inner-workings of the event process examined. This can be a useful educational tool or for de-bugging purposes, although it will not generally be used during actual runs.

SWITCH [ON:OFF] - The SWITCH Subcommand simply allows the user to quickly disable a command by changing the word "ON" to "OFF". Omitting the SWITCH Subcommand is equivalent to having it set to ON. An alternative way of disabling a module is to use semicolons to turn the entire block into a comment. In experimental

uses, where you may want to quickly run alternative models with and without a particular module, using SWITCH may be faster.

Note that there are alternative ways to use defaults, or to disable a Subcommand. For example, specifying START 1 and STEP 1 is exactly equivalent to omitting them both. The START, STEP and STOP Subcommands will likely be used when intermittent use of modules is contemplated. The output Subcommands AGESEX, CASES, REPORT, and TRACE are always optional; they need be included only when output of this type is desired.

Some modules have other Subcommands. For example, ALLELES() has Subcommands DIVERSITY and HETERO, and HUNT() and CONTRACEPT() have the Subcommand NUMBER. These are explained in the individual modules section.

Editing the command file

Use a simple text or program editor to edit command files. Alternatively, a word processor can be used as long as the output can be saved as a standard ASCII formatted file. The following editing conventions and possibilities apply:

Parentheses

Each command and Subcommand must be followed by an open parenthesis, "(". This indicates to GAPPS II that everything following will be a part of that (sub)command. Before going on to the next (sub)command, a close parenthesis ")" is required. This tells GAPPS II to expect another (sub)command. Thus, parentheses delineate all information contained within a (sub)command.

As long as the proper parentheses are included, the spacing of the Subcommands is flexible. It does not matter whether you use a separate line for each new piece of information, or put them all on the same line, as long as each word, string, etc. is delimited by a parenthesis.

Figure. AIII.1. Input/Output relationships among GAPPS II compatible file structures.

Figure AIII.2. GAPPS II Command File anatomy and the mechanics of runtime execution.

APPENDIX IV. GAPPS II Command File description of a model which includes density-dependent weaning probabilities and survival for foals, yearlings, prime-age horses and past prime-age horses.

By extending the methods presented on modeling survival in phases using Siler's (1979) equations, relationships with respect to density can be described for any number of age classes in the population. The model presented here (Table AIV.1) has survival represented explicitly for all ages which the phase describes. I used the SAS macros to report survival for all ages at population sizes of 20, 100 and 180. After converting survival (i.e., l_x) to survival rate (i.e., p_x), I then summarized over the age groups indicated in the GAPPS II Command File. Plotting these values on population size permitted a crude characterization (Fig. AIV.1) of how each phase (or age group) changed with increasing density. As test of how the mortality was being distributed among the phases, I used the AGESEX[] Subcommand in the SUMMARY() module to see exactly which horses were dying and when. The three phase mortality Command File seems to be performing according to expectation (Fig. AIV.2).

