Simulating the primary productivity of a Sonoran ecosystem: Model parameterization and validation

Integrating Pattern, Process, Scale and Hierarchy
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CAP LTER
Central Arizona–Phoenix Long-Term Ecological Research

ABSTRACT

We have adapted and reparameterized the PALS-FT model, originally developed for the Chihuahuan Desert, to simulate the aboveground net primary productivity (ANPP) of a creosotebush (*Larrea tridentata*) and bursage (*Ambrosia deltoidea*) co-dominated Sonoran desert ecosystem in the CAP-LTER study area. Model predictions were validated using field observations from an independent test site in the San Simon Valley of the southeastern Arizona. The results showed that PALS-FT was able to simulate ANPP of this typical Sonoran Desert ecosystem reasonably well, with a relative error of -8.8% at the ecosystem level and generally <25% at the functional type level. We then used the model to simulate ANPP and its seasonal and inter-annual dynamics of a similar ecosystem in the northwestern part of the CAP-LTER study area. The model predicted average annual ANPP of the Sonoran ecosystem was 72.3 g $m^{-2}y^{-1}$, ranging from 11.3 g $m^{-2}y^{-1}$ to 229.6 g $m^{-2}y^{-1}$ in a 15-year simulation, which is close to the range of ANPP for arid and semiarid ecosystems reported by other researchers. The dynamics of ecosystem ANPP in response to fluctuations in annual precipitation simulated by the model seemed to agree well with the known relationship between ANPP and precipitation in arid and semiarid systems. An closer examination of this relationship at the level of plant functional types further revealed that the seasonal distribution of rainfall significantly affected ANPP.

RESEARCH OBJECTIVES

- As part of the effort to understand and predict how urbanization affects ecosystem processes in metropolitan Phoenix, Arizona, U.S.A., the main objective of this study was to adapt and evaluate a process-based desert ecosystem model, Patch Arid Land Simulator (PALS-FT), and use the model to address ecological questions in the Sonoran Desert.
- Our future research goals include using the (partly) validated model to investigate how native desert ecosystems respond to changes in multiple environmental factors induced by urbanization, such as rising air temperature, elevated atmospheric CO_2 concentration, and increasing nitrogen deposition.

MODEL DESCRIPTION

PALS-FT is a physiologically-based ecosystem model that simulates the dynamics of C, N, H_2O cycling of a desert ecosystem in a daily time step, with explicit consideration of plant functional types of shrub, subshrub, C4 summer and C3 winter annual grasses, perennial grasses, and forbs. PALS-FT consists of four interacting modules: data organization and input module, water cycling module (**Fig. 1**), plant production module (**Fig. 2**), and nutrient (C, N) cycling module (**Fig. 3**). Model input includes data on climatic conditions, plant and soil C and N storage, and plant ecophysiological parameters. Major model output variables include net primary productivity, soil evaporation, canopy transpiration, vegetation cover of FTs within the modeled patch, and soil organic matter.

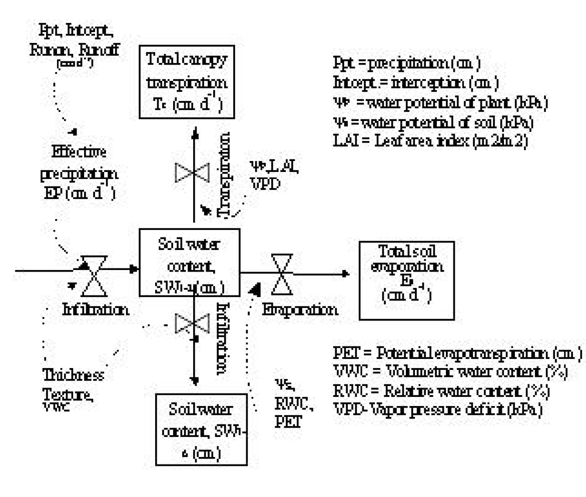

Fig.1. Flow diagram for water cycling processes in the PALS-FT model.

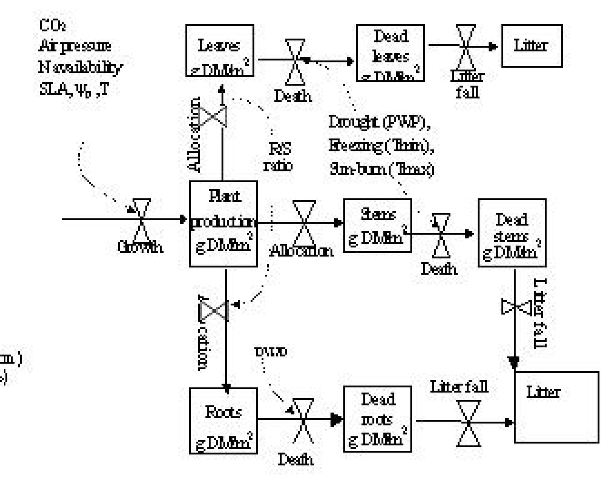

Fig. 2. Schematic diagram of the plant production module for shrubs in the PALS-FT model.

