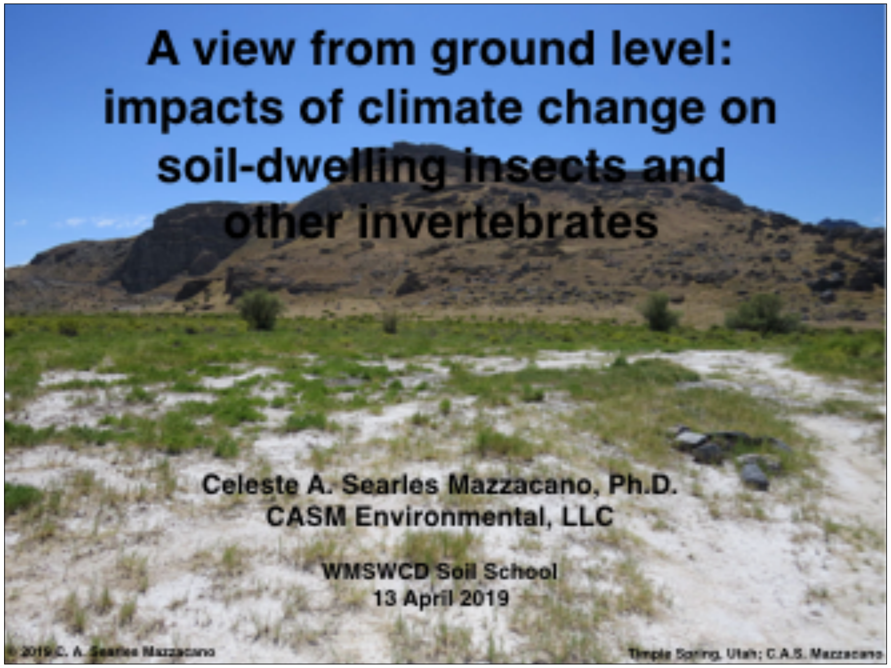
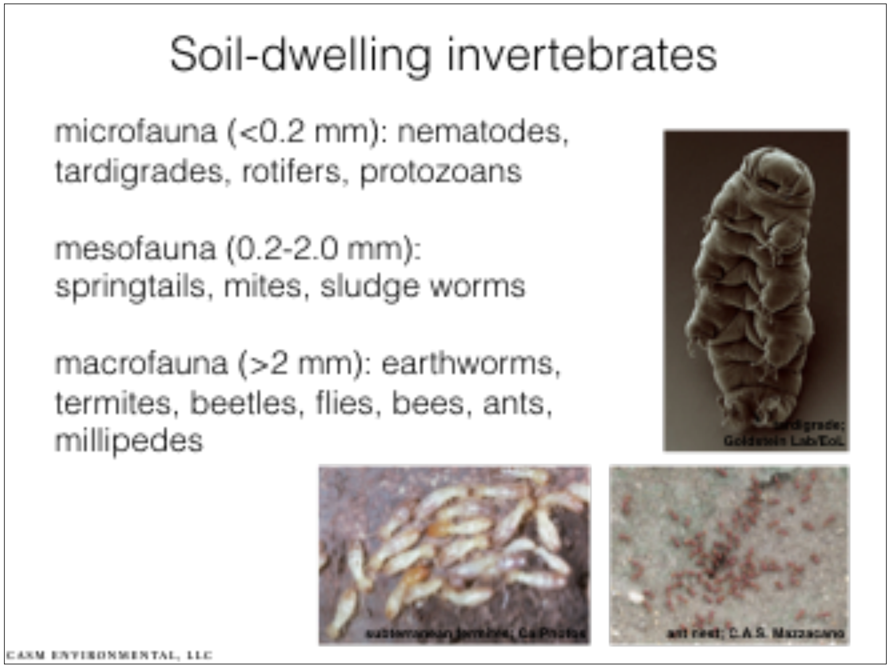


A view from ground level: impacts of climate change on soil-dwelling insects and other invertebrates

Celeste A. Searles Mazzacano, Ph.D.
CASM Environmental, LLC

WMSWCD Soil School
13 April 2019

Temple Spring, Utah; C.A.S. Mazzacano



Soil-dwelling invertebrates

microfauna (<0.2 mm): nematodes, tardigrades, rotifers, protozoans

mesofauna (0.2-2.0 mm): springtails, mites, sludge worms

macrofauna (>2 mm): earthworms, termites, beetles, flies, bees, ants, millipedes

tardigrade; Goldstein Lab/EoL

subterranean termites; CalPhotos

ant nest; C.A.S. Mazzacano

CASM ENVIRONMENTAL, LLC

soil health

Lumbricus terrestris Common Earthworm; David Hobern

Carabus Ground Beetle; [illegible]

millipede; C.A.S. Mazzacano

Armadillidium vulgare Common Pill Woodlouse; hormiguet/Naturalist

springtail; [illegible]

[illegible]

CASM ENVIRONMENTAL, LLC

soil health

burrowing, nesting, defecating influences:

porosity, aeration, water penetration

soil formation & aggregation

microbial communities

plant health & production

CASM ENVIRONMENTAL, LLC

nutrient cycling

Canthon pilularius dung beetle; C.A.S. Mazzacano

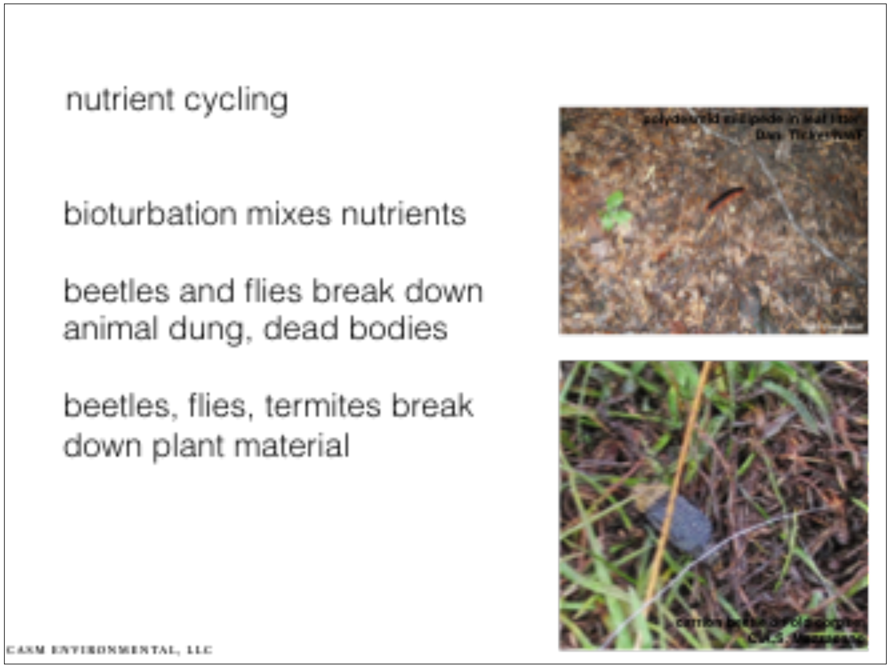
millipede C.A.S. Mazzacano

[illegible] stag beetle; C.A.S. Mazzacano

Nicrophorus defodiens burying beetle; C.A.S. Mazzacano

ant hill, Veracruz MX C.A.S. Mazzacano

Reticulitermes [illegible] termites; Univ. of FL



nutrient cycling

bioturbation mixes nutrients

beetles and flies break down animal dung, dead bodies

beetles, flies, termites break down plant material

polydesmid millipede in leaf litter; [illegible]

carrion beetle [illegible]; C.A.S. Mazzacano

pest control

Vespula pensylvanica Western Yellowjacket; C.A.S. Mazzacano

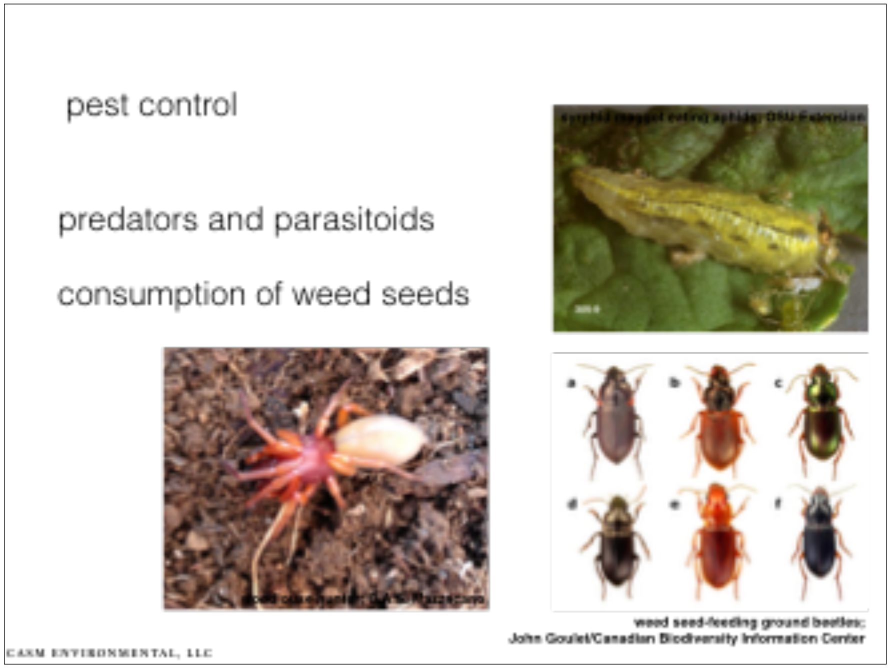
Agelenopsis Funnel-web Weaver; C.A.S. Mazzacano

Myrmeleon [illegible] ant lion, Oregon; C.A.S. Mazzacano

Ammophila wasp with geometrid larva; C.A.S. Mazzacano

Cicindela oregona Western Tiger Beetle; C.A.S. Mazzacano

Scolopocryptopidae centipede; [illegible]



pest control

predators and parasitoids

consumption of weed seeds

syrphid maggot eating aphids; OSU Extension

[illegible]; C.A.S. Mazzacano

weed seed-feeding ground beetles;
John Goulet/Canadian Biodiversity Information Center

