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{Designing a software tool for environmental modelling and decision making in managing of biological invasion cases}

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Invasive species

- organisms (plant, animal, fungus, or bacterium) occurring in nonnative locations outside of their natural habitat, being able to successfully compete with indigenous populations to establish themselves in foreign environments and spread to the extent of causing damages to the environment, economy and human health
- in the United States 50,000 non-native species have either been introduced or escaped within natural or managed ecosystems

Introduction

introduction

intentional

unintentional/
accidental

economic
environmental
social

byproduct of human activities:
Cargo ships
Ballast water

Intentional introduction

- purposely released for establishment in the wild
- *economic* gain - most common motivation (non-native crops and livestock comprise 98% of US food)
- to solve *environmental* problems: erosion control, biological control as a natural enemy of the target native species
- *social* aspects: recreation activities, sport fishing and hunting, pat animals, aesthetical improvement




Unintentional introduction

- Unintentional or accidental introductions are most often a byproduct of human movements, but are not bound to human motivations
- rats (the black, Norway and Polynesian) have spread to most of the world as hitchhikers on ships
- marine organisms transported in ballast water (e.g., zebra mussel)
- accidental release of the Africanized honey bees to Brazil in 1957
- introduced plant carries a parasite (e.g., *oleander aphid*)




Threats to sustainable development

- a major danger to both marine and terrestrial biodiversity
- leading threat to the diversity of freshwater lakes world-wide
- primary means for human-accelerated global change
- rework ecosystem arrangements, tasks and services
- induce huge economic costs and serious health complications
- major environmental damages and losses in the USA - $120 billion per year
- 80% of the endangered species are threatened and at risk

