C20 Ecology
Unit 4:

Ecosystem Stability:

Ecosystem stability is the ability of an ecosystem to maintain a steady state (*equilibrium)*, even after a stress or disturbance has occurred. In order for an ecosystem to be considered stable, it needs to have mechanisms in place that help it return to its original state after a disturbance occurs.

OR

Stability of an ecosystem is defined as its capacity to persist in the same state.

Natural ecosystems are often incredibly sensitive to change, such as the introduction or removal of a species. A healthy ecosystem is said to be *in equilibrium*, which is a relatively stable state that keeps population sizes within a sustainable range (not too many of a certain species alive or dead).

Consider the case of bears (who only eat fish) and salmon (who are only hunted by bears):

1. If the bear population grows particularly large one year, the total population will require more fish to feed it. This will make the salmon population shrink.
2. Over time, if there are fewer salmon, there will not be enough food for all of the bears to eat. Some bears will starve and fewer cubs will be able to prosper, leading to a smaller overall population the next year.
3. As more time passes and the bear population gets smaller, the salmon population will start to increase again due to having fewer natural predators.

In a perfectly stable ecosystem, this cycle can continue indefinitely. Of course, natural ecosystems are far more complex than this simple example, but the relationship between species applies to complex ecosystems as well. Because of all of the interdependence between various species, it can be very difficult to understand the implications of small changes to an ecosystem in the real world because

1. The relationships between species can be incredibly complex and
2. Actual experimentation in real-world ecosystems can be catastrophic by the time observable changes have taken place; it's often too late to stop their effects.

Ecosystem stability is often divided into two components: resistance and resilience.

1. **Resistance:** The ability of an ecosystem to remain at equilibrium in spite of disturbances is called *resistance*.

Or

Resistance is the ability of a community or ecosystem to maintain structure and/or function in the face of potential disturbance. (*A small change in species abundance due to some disturbance implies greater resistance than does a larger change.)*

Note: Resistance to ecological change is usually studied in its absence, when a system finally changes in the face of ecosystem alteration. These studies often show that change occurs more quickly when ecological redundancy is low and the ecological role of key species cannot be replaced by other species within the ecosystem. Particularly in marine systems, recent human removal of key species, such as top predators, can dramatically reduce redundancy and therefore alter the ability of ecosystems to resist ecological change.

Example:

I. Drought-resistant soils are those rich in organic matter and high in biodiversity

Healthy soils rich in organic matter, as the ones nurtured by agro ecological fertilizers (green manures, compost, animal dung, etc.), are less prone to erosion and more able to hold water. A large amount of scientific evidence shows that organic matter is the most important trait in making soils more resistant to drought and able to cope (manage) better with less and more erratic rainfall. Organic matter increases the pore

space in the soil, where water can be held more easily, making the soil capable of storing more water during a longer period and facilitating infiltration during heavy rains so that more water overall can be captured. As a consequence, a soil rich in organic matter needs less water to grow a crop than a soil poor in organic matter. Organic matter also improves the activity of microorganisms, earthworms and fungi, which makes the soil less dense; less compacted and with gives it better physical properties for storing water. All these characteristics make soils rich in organic matter more drought-resistant, increasing the water-use efficiency of not only the crop but also the whole farm.

II. Invasion Resistance

In several marine ecosystems, decreases in the richness of native taxa were correlated with increased survival and percentage cover of invading species. This suggests that, as in terrestrial plant ecosystems, invasion resistance is enhanced by the integrity of the native species pool.

For example, diverse systems use resources such as available space more completely. In experimentally assembled benthic (sea floor) communities, decreasing the richness of native taxa was correlated with increased survival and percent cover of invading species. Open space was the limiting resource for invaders, and a higher species richness buffered communities against invasion through increasing temporal stability. High biodiversity is also expected to contribute to community resilience by creating insurance through functional redundancy. Although there are few studies of the effects of biodiversity in marine ecosystems, the available evidence suggests that marine systems may possess similar mechanisms of invasion resistance as found in terrestrial systems.

2. **Resilience:** How readily an ecosystem returns to equilibrium after being disturbed is called *resilience*.

Or

The ability to bounce back after a disturbance is called resilience. A resilient community or ecosystem may be completely disrupted by disturbance but quickly return to its former state.

Or

Ecosystem resilience refers to the capacity of an ecosystem to recover from disturbance or withstand ongoing pressures.

It is a measure of how well an ecosystem can tolerate disturbance without collapsing into a different state that is controlled by a different set of processes. Resilience is not about a single ideal ecological state, but an ever-changing system of disturbance and recovery.

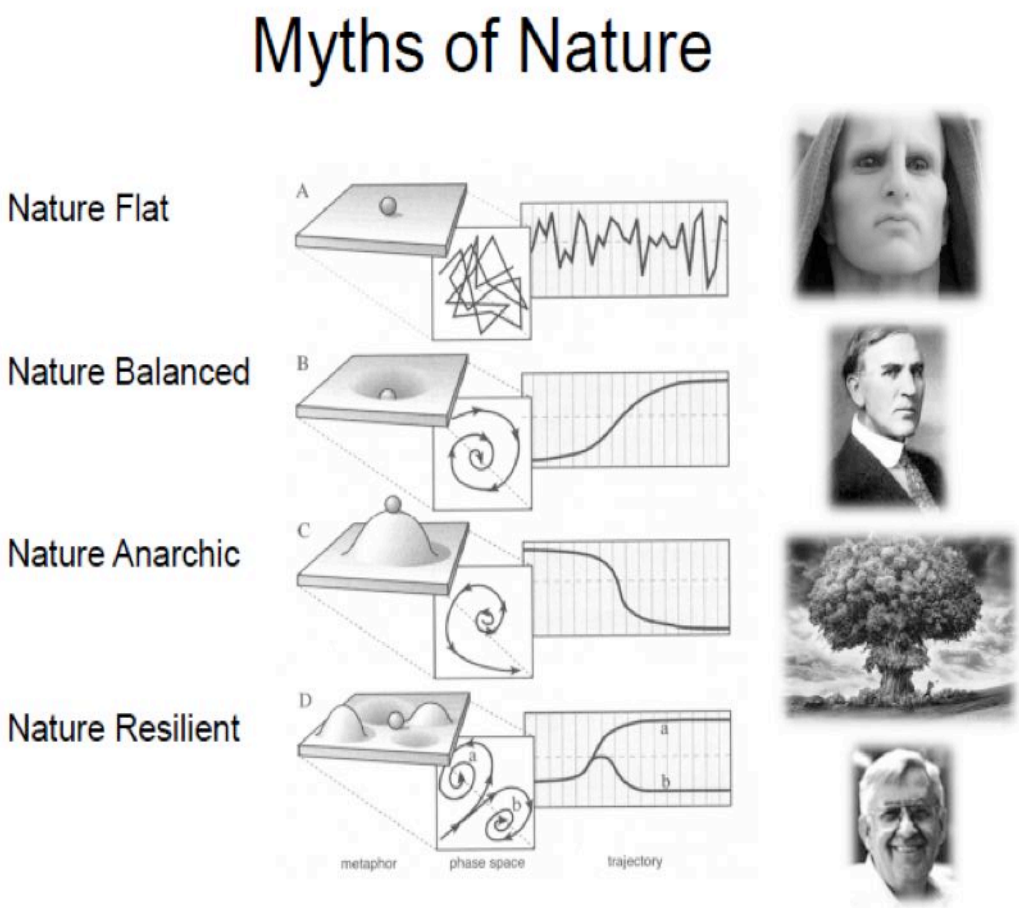
Note: ***Thresholds define the limits of natural variability, and are crossed when an ecosystem does not return to the original state via natural processes after disturbance or invasion and transitions to a new, alternative state***

