Simulation and management implications of feral horse grazing on Cumberland Island, Georgia

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Abstract

Cumberland Island National Seashore, Georgia, is inhabited by a population of feral horses that intensively graze the island's salt marshes. Based on 18 months of experimental grazing studies, a carbon flow simulation model was developed for a medium height *Spartina alterniflora* marsh and used to estimate an acceptable population size of feral horses. Five-year simulations indicated a threshold of 2,700 kg/ha aboveground *Spartina* biomass below which the system did not recover if intensive grazing continued. The difference between this threshold and annual peak biomass of ungrazed *Spartina* was used to estimate horse densities that would not cause marsh degradation. Results suggest the horse population should number between 49 and 73 horses if excessive damage to the salt marshes is to be prevented. Thus, the current population of 180 horses should be reduced.

Key Words: simulation model, salt marsh, *Spartina alterniflora*, feral horses, *Equus caballus* population size, Cumberland Island National Seashore

The impacts of exotic species, including feral animals, have been documented in numerous ecosystems (e.g., Bratton 1975, Petrides 1975, Rudge and Campbell 1977, Turner 1984). During the last century, horses *(Equus caballus)*, pigs *(Sus scrofa)*, and cattle *(Bos taurus)* have ranged free on Cumberland Island National Seashore, Georgia. The U.S. National Park Service removed the cattle in 1974 and has greatly reduced the hog population through trapping. The horse population, however, remains unmanaged and appears to be increasing at a rate of approximately 5% annually. The population has increased from a minimum of 144 horses in 1981 (Lenarz 1983), to 154 horses in 1983 (Ambrose et al. 1983), and 180 horses in 1985 (Finley 1985).

Feral horses on Cumberland Island feed primarily in salt marshes, dunes, interdune meadows, and lawn areas. Lenarz (1983) reported that 51.7% of his observations of feral horse feeding occurred in salt marshes, which encompass 34.1% of the island (Hillestad et al. 1975). Vertebrate herbivory in salt marshes may alter the structure of the vegetation (Chabreck 1968, Shanholtzer 1974), reduce net aboveground primary production (Reimold et al. 1975), reduce standing stocks of belowground biomass (Smith and Odum 1981), result in a network of paths (Howell 1984), or reduce invertebrate populations (Reimold et al. 1975). In mixed species marshes, relative species abundance or successional patterns may be changed (Ranwell 1961, Bakker 1978, 1985, Dijkema 1984). With ungulate grazing, plant regeneration may be slow because of trampling (Chabreck 1968, Jensen 1985).

Horses presently remove up to 98% of the aboveground standing stock of *Spartina alterniflora* in heavily grazed marshes on Cumberland Island, and trampling alone can decrease net aboveground primary production (NAPP) by 40% (Turner 1987). Horses may also be having significant impacts on other plant communities on the island (Turner and Bratton 1987). Management of the horse population requires an estimate of the number of horses that can be maintained without excessive damage to natural ecosystems. Based on 18 months of experimental field studies, an ecosystem simulation model of the salt marsh was developed to examine the effects of various grazing intensities on standing stocks of *Spartina*. The objective was to determine an acceptable population size of horses based on impacts on the salt marsh, their major foraging community. The simulation model and its management implications are described in this paper.
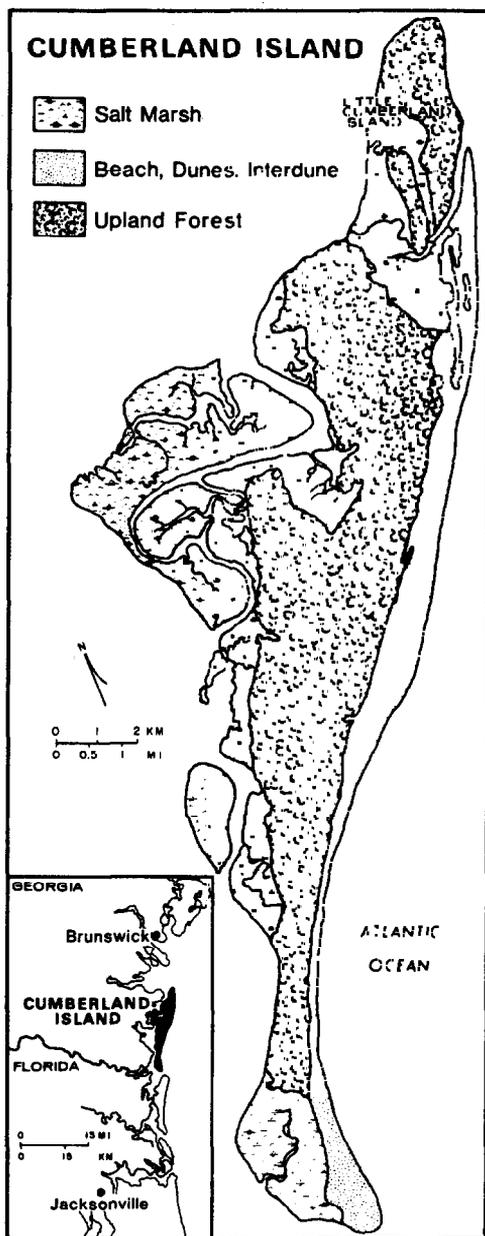
Fig. 1. *Map of Cumberland Island, Georgia, showing major vegetation communities.*