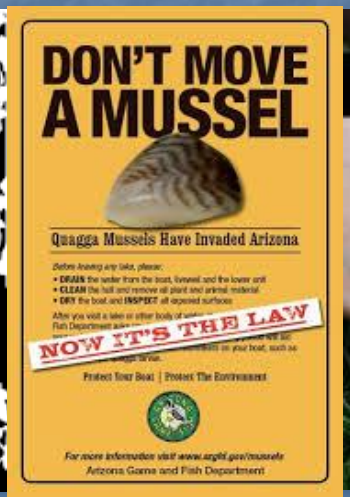
Management and Control

Directions

Prevention

Control

Restoration

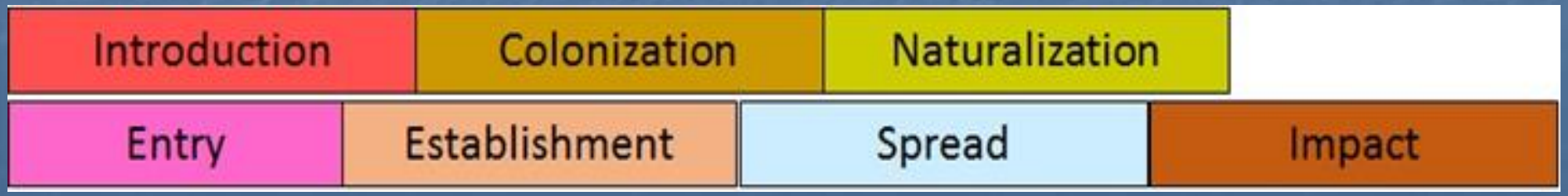


Methodology

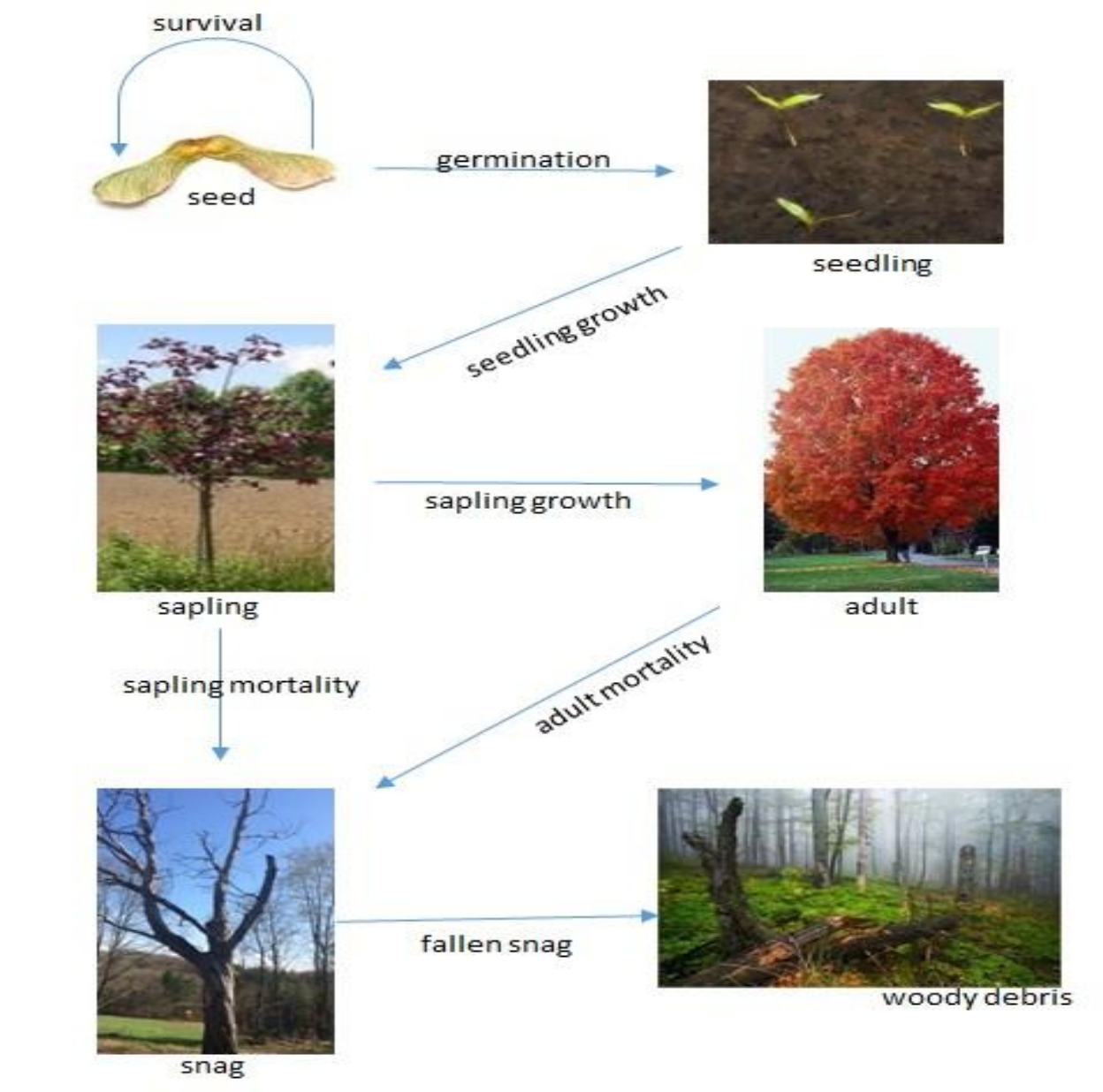
Phases of invasion process

Three phases: introduction, colonization and naturalization (Radosevich *et al.*)

Four phases: entry (arrival of a nonindigenous species into a new environment), establishment (arrived population begins to reproduce in *situ* and escapes immediate danger of local extinction), spread (the species disperses from its initial site of establishment and occupies available habitat within its new environment) and impact (established species persists and competes in its new geographical range) (Wangen and Webster; Andersen *et al.*)



Tree development stages



Ecosystem approach

- alien species produce substantial negative effects on the composition, structure and functioning of the invaded ecosystems
- ecosystems as a whole need to be taken into consideration
- introduction of nonnative species is a stress onto invaded ecosystems
- impacted ecosystem, its components and functions will react to stress in different ways
- important to differentiate between specific categories of stress

TYPES OF ECOSYSTEM STRESSES

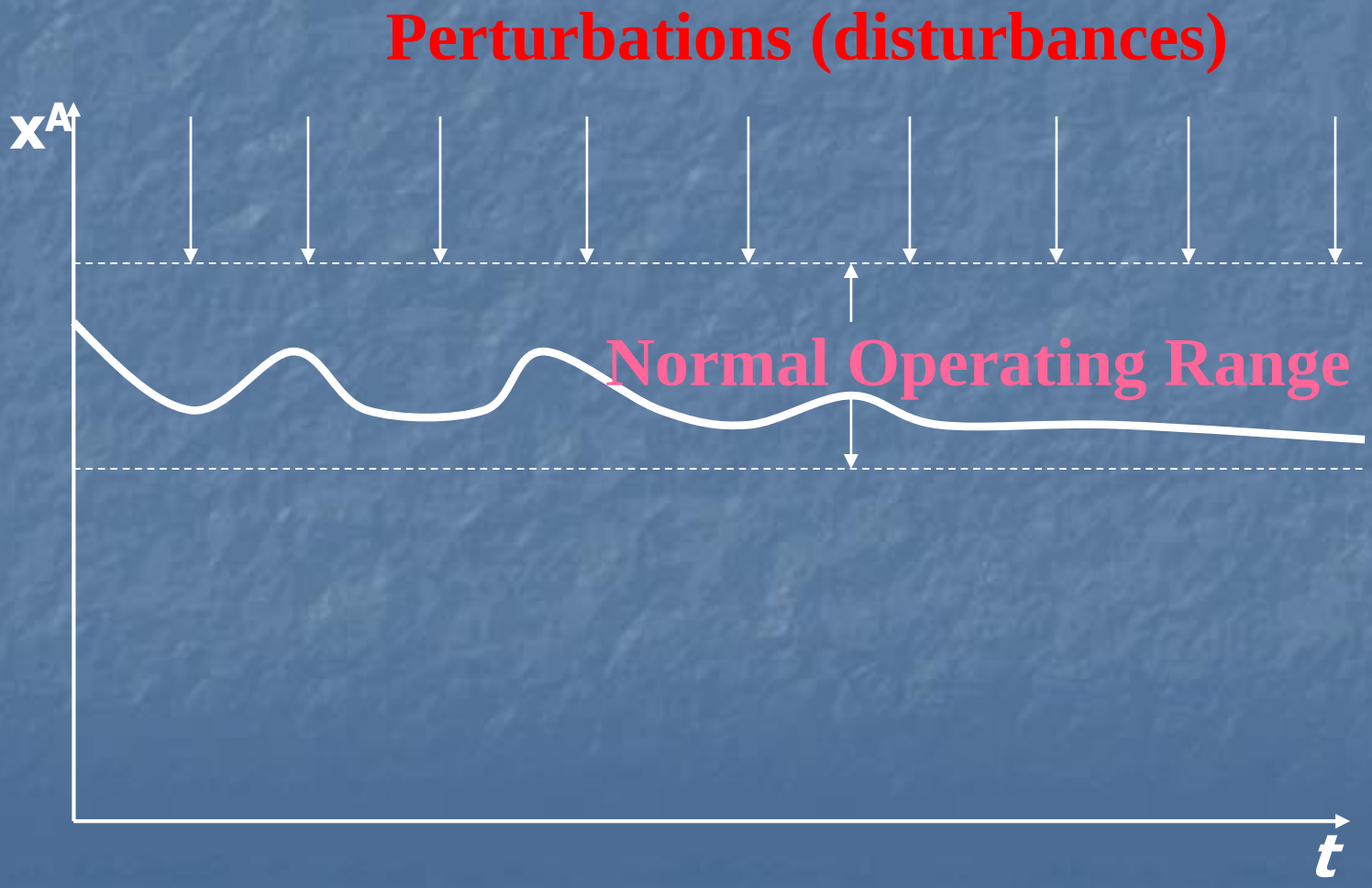
- direct impact on environmental abiotic factors (A-stress)
- that on biological populations in biotic assemblages (B-stress)
- instantaneous impulse (I-stress)
- periodic signals (P-stress)
- monotonous impact (M-stress)
- stepwise impulse (W-stress)
- initial conditions (C-stress)
- parameter values (P-stress)
- ecosystem structure (S-stress)