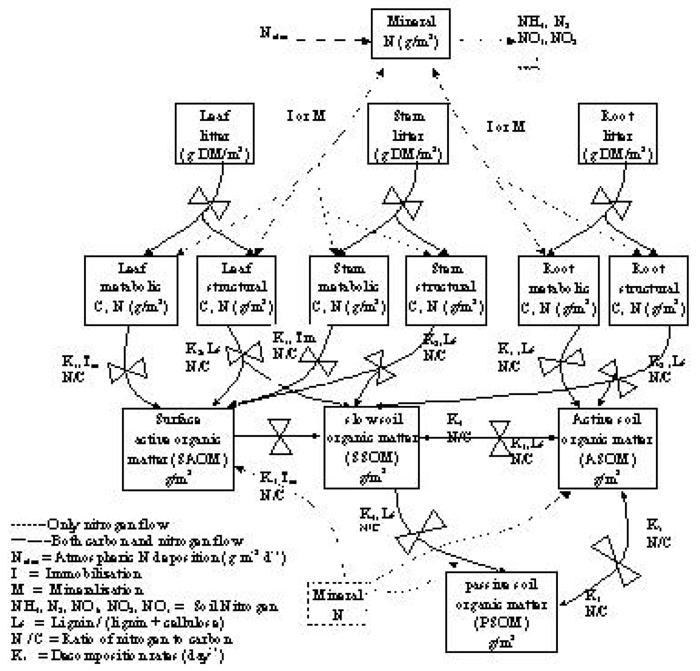

Fig. 3. Schematic diagram of the nutrient cycling module in the PALS-FT model.

MODEL PARAMETERIZATION

The input parameters of PALS-FT model were classified into two groups: site-specific parameters and plant ecophysiological parameters. Site parameters include climatic parameters, living and dead plant biomass, and soil physical and chemical properties, etc. The plant ecophysiological parameters include plant root distribution fractions at different soil layers, contents of nitrogen, carbon, lignin and cellulose in leaves, stems and roots, production allocation ratios, and so on. The CAP-LTER 200-point survey data were the major source for site-specific parameters, although climatic data were obtained from the Wadell Weather Station (**Fig. 4**) The ecophysiological parameters were mainly obtained from publications and the built-in parameters in the original PALS-FT model.

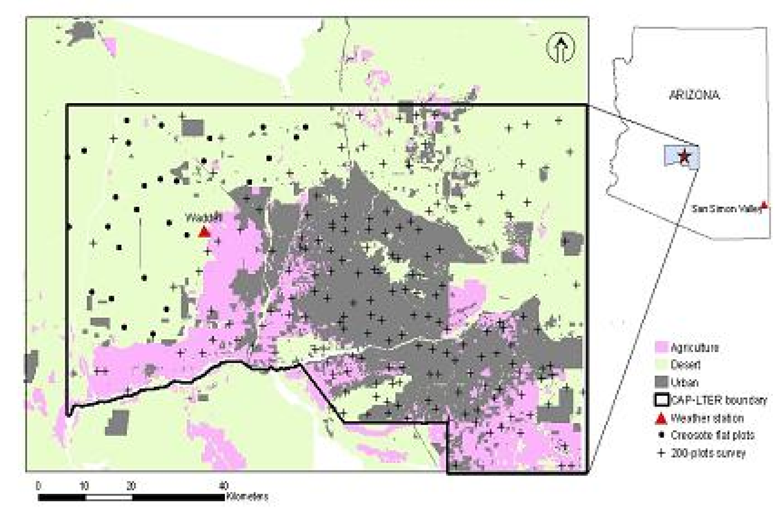

Fig. 4. Maps showing the research sites of this study. Solid dots represent sampling plots of the Larrea ecosystem in the CAP-LTER research area. Solid triangles represent the positions of weather stations from where the meteorological data were obtained for driving the PALS-FT model. The San Simon Valley is the place Chew and Chew conducted their field research on biomass and NPP of a Larrea ecosystem, which was used to validate the model.