Study Area

Cumberland Island, Georgia (30°48′ N. lat., 81°26′W. long.) is the largest and most southern of the Georgia barrier islands (Fig. 1), measuring 25 km in length and 9 km across at its widest point. Designated a National Seashore in 1972, the federal boundaries encompass approximately 14,500 ha, owned, and administered by the U.S. National Park Service. The geology, soils, water resources, vegetation, and fauna of Cumberland have been described by Hillestad et al. (1975). The interior of the island is of Pleistocene origin whereas the seaward portion is of the more recent Holocene. Except in dune areas which may reach elevations of 18 m, the island is generally of low relief (5–8 m above sea level). The climate is warm temperate to subtropical and is characteristically warm and humid. Major plant communities are those typical for Georgia barrier islands (Johnson et al. 1974). Salt marshes occur throughout the tidal land on the mainland side of the island, characterized by a dominant macrophyte, the smooth cordgrass *Spartina alterni-*

flora. The upper margin of the marsh grades into a grass-forb community composed primarily of glass wort *(Salicornia virginica)*, salt grass *(Distichlis spicata)*, and occasional stands of needle rush *(Juncus roemerianus)*.

The upland portions of the marsh are bounded by tidal creeks that horses do not readily cross. To determine the marsh area accessible to horses, color infrared aerial photographs from 1983 (nominal scale of 1:24,000) and a Bausch and Lomb Zoom Transfer Scope were used. Area was calculated by planimetry. Results indicated that 411 ha of salt marsh were potentially available to the horse population. However, approximately half of this marsh area is only available at mean low tide and is not frequently grazed by horses. The remaining half of the marsh (approximately 205 ha) is used frequently and is already severely overgrazed *(personal observation)*. The current population of 180 animals (Finley 1985) is at a density of 0.88 horse • ha^{-1} of frequently used salt marsh.

Model Structure

The model contained 7 compartments (Fig. 2) and was developed to simulate carbon flow through the system on a yearly basis. The objectives of the model were to (1) adequately simulate the ungrazed, or nominal condition, of the salt marsh; (2) simulate current intensities of horse grazing; and (3) predict potential impacts on the marsh due to increased horse grazing.

Table 1. Differential equations used for state variables in the ecosystem simulation model.

State variable	Equation
X_1, Live aboveground *Spartina*	$dX_1/dt = F_{01}+F_{31}-F_{12}-F_{13}-F_{14}-F_{17}-F_{10}$
X_2, Dead aboveground *Spartina*	$dX_2/dt = F_{12}-F_{20}$
X_3, Live belowground *Spartina*	$dX_3/dt = F_{13}-F_{36}-F_{30}-F_{31}$
X_4, Insect grazers	$dX_4/dt = F_{14}-F_{40}$
X_5, Sediment macroorganic matter	$dX_5/dt = F_{65}-F_{50}$
X_6, Aerobic sediment heterotrophs	$dX_6/dt = F_{36}-F_{65}-F_{60}$

Notation F_{ij} indicates a flow of carbon from compartment i to compartment j.

