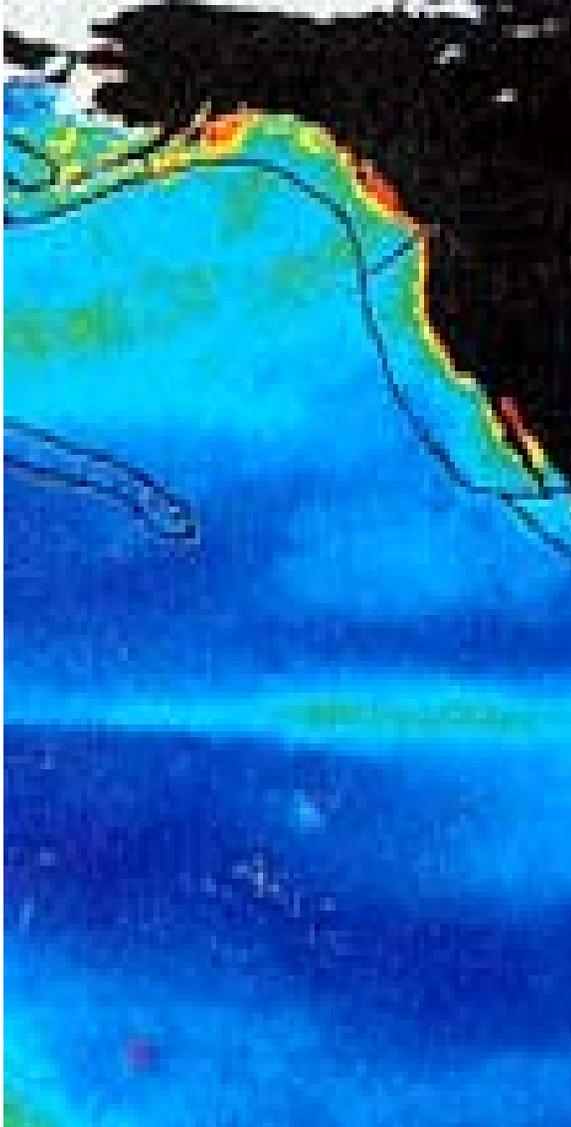
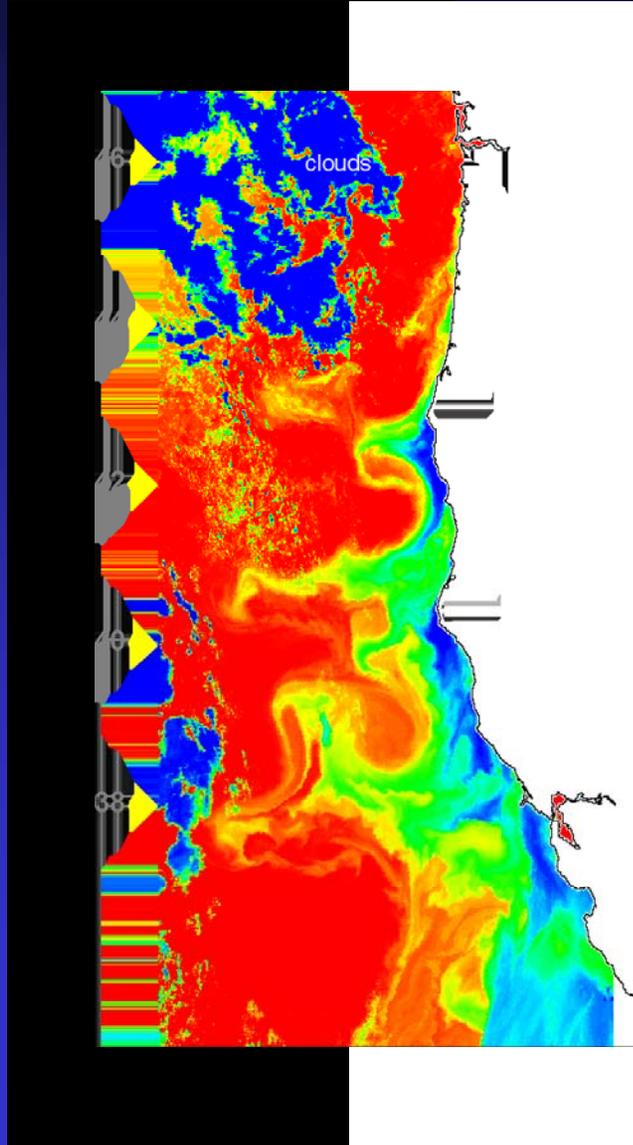


Ocean biomes are grouped into large marine ecosystems describing the geography of species assemblages



**The
California
Current
Large
Marine
Ecosystem**

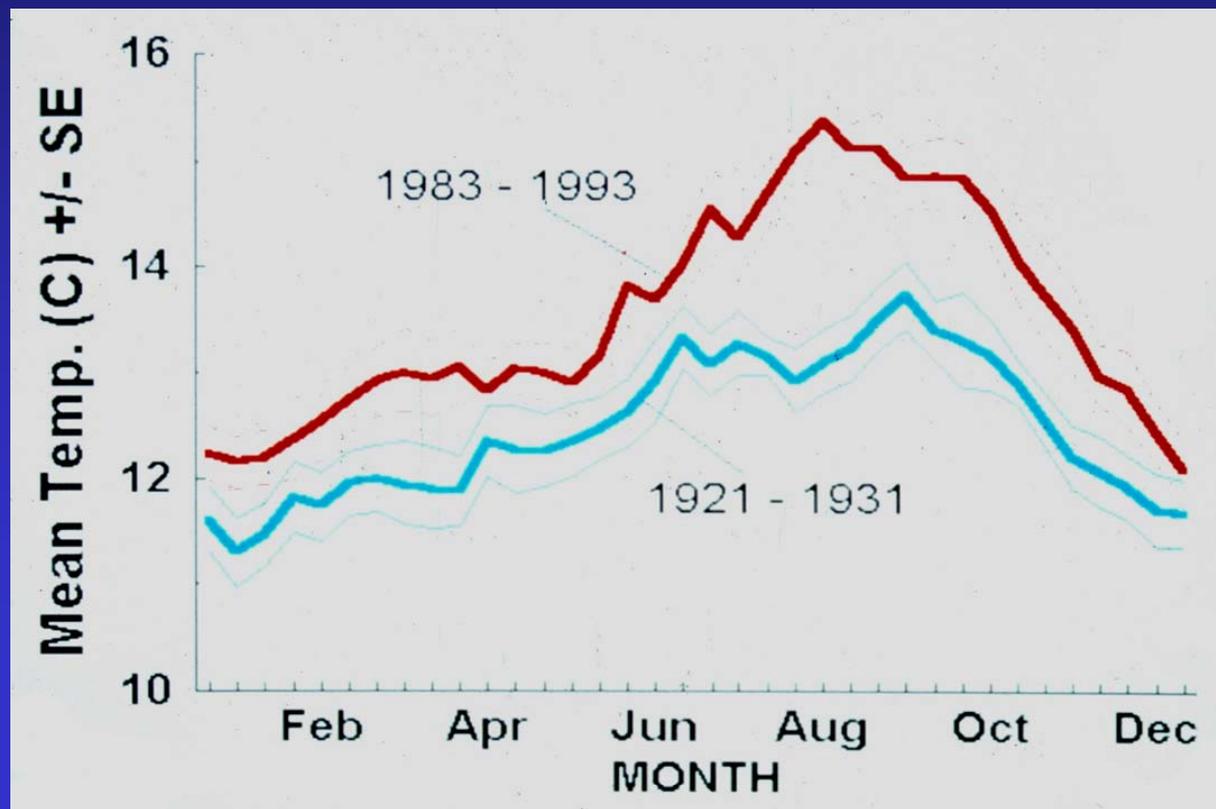
Large marine ecosystems contain environmental mosaics and clines



How do species use this variation? Are environmental tolerances relatively immutable? What mechanisms allow a species to shift tolerances?