What is Resilience thinking?

1. Recognises system complexity
2. Recognises interdependence of social and biophysical systems
3. Recognises that systems are non linear
4. Encourages anticipation of surprises, thresholds
5. Encourages reflection on how a system works and adaptive management

Why is Resilience important?

1. Pressure on Ecosystems is increasing
2. Systems are increasingly subject to novel pressures (fire suppression, invasive species, soil erosion)
3. Novel Ecosystems are increasing
4. Legacy of past mismanagement
5. Uncertainty Risk
   - Process uncertainty
   - Model uncertainty
   - Observational uncertainty



Example: Coral reef and other tropical marine ecosystems are subject to frequent disturbances, from threats such as cyclones, crown-of-thorns starfish outbreaks and influxes of freshwater as well as from a range of human activities. These events often damage, stress or kill components of the ecosystem. Given enough time, a resilient ecosystem will be able to fully recover from such disturbances and become as bio diverse and healthy as before the impact. Similarly, a resilient ecosystem may be able to absorb the stresses caused by these disturbances with little or no sign of degradation.

Factors that affect resilience: Ecosystem resilience is complex to understand and assess because a number of factors can affect it. An ecosystem's ability to absorb or recover from impacts, and its rate of recovery, depend on the inherent biology and ecology of its component species or habitats; the condition of these individual components; the nature, severity and duration of the impacts and the degree to which potential impacts have been removed or reduced. If all of these features are in place, populations of species or habitats can often absorb or recover from impacts, thus allowing the ecosystem to continue to function. However, if any limitations exist, the

capacity of the ecosystem to absorb impacts without changing will be lower than optimal and recovery will take much longer, or even fail.

Recovery after disturbance

Assessment component	Summary	Assessment Grade: Very good	Good	Poor	Very poor
Coral reef habitats	Coral reef habitats are recovering from multiple short-term disturbances. Predicted increases in frequency and severity of disturbances will likely reduce the capacity for coral reefs to recover.		●		
Lagoon floor habitats	Some lagoon floor habitats previously at risk are recovering from disturbances. Full recovery will take decades.		●		
Black teatfish	Populations of black teatfish are low and are not recovering.				○
Coral trout	The number and size of coral trout is increasing rapidly in zones closed to fishing.		●		
Loggerhead turtles	Trawl turtle excluder devices have arrested the decline in loggerhead turtles but other pressures will influence their recovery.			○	
Urban coast dugongs	The urban coast dugong population may take more than a century to recover and is subject to many continuing pressures.				○
Humpback whales	Humpback whales appear to be recovering at their maximum population growth rate 45 years after whaling stopped.	●			
Recovery after disturbance	Some disturbed populations and habitats have demonstrated recovery after disturbance (for example coral reefs, lagoon floor, coral trout, humpback whales). For some species recovery has been very slow (for example loggerhead turtles) or not evident (black teatfish, dugongs) and is dependent on the removal of all major threats. Increasing frequency and extent of threats are likely to reduce the resilience of species and habitats.		◉		

GRADING STATEMENTS

Very good - Under current management, throughout the ecosystem, populations of affected species are recovering well, at rates close to their maximum reproductive capacity. Affected habitats are recovering within expected natural timeframes, following natural cycles of regeneration.

Good - Populations of affected species are recovering at rates below their maximum reproductive capacity. Recovery of affected habitats is slower than naturally expected but structure and function are ultimately restored within a reasonable timeframe.

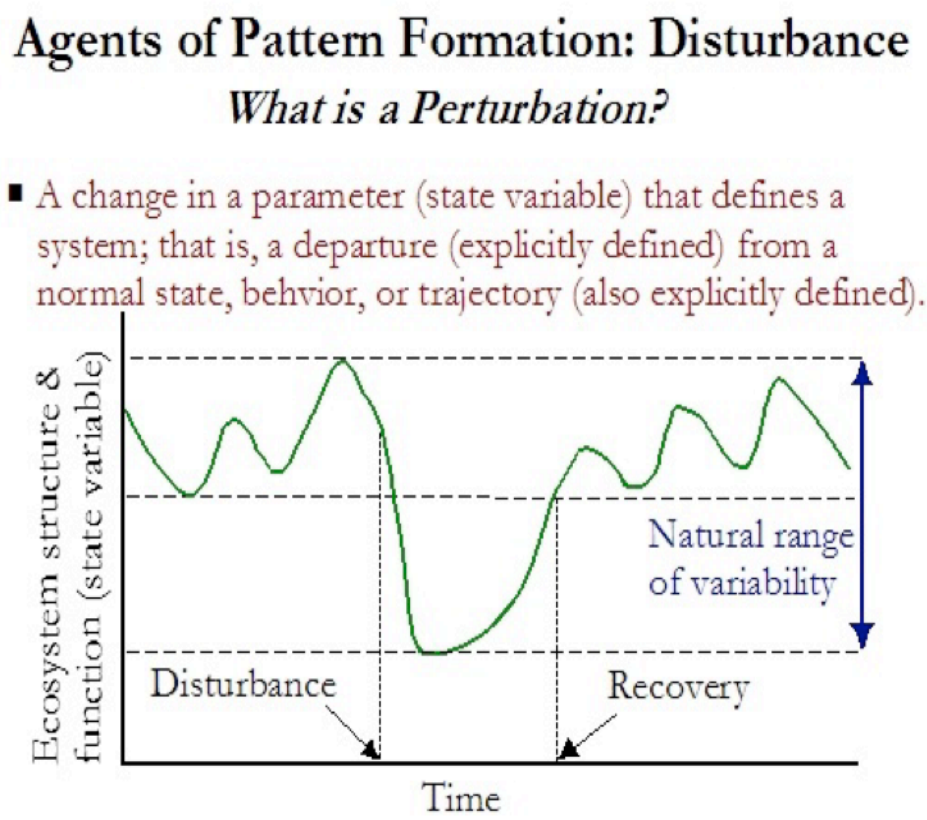
Poor - Populations of affected species are recovering poorly, at rates well below their maximum reproductive capacity. Recovery of affected habitats is much slower than expected natural timeframes and the resultant habitat is substantially different.

