

Forecasting Landscape Change Using State-and-Transition Simulation Models

ESA Workshop

Presented by

Colin Daniel & Bronwyn Rayfield
Apex Resource Management Solutions
apexrms.com

August 16, 2022

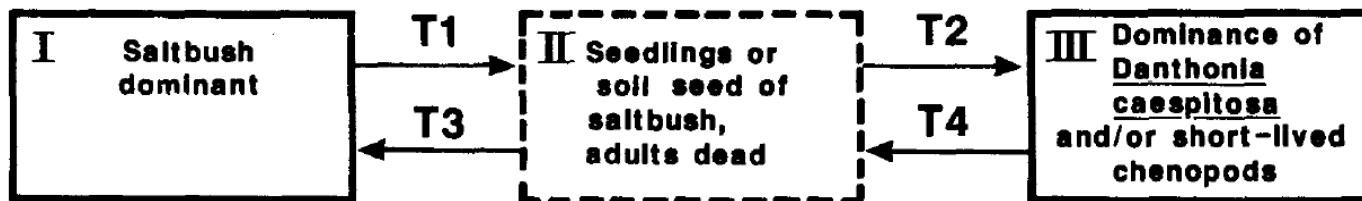
Workshop Objectives

1. **Conceptual overview** of state-and-transition simulation models
2. **Creating and running models** using *SyncroSim* and *ST-Sim*
3. **Scripting modeling workflows** using *rsyncrosim* R package
4. **Case study examples:**
 - U.S. national reference vegetation condition models
 - Forecasting ecological connectivity
 - Species distribution modeling

Origins of State & Transition Modeling

Conceptual State & Transition Models:

- Westoby et al. (1989) for Australian rangelands
- Defines the **states of vegetation** on one piece of ground and the discrete **transitions between states**
- **States:** any suite of vegetation communities
- **Transitions:** process (natural or management) that can move vegetation between states



Source: Westoby et al. (1989)

→ Describe vegetation dynamics

What is a “state-and-transition simulation model” (STSM)?

- Quantitative equivalent of state & transition models
- First developed in early 1990s
→ *mixed vegetation landscapes of western U.S.*
- “Wall-to-wall” representation of different ecological systems
→ *e.g. forests, grasslands, wetlands + land use/land cover*

Methods in Ecology and Evolution



Methods in Ecology and Evolution 2016, 7, 1413–1423

doi: 10.1111/2041-210X.12597

State-and-transition simulation models: a framework for forecasting landscape change

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STSM Approach

State Classes:

D	Deciduous
M	Mixedwood
C	Coniferous

Landscape $t=0$

D5	D4	D4	C21	C22	C22	C23	C24
D2	D8	D8	M14	C21	C26	C27	C28
D1	D3	M11	M12	C22	C26	C28	C30
D1	D1	D2	M17	M18	M18	C29	C31
M19	M18	M18	M17	M19	C32	C33	C36
M17	M17	M18	D3	C20	C29	C41	C45
D8	D7	M19	M18	C22	C22	C28	C36
D8	M17	M17	M16	M15	C21	C20	C21

...Add ages

Daniel et al 2016.
Methods Ecol Evol

STSM Approach

State Classes:

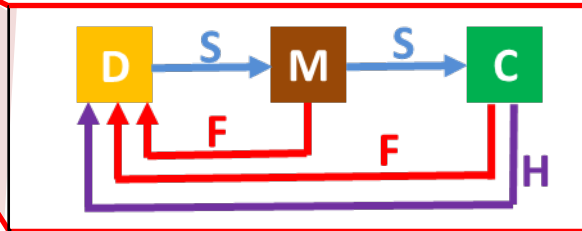
- D** Deciduous
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D1	D1	D2	M17	M18	M18	C29	C31
M19	M18	M18	M17	M19	C32	C33	C36
M17	M17	M18	D3	C20	C29	C41	C45
D8	D7	M19	M18	C22	C22	C28	C36
D8	M17	M17	M16	M15	C21	C20	C21

Transition Types:

- **S** – Succession
- **F** – Fire
- **H** – Harvest



Daniel et al 2016.
Methods Ecol Evol

STSM Approach

State Classes:

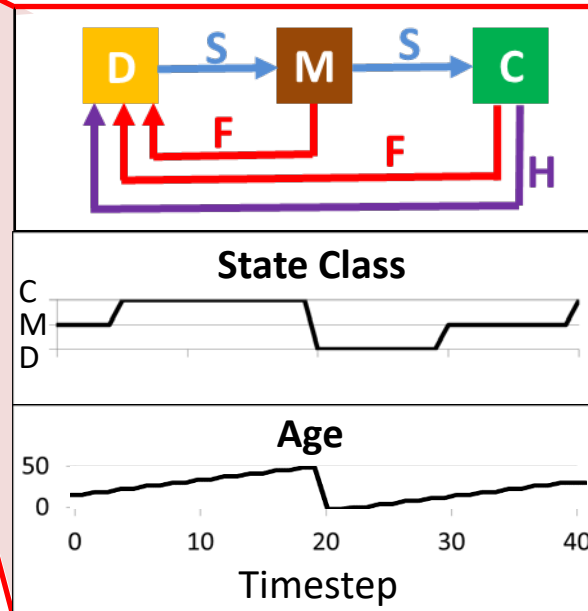
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D1	D1	D2	M17	M18	M18	C29	C31
M19	M18	M18	M17	M19	C32	C33	C36
M17	M17	M18	D3	C20	C29	C41	C45
D8	D7	M19	M18	C22	C22	C28	C36
D8	M17	M17	M16	M15	C21	C20	C21

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Daniel et al 2016.
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D8	M17	M17	M16	M15	C21	C20	C21

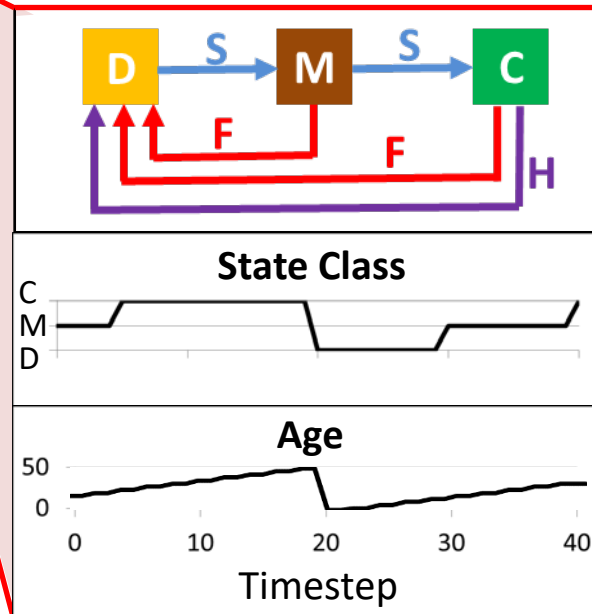
Landscape $t=40$

C45	M11	M11	M12	C22	D2	D3	D3
C42	C48	C48	M17	C21	C22	D2	M11
C41	C43	D1	D2	C24	C24	C25	M9
C41	C41	D2	D3	C30	C31	D8	D8
C23	C24	D2	D3	D5	M13	D9	M18
C23	C23	C22	C43	M13	M14	M13	M17
M12	M12	C20	C23	D2	D3	M15	M16
M11	D6	C21	C21	C22	C33	C34	C33

Transition Types:

- **S** – Succession
- **F** – Fire
- **H** – Harvest

→ *Can vary over space & time*



Daniel et al 2016.
Methods Ecol Evol

STSM Approach

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D5	D4	D4	C21	C22	C22	C23	C24
D2	D8	D8	M14	C21	C26	C27	C28
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D1	D1	D2	M17	M18	M18	C29	C31
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M17	M17	M18	D3	C20	C29	C41	C45
D8	D7	M19	M18	C22	C22	C28	C36
D8	M17	M17	M16	M15	C21	C20	C21

Realization 1
Realization 2
Realization 3

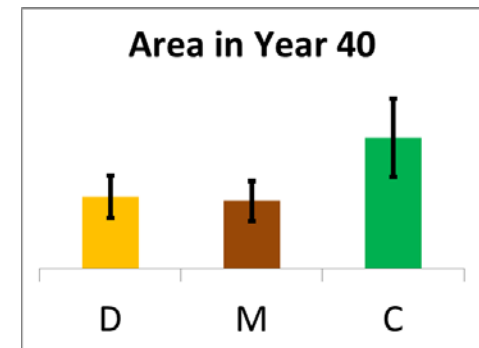


Landscape $t=40$

C							
C							
C	C45	M11	M11	M12	C22	D2	D3
C	C42	C48	C48	M17	C21	C22	D2
C	C41	C43	D1	D2	C24	C24	C25
C	C41	C41	D2	D3	C30	C31	D8
C	C23	C24	D2	D3	D5	M13	D9
C	C23	C23	C22	C43	M13	M14	M13
M	M12	M12	C20	C23	D2	D3	M15
M	M11	D6	C21	C21	C22	C33	C34