In Monterey Bay surface temperature has warmed and gotten more extreme

- Average temperature: up by 1.25°F
- Peak summer temperatures: up by 4°F



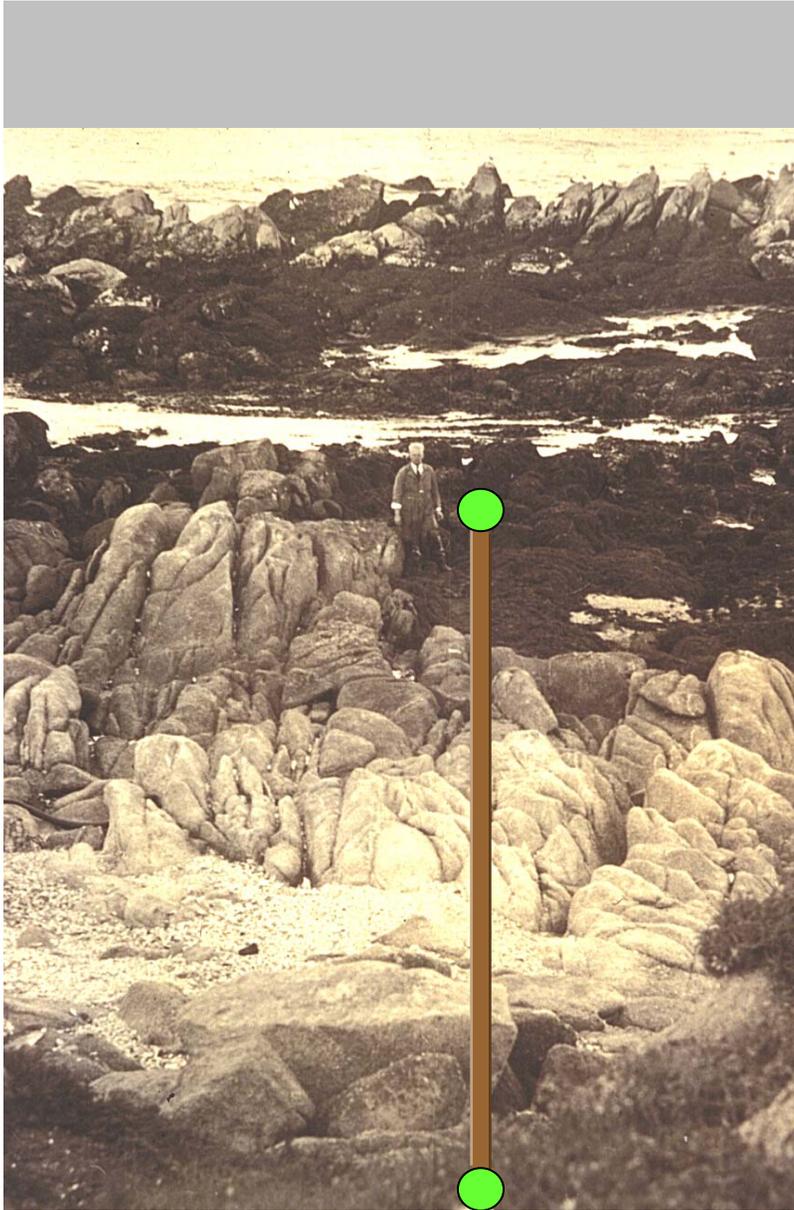
**How CO₂
levels may
look**

**And how
this is
likely to
affect
ocean pH.**

QuickTime™
TIFF (Uncompressed)
are needed to see t

Species survival under climate change may demand:

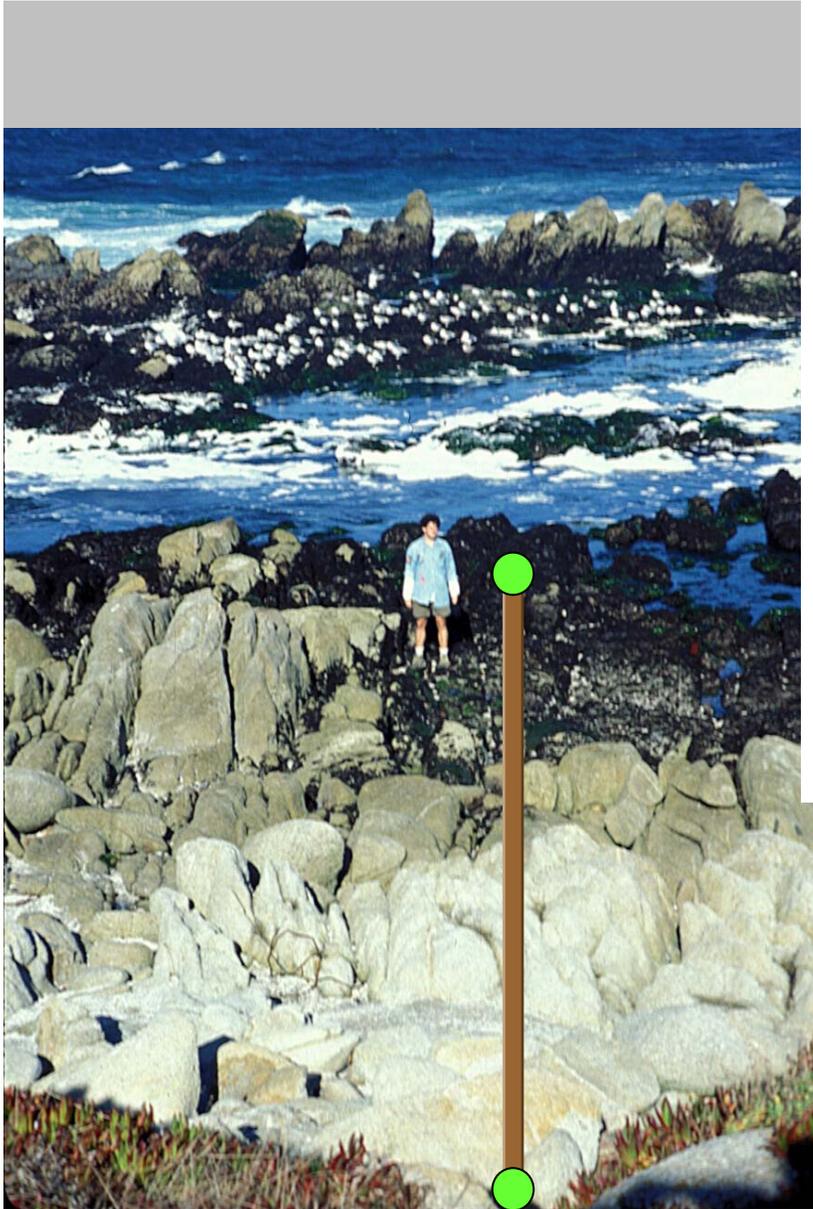
- Biogeographic shifts and species immigration
- If species can adjust:
 1. Physiological or gene expression acclimation may shift the fundamental niche within an individual's lifetime
 2. Evolution and local adaptation may mean that a species has multiple niches across its range or from time to time.



