Plant Parameter Specifications for the Area 5 and Area 3 RWMS Models

29 September 2005

Prepared by

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Neptune and Company, Inc.

1. Title: Plant Parameter Specifications for the Area 5 and Area 3 RWMS Models

2. File Name: Plant Parameter Specifications.sxw

3. Describe Use: This documents the statistical development of parameters used to define plants in the Area 5 RWMS model.

	Printed Name	Signature	Date
4. Originator	John Tauxe		4 Feb 2005
5. Reviewer	Michele Wolf		30 Mar 2005

6. Remarks:

This document was rebuilt using the OOoW template, and incorporates the simplified plant model used in the Area 5 RWMS Model v3.0 et seq. The editing log starts at this point, even though Tom Stockton is the original author. The data contained in this report were used as the basis for the Area 5 RWMS Model v3.0.

Several automation features were added, in particular all figures (these use the Illustration style in this document), equations, and tables were given automated cross-references, and references in the Summary section to specific parts in the text (e.g. to the discussion of a distribution derivation) are linked to reference codes in the text in order to simplify QA.

Some references, such as parameter values in the Summary cross-referenced to text passages, are inserted near where the value is mentioned. These are inserted using the command Insert | Cross-reference | tab: References | item: Set Reference. Very handy.

Note that since OOoW does not use font formatting in the tables contents, figures, or tables, a bit of touching up (italics, subscripts, etc.) might be necessary after any of these tables is updated.

r3.02: Changed equation 2 so that b >= 1. - JT

r3.03: Modified formatting of headers and footers. - JT

31 Mar 05 – Final cleanup before v3.1 release. - JT

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FIGURES

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1.0 Area 5 Plant Summary

Listed below are the plant fate and transport model parameter distributions for version 3.1 of the Area 5 Radioactive Waste Management Site Model (Area 5 RWMS Model v3.1) summarized in this document:

- Shrub Primary Production (including creosote, sage, saltbush, and other shrubs):
  \TransportProcesses\PlantTransport\BiomassCalcs\TotalBiomass_Shrubs

  ~ N(294, 34.4, min = 0, max = arbitrarily large) [kg/ha-y] (see Figure 3, page 14)
- Grass Primary Production:
  \TransportProcesses\PlantTransport\BiomassCalcs\TotalBiomass_Grass

  ~ N(6.2, 2.2, min = 0, max = arbitrarily large) [kg/ha-y] (see Figure 6, page 21)
- Creosote Root to Shoot Ratio:
  \TransportProcesses\PlantTransport\CreosoteData\RootShoot_Ratio

  ~ U(0.3, 1.24) (see page 36)
- Saltbush Root to Shoot Ratio:
  \TransportProcesses\PlantTransport\SaltbushData\RootShoot_Ratio

  ~ U(0.44, 0.67) (see page 36)
- Other Shrubs Root to Shoot Ratio:
  \TransportProcesses\PlantTransport\ShrubData\RootShoot_Ratio

  ~ N(0.78, 0.067) (see Figure 8 and page 36)
- Grass Root to Shoot Ratio:
  \TransportProcesses\PlantTransport\GrassData\RootShoot_Ratio

  ~ Tri(1, 1.53, 2) (see page 36)
- Creosote maximum rooting depth:

  \TransportProcesses\PlantTransport\CreosoteData\MaxDepth = 315 [cm] (see page 39)
- Saltbush maximum rooting depth:

  \TransportProcesses\PlantTransport\SaltbushData\MaxDepth = 360 [cm] (see page 39)
- Other maximum rooting depth:

  \TransportProcesses\PlantTransport\ShrubData\MaxDepth = 320 [cm] (see page 39)
- Grasses maximum rooting depth:
  \TransportProcesses\PlantTransport\GrassData\MaxDepth = 158 [cm] (see page 39)
- Creosote *b* parameter for root depth distribution function:
  \TransportProcesses\PlantTransport\CreosoteData\b

~ N(14.6, 0.0807, min = 1) (see Figure 9 and page 50)

- Saltbush *b* parameter for root depth distribution function: \TransportProcesses\PlantTransport\SaltbushData\b

  ~ N(23.9, 0.313, min = 1) (see Figure 10 and page 50)

- Other Shrubs *b* parameter for root depth distribution function: \TransportProcesses\PlantTransport\ShrubData\b

  ~ N(11.3, 0.157, min = 1) (see Figure 11 and page 50)

- Grasses *b* parameter for root mass by depth distribution function: \TransportProcesses\PlantTransport\GrassData\b

  ~ N(2.19, 0.036, min=1) (see Figure 12 and page 54)

2.0 Area 3 Plant Summary

Listed below are the plant fate and transport model parameter distributions for the Area 3 Radioactive Waste Management Site Model summarized in this document:

- Shrub Primary Production (including creosote, sage, saltbush, and other shrubs): \TransportProcesses\PlantTransport\BiomassCalcs\TotalBiomass_Shrubs

  ~ N(249, 30.7, min = 0, max = arbitrarily large) [kg/ha-y] (see Figure 4, page 14)
- Grass Primary Production: \TransportProcesses\PlantTransport\BiomassCalcs\TotalBiomass_Grass

  ~ N(6.2, 2.2, min = 0, max = arbitrarily large) [kg/ha-y] (see Figure 6, page 21)
- Creosote Root to Shoot Ratio: \TransportProcesses\PlantTransport\CreosoteData\RootShoot_Ratio

  ~ U(0.3, 1.24) (see page 36)
- Saltbush Root to Shoot Ratio: \TransportProcesses\PlantTransport\SaltbushData\RootShoot_Ratio

  ~ U(0.44, 0.67) (see page 36)
- Other Shrubs Root to Shoot Ratio: \TransportProcesses\PlantTransport\ShrubData\RootShoot_Ratio

  ~ N(0.78, 0.067) (see Figure 8 and page 36)
- Grass Root to Shoot Ratio: \TransportProcesses\PlantTransport\GrassData\RootShoot_Ratio

  ~ Tri(1, 1.53, 2) (see page 36)
- Creosote maximum rooting depth:

  \TransportProcesses\PlantTransport\CreosoteData\MaxDepth = 315 [cm] (see page 39)
- Saltbush maximum rooting depth:

  \TransportProcesses\PlantTransport\SaltbushData\MaxDepth = 360 [cm] (see page 39)
- Other maximum rooting depth:

  \TransportProcesses\PlantTransport\ShrubData\MaxDepth = 320 [cm] (see page 39)
- Grasses maximum rooting depth: \TransportProcesses\PlantTransport\GrassData\MaxDepth = 158 [cm] (see page 39)
- Creosote *b* parameter for root depth distribution function: \TransportProcesses\PlantTransport\CreosoteData\b

  ~ N(14.6, 0.0807, min = 1) (see Figure 9 and page 50)

- Saltbush *b* parameter for root depth distribution function:
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- Grasses *b* parameter for root mass by depth distribution function:
  \TransportProcesses\PlantTransport\GrassData\b

  ~ N(2.19, 0.036, min=1) (see Figure 12 and page 54)

3.0 Introduction

Probabilistic contaminant fate and transport models are currently under development for the Area 5 and Area 3 RWMSs at the Nevada Test Site in order to evaluate the redistribution of contaminants within the soil, in part by native flora and fauna. The biotic models are part of a larger decision model that is being built to evaluate the risk consequences of contaminant migration from the Area 5 and 3 RWMSs. The intent of the decision model is to provide a decision management system for NNSA/NV that will support future disposal, closure and long term monitoring decisions, as well as supporting all regulatory requirements of Performance Assessments (PAs) and other environmental assessments for these radioactive waste disposal systems.

4.0 Plant Conceptual Model

Plant-induced transport of contaminants is assumed to occur via absorption of contaminants into the roots and subsequent redistribution of those contaminants throughout the tissues of the plant, both above ground and below ground. Upon senescence, the aboveground plant parts are incorporated into surface soils, and the roots are incorporated into soils at their respective depths (Figure 1).

The calculations of contaminant transport due to plant uptake and redistribution take place in a series of conceptual steps:

1. Calculate the fraction of plant roots in each layer for each plant type.
2. Calculate uptake of contaminants into shoots (all aboveground plant tissues) via plant roots in each layer.
3. Sum the contaminant uptake to determine the total uptake by all plants for each contaminant.
4. Assuming that the plant returns all contaminants fixed in the roots to adjacent soils upon senescence, the roots have a net contribution to transport of zero. The aboveground plant parts that are shed upon senescence are mixed in the uppermost layer. Assuming a constant aboveground biomass, this is equal to the net annual primary productivity.
5. Calculate the fraction of contaminants in each layer that is transported to the shoots and thence to the top layer due to steps 1-4. These "fluxes" are implemented as transport links between the GoldSim cells (each layer is a GoldSim cell).

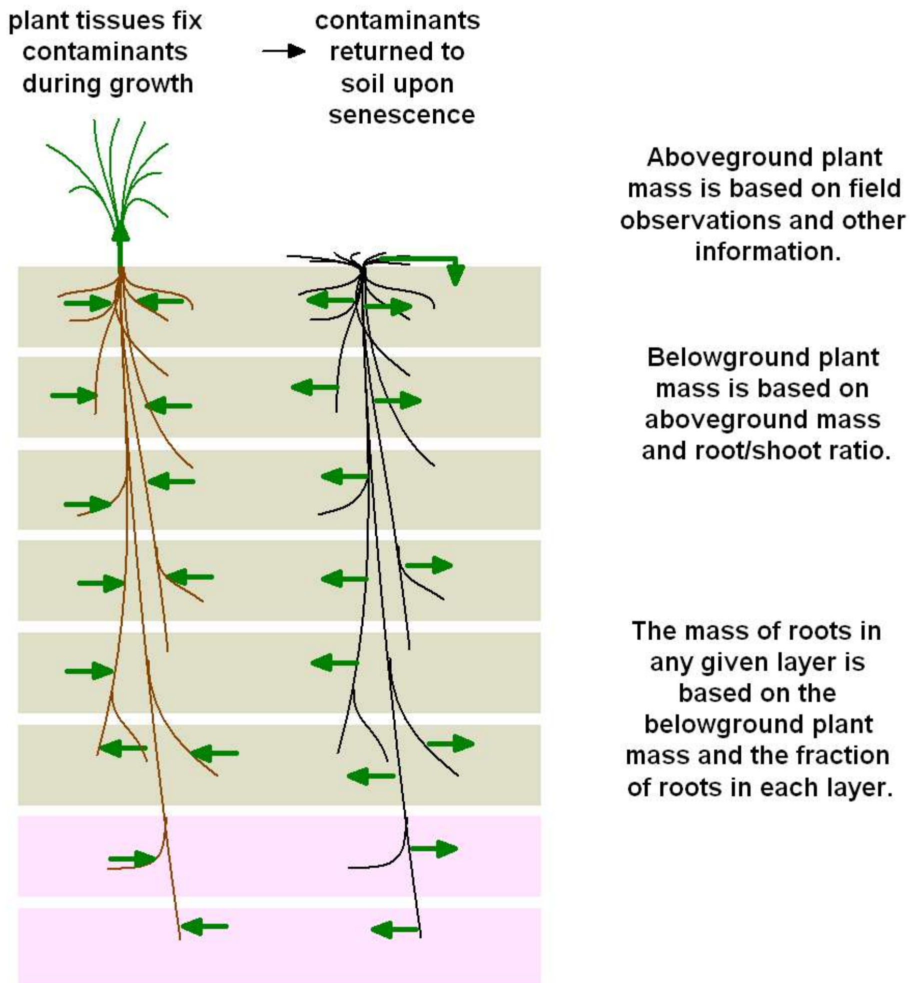

Figure 1. Plant conceptual model.

This chapter presents the plant system (Step 1 above, depicted in Figure 2) of the RWMS Area 5 and Area 3 Models, describing the functional factors that contribute to the parameterization of the models. Such factors include identifying dominant plant species, grouping plant species into categories that are significantly similar in form and function with respect to the modeling effort, calculating net annual primary productivity (NAPP, an inherently rate-dependent measure of biomass generation), determining relative abundance of plants or plant groups, evaluating root/shoot mass ratios, and representing density of plant roots as a function of depth. The purpose of this chapter is to explain the initial algorithm for arriving at final constituent mass distributions by depth, while utilizing information salient to biotically-induced contaminant redistribution processes. The data used for each step of the algorithm are presented, outstanding issues with the data are identified, and the issues that deserve attention for the next model iteration are described.

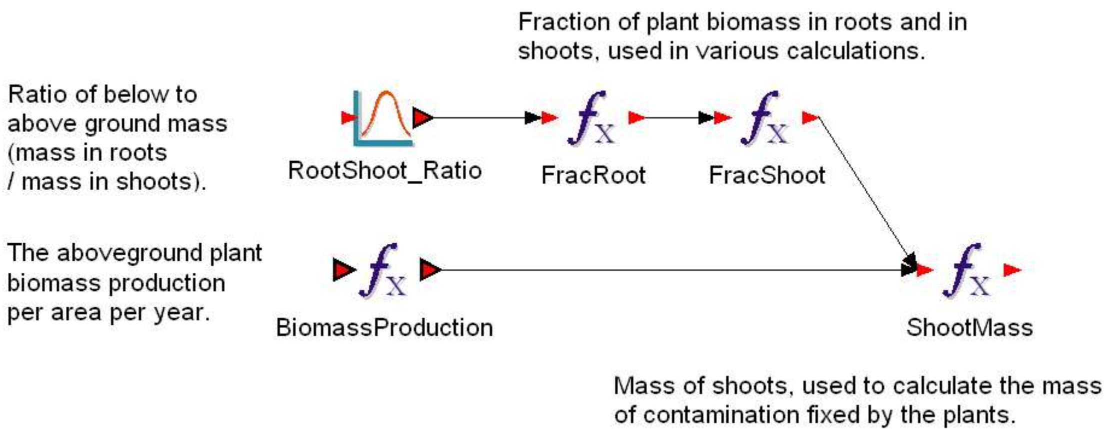

Figure 2. GoldSim representation of a plant community component.

The basic algorithm involves the following considerations:

1. Identify the data sets that contain plant biota relevant to the NTS including those plant types whose root systems may penetrate buried wastes. Such plant types include perennial shrubs and perennial grasses.
2. Divide shrubs into distinct and functionally similar groups. Perennial shrub groups that have been identified include “creosote bush”, “saltbush”, “basin big sage”, and “other”. Perennial shrub species included in the “Other” category are those specifically relevant to Area 5 and Area 3, and are known to be dominant species of the plant community. Perennial grasses are a distinct and unitarily similar functional group. Note basin big sage does not currently exist at the Area 5 or Area 3 RWMS, however it is included in both models as placeholders. This category would be explored in future modeling efforts that involved including a climate change scenario.
3. Develop above ground biomass production distributions from available NAPP data for the shrub functional groups, as well as the perennial grass group.
4. Calculate approximations of NAPP for individual shrub species using community NAPP and relative shrub abundance data.
5. Develop below ground biomass production distributions from appropriate combinations of NAPP and root/shoot ratios for the shrub functional groups, as well as the perennial grass group.

6. Develop parametric distributions of relative root mass by depth using available relative root mass by depth data for the shrub and grass categories.

In the RWMS models, the soil horizon is discretized into horizontal layers based on various functional attributes of soil-based biotic communities at large (plants and animals), as well as the configuration of buried wastes. The models are ultimately used to simulate radionuclide transport throughout the soil layers, in part vis-à-vis calculations of primary productivity for all plants and relative redistribution of contaminants. Utilizing the information provided in steps 1 through 6 above, distributions of above ground and below ground NAPP for grasses and each shrub category are developed. Above ground biomass is assigned to the topsoil cell (a 50-cm layer) in the model. Below ground NAPP is divided respectively by cell-depth interval according to root mass distribution. In order to reflect the redistribution of radionuclides, these calculations required the use of plant uptake factors (concentration ratios) used to model the relative uptake of contaminants from soil by plants. Unfortunately, the uptake factors have been developed for food plants and are not specific to the plant species found on the NTS. This document describes the biotic model up to the point at which contaminant uptake occurs. The distributions of plant uptake factors are described in the succeeding document.