Table AIV.1. GAPPS II Command File description of a model which includes density-dependent weaning probabilities and survival for foals (0 yrs), yearlings (1 yrs), prime-age (2-10 yrs) horses and past prime-age (11-20 yrs) horses.

```

SETUP(TITLE ("GROWTH WITH TRANSFERS AND OTHER MORTALITY"))
BEGIN (RUN (100))
RESEED(SEED(0))
    ; USE CURRENT.DBF FOR HIGH DENSITY OR HSGPOP.DBF FOR LOW;
    READ(INPUT (HSGPOP.DBF))

    ; Comment: start simulation;
    BEGIN (YEAR (18))

        ; Remove Drowned Horses: January Storm;
        HUNT (NUMBER(11) RATES(CATAS.DBF) START(18) STOP(18))

        ; Conduct Census During March (reflected in dbf file);
        CENSUS (VAR(MPOP))

        ; Density-dependent weaning rate;
        SET (EXPMPOP = .8654*(EXP(-.004109*MPOP)))

        ; Density-dependent survival rate for foals;
        SET (TMPOP0 = .9841064+MPOP*(.0000223-.0000049*MPOP))
        ; Density-dependent survival rate for yearlings;
        SET (TMPOP1 = .9896559+MPOP*(.0000070-.0000023*MPOP))
        ; Density-dependent survival rate for prime-aged (2-10) horses;
        SET (TMPOP2 = .9901000-MPOP*(.0001531-.0000005*MPOP))
        ; Density-dependent survival rate for past-prime (11-20) horses;
        SET (TMPOP3 = .8054000+MPOP*(.0007609-.0000144*MPOP))

        ; Remove Specific Transfers;
        HUNT (NUMBER(1) RATES(TRANS.DBF) START(6) STOP(6))
        HUNT (NUMBER(9) RATES(TRANS.DBF) START(10) STOP(10))
        HUNT (NUMBER(7) RATES(TRANS.DBF) START(13) STOP(13))
        HUNT (NUMBER(12) RATES(TRANS.DBF) START(14) STOP(14))
        HUNT (NUMBER(6) RATES(TRANS.DBF) START(15) STOP(15))
        HUNT (NUMBER(1) RATES(TRANS.DBF) START(17) STOP(17))

        ; Census Adult Female Segment;
        CENSUS (AGES(2-29) SEXES(FEMALES) VAR(ADFE))

        ; Density-dependent Weaning Probability;
        ; set by EXPMPOP using Method 2 (see text);
        WEAN (RATES (HSWEAN.DBF) PAUSE(OFF))

        AGE()
        ; Maximum age-specific productivity;
        BREED (RATES (HSBREED.DBF))

```

```

; Males Breeding Determined from Literature;
MATE (RATES (HSMATE.DBF))

; Probability of Litter Size Being 1 is 1.0;
LITTER (RATES (HSLITT.DBF))

; Sex Ratio is 50:50;
BIRTH (RATES (HSGENDER.DBF) VAR (FOALS))
SET (FR = FOALS/ADFE)

; Census Population at End of Foaling Season;
CENSUS (VAR(SPOP))
SET (CATPRP = ROUND(0.10*SPOP))
SET (CHRPRP = ROUND(0.01*SPOP))

; Remove 10% In Each of 2 Years Due to Catastrophic Losses (mostly EEE);
HUNT (NUMBER(CATPRP) RATES(CATAS.DBF) START(14) STOP(15))

; Remove 1% In Each Year Due to Chronic Losses;
HUNT (NUMBER(CHRPRP) RATES(CATAS.DBF))

; Revised Density-dependent Annual Survival Probabilities;
SURVIVE (RATES (HSSURV2.DBF) PAUSE(OFF) VAR (DEAD))

SUMMARY (REPORT (GRWSEN.PRN) SYMBOLS (MPOP,ADFE,FOALS,SPOP,FR,DEAD))
END ()
PURGE ()
END ()

```

Figure AIV.1. Phase-specific survival rates derived from models of feral horse survival which include a population effect. Simple polynomials are used to smoothly connect the three data points. HSURV2.dbf ensures that predicted survival will be constrained between 0-1.

Figure AIV.2. Plot of the number of horses in each age group dying as population size increases from about 30 horses to nearly 200 horses. Most of the mortality occurs in the very youngest and oldest horses.

