Section 4: Causes of pest and vectored disease outbreak

- Individual insects are rather small, though voracious species can consume their own weight in plant foliage each day.
- However, they are incredibly abundant, and collectively they can have great impact.

  For example, an aphid population of 200 million per hectare (2.5 acres) is not unusual.

Grasshoppers are just one type of insect that attains plague densities

Insect abundance

- Abundance, combined (in some species) with ability to spread disease (which magnifies their damaging effects) results in enormous impact to crops, forests, livestock, and humans, as well as our personal environment (home, yard, etc.)
- Insects are the principal competitor of humans for resources

Insect abundance

Winged termites emerging from a log. Huge numbers of many insects, not just termites, commonly exist without being apparent until you discover their damage.

As alarming as a termite swarm might be in a log, it pales in comparison to a termite swarm emerging from a house (below). Even concrete block structures, such as the one shown here, usually have enough wood to make emergence of a swarm quite worrisome, and should cause you to ask “why are these insects here, and why are they so abundant?”

Important questions

- Relative to insect abundance and damage, there are 3 important questions that must be considered:

  1. What causes some insects to become so abundant?
  2. Why are insects not always abundant?
  3. Is the answer to the second question the inverse of the first question?

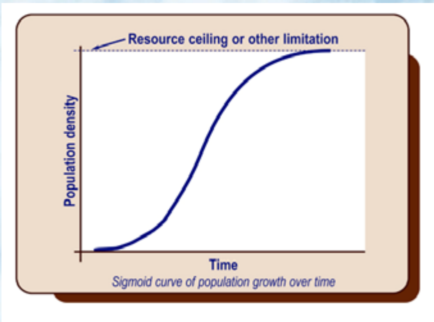
Births and deaths

- Animal populations change as a result of shifts in births (natality) and deaths (mortality). A population with more births or less deaths - or both - will increase in abundance.
- It is important to know when abundance will increase, so preventative measures can be instituted. Also, there is not much sense in planning suppression if the population is decreasing naturally.

Population increase

- Population increase generally follows a S-shaped (sigmoid) growth curve.
- At low densities, individuals may be so rare that they can't find one another and mate.
- However, with more births (or fewer deaths) there is a linear increase in abundance.
- No population can increase indefinitely, so at some point competition for resources (or other factors)will cause the growth rate to decline, and the population to stabilize or decrease.

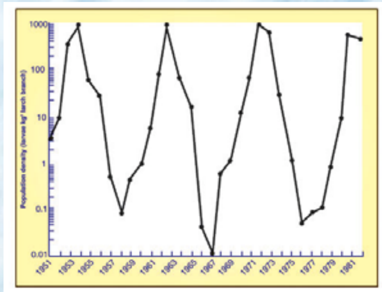
Sigmoid growth curve



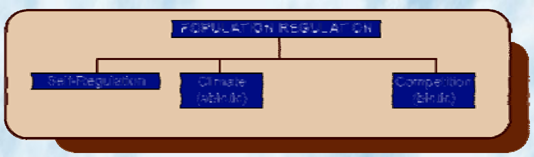
"Normal" abundance

- So insects occur within bounds, and some can even be said to have "normal" abundance (e.g, typically abundant, or not abundant) but more often their abundance changes from year to year.
- Population cycles wherein they are abundant for a few years, then dissipate, only to rebuild in a few years, are quite common, though the nature of the cycle varies among species.

This graph shows the population cycles of larch budmoth in Switzerland. It is strikingly repetitive, though not all species display this, and the interval between cycles varies among species (after Baltensweiler 1984)



Factors affecting abundance

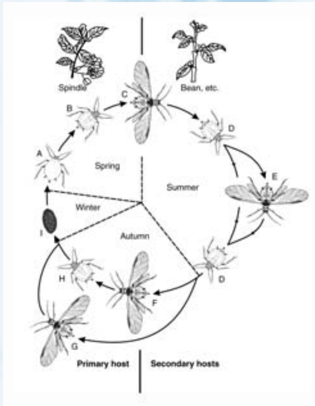


Self regulation of density

- Self-regulation of density occurs, usually as a result of emigration (dispersal), but also due to genetic and non-genetic qualitative shifts in the population.