Hewatt: early 1930's

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

*Changes in who lives at the
Hopkins Marine Station:
across 60 years of ocean
change*



Sagarin: early 1990's

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

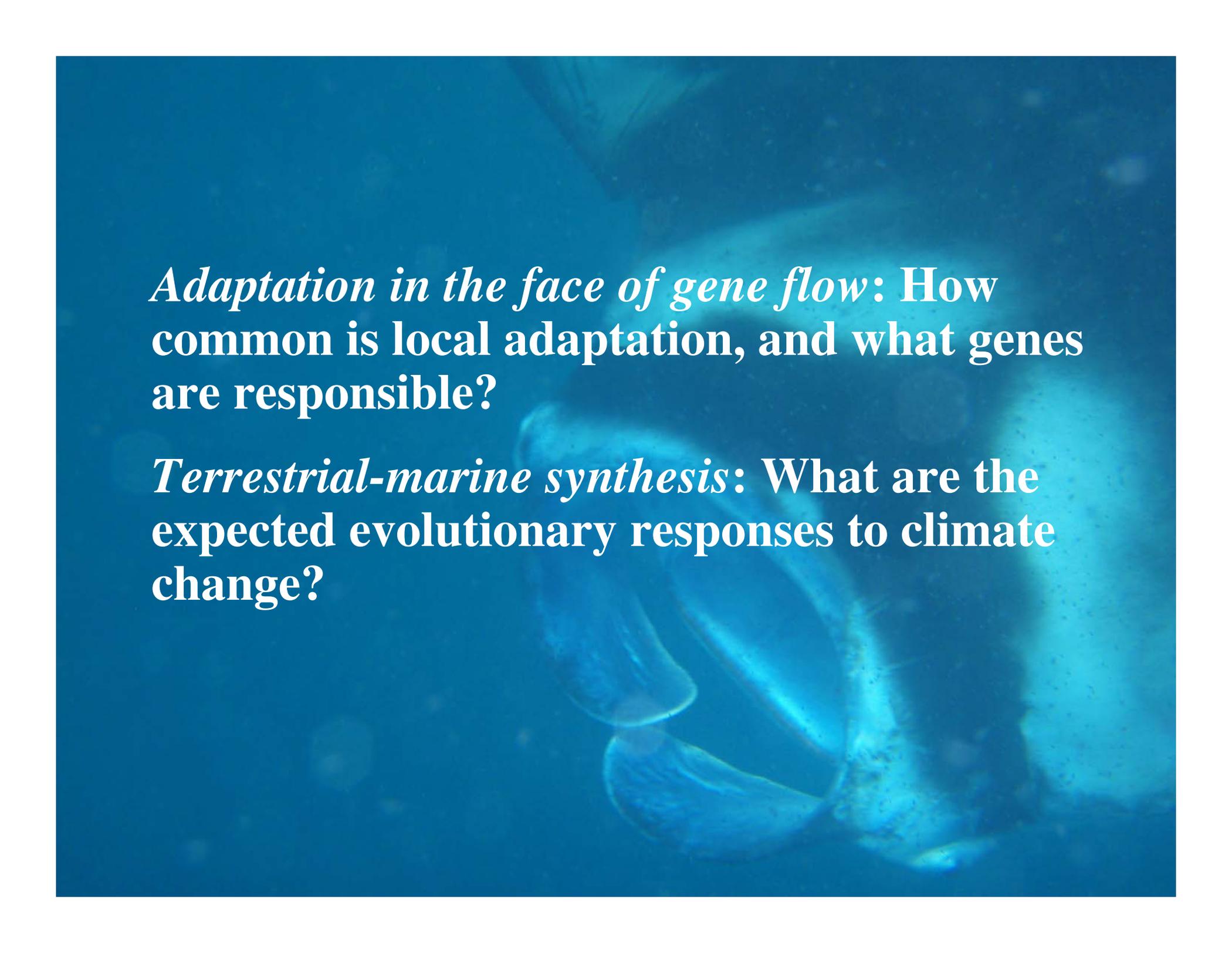
*Changes in who lives at the
Hopkins Marine Station:
across 60 years of ocean
change*

Comparing 1933 to 1993, additional species are largely from the south.

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are needed to see this picture.

For species that occurred in 1933 and 1993, 90% of southern species increased in abundance, but 80% of northern species decreased.

From Sagarin et al. 1999



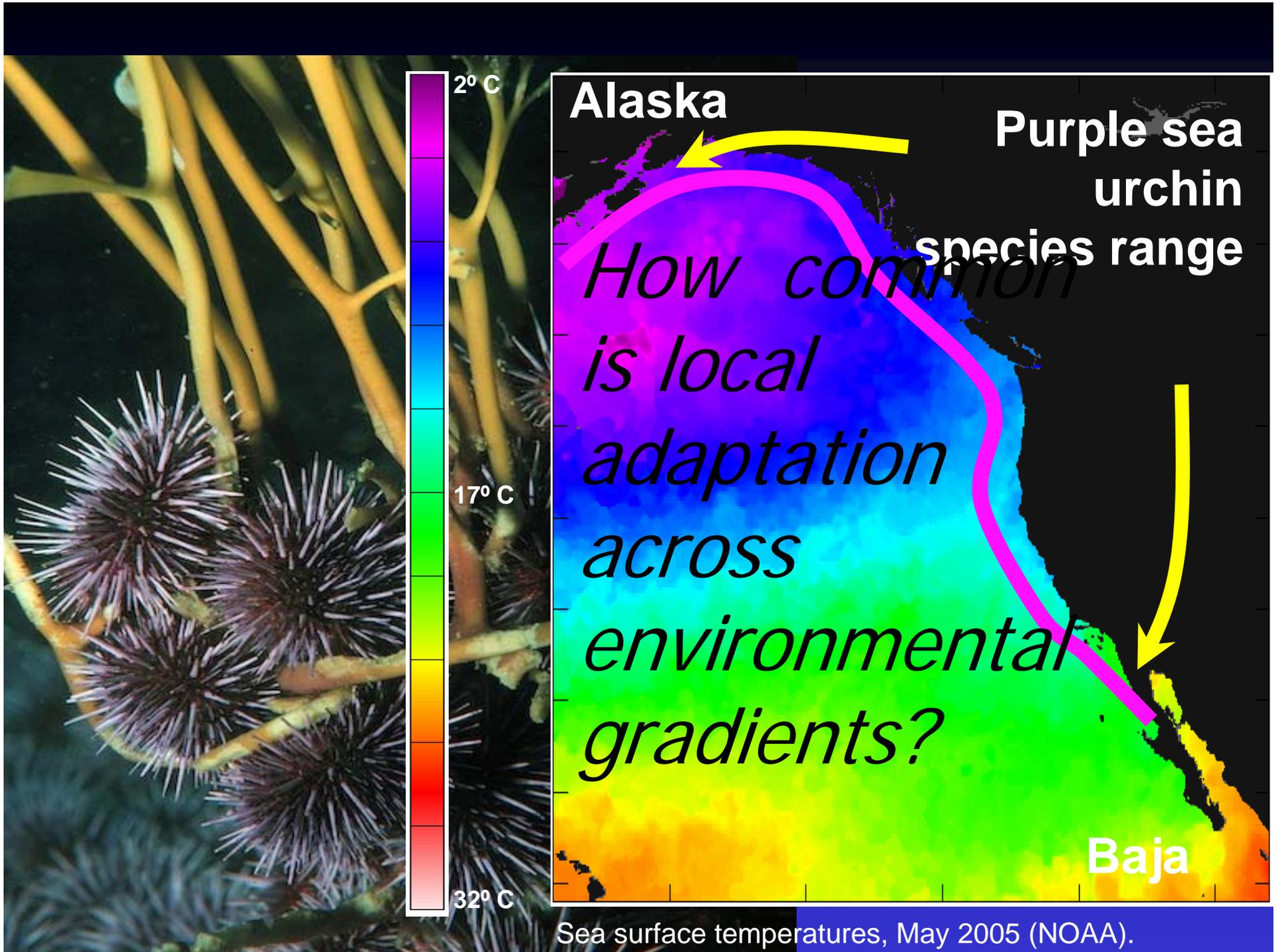
Adaptation in the face of gene flow: How common is local adaptation, and what genes are responsible?