ECOLOGICAL DYNAMICS AND STABILITY

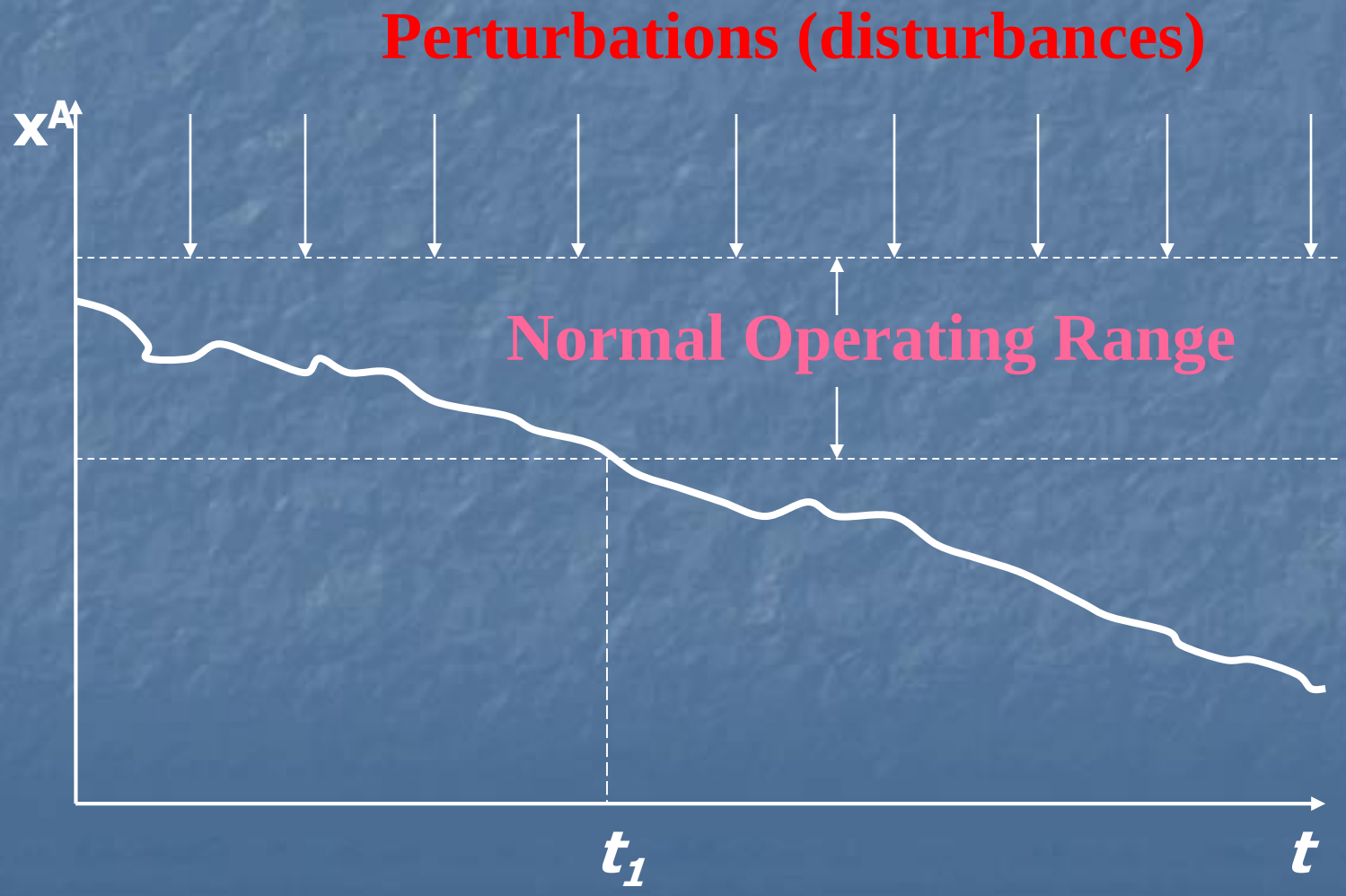
- Resistance stability (RT-type dynamics)
- Deformation (DF-type dynamics)
- Resilience stability (RL-type dynamics)
- Degradation (DR-type dynamics)
- Shift (SS-type dynamics)

