## Adaptive genetic variation, conservation, and fisheries management in the age of genomics

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>**Population Genetics** has many roles in conservation:

>Delineate ESU/DPS boundaries based on shared ancestry, stock identification (GSI), parentage based tagging, relatedness, hatchery broodstock management, etc.

>Historically "data limited".

>Theory dating back to modern synthesis (Wright-Haldane-Fisher).

>Based on the 'neutral theory' (Kimura 1968).



## >Genomic data is now almost limitless.



>Neutral vs Adaptive can be viewed as a fundamental dichotomy, but is really a continuum!



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## >What is 'Conservation Genomics' and is it different?

## Short answer is NO. But see....

(Primmer, 2009; Allendorf *et al.*, 2010; Ouborg *et al.*, 2010; Funk *et al.*, 2012; Shafer *et al.*, 2015, 2016; Benestan *et al.*, 2016; Prince et al. 2016; Garner *et al.*, 2016; Pearse 2016 )



## Early vs. Late Age-of-Return in Atlantic Salmon:







>Sex-dependent

dominance reversal.

>Explains 39% of variance.

>VGLL3 is associated with lipid storage and age of puberty in humans.

Barson et al. 2015



## **Genomic divergence in coastal and migratory Cod:**



National Marine Fisheries Service

## **Genomic Basis of Male Mating Morphs in Ruff**



of the genome (right). (d) The 4.5-Mb inversion disrupts *CENPN*. (e) Diagnostic test for the inversion: design and genotype results. Primer binding sites are indicated by red arrows, and predicted PCR products are shown below as gray boxes. (f) Conserved synteny between chicken chromosome 11 and ruff scaffold 28 based on an independent male; colored blocks represent individual genes.

Lamichhaney et al. 2016 *Nature Genetics* Kupper et al. 2016 *Nature Genetics* 



# SO, what does all this mean for conservation and management of Central Valley salmonids?

BIOLOGY



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# Saving the spandrels? Adaptive genomic variation in conservation and fisheries management

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## **Saving the Spandrels?**

Proc. R. Soc. Lond. B 205, 581–598 (1979) Printed in Great Britain

The spandrels of San Marco and the Panglossian paradigm: a critique of the adaptationist programme

> BY S. J. GOULD AND R. C. LEWONTIN Museum of Comparative Zoology, Harvard University, Cambridge, Massachusetts 02138, U.S.A.





- 1) Don't assume selection.
- 2) Traits are not independent; consider the whole.



## Molecular spandrels: tests of adaptation at the genetic level

Rowan D. H. Barrett and Hopi E. Hoekstra



Nature Reviews Genetics, 2011

Genomics gives us the tools to:

>Identify adaptive genomic variants.

>Connect to phenotypes and environmental variables

Stapely et al. 2010, TREE Narum & Hess 2011, Mol Ecol Res Vincent et al. 2013, Evolution Poh et al. 2014, Plos One; Springer et al. 2016, BioRxiv



### Oncorhynchus mykiss

 Steelhead: Anadromous, spend 1-2 years in freshwater and 1-4 years in salt water prior to spawning. Iteroparous.
 Rainbow Trout: Stay in stream entire life as Residents. Populations may exisit in isolated freshwater systems.

Determined by some combination of genetics (heritable) and response to environmental effects (phenotypic placticity).



ESA listing protects "all naturally spawned anadromous *O. mykiss* (steelhead) populations below natural and manmade impassable barriers" NMFS 2006



## **Genomic Basis of Anadromy/Residency**

#### >Numerous studies on genetic basis of life-history in O. mykiss:

Robison et al. 2001; O'Malley et al. 2003; Leder et al. 2006; Phillips et al. 2006; Nichols et al. 2007, 2008; Haidle et al. 2008; Colihueque et al. 2010; Paibomesai et al. 2010; Easton et al. 2011; Le Bras et al. 2011; Martínez et al. 2011; Miller et al. 2012; Narum et al. 2011; Limborg et al. 2012; Hecht et al. 2012a,b; Hale et al. 2014; Pearse et al. 2014; McKinney et al. 2015; Baerwald et al. 2015.

#### >Results highly variable, but many have associated one part of chromosome Omy5 with correlated life-history traits.



Lein et al. In Prep; Campbell et al. In Prep.



>We can now detect adaptive genomic variation, but the existence of such variation has long been recognized (J. B. S. Haldane, 1932).

>Phenotypic 'proxies' for ecotypes with unknown AGV have been incorporated into conservation plans. (Dizon et al. 1992; Waples 2006)

>False Positives and Negatives.
 -Polygenic traits, Pleiotropy, Epistasis, Penetrance
 Bias in detecting strong signals.
 -Will never detect all AGV.

>AGV associated with unclear phenotypes?





AGV is subject to same genome-wide forces as neutral loci



Allendorf et al. 2010, Nature Reviews Genetics



## Good news!

>This means that for the most part we are already doing what we need to do from an evolutionary genetic perspective to protect genetic diversity.

>Continued action is needed.

(better tools serve to improve efficiency)

>Protection of ancestral diversity plus recognition of ecotypic variants, regardless of underlying AGV.



## Levels of management: population vs. individual effects

>Unit of concern for conservation is population, not individual. -In contrast, medical genomics is individual-based.

>Marker-Assisted Selection in conservation? -Hatchery broodstock selection?

>Use of genotype at specific loci to select individuals for breeding.

>Widely used for livestock and crops.

-Released animals must be fit in the environment.





### **Conservation unit delineation**

>Follows from existing ESA listing process.

>Additional potential levels for Management Unit designations and Adaptive Groups.

>Identify source populations for re-introductions. (He et al. 2016 Con Bio; Pearse 2016)



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TRENDS in Ecology & Evolution





## **Genomic basis of anadromy**

>Omy5 MAR associated with adfluvial populations above reservoirs.



National Marine Fisheries Service



**Piccolo 2016; Journal of Fish Biology** 11 OCT 2016 DOI: 10.1111/jfb.13172 http://onlinelibrary.wiley.com/doi/10.1111/jfb.13172/full#jfb13172-fig-0001

### **Conclusions**

Adaptive genomic variation can be targeted for conservation. Evaluate diversity using both neutral and adaptive loci.

Even genes of major effect are probabilistic indicators of individual phenotype, and can't capture the full extent of phenotypic variation related to fitness.

(Major exception; immune system genes)

Focus on evolutionary processes that promote diversity. This is consistant with 'evolutionarily enlightened management' or 'prescriptive evolution'

(Ashley et al., 2003; Smith et al., 2014; Pearse

2016).



## Thank you!

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... then he yelled "evolution!" and simply jumped out ...