What remains a challenge for these models is an overall paucity of data, marginal applicability of some of the data to each of the models variables, distributions that may lack appropriate rigor (due to data paucity or marginal applicability) to represent the variables of interest, and consequent insufficient mathematical/statistical development of distributions for each step. In particular, there are concerns with ensuring that data sufficiently support the development of distributions of averages for each parameter where large scale spatial and temporal averaging is implied by the conceptual model. We are interested in distributions of average values that could be expected over hundreds of hectares in area and thousands of years of time. Every effort has been made to achieve this goal with the available data. It is important to realize that exactness of distributions in some sense is not necessary. Instead the distributions should be viewed as prior distribution that can be refined, improved, or updated based on new information. That is, these distributions are starting points. If the model sensitivity analysis ultimately shows that one of these parameters is important in the model and that there is value in collecting more information to reduce parameter uncertainty, then new data should be collected. Otherwise the distributions presented herein can be considered adequate for use in the NTS RWMS decision models. The distributions have been subjected to internal peer review, including review by domain experts. Upon external peer review their acceptance should become formal.

5.0 Identification of Data Sets Containing Plant Biota Relevant to the NTS

There are several sets of data that have been obtained from the literature that are relevant to the algorithm and the initial definition of shrub and grass categories, these are presented in Hooten et al. (2004):

1. NAPP for shrubs (Hooten et al. 2004, Tables 6, 7 and 8).

2. NAPP for grasses (Hooten et al. 2004, Table 8).
3. Relative abundance of shrub categories (Ostler et al. 2000, Appendix E).
4. Root/shoot ratios for the shrub categories, obtained from available data on shrub-specific root/shoot ratios (Hooten et al. 2004, Table 10).
5. Root/shoot ratios for the grasses group (Hooten et al. 2004, Table 10).
6. Data for the distribution of root mass by depth for each shrub category (Hooten et al. 2004, Table 5).
7. Data for the distributions of root mass by depth for the grasses group (Hooten et al. 2004, Table 5).

The data are not ideally suited for many of the input parameters required by the model. In particular, there was no statistical design with the current endpoint of estimating distributions in mind. A vast literature review has been performed (Hooten et al. 2004), and the intent of this effort is to find reasonable distributions given the sparse and haphazard data and information sources. This also requires documentation of the choices that were made and the rationale for those choices. In the following sections the available data and the methods for fitting distributions are described. Table 1 provides a list of shrubs and grasses for which data are available across each input variable.

Table 1. Crosswalk between and shrub species and available data.

Genus	Species	Category	Relative Abundance	Root/Shoot Ratio	Relative root mass by depth
Larrea	*tridentata*	Creosote Bush	X	X	X
Atriplex	*canescens*	Saltbush	X	X	X
Atriplex	*confertifolia*	Saltbush	X	X	X
Artemisia	*tridentata*	Basin Big Sage	X		
Acacia	*greggii*	Other		X	
Acamptopappus	*shockleyi*	Other	X	X	
Ambrosia	*dumosa*	Other	X	X	X
Ambrosia	*eriocentra*	Other	X		
Ambrosia	*acanthicarpa*	Other	X		X
Artemisia	*spinescens*	Other	X	X	
Atriplex	*hymenelytra*	Other	X		
Atriplex	*polycarpa*	Other	X		
Brickellia	*incana*	Other		X	
Brickellia	*longifolia*	Other	X		
Brickellia	*microphylla*	Other	X		
Buddleja	*utahensis*	Other	X		
Chrysothamnus	*viscidiflorus*	Other	X		
Coleogyne	*ramosissima*	Other	X		
Encelia	*virginensis*	Other	X		
Ephedra	*funerea*	Other	X		
Ephedra	*torreyana*	Other	X		
Ephedra	*viridis*	Other	X		
Ephedra	*nevadensis*	Other	X	X	X
Ericameria	*cooperi*	Other	X		
Ericameria	*teretifolia*	Other	X		
Ericameria	*paniculata*	Other	X		
Ericameria	*nauseosa*	Other	X	X	X
Eriogonum	*fasciculatum*	Other	X	X	
Eriogonum	*microthecum*	Other	X		
Eriogonum	*heermannii*	Other	X		
Gutierrezia	*sarothrae*	Other	X		
Grayia	*spinosa*	Other	X	X	
Hymenoclea	*salsola*	Other	X	X	
Kochia	*americana*	Other	X		
Krameria	*erecta*	Other	X	X	X
Krameria	*grayi*	Other		X	
Krascheninnikovia	*lanata*	Other	X	X	
Lepidium	*fremontii*	Other	X		
Leptodactylon	*pungens*	Other	X		
Lycium	*andersonii*	Other	X	X	X
Lycium	*shockleyi*	Other	X		
Lycium	*pallidum*	Other	X		
Menodora	*spinescens*	Other	X		
Prunus	*fasciculata*	Other	X		
Psorothamnus	*fremontii*	Other	X		
Psorothamnus	*polydenius*	Other	X		
Purshia	*glandulosa*	Other	X		
Purshia	*stansburiana*	Other	X		

6.0 Definition of Shrub and Grass Categories

There are five plant categories defined and maintained within the plant component of the Area 5 and Area 3 models, four shrub categories and a single grass category. For shrubs, the four categories identified for the Area 5 and Area 3 models are creosote bush, saltbush, basin big sage, and other. These categories are based on the expert opinion (Hooten, 2004) that these categories would represent a full spectrum of potential differences in below ground rooting distributions and root morphologies. Additionally, creosote bush *(Larrea tridentata)* and saltbush *(Atriplex spp.)* form conspicuously dominant vegetational mosaics in the landscape on Area 5 and Area 3 of the NTS. Although other shrubs also may be conspicuous or dominant in a given area, a qualitative comparison of their rooting distributions suggests sufficient similarities such that a catchall category of “other shrubs” was formed. Currently, all four categories of shrub are included in the Area 5 and Area 3 models, however basin big sage is included solely as a placeholder for future modeling efforts. This category is maintained in the model since it could potentially play a role in the plant community given certain climatic changes occur. Therefore, the number of shrub categories is effectively reduced to 3 in each model.

Perennial grasses comprise one of the categories within the plant transport compartment of the Area 5 and Area 3 RWMS models. Currently, there is limited data available for perennial grasses on either of the Area 5 or 3 RWMSs. However, data are readily available from studies conducted on the vegetation and ecology of Yucca Mountain (Hessing et al., 1996). The data for perennial grasses from Hessing et al. (1996) spans six years and involved characterizing four plant associations. While all four associations may not directly extend to the associations on Frenchmen Flat, these data are the most relevant and therefore will be used for the modeling effort.

7.0 Development of Aboveground Biomass Production (Net Annual Primary Production) Distributions for Perennial Shrubs and Grasses

7.1 Step 3A: Perennial Shrub Net Annual Primary Productivity (NAPP)

The first step in the algorithm is to form a distribution for shrub NAPP. Data used for this effort are from Wallace and Romney (1972), Rundel and Gibson (1996), and Hessing et al. (1996). These data are assembled in Hooten et al. (2004) as Tables 6, 7 and 8 and are reproduced in this document as Tables 2, 3, and 4, respectively, so that the data are readily available to examine and use. Hooten et al. also report data derived from measurements on a Grand Junction, Colorado site (Table 9 in Hooten et al. 2004), but these data have been dismissed for this modeling effort due to lack of relevance to the ecology of the NTS.

Data in Tables 2 and 3 were collected from Rock Valley over a three year period from 1966 to 1968. Data from Table 4 is from Yucca Mountain and was collected from 1971 to 1976. Rock Valley is just south of Frenchman Flat, near Mercury Nevada, and Yucca Mountain is to the south-west of Frenchman Flat just outside the NTS boundary. This is somewhat disadvantageous, as the data are not a direct reflection of what one might measure for the plant associations of Frenchman Flat or Yucca Flat. Nevertheless, one might expect that NAPP will likely be similar for plant communities in Rock Valley and Frenchman Flat, and this is the assumption that has been made. Therefore these data will be used to model NAPP for shrubs and grasses for both the Area 5 and Area 3 models.

Table 2. NAPP of leaves and fruits (kg/ha-y) for eleven species of perennial shrubs in four plots from Rock Valley from years 1966, 1967, and 1968 (Wallace and Romney 1972, p. 238).

	Year				
Plot	**1966**	**1967**	**1968**	**Mean (year)**	**s.d.* (year)**
A	532.5	311.7	445.3	430	11
B	432.2	282.8	393.3	369	78
C	632.5	379.8	547.7	520	129
D	354.3	247.6	334.1	312	57
Mean (plots)	488	305	430	**Mean (Grand)**	**s.d.* (Grand)**
s.d.* (plots)	121	56	91	**408**	**118**

* Sample Standard Deviation

Table 3. NAPP (kg/ha-y) for nine species of Rock Valley perennial shrubs (plus a tenth category of "other perennial species") from 1971 through 1976 (Rundel and Gibson 1996, p. 101).

Year					
1971	1972	1973	1974	1975	1976
183	206	682	220	210	380
mean = 314, standard deviation = 194					

Table 4. NAPP (kg/ha-y) for perennial shrubs and grasses of four plant associations for Yucca Mountain.

Association		Year						Mean across years	s.d.* across years
		1989	1990	1991	1992	1993	1994		
Coleogyne	Shrubs	0.2	20.6	108	213.6	NR	NR	85.60	97.30
	Grasses Forbs	0	0	1	4.2	NR	NR	1.30	1.99
Larrea-Ambrosia	Shrubs	0.9	9	168.9	325.8	NR	NR	126.15	153.95
	Grasses Forbs	0	0.1	0.3	2.1	NR	NR	0.63	0.99
Lycium-Grayia	Shrubs	0.1	36.2	189.8	232.4	NR	NR	114.63	113.71
	Grasses Forbs	0	7.2	25.6	28.6	NR	NR	15.35	13.94
Larrea-Lycium-Grayia	Shrubs	1.7	14.7	114.1	235.5	289.4	NR	131.08	128.98
	Grasses Forbs	0	0	2	15.8	22.4	1.7	6.98	9.65
Mean within years	Shrubs	0.73	20.13	145.20	251.83	289.40	NA		
	Grasses Forbs	0.00	1.83	7.23	12.68	22.40	1.70		
s.d.* within years	Shrubs	0.74	11.72	40.42	50.26	NA	NA		
	Grasses Forbs	0.00	3.58	12.27	12.21	NA	NA		

NA = Not Applicable; NR = Not Recorded

7.1.1 Area 5 Shrub Net Annual Primary Production

All of the data from Tables 2 and 3 were used to support development of the Area 5 NAPP shrub distribution. However, from Table 4, only data from the *Larrea-Ambrosia* and the *Larrea-Lycium-Grayia* associations were used because the other two plant associations do not occur on or near the Area 5 RWMS. Consequently, 27 data points were used as the basis for developing a NAPP distribution for shrubs (12 data points from Table 2, 6 from Table 3, and nine from the two relevant plant associations in Table 4). These data are used to form a prior distribution on the mean NAPP in the area and time frame of interest. A simple approach to estimating such a prior distribution is to use standard classical statistical techniques. In lieu of assuming some underlying distributional form, bootstrap sampling was used to determine the distribution of the sample mean. A single bootstrap sample consists of obtaining a single random sample of the same size as the original data set and calculating the mean for that sample. The data is sampled many times, with the data values replaced after each draw, and a histogram of the means evaluated. Based on a comparison of the cumulative distribution of the bootstrapped means and the cumulative distribution of a random normal distribution (Figure 3), the distribution of mean shrub NAPP was determined to be normal with a mean of 294 kg/ha-yr and a standard deviation of 34.4 kg/ha-yr. Note that it is common for distributions of means to appear roughly normal, as prescribed by the Central Limit Theorem. This is the distribution that is used in version 3.1 of the Area 5 model.

7.1.2 Area 3 Shrub Net Annual Primary Production

For the Area 3 model, again all of the data from Tables 2 and 3 were used to support development of the NAPP distribution for shrubs. From Table 4, all data from the 4 associations were used since all of these associations occur within the vicinity of the Area 3 RWMS. Therefore, the data set for the development of the Area 3 NAPP distribution consists of 35 data points (12 data points from Table 2, 6 from Table 3, and 17 from Table 4). Bootstrap sampling was used again to determine the distribution of the sample mean. Both the cumulative distribution of the bootstrapped means and the cumulative distribution of a random normal distribution are presented in Figure 4. The normal distribution with a mean of 249 kg/ha-yr and a standard deviation of 30.7 kg/ha-yr appears to be an adequate fit to the bootstrapped data, therefore it is used to model Area 3 NAPP.

Note the data points used for modeling both Area 5 and Area 3 NAPP are treated statistically as though they are independent and random realizations from some underlying distribution. This is a simplification that has been assumed in order to be able to form a distribution of NAPP that can be used in the modeling effort. In essence this distribution can be thought of as a prior distribution that provides information about what is thought to be known (the mean) and what is not known (the uncertainty in the mean). The reasonableness of the distribution is a dependent on the data from which it was developed and the judgment of domain experts on its final form. If this proves to be a sensitive parameter in the overall Area 5 or Area 3 models, then further information should be collected to refine this component of the model. Otherwise, this distribution might prove adequate.

Another note that is important to mention is that the parameter of interest is the mean NAPP, where mean refers to the spatial and temporal scale of the Area 5 and 3 models. For example, some of the data points suggest that NAPP could be near zero kg/ha-yr in any given year, and within the spatial domain in which the data were collected. But, it does not make sense to use a value of 0 kg/ha-yr in the Area 5 and 3 models where this value is applied to a potentially much larger area and to a time frame of 1,000 years. That is, it is unreasonable to believe that NAPP could be close to zero every year for the next 1,000 years (if it is, then there are many more important problems than disposal of radioactive waste). Running the model involves sampling from a distribution and using the realized value throughout a simulation across the whole spatial and temporal frame of the model. This is why it is important that the average NAPP is represented in the model (and, in general, the average of any parameters that are the basis for a large spatial or temporal scale), since this is what is expected to affect the environmental system across the large spatio-temporal scale of interest. The variance in the mean estimate reflects the uncertainty in the mean estimate, either because of limited sampling data or because of insufficient expert opinion.

