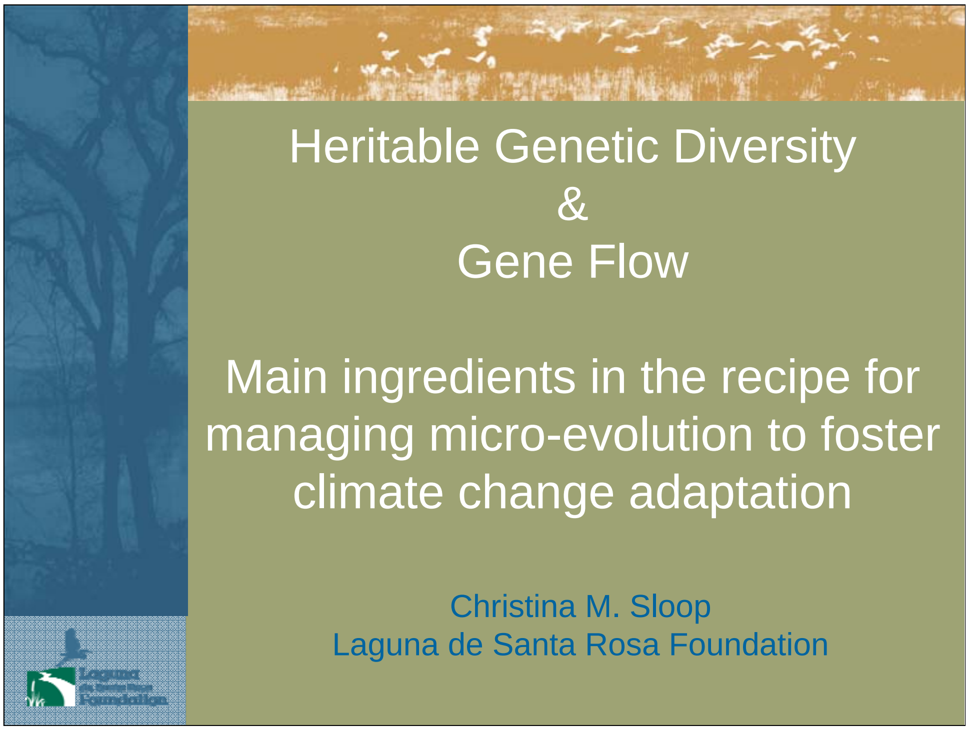


Heritable Genetic Diversity
&
Gene Flow

Main ingredients in the recipe for managing micro-evolution to foster climate change adaptation

Christina M. Sloop
Laguna de Santa Rosa Foundation

How will Species Avoid Extinction in the Face of Climate Change?

Capacity to Migrate – Ecological Response

- Explored in climate change predictive models
- Not always feasible
  - Specialized habitat, habitat destruction & lack of connectivity
  - Disassociation of mutualistic species interactions (seed dispersers)

