Course Title :
Population Dynamics [Environmental Sciences]
Environmental Management and Policy III

(Advanced course of)

The Theory in Bio-Demography

Kinya Nishimura & Takenori Takada

Application of matrix model to field data

Oct. 10 and 17

Chapter 8

Application of matrix model to field data

Studies on conservation biology

- Gilpin & Soule(1986)
- Shaffer(1990, 1991)
- Menges(1991)

Population Viability Analysis(PVA)
demographic stochasticity
environmental stochasticity important factors
catastrophe

- Schaffer & Samson(1985) Grizzly (Gray bear)
- Lande(1988) Owl
- Damman & Cain(1998) Herbaceous plants
- Lindborg & Ehrlen(2000) Wild maze
- Park et al. (2002) Pathogen
- Garcia(2003) Yam potato

Conservation studies

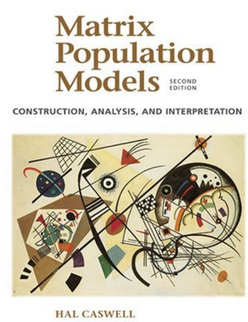
:
:

- Tuljapurkur(1989) Stochasticity in population dynamics
- Iwasa & Hakoyama (1997) stochastic differential equation
- Enright et al.(1998) Elasticity analysis in transition matrix model
- Caswell(2005) Sensitivity analysis in transition matrix model

Theoretical studies

Searching the keyword "Population Viability Analysis",
---> Academic papers 1300

Hal Caswell (2001) 720pp.
Standard textbook



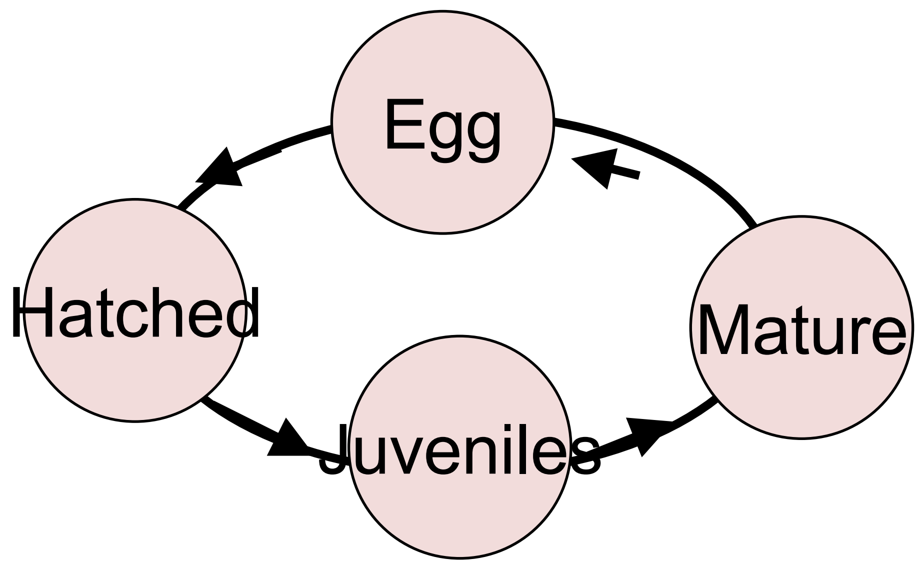
Section 1　Sea Turtle

Conservation of sea turtles

- All the sea turtles (7 species) is nominated as “endangered species”.
- Only eggs and juveniles just after hatching are cared (traditional conservation effort).

Q1：Really endangered？
Q2：What is the direct cause of extinction?
Q3：Is it due to human activity？
Q4：Is the present conservation effort necessary?
Q5：Is the present conservation effort sufficient?

Needs the data on whole life history.



Red sea turtle
(1987 by Crouse et al.)

- An island of Georgia state of US
- 20-year census data
- Setting 7 stages

（Hatched, Juvenile1, Juvenile2,
Pre-mature, Mature1, Mature2, Mature3）

Stage structure model is necessary to follow the whole life history and to answer Q1 to Q5.

1. Population growth rate（Q1）
2. Sensitivity analysis（Q2、Q4）
3. Simulation （Q5）

Population matrix

	Hatched	Juveniles 1	Juveniles 2	Premature	Mature1	Mature2	Mature3
Hatched	0	0	0	0	127	4	80
Juveniles1	0.675	0.737	0	0	0	0	0
Juveniles2	0	0.049	0.661	0	0	0	0
Premature	0	0	0.015	0.691	0	0	0
Mature1	0	0	0	0.052	0	0	0
Mature2	0	0	0	0	0.809	0	0
Mature3	0	0	0	0	0	0.809	0.808

Population growth rate 0. 945

Low sensitivity

Sensitivity matrix

	Hatched	Juveniles 1	Juveniles 2	Premature	Mature1	Mature2	Mature3
Hatched	–	–	–	–	0.012	0.000	0.039
Juveniles1	0.051	0.180	–	–	–	–	–
Juveniles2	–	0.051	0.119	–	–	–	–
Premature	–	–	0.051	0.139	–	–	–
Mature1	–	–	–	0.051	–	–	–
Mature2	–	–	–	–	0.039	–	–
Mature3	–	–	–	–	–	0.038	0.229

Maximum

Simulation in red sea turtle population

(See file "turtle")

Original

$$\begin{pmatrix} 0 & 0 & 0 & 0 & 127 & 4 & 80 \\ 0.675 & 0.737 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.049 & 0.661 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.015 & 0.691 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.052 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.809 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.809 & 0.808 \end{pmatrix}$$

$\lambda = 0.946222$

2 x Egg No.

$$\begin{pmatrix} 0 & 0 & 0 & 0 & 254 & 8 & 160 \\ 0.675 & 0.737 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.049 & 0.661 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.015 & 0.691 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.052 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.809 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.809 & 0.808 \end{pmatrix}$$

$\lambda = 0.983198$

100% survival at hatching

$$\begin{pmatrix} 0 & 0 & 0 & 0 & 127 & 4 & 80 \\ 1 & 0.737 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.049 & 0.661 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.015 & 0.691 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.052 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.809 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.809 & 0.808 \end{pmatrix}$$

$\lambda = 0.9665058$

Summary

1. Population growth rate is less than 1 (bad)
2. Survival of mature and Juveniles is a key factor (sensitivity analysis).
3. Twice egg number or 100% of survival at hatching --→ Population growth rate is less than1 (from the simulation result)
4. Main cause of death is the nets for lobster; Accidental death

↓

The regulation (law) in several states of US requires turtle escaping devices of nets.