Terrestrial-marine synthesis: What are the expected evolutionary responses to climate change?

Adaptation in the face of gene flow: Melissa Pespeni, Mollie Manier, Emily Jacobs-Palmer, Ryan Kelly

Terrestrial-marine synthesis: Blame Steve

Funding: NSF, PISCO, Mellon Foundation, GB Moore, DL Packard Foundations, Hopkins Marine Life Observatory



Many marine larvae have long planktonic periods

Conventional wisdom is that dispersal trumps selection and that local adaptation is rare

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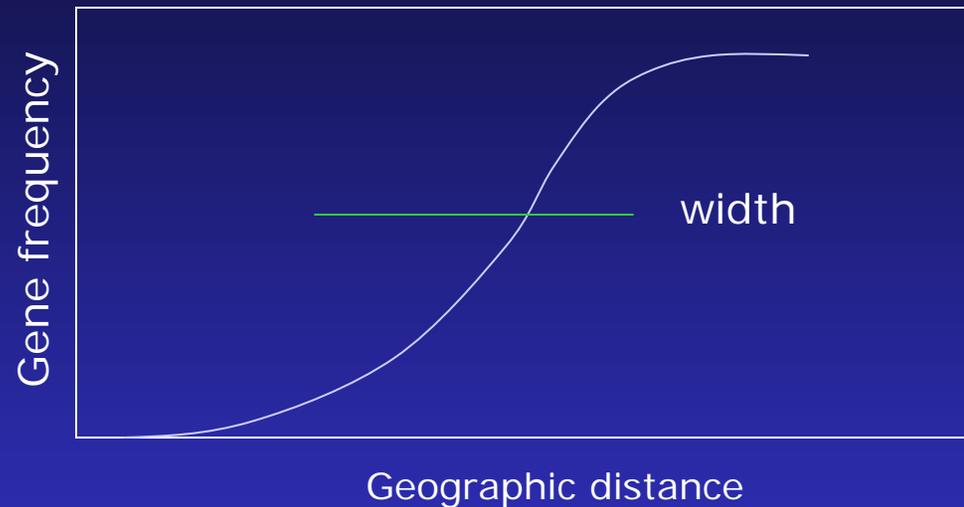
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QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

When can selection overcome gene flow along an environmental cline?