APPENDIX V. CENSUS2.prg, a dBASE III+ program file for reconstructing the feral horse population of Assateague Island National Seashore using a probabilistic framework. The database structure was designed specifically with this framework in mind. Note: this program requires one or more third-party add-ons to execute properly. These add-ons have been made available on the distribution disk.

```

*CENSUS2.PRG --      PROGRAM TO COMPUTE MONTHLY CENSUS FIGURES FOR HORSES ON
*                      ASSATEAGUE ISLAND NATIONAL SEASHORE, ACCOUNTING FOR ANIMALS
*                      WITH NO BIRTHDATES AND IMPRECISE
*                      DATES OF DEATH.
* PROGRAMMED BY BRIAN UNDERWOOD, 1993
SET PROCEDURE TO _CENSUS

CLEAR
* SET ENVIRONMENT SWITCHES
SET TALK OFF
SET SAFE OFF
SET DECIMALS TO 4
SET FIXED ON
SET EXACT ON

* INITIALIZE CTOOLS
DO INIT_MY_PROG

* RECALL LAST RUN'S INDEX
RESTORE FROM CENSUS ADDITIVE
LR=LTRIM(STR(LASTRUN))

DO WHILE LASTRUN <= 500
SET ALTER TO RUN&LR

USE SIMULATE
SET TALK ON
INDEX ON ID TO TEMP
COPY TO TESTSIM
SET TALK OFF
CLEAR

CLOSE DATABASES
USE TESTSIM
REPLACE ALL CFLAG WITH '0'

* SET FOCUS MONTH FOR AGE STRUCTURE TABULATIONS
FOCUS = 2          && Month of March (i.e., 0, 1, 2)

* First Assign Birth Year and Month, to Horses that need them
GOTO TOP
DO WHILE .NOT. EOF()
IF NOBMO = '1'          && Start with Month
                        && If it's a progenitor, assign default
    IF PROGEN='1'
        YR='71'
        MO='01'
    ELSE
        DO BIRTH          && Call Procedure
        IF LEN(LTRIM(STR(OUTCOME))) < 2
            STORE '0'+LTRIM(STR(OUTCOME)) TO MO
        ELSE
            STORE LTRIM(STR(OUTCOME)) TO MO
        ENDIF
        IF NOBYR = '1'      && Now do Year
            * DRAW A RANDOM YEAR
            DO WHILE .T.
                CALL CFUNC WITH 'RAND 75,92'      && Modified 10/11
                YR = LTRIM(STR(C_N_RESULT))
                * Set Acceptance Criteria
                IF .NOT. (STATUS = 'L' .OR. REJECT = '1') .AND.
                    VAL(SUBSTR(LTRIM(STR(TERMINATE)),1,2)) < VAL(YR)
            LOOP
        ELSE
            EXIT
        ENDIF
    ENDIF
ENDIF

```

```

                ENDDO
            ELSE
                YR=SUBSTR(LTRIM(STR(BORN)),1,2)
            ENDIF
        ENDIF
        REPLACE BORN WITH VAL(YR+MO+'00')
    ENDF
    SKIP
    ENDDO

* Done with Assignment of Birth Year and Month
*-----

* INPUT THE STARTING CENSUS YEAR
STORE 75 TO CURYR

DO WHILE .T.                                && Principal Loop for Years

    * CREATE ARRAY STRUCTURES TO HOLD DATA
    CALL CFUNC WITH 'CRARRAY CALENDAR, 300x12, N'    && Monthly Census Figures
    CALL CFUNC WITH 'CRARRAY ID, 300, C'            && Horse Identifications

    GOTO TOP
    I = 0                                           && I is the row index

    DO WHILE .NOT. EOF()

        * SET UP TEMPORARY VARIABLES
        BEGIN_YR = VAL(SUBSTR(LTRIM(STR(BORN)),1,2))
        BEGIN_MO = VAL(SUBSTR(LTRIM(STR(BORN)),3,2))

        * If census year is before birth, skip and start over
        IF CURYR < BEGIN_YR
            SKIP
            LOOP
        ENDIF

        * If dead, missing or transferred, and termination date unacceptable
        IF (.NOT. STATUS = 'L') .AND. RCODE = 'U' .OR. RCODE = 'V'
            IF RTRIM(ROPER_1) = "=" && Single Condition
                STORE SUBSTR(RRANGE_1,3,2) TO YR

                * Get Month of Death from Multinomial Draw
                DO DEATH && Call Procedure
                IF LEN(LTRIM(STR(OUTCOME))) < 2
                    STORE "0"+LTRIM(STR(OUTCOME)) TO MO
                ELSE
                    STORE LTRIM(STR(OUTCOME)) TO MO
                ENDIF

                REPLACE TERMINATE WITH VAL(YR+MO+'00')
                && Multiple Conditions
            ELSE
                STORE VAL(SUBSTR(RRANGE_1,1,2)) TO MO
                STORE VAL(SUBSTR(RRANGE_1,3,2)) TO YR

                DO WHILE .T.
                    DAY=0
                    * Convert to Julian Dates
                    DO TOJULIAN WITH DAY,MO,YR
                    STORE LTRIM(STR(JULDAY,15,4)) TO FIRST

                    STORE VAL(SUBSTR(RRANGE_2,1,2)) TO MO
                    STORE VAL(SUBSTR(RRANGE_2,3,2)) TO YR
                    DO TOJULIAN WITH DAY,MO,YR
                    STORE LTRIM(STR(JULDAY,15,4)) TO LAST

                    * Draw a Random Month From Multinomial
                    DO DEATH && Call Procedure
                    STORE OUTCOME TO MO

                    * Draw a Random Year
                    DO WHILE .T. && Conditional Loop

                        CALL CFUNC WITH 'RAND 75,92'

                        STORE C_N RESULT TO YR
                        IF YR < BEGIN_YR