pollination

flower scarabs; C.A.S. Mazzacano

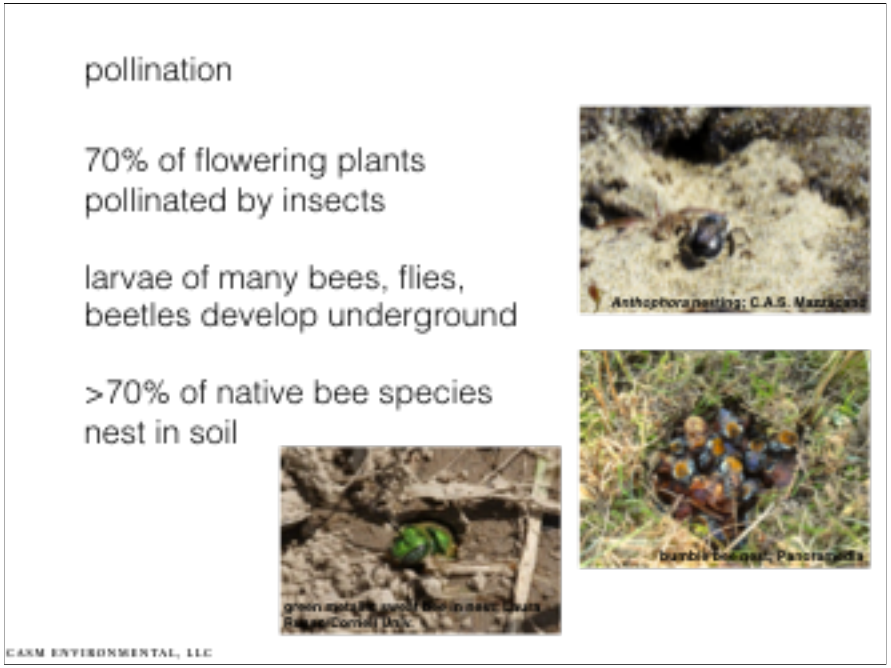
Mining bee; C.A.S. Mazzacano

Soldier Beetle; David Hebert

Sweat Bee; C.A.S. Mazzacano

Flower Fly; C.A.S. Mazzacano

Bombus californicus; C.A.S. Mazzacano



pollination

70% of flowering plants pollinated by insects

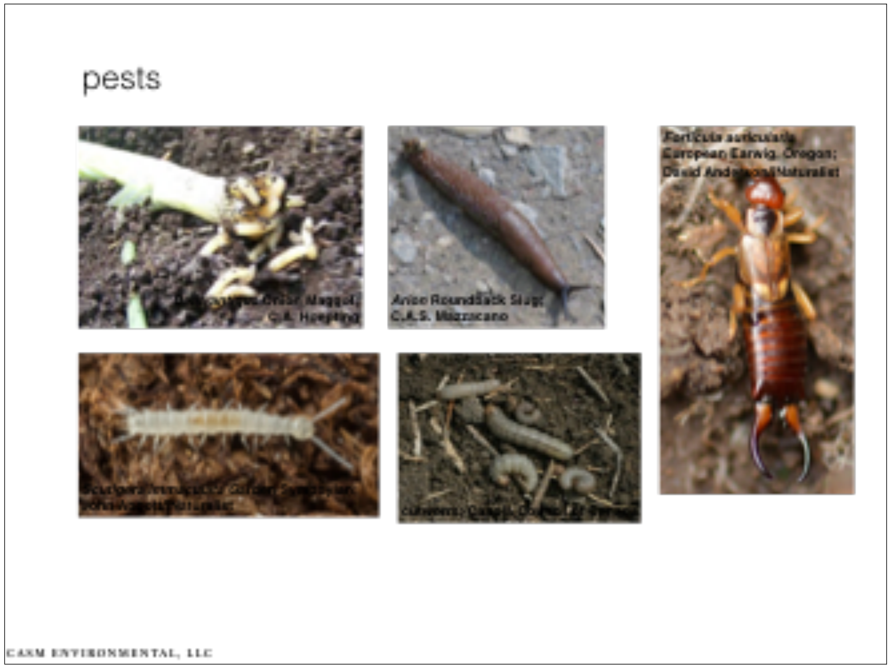
larvae of many bees, flies, beetles develop underground

>70% of native bee species nest in soil

Anthophora nesting; C.A.S. Mazzacano

green metallic sweat bee in nest; Laura Russo/Cornell Univ.

bumble bee nest; [illegible]



pests

[illegible] Maggot; C.A. Hoepting

Arion Roundback Slug; C.A.S. Mazzacano

Forficula auricularia European Earwig, Oregon; David Anderson/Naturalist

Scutigerella immaculata Garden Symphylan; [illegible]/Naturalist

cutworms; [illegible]

pests

plant parasitic nematodes

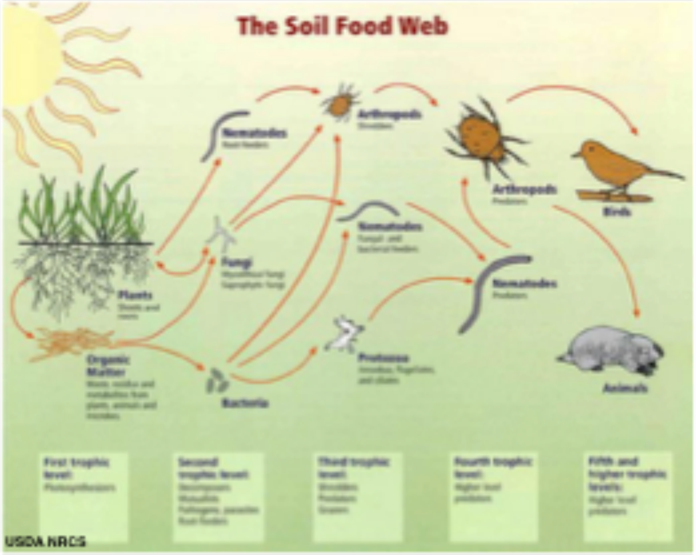
root, shoot, or crown-feeding insect larvae, aphids, symphylans

strawberries damaged by symphylans; J.K. Clark/UC Extension

root knot nematode in lettuce; J.K. Clark/UC Extension

wireworms [illegible]

food resource



USDA NRCS

Invertebrate responses to climate change matter

increased eCO_2

changes in precipitation

changes in temperature

direct & indirect impacts

USEPA: Projected changes in several climate variables for 2046-2065 with respect to the 1981-2000 average for the RCP8.5 scenario.