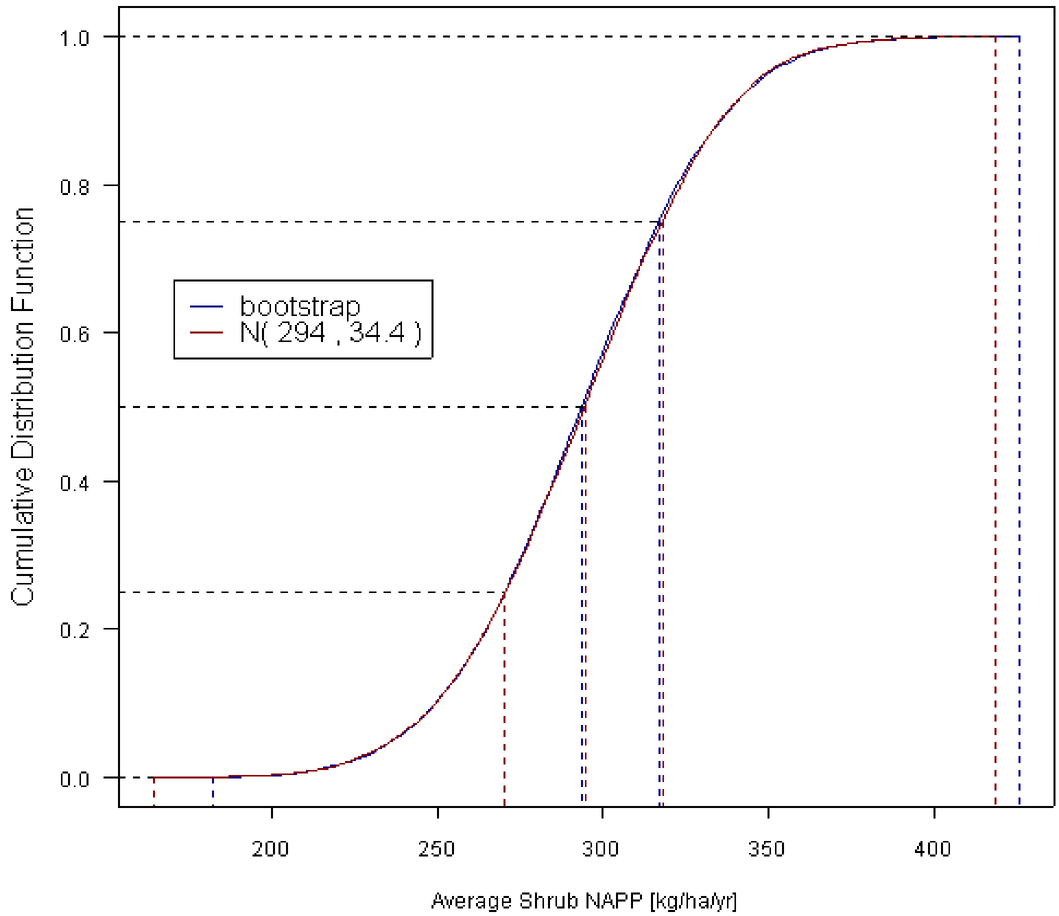

Figure 3. Cumulative distribution functions for bootstrapped and normal perennial shrub NAPP data. This distribution is used to model the Area 5 NAPP.

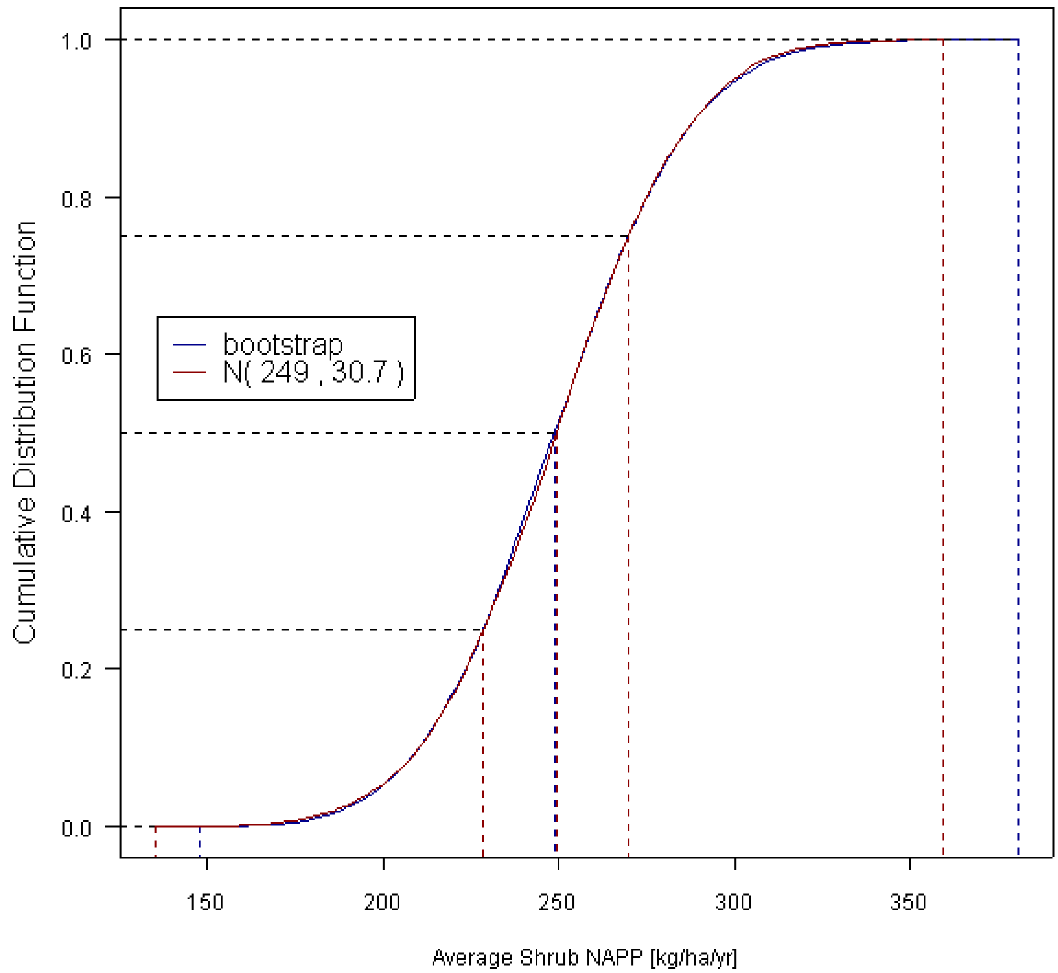

Figure 4. Cumulative distribution functions for bootstrapped and normal perennial shrub NAPP data. This distribution is used to model the Area 3 NAPP.

7.1.3 Alternative Approach to Modeling NAPP

An alternative approach to bolstering the data set also was explored. This approach involves using a regression equation first proposed by Rundel and Gibson (1996). The equation uses precipitation data (PPT) as the predictor variable to obtain NAAP (net annual above ground production) as the response. Specifically, to obtain the relationship between precipitation and NAPP, Rundel and Gibson used the data in Tables 2 and 3 and available data on precipitation records for Rock Valley to derive the following mathematical relationship (Rundel and Gibson 1996, p. 102):

$$NAAP = 0.31(PPT) - 8.35 \tag{1}$$

where

$NAAP$ = net annual aboveground primary production in g/m^2-yr and
PPT = hydrologic year (September to August) precipitation reported in mm.

Rundel and Gibson found a strong correlation ($r = 0.95$) between NAAP and PPT. Note that the acronym Rundel and Gibson used, NAAP, refers to net annual aboveground primary production, which measures the same quantity for which the acronym NAPP is used in this document. In some documents NAPP is used to represent both aboveground and below ground primary productivity.

The relationship in Equation 1 was used to obtain estimated shrub NAPP to enhance the existing data set. Table 5 shows precipitation values obtained from NOAA (NOAA, 2004) for Frenchman Flat and results of the calculations used to obtain estimated NAPP for the 41 years of available precipitation data. Precipitation was converted from inches to millimeters and then used in Equation 1 to obtain NAPP in g/m^2. These values were then converted to kg/ha.

Bootstrap sampling was then used on the predicted data to estimate the distribution of the sample mean. Based on the histogram of the means and a comparison of the cumulative distribution of the bootstrapped means and the cumulative distribution of a random normal distribution (Figure 5), the distribution of mean shrub NAPP was estimated to be normal with a mean of 299 kg/ha-yr and a standard deviation of 26.2 kg/ha-yr. The results, perhaps, should be expected considering the origin of the data. That is, the regression developed by Rundel and Gibson depends on the same data presented in Tables 2 and 3, the regression model has a good fit, therefore similar results can be expected. The standard error of the mean (the standard deviation) should be expected to be smaller because the sample size is larger. However, this analysis provides some validation of the distribution selected above, and provides some indication that precipitation data could be used more extensively to support biotic arguments.

Table 5. Precipitation data and Predicted NAPP for years 1962 through 2002

Year	PPT (mm)	NAPP (g/m^2-yr)	NAPP (kg/ha-yr)
1962	61.72	10.78	107.84
1963	126.24	30.78	307.84
1964	100.08	22.67	226.74
1965	128.52	31.49	314.92
1966	94.49	20.94	209.41
1967	101.09	22.99	229.89
1968	175.77	46.14	461.38
1969	76.2	15.27	152.72
1970	72.64	14.17	141.7
1971	68.58	12.91	129.1
1972	189.99	50.55	505.48
1973	119.38	28.66	286.58
1974	98.04	22.04	220.44
1975	88.14	18.97	189.73
1976	142.49	35.82	358.23
1977	198.12	53.07	530.67
1978	148.84	37.79	377.92
1979	143.26	36.06	360.59
1980	57.91	9.6	96.03
1981	173.74	45.51	455.08
1982	215.14	58.34	583.43
1983	200.15	53.7	536.97
1984	147.57	37.4	373.98
1985	145.29	36.69	366.89
1986	162.05	41.89	418.86
1987	158.5	40.78	407.84
1988	35.81	2.75	27.52
1989	61.21	10.63	106.26
1990	81.53	16.93	169.26
1991	127	31.02	310.2
1992	187.71	49.84	498.39
1993	84.07	17.71	177.13
1994	204.98	55.19	551.93
1995	28.96	0.63	6.26
1996	81.03	16.77	167.68
1997	276.35	77.32	773.19
1998	100.84	22.91	229.1

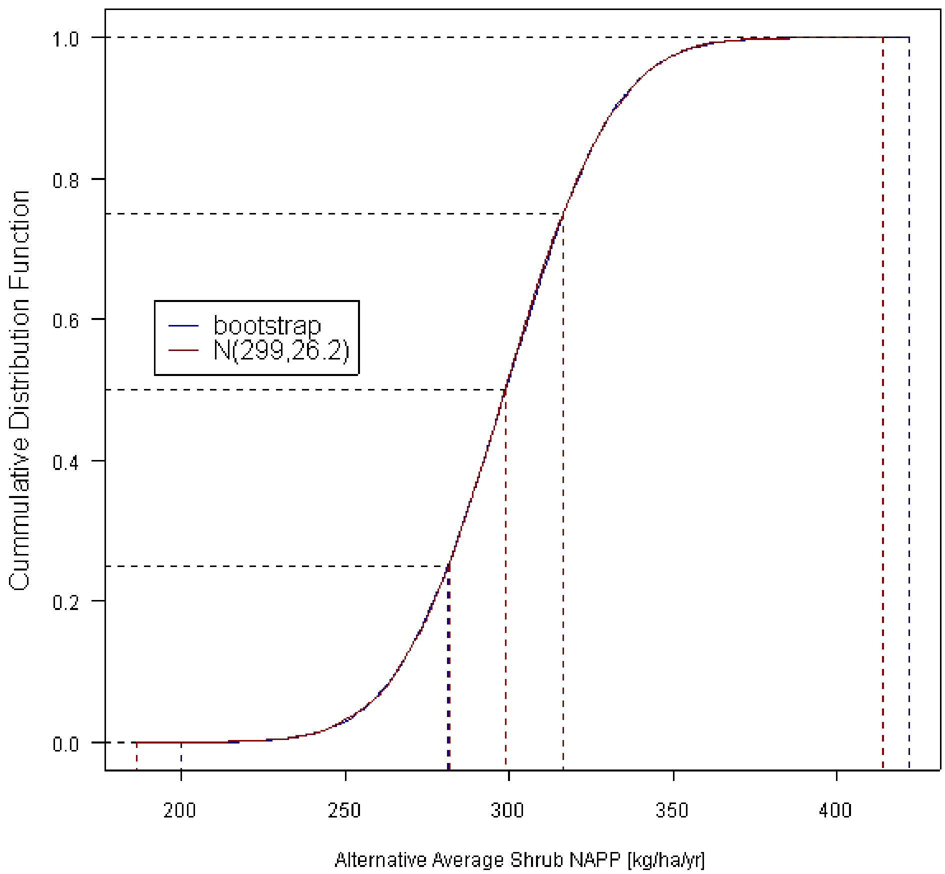

Figure 5. Cumulative distribution functions for bootstrapped and normal perennial shrub NAPP data using the regression equation proposed by Rundel and Gibson (1996) and precipitation data..

7.1.4 Outstanding Issues in Shrub NAPP

There are several outstanding issues regarding aboveground NAPP for perennial shrubs, those include:

1. The data currently being used in the model do not have a direct connection to NAPP on a per-species basis. Thus, models that use such measures must be generalized and consequently do not directly address the relative contributions of dominant species in various plant communities for mass transport due to plant growth activities. Individual plant species considered dominant across the NTS are target species for understanding NAPP on a species-specific and relative dominance basis.

2. As more data are gathered and the relevance of the data improves, a re-evaluation of the fit of the various distributions to the data might be warranted.
3. Categorization of the shrubs is used as a convenience to simplify the model. The current formulation is coarse, but would a finer formulation provide enough difference in the outcome of the model to justify the greater effort and sensitivity to inputs?
4. Different plant (shrub) associations will enter and exit the vicinity of the Area 5 RWMS over the course of the next 1,000 years. This has recently been documented on a much more compressed time scale (<40 years, Webb et al. 2001, and *personal discussion* June 2002). The model is currently not designed to allow for periodic changes in plant regimes. Incorporating changing plant communities in the model would require developing the model described herein for each plant regime.
5. The distributions presented are potentially more relevant to Area 5 than they are to Area 3. When the transition is made from the Area 5 model to the Area 3 model, some consideration should be given to different plant groups.

7.2 Step 3 B: Perennial Grass Net Annual Primary Productivity (NAPP)

The first step in the algorithm is to form a distribution for grass NAPP. Data used for this effort are from Hessing et al. (1996) and can be found reproduced in this document as Table 4. Since grass NAPP data are limited, data from all plant associations and all years are used in the modeling process. Moreover, this data is used to model grass NAPP for both the Area 5 and Area 3 GoldSim models.

7.2.1 Area 5 and Area 3 Perennial Grass Net Annual Primary Production

Data from Table 4 were bootstrapped and the cumulative distributions of the bootstrapped data and normal data simulated using the mean and standard deviation from the bootstrapped data compared (Figure 6). The normal distribution appears to be an adequate fit to the bootstrapped data. Therefore the normal distribution with a mean of 6.2 kg/ha-yr and a standard deviation of 2.2 kg/ha-yr is used to parameterize average grass NAPP in both Area 5 and Area 3. Both distributions are truncated at zero to prevent negative NAPP from occurring. In GoldSim, if one tail of the distribution is truncated, the other tail also must be truncated. Thus, both distributions are truncated at 1.0e+20 so as not to affect simulations.