Capacity to Adapt – Evolutionary Response

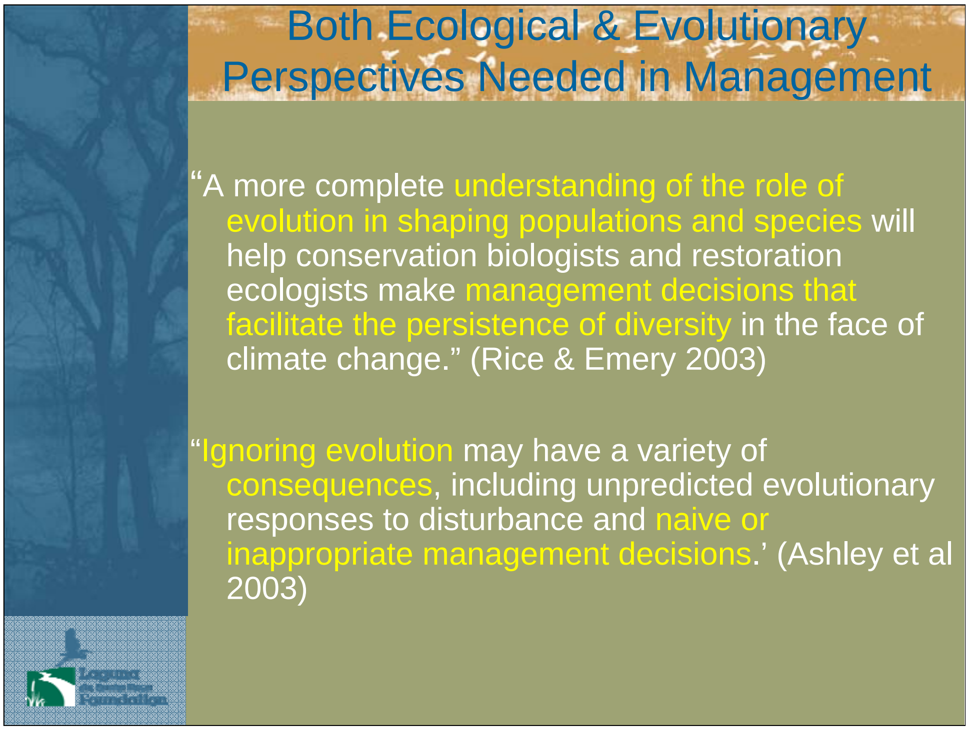
- Not addressed in most predictive models
- May be feasible for most species **IF**
  - Reduction of additional stressors
  - Considered in restoration, conservation & management actions

When considering climate change, one of the main questions we have to ask is HOW WILL SPECIES AVOID EXTINCTION UNDER CHANGING CONDITIONS?

AN ECOLOGICAL REPSONSE would be to migrate – which is explored in most climate change predictive models

MIGRATION is NOT FEASIBLE for many species because they live in specialized/unique habitats and cannot find this elsewhere OR their habitat type is mainly destroyed and there is a lack of connectivity. Also DISASSOCIATION ofpollinators or seed dispersers will throw a wrench into the ability for some species tp migrate to more suitable climes

The EVOLTIONARY RESPONSE would be to quickly adapt to changed conditions – which is to my knowledge not addressed in most predictive models; but this strategy may be feasible for a large number of species IF we help reduce additional stressors and consider evolutionary response in restoration, conservation & management



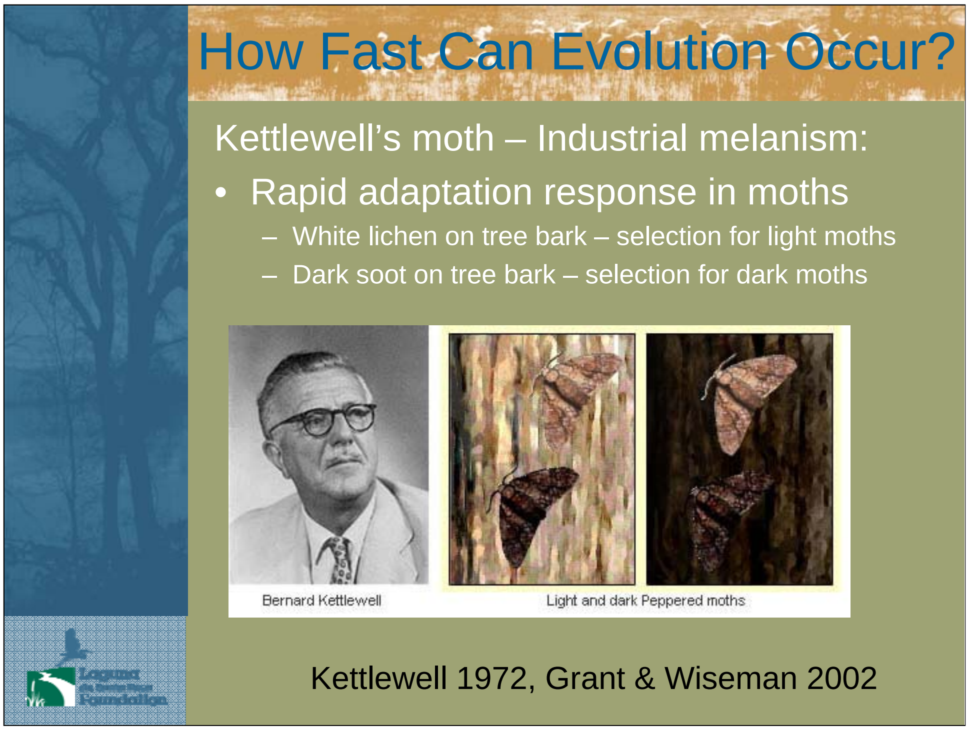
Both Ecological & Evolutionary Perspectives Needed in Management

