Soil, biodiversity and ecosystem services

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Scope of this talk

- Soil biota and functions of soil biodiversity
  - Waste recycling, N fixation, bioremediation,……………
  - Soil C and N cycles; relevance to GHG emissions
- Soil effects on crop biodiversity
  - Elevated CO_2 and crop ecophysiology
  - Water, salinity, and nutrient stress
  - Genetic resources
- Soil properties and landscape agrobiodiversity
  - Soil management, land use, and effects on aboveground biodiversity in agricultural landscapes
  - Place-based analysis of climate change responses
- Research needs: a DIVERSITAS viewpoint

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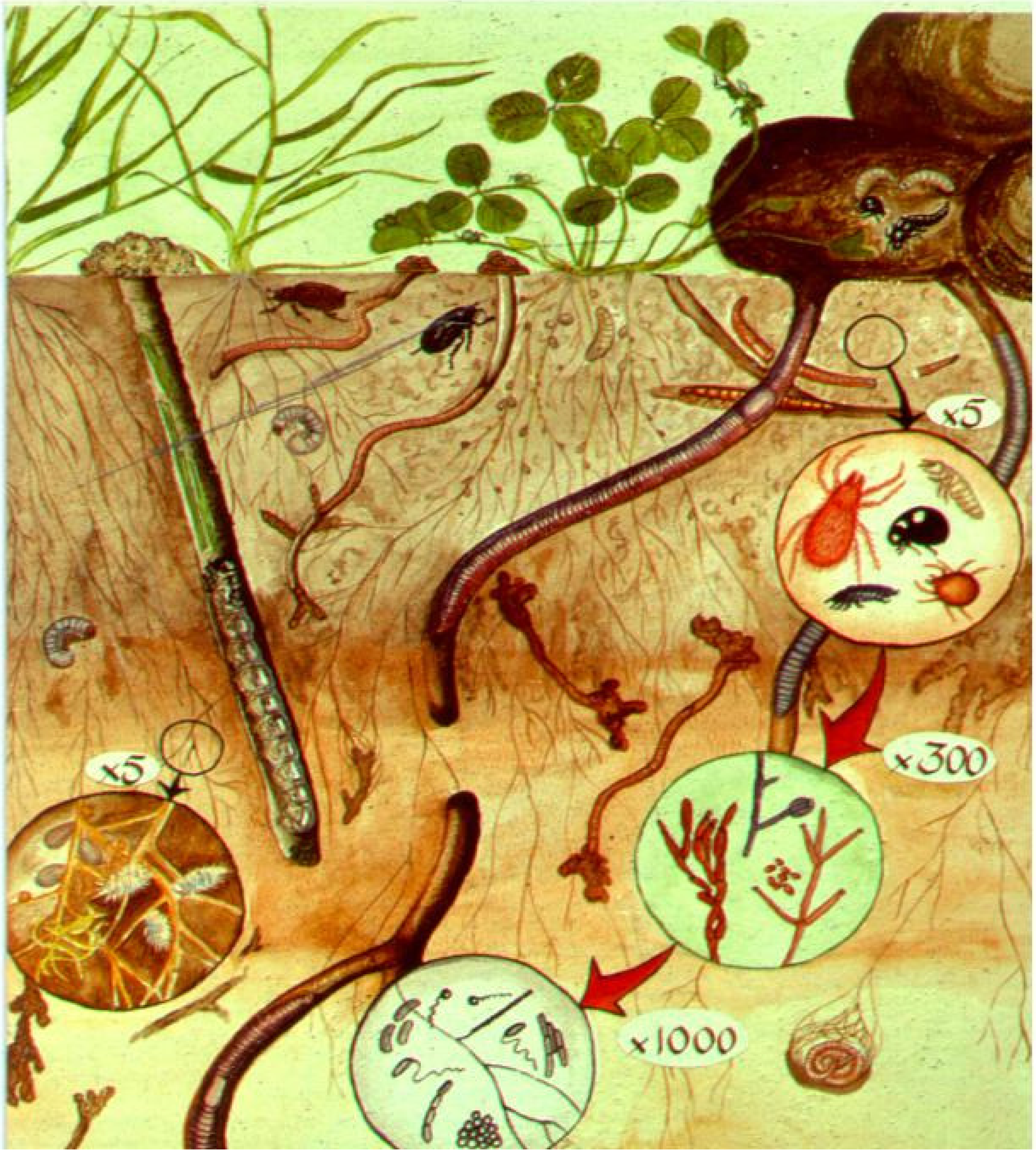
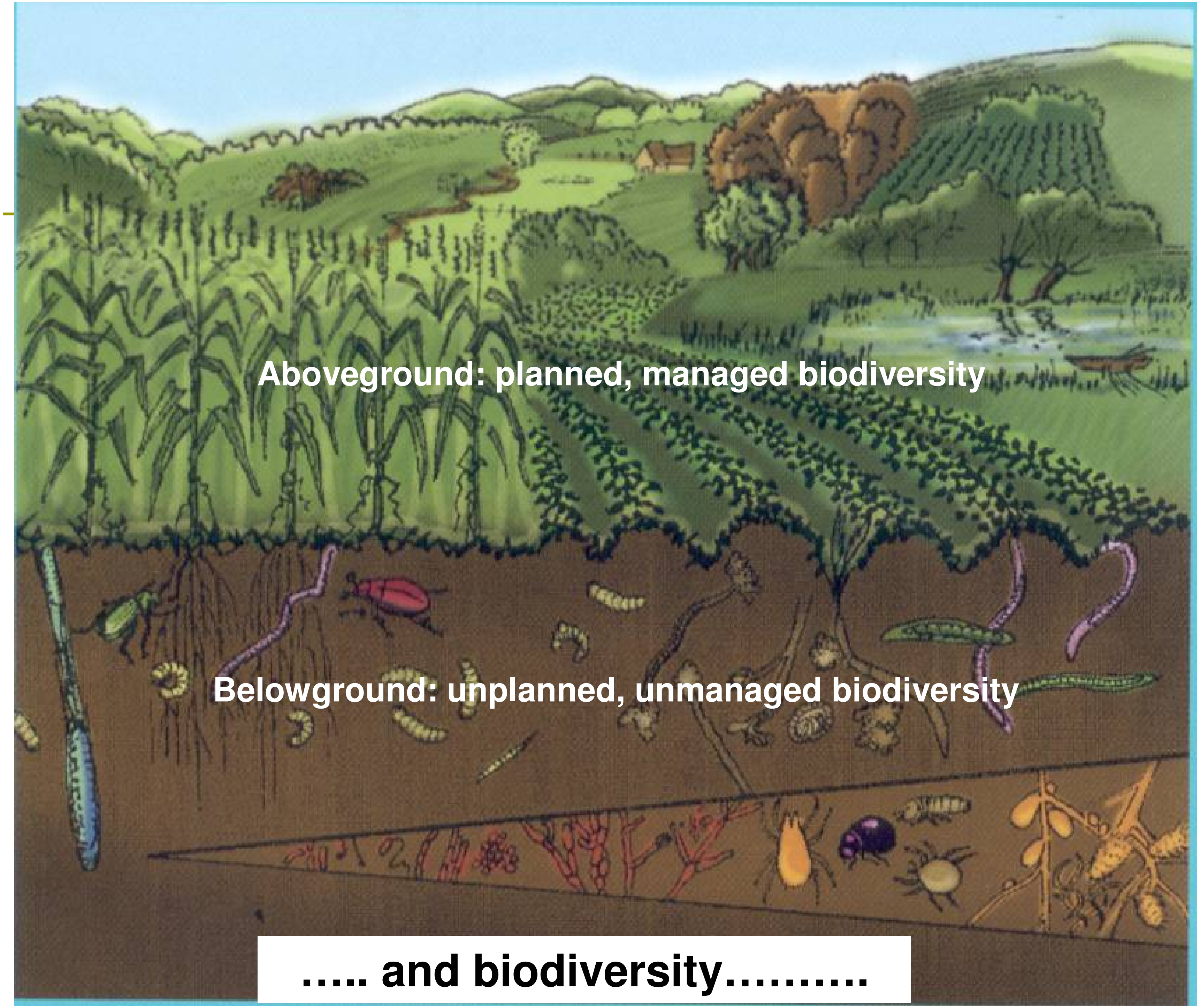
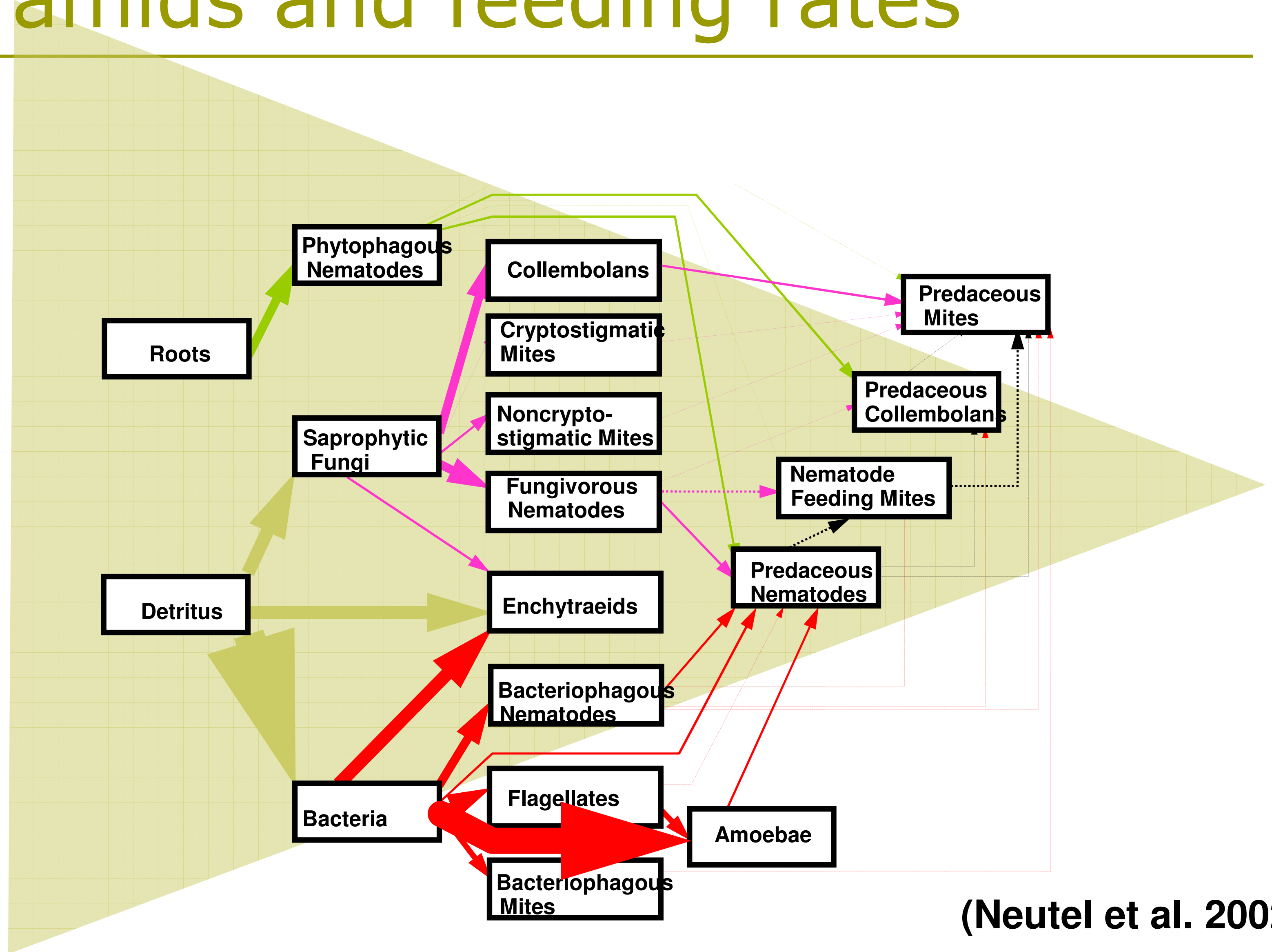
Soil food webs…..