Again

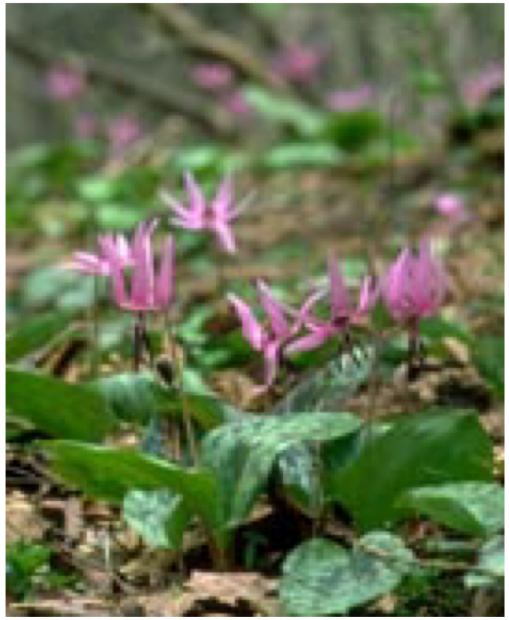
Significance of constructing models

- It allows quantitative analysis from field data.
- Established method (linear algebra) can be applied.
- Can grasp which parameter is a key factor.
- Can estimate the change of result when the assumption is changed.

（Using simulation model of environmental change or change in life history traits ）

Section 2　Dogtooth violet
(*Erythronium japonicum*)

Dogtooth violet population

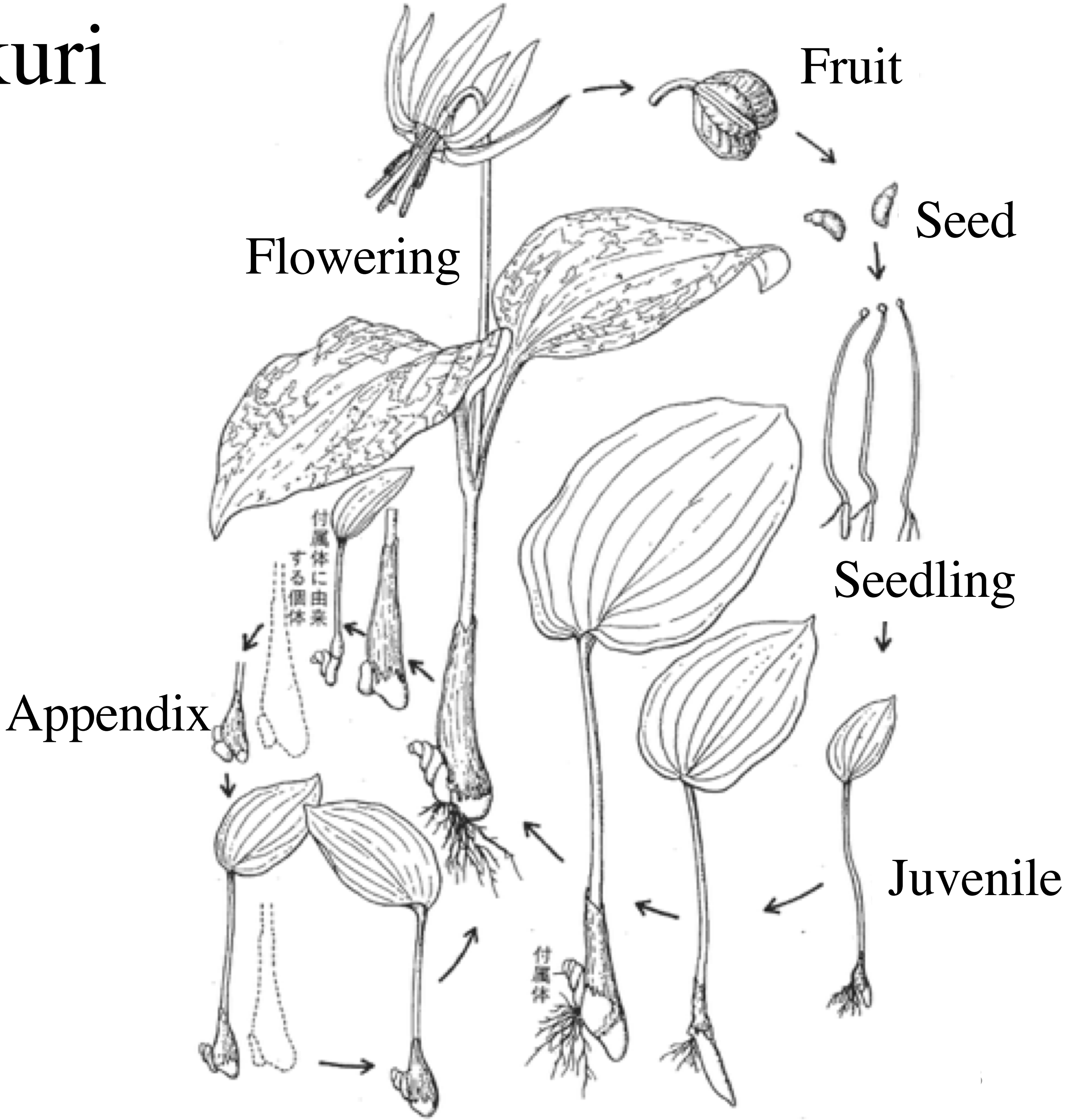


Typical liliaceous species in northern Japan

"Katakuri" in Japanese (*Erythronium japonicum*)

- ✦ Cold temperate zone, Liliaceous,
- ✦ Woodland perennial and polycarpic herbs
- ✦ Make one flower from April to May
- ✦ Pollinated by insects, seeds are transported by ants.
- ✦ It takes at least 8 years to become mature. Long-lived?
- ✦ The data tracing the fate of each individual during 20 years

Life of Katakuri



Population matrix of Katakuri

Seedling | Juvenile | Pre-mature | Mature indi.