→ Monte Carlo simulations provide uncertainty estimates in forecasts

“State-and-transition simulation model” (STSM)



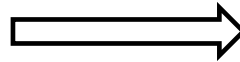
Daniel et al 2016.
 Methods Ecol Evol

Key Features of the STSM Approach

D Deciduous
M Mixedwood
C Coniferous

Landscape $t=n$

D5	D4	D4	C21	C22	C22	C23	C24
D2	D8	D8	M14	C21	C26	C27	C28
D1	D3	M11	M12	C22	C26	C28	C30
D1	D1	D2	M17	M18	M18	C29	C31
M19	M18	M18	M17	M19	C32	C33	C36
M17	M17	M18	D3	C20	C29	C41	C45
D8	D7	M19	M18	C22	C22	C28	C36
D8	M17	M17	M16	M15	C21	C20	C21



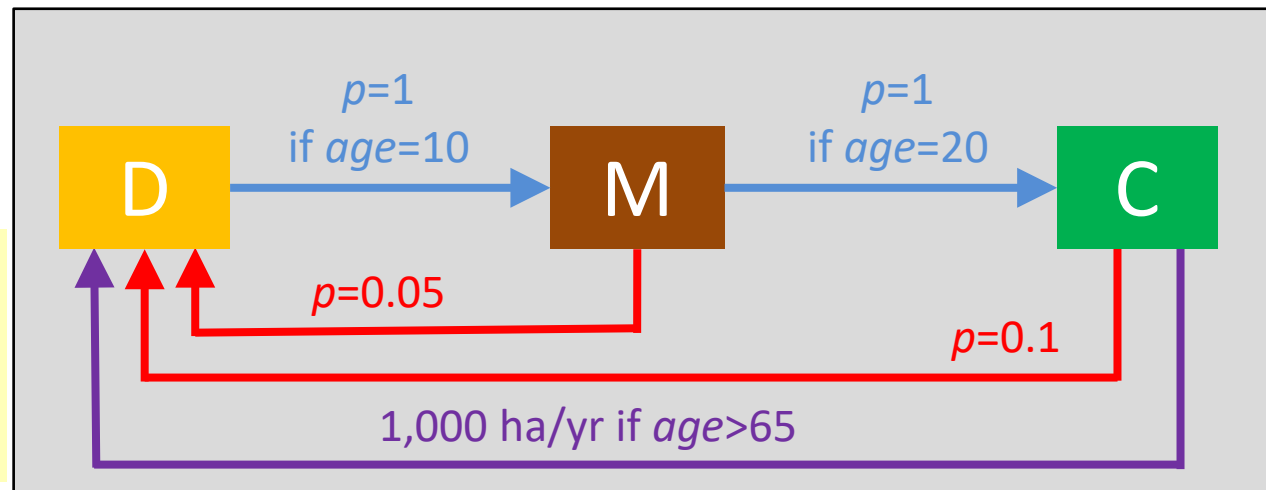
Landscape $t=n+1$

C45	M11	M11	M12	C22	D2	D3	D3
C42	C48	C48	M17	C21	C22	D2	M11
C41	C43	D1	D2	C24	C24	C25	M9
C41	C41	D2	D3	C30	C31	D8	D8
C23	C24	D2	D3	D5	M13	D9	M18
C23	C23	C22	C43	M13	M14	M13	M17
M12	M12	C20	C23	D2	D3	M15	M16
M11	D6	C21	C21	C22	C33	C34	C33

Fire
Succession
Harvest

STSM Features:

- Age as state variable
- Targets for transitions
- Multiple pathways



Adding Temporal Variability

D Deciduous
M Mixedwood
C Coniferous

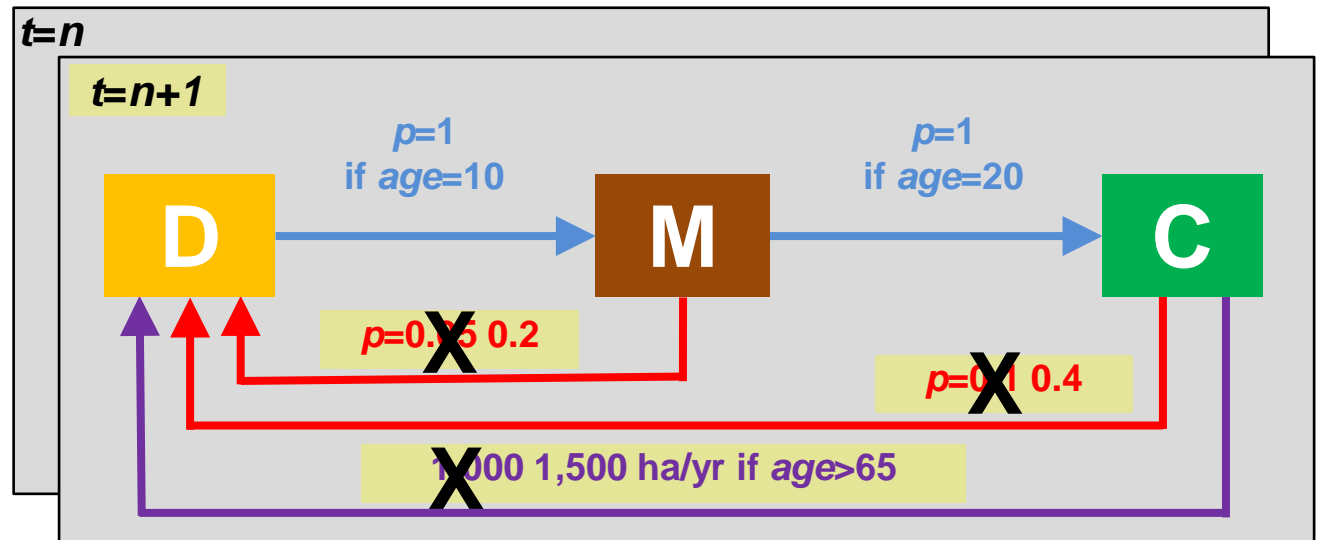
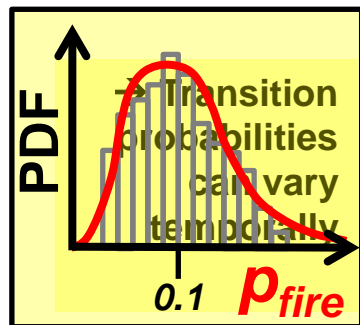
Landscape $t=n$

D5	D4	D4	C21	C22	C22	C23	C24
D2	D8	D8	M14	C21	C26	C27	C28
D1	D3	M11	M12	C22	C26	C28	C30
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D8	D7	M19	M18	C22	C22	C28	C36
D8	M17	M17	M16	M15	C21	C20	C21

Landscape $t=n+1$

C45	M11	M11	M12	C22	D2	D3	D3
C42	C48	C48	M17	C21	C22	D2	M11
C41	C43	D1	D2	C24	C24	C25	M9
C41	C41	D2	D3	C30	C31	D8	D8
C23	C24	D2	D3	D5	M13	D9	M18
C23	C23	C22	C43	M13	M14	M13	M17
M12	M12	C20	C23	D2	D3	M15	M16
M11	D6	C21	C21	C22	C33	C34	C33

➔ Fire
➔ Succession
➔ Harvest



Adding Spatial Variability

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M Mixedwood
C Coniferous

Landscape $t=n$

D5	D4	D4	C21	C22	C22	C23	C24
D2	D8	D8	M14	C21	C26	C27	C28
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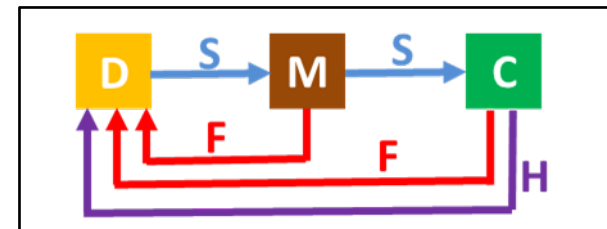
Fire probabilities $t=n$

Fire Model

0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	1
0	0	0	0	0	1	1	1
0	0	0	0	0	1	1	0
0	0	0	0	0	1	0	0
0	0	0	0	0	0	0	0

Landscape $t=n+1$

D6	D5	D5	C22	C23	C23	C24	C25
D3	D8	D9	M15	C22	C27	C28	C29
D2	D4	M12	M13	C23	C27	C29	C31
D2	D2	D3	M18	M19	M19	D1	D1
C20	M19	M19	M18	C20	D1	D1	D1
M18	M18	M19	D4	C21	D1	D1	C45
D9	D8	C20	M19	C23	D1	C29	C37
D9	M18	M18	M17	M16	C22	C21	C22