Invertebrate responses to climate change matter

biodiversity

conservation

food security

public health

climate regulation

oak forest, WA; C.A.S. Mazzacano

invertebrates adapt to local climatic conditions via:

changes in phenology

thermal tolerance

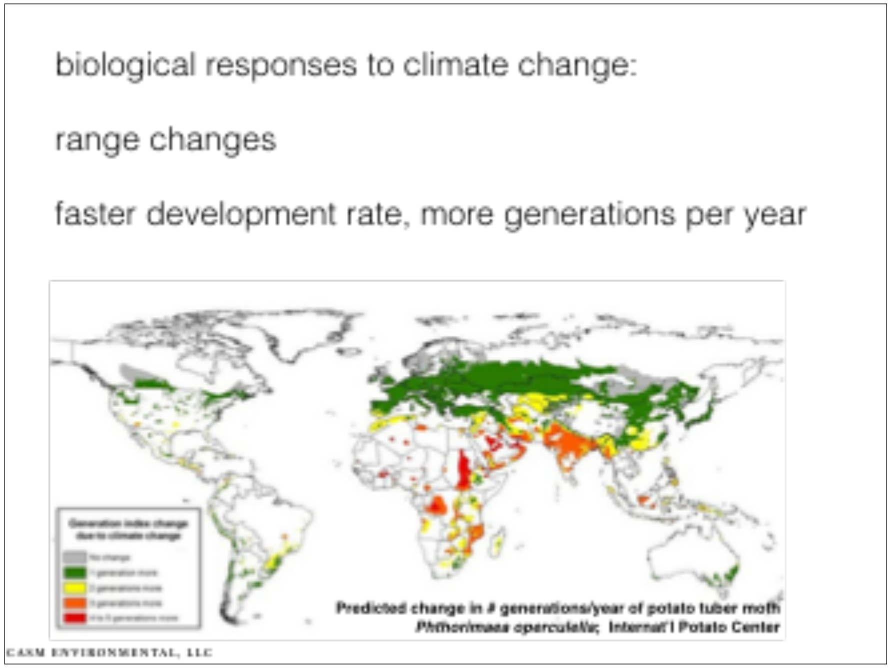
desiccation tolerance

diapause

body size

melanization

Four-spotted Pennant obelisking: C.A.S. Mazzacano

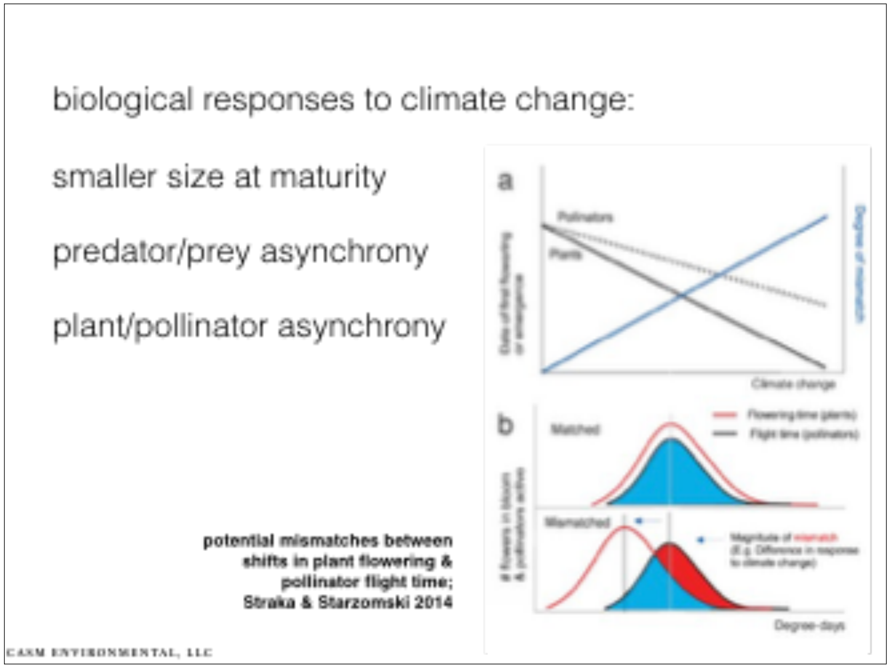


biological responses to climate change:

range changes

faster development rate, more generations per year

Predicted change in # generations/year of potato tuber moth *Phthorimaea operculella*; Internat'l Potato Center



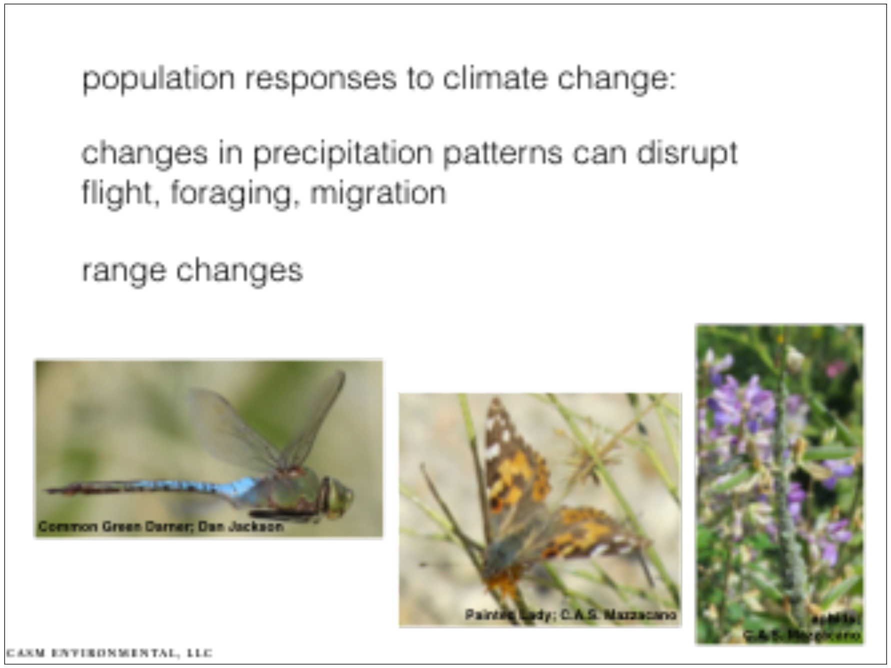
biological responses to climate change:

smaller size at maturity

predator/prey asynchrony

plant/pollinator asynchrony

potential mismatches between shifts in plant flowering & pollinator flight time; Straka & Starzomski 2014



population responses to climate change:

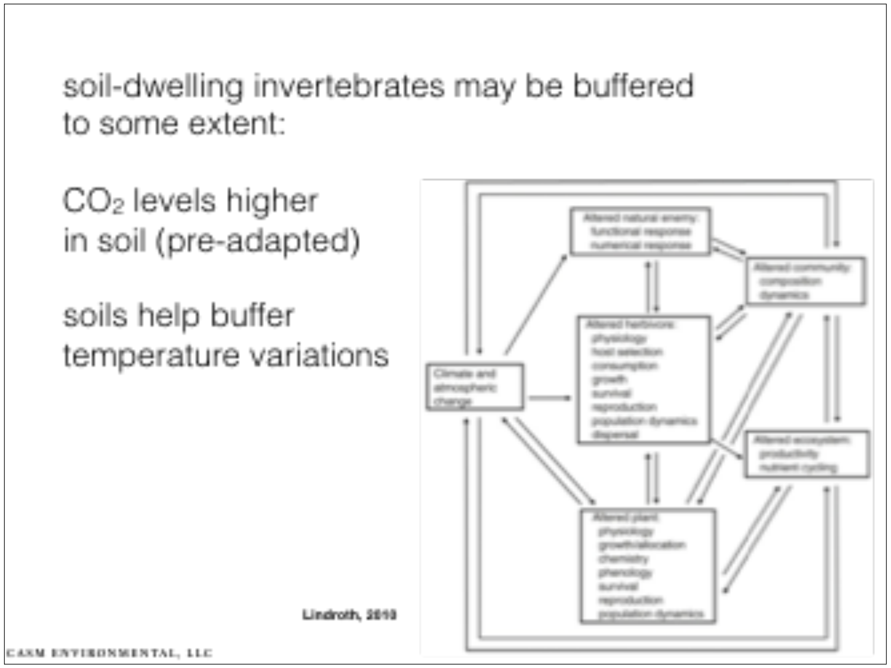
changes in precipitation patterns can disrupt flight, foraging, migration

range changes

Common Green Darner; Dan Jackson

Painted Lady; C.A.S. Mazzacano

aphids; C.A.S. Mazzacano



soil-dwelling invertebrates may be buffered to some extent:

CO_2 levels higher in soil (pre-adapted)

soils help buffer temperature variations

Lindroth, 2010

Observed responses: spring flight

butterfly species in Europe and NA appearing 4-16 days/decade earlier since 1970s (Forister & Shapiro 2003; Kearney et al. 2010; Gordo & Sanz 2006)

spring-active bumble, mining, and cellophane bees in NE US appearing ~10 days earlier (Bartomeus et al. 2011)

Observed responses: distribution

latitude: 63% of non-migratory European butterfly ranges shifted north 35-240 km in 20th century, 3% shifted south (Parmesan et al. 1999)

altitude: 63-90% of dung beetles in France & Spain shifted ranges up-slope consistent with level of warming (Menendez et al. 2013)

Observed responses: distribution

meta-analysis in UK found 33% of wild bees & hover flies decreased from 1980-2013; 10% increased, rest with no clear trend (Powney et al., 2019)

bee declines all post-2007

hover flies in steady decline

increases occurred mostly among dominant crop pollinator spp.

Observed responses: active period

longer flight season in UK butterflies; some had extra generation (Roy & Sparks 2000)

wintertime bumble bee activity in UK gardens (Stelzer et al. 2010)

alpine muscid & chironomid flies declined >60% since 1996; temps 2.5C higher, flowering period 5 days shorter (Høye et al. 2013)

Knowledge gaps

little long-term monitoring

many species poorly known

few to no targeted experiments

lack of standardization

difference in lab vs. field

biotic & abiotic interactions

mechanisms not always clear


Prettycons/The Noun Project

Soil core transplant experiments:

different elevations, moisture, temps.: changes in community composition & abundance of worms, fly larvae, tardigrades; some moved deeper into soil in response to drying, some more abundant at warmer temps (Briones et al 1997)

prairie cores swapped between moist and dry sites: mites & total micro-arthropods more abundant at drier site (O'Lear & Blair 1999)


Centre for Biodiversity Genomics

Impacts on bees:

differential impacts of shorter winters:

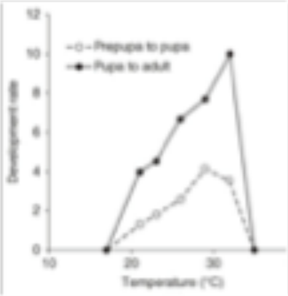
Bumble bee queens use fewer stored resources during hibernation; mason & leaf-cutter bees lost more mass, had lower survival (Bosch & Kemp 2003, 2004)

some brood parasites benefit more from warmer temps than their hosts (Stone & Willmer 1989, Straka & Bogusch 2007, Rozen et al 2009)


California Bumble Bee: C.A.S. mazzacano

ground-nesting bee activity increases with increasing soil & ambient temp.; at upper limit (~45-50C) have heat stress, reduced longevity, lower activity, larval & adult mortality (Cameron et al 1996, Herrera 1995)

smaller adults from bees developing at warmer temps, impacting flower types visited, pollen-carrying distances (Davidowitz et al 2004; Radmacher & Strohm 2010)