```

```

                                LOOP
                                ELSE
                                EXIT
                                ENDIF
                                ENDDO    && WHILE TRUE

                                DO TOJULIAN WITH DAY,MO,YR
                                STORE LTRIM(STR(JULDAY,15,4)) TO DRAW

                                STORE DRAW+ROPER_1+FIRST+" .AND. "+DRAW+ROPER_2+LAST TO TEST

                                IF &TEST                                && Test Conditions Defined in Dbase
                                    IF LEN(LTRIM(STR(MO))) < 2
                                        REPLACE TERMINATE WITH
                                            VAL(LTRIM(STR(YR))+ '0'+LTRIM(STR(MO))+ '00')
                                    ELSE
                                        REPLACE TERMINATE WITH
                                            VAL(LTRIM(STR(YR))+LTRIM(STR(MO))+ '00')
                                    ENDIF
                                EXIT
                                ENDIF
                                ENDDO    && WHILE TRUE
                                ENDIF
                                ENDIF
* -----
* At this point, all animals have a valid birth yr+mo and death yr+mo.

* CHECK FOR VALID STATUS BEFORE ASSIGNMENT OF TEMPORARY VARIABLES
IF .NOT. STATUS = 'L'
    END_YR = VAL(SUBSTR(LTRIM(STR(TERMINATE)),1,2))
    END_MO = VAL(SUBSTR(LTRIM(STR(TERMINATE)),3,2))
ENDIF

* Check for a valid ID; if not, replace with name
IF LEN(TRIM(ID))=0
    TAG=RTRIM(NAME)
ELSE
    TAG=RTRIM(ID)
ENDIF

* Processes conditions so far (i.e., horse living, dead, missing or transferred)
IF STATUS = 'L'                                && Horse is living so fill all months with a '1'
    CALL CFUNC WITH 'PUTARRAY ID'+','+'+STR(I)+','+'+TRIM(TAG)

    IF CURYR = BEGIN_YR                                && J is the column index
        J = BEGIN_MO-1                                && Subtract 1 for array offset
        AGE = 0
        IF BEGIN_MO <= FOCUS
            REPLACE CFLAG WITH '1'
        ENDIF
    ELSE
        J = 0
        AGE = CURYR - BEGIN_YR
        REPLACE CFLAG WITH '1'
    ENDIF

    REPLACE SIMAGE WITH AGE

    DO CASE
        CASE SEX = 'F'
            REPLACE SIMSEX WITH SEX
        CASE SEX = 'M'
            REPLACE SIMSEX WITH SEX
        CASE SEX = 'U'
            DO WHILE .T.
                CALL CFUNC WITH 'RAND 0, 10'
                DO CASE
                    CASE C_N_RESULT < 5
                        REPLACE SIMSEX WITH 'F'
                        EXIT
                    CASE C_N_RESULT > 5
                        REPLACE SIMSEX WITH 'M'
                        EXIT
                    OTHERWISE
                ENDCASE
            ENDDO
        ENDCASE
    ENDCASE