- Cline width set by dispersal, balanced against selection

$$w^2 \approx \frac{\sigma^2}{s}$$



σ = average dispersal distance

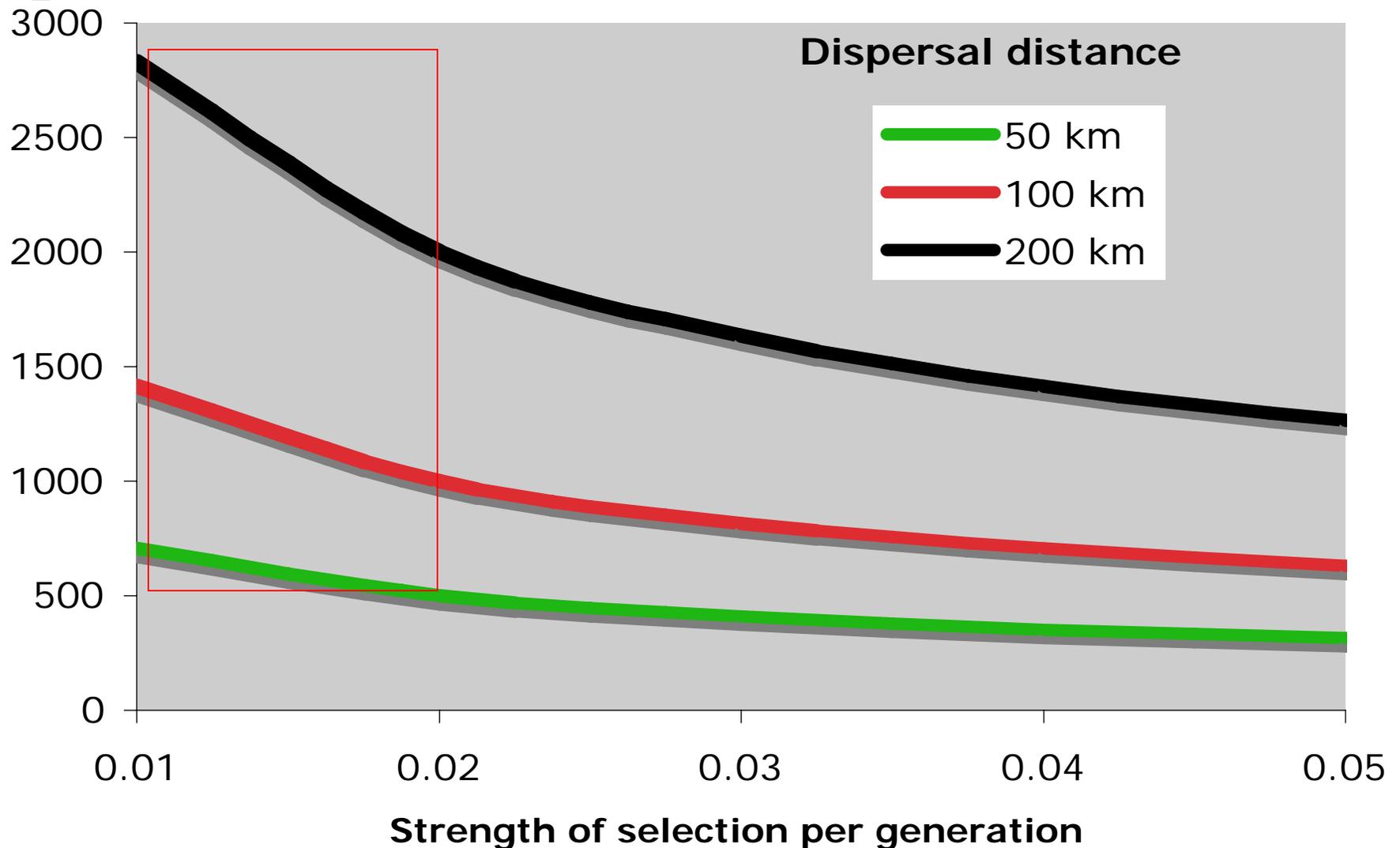
s = selection

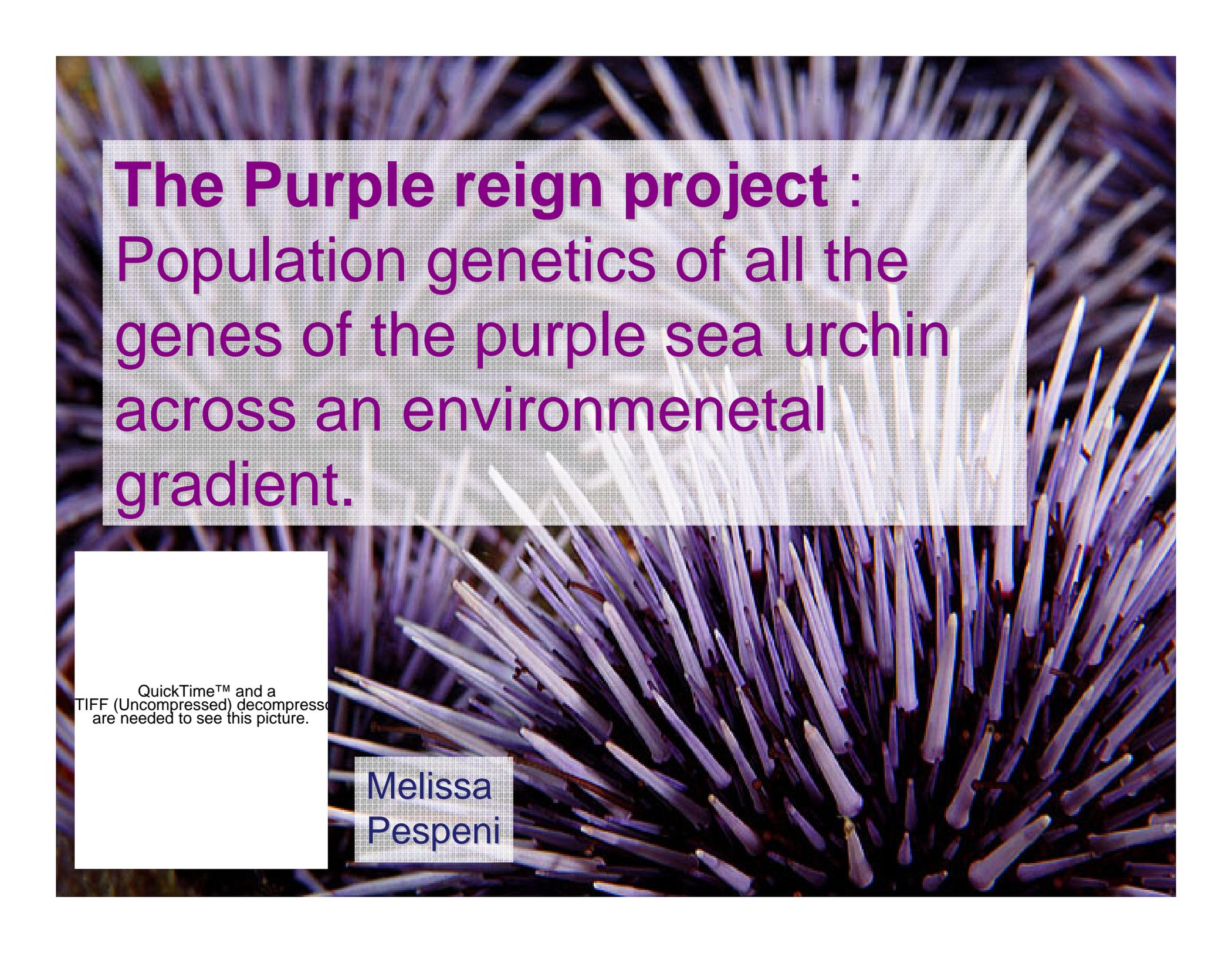
w = clinal width

*Assuming symmetric gene flow,
constant population sizes, etc*

(from Barton 1986, Mallet 2001)

Could local adaptation in the oceans be common?
For 1-2% selection, adaptive clines are predicted to span 500-2700 km



A close-up photograph of a purple sea urchin, showing its numerous sharp, purple spines radiating from a central point. The spines are densely packed and have a slightly translucent appearance. The background is dark, making the purple spines stand out.

The Purple reign project :

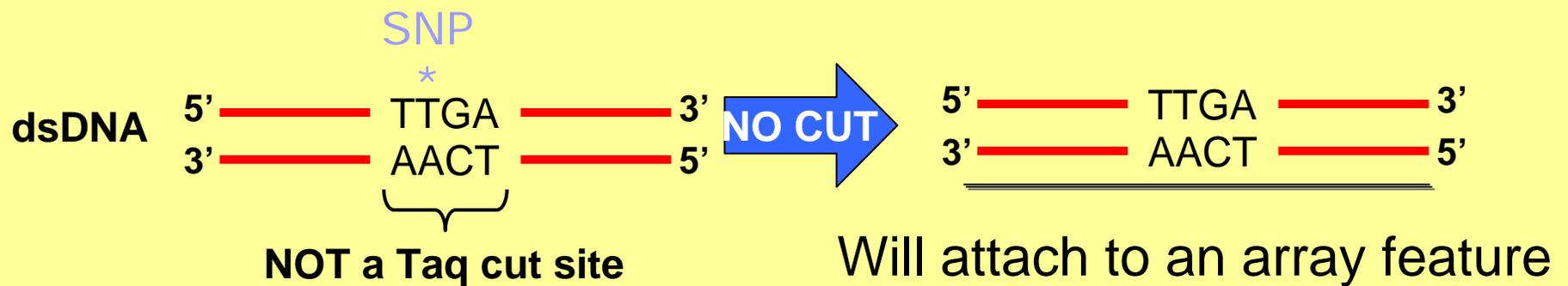
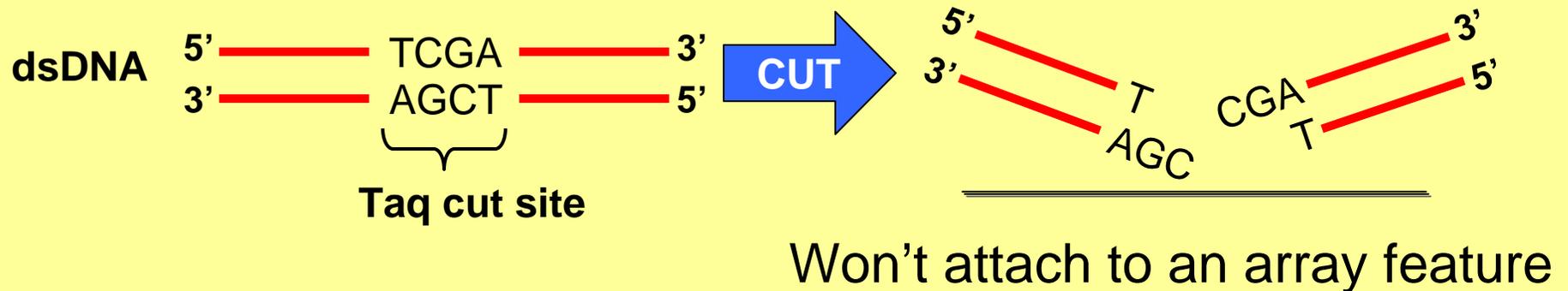
Population genetics of all the genes of the purple sea urchin across an environmental gradient.