….. and biodiversity……….

Pyramids and feeding rates



(Neutel et al. 2002)

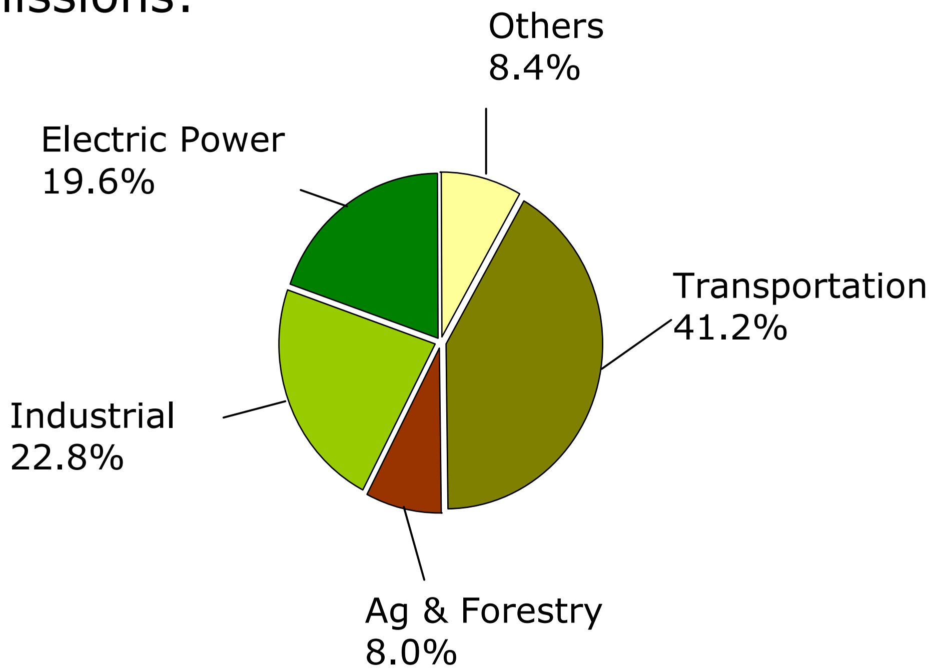
Ecosystem service	Soil organisms involved	Global economic benefits (USD x 10^9 yr^{-1})
Waste recycling	**Various saprophytic and litter feeding invertebrates (detritivores), fungi, bacteria, actinomycetes and other microorganisms**	**760**
Soil formation	**Various soil biota facilitate soil formation (e.g., fungi, bacteria, termites, earthworms)**	**25**
Nitrogen fixation	**Various symbiotic and asymbiotic microorganisms (diazotrophic bacteria)**	**90**
Bioremediation of chemical pollutants	**Mostly microorganisms (bacteria, fungi)**	**121**
Provision of industrial and pharmaceutical goods, including medicines	**Many microorganisms extracted from the soil are used for various industrial and pharmaceutical purposes (e.g., food processing and production, biocides, antibiotics and other natural products)**	**6**
Biological control of pests (insects and pathogens)	**Many natural enemies of pests live in the soil (e.g., fungi, bacteria, viruses, invertebrates)**	**160**
Pollination	**Many insect pollinators that have an edaphic phase in their life-cycle**	**200**
Provision of wild products (food)	**Mushrooms, insects, roots**	**180**
TOTAL		**1,542**