"A more complete understanding of the role of evolution in shaping populations and species will help conservation biologists and restoration ecologists make management decisions that facilitate the persistence of diversity in the face of climate change." (Rice & Emery 2003)

"Ignoring evolution may have a variety of consequences, including unpredicted evolutionary responses to disturbance and naive or inappropriate management decisions.' (Ashley et al 2003)

Both ECOLOGICAL and EVOLUTIONARY perspectives are needed in Management in the face of climate change

This is supported in the recent scientific literature by Rice & Emery, who state that a better understanding of the role of evolution will help conservation and restoration biologists make management decisions maximizing biodiversity in the face of climate change. Ashley & colleagues caution that ingnoring evolution may have consequences including naïve or inappropriate management decisions



How Fast Can Evolution Occur?

Kettlewell's moth – Industrial melanism:

- Rapid adaptation response in moths
  - White lichen on tree bark – selection for light moths
  - Dark soot on tree bark – selection for dark moths

Bernard Kettlewell

Light and dark Peppered moths

Kettlewell 1972, Grant & Wiseman 2002

So to consider evolutionary adaptation we have to ask how fast can it occur?

One classic example of rapid adaptation is industrial melanism or Kettlewells' moth study. Moths usually hiding on white lichen covered tree bark were selected for light color to blend in. As soot from industrialization covered the lichen and made the tree bark dark, the darker moths were selected for, since they now blended in better and avoided predation. Nowadays, as the air is clean again over England, the moths are again white in color. All these changes happened within decades only!

Microevolution & Invasiveness

Spartina – cordgrass hybrids (Sloop 2005 & 2009)

- Colonization of SF Bay tidal mudflats
- Self-fertilization

Invasive species may be a model system to study microevolution

One example in my own work: Spartina hybrids in SF Bay.

A hybrid swarm formed after exotic cordgrass was introduced to SF Bay and successfully bred with the native CA cordgrass.

Spartina is usually restricted to shoreline salt marshes – but a highly genetically diverse hybrid swarm fostered individuals that were able to colonize the SF Bay tidal mudflats

Hybrids germinate on the mudflats, then grow into circular pattern – some grow far out into the mudflats

Wind pollinated – individuals@ leading colonization edge evolved self-fertilization