Development rate of Alkali Bee; O'Neill et al., 2011


Alkali Bee at nest; James Cane/USFS

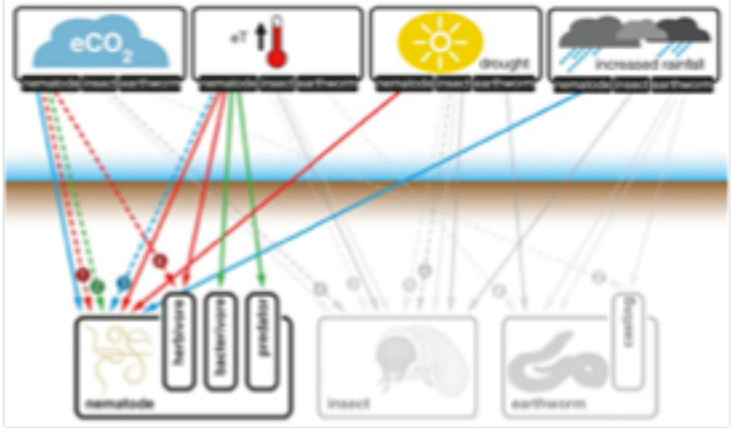
changes in predator/prey relationships:

grassland spiders & grasshoppers: warming made spiders but not grasshoppers move lower in veg. = less predation, more grasshopper growth & survival, increased grass biomass & decreased forb biomass (Barton 2010, 2011)

warmer temps impaired ant-corn leaf aphid mutualism, more aphid predation by lady beetles (Barton & Ives, 2014)


wolf spider; C.A.S. Mazzacano

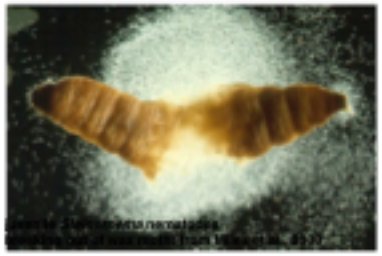
changes in soil invertebrates: nematodes



solid = direct, dashed = indirect; shift in community; positive impact; negative impact (after Hiltpold et al., 2017)

nematode community composition strongly related to climate; in field studies, increased CO_2 changed abundance of different trophic groups (Nielsen et al 2014)

nematodes adapted to higher soil CO_2 levels so likely to see indirect impacts, i.e. changes in plant C:N ratio altering food quality; CO_2-enhanced growth of fine roots decreasing ability of entomopathogenic nematodes to find/infect insect hosts in rhizosphere (Demarta et al 2014)

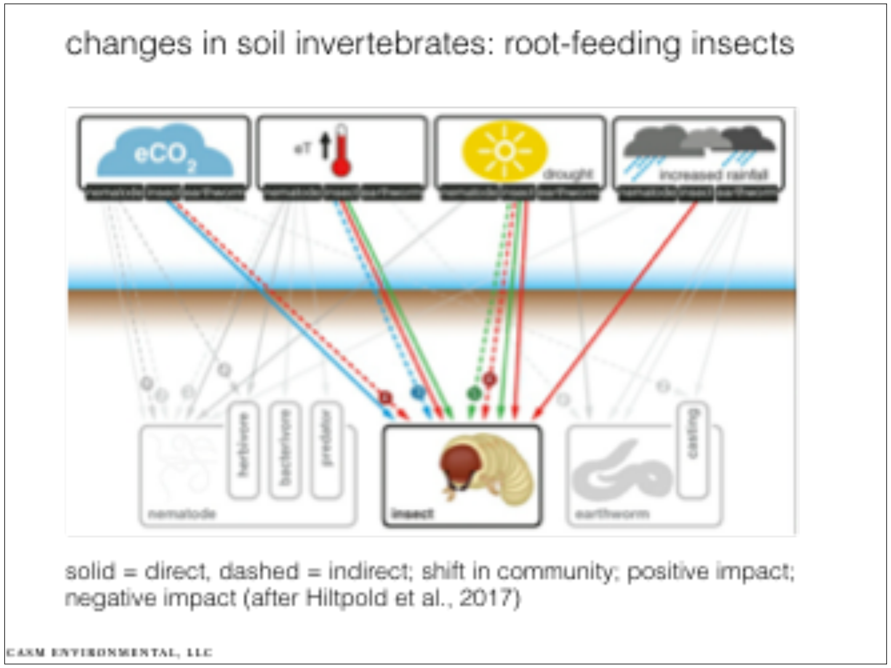


increased temps likely to increase nematode activity, metabolic rate, reproduction;

results from field studies vary greatly; often see changes in species composition & dominance even if total abundance unchanged

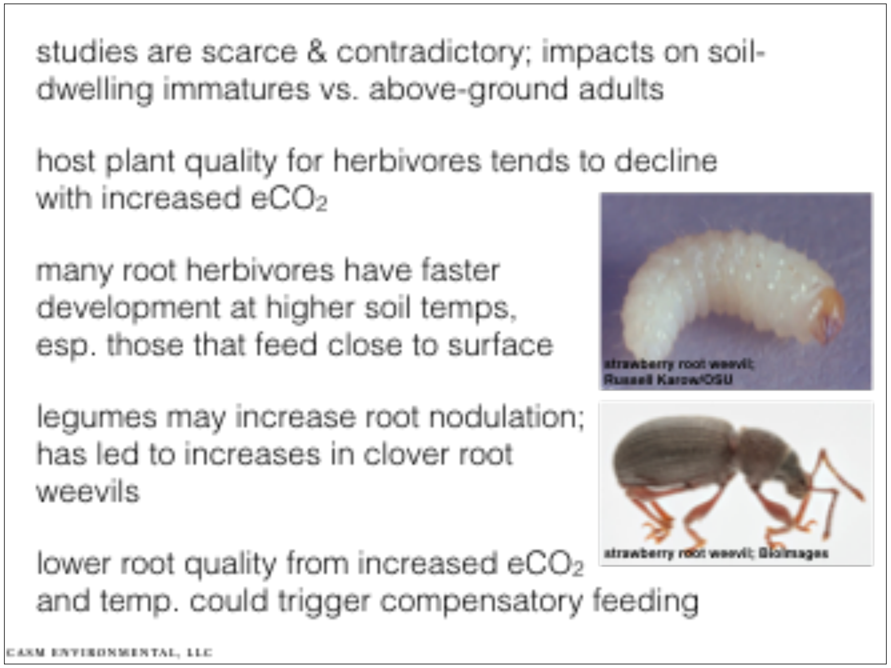
similarly varied results in experiments looking at increased/decreased soil moisture