	SD	S1	S2	S3	S4	S5	S6	S7	S8-10	S11-13	F8-10	F11-13	F14-16
SD	---	---	---	---	---	---	---	---	---	---	1.70	2.42	2.27
S1	0.17	0.29	0.11	0.03	0.01	---	---	---	---	---	---	---	---
S2	0.27	0.17	0.27	0.07	0.02	0.01	---	---	---	---	---	---	---
S3	0.13	0.06	0.38	0.46	0.09	0.01	0.01	---	---	---	---	---	---
S4	0.03	0.03	0.03	0.25	0.31	0.06	0.01	0.01	---	0.01	---		
S5	---	0.01	0.02	0.05	0.46	0.51	0.05	0.03	0.01	0.01	0.02	---	---
S6	---	0.01	0.01	0.01	0.01	0.29	0.38	0.12	0.02	0.01	0.02	---	---
S7	---	---	---	---	0.01	0.03	0.32	0.14	0.02	---	0.04	---	---
S8-10	---	---	---	---	---	0.02	0.15	0.59	0.54	0.11	0.63	0.20	---
S11-13	---	---	---	---	---	---	0.01	---	0.12	0.20	0.11	0.31	0.13
F8-10	---	---	---	---	---	0.06	0.01	0.03	0.16	0.10	0.11	0.08	---
F11-13	---	---	---			---	0.01	0.02	0.10	0.52	0.07	0.37	0.47
F14-16	---	---	---	---	---	---	---	---	---	0.02	---	0.01	0.40
Survival	0.60	0.57	0.82	0.87	0.91	0.99	0.95	0.94	0.97	0.98	1.00	0.97	1.00

Become sterile

Become adult

Keep flowering

Rarely die

Population growth rate (PGR) and stable stage distribution in Katakuri population

PGR : 1.0545 (corresponding to dominant eigenvalue)

Stage dist.	frequency
Seedling	20.6%
S1	6.6%
S2	9.9%
S3	12.7%
S4	6.6%
S5	8.3%
S6	5.1%
S7	2.6%
S8–S10	12.8%
S11–S13	4.6%
F8–F10	3.8%
F11–	6.3%

(Corresponding to right eigenvector whose Elements' sum is equal to 1)

Flowering (mature) plants

Sensitivity matrix in Katakuri population

Pre-mature

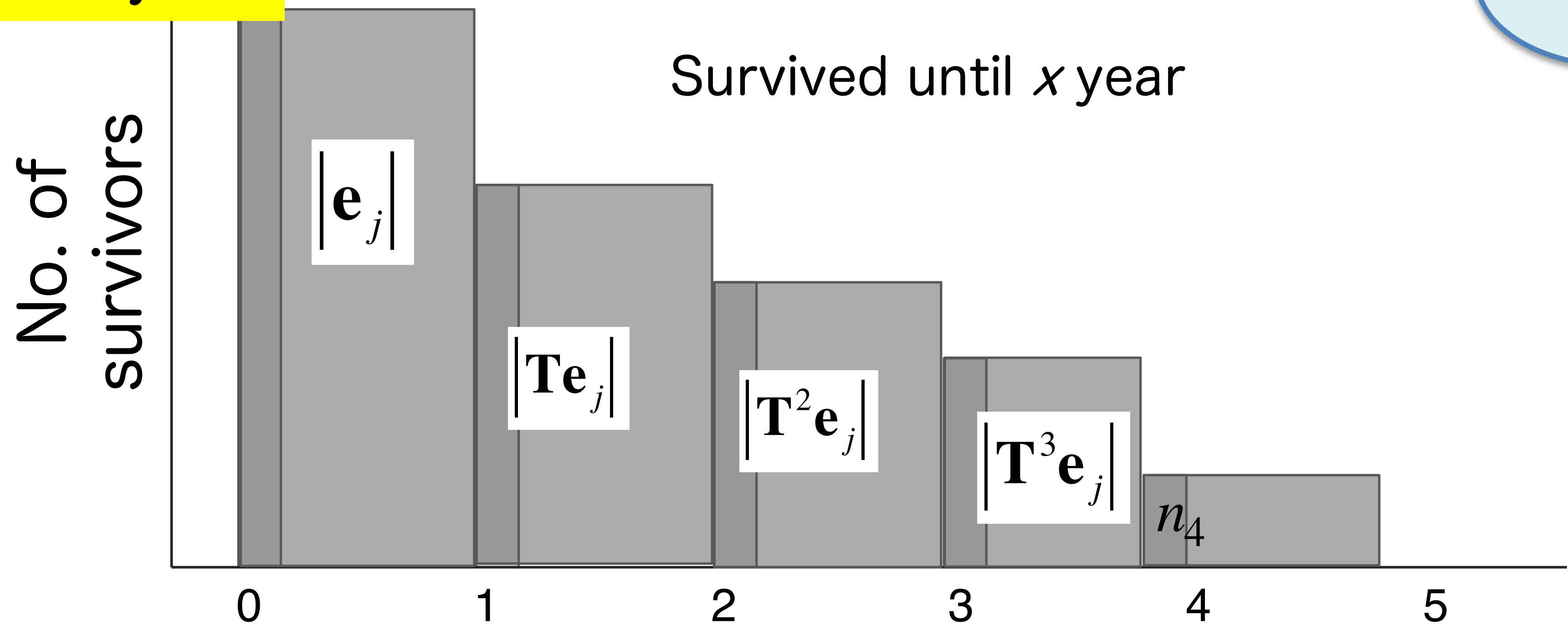
Stage with low sensitivity

Stage with high sensitivity

	SD	S1	S2	S3	S4	S5	S6	S7	S8−10	S11−13	F8−10	F11−13	F14−16
SD	---	---	---	---	---	---	---	---	---	---	0.01	0.01	0.00
S1	0.04	0.01	0.02	0.02	0.01	---	---	---	---	---	---	---	---
S2	0.08	0.02	0.04	0.05	0.02	0.03	---	---	---	---	---	---	---
S3	0.11	0.04	0.05	0.07	0.04	0.04	0.03	---	---	[illegible]	[illegible]	[illegible]	---
S4	0.18	0.06	0.09	0.11	0.06	0.07	0.04	0.02	---	[illegible]	[illegible]	[illegible]	---
S5	---	0.08	0.12	0.15	0.08	0.10	0.06	0.03	0.15	---	0.05	---	---
S6	---	0.09	0.13	0.17	0.09	0.11	0.07	0.03	0.17	0.06	0.05	---	---
S7	---	---	---	---	0.10	0.13	0.08	0.04	0.19	0.07	0.06	---	---
S8−10	---	---	---	---	---	0.15	0.09	0.05	0.23	0.08	0.07	0.01	0.00
S11−13	---	---	---	---	---	---	0.11	---	0.28	0.10	0.08	0.01	---
F8−10	---	---	---	---	---	0.18	0.11	0.06	0.28	0.10	0.08	0.02	0.00
F11−13	---	---	---	---	---	---	0.13	0.07	0.33	0.12	0.10	0.03	0.00
F14−16	---	---	---	---	---	---	---	---	---	0.14	---	0.05	0.00