  For example, after several generations of producing wingless offspring, aphids may produce winged dispersants in response to high density and host deterioration.
- Other behaviors such as cannibalism at high host densities also keep populations from increasing. Even insects that are not normally predatory may become so.

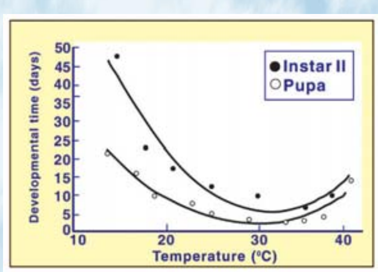
Aphid populations often have complicated life cycles with alternating host plants, one for winter and another for summer. In between dispersal events, only wingless forms may occur unless the host plant deteriorates in quality. Such self-regulation of form, behavior and abundance is quite apparent among aphids, but occurs to some degree in many insects.



Climate or weather

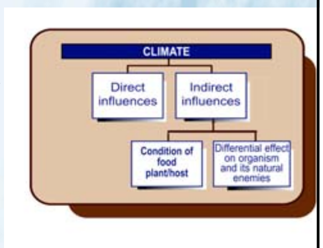
- Climatic factors such as high and low temperatures, humidity, and rainfall affect insect survival
- Effects occur directly, but also indirectly, usually by acting on other organisms such as the host plant or predators

This graph shows how a climatic factor (temperature) affects the development time of two stages of pea weevil. Note that the two stages both have similar optimal temperatures (maximum growth rate at about 32 degrees), and that it can be too hot or too cold for optimal growth (after Smith and Ward 1995).

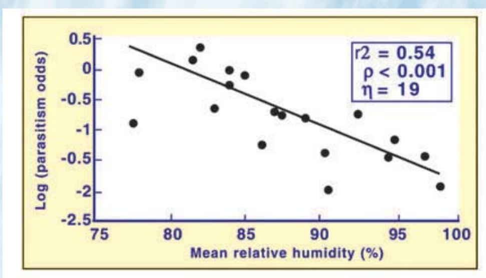


Climate or weather

- It is easy to imagine the direct effects of climate or weather on insects, but indirect influences should not be underestimated.
- The effects vary among insects, and among locations.



This graph demonstrates how humidity affects parasitism of spruce budworm eggs by Trichogramma wasps. High humidity interferes with parasitism, though it does not affect the budworm directly (after Bourchier and Smith 1986).



Effects of weather

- At the geographical limits of a species distribution it is probably more common for weather to have significant effects on species abundance.

Weather events can assist or hinder insects, often redistributing them over long distances. For example, in 1989 a hurricane moved a desert locust swarm across the Atlantic Ocean from Africa to the Caribbean and northern South America. Less dramatic events occur annually.

Competition

- 3 forms of competition: intraspecific, interspecific, and natural enemy competition.
- Within-species (intraspecific) competition for food is easy to envision.

  e.g. too many eggs deposited on a plant, leading to total defoliation and starvation

More competition

- Between-species (interspecific) competition also occurs.
- Different species can compete for the same resource

  e.g., dead animals (road-kill) attract many species of flies and beetles that oviposit on, and feed on, the cadaver. Arriving early ensures a larger food supply and better survival.

More competition

- Competition for survival - the battle of predators and parasitoids with their host insects - is widely appreciated but not always viewed as “competition.”
- Insects have evolved many behaviors to prevent being killed, but for natural enemies to occur they also must be effective at finding and using the host resource.

Examples of natural enemy competition:

Aphids release alarm pheromone when attacked, causing other aphids to leap from their host plant; in turn, some parasitoids find aphids by sensing these pheromones.

Cicadas have unusually long developmental periods, longer than the survival times of many potential natural enemies; they also emerge synchronously, overwhelming the capacity of enemies to feed on them, so many are assured survival.

Competition

- Competition effects are difficult to measure, so they are often under-appreciated.
- Parasitism is the exception, as it is more quantifiable.