Total estimated economic benefits of soil biota (modified from Pimentel et al. 1997; Brown et al., unpublished; Brussard et al., 2007)

Soil greenhouse gas (GHG) emissions: California

California 2004 statewide GHG emissions:

- Total:
  480 MMT CO_2 Eq yr^{-1}
- Agriculture:
  28 MMT CO_2 Eq yr^{-1}
- Agricultural sources:
  - **Ag soil management**
    8.3 MMT CO_2 Eq yr^{-1}
  - Enteric fermentation
    7 MMT CO_2 Eq yr^{-1}
  - Manure management
    6.9 MMT CO_2 Eq yr^{-1}
  - Energy use/fuel combustion
    4.9 MMT CO_2 Eq yr^{-1}
  - Rice cultivation
    <1 MMT CO_2 Eq yr^{-1}
  - Ag residue burning
    <1 MMT CO_2 Eq yr^{-1}



Agriculture=6% of statewide GHG emissions

California Air Resources Board, 2007

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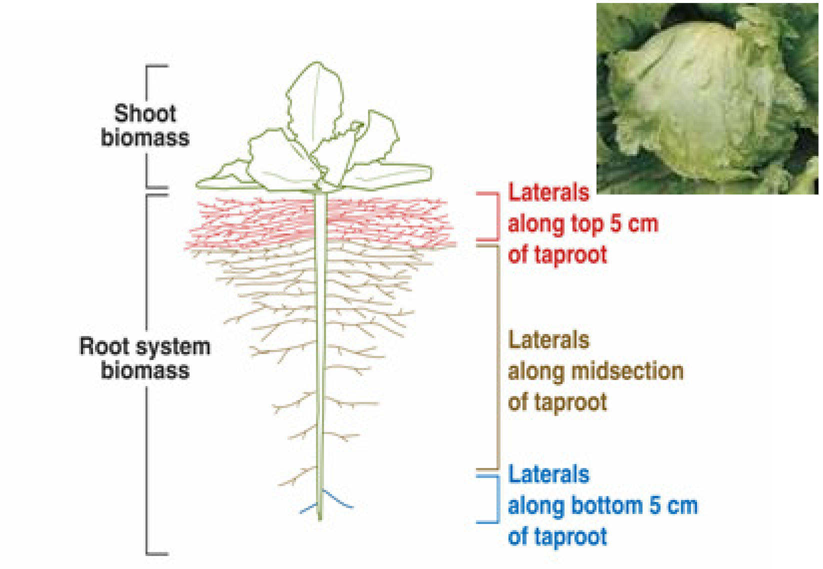
  - Soils and multifunctionality of ecosystem services: Place-based analysis of climate change responses
- Research directions: a DIVERSITAS viewpoint

Crop genetic resources to alleviate soil stress



Genes to increase yield with lower inputs of water and nutrients

- Lettuce: Value of genes for deep roots differs according to water availability
  - Genes (QTL) from wild lettuce
  - RILS with QTL for deep taproot vs. deep lateral roots
- Tomato: Value of genes for mycorrhizal colonization differs according to soil type and farming method
  - Non-mycorrhizal mutant (rmc) vs. wild type (MYC)
  - Organic farms

Johnson et al., 2000; Cavagnaro et al., 2006

Elevated CO_2 (eCO_2) and crop ecophysiology

- Higher photosynthesis rates of C_3 plants at eCO_2
- Legumes: Increase in N fixation and growth
- Non-legumes: Greater nitrogen (N) limitation at eCO_2
  - Decrease in soluble protein and N content (Cotrufo et al. 1998)
    - Dilution effect
  - Organic matter inputs to soil have higher C:N ratio (Reich et al. 2006)
    - Higher competition with soil microbes for N
  - Lower rates of shoot nitrate assimilation (Rachmilevitch et al. 2004)
    - Photorespiration increases nitrate assimilation
    - Breeding to shift to greater reliance on ammonium
  - More N fertilizer will be required, unless root systems are bred to be more efficient at scavenging N
- Unknowns
  - CO_2 fertilization effect?
  - Increased water use efficiency?
  - Higher ozone damage and thus greater water stress?
  - Extent of salinity stress?

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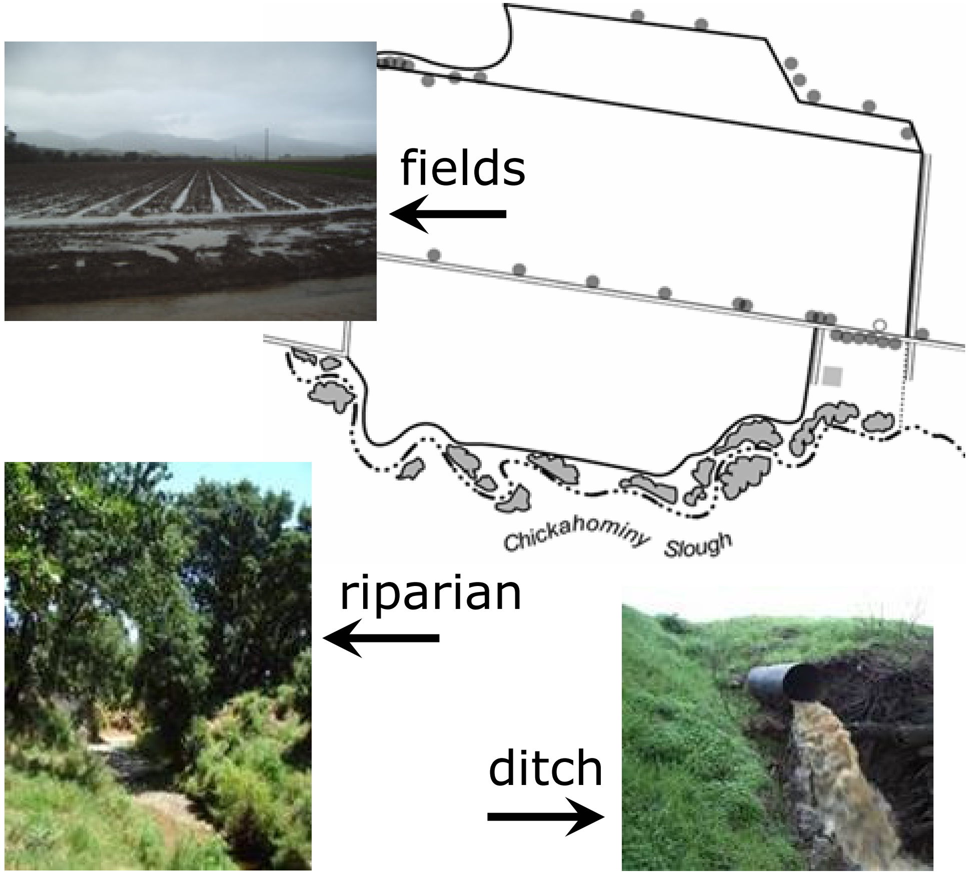
Landscape-level functions of agrobiodiversity