Very poor - Affected species are failing to recover and affected habitats are failing to recover to their natural structure and function.

Ecological perturbation is a temporary quick change in environmental conditions that causes a pronounced (noticeable) great change in an **ecosystem**, to alter the physical structure or arrangement of biotic and abiotic elements.

Or

A change in a parameter (state variable) that defines a system; that is, a departure (clearly/explicitly defined) from a normal state, behaviour, or trajectory/path (also clearly defined)



The key parts of this definition are that disturbances are discrete in time, in contrast to chronic stress or background environmental variability; and that they cause a notable change (a perturbation) in the state of the system.

Note: **<u>Disturbance</u>** *Any relatively discrete event (natural or anthropogenic) in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment, including both destructive, catastrophic (terrible) events as well as less notable, natural environmental fluctuations. Typically, a disturbance causes a significant change in the system under consideration.*

Characteristics of Disturbances and Disturbance Regimes

Disturbance "events" are individual disturbances that have a variety of spatial (e.g., size) and temporal (e.g., time of year) attributes. Disturbance "regimes" are the integration of disturbance events over time and space and they can be characterized in a variety a ways:

i. **Area/Size**: The areal extent of the disturbances, including the size of disturbance patches; the area per event per time period, and the total area per disturbance per time period.

ii. **Spatial distribution**: The spatial distribution of the disturbance; that is, the distribution of events relative to topography, soils, and so on. This typically would also impart or reinforce a characteristic spatial scale as well. This would include contagion -- tendency to, and rate of spread, and factors affecting the dispersion of the event.

iii. **Frequency**: The mean number of disturbance events per time period within a specified area. This is perhaps one of the most commonly reported attributes of a disturbance regime.

iv. **Recurrence Interval**: The mean time between disturbance events within a specified area. This is equal to the inverse of the disturbance frequency.

v. **Return Interval**: The meantime between disturbance events at the same location; that is, how frequently is the same spot of ground disturbed. This is a critical component of the disturbance regime because it directly affects the amount of time the ecosystem, community, or population has to recover (e.g., as in succession) before the next disturbance.

vi. **Rotation Period**: The mean time to cumulatively disturb an area equivalent to the entire study area. In other words, given the frequency of disturbance events and the area/size disturbed by each event, how long does it take to cumulatively disturb an area equal to the size of the entire study area. **Note**, this is not equal to the time required to disturb every location in the study area at least once, since some areas may get disturbed many times while others may not get disturbed at all within the rotation period. Also, the rotation period is equal to the return interval and is thus simply another way to describe the same

phenomenon.

vii. **Predictability**: The variance associated with the recurrence or return interval and/or frequency. If the variance is low, there is high predictability concerning when an area is likely to be disturbed based on the time since last disturbance. If the variance is high, there is a lot of variation in the return interval, making it difficult to predict with any confidence when an area is likely to be disturbed.

viii. **Magnitude**: There are two aspects of magnitude: Intensity refers to the magnitude in physical force of the event per unit area and time; Severity refers to the magnitude of impact on organism, community, or ecosystem.

ix. **Synergism**: The effects of a disturbance event on the occurrence of other disturbances. For example, there may be a synergistic relationship between insect infestations in certain forest types and the occurrence of fire.

x. **Feedbacks**: Some disturbances either engender or constrain others. For example, fire may synchronize other subsequent fires in frequency as well as patch boundaries; reciprocally, lack of fire can reinforce a system's resistance to fire.

Natural Perturbation:

They are astronomical, geological and geographical factors, which are beyond the control of man. All ecosystems have a natural disturbance regime to which they are adopted evolutionarily.

Ecological disturbances, current thinking holds, are relatively discrete events that affect landscapes in disruptive ways. Each disturbance type and even successive disturbances of the same type are unlikely to affect natural landscapes in precisely similar ways. Thus, it is difficult to predict the exact effects of the next disturbance in any natural landscape. However, if similar or different types of disturbances recur with some periodicity, then a disturbance regime is produced that may generate predictable consequences. These disturbance regimes often are characterized by the type of disturbance, frequency/return interval, and seasonal timing e.g., the intensity of windstorms, duration of floods, and the frequency and season of fires. The characteristics of disturbances often vary within landscapes and also may interact with landscape components, as well as prior disturbances, to influence the size of the area affected. Also, local effects may influence the intensity, patchiness, and frequency of gaps or voids on the biota and the environment.

Anthropogenic Perturbation:

Stability may be critical as ecosystems come under increasing pressure from myriad (many) anthropogenic drivers, from climate change to invasive alien species. Furthermore, these drivers may have a dual effect: a direct impact on ecosystem services, and an impact on biodiversity, which in turn can affect ecosystem services.

The ecosystems services debt

When assessing the flow of ecosystem services, and how they might change in the future, scientists generally assume that any habitat that remains intact will continue to provide its normal, full range of services (Isbell et al., 2014). However, habitat fragmentation can lead to an 'extinction debt' – a delay between reduction in habitat and extinction of species in the remaining fragments (Kuussaari et al., 2009). For example, an individual of a long-lived tree species may persist in a habitat fragment for a long time, but if there are not enough individuals to enable reproduction the species will become extinct. This could, in turn, lead to an 'ecosystem services debt'.