stubby root nematodes in carrot: Bonsak Hammeraas, NIBIO 5393018



changes in soil invertebrates: root-feeding insects

solid = direct, dashed = indirect; shift in community; positive impact; negative impact (after Hiltpold et al., 2017)



studies are scarce & contradictory; impacts on soil-dwelling immatures vs. above-ground adults

host plant quality for herbivores tends to decline with increased eCO_2

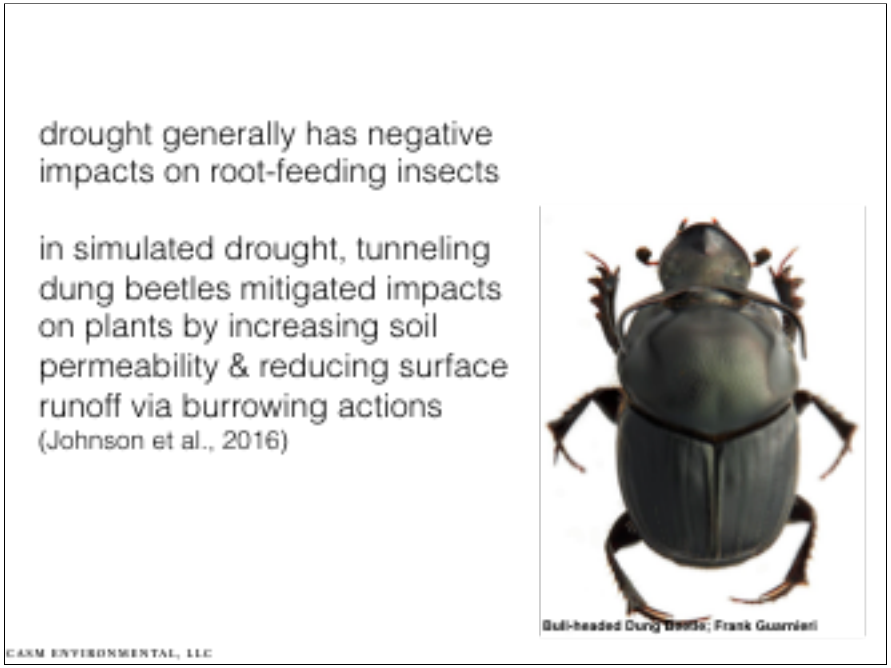
many root herbivores have faster development at higher soil temps, esp. those that feed close to surface

legumes may increase root nodulation; has led to increases in clover root weevils

lower root quality from increased eCO_2 and temp. could trigger compensatory feeding

strawberry root weevil; Russell Karow/OSU

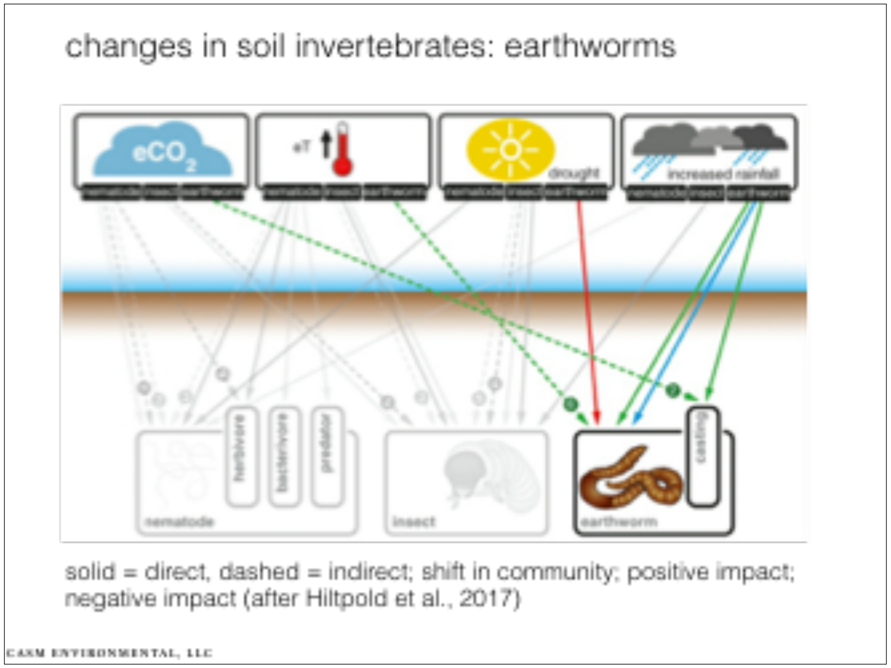
strawberry root weevil; BioImages



drought generally has negative impacts on root-feeding insects

in simulated drought, tunneling dung beetles mitigated impacts on plants by increasing soil permeability & reducing surface runoff via burrowing actions (Johnson et al., 2016)

Bull-headed Dung Beetle; Frank Guarnieri



changes in soil invertebrates: earthworms

solid = direct, dashed = indirect; shift in community; positive impact; negative impact (after Hiltpold et al., 2017) little work on effects of increased eCO_2, changes in soil moisture; results vary

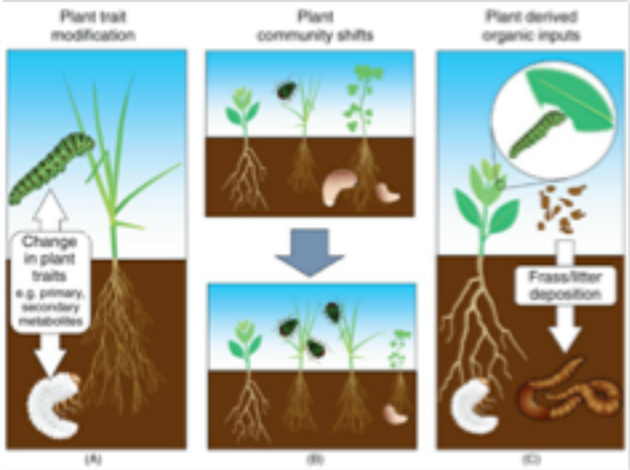
temperature alters community species composition

bioturbation activity depends on soil temp. & moisture

important ecosystem engineers, so responses will impact soil fertility


earthworm; Bioimages

changes in interactions between above- and below-ground invertebrates



Johnson et al., 2017

altered host plant suitability

altered host plant availability

altered organic deposition

black bean aphid growth rate increased on host plant with root-feeding scarab beetle larvae under low-water but not high water conditions (Gange & Brown, 1989)

root-feeding click beetle and leaf-mining moth on wild basil (Staley et al., 2007)

