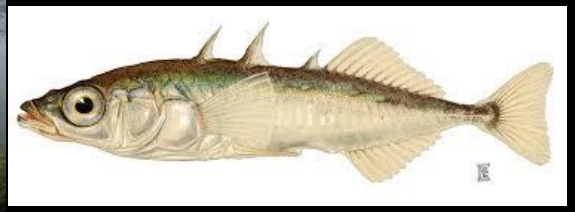
"The hidden diversity of Scottish fresh waters: what you see is not what you get!"

Colin Adams

Scottish Centre for Ecology & the Natural Environment

University of Glasgow

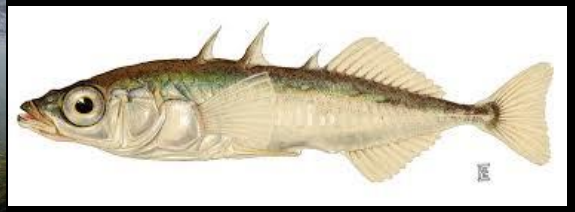



The concept of “species” dominates legislation, policy & interventions

- Conservation actions
- Wildlife management

OED: def: n. .. a groups of living organisms consisting of similar individuals …

At least 22 variant concepts of species in current usage (Mayden 1997)

The concept of “species” dominates legislation, policy & interventions

- 1806 taxa listed on Scottish Biodiversity List (Terrestrial & Freshwater)
- 99% are defined as species

We are failing to take into account:

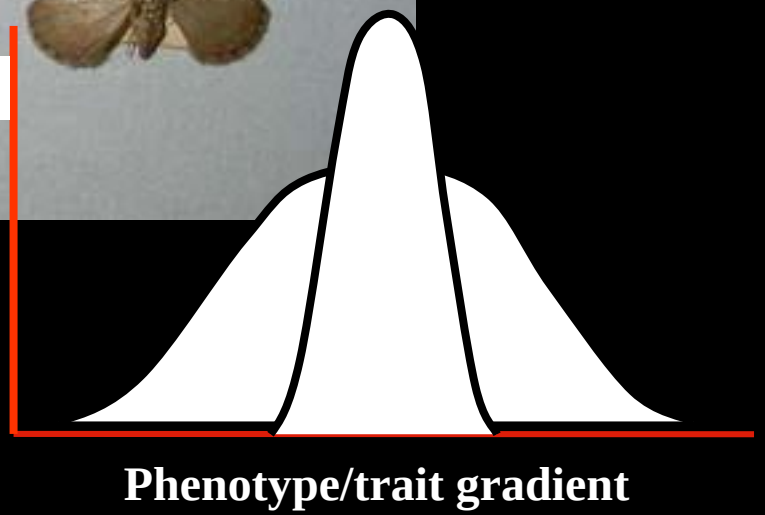
- significant biodiversity
- the mechanisms that give rise to biodiversity

As a result may be failing to protect much of our natural heritage

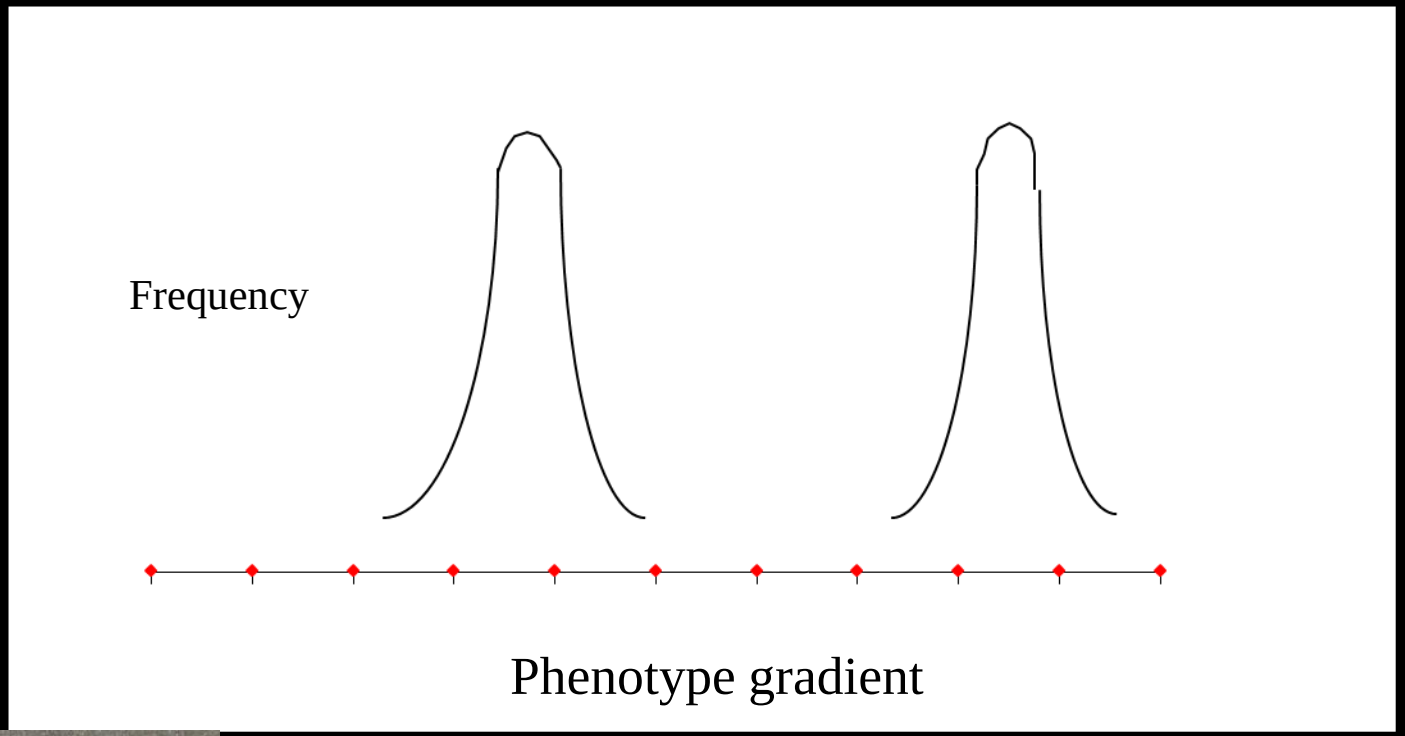
Two general points: Scottish fresh waters are young