MODEL EVALUATION/RESULTS

- To assess the accuracy of the predicted NPP at both the FT and ecosystem levels, we first conducted simulations for an independent test site. The simulated and observed NPP for the San Simon Valley test site showed reasonable agreement for different FTs and the community as a whole (**Fig. 5a**), with the relative error of -8.8% for the whole community, and generally less than 25% for different functional types (**Fig. 5b**).
- For the study area in northern Phoenix, we compared the model-predicted results with those in the literature. The simulated 15-year (1988 to 2002) average ANPP of the ecosystem was 72.3 g m^{-2} yr^{-1}, which was quite close to the observed value for desert scrub communities (70 g m^{-2} yr^{-1};Whittaker and Likens 1973, Ludwig, 1987). The simulated ANNP ranged from 11.3 g m^{-2} yr^{-1} to 229.6 g m^{-2} yr^{-1} (**Fig. 6a**), which was within the range of 10-250 g m^{-2} yr^{-1} estimated by Lieth (1973) for desert scrub ecosystems and that of 30-200 g m^{-2} yr^{-1} estimated by Noy-Meir (1973) for arid ecosystems.
- The ANPP dynamics of the whole ecosystem (Fig. 6a) and four functional types (shrubs, subshrubs, C3 winter annuals, and forbs; Fig. 6b, Fig. 8)were closely related to variations in annual and winter rainfall (Fig. 7). In contrast, the ANPP of C4 summer annuals follow the variations in summer rainfall (Fig.6c, Fig.8, Fig. 7).

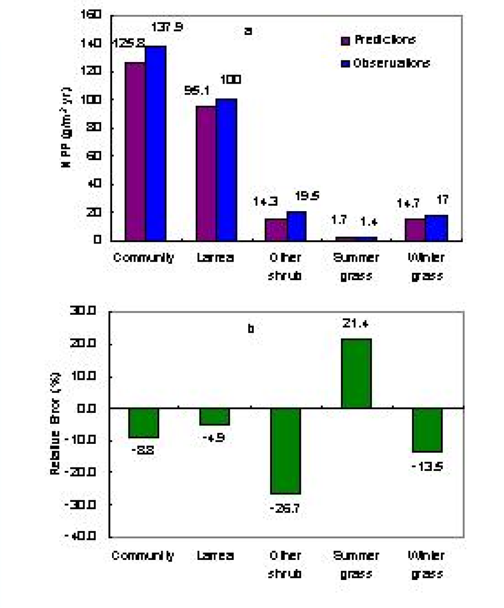

Fig. 5. Comparison of the simulated NPPs with observed NPPs of different plant functional types of the Larrea ecosystem in the San Simon Valley, southeastern Arizona. The observed NPPs are adopted from Table 7 in Chew and Chew (1965

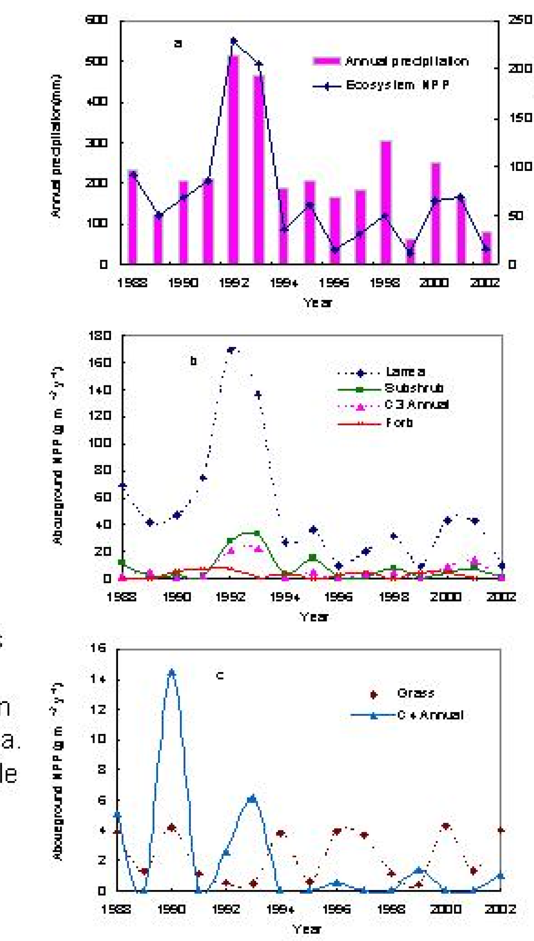

Fig. 6. Simulated decadal dynamics of the aboveground NPPs of 6 plant functional types in the Larrea ecosystem in northwestern Phoenix of the Sonoran Desert.