Microevolution & Invasiveness

Strong Natural Selection

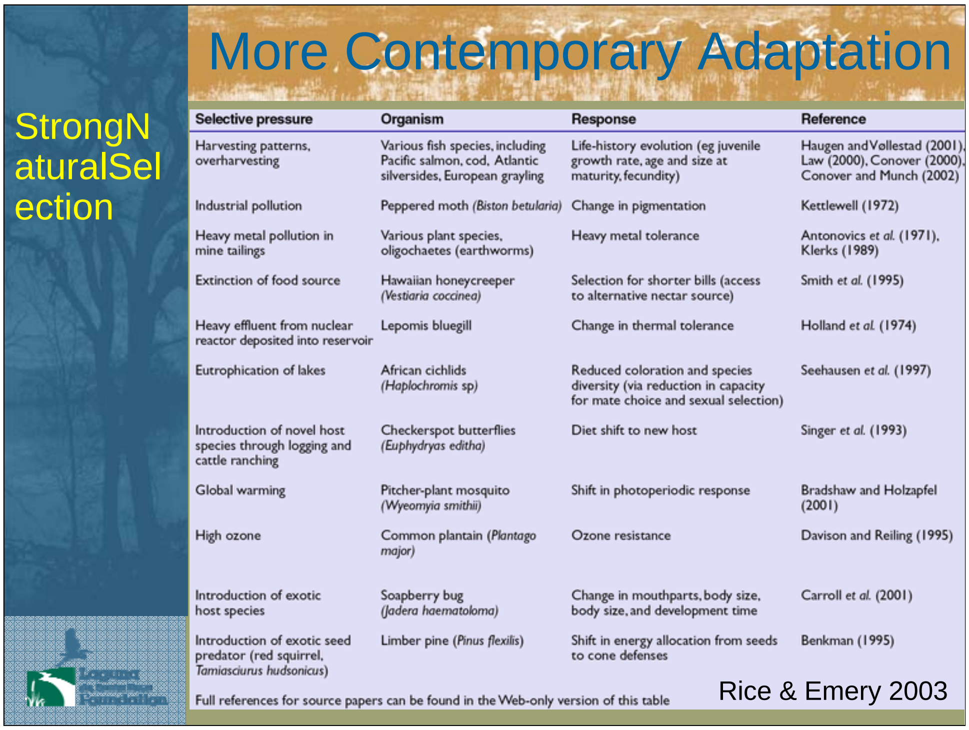
Spartina – cordgrass hybrids (Sloop 2009)

- Hybrid swarm => substantial increase in overall heritable genetic variation
- Colonization of SF Bay tidal mudflats
  - Strong selective response to extreme environmental conditions in tidal flats
  - Fast growth & tolerance to tidal submergence
  - Adaptive response preserved via evolution of self-fertilization in isolation

The hybrid swarm was a mechanism to substantially increase the heritable genetic variation in the population

Strong selection in the tidal mudflats then selected for fast growing individuals that were tolerant to tidal inundation.

Isolation at the leading edge of the colonization fostered self-fertilization which in turn allowed the adaptive response to be preserved