Variation in phenotype is common

July Highflyer *Hydriomena furcata*



Phenotypes that are discrete



Peppered Moth – *Biston betularia*

Oyster catcher – *Haematopus ostralegus*

Rainbow smelt
Osmerus mordax

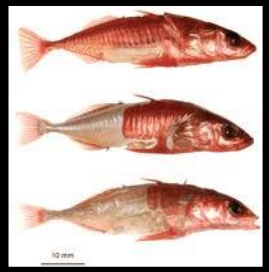
Brook charr *Salvelinus fontinalis*

Powerful techniques and a closer look reveals:
significant intraspecific structuring
in many species

- Particularly prominent in freshwater fishes
- Evidence of rapid, contemporary evolution
- Opportunity to explore evolutionary mechanisms
- very beginnings of evolutionary divergence

Considerable consequences for recording and conservation

European whitefish
Coregonus lavaretus



3-spined Stickleback

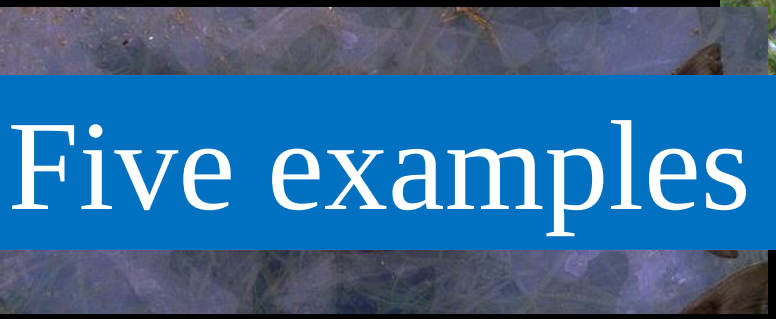
Intra-specific variation in Arctic charr phenotype