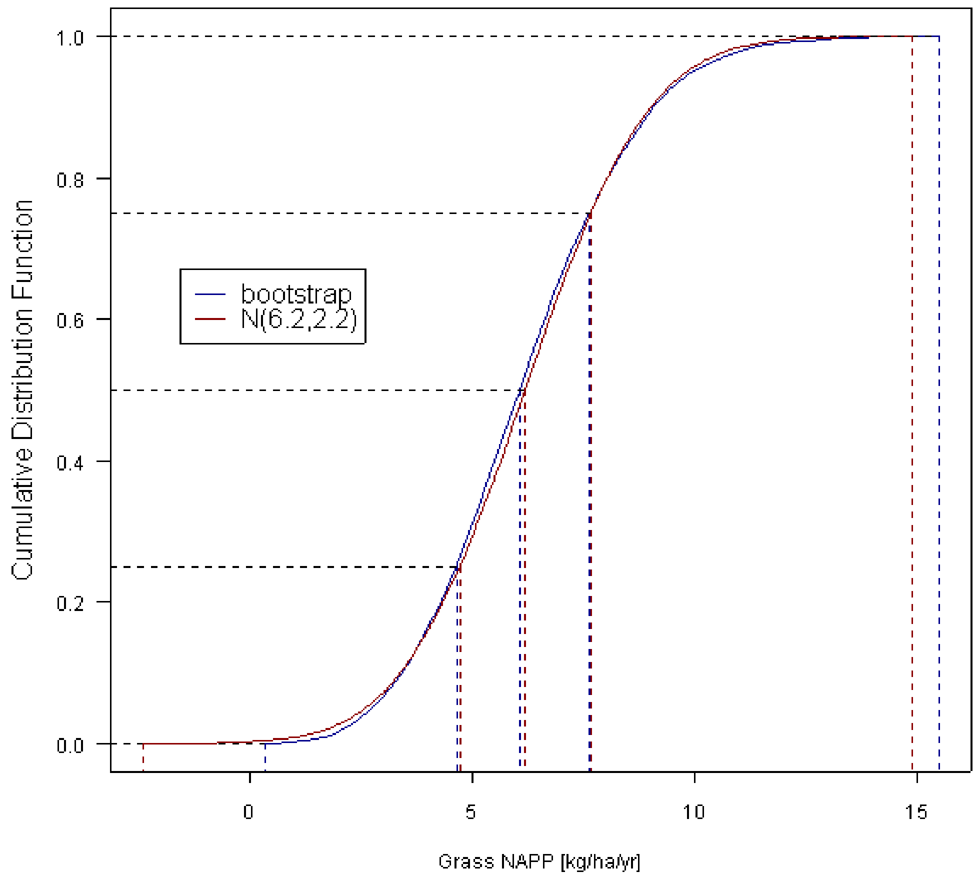

Figure 6. Cumulative distribution functions for bootstrapped and normal perennial grass NAPP data. This distribution is used to model both Area 5 and Area 3 average perennial grass NAPP distributions.

7.2.2 Outstanding Issues for Grass NAPP

Many of the issues relating to NAPP for perennial grasses are similar to those presented for perennials shrubs. For completeness, those issues will be reiterated here along with other outstanding issues regarding aboveground NAPP for perennial grasses.

1. Available data for aboveground biomass production of grasses are inadequate for discerning the measure with a high degree of confidence. This is because the data are derived from a Yucca Mountain study and because the data appear to be associated with years with relatively small precipitation. Collection of site-specific data could prove important if this parameter proves to be sensitive.

2. Should we be concerned about perennial grasses since their overall contribution to mass transport is minimal in comparison with perennial shrubs? We will rely on the sensitivity analysis to provide relevant information on this decision. If we are concerned about grasses, then we need more complete information, including NAPP for dominant species, and more complete root depth and abundance information. This information needs to be gathered over a large time scale for multiple locations on the NTS. As mentioned earlier, NAPP in grasses is poor to fair for most years, while certain years are remarkable. Remarkable years may be highly punctuated in occurrence and somewhat rare (e.g., 10- or 100-year events). So, NAPP for these grasses can have a long-term "average" poor to fair condition but are punctuated with another process (something akin to a Poisson process) where conditions allow for extraordinary NAPP. This likely will have a measurable influence on the calculation of NAPP from grasses, as "extraordinary" years may yield measures of NAPP as much as 20-100 times that of poor years.
3. Data for precipitation and temperature are available for the NTS, correlating this information to NAPP production may be beneficial to the model and could be used to extend the temporal range of the available data. However, plants respond differently depending on the time of the year, so some care will need to be taken to address these effects.
4. The distributions presented are potentially more relevant to Area 5 than they are to Area 3. When the transition is made from the Area 5 model to the Area 3 model, some consideration should be given to the different grasses.

8.0 Calculate NAPP Approximations for Each Shrub Category

Net annual primary production for the each shrub category cannot be calculated directly from available data. Rather, relative shrub abundance data and community NAPP (as calculated in Section 5.3) can be used to calculate approximations of NAPP for individual shrub species. These approximations can then be used to allocate community shrub NAPP to each shrub category within the Area 5 and Area 3 GoldSim models. Admittedly these approximations lack important details such as the size of individual shrubs, leaf density, size and function of stems, and size and density of reproductive structures, all features that strongly influence the contribution of a particular species to community NAPP; however, given the data limitations for partitioning community shrub NAPP among our 3 shrub species, these approximations are considered sufficient for our current modeling efforts.

In this document we are interested in the three shrub categories defied above for Area 5 and Area 3: creosote bush (*Larrea tridentata*), saltbush (*Atriplex canescens* and *Atriplex confertifolia*), and other (all other dominant shrub species found in Table 1). Thus, relative abundance information is needed for these groups from data for individual species.

Relative abundance data pertinent to our initial modeling effort are provided for four plant associations that are identified in Ostler et al. (2000) as comprising the vast majority of the plant communities on Frenchman Flat. Ostler et al. (2000) provide initial estimates of relative abundance by evaluating the frequency of species occurrence in plant alliances and associations measured on Frenchman Flat including the vicinity of the Area 5 and Area 3 RWMS. Moreover, additional data have been collected (associated with ongoing field data collection efforts conducted by Neptune and Bechtel Nevada) from June 2001 through June 2002, from 3 quadrats (1, 2 and 6) on the NTS. Both data sets directly pertain to the plant associations of interest on the NTS.

These data are presented in Tables 6 through 15. Specifically, Tables 6 through 9 provide relative abundance information on the four plant alliances described by Ostler et al. (2000, Table 4-1) for the Mojave Desert. Each table presents one of the alliances, the species contained within that alliance, and the relative abundance of each species within the alliance. Modeling categories creosote bush, saltbush and other correspond to Table 6, Table 7, and Tables 8 through 9, respectively. Table 10 presents data from the 3 quadrats studied in conjunction with Bechtel Nevada, while Table 11 presents data from Rundel and Gibson (1996, Table 4.10) listing NAPP for primary stems, leaves, and fruits for select shrubs on the NTS. Finally, Table 12 summarizes all of the information presented in Table 11 for select shrubs on the NTS.

Abundance data are also presented in Tables 6 through 12 and were used to derive possible minimum and maximum values of relative abundance for each shrub category. First, the total relative abundance for each shrub category was calculated (Table 13) for each of the 7 sets of source data. These data from Table 13 were condensed into the 3 shrub categories of interest (Table 14). Finally, the range of possible values for each shrub category was derived (Table 15) directly from the total shrub category relative abundance values.

There is no area-specific abundance data for either Area 5 or Area 3 of the RWMS. The data presented in Tables 6 through 13 are the most current data available for applying net annual primary production to each shrub category. Therefore these data are used to determine the fraction of NAPP that is allocated to each shrub category on both the Area 5 and Area 3 RWMSs.

Table 6. *Larrea tridentata – Ambrosia dumosa* shrubland alliance (category: "creosote bush")

Genus	species	Percent abundance	Our plant category	Dominant on NTS?
Larrea	tridentata	12.7	creosote bush	yes
Ambrosia	*dumosa*	43.1	other	yes
Lycium	*pallidum*	7.0	other	yes
Krameria	*erecta*	6.7	other	yes
Acamptopappus	*shockleyi*	3.9	other	
Krascheninnikovia	*lanata*	3.3	other	yes
Lycium	*andersonii*	3.1	other	yes
Atriplex	*confertifolia*	2.5	saltbush	yes
Grayia	*spinosa*	2.1	other	yes
Hymenoclea	*salsola*	1.7	other	yes
Psorothamnus	*fremontii*	1.4	other	
Menodora	*spinescens*	1.3	other	yes
Coleogyne	*ramosissima*	0.8	other	yes
Ericameria	*cooperi*	0.6	other	yes
Lycium	*shockleyi*	0.5	other	yes
Eriogonum	*fasciculatum*	0.4	other	yes
Atriplex	*canescens*	0.4	saltbush	yes
Thamnosa	*montana*	0.4	other	
Encelia	*virginensis*	0.3	other	
Salazaria	*mexicana*	0.3	other	
Lepidium	*fremontii*	0.2	other	
Ephedra	*funerea*	0.2	other	
Gutierrezia	*sarothrae*	0.2	other	
Psorothamnus	*polydenius*	0.1	other	
Atriplex	*polycarpa*	0.1	other	
Chrysothamnus	*viscidiflorus*	0.1	other	yes
Artemisia	*spinescens*	0.1	other	
Ericameria	*teretifolia*	<0.1	other	
Tetradymia	*axillaris*	<0.1	other	
Ambrosia	*eriocentra*	<0.1	other	
Ephedra	*torreyana*	<0.1	other	
Ephedra	*viridis*	<0.1	other	yes
Ericameria	*paniculata*	<0.1	other	
Tetradymia	*canescens*	<0.1	other	
Stanleya	*pinnata*	<0.1	other	
Brickellia	*microphylla*	<0.1	other	
Atriplex	*hymenelytra*	<0.1	other	
Tetradymia	*glabrata*	<0.1	other	
Ericameria	*nauseosa*	<0.1	other	yes
Leptodactylon	*pungens*	<0.1	other	yes

Table 7. *Atriplex confertifolia – Ambrosia dumosa* shrubland alliance (category: "saltbush")

Genus	species	Percent abundance	Our plant category	Dominant on NTS?
Larrea	*tridentata*	4.3	creosote bush	yes
Acamptopappus	*shockleyi*	0.9	other	
Artemisia	*spinescens*	0.3	other	
Brickellia	*longifolia*	0.4	other	
Brickellia	*microphylla*	0.4	other	
Buddleja	*utahensis*	0.1	other	
Chrysothamnus	*viscidiflorus*	0.6	other	yes
Chrysothamnus	*viscidiflorus*	<0.1	other	yes
Coleogyne	*ramosissima*	3.4	other	yes
Encelia	*virginensis*	0.7	other	
Ephedra	*nevadensis*	10.1	other	yes
Ephedra	*torreyana*	0.9	other	
Ephedra	*funerea*	0.1	other	
Ephedra	*viridis*	<0.1	other	yes
Ericameria	*teretifolia*	0.9	other	
Ericameria	*cooperi*	0.2	other	
Ericameria	*nauseosus*	<0.1	other	yes
Eriogonum	*fasciculatum*	1	other	yes
Eriogonum	*microthecum*	0.2	other	
Eriogonum	*heermannii*	0.1	other	
Gutierrezia	*sarothrae*	1.9	other	
Hymenoclea	*salsola*	0.8	other	yes
Krameria	*erecta*	4.3	other	yes
Krascheninnikovia	*lanata*	2.3	other	yes
Lepidium	*fremontii*	1.8	other	
Leptodactylon	*pungens*	<0.1	other	yes
Lycium	*pallidum*	3.9	other	yes
Lycium	*andersonii*	3.5	other	yes
Lycium	*shockleyi*	<0.1	other	yes
Menodora	*spinescens*	1.5	other	yes
Prunus	*fasciculata*	<0.1	other	
Psorothamnus	*fremontii*	1	other	
Psorothamnus	*polydenius*	0.2	other	
Salazaria	*mexicana*	0.9	other	
Senecio	*flaccidus*	0.1	other	
Stanleya	*pinnata*	<0.1	other	
Tetradymia	*axillaris*	0.2	other	
Tetradymia	*canescens*	0.1	other	
Thamnosa	*montana*	1	other	
Atriplex	*hymenelytra*	0.4	other	
Artemisia	*tridentata*	<0.1	basin big sage	yes
Atriplex	*confertifolia*	29.6	saltbush	yes
Atriplex	*canescens*	<0.1	saltbush	yes

Table 8. *Atriplex canescens – Krascheninnikovia lanata* shrubland (category: "other")

Genus	species	Percent abundance	Our plant category	Dominant on NTS?
Acamptopappus	*shockleyi*	0.8	other	
Ambrosia	*dumosa*	0.4	other	yes
Artemisia	*spinescens*	0.8	other	
Artemisia	*tridentata*	0.3	other	yes
Chrysothamnus	*viscidiflorus*	0.9	other	yes
Coleogyne	*ramosissima*	1.8	other	yes
Encelia	*virginensis*	<0.1	other	
Ephedra	*nevadensis*	2.8	other	yes
Ephedra	*viridis*	0.4	other	yes
Ephedra	*torreyana*	0.1	other	
Ericameria	*nauseosa*	0.5	other	yes
Ericameria	*teretifolia*	0.1	other	
Ericameria	*cooperi*	<0.1	other	
Eriogonum	*fasciculatum*	0.1	other	yes
Grayia	*spinosa*	3.2	other	yes
Hymenoclea	*salsola*	3.9	other	yes
Kochia	*americana*	0.9	other	yes
Krameria	*erecta*	0.2	other	yes
Krascheninnikovia	*lanata*	10.8	other	yes
Larrea	*tridentata*	0.9	other	yes
Lepidium	*fremontii*	1.1	other	
Lycium	*andersonii*	4.9	other	yes
Lycium	*pallidum*	1	other	yes
Lycium	*shockleyi*	0.8	other	yes
Menodora	*spinescens*	0.3	other	yes
Psorothamnus	*fremontii*	0.1	other	
Psorothamnus	*polydenius*	0.1	other	
Purshia	*glandulosa*	0.7	other	yes
Purshia	*stansburiana*	0.2	other	yes
Salazaria	*mexicana*	<0.1	other	
Stanleya	*pinnata*	0.1	other	
Symphoricarpos	*longiflorus*	<0.1	other	
Tetradymia	*canescens*	0.3	other	
Tetradymia	*axillaris*	<0.1	other	
Thamnosa	*montana*	0.2	other	
Atriplex	*canescens*	57.8	saltbush	yes
Atriplex	*confertifolia*	3.3	saltbush	yes

Table 9. *Lycium shockleyi - L. pallidum* shrubland (category: "other")

Genus	species	Percent abundance	Our plant category	Dominant on NTS?
Lycium	*shockleyi*	32	other	yes
Lycium	*pallidum*	29.2	other	yes
Ambrosia	*dumosa*	14.7	other	yes
Atriplex	*canescens*	9.5	saltbush	yes
Krascheninnikovia	*lanata*	6	other	yes
Atriplex	*confertifolia*	5	saltbush	yes
Acamptopappus	*shockleyi*	2	other	
Artemisia	*spinescens*	1	other	
Hymenoclea	*salsola*	0.3	other	yes
Kochia	*americana*	0.3	other	yes
Chrysothamnus	*viscidiflorus*	<0.1	other	yes
Grayia	*spinosa*	<0.1	other	yes
Stanleya	*pinnata*	<0.1	other	
Tetradymia	*axillaries*	<0.1	other	

Table 10. Percent abundance of dominant shrubs on Quadrats 1, 2, and 6.

Quadrat 1

Genus	species	No. per hectare	Proportional abundance	Shrub category	Dominant on NTS?	Mean plant volume	Std. Dev. volume	n
Larrea	*tridentata*	860	0.60	creosote bush	yes	2.373	1.588	24
Acamptopappus	*shockleyi*	323	0.23	other		0.020	0.011	9
Ambrosia	*dumosa*	108	0.08	other	yes	0.021	0.004	3
Lycium	*andersonii*	72	0.05	other	yes	0.263	0.138	2
Krameria	*erecta*	36	0.03	other	yes	0.265	n/a	1
Krascheninnikovia	*lanata*	36	0.03	other	yes	0.021	n/a	1

Quadrat 2

Genus	species	No. per hectare	Proportional abundance	Shrub category	Dominant on NTS?	Mean plant volume	Std. Dev. Vol	n
Ambrosia	*dumosa*	2267	0.47	other	yes	0.024	0.031	19
Acamptopappus	*shockleyi*	1074	0.23	other		0.027	0.021	9
Larrea	*tridentata*	597	0.13	creosote bush	yes	2.261	2.918	5
Krameria	*erecta*	239	0.05	other	yes	0.076	0.103	2
Lycium	*andersonii*	239	0.05	other	yes	0.119	0.141	2
Krascheninnikovia	*lanata*	119	0.02	other	yes	0.124	n/a	1
Ephedra	*nevadensis*	119	0.02	other	yes	0.038	n/a	1
Grayia	*spinosa*	119	0.02	other	yes	0.179	n/a	1

Quadrat 6

Genus	species	No. per hectare	proportional abundance	Shrub category	Dominant on NTS?	Mean plant volume	Std. Dev. Vol	n
Larrea	*tridentata*	860	0.67	creosote bush	yes	1.860	2.001	36
Acamptopappus	*shockleyi*	323	0.25	other		0.005	0.005	2
Ambrosia	*dumosa*	108	0.08	other	yes	0.003	0.001	2

Table 11. NAPP (kg/ha-y) and proportional NAPP for primary stems, leaves, and fruits for select shrubs on the NTS (Table 4.10 of Rundel and Gibson).