Parasitism

- A gypsy moth parasitoid stinging the caterpillar

- Corn earworm pupa under attack by a parasitoid

(Photos by S. Bauer, ARS)

Assessing the factors that regulate populations

- One interesting way to assess the relative importance of the different factors that affect insect populations is the use of life tables.
- Life tables are sequential records of survival of a generation of insects throughout the entire generation (e.g., from egg production to egg production).
- Not only is the pattern of survival of death recorded, but the cause of death at each time period. It allows the calculation of factors accounting for most of the variation in abundance, and those most capable of population regulation (most density-dependent).

Life tables

- A simple life table looks something like this:

Age interval	No. alive	Death factor	No. dying	% mortality	Survival rate
Eggs	658	infertility	8	1.2	0.99
Young larvae	650	rainfall	328	50.5	0.50
Older larvae	322	virus	219	68	
		rainfall	7	2.2	
		Parasite 1	1	0.3	
		Stage total	227	70.5	0.29

Life tables

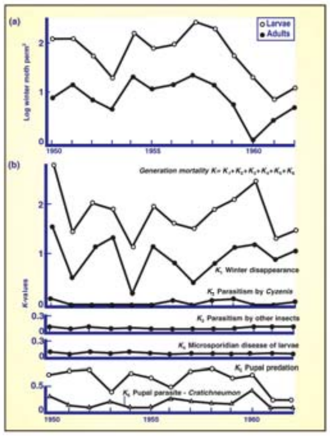
- The life table continues on, of course, recording the other stages including sex ratio of survivors and reproductive success.
- The value of the table is that it allows assessment of when high levels of mortality occur, and what factors are responsible.
- Some factors are usually apparent, such as parasitism and disease - others more subtle, such as drowning due to large rainfall events.
- What the life table doesn't show is how each mortality factor contributes to the production of the next generation. In other words, what factors cause the population to increase or decrease.
- Entomologists sometimes make the mistake of believing that the factor accounting for the highest level of mortality is most important factor in determining population trends. Usually, the trend over time is determined by density-dependent factors.

Key factor analysis

- A technique that assesses the relative contributions of each mortality factor to generation trends is called key factor analysis.
- Total mortality (designated K) is calculated by combining individual mortalities attributable to each factor ($k_1 + k_2 + k_3 \dots$)
- By plotting the mortalities for each year that are attributable to individual factors, and comparing them to overall or total mortality, it becomes apparent what stage in the life cycle is most responsible for the magnitude in fluctuation of total mortality, and what factor causes this; this is the key factor. In the winter moth case, winter disappearance is the key factor.

- However, the factor that displays the greatest density dependence is most important in population regulation (determining the population in the next generation).
- This is determined by plotting the values of each k factor (mortality) against population density. A positive slope indicates density dependence.
- In the winter moth case, pupal predation is the most important regulatory factor. Identification of density dependence is important in understanding effective biological control.
- Both over-wintering disappearance and pupal predation affect winter moth abundance, but from the perspective of biological control, pupal predation is critical.

These graphs show trends in winter moth abundance (above), as well as generation and individual mortalities over several years. Two lines parallel generation mortality, that of winter disappearance, and pupal predation. In this case, winter disappearance was most highly correlated with overall mortality (the key factor), though pupal predation was found to be an important density-dependent mortality factor. Key factor analysis is not without its critics, but it is a useful way of assessing population system dynamics.



Density dependence

- Population regulation factors work in both a density-independent and density-dependent manner.
- Density independent factors act the same regardless of insect density

  e.g., a killing frost or drought may kill mosquitoes regardless of their abundance

More on density dependence

- Density dependent factors change in impact as population density changes

  e.g., when predators have a hard time locating prey due to low abundance, they waste time searching and don’t consume many. However, when prey are abundant they eat proportionally more, perhaps depressing they abundance of the prey.

Density-dependent responses

- Density-dependent responses are due to functional (behavioral) responses as well as numerical (population) responses.
- Functional responses occur rapidly, numerical responses are delayed. Ultimately, numerical responses are usually required for large population changes to occur. Effective biological control agents display density-dependent responses to prey.