Higher agrobiodiversity in the landscape can increase indirect use value, resilience and risk mitigation (Swift et al., 2004), but valuation of multifunctionality is difficult

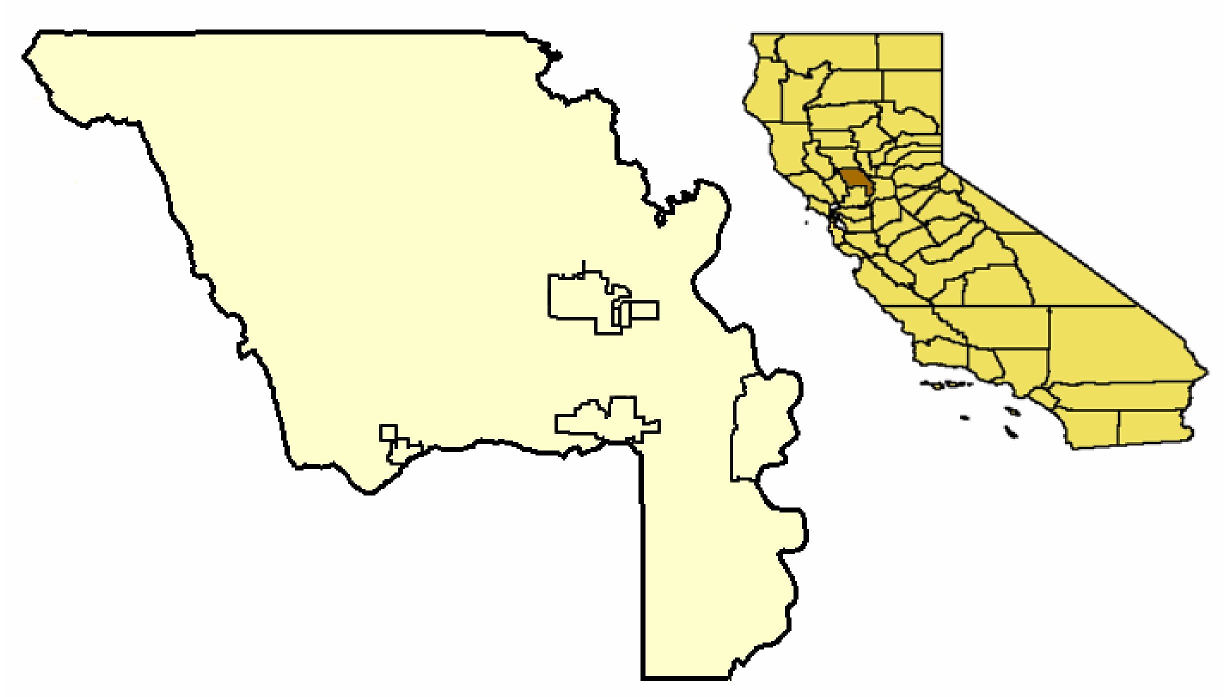
- Habitats in the farmscape
  - Carbon, nitrogen, and phosphorus retention (GHG, stores)
  - Biodiversity
    - Plant species
    - Soil microbes, nematodes
    - Pests
  - Agricultural production and economic profitability



Tomato and grain fields, riparian, hedgerow, drainage ditch and ponds habitats at an organic farm in California

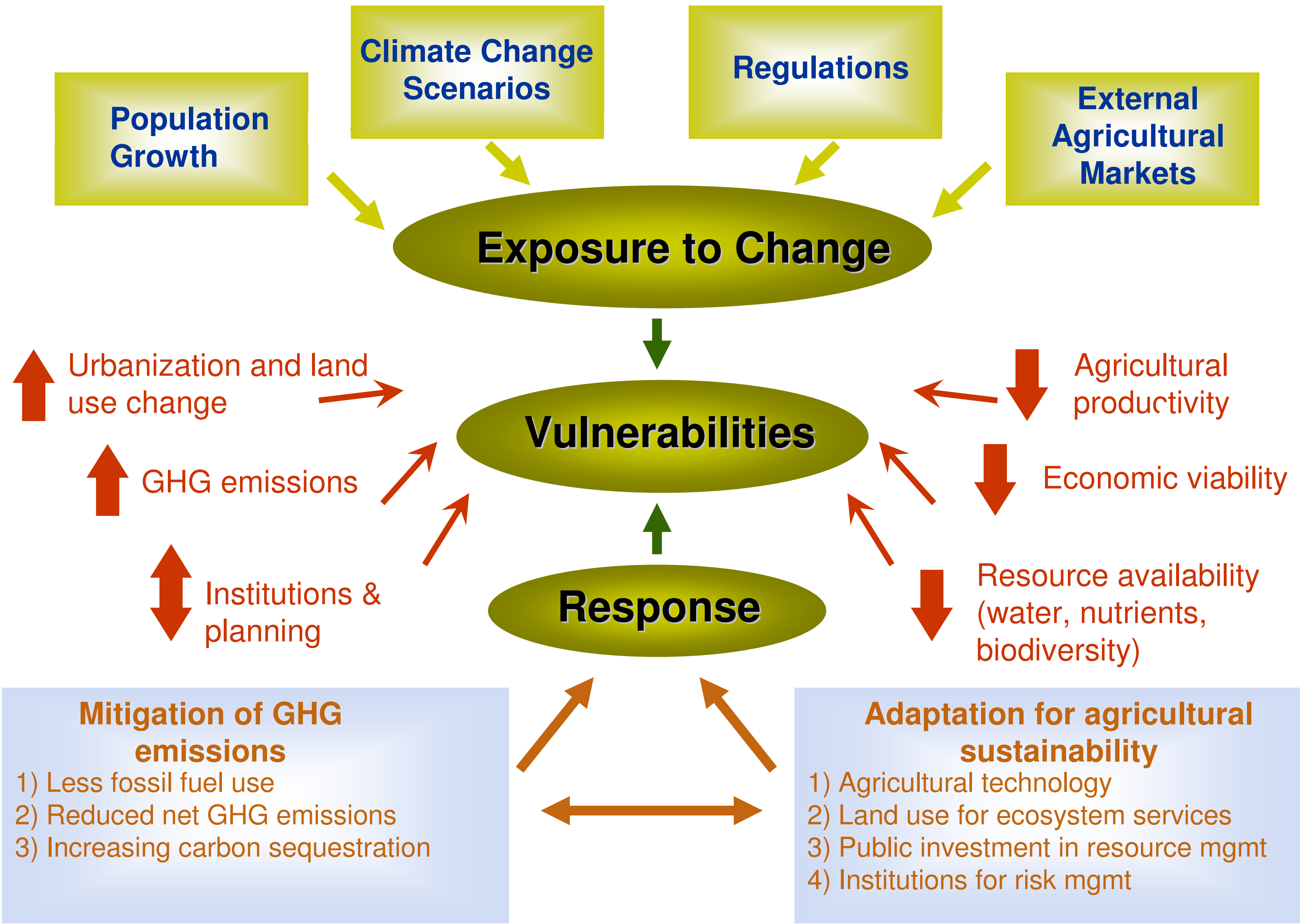
California regional analysis of climate change responses

- Yolo County, Sacramento Valley
- River delta to upland hills
- ~10% ag economy; family farms and agribusiness
- $370 million gross agriculture (2006)