Isbell et al. (2014) developed an approach for assessing this phenomenon for the ecosystem service carbon storage. They found that between 2 000 and 21 000 megatonnes of carbon could be gradually released as a result of plant species loss due to habitat destruction in nearby areas. The wide range of the estimate stems from uncertainties surrounding how many plants will be lost, whether it will also affect soil carbon and the effects on ecosystem functioning. Nevertheless, the authors

say the results show that ecosystem services debts could be globally substantial and should be accounted for when quantifying the effects of habitat destruction.

Perturbations in the carbon budget from land to ocean aquatic continuum:

A substantial amount of atmospheric carbon taken up on land through photosynthesis and chemical weathering is transported laterally along the aquatic continuum from upland terrestrial ecosystems into the ocean. Anthropogenic perturbations to the land-ocean aquatic continuum have increased the flux of carbon to inland waters by as much as 1 Pg C yr^{-1} since preindustrial times, mainly by enhanced carbon exports from soils. Most of this input to upstream rivers is either lost back to the atmosphere by CO_2 outgassing/release (~0.4 Pg C yr^{-1}) or sequestered in sediments (~0.5 Pg C yr^{-1}) along the freshwater-estuarine-coastal waters continuum, leaving only a perturbation carbon input of ~0.1 Pg C yr^{-1} to the open ocean. According to analysis, terrestrial ecosystems store ~0.9 Pg C yr^{-1} at present.

Inland waters annually receive, from a combination of background and anthropogenically altered sources, on the order of 1.9 Pg C y^{-1} from the terrestrial landscape, of which about 0.2 is buried in aquatic sediments, at least 0.8 (possibly much more) is returned to the atmosphere as gas exchange while the remaining 0.9 Pg y^{-1} is delivered to the oceans, roughly equally as inorganic and organic carbon. Thus, roughly twice as much C enters inland aquatic systems from land as is exported from land to the sea. Over prolonged time net carbon fluxes in aquatic systems tend to be greater per unit area than in much of the surrounding land.

Petagrams is a unit of mass equal to (10^{15}) grams. Symbol: Pg. Sometimes used in Carbon Dioxide numbers, it is equivalent to Metric Gigatons (Giga) 10^9 x (Ton) 10^3 x (Kg) 10^3 = 10^{15}.

Plant Invasion Ecology

Invasion ecology is the study of the human mediated introductions of organisms, especially to areas well outside their potential range as defined by their natural dispersal mechanisms and biogeographic barriers. The field covers all aspects relating to the introduction of organisms, their capacity to naturalize and invade in the target region, their interactions with resident biota and, increasingly, the consideration of costs and benefits of their presence and abundance with reference to human value systems.

Panel A

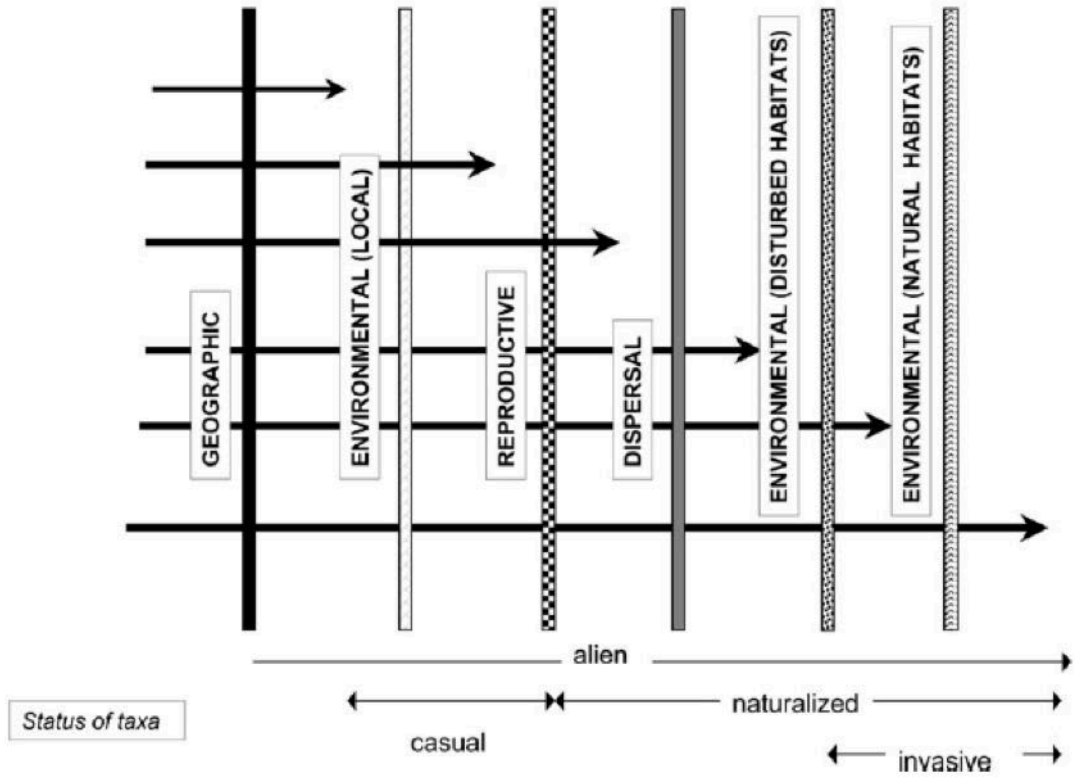


Figure 1. The 'naturalization-invasion continuum' (panel A) conceptualizes the various barriers that a plant must overcome to become alien, casual, naturalized or invasive in a new environment.

The above given scheme also provides a framework for the objective definition of categories of alien plants. **Alien plants** are those whose presence in an area is the result of human-mediated transport. **Casual alien plants** are alien plants that may flourish and even reproduce occasionally outside cultivation but that eventually die out because they do not form self-replacing populations; they rely (depend) on repeated introductions for their persistence. **Naturalized plants** are those aliens that form self-replacing populations for at least 10 years without

direct intervention by people (or despite human intervention) by recruitment from seeds or ramets capable of independent growth.