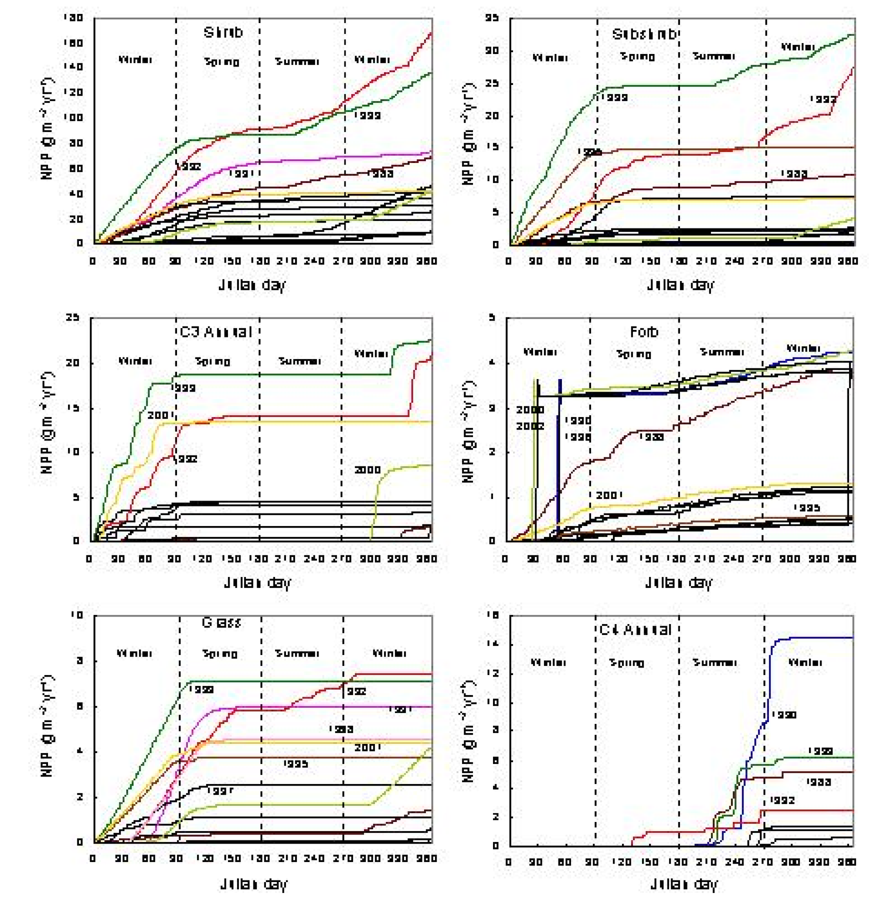

Fig. 8 Seasonal variation of NPPs of different plant functional types in 16 years (1988-2002). Note only those years with larger NPPs are marked.

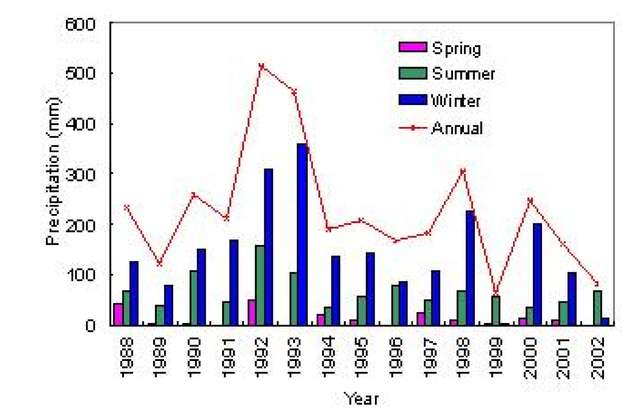

Fig. 7. Seasonal distribution and amount of rainfall in 15 years from 1988 to 2002 in the Northwestern Phoenix of the Sonoran Desert. The three seasons are defined as: spring (April 1 – June 31), summer (July 1 – September 31), and winter (October 1 – March 31).

CONCLUSIONS

- The PALS-FT model was able to simulate the dynamics of net primary productivity of the Sonoran desert ecosystem reasonably well.
- Rainfall seasonality (esp. winter rain) plays an important role in determining NPP of most plant functional types in the Sonoran Desert.
- The PLAS-FT model can be used for understanding the structure and functioning of the native Sonoran desert ecosystem and its response to urbanization-induced environmental changes (e.g., CO_2, temperature, and N deposition).

ACKNOWLEDGEMENTS

We would like to thank Corinna Gries and Diane Hope for help with the preparation of the 200-point survey data and useful suggestions during the course of the study. We also thank Alexander Buyantuyev for creating the map of the study area.