Laws and regulations for GHG emissions in California

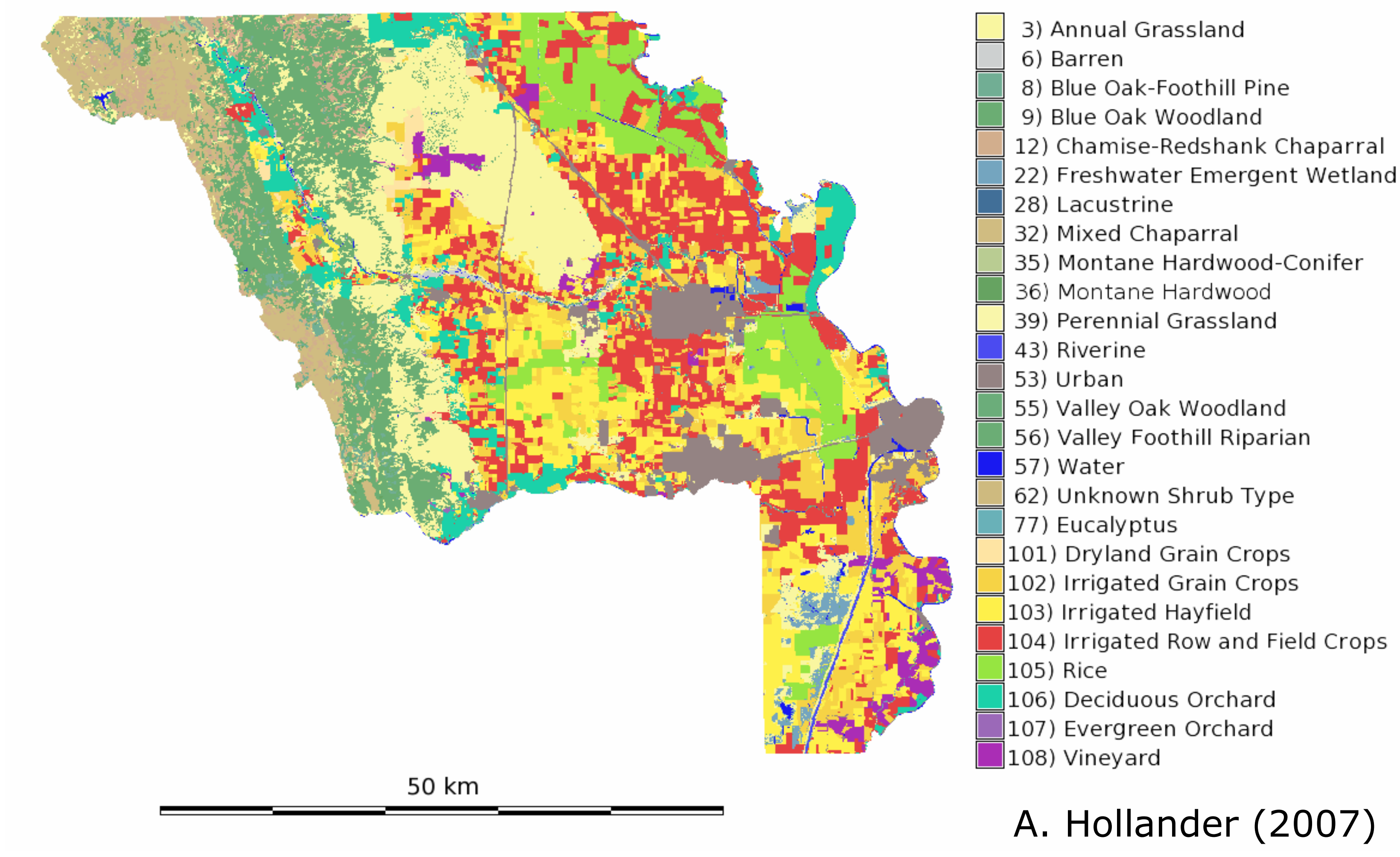
- AB 32 (Global Warming Solutions Act)
  - Establishes a GHG cap to reduce emissions
    - 2000 levels by 2010
    - 1990 levels by 2020
    - 80% below 1990 by 2050
  - Enforces benchmarks beginning in 2012 that include a multi-sector market-based program to reduce GHG emissions in the most cost-effective manner
  - Requires mandatory reporting of GHG emissions for the largest sectors (oil and gas extraction, oil refining, electric power, cement manufacturing, and solid waste landfills)
- AB 1493 (Pavley Bill)
  - Limits the amount of greenhouse gas that may be released from new cars, SUVs, and pickups (2009)



Climate Change Scenarios
Regulations
Population Growth
External Agricultural Markets
Exposure to Change
Urbanization and land use change
Agricultural productivity
Vulnerabilities
GHG emissions
Economic viability
Institutions & planning
Response
Resource availability (water, nutrients, biodiversity)
Mitigation of GHG emissions
1) Less fossil fuel use
2) Reduced net GHG emissions
3) Increasing carbon sequestration
Adaptation for agricultural sustainability
1) Agricultural technology
2) Land use for ecosystem services
3) Public investment in resource mgmt
4) Institutions for risk mgmt

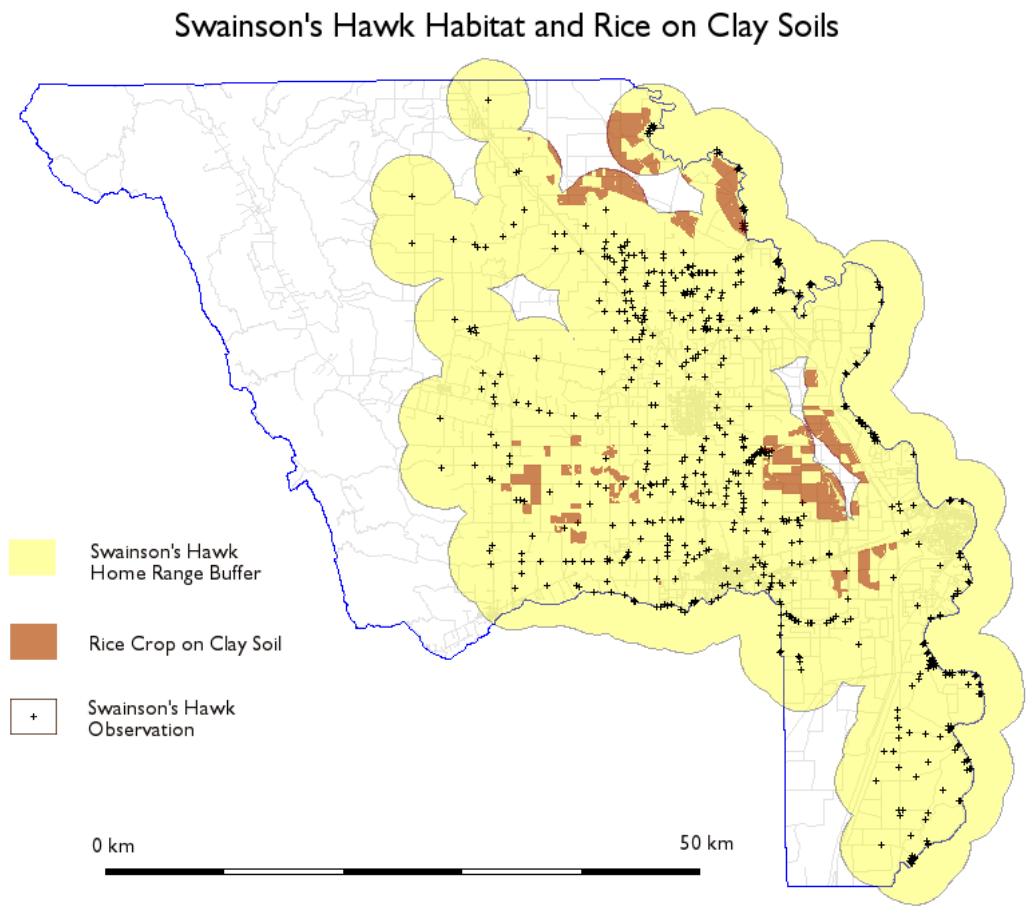
Yolo County land cover

California Wildlife Habitat Relationship (CWHR) and
Dept. of Water Resources (DWR) land cover classes