Invasive plants are a subset of naturalized plants that produce reproductive offspring, often in large numbers, at considerable distances from parent plants, and thus have the potential to spread over a large area. Understanding of the dynamics of plant invasions requires insights on traits of the plant (elements of species invasiveness) and features of the environment (components of community invasibility), but neither aspect can be fully evaluated without reference to the other (**panel B**). Invasions are context specific, and invasiveness only materializes when certain environmental requirements are met.

Panel B

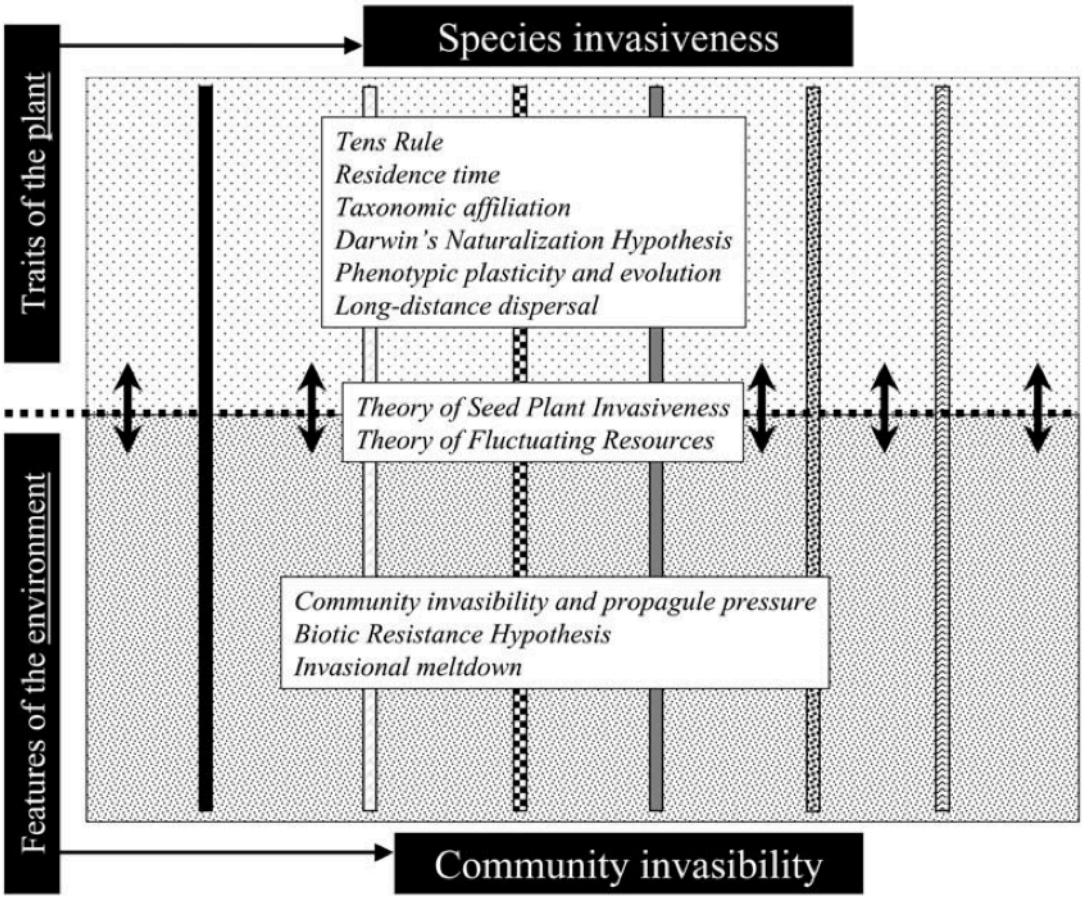


Figure 1. Continued-The 'naturalization-invasion continuum' (panel B)

Theories/Hypotheses/Factors for Invasion

Several theories have been proposed pertaining to ecological attributes or mechanisms responsible for invasion (Fig. 2). Ultimately, it is unlikely that any single theory will be able to account for all differences in invasibility among all environments. A plant community becomes more susceptible to invasion whenever there is an increase in the amount of unused resources. In the recent article in Nature, Seastedt (2009) indirectly supported 'resource and enemy release hypothesis' (R-ERH), given by Blumenthal (2006). He reported that resource fluctuations and lack of enemies (fungal and viral pathogens) might act in concert/performance, underpinning/sustaining for invasion success. However, these two factors, instead of acting as drivers, merely act as passengers along for the invasion ride. Nevertheless, there exists a cascade of mechanisms behind the invasion success.