The compartments, or state variables, are related by flows of carbon as shown in Figure 2. Changes in the state variables are calculated by a series of differential equations (Table 1) which incorporate the flows between compartments (Table 2). Season is an important control on many flows, for example, on photosynthesis and respiration. Seasonal variability is included in the model by changing relevant parameters at approximately 90–day intervals during the simulation. Two types of feedback control are also used in the model: (1) space-related feedbacks, such as overcrowding or self-shading; and (2) resource-related feedbacks, such as resource refuge levels and consumer satiation levels. The general forms of these controls are shown in Table 3, and the functions are fully described by Wiegert (1979). Values of the parameters used in the simulations are listed in Table 4. The computer program was written in BASIC, and calculations in the model are done on a daily basis. Initial conditions were obtained from field data (Turner 1985, 1987) and are set at the January values at the beginning of each simulation.

Grazing simulations were done for 5 years. The effects of horse grazing on other compartments were simulated, but the population dynamics of the herd (birth rate, death rate, etc.) were not generated internally in the model. Horse density was specified at the beginning of each simulation, either as a constant or with an annual rate of increase.

SALT MARSH SIMULATION MODEL

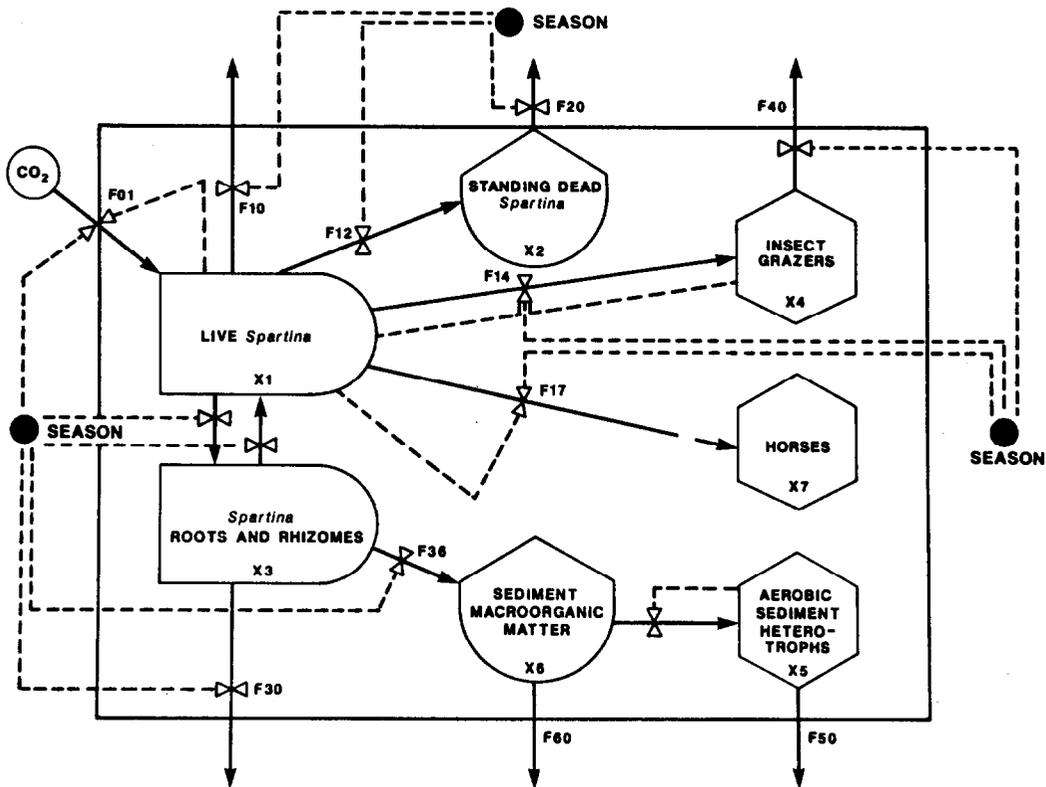**Fig. 2.** *Diagram of the salt marsh simulation model. Solid lines indicate carbon flow pathways; broken lines are control pathways.*
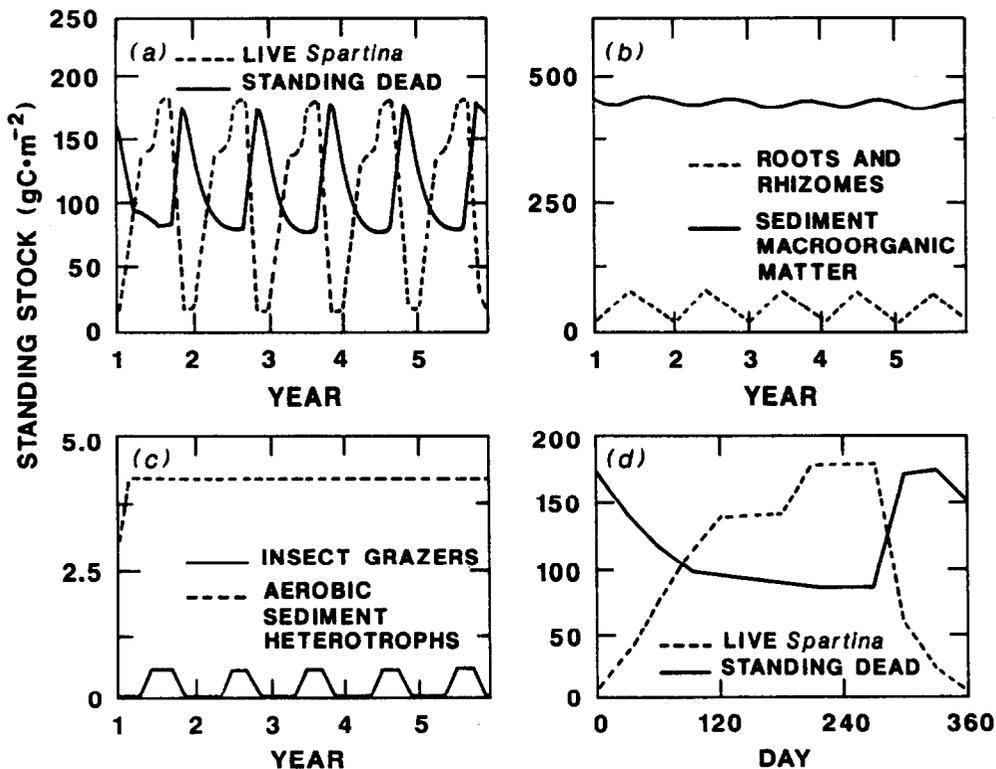
NOMINAL SIMULATION