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

Melissa
Pespeni

RSTA array: Restriction Site Tiling Assay Array

Build an Agilent gene chip with 140,000 60 bp DNA sections each centered on a *Taq I* restriction site



RSTA array for purple sea urchins:

Assays 50,935 *Taq* I restriction sites (ca. 236,000 bp)

- 27,128 in within all single copy genes
- 9,418 in upstream (-1000 bp) regulatory regions
- 14,389 in intergenic regions

TIFF (Uncompressed) decompressor
are needed to see this picture.

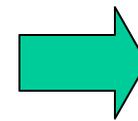
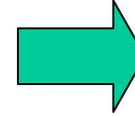
QuickTime™ and a

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are needed to see this picture.



Compare the behavior of each RSTA feature among 10 Oregon and 10 San Diego urchins to estimate gene divergence



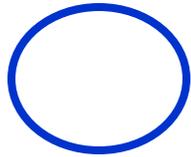
Variation in logRatio in digested and non-digested DNA from different individuals hybridized to the RSTA array

Pyruvate kinase

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Restriction site genotypes of amplified exons confirm that RSTA differences reflect individual SNPs

Pyruvate kinase



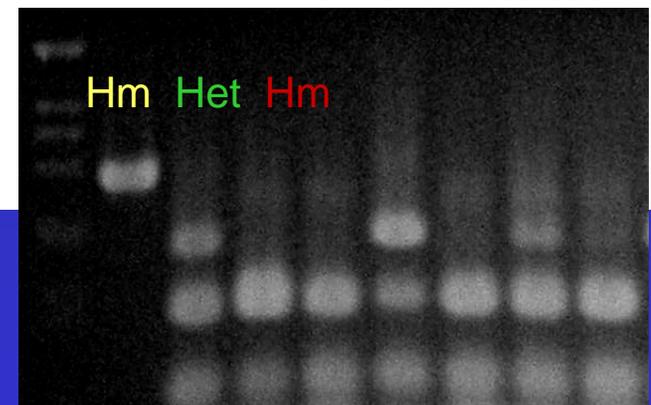
Homozygous
no-cut/no-cut



Heterozygous
cut/no-cut



Homozygous
cut/cut



Accuracy:

- **Out of 135 sequenced restriction site regions across 10 loci, 134 sequences matched the RSTA array pattern.**

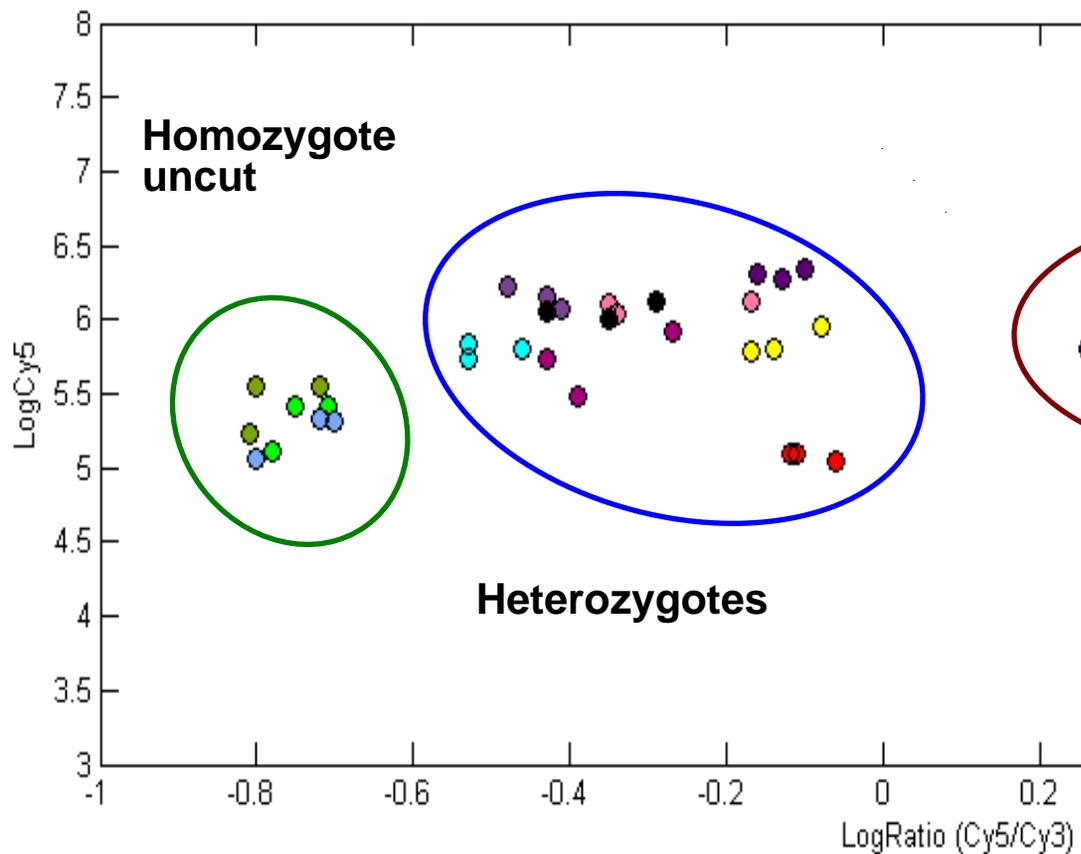


Some loci showing significant clines

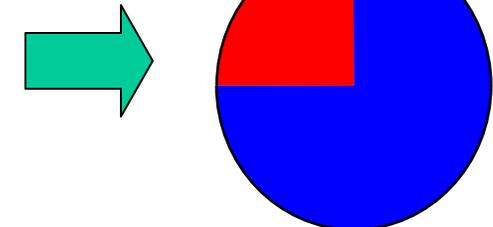
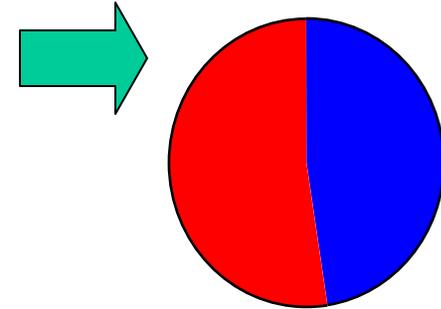


Transcription factor protein, expressed in embryos and larvae but not adults.