StrongNaturalSelection

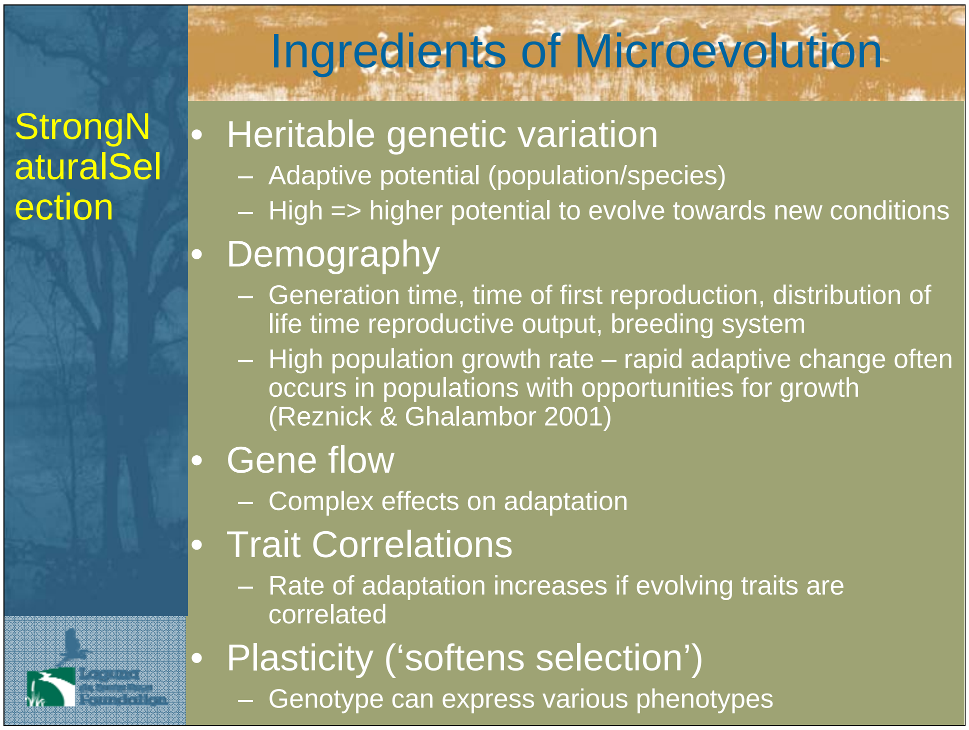
More Contemporary Adaptation

Selective pressure	Organism	Response	Reference
Harvesting patterns, overharvesting	Various fish species, including Pacific salmon, cod, Atlantic silversides, European grayling	Life-history evolution (eg juvenile growth rate, age and size at maturity, fecundity)	Haugen and Vøllestad (2001), Law (2000), Conover (2000), Conover and Munch (2002)
Industrial pollution	Peppered moth *(Biston betularia)*	Change in pigmentation	Kettlewell (1972)
Heavy metal pollution in mine tailings	Various plant species, oligochaetes (earthworms)	Heavy metal tolerance	Antonovics *et al.* (1971), Klerks (1989)
Extinction of food source	Hawaiian honeycreeper *(Vestiaria coccinea)*	Selection for shorter bills (access to alternative nectar source)	Smith *et al.* (1995)
Heavy effluent from nuclear reactor deposited into reservoir	Lepomis bluegill	Change in thermal tolerance	Holland *et al.* (1974)
Eutrophication of lakes	African cichlids *(Haplochromis* sp)	Reduced coloration and species diversity (via reduction in capacity for mate choice and sexual selection)	Seehausen *et al.* (1997)
Introduction of novel host species through logging and cattle ranching	Checkerspot butterflies *(Euphydryas editha)*	Diet shift to new host	Singer *et al.* (1993)
Global warming	Pitcher-plant mosquito *(Wyeomyia smithii)*	Shift in photoperiodic response	Bradshaw and Holzapfel (2001)
High ozone	Common plantain (*Plantago major)*	Ozone resistance	Davison and Reiling (1995)
Introduction of exotic host species	Soapberry bug *(Jadera haematoloma)*	Change in mouthparts, body size, body size, and development time	Carroll *et al.* (2001)
Introduction of exotic seed predator (red squirrel, *Tamiasciurus hudsonicus*)	Limber pine (*Pinus flexilis*)	Shift in energy allocation from seeds to cone defenses	Benkman (1995)

Full references for source papers can be found in the Web-only version of this table