Matrix way

Again



Remaining lifetime at stage *j*: $\lfloor \mathbf{T}^0 \boldsymbol{e}_j \rfloor + \lfloor \mathbf{T}^1 \boldsymbol{e}_j \rfloor + \lfloor \mathbf{T}^2 \boldsymbol{e}_j \rfloor + \cdots$

$= \sum_{i=0}^{\infty} \lfloor \mathbf{T}^i \boldsymbol{e}_j \rfloor$

| $\mathbf{e}_j$ |: the sum of the elements in the vector

T: Transition matrix)

Remaining life time of Katakuri

Stage		Remaining life time	
Seedlings	SD	10.9	
Juvenile	S1	9.5	
	S2	16.9	
	S3	22.0	
	S4	29.3	
	S5	35.1	
	S6	34.3	
	S7	35.2	
Infertile indi.	S8-10	37.2	Pre-mature
	S11-13	37.7	
Fertile indi.	F8-10	38.2	Mature
	F11-13	37.4	
	F14-16	39.1	

Today's quiz as Report 2 (2020. 10. 17)

Comment on population dynamics of *Erythronium japnicum*

Complete your own comments on the population dynamics of *Erythronium japonicum* based on the data and the result of analysis in this file (One-page Word file).

+

Feel free to write your comments on my lecture

- ✓ **The due date and time : Nov. 15**
- ✓ **Filename: Your name and student number**
- ✓ **Send to: takada@ees.hokudai.ac.jp**

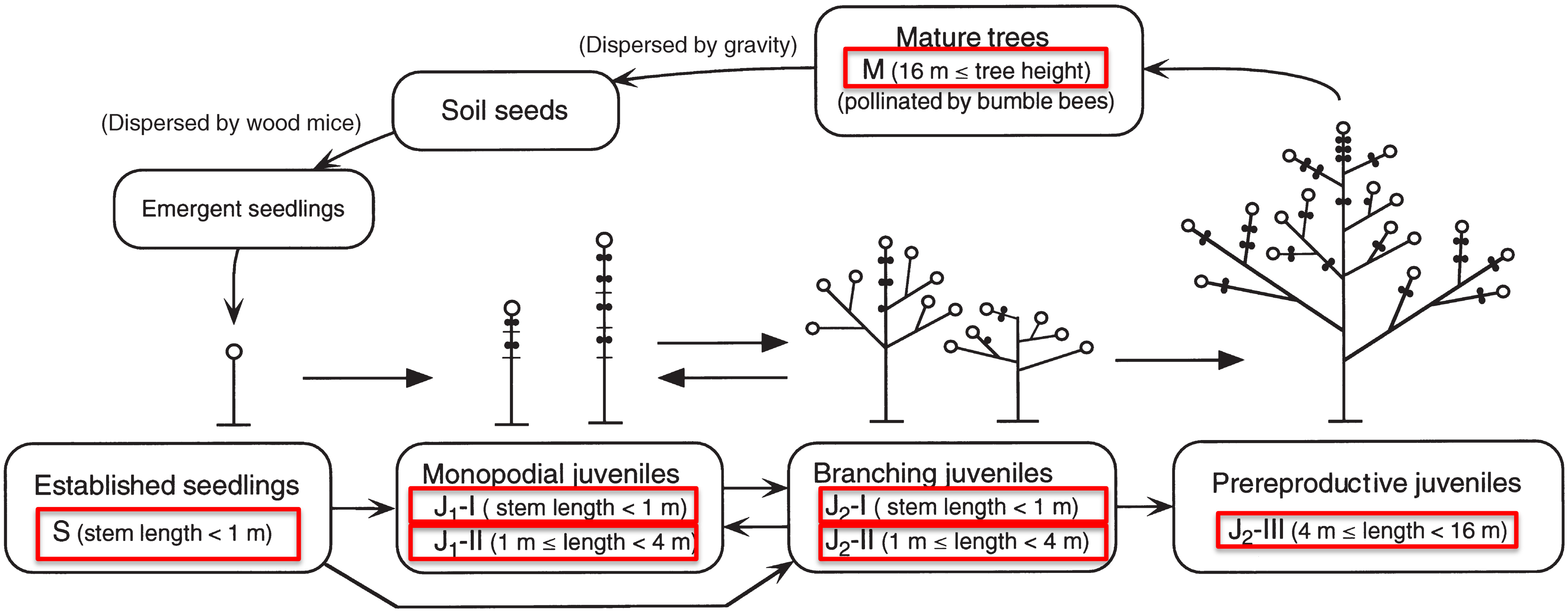
Section 3　Horse Chestnut
(*Aesuculus turbinata*)

Kaneko et al. (1999)
Plant species biology, *14*(1), 47-68.