Year:	**1971**		**1972**		**1973**		**1974**		**1975**		**1976**	
Species	**NAPP**	**Prop**	**NAPP**	**Prop**	**NAPP**	**Prop**	**NAPP**	**Prop**	**NAPP**	**Prop**	**NAPP**	**Prop**
Ambrosia dumosa	21	0.11	35	0.17	127	0.19	30	0.14	25	0.12	55	0.14
Atriplex confertifolia	10	0.05	11	0.05	38	0.06	11	0.05	8	0.04	17	0.04
Krascheninnikovia lanata	5	0.03	4	0.02	10	0.01	7	0.03	6	0.03	17	0.04
Ephedra nevadensis	15	0.08	17	0.08	60	0.09	1	0.00	51	0.24	31	0.08
Grayia spinosa	16	0.09	22	0.11	50	0.07	47	0.22	28	0.13	66	0.17
Krameria erecta	52	0.28	52	0.25	105	0.15	34	0.16	32	0.15	37	0.10
Larrea tridentata	17	0.09	16	0.08	42	0.06	17	0.08	14	0.07	29	0.08
Lycium andersonii	29	0.16	31	0.15	138	0.20	33	0.16	23	0.11	66	0.17
Lycium pallidum	15	0.08	14	0.07	102	0.15	30	0.14	20	0.10	58	0.15
Other	3	0.02	4	0.02	10	0.01	2	0.01	3	0.01	4	0.01

Table 12. Summary statistics calculated for NAPP and proportional NAPP from values found in Table 11 for all six years combined.

Species	Average NAPP	Standard Deviation of NAPP	Proportional Average	Proportional Standard Deviation
Ambrosia dumosa	48.83	40.09	0.15	0.03
Atriplex confertifolia	15.83	11.27	0.05	0.01
Krascheninnikovia lanata	8.17	4.79	0.03	0.01
Ephedra nevadensis	29.17	22.68	0.10	0.08
Grayia spinosa	38.17	19.23	0.13	0.06
Krameria erecta	52.00	27.42	0.18	0.07
Larrea tridentata	22.50	10.93	0.08	0.01
Lycium andersonii	53.33	44.17	0.16	0.03
Lycium pallidum	39.83	34.55	0.12	0.04
Other	4.33	2.88	0.01	0.01

Table 13. Relative abundance of shrubs grouped on the basis of shrub category (from Ostler et al. 2000).

Plant Association	Genus	species	Relative Abundance (%)
Lycium shockleyi - L. pallidum	*Atriplex*	*canescens*	9.5
	Atriplex	*confertifolia*	5
	Larrea	*tridentata*	0
	Atriplex	*spp.*	14.5
	other		85.5
Larrea tridentata – Ambrosia dumosa	*Larrea*	*tridentata*	12.7
	Atriplex	*confertifolia*	2.5
	Atriplex	*canescens*	0.4
	Atriplex	*spp.*	2.9
	other		84.4
Atriplex confertifolia – Ambrosia dumosa	*Atriplex*	*confertifolia*	29.6
	Atriplex	*hymenelytra*	0.4
	Atriplex	*canescens*	0.1
	Atriplex	*spp.*	30.1
	Larrea	*tridentata*	4.3
	other		65.6
Atriplex canescens – Krascheninnikovia lanata	*Atriplex*	*canescens*	57.8
	Atriplex	*confertifolia*	3.3
	Atriplex	*spp.*	61.1
	Larrea	*tridentata*	0.9
	other		38

Table 14. Relative abundance of shrubs grouped on the basis of shrub category (from fieldwork on conducted on quadrats Q1, Q2, and Q6, June 2001 – June 2002).

Quadrat	Genus	species	Relative Abundance (%)
Q1	*Larrea*	*tridentata*	59.9
	Atriplex	*spp.*	0.0
	other		40.1
Q2	*Larrea*	*tridentata*	12.5
	Atriplex	*spp.*	0.0
	other		87.5
Q6	*Larrea*	*tridentata*	40.8
	Atriplex	*spp.*	0.0
	other		59.2

Table 15. Relative percent abundance ranges per shrub category. (Based on information from Tables 13 and 14).

Shrub category	low	high
creosote bush	0.0	59.9
saltbush*	2.9	61.1
other	38.0	87.5

* The low value for saltbush of 2.9% is chosen since this is the low value for the larger work of Ostler et al. 2000.

There are three major assumptions underlying the process of establishing shrub category ranges depicted in Table 15. First, relative abundance is being used as a surrogate for relative contribution to total aboveground biomass. This measure does not directly include any measure of mass or volume of plant material. Unfortunately biomass production on a per species basis is simply not available for the NTS at large. Secondly, and as a corollary of the first assumption, it is assumed that community biomass production estimates are measured across the entire plant community and that it can be divided, at least cursorily, among species on the basis of species relative abundance. Third, and probably most important, it is assumed that any of the plant associations mentioned heretofore could occur throughout the duration of the compliance period (1000 years). This is why the ranges suggested above are given such great width. If one plant association were assumed for the duration of the compliance period, then the range would be much narrower.

One alternative is to model this factor as a random process by which different plant associations can occur at different times in the vicinity of the RWMS, then choose relative abundance numbers for species at random within any plant association chosen. However, this is not appropriate or consistent with the current modeling methods used in the Area 5 RWMS model. Furthermore, this requires vastly more developed knowledge of the system than is currently available as well as extensive modifications to accommodate root mass by depth and root/shoot ratios.

Related to these three assumptions, special attention must be paid to marginalization and conditioning of parameters within the model to make sure that the system is modeled appropriately. Most importantly, the biotic system information needs to be modeled completely and represented in full, rather than that for any given species. This is true since it is the net effect of the system that will affect the overall results of the model more so than individual effects of partial components thereof.

Table 15 contains relative percent abundance ranges per shrub category. However, incorporating the information into the Area 3 and 5 models is problematic. There are constraints that must be placed on each of these distributions (ranges). If values are drawn independently from each of the “uniform” distributions (ranges), then there is no guarantee that the simulated fractions will sum to 1. There are two different approaches that can be used to remedy this problem. First, re-normalize the sum of the independent draws to 1, or second, pull values from the plant categories one at a time until the sum of their contributions is 1, then assign to the last category the remainder. Either approach is problematic. The first approach is difficult because re-normalization might result in values that are out of range for the inputs while the second approach is difficult because the possibility exists to not reach 1. Additionally, for the latter approach the results may be biased by the order in which the draws are made.

These issues are difficult to address within the GoldSim programming environment, therefore simulations were performed externally (using R) and the resultant simulated (vector) distributions were fed into the GoldSim programs. Of the two options, the first method was preferred because it does not introduce a bias, though it does result in slightly reduced variance. It is not possible, without accounting directly for the correlation structure, to randomly draw values from the 3 uniform distributions, deal with the constraints (renormalization), and then obtain 3 uniform distributions in result. Figure 7 shows output from the external simulation process. Note that the distributions do not appear uniform, however, the treatment of all of them is the same. This effect is a consequence of the sampling algorithm employed, one that is difficult to avoid unless a joint distribution is formed for simulation purposes (for which a covariance matrix is needed, etc.).

Essentially, each set of simulated results is tagged with a number (1 to 1,000 assuming 1,000 simulations), and the model selects at random one of the 1,000 sets of results (vectors of size 3 for the 3 shrub categories) from the list provided. Any number of sets of vectors could have been fed into the model, but 1,000 simulations are considered sufficiently representative and refined for current purposes.

At this point in the algorithm, the model contains a distribution to represent NAPP for the entire plant community and a set of 1,000 simulated vectors to represent the relative fractions of NAPP attributed to each shrub category. These sources are combined in the model to form distributions of NAPP for each shrub category.

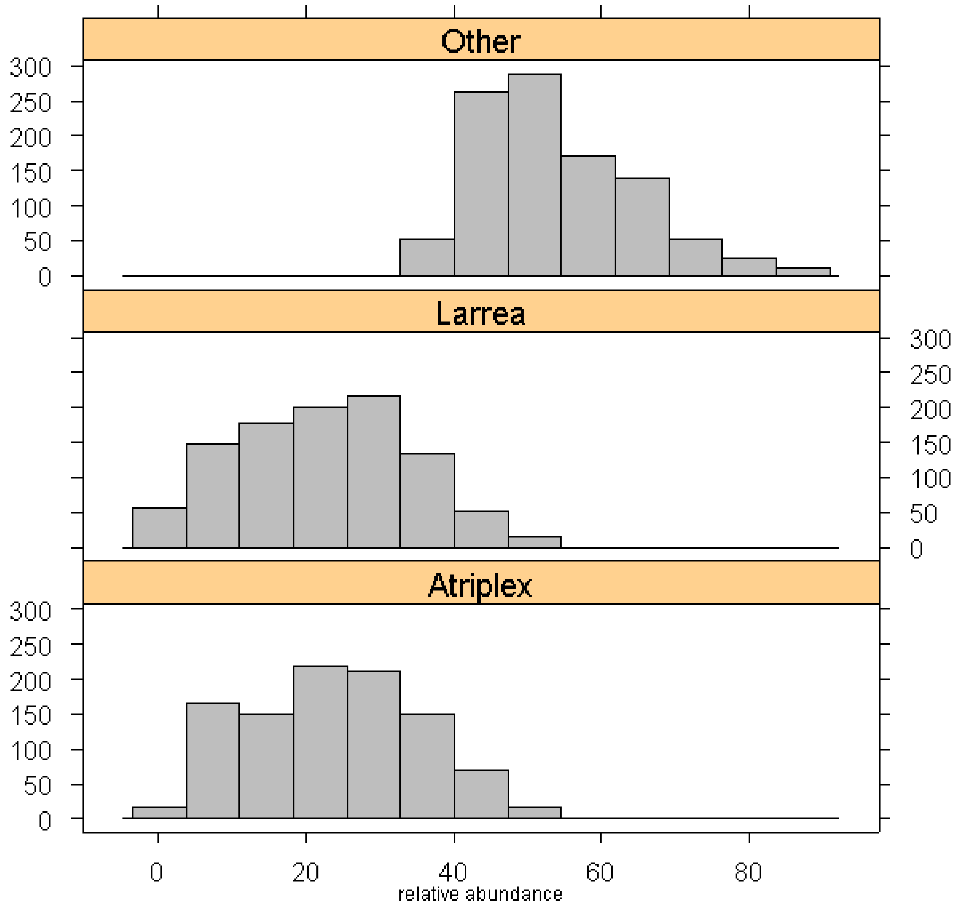

Figure 7. Simulated relative abundance data for each of the shrub categories based on renormalization of data when drawn from uniform distributions provided in Table 15.

For grasses, relative abundance is not considered since there is only one plant category of grasses and we have already developed a distribution on NAPP for this variable (See Section 7.2). Therefore at this stage of the modeling process, distributions for aboveground NAPP are simulated and assigned to three shrub categories and one grass category. The next step is to take this simulated information and apply root/shoot ratios to develop distributions for below ground biomass production.

8.1 Outstanding Issues in Relative Abundance

There are outstanding issues regarding relative abundance of shrubs, or related issues that could be considered for the next iteration of the model. Those issues are discussed below.

1. In the model, relative abundance data are used as a surrogate for measuring relative contribution of each shrub type to total NAPP. Is this a sensitive parameter, and if so, what would constitute better or more appropriate data for our purposes? Specifically, should we be collecting NAPP data for each major plant species?
2. Assuming we accept relative abundance as a good surrogate for relative contribution to NAPP, there is an issue of appropriateness of the data. Relative abundance has been collected in two ways, first by the percent occurrence on the ELUs counting the species as present (or absent) and second by direct count of shrubs on a transect and subsequent estimation of the number of individuals of a species per hectare. In the communities of concern for the Area 5 RWMS, samples should be collected in a fashion similar to the second method in order to be completely consistent with our basis of measurement. This will require a thorough sampling procedure for each of the four plant associations of concern.
3. Data have been summarized such that distributions for relative abundance of each shrub category have been defined (Table 15). These distributions cover the range of plant associations as described in Tables 6 through 9. There are two outstanding issues concerning Table 15. First, methods for combining these data are *ad hoc* (picking the minimum and maximum from seven data sets). When additional data become available, combining data via *ad hoc* methods will no longer be needed. Second, methods for selecting values from each of the shrub distributions in Table 15 (already discussed in the text and shown in Figure 7) are problematic. An alternative that should be pursued is to place Dirichlet distributions on the multinomial components of the distributions of relative abundance. It is unlikely that GoldSim can handle such an operation, so it may be necessary do this externally in R.
4. Once uniform (or other) distributions are derived for the shrub categories, there is again an issue of hierarchy of parameters and the placement of distributions on parameters of the initial distribution. It is not clear how this can be accomplished with current data, or if the issue of hierarchy is necessary or appropriate.
5. It is critical that the spatial and temporal scales used during data collection (data generation) are the same as those used in the Area 3 and Area 5 models. A full understanding of how the data were collected ensures that the appropriate levels of hierarchy for data attribution are modeled.

9.0 Develop Distributions of Belowground Biomass Production for Perennial Shrubs and Grasses

Distributions of below ground biomass production for perennial shrubs and grasses will be developed in this section based on root/shoot ratio data described in Table 16. While there exists data for various shrub species, the only data available for grasses consist of one point from Winkel et al. (1995), which indicates a value of 1.53 for *Achnatherum hymenoides*.

Root/shoot ratios are used in this model to estimate below ground NAPP from above ground NAPP measures. The root/shoot ratio is the ratio of below ground (root) mass to above ground (shoot) mass. Estimates of below ground NAPP are determined by multiplying aboveground NAPP by the root-shoot ratio of the species of concern. Thus, the assumption is that below ground NAPP is directly proportional to the root-shoot ratio. Since below ground NAPP is almost never measured directly, this approach might be sufficient.

9.1 Area 5 and Area 3 Below Ground Net Annual Primary Production

Aggregate root/shoot ratios are needed for each shrub category and for grasses separately. Currently, no field data exist for root/shoot ratios for shrubs or grasses on the NTS. Therefore literature values have been used as a surrogate. For the creosote shrub category, the only root/shoot ratio literature entries are for *Larrea tridentata* with values of 0.3 and 1.24. Consequently, a uniform distribution is proposed with these two values as endpoints of the distribution. For the saltbush shrub category, there is one entry each for the two *Atriplex* species, *Atriplex canescens* and *Atriplex confertifolia*, with root/shoot ratio values of 0.44 and 0.67, respectively. Again, a uniform distribution is proposed with these endpoints.

For the “other” shrub category, root/shoot ratio values range from 0.3 to 1.64. As discussed in the section on estimating above ground NAPP distributions, in lieu of assuming some underlying distributional form, bootstrap sampling was used to determine the distribution of the root/shoot ratio sample mean. Based on the histogram of the means and a comparison of the cumulative distribution of the bootstrapped means and the cumulative distribution of a random normal distribution (Figure 8), the distribution of mean root/shoot ratios for the other category is modeled as a normal with a mean of 0.78 and a standard deviation of 0.067.