Learning

- Among animals, changes in behavior often result from learning.

Why do you suppose that functional responses, though important, often are less important than numerical responses in regulating insect abundance?

Predation: a density-dependent response

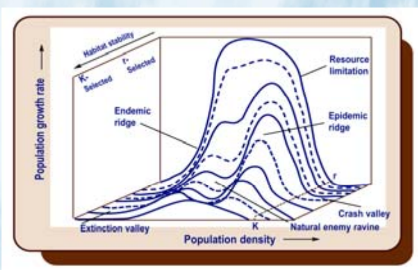
- Adult ladybird beetles will remain in the area and feed voraciously if there is adequate food (a functional response). Immature ladybeetle larvae (as shown here, produced as a numerical response to food availability) have little option as they can't leave until they mature and grow wings.

Integration

- Insect populations are affected by both density-dependent and density-independent factors, and different insects respond differently to such disturbances.

  With so much variability, is it possible to predict what factors are important?
- T.R.E. Southwood developed a synoptic model that integrates disturbances and results

Southwood’s model



About Southwood’s model

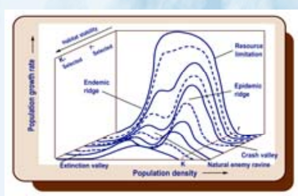
- Southwood considers that insects inhabit different habitats, some stable and some ephemeral.
- Those inhabiting ephemeral habitats (toward the back of the graph) must be highly mobile, and capable of rapid use of the resources. Thus, they tend to be small and short-lived, to reproduce only once, and to colonize annually.
- These insects are called r-strategists, or are said to be r-selected.

More about Southwood’s model

- Those inhabiting stable habitats (toward the front of the graph) must be competitive, more adapted to their resource, and less prone to destroy the resources. They tend to be larger and longer-lived, to reproduce repeatedly, and to occupy their niche continuously.
- These insects are called K-strategists, or are said to be K-selected.

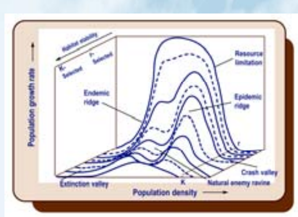
More about Southwood’s model

Note that in this model, the r-strategists display high rates of population growth, while the K-strategists display relatively low rates.



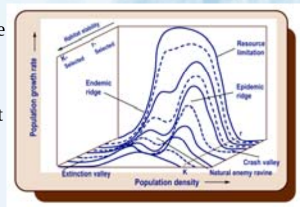
More about Southwood’s model

- The population of K-strategists tends to be limited by self-regulation or density-dependent factors, primarily natural enemies. Note that with their relatively low reproductive rate, they do not often escape from host-related or natural enemy-related limitations.



More about Southwood’s model

- The population of r-strategists tends to be limited by density-independent factors such as onset of inclement weather, but sometimes by exhaustion of the food supply. There is no natural enemy ravine here because natural enemies are not that important.



More about Southwood’s model

- Both r- and K-strategists can cause injury, regardless of their population growth rates and population densities.
- r-strategists are insects such as aphids and whiteflies -insects that become very abundant in annual crops, and overwhelm them by their numerical abundance.
- K-strategists inhabit more stable, perennial crops such as fruit orchards, where tolerance to injury is low and even a few insects can be damaging.

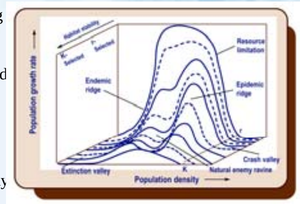
Insect reproduction

- Aphids and some r-selected insects reproduce at very high rates, allowing their population to explode!

Note that this aphid is giving birth to living nymphs. No waiting for eggs to hatch!