Fig. 3. *Simulation of the ungrazed marsh. Figures 3a, 3b, and 3c show dynamics of each compartment in 5-year simulations. Figure 3d is an expanded view of aboveground* Spartina *dynamics during 1 year of the simulation, showing seasonal patterns.*

Table 2. Description of flows (F_{ij}) used in the differential equations.

F_{01} **Gross photosynthesis of *Spartina***
[(maximum gross photosynthetic rate by season)(standing stock of *Spartina*)
(space related feedback control with response threshold and carrying capacity)]

F_{31} **Translocation of carbon from roots to shoots in *Spartina***
[(specific rate of translocation per season)(standing stock of roots and rhizomes)]

F_{10} **Respiration of *Spartina* shoots**
[(specific rate of respiration by season)(standing stock of shoots)]

F_{12} **Nonpredatory mortality of *Spartina* shoots**
[(death rate of shoots by season)(standing stock of shoots)]

F_{13} **Translocation of carbon from shoots to roots in *Spartina***
[(specific rate of translocation per season)(standing stock of shoots)]

F_{14} **Ingestion of *Spartina* by insect grazers**
[(maximum rate of ingestion)(standing stock of insects)(space feedback)
(resource feedback control with satiation level and refuge level)]

F_{17} **Ingestion of *Spartina* by horses**
[(maximum ingestion rate per horse by season)(standing stock of horses)
(space feedback)(resource feedback)]

F_{36} **Death of live roots and rhizomes, becoming sediment macroorganic matter**
[(seasonal death rate)(standing stock of roots and rhizomes)]

F_{65} **Ingestion of macroorganic matter by aerobic heterotrophs**
[(maximum ingestion rate)(standing stock of heterotrophs)(space related feedback
term)(1-egestion)]

F_{60} **Loss of macroorganic matter from the marsh, e.g., sinking, tidal export**
[(specific loss rate)(standing stock of macroorganic matter)]

F_{40} **Respiration of insect grazers**
[(seasonal specific rate of respiration)(standing stock of insects)]

F_{50} **Respiration of aerobic heterotrophs in the sediment**
[(seasonal specific rate of respiration)(standing stock of microbes)]

F_{20} **Loss of standing dead from the system**
[(seasonal specific loss rate)(standing stock of standing dead *Spartina*)]

F_{30} **Respiration and leaching of live *Spartina* roots and rhizomes**
[(seasonal specific loss rate)(standing stock of roots and rhizomes)]

Table 3. General forms of feedback controls on rates of carbon transfer.