The data for grasses consist of one data point from Winkel, et al. (1995), which provides a value of 1.53 for *Acnatherum hymenoides*. Based on this value and our best professional judgment, a triangular distribution was developed for perennial grass root/shoot ratios. The single data point for *Achnatherum hymenoides* is used for the mode of the distribution. Furthermore, since root/shoot ratios for grasses are believed to vary from 1:1 to 2:1 the endpoints of the distribution are set at a minimum of 1 and a maximum of 2.

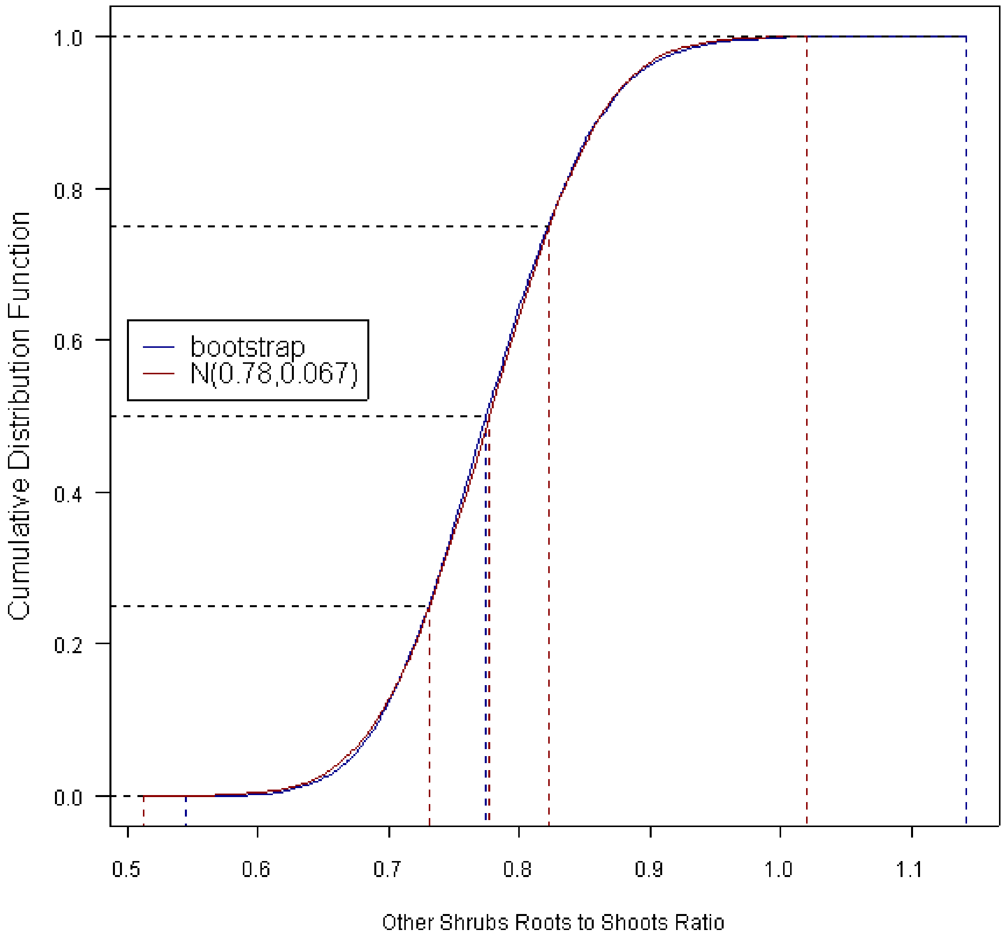

Figure 8. Cumulative distribution functions for bootstrapped and normal "other" shrub root-shoot ratio data.

Table 16. Root-shoot ratios for various species of desert shrubs.

Species[1]	Common name	Barbour 1973	Wallace et al. 1974	Winkel et al. 1995	Group
Larrea tridentata (divaricata)	creosote bush	0.3	1.24	From Wallace et al. 1974	creosote bush
Acacia greggii	catclaw acacia	1.2	NR	NR[2]	other
Acamptopappus shockleyi	Shockley's goldenhead	NR	0.56	From Wallace et al. 1974	other
Ambrosia (Franseria) dumosa	white bursage	0.6	1.16	From Wallace et al. 1974	other
Artemisia spp.[3]	sagebrush	0.40 to 1.80	NR	NR	other
Brickellia incana	woolly (white) brickelbrush	0.5	NR	NR	other
Senna (Cassia) armata	desert senna	0.7	NR	NR	other
Ericameria nauseosa (Chrysothamnus nauseosus)	rubber rabbitbrush (gray rabbitbrush)	NR	NR	0.53	other
Ephedra nevadensis	Nevada ephedra	1.2	0.83	From Wallace et al. 1974	other
Eriogonum fasciculatum	Eastern Mojave buckwheat	0.4	NR	NR	other
Grayia spinosa	spiny hopsage	NR	0.72	From Wallace et al. 1974	other
Hymenoclea salsola	white burrobrush	0.7	NR	0.7	other
Krameria grayi	white ratany	0.4	NR	NR	other
Krameria erecta (parvifolia)	range ratany	0.6	0.79	From Wallace et al. 1974	other
Krascheninnikovia (Eurotia) lanata	winterfat	NR	0.9	From Wallace et al. 1974	other
Lycium andersonii	Anderson's wolfberry	NR	0.83	From Wallace et al. 1974	other
Lycium pallidum	rabbit thorn	NR	1.64	NR	other
Salazaria mexicana	Mexican bladdersage	0.7	NR	NR	other
Thamnosma montana	turpentine broom	0.3	NR	NR	other
Atriplex canescens	four-winged saltbush	NR	NR	0.67	saltbush
Atriplex confertifolia	shadscale saltbush	NR	0.44	From Wallace et al. 1974	saltbush

[1] Species or genus epithets indicated in parentheses are synonyms listed by authors.
[2] NR = not recorded.

Once the root/shoot ratio distributions have been developed for each shrub and grass category, below ground NAPP can be calculated using aboveground NAPP and the root/shoot ratio as a multiplier on aboveground NAPP.

9.2 Outstanding Issues for Shrub and Grass Root/Shoot Ratios

There are outstanding issues regarding the formulation of the root/shoot distributions and the data used to determine those distributions for both shrub and grasses.

1. Root/shoot ratio distributions are based on literature values since no field data exist for root/shoot ratios for the NTS. However, even the literature values are scarce for the creosote and saltbush shrub categories. Thus, there is a real need to obtain more data, either literature or field, to enhance root/shoot ratio distributions.
2. Data for actual below ground NAPP do not exist for the NTS, therefore root/shoot ratios are based on mass of plant material below and above the ground surface. Using these ratios as a surrogate for measuring below ground biomass production leaves the primary issue of actual below ground NAPP unaddressed. It is not clear that this can be avoided, but some understanding of the implications of this substitution is worthwhile.
3. For root-shoot ratios, averages are obtained across species within a shrub category. In this aggregation across all plants, the chosen root/shoot distribution implies data independence that likely does not hold true.

10.0 Maximum Rooting Depths

Maximum root depths for all plant types are simply the maximum observed root depth as reported from field trips to the NTS and in the literature. These maximum rooting depths are only briefly discussed in this section. They are used extensively in Section 11 to determine the root mass by depth distributions for the three shrub and single grass category.

Maximum depths are summarized in Tables 17 and 18. For creosote (*Larrea tridentata*), the maximum depth observed by Hooten at the NTS is 315 cm (Table 18), for saltbush (*Atriplex confertifolia*) Gibbens and Lenz (2001) give a value of 360cm, for other shrubs Klepper et al. (1985) report a value for *Purshia tridentata* of 296cm ± 8 (Table 18), and for grasses a value of 158cm is reported for *Achnatherum hymenoides* by Hooten et al. (2003). Since this is the best data available for both Area 5 and Area 3, the maximum rooting depths for creosote, saltbush, others and grasses are set to 315cm, 360cm, 320cm and 158cm, respectively, in both of the GoldSim models.

Table 17. Depth and spread of roots for the dominant shrub, tree, and grass species found on the NTS.[1]

<table>
<tr><th>Species</th><th>Reported Root Depth (cm ± sd)[2]</th><th colspan="2">Reported Root Spread (cm ± sd)[2]</th><th># obs</th><th>Author</th></tr>
<tr><td colspan="6">Shrubs</td></tr>
<tr><td rowspan="4">Ambrosia dumosa [White bursage] Root information for A. acanthicarpa Hook found in parentheses.</td><td>50–86</td><td colspan="2">NR [3]</td><td>8</td><td>Winkel et al. 1995</td></tr>
<tr><td>(183 ± 33)</td><td colspan="2">(NR [“many threadlike laterals”])</td><td>9</td><td>Klepper et al. 1985</td></tr>
<tr><td>70</td><td colspan="2">NR</td><td>NR</td><td>Marshall and Korthuis 1994</td></tr>
<tr><td>86</td><td colspan="2">65</td><td>NR</td><td>Wallace and Romney 1972 [4]</td></tr>
<tr><td>Artemisia nova [black sagebrush]</td><td>NR (“a shallower, more fibrous root system than big sagebrush“)</td><td colspan="2">NR</td><td></td><td>McMurray 1986</td></tr>
<tr><td rowspan="9">Artemisia tridentata [basin big sagebrush]</td><td rowspan="5">50 – 75</td><td>Depth</td><td>Spread</td><td rowspan="5">NR</td><td rowspan="5">Abbott et al. 1991 [6]</td></tr>
<tr><td>25</td><td>45</td></tr>
<tr><td>50</td><td>30</td></tr>
<tr><td>75</td><td>40</td></tr>
<tr><td>100</td><td>0</td></tr>
<tr><td>100 (inferential)</td><td colspan="2">NR</td><td>NR</td><td>Anderson et al. 1993</td></tr>
<tr><td>200 ± 40</td><td colspan="2">NR (“well developed laterals in upper meter”)</td><td>11</td><td>Klepper et al. 1985</td></tr>
<tr><td></td><td colspan="2"></td><td></td><td></td></tr>
<tr><td colspan="5" style="display:none"></td></tr>
<tr><td rowspan="2">Atriplex canescens [four-winged saltbush]</td><td>198</td><td colspan="2">305</td><td>NR</td><td>Tirmenstein 1986</td></tr>
<tr><td>594</td><td colspan="2"></td><td>NR</td><td>Tirmenstein 1986</td></tr>
<tr><td>Atriplex confertifolia (A. spinosa) [shadscale saltbush]</td><td>70</td><td colspan="2">NR</td><td>7</td><td>Winkel et al. 1995</td></tr>
<tr><td>Chrysothamnus viscidiflorus ssp. puberulus [fuzzy green rabbitbrush]</td><td>not found</td><td colspan="2">not found</td><td></td><td></td></tr>
</table>

<table>
<tr><th>Species</th><th>Reported Root Depth (cm ± sd)[2]</th><th>Reported Root Spread (cm ± sd)[2]</th><th># obs</th><th>Author</th></tr>
<tr><td rowspan="4">Chrysothamnus viscidiflorus ssp. viscidiflorus [sticky green rabbitbrush]</td><td>50–190</td><td>NR</td><td>NR</td><td>Winkel et al. 1995</td></tr>
<tr><td>50 – 100 (C. viscidiflorus)</td><td><table><tr><td>Depth</td><td>Spread</td></tr><tr><td>6</td><td>42</td></tr><tr><td>60</td><td>30</td></tr><tr><td>60</td><td>NR</td></tr><tr><td>100</td><td>50</td></tr></table></td><td>NR</td><td>Abbott et al. 1991 [6]</td></tr>
<tr><td>153 ± 11 (C. viscidiflorus)</td><td>NR (“few laterals in upper meter”)</td><td>2</td><td>Klepper et al. 1985</td></tr>
<tr><td>60 (C. viscidiflorus)</td><td>NR (“many major secondary roots extend laterally”)</td><td>NR</td><td>Tirmenstein 1999</td></tr>
<tr><td>Coleogyne ramosissima [blackbrush]</td><td>not found</td><td>not found</td><td></td><td></td></tr>
<tr><td rowspan="2">Ephedra nevadensis [Nevada jointfir]</td><td>50–91</td><td>84</td><td>7</td><td>Winkel et al. 1995</td></tr>
<tr><td>223</td><td>229</td><td>NR</td><td>Wallace and Romney 1972 [4]</td></tr>
<tr><td>Ephedra viridis [Mormon tea]</td><td>not found</td><td>not found</td><td></td><td></td></tr>
<tr><td>Ericameria cooperi [Cooper’s heathgoldenrod]</td><td>not found</td><td>not found</td><td></td><td></td></tr>
<tr><td>Ericameria nauseosa (= Chrysothamnus nauseosus) [rubber (gray) rabbitbrush]</td><td>183 ± 33</td><td>(NR (“few laterals in upper meter”)</td><td>9</td><td>Klepper et al. 1985</td></tr>
<tr><td>Eriogonum fasciculatum [eastern Mojave buckwheat] Root information for E. niveum Dougl. ex Benth. found in parentheses.</td><td>(150)</td><td>(NR [“many laterals about 5–10 cm below surface”])</td><td>1</td><td>Klepper et al. 1985</td></tr>
</table>

Species	Reported Root Depth (cm ± sd)[2]	Reported Root Spread (cm ± sd)[2]	# obs	Author
Grayia spinosa [spiny hopsage]	195	NR ("many woody roots in upper meter")	1	Klepper et al. 1985
	65–215	73	NR	Winkel et al. 1995
	97	122	NR	Wallace and Romney 1972 [4]
Hymenoclea salsola white burrobrush]	81–100	84	NR	Winkel et al. 1995
	143	83	NR	Wallace and Romney 1972 [4]
Juniperus osteosperma [Utah juniper]	450	3030	NR	Zlatnik 1999a
Kochia americana [green molly] Root information for *K. scoparia* (L.) Schrad. found in parentheses	(180–240 "generally") (480 max single record in a Kansas sorghum field)	(660)	NR	Esser 1995
Krameria erecta [range ratany] (= *K. parvifolia*)	50	NR	8	Winkel et al. 1995
	93	110	NR	Wallace and Romney 1972 [4]
Krascheninnikovia lanata [winterfat]	64	62	NR	Wallace and Romney 1972 [4]
	100–145 "fibrous roots" 100-180 "tap roots" (One tap root observation at 7.4m – no record of soil/bedrock conditions)	NR	NR	Carey and Holifield 1995
Larrea tridentata [creosote bush]	20–80	300	NR	Marshall and Korthuis 1995
	50–168	300	3	Winkel et al. 1995
	168	136	NR	Wallace and Romney 1972 [4]
Leptodactylon pungens [granite prickly gilia]	not found	not found		
Lycium andersonii [Anderson's wolfberry]	50–122	760–910	5	Winkel et al. 1995
	122	84	NR	Wallace and Romney 1972 [4]