From: Holling (1973), Odum (1983), Pimm (1984), Carpenter et al. (1999), Scheffer et al. (2001), Folke et al. (2004), Khaiter (2005), Khaiter and Erechtchoukova (2007)

Resistance (RT-type dynamics)

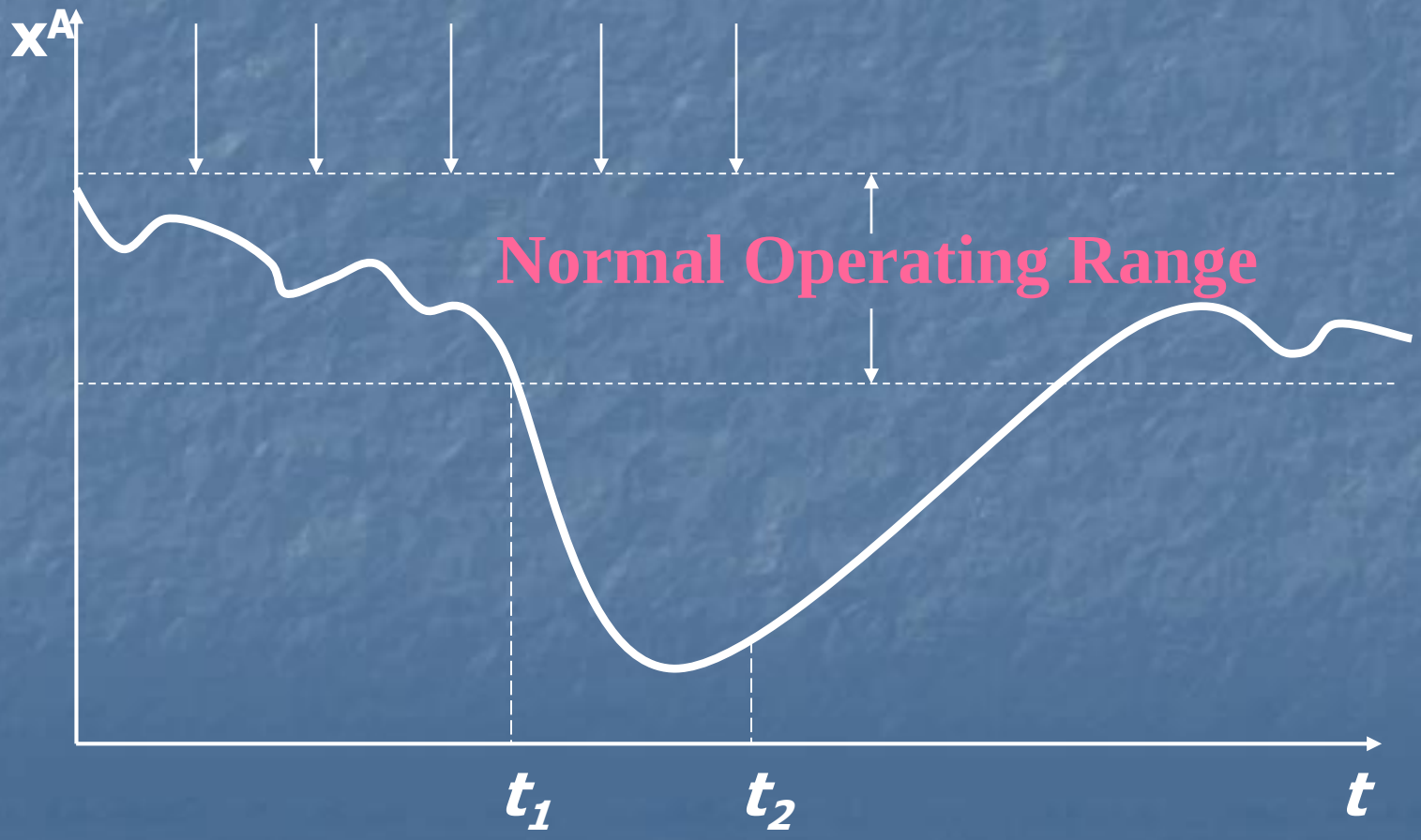


Deformation (DF-type dynamics)