→ Transition probabilities can also vary spatially

Discrete vs. Continuous State Variables

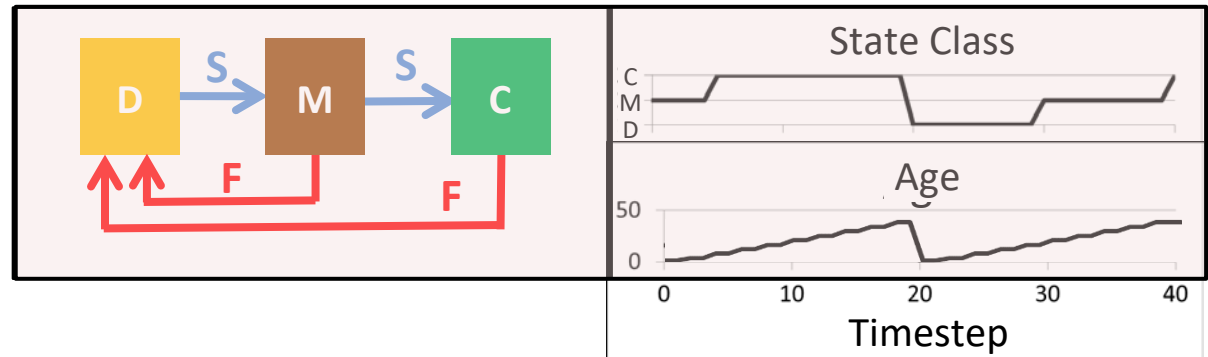
State Classes:

- D** Deciduous
- M** Mixedwood
- C** Coniferous

Transition Types:

- S** - Succession
- F** - Fire

*For
every
cell...*



State Class & Age are both discrete random variables

→ What about adding continuous variables?
e.g. ecosystem carbon

Adding Continuous State Variables

State Classes:

- D** Deciduous
- M** Mixedwood
- C** Coniferous

Transition Types:

- **S** - Succession
- **F** - Fire

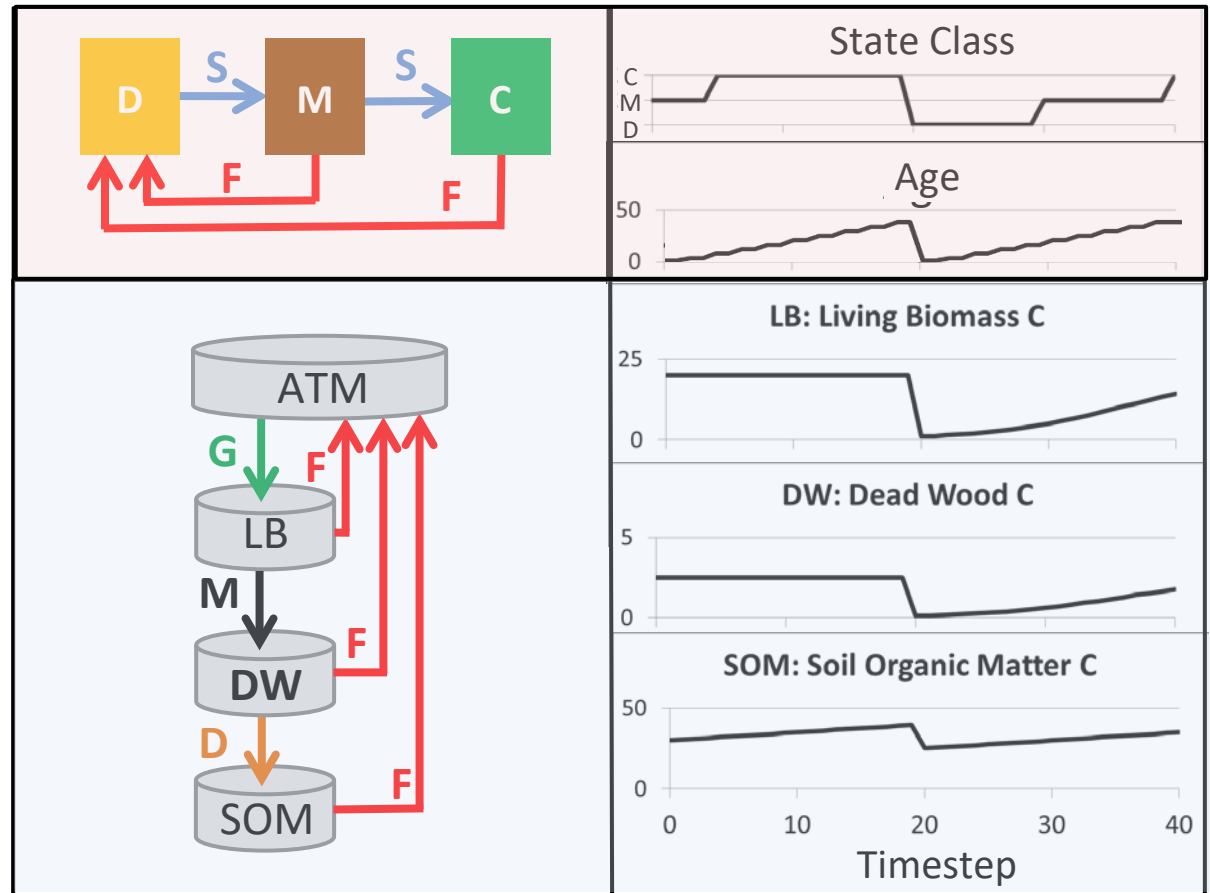
Stock Types:

- ATM** - Atmosphere C
- LB** - Living Biomass C
- DW** - Dead Wood C
- SOM** - Soil Organic Matter C

Flow Types:

- **G** - Growth
- **M** - Mortality
- **D** - Decomposition
- **F** - Fire Emission

For every cell...



Methods in Ecology and Evolution



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Integrating continuous stocks and flows into state-and-transition simulation models of landscape change

Colin J. Daniel [✉](#) Benjamin M. Sleeter, Leonardo Frid, Marie-Josée Fortin

flows =
 f (state classes, transitions)

Software: SyncroSim & ST-Sim

SyncroSim:

- Software framework for scenario-based stochastic simulations over space and time
- Supports “pipelines” of data & models as plug-in *packages*
- see syncrosim.com

Key Sponsors:



ST-Sim:

- Open-source SyncroSim *package* for developing spatially-explicit state-and-transition simulation models (STSMs)
- Hundreds of users
- 30+ peer-reviewed publications
- see stsim.net

ST-Sim Demonstration

Command line version of SyncroSim

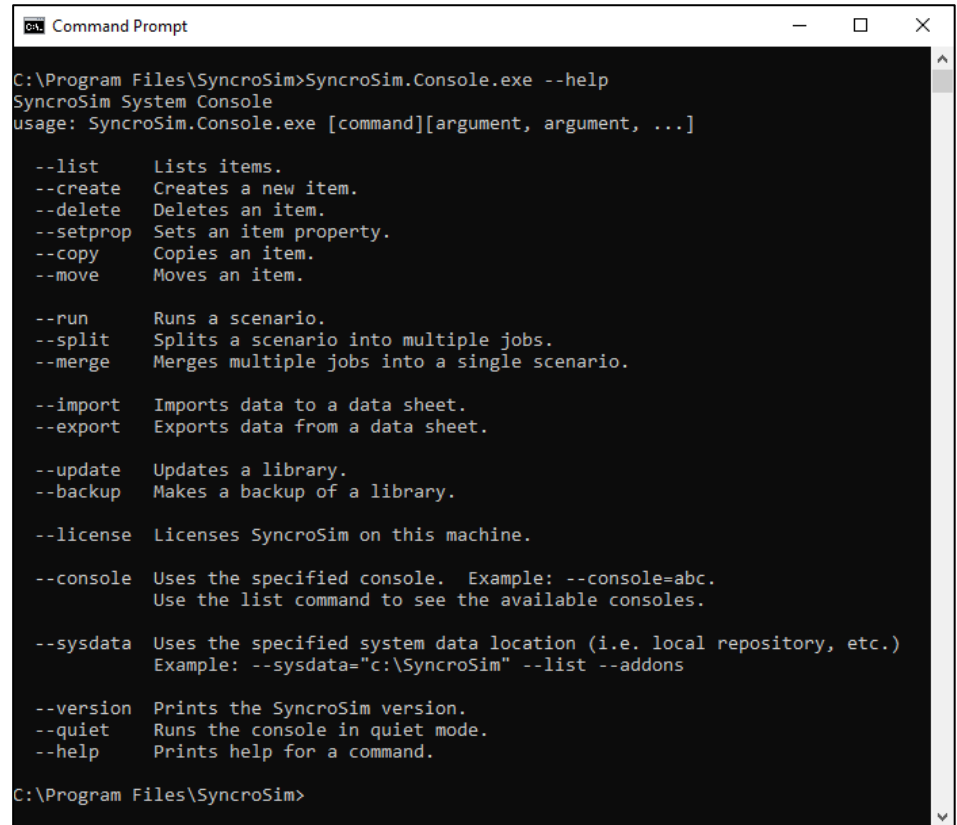
Full functionality available from command line (Windows & Linux)

rsyncrosim R package (available on CRAN)

pysyncrosim Python package (available on PyPi and Anaconda)