A. Generalized logistic for space-related controls:

$$f(X_j) = \{1 - (\lambda/\tau) [(X_j - \alpha_{jj}) / (K_j - \alpha_{jj})]\}$$

where

λ = specific loss rate of X_i,

τ = specific rate of ingestion of X_i,

α_{jj} = density of X_j at which the density response begins,

K_j = carrying capacity of X_i,

such that the function ranges between 0 and 1, such that when $X_j < \alpha_{jj}$, $f(X_j)=1$

and when $X_j \geq K_j$, $f(X_j) = 0$; between these points the function is linear.

B. Generalized resource-related feedbacks:

$$f(X_i) = (1 - [(\gamma_{ij} - X_i) / (\gamma_{ij} - \alpha_{ij})])$$

where

γ_{ij} = the satiation level of resource X_i for consumer X_j beyond
which the ingestion rate will no longer increase,

α_{ij} = the refuge level of resource X_i below which it is not
available to consumer X_j,

such that the function ranges from 0 to 1, such that when $X_i < \alpha_{ij}$, then $f(X_i) = 0$ and
consumption by X_j will also be 0, and when $X_i \geq \gamma_{ij}$ then $f(X_i) = 1$ and consumption by
X_j will be at a maximum; between α and γ, the function is linear.

Table 4. Values of parameters used in the simulation model.

Parameter	Description	Value Winter	Spring	Summer	Fall
	Specific rates used in flow equations (day^{-1})				
TAU01	maximum photosynthetic rate of Spartina	.062	.136	.136	.044[a]
TAU13	specific rate of translocation from shoots to roots	.02	.05	.01	.02[a]
TAU31	specific rate of translocation from roots to shoots	.0001	.003	.0001	.003[b]
TAU65	maximum ingestion rate of aerobic heterotrophs in the sediment	.38	.38	.38	.38[b]
TAU14	maximum ingestion rate of insect grazers on Spartina shoots	.25	.25	.25	.25[c]
TAU17	maximum ingestion rate of horses	.0506	.0482	.06	.0808[d]
LAM10	specific rate of shoot respiration	.0035	.0048	.0026	.0019[b]
LAM20	specific rate of loss of standing dead from the system	.007	.003	.024	.01[b]
LAM30	specific rate of respiratory and leaching losses from roots and rhizomes to interstitial water	.00097,	.01148,	.007653,	.01[b]
LAM40	specific rate of insect respiration	.114	.12	.12	.114[b]
LAM50	specific loss rate of aerobic heterotrophs including respiration	.11	.11	.11	.11[b]
LAM60	specific loss rate of macroorganic matter including tidal loss and settling	.0004	.0004	.0004	.0004[b]
MU12	specific death rate of shoots	.0023	.0015	.012	.042[b]
MU36	specific death rate of roots and rhizomes	.0031	.0043	.004	.0035[b]
MU56	specific death rate of aerobic heterotrophs	.005	.005	.005	.005[d]
	Parameters in control feedback functions (g C · m^{-2})				
EPS65	proportion of material egested by aerobic heterotrophs in the sediment		.25 (unitless)[d]		
ALPHA11	threshold response density of shoots		10[d]		
ALPHA44	threshold response density of insect grazers		1.25[e]		
ALPHA55	threshold response density of aerobic heterotrophs		7.44[a]		
K1	carrying capacity of shoots		200[d]		
K4	carrying capacity of insect grazers		1.25[e]		
K5	carrying capacity of aerobic heterotrophs		9.0[b]		
ALPHA17	refuge level of shoots from horse grazing		7.26[d]		
GAMMA17	satiation level of shoots with regard to horses		40[d]		

[a]Modified from Wiegert and Wetzel (1979) using data from Turner (1985,1987).
[b]From Wiegert and Wetzel (1979).
[c]From Smalley (1959).
[d]From Turner (1985, 1987).
[e]From Wiegert et al. (1975).