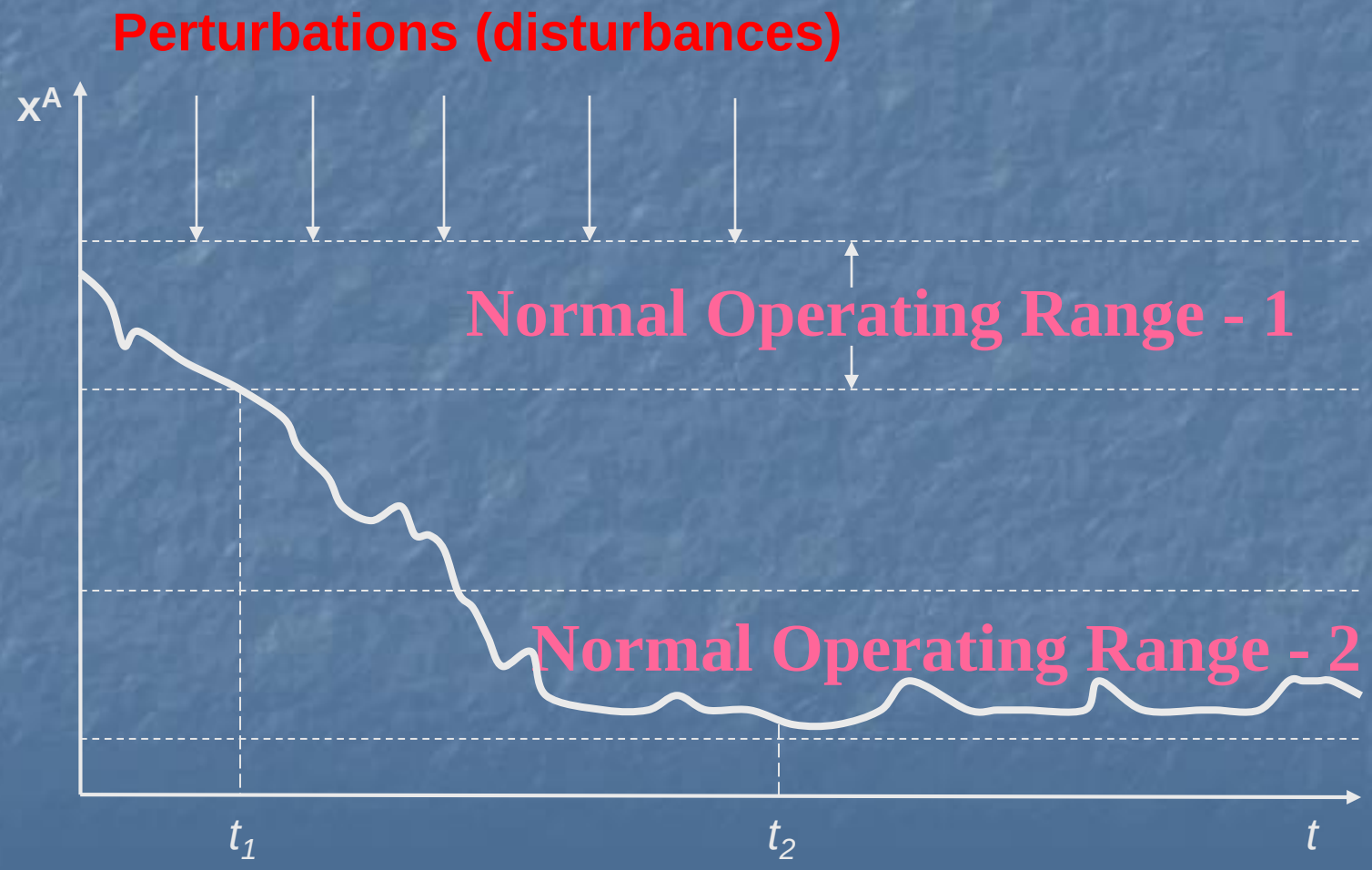


Resilience (RL-type dynamics)

Perturbations (disturbances)