```

```

DO WHILE J < 12
    CALL CFUNC WITH 'PUTARRAY CALENDAR'+','+'STR(I)+'x'+STR(J)+'','+1'
    J= J+1
ENDDO

ELSE
    * If census year is less than year of death, censor, or transfer,
    * it's still alive and in population
    DO CASE
    CASE CURYR < END_YR                && Horse is still alive; process all months
                                        && starting with month of birth

        CALL CFUNC WITH 'PUTARRAY ID'+','+'STR(I)+'','+TRIM(TAG)

    IF CURYR = BEGIN_YR                && If this is the year of birth...
        J = BEGIN_MO-1
        AGE = 0
        IF BEGIN_MO <= FOCUS
            REPLACE CFLAG WITH '1'
        ENDIF
    ELSE
        J = 0
        AGE = CURYR - BEGIN_YR
        REPLACE CFLAG WITH '1'
    ENDIF

    REPLACE SIMAGE WITH AGE

    DO CASE
    CASE SEX = 'F'
        REPLACE SIMSEX WITH SEX
    CASE SEX = 'M'
        REPLACE SIMSEX WITH SEX
    CASE SEX = 'U'
        DO WHILE .T.
            CALL CFUNC WITH 'RAND 0, 10'
            DO CASE
            CASE C_N_RESULT < 5
                REPLACE SIMSEX WITH 'F'
                EXIT
            CASE C_N_RESULT > 5
                REPLACE SIMSEX WITH 'M'
                EXIT
            OTHERWISE
            ENDIF
        ENDWHILE
    ENDIF
    ENDDO

    ENDCASE

DO WHILE J < 12
    CALL CFUNC WITH 'PUTARRAY CALENDAR'+','+'STR(I)+'x'+STR(J)+'','+1'
    J = J+1
ENDDO

CASE CURYR = END_YR                && Horse dies during this year
    * Find out in what month it died, fill CALENDAR
    * only up to that month
    CALL CFUNC WITH 'PUTARRAY ID'+','+'STR(I)+'','+TRIM(TAG)

    IF CURYR = BEGIN_YR  && If it's also year of birth, set specific column
                                                offset
        J = BEGIN_MO-1
        AGE = 0
        IF BEGIN_MO <= FOCUS
            REPLACE CFLAG WITH '1'
        ENDIF
    ELSE
        J = 0
        AGE = CURYR - BEGIN_YR
    ENDIF

    REPLACE SIMAGE WITH AGE

    DO CASE
    CASE SEX = 'F'
        REPLACE SIMSEX WITH SEX
    CASE SEX = 'M'
        REPLACE SIMSEX WITH SEX

```

```

CASE SEX = 'U'
    DO WHILE .T.
        CALL CFUNC WITH 'RAND 0, 10'
        DO CASE
            CASE C_N_RESULT < 5
                REPLACE SIMSEX WITH 'F'
                EXIT
            CASE C_N_RESULT > 5
                REPLACE SIMSEX WITH 'M'
                EXIT
            OTHERWISE
                ENDCASE
        ENDDO
    ENDCASE

DO WHILE J < END_MO  && Fill in columns to month or death or censor
    CALL CFUNC WITH 'PUTARRAY CALENDAR'+','+'STR(I)+'x'+STR(J)+' ','+1'
    IF J <= FOCUS
        REPLACE CFLAG WITH '1'
    ENDIF
    J = J+1
ENDDO

OTHERWISE

    * Animal died in a previous year, so move on
    REPLACE CFLAG WITH '0'
    SKIP
    LOOP                && As not to increment row index
ENDCASE

ENDIF

SKIP
I = I+1
ENDDO                && While .NOT. End-of-File
* Done with Accounting for Horses in this Year
*-----
* Being Reporting Process

MAXROWS = I
I = 0

*SET ALTER ON
*? SPACE(20)+'Census Year: '+'19'+LTRIM(STR(CURYR))
*SET ALTER OFF

* Initialize Macro Variables                && Brian's Tricks for summing down array columns
M1 = 0
M2 = 0
M3 = 0
M4 = 0
M5 = 0
M6 = 0
M7 = 0
M8 = 0
M9 = 0
M10 = 0
M11 = 0
M12 = 0

DO WHILE I < MAXROWS
    * To fix CTOOLS bug
    C_C_RESULT=SPACE(20)
    CALL CFUNC WITH 'SETDVAR C'
    CALL CFUNC WITH C_C_RESULT
    CALL CFUNC WITH 'GETARRAY ID'+','+'STR(I)
    PAD = 25-LEN(RTRIM(C_C_RESULT))
    *   SET ALTER ON
    *   ? RTRIM(C_C_RESULT)+SPACE(PAD)
    *   SET ALTER OFF
    J = 0
    NUM = LTRIM(STR(J+1))
    DO WHILE J < 12
        CALL CFUNC WITH 'GETARRAY CALENDAR'+','+'STR(I)+'x'+STR(J)
        M&NUM = M&NUM + C_N_RESULT
        *   SET ALTER ON
        *   ?? LTRIM(STR(C_N_RESULT))+SPACE(2)