GLEAN3 02852



GLN3_2852

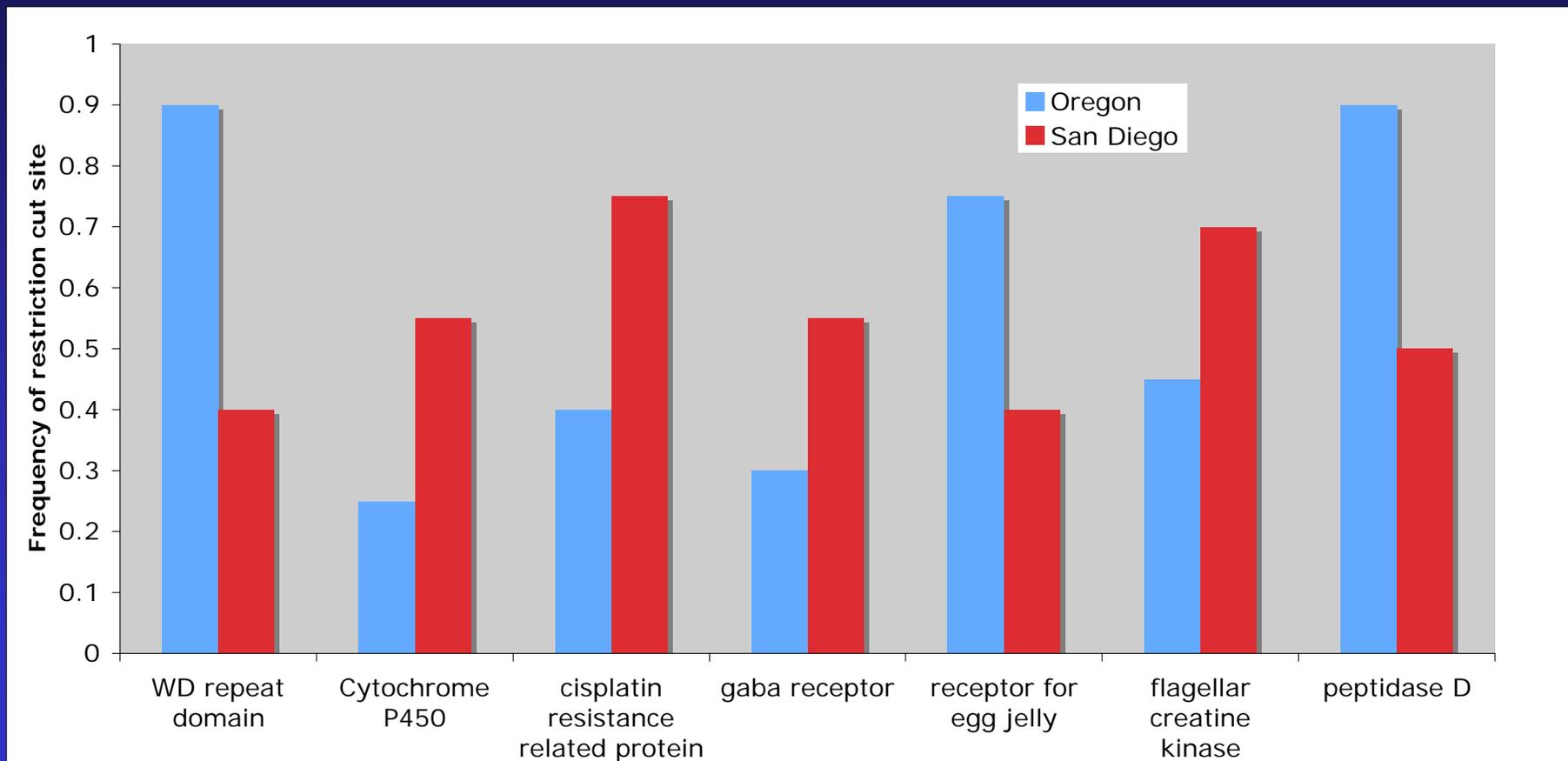


Geographic variation:

- **Out of 28,000 genes, average genetic differentiation is low ($F_{ST} = 0.01$). About 100 show significant structure between San Diego and Oregon ($p < 0.0001$) along the coast. About 50 genes have high $F_{ST} > 0.20$.**



Allelic variation at seven representative loci showing significant differentiation from Oregon to San Diego *(Pespeni and Palumbi, in prep.)*