A. Hollander (2007)

GIS query: soil type, crop production, and wild species habitat



- Rice production will decrease with water shortages
- No other crops are grown on clay soils now in rice
- Swainson hawk preferred habitat is irrigated agriculture
- Land retirement will decrease habitat for this species of concern

- Assumes 3.5 km buffer from nest sites
- Clay soil = >40% clay

A2 and B1 scenarios for Yolo County

Disciplinary topics:

- Agricultural productivity for major crops
- Effects of reduced water resources on economics
- Agricultural energy budgets
- World market shifts and choice of crops
- Land use change
- Changes in biodiversity

Greatest academic interest

Interdisciplinary synthesis:

- Mitigation+adaptation strategies for whole farms
- Planning horizons
- Grower decision tools
- Multifunctional land use for multiple benefits
- GIS landscape queries
- Environmental justice
- Zoning and city/county planning options

Greatest stakeholder interest

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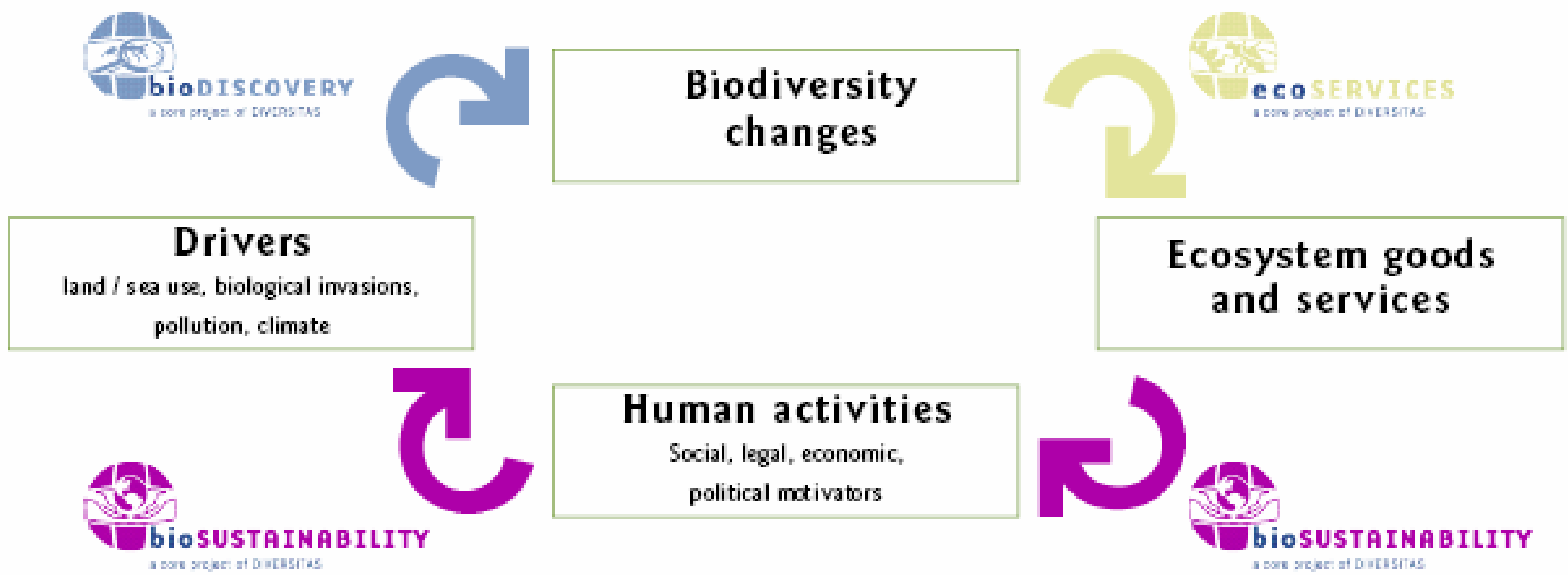
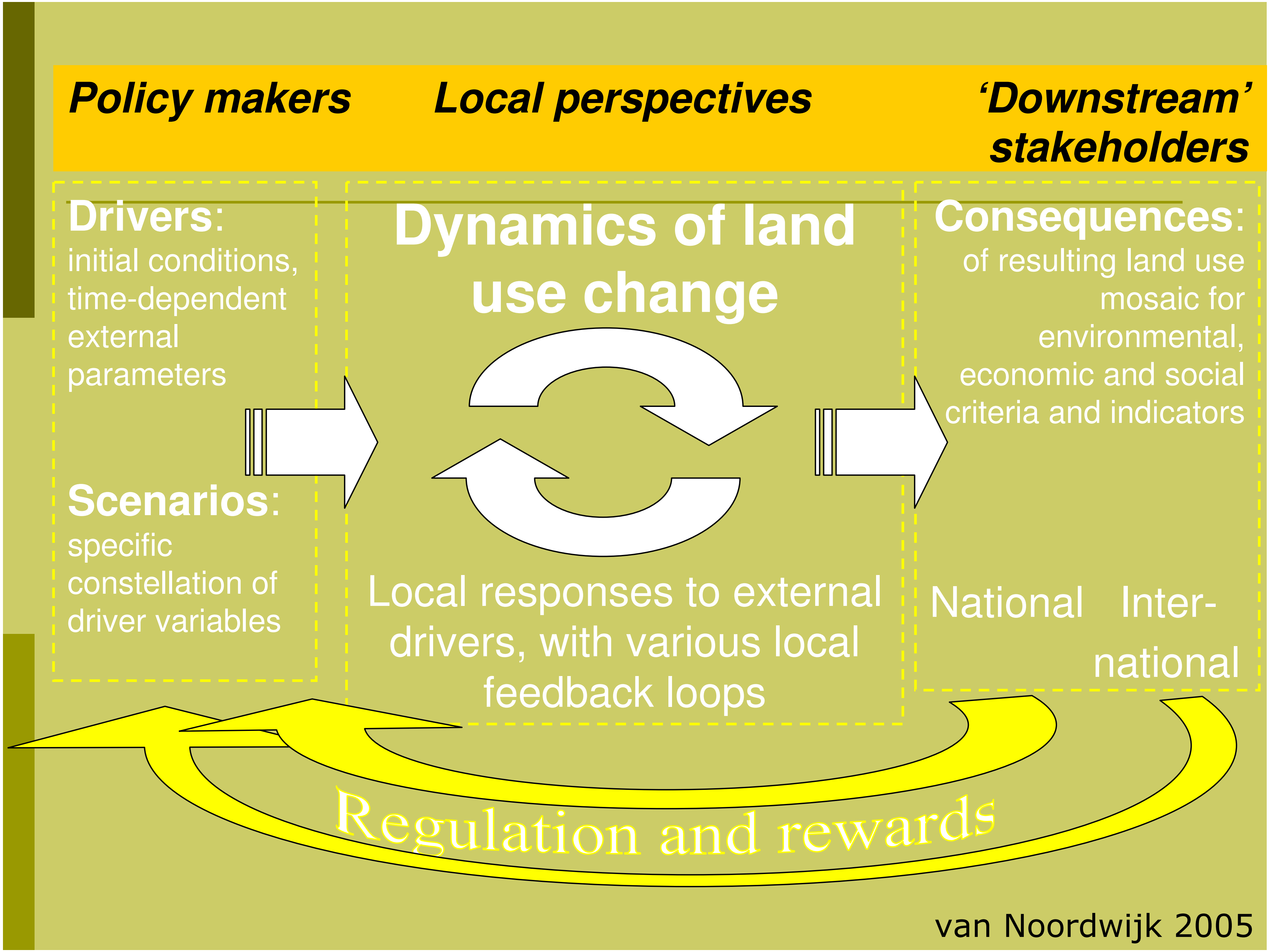
Research needs: a DIVERSITAS perspective