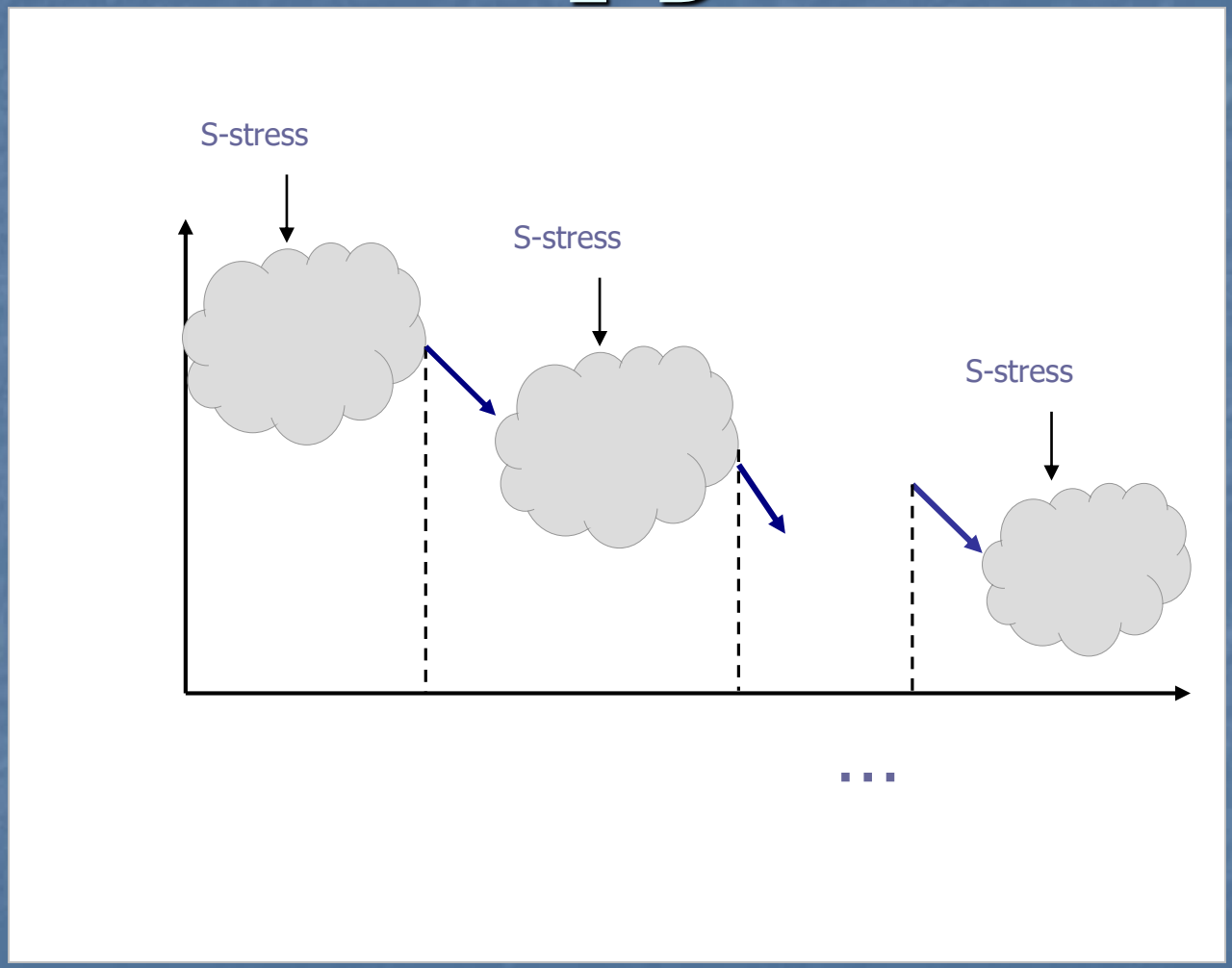


Degradation (DR-type dynamics)



Shift (SS-type dynamics)

Critical points and structural domains in 1-D



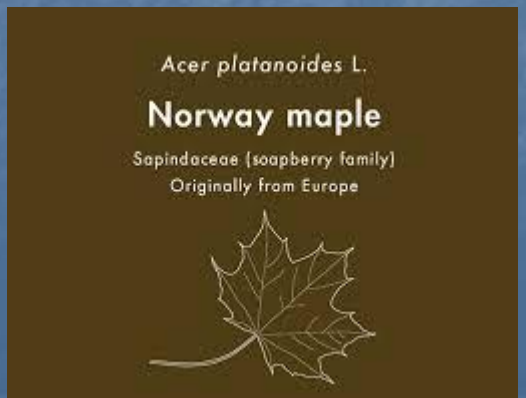
$$M_0 \xrightarrow[t_1^{crit}]{\text{S-stress}} M_1 \xrightarrow[t_2^{crit}]{\text{S-stress}} \dots \xrightarrow[t_l^{crit}]{\text{S-stress}} M_l .$$

Invasion persistence=competition

- resistance to invasion is greater in intact or undisturbed communities (Elton, 1958)
- more complicated interplay of biotic and environmental drivers in the resulting ecosystem resistance (Webb et al., 2000); modified by the environmental factors
- light
- soil nutrients and moisture
- allelopathic interference
- disruption of mycorrhizal associations
- novel symbiotic mutualisms
- can affect critical functions (services)

Norway maple case

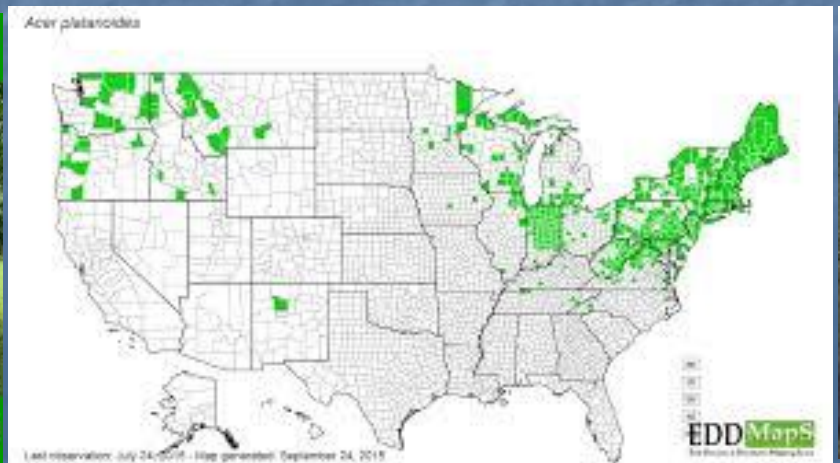
- Norway maple (*Acer platanoides*) is a species of maple native to eastern and central Europe and western Asia, from France east to Russia, north to southern Scandinavia and southeast to northern Iran. Invasive in North America
- North American native sugar maple (*Acer saccharum*)
- Norway maple is a fast-growing, deciduous tree commonly 40 to 50 feet in height, but can reach up to about 100 feet