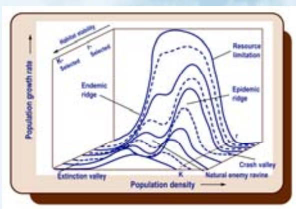
More about Southwood's model

- Perhaps the most interesting insects are those with life history characteristics that are intermediate in the r- and K-strategist continuum.
- These display two peaks in population growth rate, separated by a natural enemy ravine. This means that the lower peak (called the endemic ridge) is generally maintained by natural enemies, but weather or other perturbations occasionally allows the population to "escape" to a higher density.



More about Southwood's model

- Once escaping the natural enemy ravine, the population is limited by competition or resource depletion, or a reversal of the stimulatory weather conditions, and the rate of population increase falls. This upper limit of population increase is called the epidemic ridge.



So what does it all mean?

- Southwood's model allows us to see how the differing innate life history characteristics of insects, and their environments, interact to affect population densities.
- Southwood's model is not meant to have strict predictive abilities, but there are some outcomes that have utility:

Some conclusions…

- Both abiotic (weather) and biotic (natural enemies) are important in population regulation.
- Weather often provides the critical stimulus allowing the population to increase, which may or may not involve escape from natural enemies.

Weather that affects insects takes many forms: insects are susceptible to heat, cold, rainfall, humidity and wind.

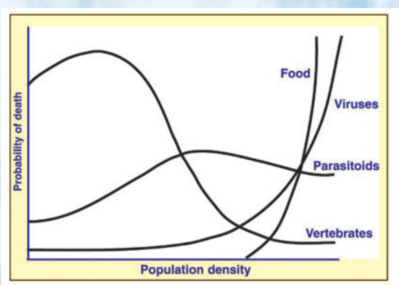
Natural enemies

- Natural enemies, as density dependent factors, can respond to increased availability of hosts and suppress abundance of their hosts. Natural enemies are important over a broad range of the r-K continuum, but least important with r-strategists.

…and applications

- With r-strategists, which have an explosively high reproductive potential, counting on the actions of natural enemies is probably fruitless. It is best to try to exclude pests from entering the crop through isolation, or to have an insecticide in place to kill any invaders.
- Pests that are intermediate on the r-K continuum are susceptible to natural enemies, so fostering natural enemies by conservation is a valuable practice.
- For K-strategists, which have a low reproductive rate, approaches that interfere with reproduction, such as trapping or confusion techniques, are very appropriate.

This graphic shows how the probability of gypsy moth being killed by various mortality factors changes with density of the insect (after Campbell 1975). It is consistent with Southwood's model.



Causes of insect epidemics (outbreaks)

- There are many potential causes of insect outbreaks; we have already alluded to weather (short-term climatic events) but there are others worth mentioning, including

  Increases in food or host resource availability
  Movement of humans, crops and insects
  Changes in crop and land management practices
  Changes in climate
  Pesticides

Increases in food

- Crop monocultures affect occurrence of pests, both because they are grown in a certain manner and because they are bred to have certain characteristics.
- In a mosaic of vegetation (natural conditions), it is difficult for insects to locate hosts.
- Nutrient conditions are higher, and anti-herbivore defenses are lower, in crop plants relative to natural vegetation.

Monocultures

- Crops such as the alfalfa grown here are grown in huge monocultural stands. Should an invading insect be well adapted to thrive on the crop, there is little in the way of physical or spatial impediments to movement from plant to plant.

Increased abundance of animal hosts affects the ability of disease vectors and disease to flourish. Here you see a wood rat, a host of plague-transmitting fleas, and a ground squirrel that has succumbed to plague.

Where do the fleas go after the host has died?

Polycultures

- There are various polycultural scenarios that help avoid the problems with insects moving easily among large tracts of the same crop. Here you can see strip cropping (narrow strips of different crops). In Latin America, a common strategy is to interplant (various crops, often corn and beans) within the same row.

When "attractive" wildlife such as deer (which are important hosts of ticks) become very abundant, the threat of humans contracting tick-transmitted disease can increase. You may meet resistance to the idea of increasing diversity by thinning out animal populations.