- Earth System Science Partnership (IGBP, IHDP, GWSP, GECAFS): Global change programs
- Interactive biodiversity science, linking biological, ecological and social disciplines to produce



Overview suggestions

- View soil as a major driver of climate change responses
- Place greater emphasis on managing landscapes for unplanned biodiversity for its ecosystem services
  - Food webs and trophic interactions
  - ‘integrated soil biological management practices as an integral part of their agricultural and sustainable livelihood strategies’ (CBD Soil Biodiversity Initiative)
- Utilize ‘place-based’ analysis of climate change responses
  - Soil constraints that effect land use change
  - Multifunctionality of biodiversity-based ecosystem services: source of resilience
  - Merging mitigation and adaptation


Policy makers
Local perspectives
'Downstream' stakeholders
Drivers: initial conditions, time-dependent external parameters
Dynamics of land use change
Consequences: of resulting land use mosaic for environmental, economic and social criteria and indicators
Scenarios: specific constellation of driver variables
Local responses to external drivers, with various local feedback loops
National
Inter-national
Regulation and rewards
van Noordwijk 2005

SBSTTA—Soil biodiversity

- CBD Soil Biodiversity Initiative
  - **awareness raising, knowledge and understanding** of key roles, functional groups and impacts of diverse management practices in different farming systems and agro-ecological and socio-economic context
  - promoting **ownership and adaptation** by farmers of integrated soil biological management practices as an integral part of their agricultural and sustainable livelihood strategies.
  - Soil Biodiversity Manual (Swift & Bignell 2001)

GHG emissions for Yolo Co. agriculture

- Attempt a very rough estimate for the County
- Suggest mitigation options (3 scenarios) and rank feasibility given other economic tradeoffs
- Estimate ag reductions in CO_2E for the County

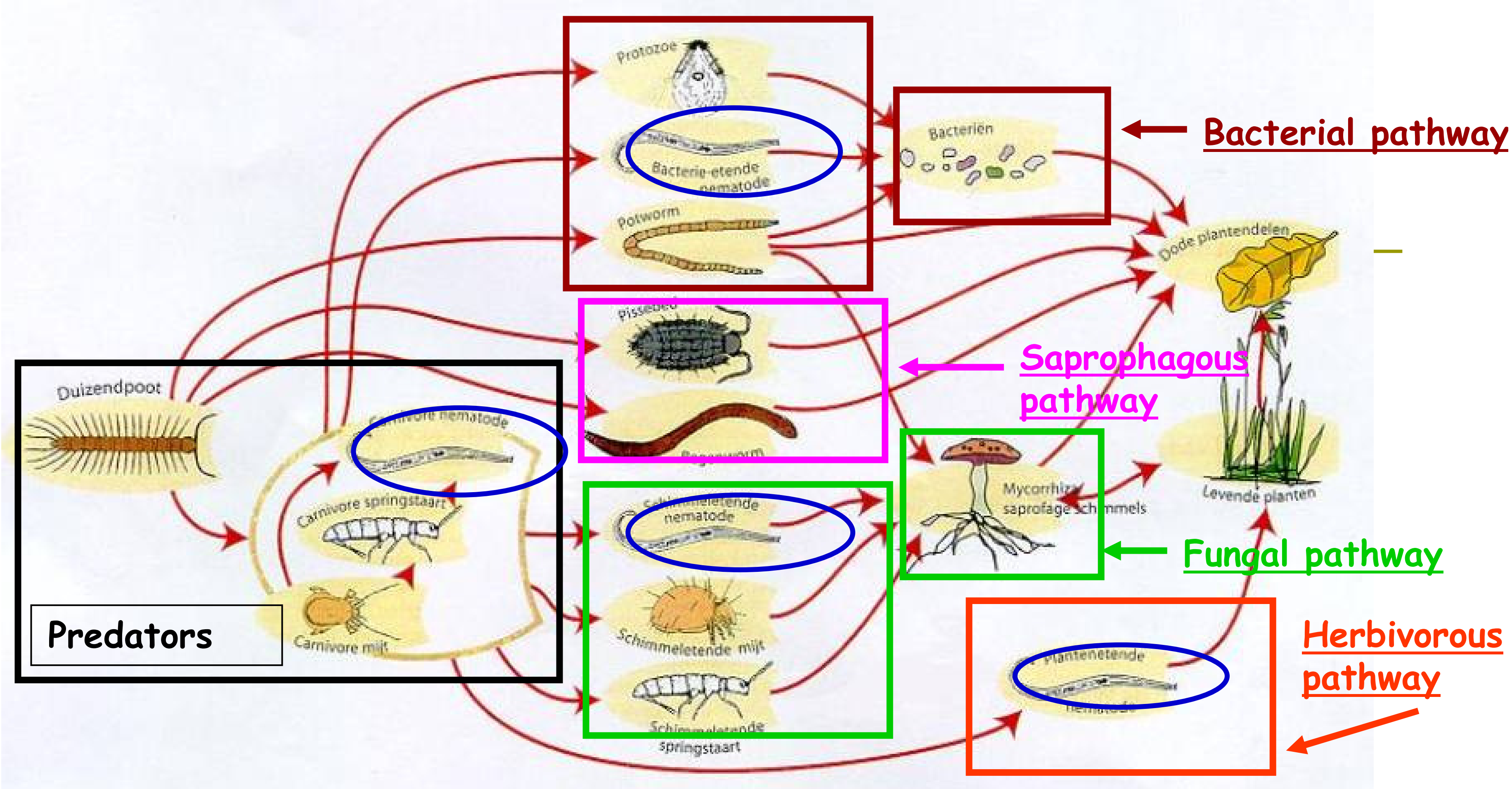
From CARB ETAAC draft report (statewide) of 174 $MMTCO_2E$ by 2020:

Table 1: Summary of California Agricultural Programs to Reduce GHG Emissions

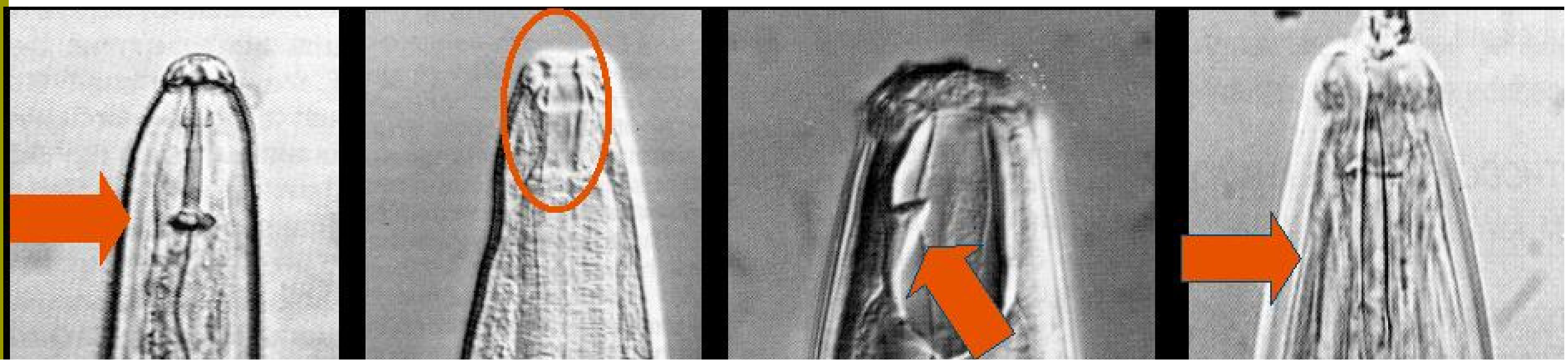
Technologies	*Potential California Program Size*			*Estimated Reduction*	*Net Annual California Reduction Potential*	
	Gross (units/yr)	Technical (units/yr)	Units	Unit Factor ($MTCO_2E$/yr)	Gross ($MMTCO_2E$)	Technical ($MMTCO_2E$)
Manure-to-Energy Facilities	3,600,000	1,800,000	Head	1.70	*6.1*	*3.1*
Enteric Fermentation	4,100,000	2,050,000	Head	0.39	*1.6*	*0.8*
Agricultural Biomass Utilization	21,000,000	8,000,000	dry tons	0.51	*10.7*	*4.1*
Dedicated Bio-fuels Crops	1,000,000	500,000	acres	1.92	*1.9*	*1.0*
Soil Carbon Sequestration	10,000,000	5,000,000	acres	0.61	*6.1*	*3.1*
Farmscapes Sequestration	500,000	500,000	acres	5.80	*2.9*	*2.9*
Fertilizer Use Efficiency	10,000,000	5,000,000	acres	0.36	*3.6*	*1.8*
Total					***33.0***	***16.7***

Climate change scenarios

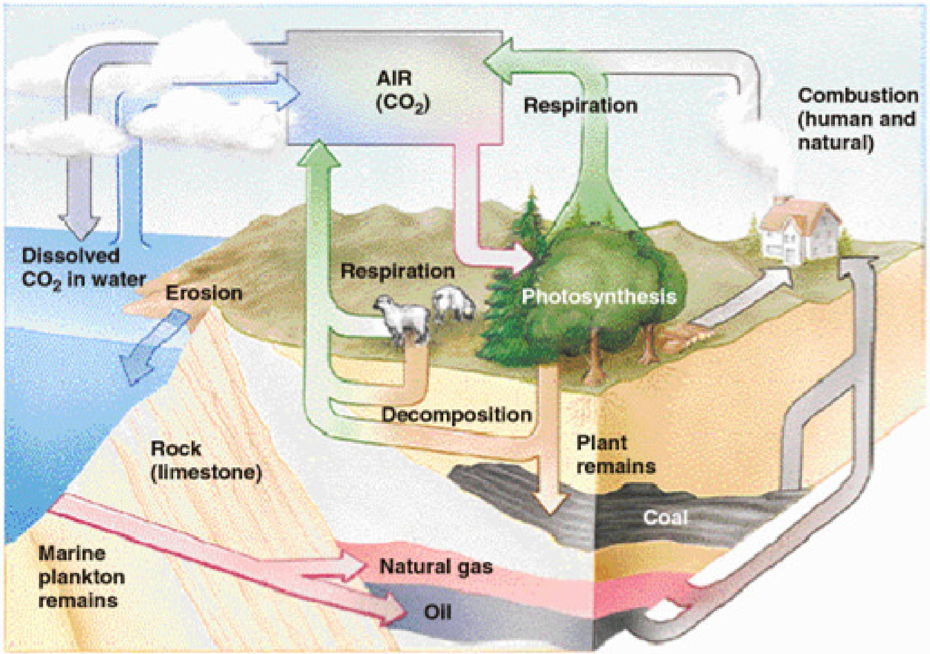
- Regional Enterprise
  - IPCC A2 – High climate change scenario
    - High population growth
    - High energy use
    - Med/High land-use change
  - Focus: Self reliance, preservation of local entities
  - Higher environmental stress
  - Environment = commodity which can be traded
  - ↓ag subsidies & ↑exposure to global markets
- Global Sustainability
  - IPCC B1 – Low climate change scenario
    - Low population growth
    - Low energy use
    - High land-use change
  - Focus: Wider, global impacts of individual actions
  - Lower environmental stress
  - Environmental taxation and subsidies for mitigation and adaptation to climate change

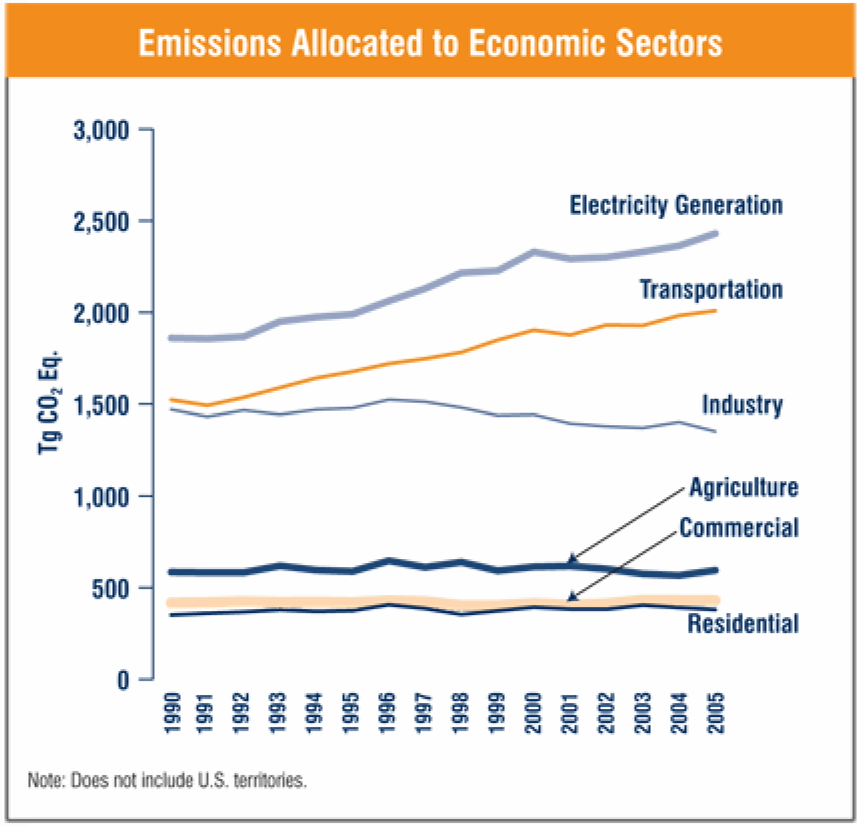


Protozoe
Bacterie-etende nematode
Potworm
Bacterien
Dode plantendelen
Duizendpoot
Carnivore springstaart
Carnivore mijt
nematode
Schimmeletende mijt
springstaart
Mycorrhiza
Levende planten
Predators
Bacterial pathway
Saprophagous pathway
Fungal pathway
Herbivorous pathway



Carbon Cycle





http://www.epa.gov/climatechange/emissions/usgginventory.html