Rice & Emery 2003

Rice & Emery list more recent examples of contemporary adaptation



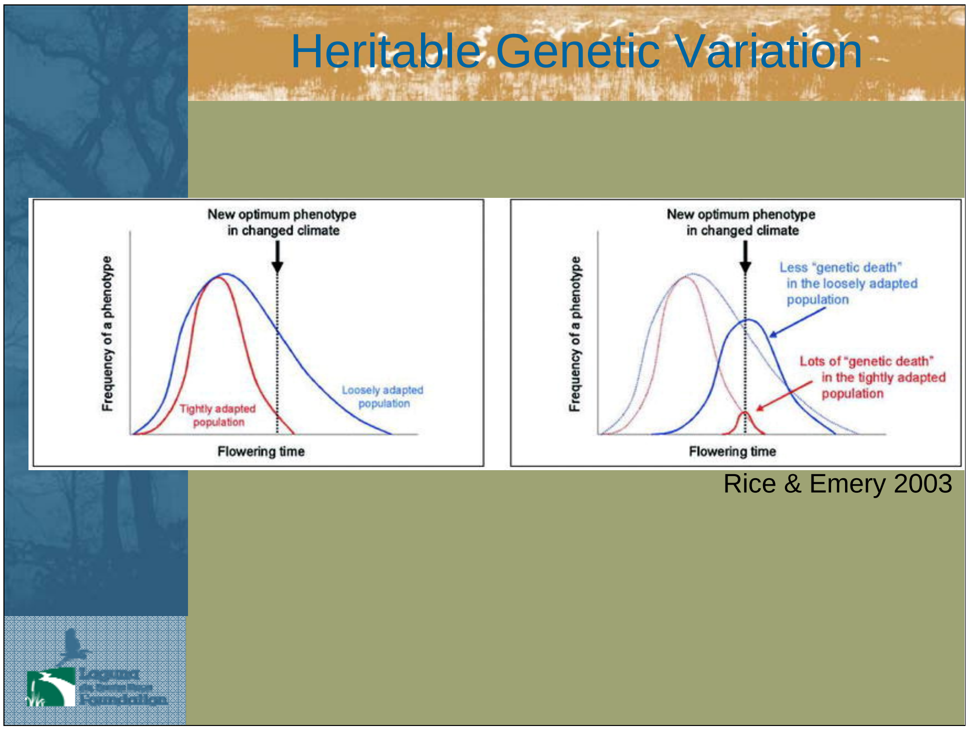
Ingredients of Microevolution

StrongNaturalSelection

- Heritable genetic variation
  - Adaptive potential (population/species)
  - High => higher potential to evolve towards new conditions
- Demography
  - Generation time, time of first reproduction, distribution of life time reproductive output, breeding system
  - High population growth rate – rapid adaptive change often occurs in populations with opportunities for growth (Reznick & Ghalambor 2001)
- Gene flow
  - Complex effects on adaptation
- Trait Correlations
  - Rate of adaptation increases if evolving traits are correlated
- Plasticity (‘softens selection’)
  - Genotype can express various phenotypes

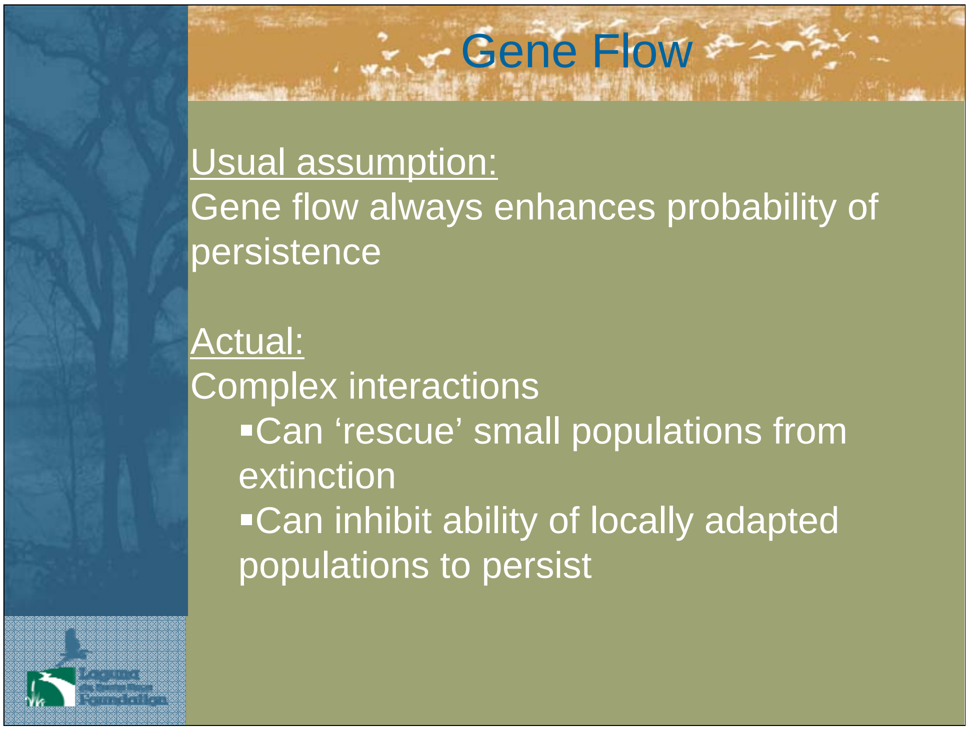
What are then the main ingredients in the cocktail for fast microevolutionary response?