Develop end-to-end model workflows:

- pre-processing inputs
- creating models
- running scenarios
- post-processing outputs



```
C:\Program Files\SyncroSim>SyncroSim.Console.exe --help
SyncroSim System Console
usage: SyncroSim.Console.exe [command][argument, argument, ...]

--list      Lists items.
--create    Creates a new item.
--delete    Deletes an item.
--setprop   Sets an item property.
--copy      Copies an item.
--move      Moves an item.

--run       Runs a scenario.
--split     Splits a scenario into multiple jobs.
--merge     Merges multiple jobs into a single scenario.

--import     Imports data to a data sheet.
--export     Exports data from a data sheet.

--update     Updates a library.
--backup     Makes a backup of a library.

--license    Licenses SyncroSim on this machine.

--console    Uses the specified console. Example: --console=abc.
             Use the list command to see the available consoles.

--sysdata    Uses the specified system data location (i.e. local repository, etc.)
             Example: --sysdata="c:\SyncroSim" --list --addons

--version    Prints the SyncroSim version.
--quiet      Runs the console in quiet mode.
--help       Prints help for a command.

C:\Program Files\SyncroSim>
```

docs.syncrosim.com

syncrosim.github.io/rsyncrosim


pysyncrosim.readthedocs.io

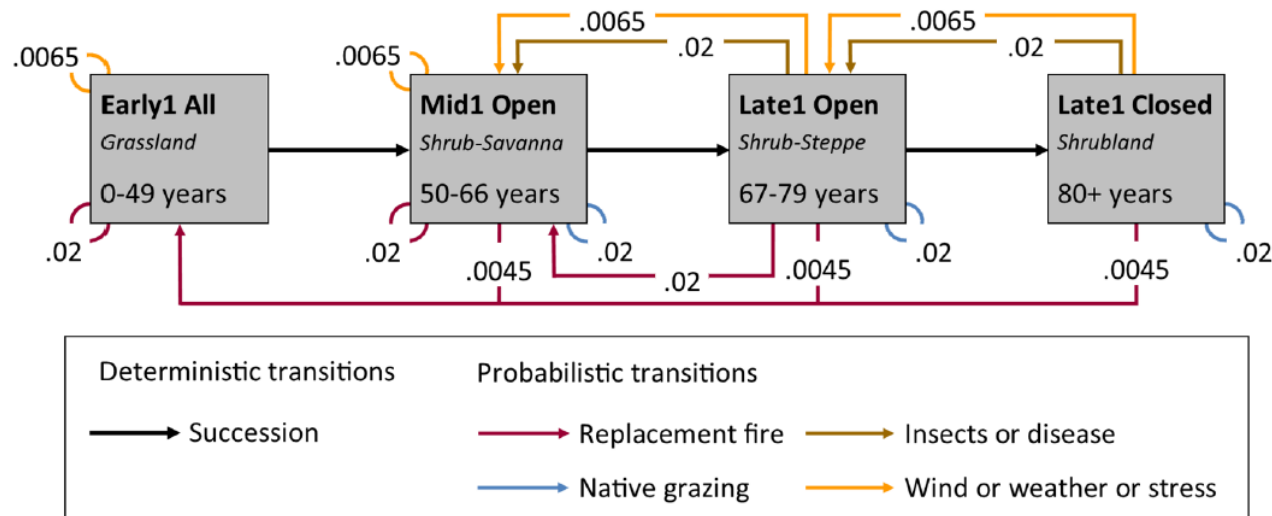
Case Study Example #1



ECOSPHERE

Vegetation dynamics models: a comprehensive set for natural resource assessment and planning in the United States