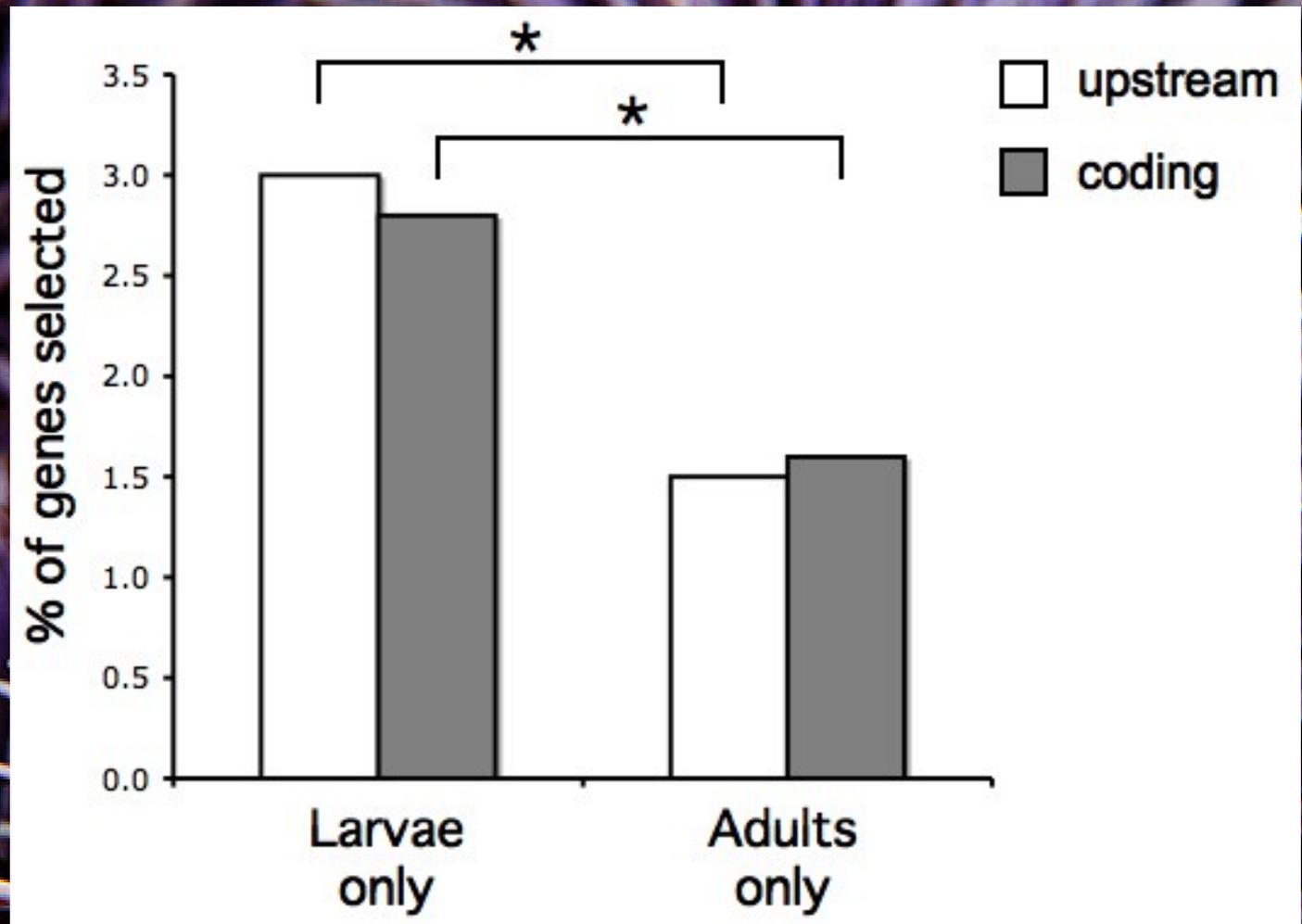


The most differentiated loci tend to be expressed only in larvae:

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Expression data for all urchin genes from the Angerer lab and Mollie Manier

Genes expressed only in larvae are more likely to be differentiated.



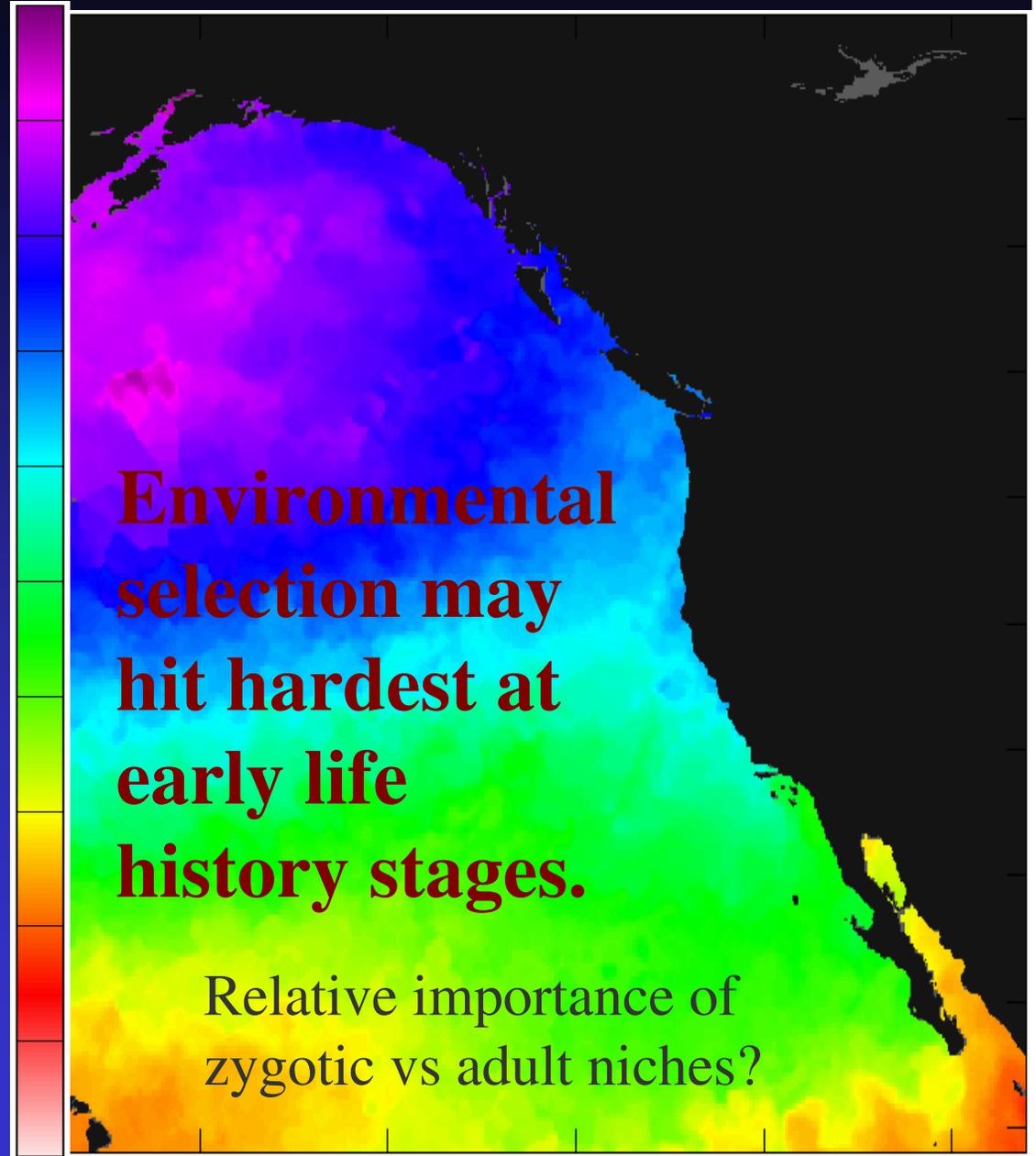
Latitudinal
environmental
gradients are the
norm.

Widely distributed
species may
harbor genetic
adaptations to
local environment
despite high
dispersal.

2° C

17° C

32° C



Sea surface temperatures, May 2005 (NOAA).

Three species responses to climate change

- **Biogeographic shifts**
- **Acclimation**
- **Evolutionary adaptation**

Key research questions: What are the limits of these responses? What other levels of resilience are there?

Other response mechanisms: behavioral shifts in diet, etc.



Hierarchical responses of ecosystems to climate changes and mechanisms of resilience

Changed

Environment: Organisms adjust behaviorally to stabilize the environment they experience.

Acclimation: Organisms adjust gene expression and physiology to maintain unchanged fitness.

Adaptation: Populations adapt genetically to maintain unchanged fitness.

Biogeography: Species can change ranges to experience the same environment as previously.

Ecosystem: Community interactions adjust to new species in ways that maintains productivity and diversity.

If resilience at this level is exceeded:

Organisms experience changed environment

Physiological limits are reached - fitness declines

Selective mortality continues to decrease population size

Species dispersal and range expansion lags behind climate change

Ecosystem functioning is altered

One goal - to understand the limits of resilience to environmental change of whole ecosystems at levels from behavior to species interactions.

Use this information to predict the tipping point for sustained ecosystem function in future climate change scenarios.

Let's not all be stuck here.