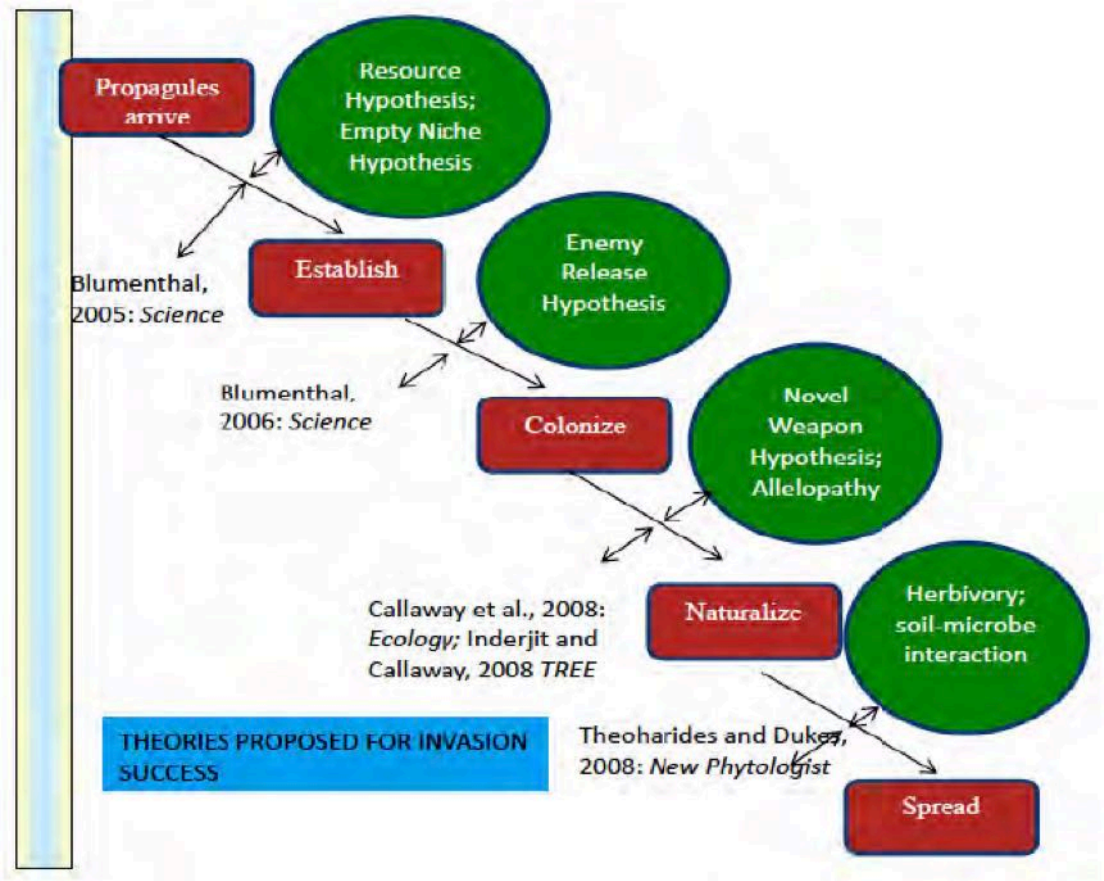
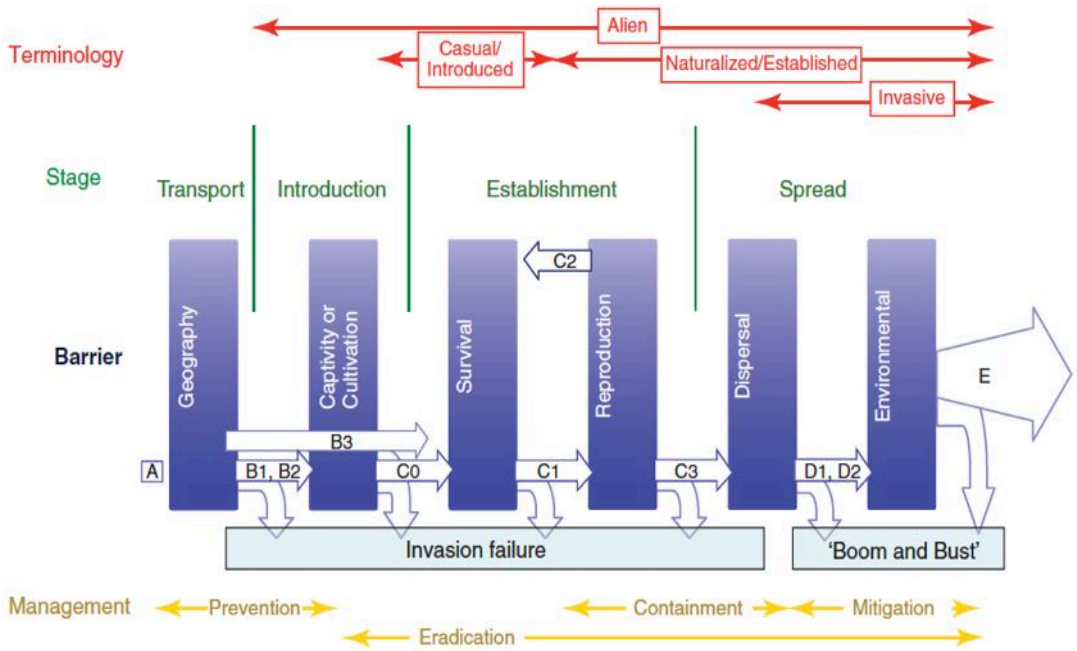


Figure 2. Salient hypothesis/theories applicable at varying invasion stages

ECOLOGY OF PLANT INVASION

Invasive species

- Non-native
- Capable of surviving without direct help from people (established or naturalized)
- Spreading away from sites of initial establishment
- Often with negative ecological and economic consequences

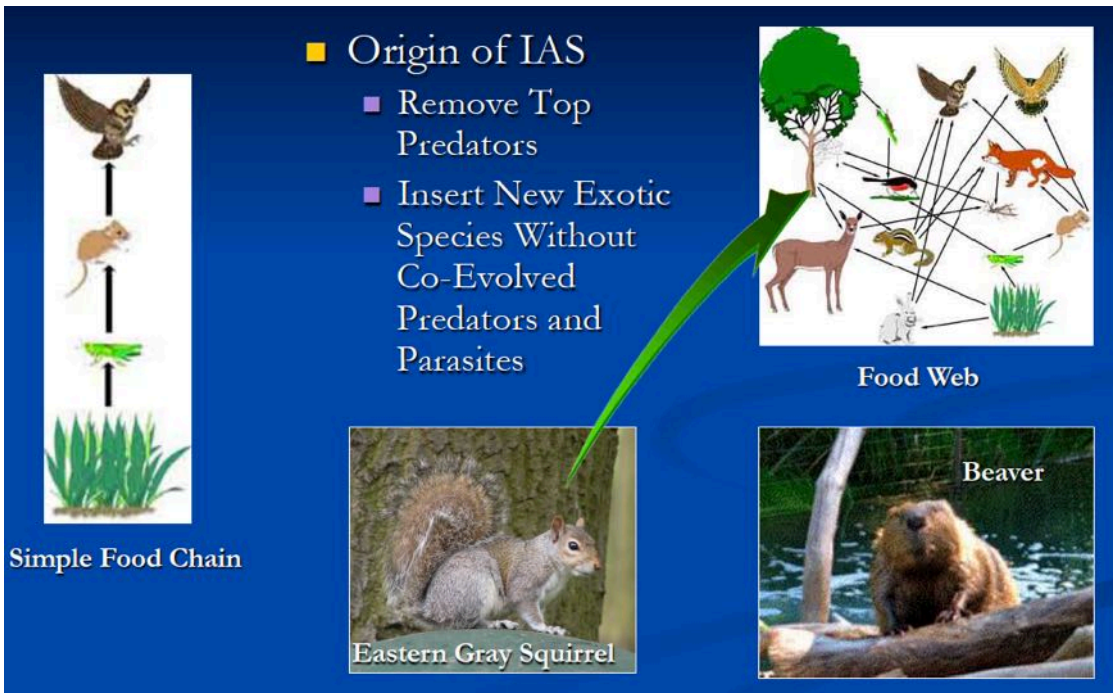


The path to invasion is marked by many opportunities for failure

The proposed unified framework for biological invasions. The proposed framework recognizes that the invasion process can be divided into a series of stages, that in each stage there are barriers that need to be overcome for a species or population to pass on to the next stage, that species are referred to by different terms in the terminology depending on where in the invasion process they have reached, and that different management interventions apply at different stages. Different parts of this framework emphasise views of invasions that focus on individual, population, process, or species. The unfilled block arrows describe the movement of species along the invasion framework with respect to the barriers, and the alphanumeric codes associated with the arrows relate to the categorization of species with respect to the invasion pathway given in ***Table 1***