<table>
<tr><th>Species</th><th>Reported Root Depth (cm ± sd)[2]</th><th>Reported Root Spread (cm ± sd)[2]</th><th># obs</th><th>Author</th></tr>
<tr><td>Lycium pallidum
[rabbit thorn]</td><td>50–100</td><td>750–900</td><td>NR</td><td>Matthews 1994</td></tr>
<tr><td>Lycium shockleyi
[Shockley’s desert thorn]</td><td>not found</td><td>not found</td><td></td><td></td></tr>
<tr><td>Menodora spinescens
[spiny menodora]</td><td>not found</td><td>not found</td><td></td><td></td></tr>
<tr><td rowspan="2">Picrothamnus desertorum (Artemisia spinescens)
[budsage]</td><td>125</td><td>36</td><td>NR</td><td>Winkel et al. 1995</td></tr>
<tr><td>15–55</td><td>NR (short taproot with “long with numerous small horizontal branches”)</td><td>NR</td><td>Hickerson 1986</td></tr>
<tr><td rowspan="2">Pinus monophylla
[singleleaf piñon]
Root information for P. edulis Engelm. found in parentheses</td><td>NR</td><td>1830–3660 (inferential: “2–3 times height”)</td><td>NR</td><td>Meeuwig 1990</td></tr>
<tr><td>(640)</td><td>NR</td><td>NR</td><td>Ronco 1990</td></tr>
<tr><td>Purshia glandulosa
[desert bitterbrush]</td><td>not found</td><td>not found</td><td></td><td></td></tr>
<tr><td>Purshia stansburiana (P. mexicana var. stansburiana)
[Stansbury cliffrose]</td><td>240</td><td>”widely spreading lateral roots”</td><td>NR</td><td>Howard and Holifield 1995</td></tr>
<tr><td rowspan="2">Purshia tridentata
[antelope bitterbrush]</td><td>296 ± 8</td><td>NR (“a number of small lateral roots in upper meter”)</td><td>4</td><td>Klepper et al. 1985</td></tr>
<tr><td>450 – 540</td><td>NR</td><td></td><td>Zlatnik 1999b [5]</td></tr>
<tr><td colspan="5" align="center">Grasses</td></tr>
<tr><td rowspan="2">Achnatherum (Oryzopsis) hymenoides
[Indian ricegrass]</td><td>119 ± 7</td><td>100 (no sd provided)</td><td>3</td><td>Klepper et al. 1985</td></tr>
<tr><td>45 – 122</td><td>NR</td><td>2</td><td>Foxx et al. 1984a</td></tr>
<tr><td>Bromus rubens
[foxtail brome]</td><td>not found</td><td>not found</td><td></td><td></td></tr>
<tr><td rowspan="2">Elymus elymoides
[bottlebrush squirreltail]
Root information for E. lanceolatus (Scribn. & J.G. Sm.) Gould found in parentheses</td><td>50
(50 – 75)</td><td><table><tr><th>Depth</th><th>Spread</th></tr><tr><td>25</td><td>30 (28)</td></tr><tr><td>50</td><td>60 (80)</td></tr><tr><td>75</td><td>0 (22)</td></tr><tr><td>100</td><td>0</td></tr></table></td><td>NR</td><td>Abbott et al. 1991 [6]</td></tr>
<tr><td>(120)</td><td>NR</td><td>NR</td><td>Anderson et al. 1993</td></tr>
</table>

Species	Reported Root Depth (cm ± sd)[2]	Reported Root Spread (cm ± sd)[2]	# obs	Author
Achnatherum speciosum [desert needlegrass]	not found	not found		
Bromus tectorum [cheatgrass]	30 – 110	not found	2	Foxx et al. 1984

[1] When species information was not available, congener information was reported if available (noted parenthetically). Multiple observations are noted, otherwise a range or single observation is provided.

[2] Values indicated are either a maximum observed, a range of maxima observed (>1 plant), or an average maximum observed provided with standard deviation of the mean.

[3] NR = not reported.

[4] Approximated from figures provided in the chapter entitled Root Systems of Some Shrubs in the Sandy Wash Area of Rock Valley, Figures 2–6 (Wallace and Romney 1972).

[5] These depths are dependent on adequate soil moisture available for root elongation. Zlatnik (1999b) describes environmental conditions for optimal growth.

[6] Values for Abbott et al. (1991) are reported only for undisturbed (native) soils, and taken from Figures 4 through 7.

Table 18. Literature and field values of maximum depths for the three shrub and a single grass categories.

Name	Author	Group	Class	Max Root Depth (cm)
Elymus elymoides	Abbott et al. 19916	Grass	other	62.5
Achnatherum (Oryzopsis) hymenoides	Hooten et al. April 2004 Fieldtrip	Grass	other	75
Achnatherum (Oryzopsis) hymenoides	Hooten et al. April 2004 Fieldtrip	Grass	other	85
Achnatherum (Oryzopsis) hymenoides	Klepper et al. 1985	Grass	other	119
Atriplex confertifolia (A. spinosa)	Winkel et al. 1995	Shrub	atriplex	70
Larrea tridentata	Hooten et al. April 2004 Fieldtrip	Shrub	larrea	210
Larrea tridentata	Hooten et al. April 2004 Fieldtrip	Shrub	larrea	305
Larrea tridentata	Hooten et al. Feb. 2004 Fieldtrip	Shrub	larrea	142
Larrea tridentata	Hooten et al. Feb. 2004 Fieldtrip	Shrub	larrea	92
Larrea tridentata	Hooten et al. Feb. 2004 Fieldtrip	Shrub	larrea	250
Larrea tridentata	Hooten et al. Feb. 2004 Fieldtrip	Shrub	larrea	74
Larrea tridentata	Hooten et al. Oct. 2004 Fieldtrip	Shrub	larrea	315
Larrea tridentata	Wallace and Romney 19725	Shrub	larrea	168
Larrea tridentata	Winkel et al. 1995	Shrub	larrea	109
Artemisia tridentata	Abbott et al. 19916	Shrub	other	62.5
Chrysothamnus viscidiflorus ssp. viscidiflorus	Abbott et al. 19916	Shrub	other	75
Artemisia tridentata	Anderson et al. 1993	Shrub	other	100

Artemisia spinescens	Hickerson 1986	Shrub	other	35
Menodora spinescens	Hooten et al. April 2004 Fieldtrip	Shrub	other	100
Lycium andersonii	Hooten et al. Feb. 2004 Fieldtrip	Shrub	other	123
Lycium andersonii	Hooten et al. Feb. 2004 Fieldtrip	Shrub	other	105
Ambrosia dumosa	Klepper et al. 1985	Shrub	other	183
Artemisia tridentata	Klepper et al. 1985	Shrub	other	200
Chrysothamnus viscidiflorus ssp. viscidiflorus	Klepper et al. 1985	Shrub	other	153
Ericameria nauseosa (Chrysothamnus nauseosus)	Klepper et al. 1985	Shrub	other	183
Eriogonum fasciculatum	Klepper et al. 1985	Shrub	other	150
Grayia spinosa	Klepper et al. 1985	Shrub	other	195
Purshia tridentata	Klepper et al. 1985	Shrub	other	296
Ambrosia dumosa	Marshall and Korthuis 1994	Shrub	other	70
Artemisia nova	McMurray 1986	Shrub	other	NA
Chrysothamnus viscidiflorus ssp. puberulus	NA	Shrub	other	NA
Coleogyne ramosissima	NA	Shrub	other	NA
Ephedra viridis	NA	Shrub	other	NA
Ericameria coopei	NA	Shrub	other	NA
Leptodactylon pungens	NA	Shrub	other	NA
Lycium shockleyi	NA	Shrub	other	NA
Menodora spinescens	NA	Shrub	other	NA
Purshia glandulosa	NA	Shrub	other	NA
Ambrosia dumosa	Wallace and Romney 19725	Shrub	other	86
Ephedra nevadensis	Wallace and Romney 19725	Shrub	other	223
Grayia spinosa	Wallace and Romney 19725	Shrub	other	97

Hymenoclea salsola	Wallace and Romney 19725	Shrub	other	143
Krameria erecta	Wallace and Romney 19725	Shrub	other	93
Krascheninnikovia lanata	Wallace and Romney 19725	Shrub	other	64
Lycium andersonii	Wallace and Romney 19725	Shrub	other	122
Ambrosia dumosa	Winkel et al. 1995	Shrub	other	68
Artemisia spinescens	Winkel et al. 1995	Shrub	other	125
Chrysothamnus viscidiflorus ssp. viscidiflorus	Winkel et al. 1995	Shrub	other	120
Ephedra nevadensis	Winkel et al. 1995	Shrub	other	70.5
Grayia spinosa	Winkel et al. 1995	Shrub	other	140
Hymenoclea salsola	Winkel et al. 1995	Shrub	other	90.5
Krameria erecta	Winkel et al. 1995	Shrub	other	NA
Lycium andersonii	Winkel et al. 1995	Shrub	other	86
Achnatherum hymenoides	Hooten et al. March 27 2003	Grass	other	91
Achnatherum hymenoides	Hooten et al. March 27 2003	Grass	other	88
Achnatherum hymenoides	Hooten et al. March 27 2003	Grass	other	92
Achnatherum hymenoides	Hooten et al. March 27 2003	Grass	other	90
Achnatherum hymenoides	Hooten et al. March 27 2003	Grass	other	88
Achnatherum speciosum	Hooten et al. March 27 2003	Grass	other	123
Achnatherum speciosum	Hooten et al. March 27 2003	Grass	other	88
Achnatherum speciosum	Hooten et al. March 27 2003	Grass	other	85
Achnatherum speciosum	Hooten et al. March 27 2003	Grass	other	77
Achnatherum speciosum	Hooten et al. March 27 2003	Grass	other	NA
Achnatherum speciosum	Hooten et al. March 27 2003	Grass	other	158

Achnatherum hymenoides	Hooten et al. March 27 2003	Grass	other	131
Achnatherum hymenoides	Hooten et al. March 27 2003	Grass	other	118
Achnatherum hymenoides	Hooten et al. March 27 2003	Grass	other	96
Achnatherum hymenoides	Hooten et al. March 27 2003	Grass	other	105
Achnatherum hymenoides	Hooten et al. March 27 2003	Grass	other	98

11.0 Relative Root Mass by Depth Distributions

This section describes the methodology used to apportion below ground biomass production to depth layers or "cells" within the Area 5 and Area 3 models. The first section describes the methodology used for each of the three shrub categories. The second section describes the methodology used for the grasses category. While the methodology for grasses is similar, it involves an additional step in determining average b.

11.1 Root Mass by Depth Distributions for Each Shrub Category

The first step entails modeling the depth distribution of plant mass for each shrub species. Once this is accomplished, a model is applied to the aggregate within each layer. For the shrub categories, this was accomplished using the available data on root mass by depth as presented in Hooten et al. (2004), the available maximum rooting depths in Section 6.0, and the following procedure.

1. Fit a function describing the root mass by depth for each species having sufficient available data. Then average root mass (within a cell) across all vertical soil profiles using the most coarse interval available (50 cm) for each shrub category.
2. Using estimates of mean and variance from step 1, simulate a normal distribution for each depth layer for each of the shrub categories. Randomly draw one data point from each normal distribution at each depth, thus creating a new depth profile.
3. Fit a Beta CDF to each of the newly simulated depth profiles from step 2 to obtain a distribution for the *b* parameter in the Beta CDF.
4. Bootstrap the newly developed *b* distribution to obtain a distribution for the average *b* parameter. Fit a normal distribution to the average *b* distribution to determine the fit of the bootstrapped distribution to the normal distribution.

Each step in the procedure will now be described in more detail.

Step 1:

Root mass by depth data exist for ten shrub species on the NTS. The data for the ten species can be allocated into the existing three shrub categories such that the creosote bush category consists of one species, the saltbush category consists of two species, and the others category comprises the seven remaining species. The original data (Hooten et. al 2001, Table 5) for root mass density by depth are reproduced in Tables 19 and 20 for each of the three shrub categories. Root mass density information was averaged across the vertical soil profiles using the most coarse interval available. For example, the others shrub category was averaged in 50cm sections. Five species out of seven had root distributions reported entirely within the top 50cm of soil. The other two species had data suggesting findings of root mass at 50cm, 100cm, 150cm, and 200cm. Therefore, root density averages for each shrub category were averaged at 50cm intervals. Due to the lack of any existing covariance information, their variances were combined as though the root densities for the individual species were independent random variables.

Step 2:

Step 1 provided mean and standard deviation estimates for each root density depth for each of the three shrub categories. Data were then simulated using these statistics. A normal distribution was constructed for each depth using the mean and standard deviation from that depth as the mean and standard deviation for the normal distribution. An assumption of normality for each of the depth intervals was made since no distributional information was available for the root mass in each depth presented in Tables 19 and 20. Mean estimates for each depth interval often did not sum to unity indicating that there is likely some skew to the data. But without having more information, an assumption of normality seemed the most reasonable choice. One value was selected at random from each of the normal distributions until all depths had been sampled, creating a root mass fraction distribution by depth. These fractions were summed. If the sum was less than one, then the profile was adjusted so that the remaining portion was assigned to the maximum depth layer. If the sum was greater than one, then the layers whose fractions were less than one were included in the profile and the next deepest depth was assigned a value of one. Once a cumulative fractional sum had reached one, the layers down to the maximum rooting depth were assigned zero fractional weight. Maximum rooting depths were fixed for Creosote, Saltbush and the Other categories at 315cm, 360cm and 320cm respectively. The data used to evaluate maximum rooting depths for the three shrub and single grass categories can be found in Table 18.

Step 3:

A function was fit to simulated depth interval data from step 2. Cumulative root mass by depth F_{mass} has been assumed to follow a Beta distribution of the form:

$$F_{mass}(z) = 1 - \left(1 - \frac{z}{z_{max}}\right)^b, \quad 0 < z < z_{max}, \quad b \geq 1. \tag{2}$$

Therefore the simulated depth interval data was fit with the Beta CDF shown in equation 2. Each of the depth intervals from Step 2 were fit using non-linear least-squares with the Beta CDF. This process produced a range of possible *b* values that would fit equation 2. For creosote and saltbush, the fitting process produced reasonable values for *b*. However, for the other category, the fitting process obtained some extreme values for *b* as a mathematical artifact of fitting equation 2. This was clear from the plot of *b* values for the other category. A bimodal distribution was apparent with the majority of the data centered around 10.5 and a small portion (~3.0%) of the data located at 200. Since these values in the upper tail of the distribution do not represent *b* values obtained from a properly fit Beta CDF, these values were eliminated from the distribution and not used for the fitting process performed in Step 4.

Step 4:

Bootstrapping was used to determine the distribution for the average *b* for each of three shrub categories (creosote bush, saltbush, and "other"). Recall that the *b* values for the other category were truncated (see Step 3) prior to bootstrapping. The distributions on *b* for all three categories appeared normal and so there was no need to fit any other distributions. For creosote, average *b* is assumed to be normal with mean of 14.6, standard deviation of 0.0807 and truncated at 1. Saltbush average *b* is assumed to be normal with mean of 23.9, standard deviation of 0.313, and truncated at 1. Finally, the other category average *b* is assumed to be normal with a mean of 11.3, standard deviation of 0.157, and truncated at 1. Values of *b* less than one produce an inverted root mass by depth where root mass increases with depth. Since this is contrary to the current knowledge regarding root mass with depth on the NTS, the average distributions for *b* were truncated at 1 so that values less than 1 would be excluded from the model. In GoldSim if the lower end of the distribution is truncated, then the upper end of the distribution must be truncated as well. Therefore, these distributions also were truncated at 1e+20. Figures 9, 10 and 11 show the bootstrapped distributions for the average *b* parameter and the normal distributions fit to those data for creosote, saltbush and the other shrub categories. Since there is very little data available for modeling average *b*, these distributions are used in both the Area 5 and Area 3 GoldSim models.