Heritable Genetic Variation



Rice & Emery 2003

Looking at Heritable genetic variation or adaptive potential shows that are more loosely adapted population is better suited for a fast adaptive response to changing conditions



Gene Flow

Usual assumption:
Gene flow always enhances probability of persistence

Actual:
Complex interactions
- Can ‘rescue’ small populations from extinction
- Can inhibit ability of locally adapted populations to persist

With regard to gene flow the usual assumption is that it ALWAYS enhances the probability of persistence

Unfortunately it is more complex than that and in the simplest terms:

Gene flow can rescue SMALL populations from gene flow, but it can also inhibit the the ability of locally adapted populations to persist

Restoration Challenges

Restoration Critical for Saving Biodiversity in Face of Climate Change

Augment species migration & establishment

Consequences of Restoration Actions

Facilitate or foil organisms' capacity to adapt in face of climate change?

Human manipulation of microevolution

- Restoration plantings
  - Decision about best restoration seed source
  - Seed availability - Viability of 'seed increases' in native plant nurseries
  - Use of 'coarsely adapted' genetic mixtures
- Special concern species
  - Monitoring vs. active intervention
    - Demographic viability
      - Population size
      - Breeding system
    - Heritable Genetic Variation
    - Gene flow

So how can we incorporate evolutionary thinking into restoration?

There is overall agreement that Restoration is critical to saving biodiversity

We have to ask ourselves the question: WHAT ARE THE CONSEQUENCES OF OUR RESORATION ACTIONS – will we indeed facilitate or foil organisms capacity to adapt to changing climate conditions?

This would pertain to both restoration plantings and restoration and conservation management of special concern species

Decisions like which type of seed source to use, how to incorporate the necessary genetic variation into the planting are becoming more crucial

Whether to just keep an eye on endangered species via regular monitoring or whether to actively manipulate populations to maximize their persistence in the face of changing conditions is to be decided

In this case we need to consider demography, genetic variation & gene flow, among other things

Restoration Management Examples

Vernal pool endangered *Meadowfoam* species

Goal: Maximize Adaptive Potential

Butte County Meadowfoam *(Sloop 2008)*

- Heritable Genetic Variation: Predominantly self-fertilizing; Low genetic variability @ neutral markers
- Demography: Annual, with seed bank (size unknown)
- Gene flow: Low levels of gene flow, variable across extant populations

- Consider active manipulation in small populations
- Monitor all extant populations populations (annual abundance & seed set, seed bank, threats, community composition, etc)
- Determine cause of inbreeding
- Collect seeds for *ex situ* storage across many years

For example the endangered Butte county Meadowfoam, a vernal pool annual plant is suspected to have low HGV, Population sizes are low at certain locations, and generally low levels of gene flow.

In this case I would recommend to … as an initial adaptive management strategy

Restoration Management Examples

Vernal pool endangered *Meadowfoam* species

Goal: Maximize Adaptive Potential

Sebastopol Meadowfoam *(Sloop & Ayres 2008)*

- Heritable Genetic Variation: Predominantly out-crossing; able to self; moderate genetic variability @ neutral markers
- Demography: Annual, with seed bank (size unknown); Population trend unknown; seeded into constructed pools
- Gene flow: Evidence of natural and artificial gene flow, variable across extant populations

- Monitor all populations (annual abundance & seed set, seed bank, threats, community composition etc)
- Stop artificial gene flow
- Collect seeds for *ex situ* storage across many years