```

```

*                SET ALTER OFF
                J = J+1
                NUM = LTRIM(STR(J+1))
            ENDDO
I = I+1
ENDDO                && While I < MaxRows
K = 1
NUM = LTRIM(STR(K))

*SET ALTER ON
*? SPACE(18)
*SET ALTER OFF

DO WHILE K <= 12
    SET ALTER ON
    ?? LTRIM(STR(M&NUM))+SPACE(2)
    SET ALTER OFF
    K = K+1
    NUM = LTRIM(STR(K))
ENDDO

SET FILTER TO CFLAG = '1'
COUNT TO N
CALL CFUNC WITH 'CRARRAY SAS, '+LTRIM(STR(N))+', N'                && Standing Age Structure
CALL CFUNC WITH 'CRARRAY SORTED, '+LTRIM(STR(N))+', N'
CALL CFUNC WITH 'CRARRAY DISTINCT, '+LTRIM(STR(N))+', N'
CALL CFUNC WITH 'CRARRAY FREQUENCY, '+LTRIM(STR(N))+', N'

GOTO TOP
I = 0
DO WHILE .NOT. EOF()
    CALL CFUNC WITH 'PUTARRAY SAS, '+LTRIM(STR(I))+', '+LTRIM(STR(SIMAGE))
    I = I+1
    SKIP
ENDDO

CY = LTRIM(STR(CURYR))

CALL CFUNC WITH 'DIST SAS, SORTED, DISTINCT, FREQUENCY'
*CALL CFUNC WITH 'ASAVE DISTINCT, D&LR.&CY..SAV'
*CALL CFUNC WITH 'ASAVE FREQUENCY, F&LR.&CY..SAV'

*I = 0
*N = C_N_RESULT

*DO WHILE I < N
*    CALL CFUNC WITH 'GETARRAY DISTINCT, '+STR(I)
*    SET ALTER ON
*    ? C_N_RESULT
*    SET ALTER OFF
*    CALL CFUNC WITH 'GETARRAY FREQUENCY, '+STR(I)
*    SET ALTER ON
*    ?? C_N_RESULT
*    SET ALTER OFF
*    I = I+1
*ENDDO

SET FILTER TO
CALL CFUNC WITH 'FRARRAY ALL'
CURYR = CURYR+1

IF CURYR <= 92                && Check Program Exit Criterion
    SET ALTER ON
    ?
    SET ALTER OFF
    LOOP
ELSE
    EXIT
ENDIF

ENDDO                && WHILE TRUE

LASTRUN = LASTRUN + 1                && Save Counter for Simulations
SAVE TO CENSUS ALL LIKE LASTRUN

SET ALTER TO
RELEASE ALL

```

CLOSE DATABASES

* RECALL LAST RUN'S INDEX
RESTORE FROM CENSUS ADDITIVE
LR=LTRIM(STR(LASTRUN))
ENDDO

* Housekeeping
CLEAR ALL
CLOSE ALL
ERASE TEMP.NDX
ERASE TESTSIM.DBF
SET TALK ON
SET SAFE ON
SET FIXED OFF
SET DECIMALS TO
RETURN

```

* CENSUS.PRG -- COMMON PROCEDURE FILE TO ACCOMPANY CENSUS.PRG
PROCEDURE BIRTH
PUBLIC OUTCOME