Movement of humans, crops and insects

- Movement or relocation of species often results in increase in insect abundance. New crops often recruit pests that formerly existed on native non-crop plants species. Also, new pests introduced without their natural enemies are free to reproduce without much natural suppression. Such new pests may cause extraordinary damage.
- New vectors may bring with them new diseases, or result in formerly insignificant existing diseases becoming much more threatening due to increased vector number or improved disease transmission.

Examples of movement

- Introduction of potatoes to the western U.S. allowed Colorado potato beetle to move from weeds onto crops, move eastward, and become a serious pest in eastern potato-growing areas.
- Introduction of potato beetle into Europe allowed it to become a key pest there, also.
- In the first case, the insect movement was natural dispersal, but in the latter the beetles clearly "hitch-hiked" across the Atlantic Ocean.

Colorado potato beetle

In its native habitat, this devastating potato pest normally is associated with buffalo bur and other weeds (shown here) but moves readily to potatoes where it causes massive defoliation.

Natural dispersal of insects

- Natural dispersal is a common phenomenon, but increasingly a greater problem is the inadvertent transport of insects by humans

Grasshopper in flight. Some species are capable of long-distance dispersal.

More examples of movement

- Louse-borne typhus was moved around Europe by refugees and soldiers during and after World War I and II. The combination of crowded, unsanitary living conditions and introduction of lice and disease caused thousands of deaths.

More examples of movement

- Whitefly-transmitted viruses became a very serious threat to U.S. vegetable production following introduction of silverleaf whitefly in the 1980s to the southern U.S. The viruses were likely present but an efficient vector was lacking.
- In contrast, introduction of West Nile virus to the U.S. in 1999 allowed already-existing mosquito species (some native, some not) to increase in importance as they became vectors of this new disease.

Movement remains a serious problem

- Movement of new insects and diseases remains a serious problem.
- Recent research in Miami, a major air hub for both people and products, showed that over 10% of the arriving aircraft contained insects in their cargo holds, and 23% of the aircraft from Central America contained insects. Is it any wonder that insects get introduced?

Changes in crop and land management

- Changes in management practices sometimes lead to inadvertent upsurges in pest abundance and damage.
- One of the most important ways in which we inadvertently induce insect outbreaks is to prolong the availability of host plants or breeding sites.
- If crops are abandoned in the field after harvest, or cropped continuously, insects can continue to breed and increase in abundance. This is mostly an issue in warm-weather areas, where continuous crop production is an option.

Example of poor land management practices

- In Florida, the summer has traditionally been a tomato-free period, but with greater interest in cherry-type tomatoes, which can be cultured into the summer, this tomato-free period has nearly disappeared. This makes it easier for whiteflies and virus diseases found in the spring crop to survive until the fall crop.

Another example of poor land management

- Concern about storm sewer drainage into streams has led to construction of holding pods where rainfall runoff can be stored temporarily. New housing and parking facilities, as well as roadways, increasingly have small water-holding facilities constructed adjacent to them, and these are wonderful for breeding mosquitoes!

Retention ponds, if they are temporary and lack predators such as fish, or if containing vegetation or other hiding places for mosquito larvae, can produce large numbers of biters.

Changes in climate

- Changes in weather and climate can have short- and long-term changes in insect abundance. Some changes are not permanent, but reflect long-term weather cycles. For example, increase in solar flares (sun-spots) occur at 11-year intervals, with major increases at 22-year intervals. This affects weather patterns on earth.

Examples of climate-weather effects

- Grasshopper and locust populations throughout the world respond to changes in warmth and rainfall, causing major outbreaks. In North America there tends to be a minor 11-year cycle and a major 22-year cycle.
- Changes in ocean currents (e.g., El Niño phenomenon) cause mosquito and human disease outbreaks in Africa.
- Global warming is likely to increase insect and human disease problems.

Pesticides

Changes in pesticide use patterns affect insects due to :

- differing sensitivities of insect taxa (including destruction of natural enemies),
- release of insects from insecticidal suppression, and
- induction of insecticide resistance.