Results

Simulations

The nominal model simulates stable annual cycles of the components and shows no net change from year to year (Fig. 3). Seasonal growth cycles are apparent; peak biomass is reached in late summer, while peak standing dead occurs in early winter. Insect grazers increase during the summer, then decline. These simulations agree closely with field data from horse exclosures (Turner 1987), as illustrated by comparing an annual cycle of simulated and observed ungrazed live *Spartina alterniflora* biomass (Fig. 4). A series of sensitivity analyses was also done with the nominal model (see Turner 1985), indicating as expected that *Spartina* productivity was the dominant control in the marsh.

The effects of grazing on *Spartina* standing stocks with constant horse densities are shown in Figure 5a-c. With 0.136 horse/ha, *Spartina* productivity is sustained (Fig. 5a). When the horse den-

sity increases to 0.151 horse/ha, standing stocks decline gradually during the 5-year simulation (Fig 5b); and a density of 0.165 horse/ha causes a drastic reduction in *Spartina* biomass (Fig. 5c). Horse grazing also caused macroorganic matter to be lost from the system during the simulations, but the insect grazer and bacterial populations were not affected. Results of simulating the horse population using the current annual rate of increase, 0.05, and beginning with a density of 0.136 horse/ha are shown in Fig. 5d. This simulation suggests a sharp demarcation between what appear to be tolerable intensities of grazing and deleterious levels. When the aboveground peak biomass of *Spartina* falls below a threshold of about 125 g C·m^{-2} (equivalent to 2,700 kg·ha^{-1} dry weight of *Spartina*), the plants cannot recover unless grazing intensity is reduced. This occurs because primary productivity becomes insufficient to support the herbivory, and *Spartina* standing stocks fall to refuge levels; when grazing pressure is reduced, biomass will again increase.

Actual grazing patterns on the marsh vary spatially, with some areas used intensively and other areas only used sporadically. The grazing simulations correspond closely with field data from plots which had light, moderate, and high intensities of horse grazing (Fig. 6). The model generates reasonable effects of grazing, as can be seen by comparing the curves in Figure 6 with 1-year segments of the grazing simulations shown in Figure 5.

Estimating an Acceptable Horse Population Size

Biomass produced in excess of the threshold of 2,700 kg·ha^{-1} was considered a sustainable loss of *Spartina* to horse grazing. A range for the size of the horse population was then determined. This required several steps:

1. Average daily consumption of forage per horse (Table 5) was estimated at 7.7 kg dry weight per day based on standard horse nutritional requirements (National Research Council 1978) and
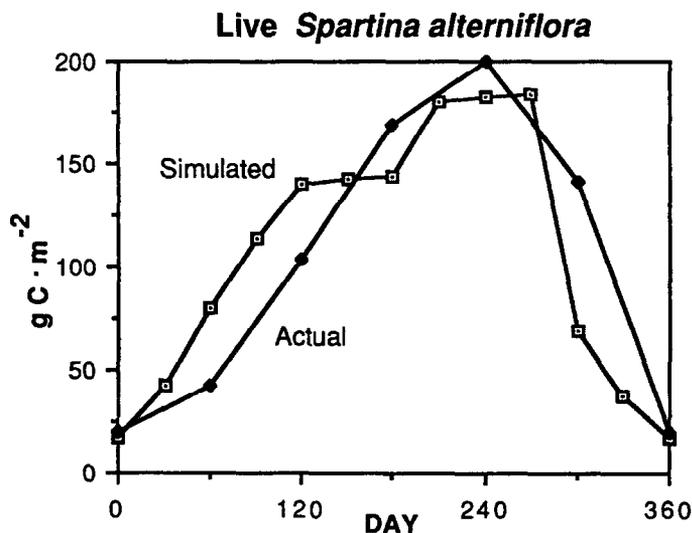

Fig. 4. *Comparison of one-year simulation of live* Spartina *and 1984 field data (from Turner 1985, 1987).*

the population structure of the herd in 1983. This value will vary with herd structure.