-increased precipitation treatment: reduced leaf-miner pupal weight when beetles present

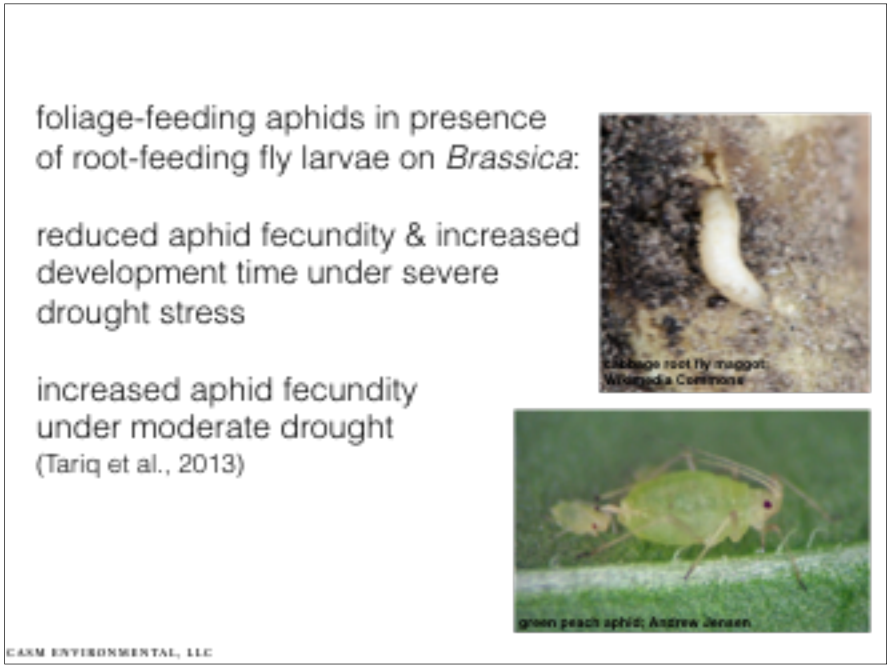

click beetle; OSU Extension


leaf-miner damage; Stewart Wright

clover root weevil (adults feed on foliage, larvae on roots) under increased CO_2:

adults increased feeding, laid fewer eggs; but larval populations increased due to increased root nodulation (Staley & Johnson, 2008; Johnson & McNicol, 2010)


clover root weevil adult; AgPest



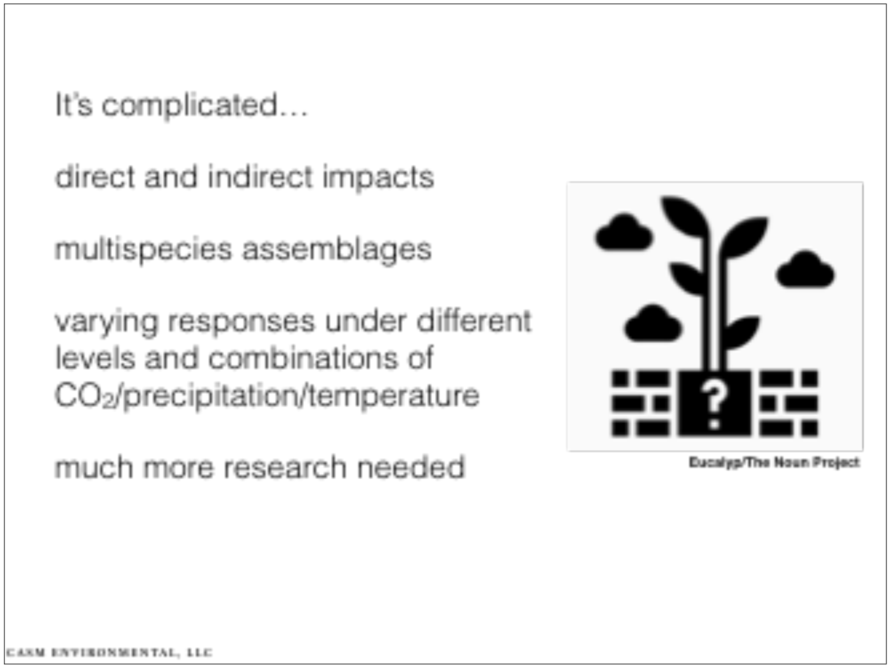
foliage-feeding aphids in presence of root-feeding fly larvae on *Brassica*:

reduced aphid fecundity & increased development time under severe drought stress

increased aphid fecundity under moderate drought
(Tariq et al., 2013)

cabbage root fly maggot; Wikimedia Commons

green peach aphid; Andrew Jensen



It's complicated…

direct and indirect impacts

multispecies assemblages

varying responses under different levels and combinations of CO_2/precipitation/temperature

much more research needed

Eucalyp/The Noun Project

Celeste A. Searles Mazzacano, cmazzacano@gmail.com

Wetsalts Tiger Beetle, Utah; C.A.S. Mazzacano

Funnel Web Weaver, Oregon; C.A.S. Mazzacano

Bee Fly, Oregon; C.A.S. Mazzacano

Pipevine Swallowtail, Texas; C.A.S. Mazzacano