```

```

* DRAW RN[0,1]
CALL CFUNC WITH 'RAND'

```

```

DO CASE
  CASE C_N_RESULT >= 0 .AND. C_N_RESULT < .005
    OUTCOME=1
  CASE C_N_RESULT >= .005 .AND. C_N_RESULT < .010
    OUTCOME=2
  CASE C_N_RESULT >= .010 .AND. C_N_RESULT < .020
    OUTCOME=3
  CASE C_N_RESULT >= .020 .AND. C_N_RESULT < .199
    OUTCOME=4
  CASE C_N_RESULT >= .199 .AND. C_N_RESULT < .617
    OUTCOME=5
  CASE C_N_RESULT >= .617 .AND. C_N_RESULT < .801
    OUTCOME=6
  CASE C_N_RESULT >= .801 .AND. C_N_RESULT < .918
    OUTCOME=7
  CASE C_N_RESULT >= .918 .AND. C_N_RESULT < .959
    OUTCOME=8
  CASE C_N_RESULT >= .959 .AND. C_N_RESULT < .985
    OUTCOME=9
  CASE C_N_RESULT >= .985 .AND. C_N_RESULT < .990
    OUTCOME=10
  CASE C_N_RESULT >= .990 .AND. C_N_RESULT < .995
    OUTCOME=11
  CASE C_N_RESULT >= .995
    OUTCOME=12
  OTHERWISE
    LOOP
ENDCASE

```

```

RETURN TO MASTER

```

```

*END PROCEDURE -----

```

```

PROCEDURE DEATH

```

```

PUBLIC OUTCOME
  * DRAW RN[0,1]
  CALL CFUNC WITH 'RAND'

```

```

DO CASE
  CASE C_N_RESULT >= 0 .AND. C_N_RESULT < .1042
    OUTCOME=1
  CASE C_N_RESULT >= .1042 .AND. C_N_RESULT < .1528
    OUTCOME=2
  CASE C_N_RESULT >= .1528 .AND. C_N_RESULT < .3472
    OUTCOME=3
  CASE C_N_RESULT >= .3472 .AND. C_N_RESULT < .4028
    OUTCOME=4
  CASE C_N_RESULT >= .4028 .AND. C_N_RESULT < .5069
    OUTCOME=5
  CASE C_N_RESULT >= .5069 .AND. C_N_RESULT < .5556
    OUTCOME=6
  CASE C_N_RESULT >= .5556 .AND. C_N_RESULT < .6042
    OUTCOME=7
  CASE C_N_RESULT >= .6042 .AND. C_N_RESULT < .7431
    OUTCOME=8
  CASE C_N_RESULT >= .7431 .AND. C_N_RESULT < .8750
    OUTCOME=9
  CASE C_N_RESULT >= .8750 .AND. C_N_RESULT < .9236
    OUTCOME=10
  CASE C_N_RESULT >= .9236 .AND. C_N_RESULT < .9375
    OUTCOME=11
  CASE C_N_RESULT >= .9375
    OUTCOME=12
  OTHERWISE

```

```

  ENDCASE

```

```

RETURN TO MASTER

```

```

*END PROCEDURE -----

```

PROCEDURE TOJULIAN
PARAMETERS D,M,Y
PUBLIC JULDAY

$$\text{JULDAY} = D - 32075 + 1461 * (Y + 4800 + (M - 14) / 12) / 4 + 367 * (M - 2 - (M - 14) / 12 * 12) / 12 - 3 * ((Y + 4900 + (M - 14) / 12) / 100) / 4$$

RETURN TO MASTER

*END PROCEDURE -----

APPENDIX VI. ALLPONY.prg, a dBASE III+ program for entering, editing and retrieving information individual horses of Assateague Island National Seashore. Note: this program requires one or more third-party add-ons to execute properly. These add-ons have been made available on the distribution disk.