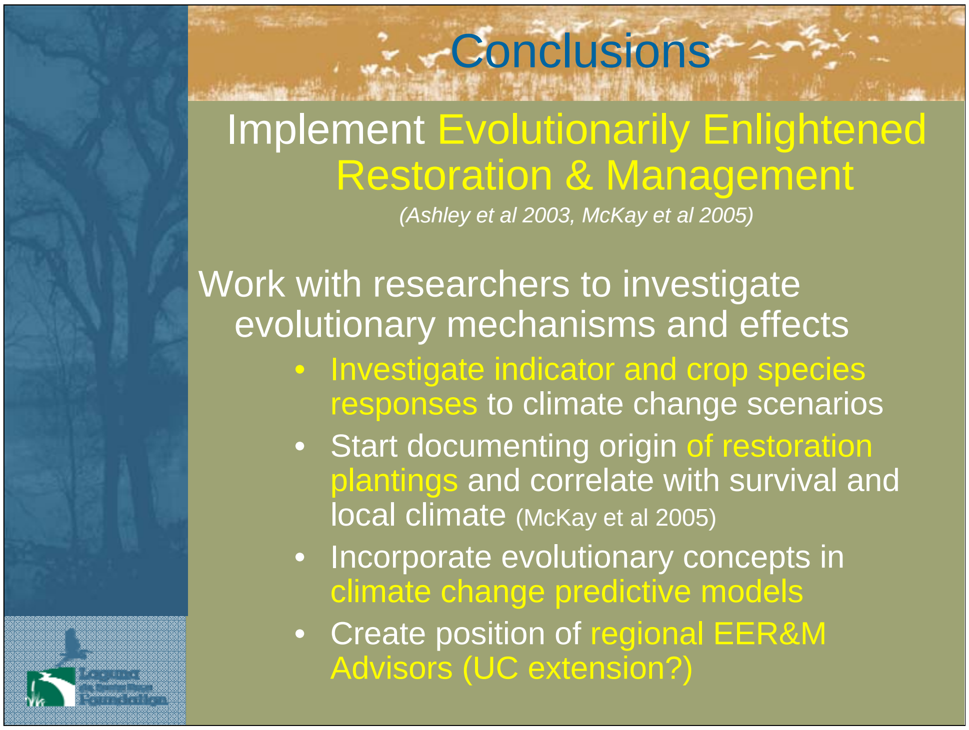
While for the Sebastopol meadowfoam, that is predominately outcrossing with moderate genetic variability, larger population sizes and some natural gene flow I would advise against active manipulation, but continually monitor … as an initial adaptive management strategy

Conclusions

Implement Evolutionarily Enlightened Restoration & Management

(Ashley et al 2003, McKay et al 2005)

- Consider both evolutionary & ecological implications of management actions
  - Focus attention on evolutionary context of a target species and its traits
  - Maintain long-term evolutionary potential of restored populations
  - Adjust management plans to promote evolutionary as well as ecological goals
  - Include coursework in evolutionary ecology in resource management training programs



Conclusions

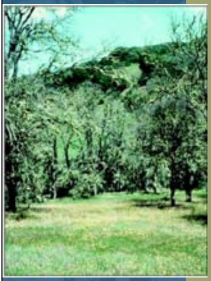
Implement Evolutionarily Enlightened Restoration & Management

(Ashley et al 2003, McKay et al 2005)

Work with researchers to investigate evolutionary mechanisms and effects

- Investigate indicator and crop species responses to climate change scenarios
- Start documenting origin of restoration plantings and correlate with survival and local climate (McKay et al 2005)
- Incorporate evolutionary concepts in climate change predictive models
- Create position of regional EER&M Advisors (UC extension?)

Restoration Management Examples



Blue Oaks – *Quercus douglasii*

(Rice & Emery 2003, Rice et al 2004)

- Demography:
  - Generation time: > 20 years,
  - Extremely low recruitment in natural stands => selection acts only on a very small number!
  - Breeding system unknown
  - Wind-pollinated
- Gene flow: Low levels of gene flow (Koenig & Ashley 2003); Regional ecotypes (Rice et al 1993)
- Heritable genetic variation: in seedling water use efficiency (Rice, unpublished data)

Valley Oaks – *Quercus lobata*

(Tyler, Mahall & Davis – UC Santa Barbara)

Study in progress