Category	Definition
A	Not transported beyond limits of native range
B1	Individuals transported beyond limits of native range, and in captivity or quarantine (i.e. individuals provided with conditions suitable for them, but explicit measures of containment are in place)
B2	Individuals transported beyond limits of native range, and in cultivation (i.e. individuals provided with conditions suitable for them but explicit measures to prevent dispersal are limited at best)
B3	Individuals transported beyond limits of native range, and directly released into novel environment
C0	Individuals released into the wild (i.e. outside of captivity or cultivation) in location where introduced, but incapable of surviving for a significant period
C1	Individuals surviving in the wild (i.e. outside of captivity or cultivation) in location where introduced, no reproduction
C2	Individuals surviving in the wild in location where introduced, reproduction occurring, but population not self-sustaining
C3	Individuals surviving in the wild in location where introduced, reproduction occurring, and population self-sustaining
D1	Self-sustaining population in the wild, with individuals surviving a significant distance from the original point of introduction
D2	Self-sustaining population in the wild, with individuals surviving and reproducing a significant distance from the original point of introduction
E	Fully invasive species, with individuals dispersing, surviving and reproducing at multiple sites across a greater or lesser spectrum of habitats and extent of occurrence

IS (INVASIVE SPECIES) - Ecosystems out of Balance



Characteristics of Invasive Species

- History of Invasiveness Outside Natural Range
- Wide Distribution in Different Habitats
- Fast Growth, Early Maturity
- High Reproduction; Seed Dormancy
- Allelopathy
- Prickles, Spines, Thorns
- Parasitism
- Same Size/Shape as Crop Seeds
- Ability to Go without Food/Water
- Roots/Rhizomes with Large Storage
- Efficient Means of Spread
- Close Association with Humans

Purple nutsedge (*Cyperus rotundus*) – *the perfect weed.*

e.g., Nutgrass (Motha)-*Cyperus rotundus*

Characteristics of Invaded Habitats

- Ecological Similarities Between Origin and Receiving Ecosystems
- Lack of Co-evolved Predators and Parasites
- Other IS already Established
- High Degree of Disturbance
- Secondary Pathways and Vectors for Further Spread

A **B**

A. Wet Tropics of Queensland, Australia**. B.** Florida Everglades, United States.

Overview of Invasive species Taxa Groups

Invasive Plants

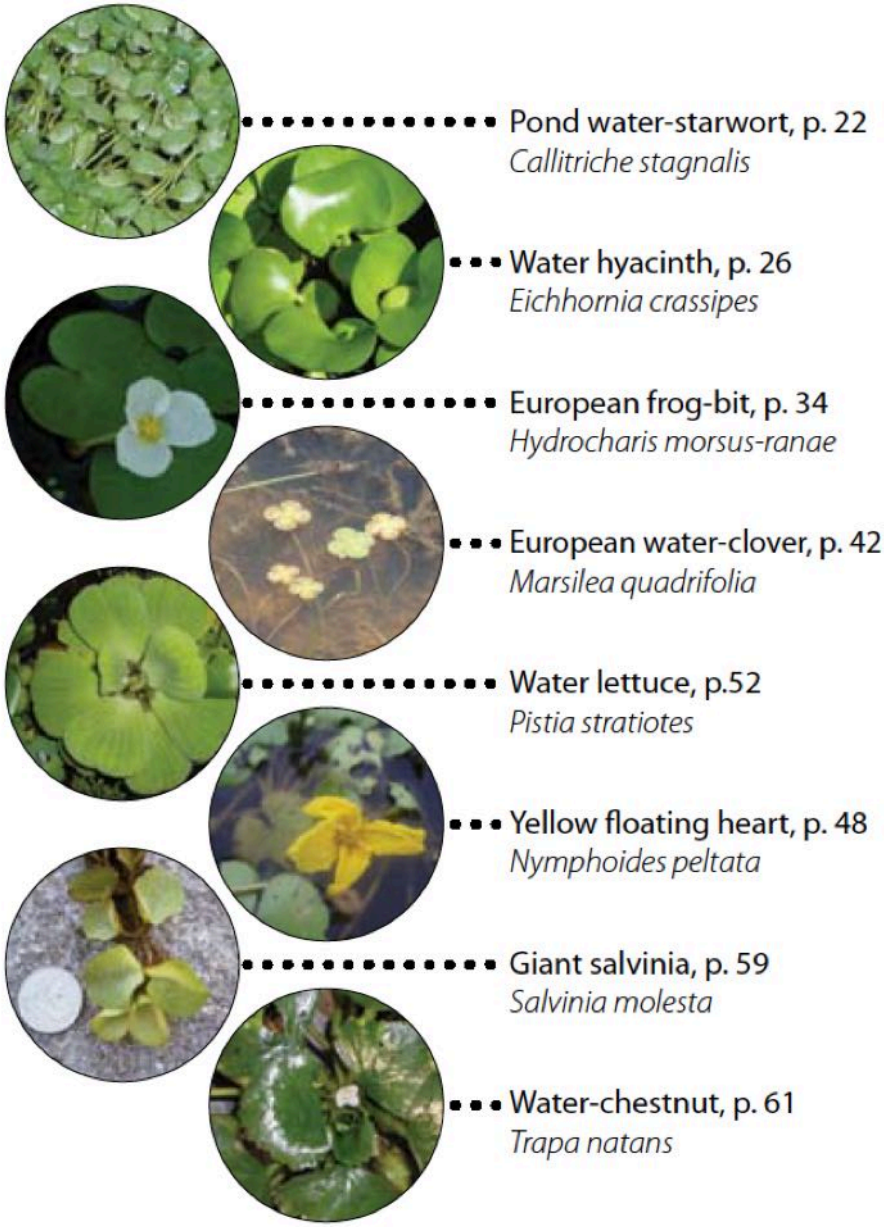
- 250,000 Plants in the World
- 22,000 Invasive Plants
- **Definitions**