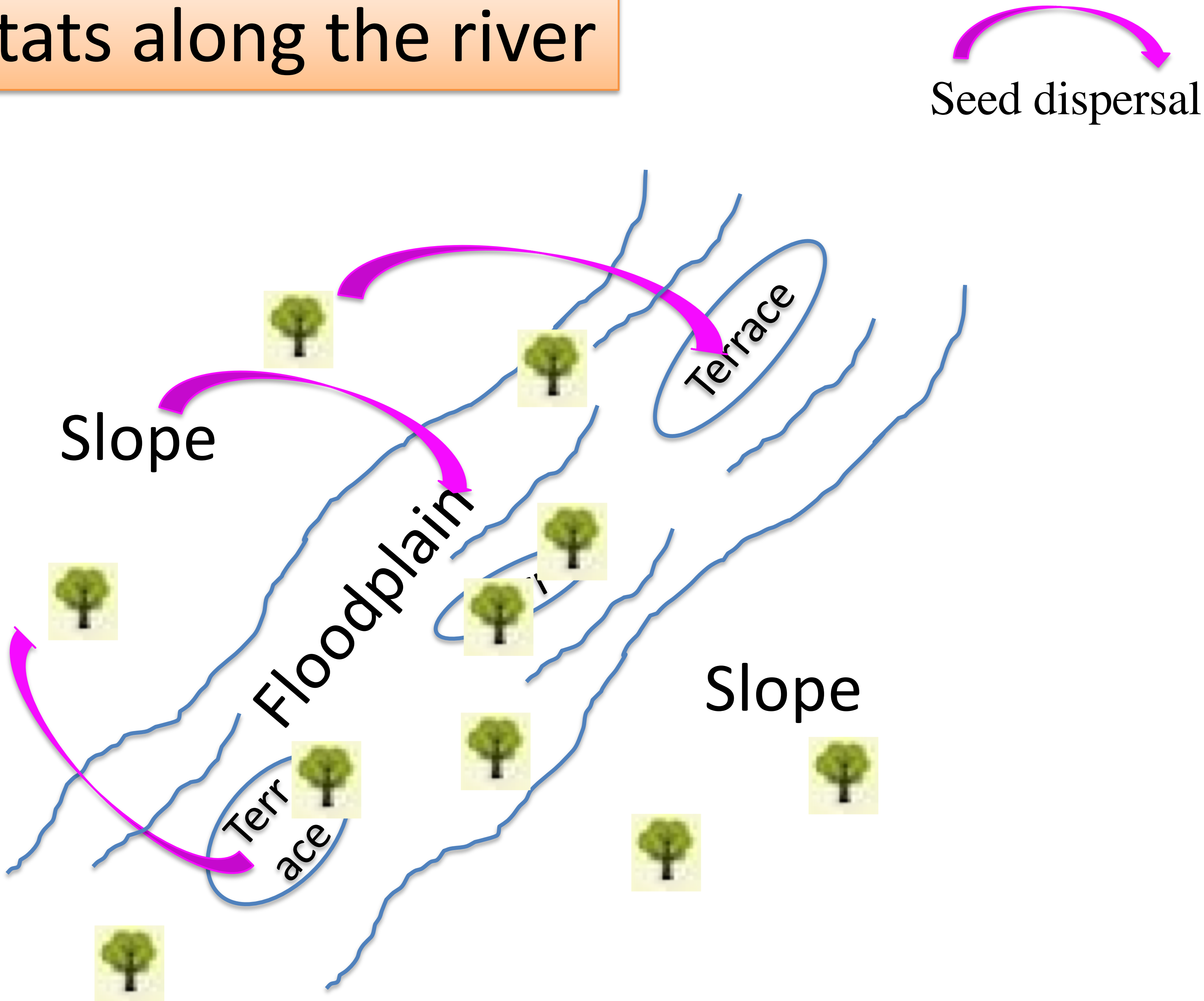
Horse chestnut (*Aesuculus turbinata*) Marronnier

- Typical riparian tree in cool-temperate forest.
- Deciduous (maximum 30 m height, DBH 1 .5 m)
- Biggest seed size in Japanese temperate forest.
- Longevity: 80 to 150 years
- The data tracing the fate of each individual during 6 years

7 developmental stages in Horse chestnut



3 habitats along the river



Metapopulation

＊ describing the heterogeneity of habitats

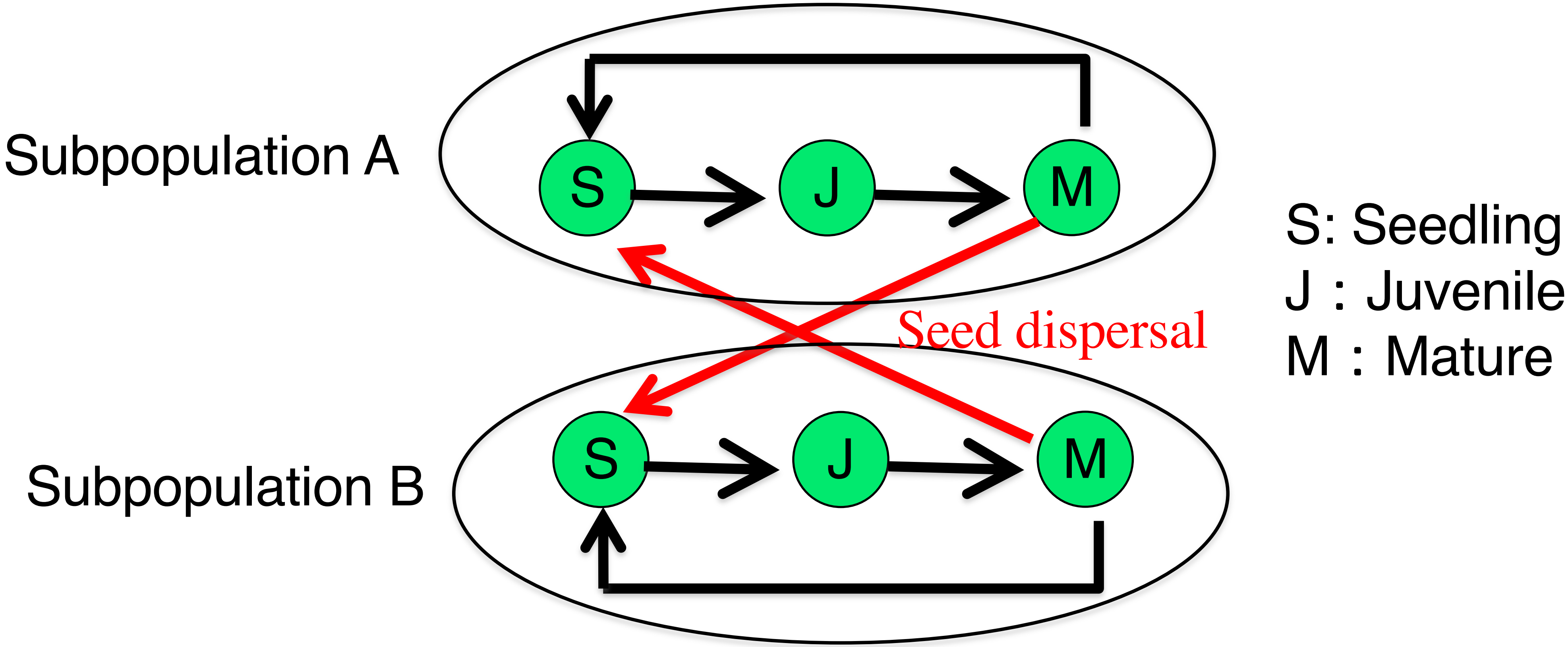
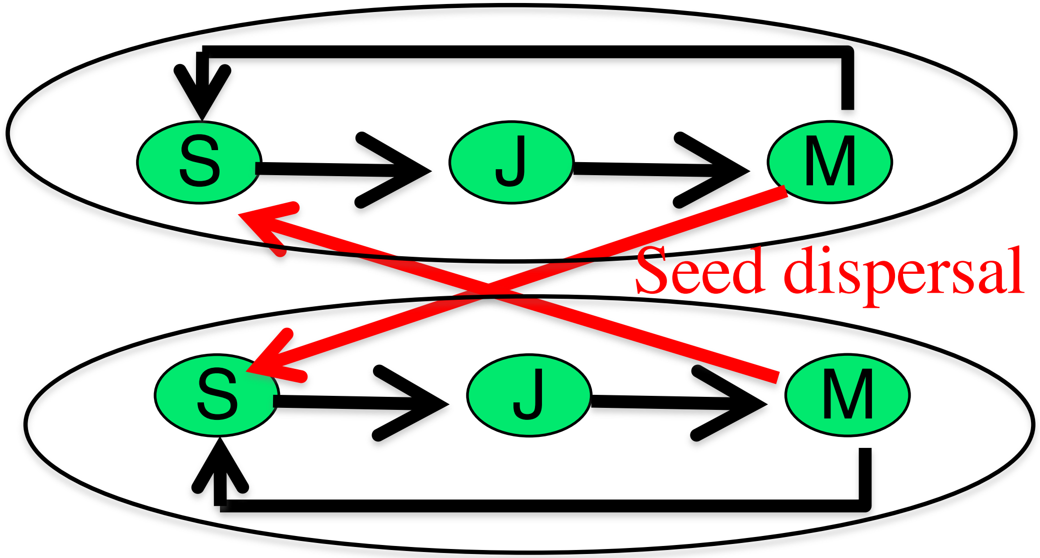