Loch Maree - Wester Ross

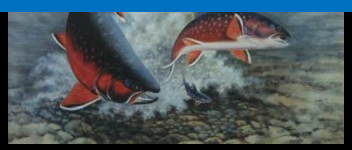
Loch Mealt - Isle of Skye

Loch Coulin - Wester Ross

Five examples from (mostly) LL&T



Loch Doine - Trossachs



Coomsaharn charr

Cwellyn charr

Cowlyd charr

Bald mountain charr - Maine

Loch More - Sutherland

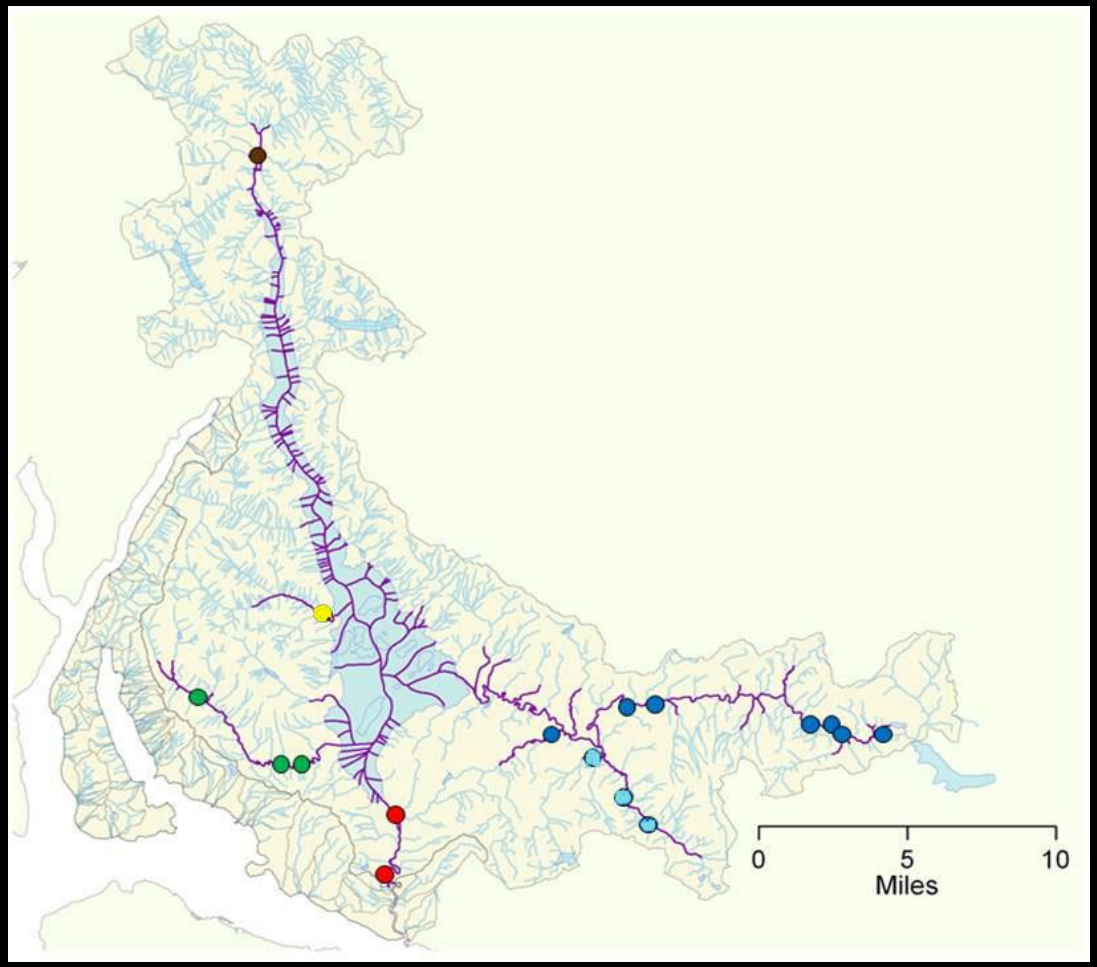
"the most variable vertebrate on earth"? (Klemetsen 2013)