2. Average daily consumption of *Spartina* per horse was estimated to be 50% of total forage, based on Lenarz's (1983) observations of horse foraging. A higher (60%) and lower (40%) proportion of *Spartina* in the diet was also examined to bracket the estimates with more and less intense grazing effects. Thus, annual *Spartina* consumption per horse is:

0.60 × 7.7 kg × 365 days = 1,686 kg/year (more intense grazing)

GRAZING SIMULATIONS
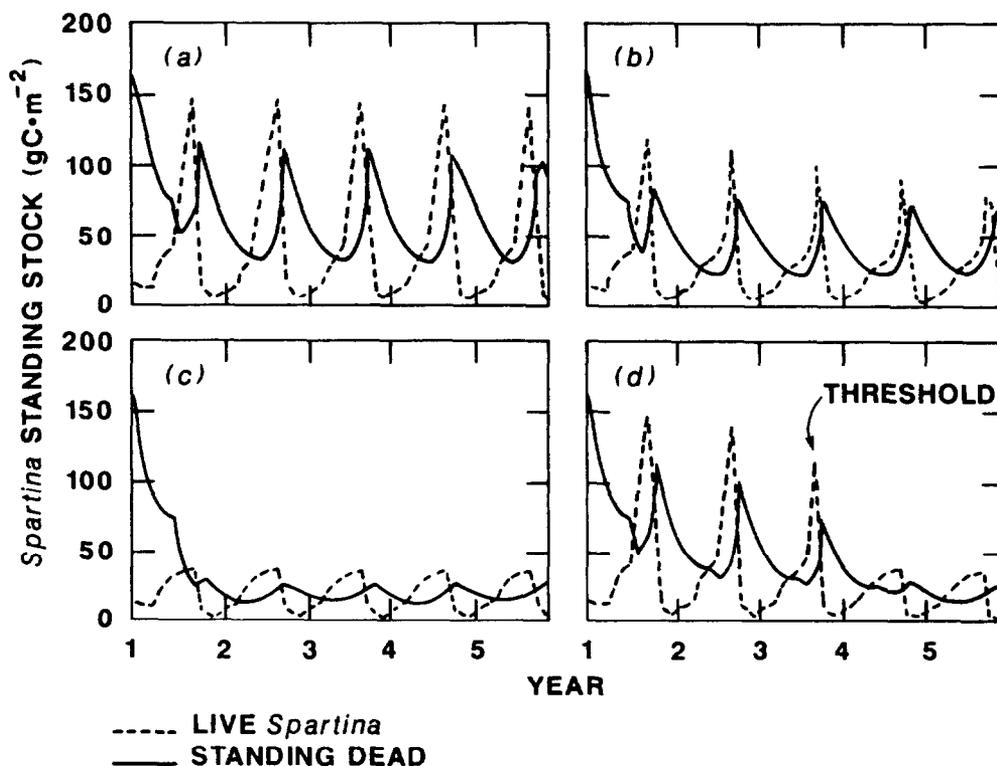

----- LIVE *Spartina*
——— STANDING DEAD

Fig. 5. *Simulated aboveground* Spartina *with different horse grazing intensities: (a) 0.136 horse/ha; (b) 0.151 horse/ha; (c) 0.165 horse/ha; (d) 0.136 horse/ha increasing at 5% per year. Note threshold level in (d) where decline in* Spartina *standing stock is quite sharp.*

Table 5. Daily forage requirements per horse for the 1984 feral horse population on Cumberland Island.

Class	Number of Horses[a]	Digestible energy required per horse[b,c] (Mcal)	Dry forage required per horse[b,d] (kg)	Total dry forage required (kg)
Mature horses	113	16.86	7.7	870.1
Lactating mares	7[e]	25.00	11.4	79.8
Foals	7	9.10	4.1	28.7
Yearlings	27	16.80	7.6	205.2
TOTAL	154	--	--	1183.8
Average	--	--	7.7	--

[a]From Ambrose et al. 1983.
[b]Data source: National Research Council (1978).
[c]Based on 400 kg manure weight, includes maintenance requirement plus 3 Mcal for walking.
[d]Based on values reported for digestible energy content of grazed grasses.
[e]Estimated from the number of foals.

0.50×7.7 kg $\times 365$ days = 1,405 kg/year (average grazing)
0.40×7.7 kg $\times 365$ days = 1,124 kg/year (less intense grazing)

3. From the model and field data, the amount of *Spartina* available to the horses if the integrity of the marsh is to be maintained was estimated at 400 kg/ha. This number was estimated as follows. Field data indicated a range of annual net aboveground primary production from 3,000 to 4,250 kg/ha (Turner 1987). The simulation model indicated a threshold level of 2,700 kg/ha of *Spartina*, below which the system could not be sustained if grazing continued at the same intensity. This suggests that a yearly loss to grazing of 300 to 1,550 kg/ha might be tolerable, depending on location; thus a loss of 800 kg/ha might be acceptable on average. But, because trampling causes a decrease in NAPP equivalent to that of consumption (Turner 1987), only half the 800 kg/ha should actually be consumed as forage.