Illustration of seed dispersal by mature trees

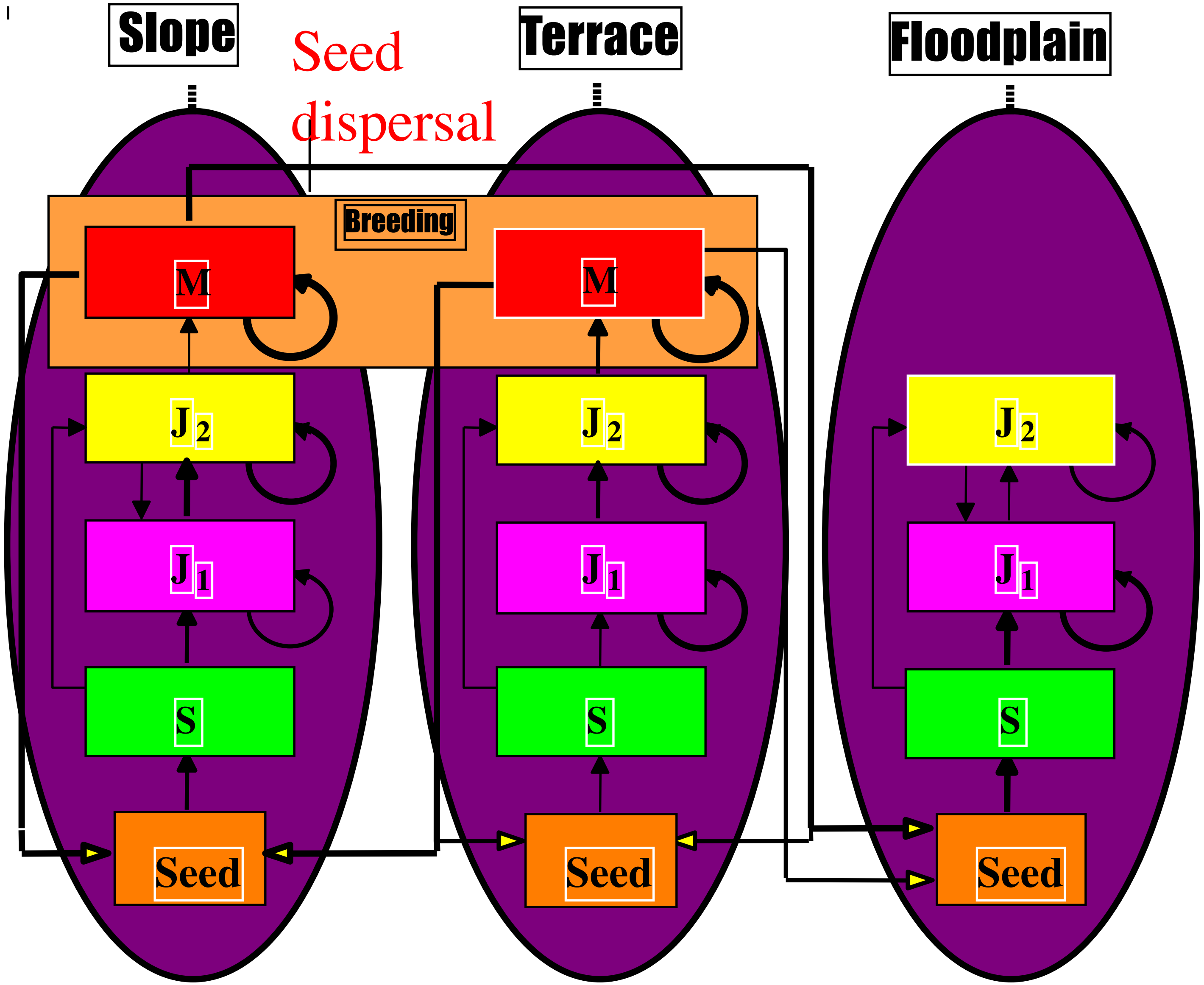
Population matrix in metapopulation



This year

			Subpopulation A			Subpopulation B		
			S	J	M	S	J	M
Next year	Sub A	S	0	0	*	0	0	g_{ba}
		J	*	0	0	0	0	0
		M	0	*	0	0	0	0
	Sub B	S	0	0	g_{ab}	0	0	*
		J	0	0	0	*	0	0
		M	0	0	0	0	*	0

Flow chart of horse chestnut



Population matrix of 3 subpopulation
(Connected by seed dispersal ; n=18194)