  Invasive Plant = Weed

  Noxious Weed = Regulated
- Weed
- Melaleuca and Pond Apple -Tale of Two Weeds in North America and Australia

Examples of Invasive species

1. Floating Plants



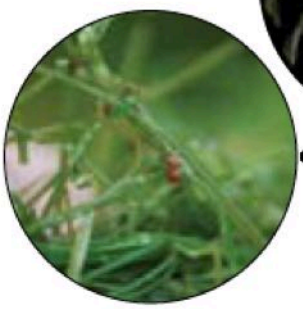
2. Submergent plants with finely divided leaves

Carolina fanwort, p. 21
Cabomba caroliniana

3. Submergent plants with undivided leaves

Brazilian water-weed, p. 25
Egeria densa

Hydrilla, p. 33
Hydrilla verticillata



Starry stonewort, p. 47
Nitellopsis obtusa

4. Woody plants

Opposite or sub-opposite leaves:

Common buckthorn, p. 57
Rhamnus cathartica

Alternate leaves:

Black alder, p. 17
Alnus glutinosa

Japanese barberry, p. 19
Berberis thunbergii

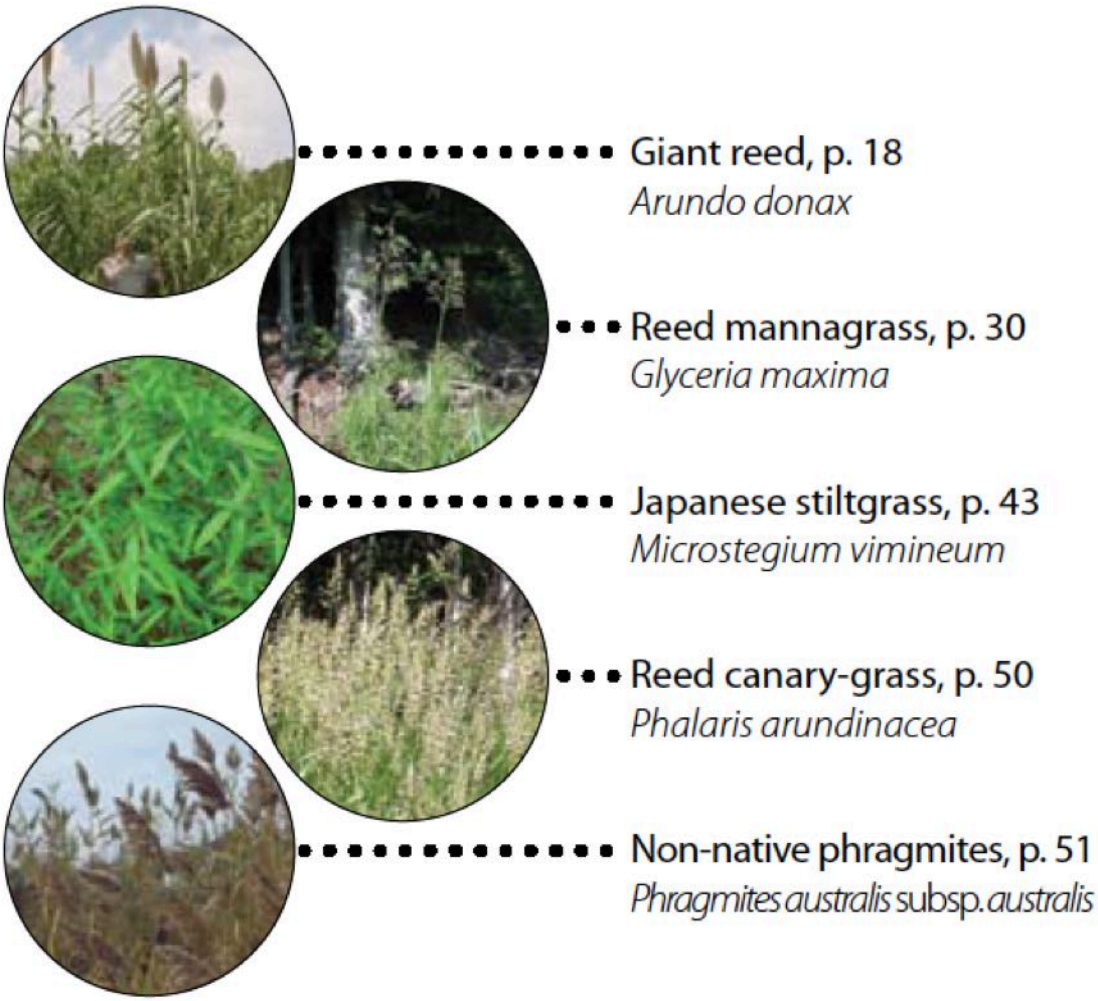
Autumn Olive, p. 27
Elaeagnus umbellata

Glossy buckthorn, p. 29
Frangula alnus

Multiflora rose, p. 58
Rosa multiflora

5. Emergent and terrestrial plants

Grasses:



Economic Effects of Invasive Species

- USA: $150 Billion
- India: US$117 Billion
- South Africa: US$17.5 Billion
- United Kingdom: US$12 Billion
- Australia: AUS$10 Billion
- New Zealand: US$10 Billion
- Africa (Aquatic Weed Control): $US60 Million

Table 1: Different levels, types and metrics of invasive plant impacts

Level	*Impact type*	*Impact metric*
Individual	Fitness	Seed number, seed viability, germination rate, recruit
	Growth	Plant size, root:shoot ratio
Community	Productivity	Biomass, net primary prod
	Diversity	Richness, evenness, alpha d
	Abundance	Number of individuals, den
	Intraspecific	Genetic diversity, intrinsic
Structure	Physiognomy	Tree, shrub, forb, grass cov
Biogeochemical	Pools	N, C, phosphorus, soil orga
	Litter	Litter nutrient content, C:N
	Fluxes	N, C turnover, pH, salinity
	Moisture	Plant-available water
Ecosystem	Food chain	Trophic connections, troph
	Interactions	Mutualists, herbivore, paras
	Fluxes	Nutrient, sediment
	Disturbance	Fire, flood frequency/intens
	Geomorphology	Hydrology, sediment gain/l