Maple family

Norway maple: invasion

- native to continental Europe and the Caucasus region
- introduced to Britain in 1683
- imported to North America (Philadelphia) in 1756
- introduced into Canada in 1778
- mode of introduction: intentionally as an ornamental shade tree



Threats to native species

- wide tolerance and adaptation for light (from full sun to part shade)
- adaptation to different soil types (from clay to loam to sand in composition, and either acidic and alkaline)
- strong tolerance for drought, pollution, poor and alkaline soil with good resistance to pests
- casts an extremely dense shade and decreased survival and growth of native species
- has a shallow root system
- early leaf expansion and late leaf drop
- higher inherent growth rate
- can colonize habitats, displace native trees (sugar maples), reduce bio-diversity

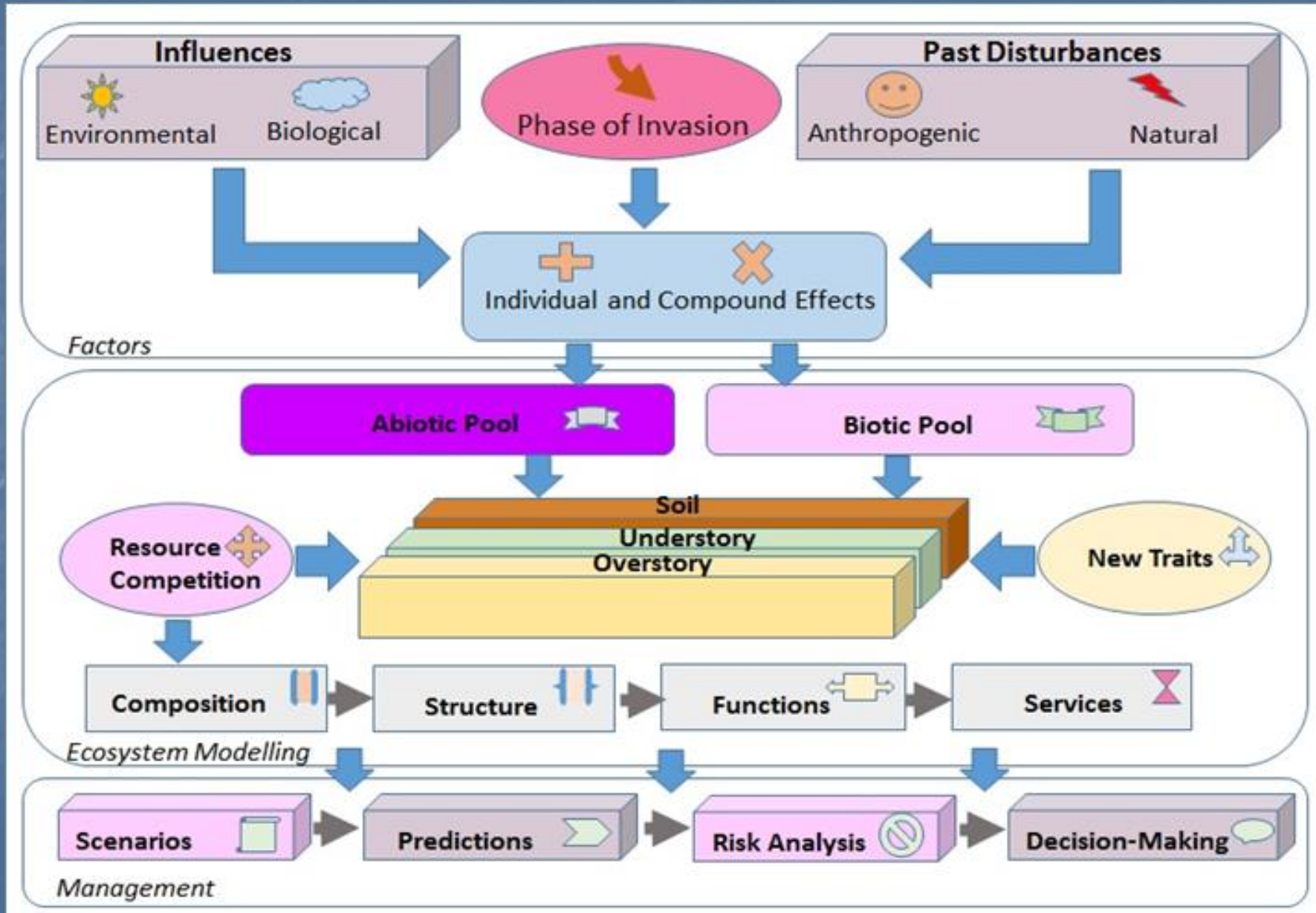
Protection and restoration

- mechanical controls (removal of *A. platanoides* from invaded areas, pull out seedlings while small, gird larger trees)
- considerable difficulty and expense
- effect is not easily foreseeable
- multifactorial and multi-attribute scope of the problem
- great level of uncertainty
- multiple, sometimes conflicting, objectives and numerous parties