20 by 20 matrix

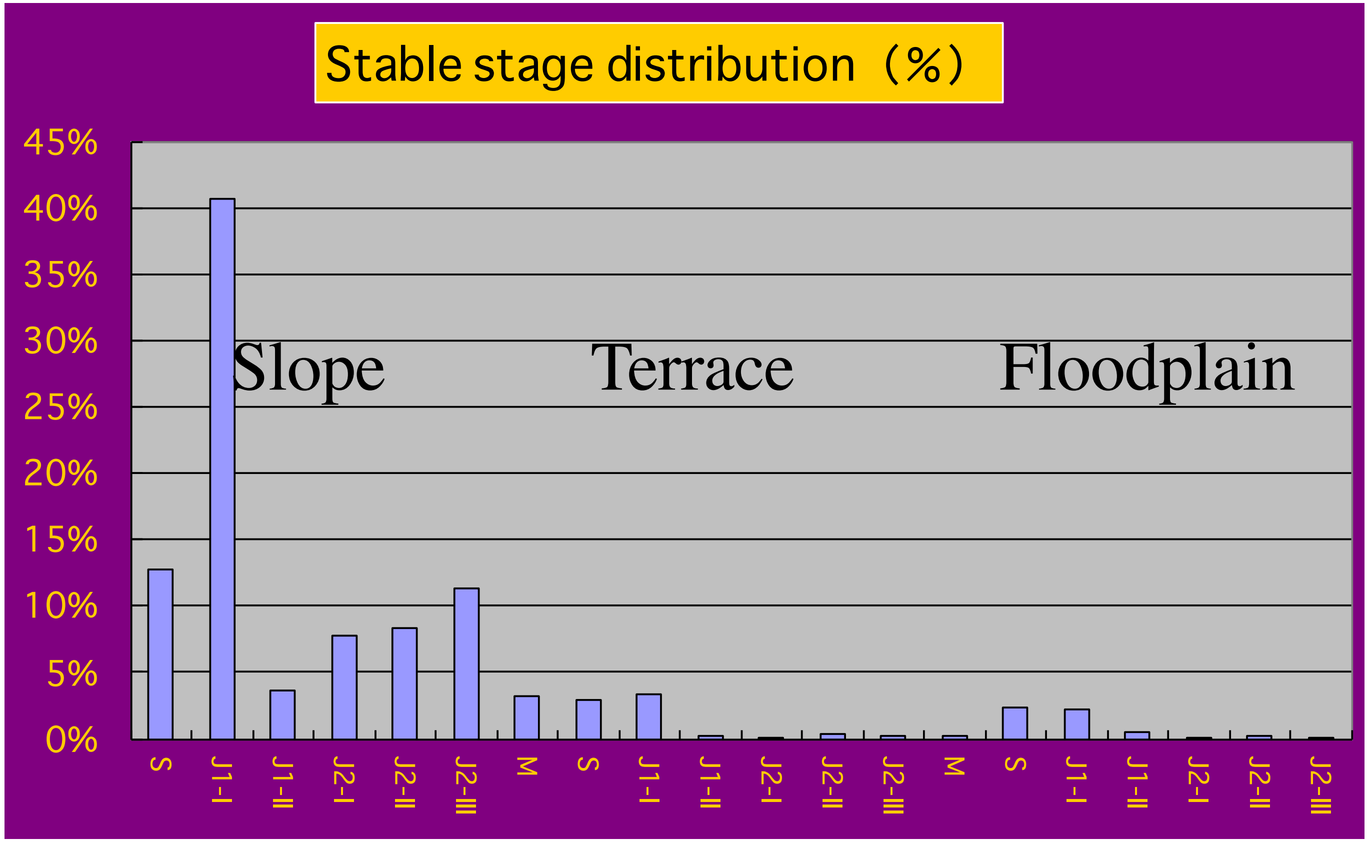
Stage-class		Slope (S)							Terrace (T)							Floodplain (F)					
at Year *t*+1		S	J_1-I	J_1-II	J_2-I	J_2-II	J_2-III	M	S	J_1-I	J_1-II	J_2-I	J_2-II	J_2-III	M	S	J_1-I	J_1-II	J_2-I	J_2-II	J_2-III
S	S	0	0	0	0	0	0	3.68							5.14						
	J_1-I	0.7830	**0.7710**	0.1670	0	0	0														
	J_1-II	0	0.0246	**0.7500**	0	0	0														
	J_2-I	0	0.0387	0	**0.8280**	0	0														
	J_2-II	0	0	0	0.1210	**0.9170**	0														
	J2-III	0	0	0	0	0.0661	**0.9810**														
	M	0	0	0	0	0	0.0095	**0.996**													
T	S							0.83	0	0	0	0	0	0	1.16						
	J_1-I								0.3080	**0.7390**	0.4000	0	0	0	0						
	J_1-II								0.026	0.0332	**0.3000**	0	0	0	0						
	J_2-I								0	0.0047	0	**0.7690**	0	0	0						
	J_2-II								0	0	0.100	0.1540	**0.9090**	0	0						
	J_2-III								0	0	0	0	0.0545	**0.9630**	0						
	M								0	0	0	0	0	0.0370	**0.9970**						
F	S							0.663							0.928	0	0	0	0	0	0
	J_1-I															0.4590	**0.5230**	0.1330	0	0	0
	J_1-II															0.0270	0.0615	**0.6000**	0	0	0
	J_2-I															0	0.0154	0	**0.5000**	0	0
	J_2-II															0	0	0	0.4000	**0.8520**	0
	J2-III															0	0	0	0	0.037	**0.8410**

Seed dispersal

Of course, we cannot obtain the population metrics by ourselves.
Programming language is necessary to calculate them.

Basic population metrics

Population growth rate （λ）= 1.0298 (dominant eigenvalue）



Normalized eigenvector (**u**)

Life expectancy

Stage		Slope	Terrace	Floodplain
Seedling	S	21.1	5.8	2.4
Small juvenile 1	J 1 – 1	25.7	12.2	2.8
Small juvenile 2	J 2 – 1	21.1	42.3	3.4
Large juvenile 1	J 1 – 2	112.6	162.7	8.7
Large juvenile 2	J 2 – 2	152.6	237.8	8.3
Pre-mature	J 2 – 3	175.7	378.9	6.3
Mature	M	247.7	363.8	[illegible]

(years)

Elasticity analysis

		Stage-class at Year t																			
Stage-class		Slope (S)							Terrace (T)							Floodplain (F)					
at Year $t+1$		S	J_1-I	J_1-II	J_2-I	J_2-II	J_2-III	M	S	J_1-I	J_1-II	J_2-I	J_2-II	J_2-III	M	S	J_1-I	J_1-II	J_2-I	J_2-II	J_2-III
	S	0	0	0	0	0	0	0.01							0						
	J_1-I	0.01	**0.04**	0	0	0	0														
S	J_1-II	0	0	0	0	0	0														
	J_2-I	0	0.01	0	**0.05**	0	0														
	J_2-II	0	0	0	0.01	**0.10**	0														
	J2-III	0	0	0	0	0.01	**0.26**														
	M	0	0	0	0	0	0.01	**0.38**													
	S							0	0	0	0	0	0	0	0						
	J_1-I								0	0	0	0	0	0	0						
T	J_1-II								0	0	0	0	0	0	0						
	J_2-I								0	0	0	0	0	0	0						
	J_2-II								0	0	0	0	**0.01**	0	0						
	J_2-III								0	0	0	0	0	**0.02**	0						
	M								0	0	0	0	0	0	**0.05**						
	S							0							0	0	0	0	0	0	0
	J_1-I															0	0	0	0	0	0
	J_1-II															0	0	0	0	0	0
F	J_2-I															0	0	0	0	0	0
	J_2-II															0	0	0	0	0	0
	J2-III															0	0	0	0	0	0

High elasticities are concentrated in slope population.