(Pesticide issues will also be treated later)

Nonindigenous and invasive species

- Only small number of nonindigenous introductions result in serious invasive situations.
- Predictability lacking; Hawaii receives 15-20 new insects per year, Florida 10-12.
- However, most severe pests are invaders.
- Homogenization of world’s biota under way; native biota suppressed.
- Risk is great: 24.8% of sea containers arriving in NZ contain nonindigenous organisms.

Invasion characteristics

- Successful invading species: those with large natural ranges, high intrinsic rate of reproduction, and that arriving with large founding populations.
- Habitats successfully invaded: those with few species present, high degree of disturbance, absence of competing species, numerous hosts available.

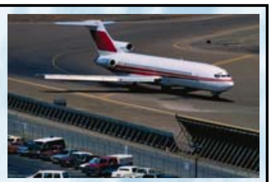
Arrival of invasives

- Insects and plant disease arrival is accidental - stowaways or hitchhikers.
- Molluscs usually stowaways, but sometimes introduced.
- Vertebrates and plants usually deliberate - for economic gain.
- Few pests move by own powers of dispersal.
- Wind, rivers, ocean currents, hurricanes provide assistance.

Historical invasions

- Ship ballast or hay dumped at shore.
- Introduction of plant material - ornamental, food, forage crops.
- Europe principal source of invaders to NA.
- Major shipping routes of British empire all heavily inoculated; later canals, railroads, now airplanes.

Future?



- Changes in immigration, trade and tourism patterns influence nature of invasion.
- Southeast Asia and China new sources of pests now.
- More rapid transport means more insects survive long trips.

Trade

- World Trade Organization (WTO) established to foster trade.
- Pest threat can be basis for exclusion, but must have scientific basis.
- Results in more rapid redistribution of pests.
- Safeguards needed to mitigate threat (inspection, eradication).
- Plant propagation materials major threat.

Currently 70% of interceptions are made at only 3 ports: Miami, New York, and Los Angeles.

In Miami, 80% are from Central America.

In New York, Europe and China predominate.

In Los Angeles, Central America, China, and Thailand predominate.

Note similar climates between pairings.

Arthropod interceptions on plant material intended for propagation in USA (top 12 countries for 1990-1999)

Origin	Total number of intercepts
Costa Rica	4723
Guatemala	1456
Mexico	1193
Netherlands	902
Honduras	886
Thailand	770
China	588
Singapore	498
Japan	339
Belize	232
South Africa	217
Dominican Republic	200

After National Research Council 2002

Major sources of invasives are:
- hitchhikers on ornamental plants
- insects infesting food or packing
- insects sold as pets or pet food
- military equipment.

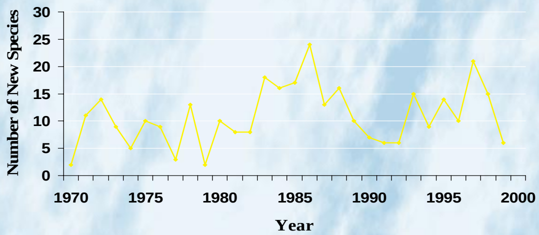
Transport faciltated by:
- air traffic
- containerization
- hand luggage?
- smuggling
- localized production areas
- informal and internet plant and seed exchange.

Probable pathways of introduction of insects into Japan

Pathway	# of species
flight (air currents, wind)	4
plant material	52
military transport	10
hay	9
fruit, tubers	8
grain	8
hitchhike	3
wood, packing	2
cut flowers	1
seeds	1

After Kiritamni and Yamamura 2002

Pattern of introduction of new insects into Florida, by year. Note high degree of variability and weak upward trend.



Inspection

- First line of defense. Not enough done for prevention.
- APHIS in USA ports, but inadequate resources. Less than 2% inspection rate in USA versus 20% in New Zealand.
- Port Information Network (PIN) documents over 50,000 interceptions per year, 60-65% insects. Widely occurring and beneficial insects not reported.

Factors influencing invasiveness:

- Climate matching
- Latitude
- Availability of hosts

European agriculturalists feared that Colorado potato beetle would invade Europe, where the climate and crops were well suited for its survival. Despite valiant efforts to keep it out, this eventually occurred.