EMDMIC

- facilitate management efforts
- integrate relevant knowledge and act as a supporting expert system
- conceptual architecture suitable for a broader range of biological invasions in the forest ecosystems
- three main modules: “Factors”, “Ecosystem modelling” and “Management”


EMDMIC


Influences
Environmental
Biological
Phase of Invasion
Past Disturbances
Anthropogenic
Natural
Individual and Compound Effects
Factors
Abiotic Pool
Biotic Pool
Soil
Understory
Overstory
Resource Competition
New Traits
Composition
Structure
Functions
Services
Ecosystem Modelling
Scenarios
Predictions
Risk Analysis
Decision-Making
Management

“Factors” module

- stage of invasion (introduction, colonization and naturalization or establishment, spread and impact
- specifies natural environmental factors (e.g., topology, geology, substrate, hydrology and meteorology)
- biological factors (e.g., shade tolerance, soil nutrient cycling, phenotypical plasticity, animal and plant parasites and pollinating insects, etc.)
- history of past disturbances both anthropogenic and natural
- assessment of their individual and compound effects and favourable conditions for successful invasion

“Ecosystem modelling” module

- formalized description of invaded ecosystem
- abiotic (or non-living) pool includes physical factors (e.g., temperature, light, pressure, energy, acidity measure, soil depth, soil moisture-retention capacity, etc.) and chemical factors (e.g., oxygen, carbon, phosphorus, nitrogen, sulphur, calcium, etc. levels and availability)
- biotic (or living) pool is organized in hierarchical structures of organisms depending on their roles in the energetic and metabolic processes at the overstory, understory and soil levels
- Invaders will compete with native species for resources (e.g., light, space, mineral nutrients, etc.)
- new traits in the ecosystem
- alter the composition, structure and functioning
- predict all of these transformations

Model groups

- Models of pre-invaded dynamics of native species and the ecosystem as a whole;
- Models of invasive dynamics of the alien species, including mechanisms underlying their invasive success;
- Models of invasive-resident species interactions (e.g., competition for light, space, nutrient resources; possible symbiotic mutualisms, etc.) and their modification by biotic and environmental drivers;
- Models of persistence capabilities to sustain the invasion and probable transformations in invaded ecosystems;
- Models of effect of invasion on critical functions of the ecosystem; that is ecosystem services;
- Models predicting ecosystem components, their short- and long-term dynamics, ecosystem persistence capacity and restoration capabilities in response to each potential managerial effort or scenario;
- Models aimed at selection of the best possible management scenario

Model equations

$$NSG = \%G * NSP \quad (1)$$

$$DBH = \exp\left(a + \frac{b}{TA}\right) \quad (2)$$

$$TH = 1.37 + c * \left[1 - \exp\left(-d * DBH^{f}\right)\right] \quad (3)$$

$$CW = \exp\left\{\frac{MSE}{2} * \left[g + h * \log(\log(DBH + 1))\right]\right\} \quad (4)$$

$$CG = D_{i,j} - (CW_i + CW_j)/2 \quad (5)$$

$$\%L = \frac{CG}{D_{i,j}} * 100\% \quad (6)$$

Model equations

$$x_i^A = TF_{i,k} * x_i^U, \qquad 0 \le TF_{i,k} \le 1, \forall i = 1,..,n, \forall k = 1,..K, \quad \textbf{(7)}$$

$$TFR = \min_{k=1,..,r} \{TF_k\}, \qquad \textbf{(8)}$$

$$TFR = \prod_{k=1}^{r} \{TF_k\}. \qquad \textbf{(9)}$$

Variables and parameters

Variable symbol	Description	Unit
NSP, NSG	Number of seeds planted and germinated	
%G	Germination rate	%
TA	Tree age	years
DBH	Diameter at breast height	m
TH	Total tree height	m
CW	Crown width	m
D	Distance between two neighbouring trees	m
CG	Canopy gap	m
%L	Light level	%
a, b, c, d, f, g, h	Species-specific parameters	

“Management” module

- possible scenarios of the management interventions both in the cases of potential entry of nonnative species and to control them after they have arrived and successfully established in a new habitat
- predictions of ecosystem components, their short- and long-term dynamics, ecosystem persistence capacity and restoration capabilities in response to each potential managerial effort
- mechanisms of invasion, typology of stresses and the common patterns in the ecosystem stress behaviour
- risk analysis due to uncertainty and likely significant cost
- recommended measures
- suggesting resilient solutions for the impacted ecosystems

DISCUSSION AND CONCLUSIONS

- predictions of the invasive stress dynamics of the ecosystems
- Prediction of the invasive potential of a certain alien species to invade a given environment (can be viewed as a problem of machine learning)
- provided that sufficient volumes of relevant empirical data are accumulated and available
- Prediction of endogenous ecosystem dynamics caused by biological invasion and resulting in compositional, structural and functional transformations most likely calls for process-based models
- The resilience limits of invaded ecosystems remain unclear
- question the ability of forest ecosystem to fully recover to the original, pre-invaded state in the face of complex interactions among anthropogenic impacts: forest fragmentation, climate change and introduction of invasive species

Acknowledgement

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Thank you for your attention!