The whole population is mainly supported by slope-subpopulation.

Summary

✧The whole population has high population growth rate (1.0298) enough to increase its size.

✧The maintenance is mainly supported by slope subpopulation.

✧Life expectancy is the largest in terrace subpopulation, while it is very low in floodplain subpopulation because of typhoon flooding.

Section 4 *COMPADRE*

Big database

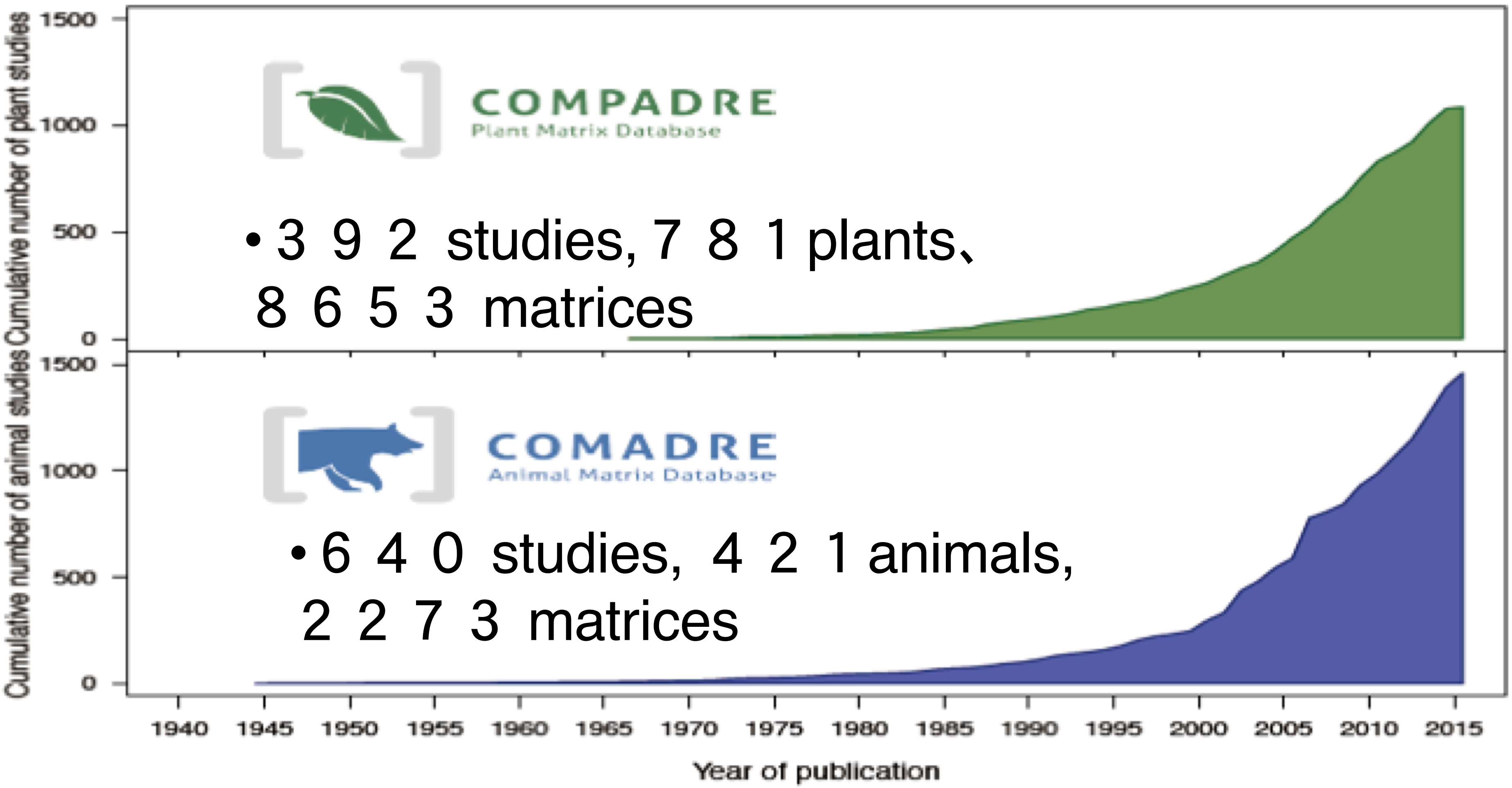
✧ We are now at the beginning of a revolutionary era in demographic research of plant and animal populations.

✧ The databases of projection matrices (COMPADRE; plant database, COMADRE; animal database) are now available online.

✧The database has been presented by Max Planck Institute for Demographic Research (Rostock, Germany).

Database of Matrix Population Model

COMPADRE Salguero-Gómez et al. (2015)
COMADRE Salguero-Gómez, Owen Jones et al. (2016)



- 3 9 2 studies, 7 8 1 plants、8 6 5 3 matrices

- 6 4 0 studies, 4 2 1 animals, 2 2 7 3 matrices

Summary of COMPADRE

Matrix information

- Additional information
  ・Taxonomic names & functional type
  ・Published paper
  ・Geolocation （Latitude/Longitude）, country, continent
- Guideline: see Salguero-Gomez et al.(2015) J. Ecol.103: 202-218.

https://taktakada.github.io/edatabase/index.html

Hello! | Researches | Publication | Population Database

Home > Population Database Introduction

Introduction

Chapter 1 The details of database (COMPADRE)

Click here!

Chapter 3 How to utilize the dataset

Chapter 4 The details of database (COMADRE)

Chapter 5 Resource for studies (COMADRE)

Introduction

About seventy years have passed since Bernardelli proposed the first projection matrix model in 1941. 2014 and 2015 are the beginning of a revolutionary era in demographic research of plant and animal populations. The databases of projection matrices (COMPADRE; plant database, COMADRE; animal database) are now available on the internet, which are the output of an extraordinary effort by Max Planck Institute for Demographic Research (Rostock, Germany). COMPADRE and COMADRE currently contain 12000 population projection matrices of 2200 plant and animal species, accumulated by researchers over the past 70 years. Demographic methods, that were developed in the last half century, enable the derivation of many population statistics such as sensitivities, mean life expectancy, population growth rate. Many related papers have been published, using

Let’s try using COMPADRE database

Pick the population matrix of each population/species and obtain their population growth rates using Mathematica.

(See file “mathma3”)