Taxa differ in propensity to become invasives.

Most common are:

- beetles
- small (cryptic) species

Asian longhorn beetle, a recent invader of North America

Number of insect species successfully invading Japan through 1986.

Taxon	# established
termites	2
cockroaches	4
thrips	11
aphids	13
whiteflies, psyllids, etc.	8
scales, mealybugs	19
stinkbugs	3
stored-product beetles	21
weevils	23
ladybird beetles	9
longhorn beetles	4
leaf beetles	6
stored-product moths	3
other moths	21
leafminer flies	4
other flies	13
ants	7
other Hymenoptera	3
wasp parasitoids	11

After Kiritani and Yamamura 2003

Factors influencing establishment:

- Population size: larger introductions more likely establish
- Temporal availability: matching species needs important
- Natural catastrophes
- Reproductive traits: inbreeding, parthenogensis
- Spatial distribution: food, patchiness
- Host relations: same or related host available
- Natural enemies: absence of predators, parasites, disease, competitors

Latency
Insects may remain nondamaging for several years after introduction, then display an upswing in abundance. Adaptation to host or weather, attain optimal location or abundance?

Subsidence
Insect abundance may subside after period of abundance. Introduction, increase in abundance, or host switching by natural enemies, shift in genetics of host, change in weather, better management?

Risk assessment and management:

Damage potential for invasives affects importation potential

- Incidence of occurrence in place of origin
- Ability to produce clean crop or destroy infestation
- Ability to detect pests
- Ability to eliminate detected organisms

Unfortunately, politics sometimes replaces science in determining importation policy.

Preclearance

Inspection before shipment, in country of origin, eliminates need for inspection at port.

Mitigation

When absence of pest cannot be guaranteed, steps to reduce likelihood of establishment taken:

- Shipment only from pest free areas
- Use pest resistant varieties
- Import only portions of host not susceptible
- Import only to locations not susceptible
- require disinfestation

Case study: USDA, PPQ Procedures for importation of avocados from Mexico to USA. Fruit flies infest this commodity in Mexico and are a threat to US avocado production.

1. Host resistance: Hass avocado, the variety produced in California, not susceptible
2. Field surveys of growing areas must demonstrate absence of flies.
3. Trapping studies must demonstrate absence, or treatment required.
4. Field sanitation required: fallen and over-ripe fruit destroyed.
5. Post-harvest safeguards including screening and double doors to reduce threat of infestation after harvest.

Case study, continued

6. Harvest and ship only during winter months. Fly activity low, off-season in USA also.
7. Packinghouse inspection including fruit cutting.
8. Port-of-arrival inspection, including phytosanitary certificates and other documentation.
6. Distribution limited to northeastern USA because no fruit production there and weather inhospitable to flies.

Mexican fruit flies

Questions

- What are the 3 major categories of factors affecting insect abundance?
- Can you describe what causes insects to become so abundant? Are some factors more likely than others? Does it matter if we are discussing natural conditions for managed ecosystems?
- Why are insects not always abundant? What keeps them from overwhelming their food resources?

Questions, continued

- Are the factors that keep insects from becoming abundant the inverse of those that stimulate abundance?
- Can you distinguish between density-dependent and density-independent mortality factors?
- Considering Southwood’s model, can you describe how insect life history characteristics are related to factors likely to affect their abundance?
- How do habitat characteristics affect the preferred approaches to insect pest management?

Questions from supplementary reading

- Reading 11, North American vegetable pests
  - This study discusses 2 major sources of pests: introduction of exotics and host switching. Which process produces the larger number of pests? The most damaging pests?
  - What is the geographic source of most NA vegetable pests? How did they get here? Why are there not more from South America, our nearest neighbor?
  - What is the trend in number of introductions in the last century? To what do you attribute this trend?

More questions from supplementary reading

- What orders are over represented among invading organisms? Among indigenous organisms? Can you explain why these particular invaders likely were successful at getting to NA?
- Do invading species tend to have a broader or narrower host range than indigenous species? How do you explain this trend?
- Explain the importance of host pre-adaptation for host plants?