4. The area of marsh required per horse could then be determined:
1,686 kg/horse/400 kg/ha = 4.2 ha/horse (more intense grazing)
1,405 kg/horse/400 kg/ha = 3.5 ha/horse (average grazing)
1,124 kg/horse/400 = 2.8 ha/horse (less intense grazing)

5. The final step then requires dividing the generally accessible marsh area (205) ha by the area required per horse:
205 ha/4.2 ha/horse = 49 (more intense grazing)
205 ha/3.5 ha/horse = 59 horses (average grazing)
205 ha/2.8 ha/horse = 73 horses (less intense grazing)

Thus, an acceptable range for the size of the horse population may be between 49 and 73 animals, which is 27% to 40% of the current population size.

Discussion

Because of the numerous potential impacts of horse grazing on Cumberland Island, the population estimates derived in this paper are probably conservative. For example, implications of horse grazing for the marsh extend beyond a reduction of *Spartina* biomass. Because accretion of sediment in marshes is a function of the density of grasses present to trap particles (Gleason et al. 1979), heavily grazed marshes may be more susceptible to erosion and storm damage. Thus, intensive grazing could create conditions that favor the loss of marsh habitat. Species distributions on the marsh may also be altered by heavy grazing, permitting *Salicornia* spp., which is unpalatable to horses, to dominate (Reimold et al. 1975). Grazing may reduce populations of fiddler crabs (Reimold et al. 1975) which are known to exert a positive influence on *Spartina* growth (Montague 1980) and are prey for consumers such as raccoons. Intense grazing by horses may also alter the detrital food web, indirectly affect other consumer populations, or change the export/import of organic matter from the marsh.

Effects on other island habitats were not considered in the
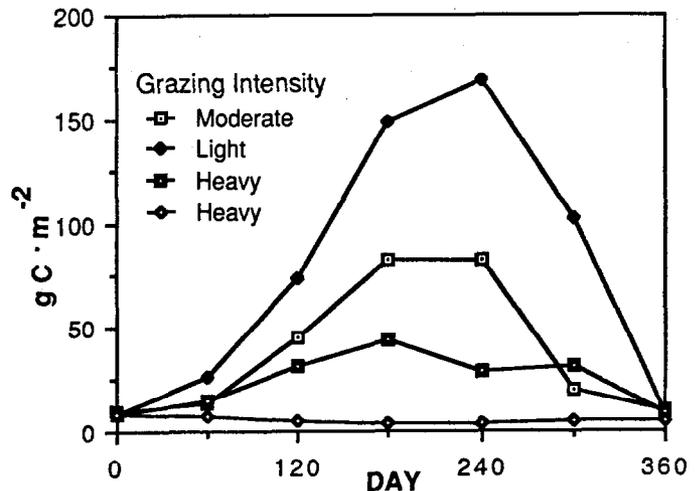

Live *Spartina alterniflora*

Fig. 6. *Aboveground live* Spartina *in 1984 with different intensities of horse grazing (data are from Turner 1985, 1987). These curves can be compared with one-year segments of the simulations shown in Figure 5.*

model. Impacts of the horses on communities such as the interdune meadow and maritime forest should be monitored. For example, the model assumes a constant proportion of *Spartina* in the horses' diet and that switching to a different forage does not occur. As the marsh becomes more severely overgrazed, horses may select an alternative food source, which may increase their impact on other habitats.

The horse population has significance in the history of Cumberland Island, and there is public interest in maintaining the herd. This study suggests that a small horse population can probably be maintained on Cumberland Island without excessive marsh deterioration. The population must be reduced from its present size, however, to permit recovery of the overgrazed marshes. This study indicates an acceptable population of 49 to 73 animals on the island based on current grazing intensities in the marshes. A smaller horse population could also be restricted to a portion of the island and excluded from the remainder, permitting a recovery from grazing. The long-term impacts of horse grazing on the marshes and other habitats should also be monitored regularly.

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