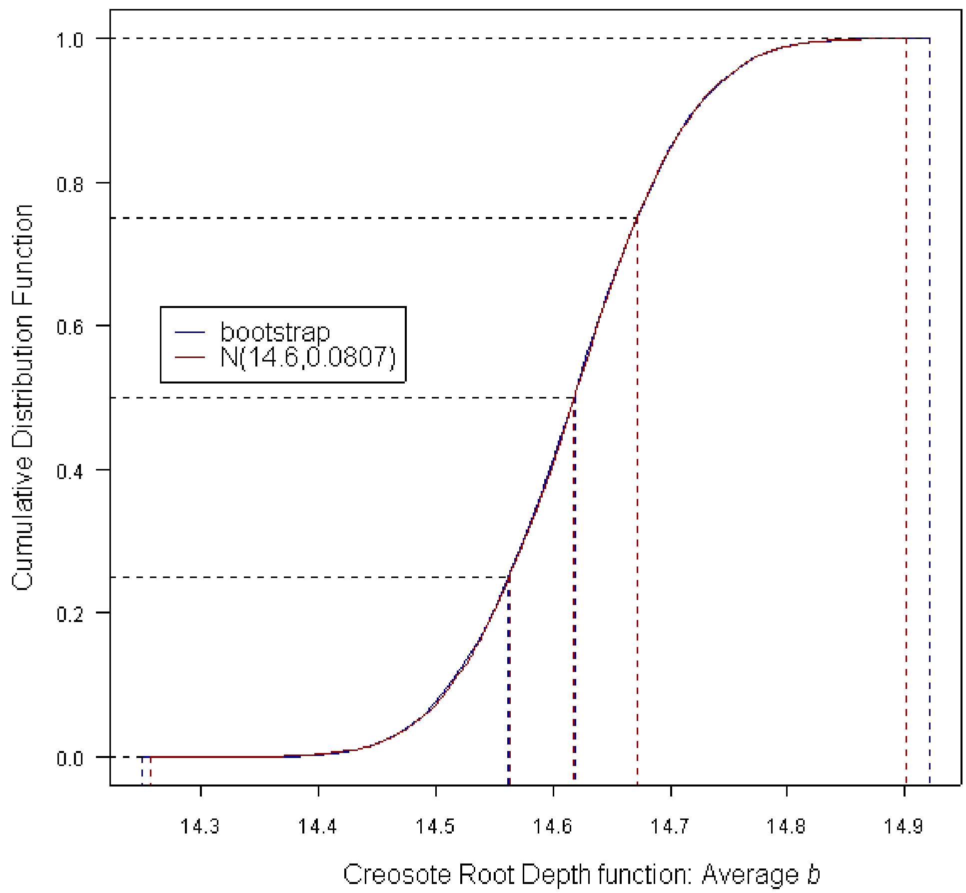

Figure 9. Comparison of bootstrapped and normal cumulative distributions for the average *b* parameter used to determine the root mass by depth distribution for the creosote shrub category. This distribution is used to model both Area 5 and Area 3 creosote average *b* distributions

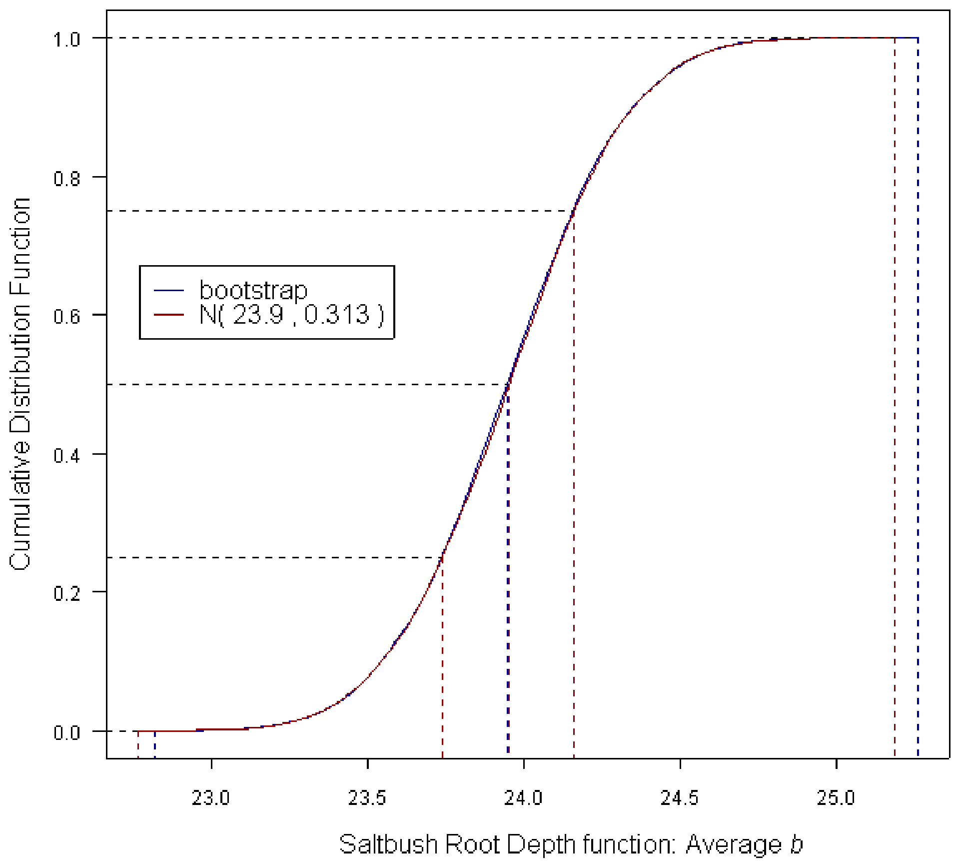

Figure 10. Comparison of bootstrapped and normal cumulative distributions for the average *b* parameter used to determine the root mass by depth distribution for the saltbush shrub category. This distribution is used to model both Area 5 and Area 3 saltbush average *b* distributions

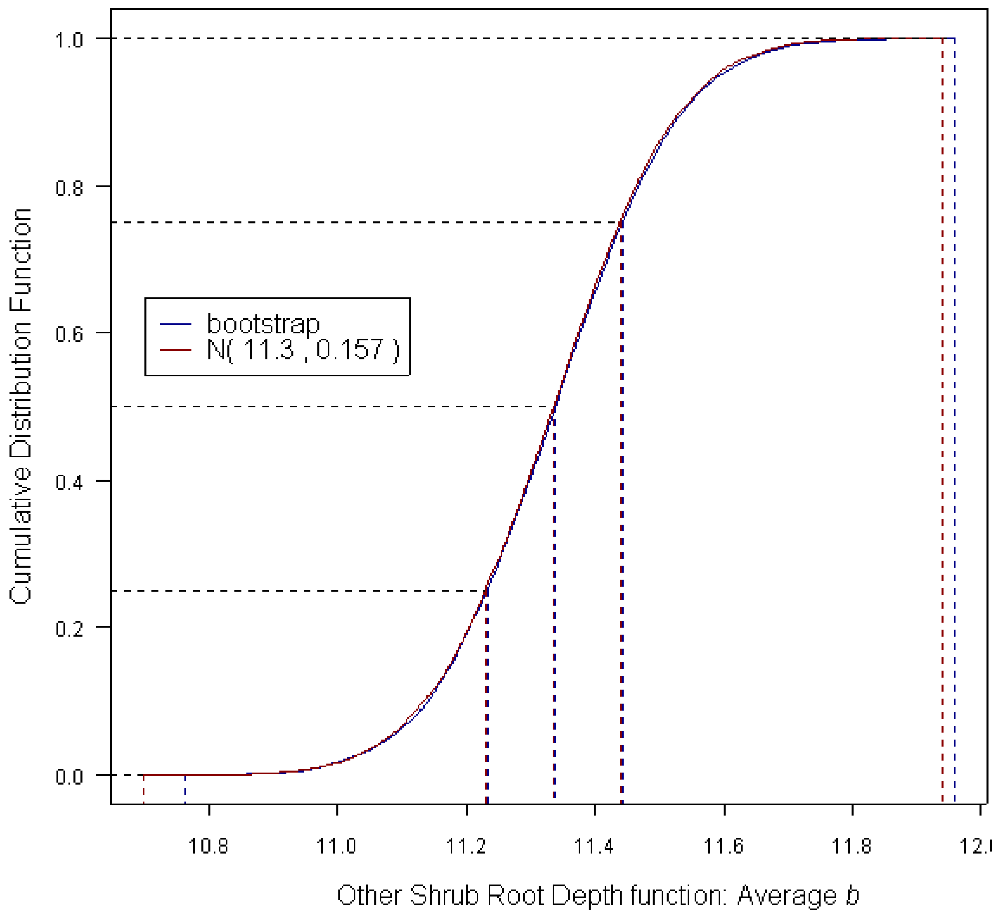

Figure 11. Comparison of bootstrapped and normal cumulative distributions for the average *b* parameter used to determine the root mass by depth distribution for the other shrub category. This distribution is used to model both Area 5 and Area 3 other shrub average *b* distributions.

11.2 Root Mass by Depth Distributions for the Grasses Category

Currently there is no literature or field data to elucidate grass root mass by depth. For grasses, the data currently available are maximum rooting depths taken from the literature and a Hooten fieldtrip in 2003 (see Table 18). Consequently, the *b* parameter for an individual plant in equation 2 is set at 1 based on the idea that grass roots have a constant density all the way to the maximum depth. However, of interest is mean root volume by depth over several grass plants, and so interest lies in finding the distribution of the mean *b* parameter over several plants. Since it is assumed the mass is evenly distributed with depth for an individual plant, the max root depth data provides a means of estimating the mean *b* distribution. This is accomplished in the following manner. First, re-sample with replacement all max depths (n = 19). Assuming a uniform mass by depth distribution for each plant, find the average mass fraction for each depth layer over the 19 plants. Next, estimate *b* using the average fraction by depth profile with the method of non-linear least squares. Perform this re-sampling 19 times total and compute the average of the *b* estimates. Finally, repeat the entire process 10,000 times to obtain the bootstrap distribution of the mean *b* parameter. The 19 max depths from Table 18 result in a mean *b* distribution that is well-modeled by a normal distribution with mean 2.19 and standard deviation of 0.036 as seen in Figure 12.

Since the data shown in Table 18 are the only data available, the distribution in Figure 12 is used to model both the Area 5 and Area 3 average *b* parameter. Finally, the distribution in the GoldSim models is truncated at 1 to keep average *b* greater than or equal to 1. This truncation was done so that root mass by depth decreases as depth increases. Values of *b* less than 1 cause root mass to increase with depth which is directly opposite to our current understanding of root mass by depth.

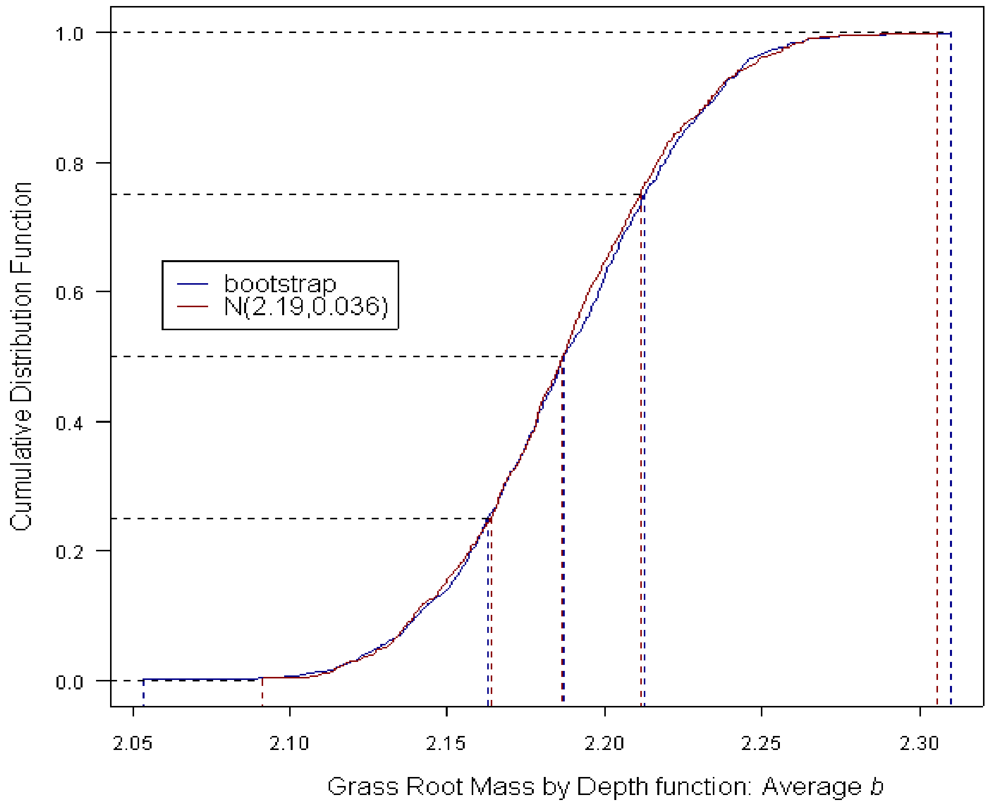

Figure 12. Comparison of bootstrapped and normal cumulative distributions for the mean *b* parameter of the grasses root mass by depth distribution. This distribution is used to model both Area 5 and Area 3 grasses average *b* distributions.

11.3 Outstanding Issues for Root Mass by Depth Distributions

There are outstanding issues regarding the development of parametric distributions of relative root mass by depth for the shrub and grass categories.

1. More information is necessary to support finer results for modeling distribution of roots in soil.
2. Future modeling may be made easier by treating each species independently instead of forming shrub categories. A concern for the number of parameters in the model has led to the current categorization of shrubs.
3. Interval statistics are difficult to work with. Limited data are difficult to impose assumptions upon, such as normality, or other distributional assumptions. Furthermore, such data are difficult to extract parameter estimates from.
4. Independence is assumed for the maximum depth parameter and the *b* parameter (Equation 1). Data may not be adequate to support the calculation of these parameters. Specifically, data from Tables 4 and 5 of Hooten et al. (2004) are not concurrent, primarily due to the difference in the studies providing the information. This leaves much to be desired in terms of the sufficiency of data to concur for the calculation of what are inherently related data issues.

Table 19. Root mass density by depth for creosote bush and saltbush shrub categories.

Top depth interval (cm)	Bottom depth interval (cm)	*Larrea tridentata* (creosote bush)		saltbush		*Atriplex canescens*		*Atriplex confertifolia*	
		%	std dev	%	std dev	%	std dev	%	std dev
	0								
0	10	26.5	2.6	44.5	12.1	43.2	14.9	45.8	19.0
10	20	33.7	6.2	25.9	8.4	25.6	11.8	26.1	11.9
20	30	19.8	6.2	16.6	6.3	19.0	9.6	14.1	8.2
30	40	11.1	5.4	9.1	4.8	9.8	7.8	8.4	5.6
40	50	6.0	6.9	7.2	4.4	10.5	7.8	3.8	4.0
50	60			2.2	3.5	2.5	5.1	1.8	4.8

Table 20. Root mass density by depth for “other” shrub category.

top depth interval (cm)	bottom depth interval (cm)	“Other” shrub category		*Ambrosia dumosa*		*Ambrosia acanthi-carpa*		*Ephedra nevadensis*		*Ericameria nauseosa*		*Krameria erecta*		*Lycium andersonii*		*Lycium palidum*	
		%	std dev	%	std dev	%	std dev	%	std dev	%	std dev	%	std dev	%	std dev	%	std dev
0	50	83.8	8.6	100	0.0	55.0	56.0	100	0.0	31.7	21.9	100	0.0	100	0.0	100	0.0
50	100	11.8	10.3	0.0	0.0	30.0	29.0	0.0	0.0	52.9	66.0	0.0	0.0	0.0	0.0	0.0	0.0
100	150	3.8	3.3	0.0	0.0	15.0	18.0	0.0	0.0	11.4	14.7	0.0	0.0	0.0	0.0	0.0	0.0
150	200	0.6	1.4	0.0	0.0	0.0	0.0	0.0	0.0	4.1	9.9	0.0	0.0	0.0	0.0	0.0	0.0

12.0 Literature Cited

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