KORI BLANKENSHIP,^{1,†} RANDY SWATY,¹ KIMBERLY R. HALL ,¹ SARAH HAGEN,¹ KELLY POHL,^{1,3}
AYN SHLISKY HUNT,^{1,4} JEANNIE PATTON,¹ LEONARDO FRID,² AND JIM SMITH¹



thenatureconservancy.github.io/landfiremodels/

Case Study Example #2



ST-Connect SyncroSim Package

RELEASE

V1.1.17



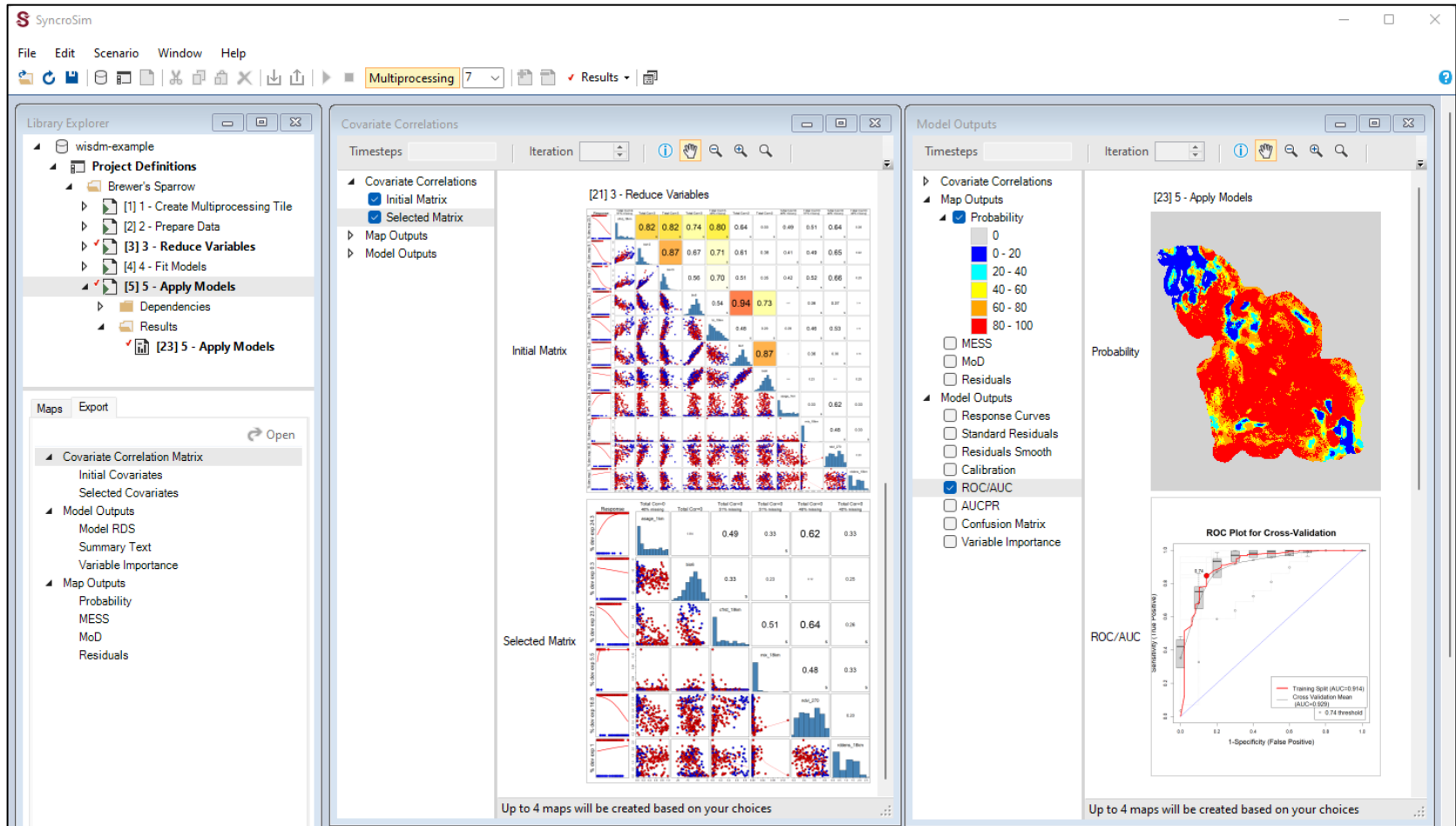
Connectivity planning for future climate and land-use change

ST-Connect is an open-source [SyncroSim](#) Base Package for forecasting landscape connectivity.

apexrms.github.io/stconnect/

Case Study Example #3

Workbench for Integrated Species Distribution Modelling



More Information

Free self-directed course in ST-Sim: apexrms.com/training

SyncroSim software: syncrosim.com

ST-Sim package: stsim.net

Questions?

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