Example 1 Atlantic salmon *Salmo salar*
Spatial structuring in Loch Lomond

Mark Coulson

Very clear genetic differences between places

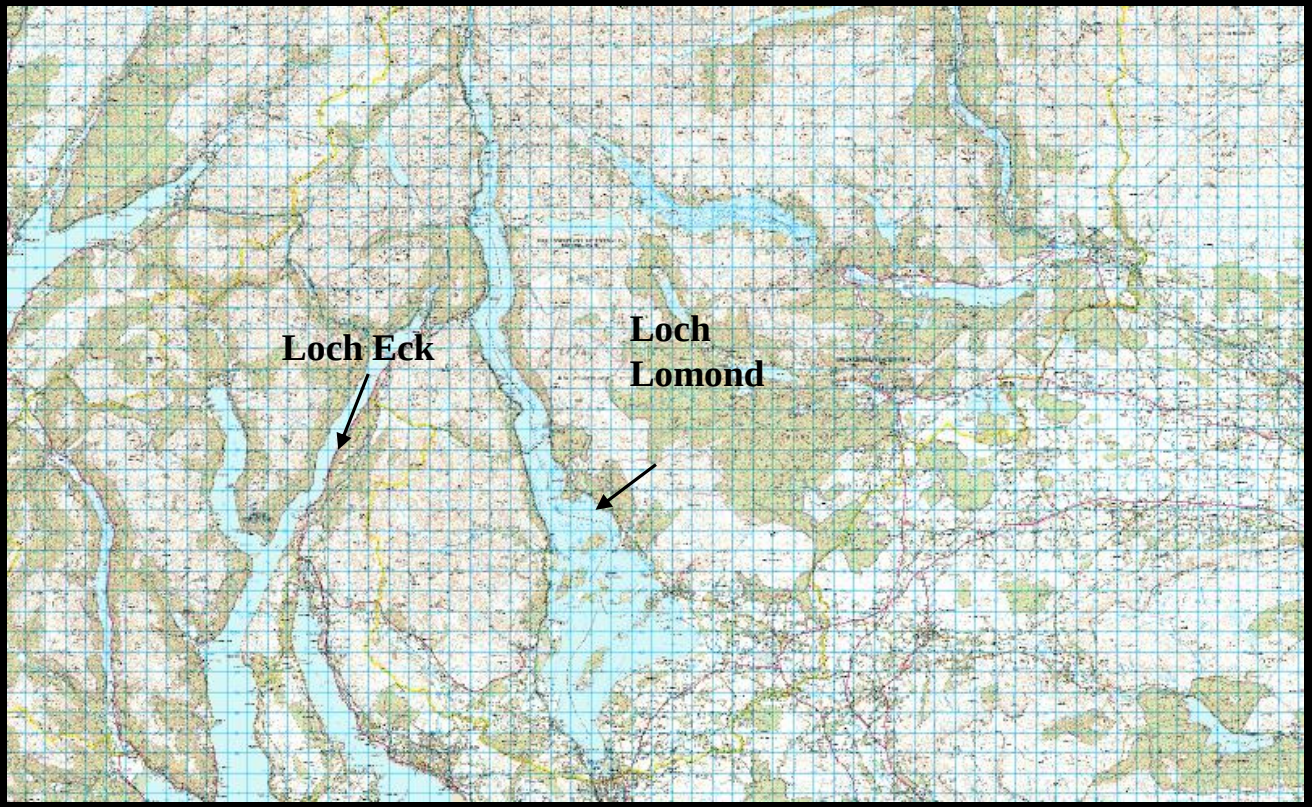
Atlantic salmon not the same in different places
Genepool is fragmented



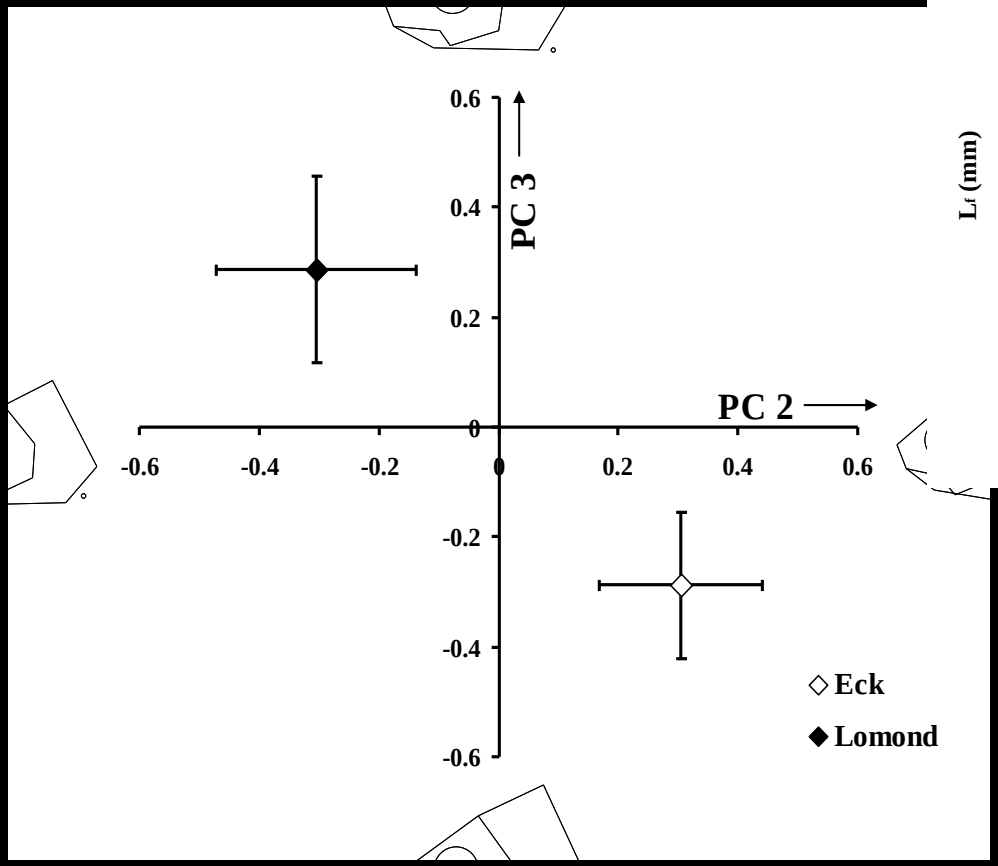
Liz Etheridge

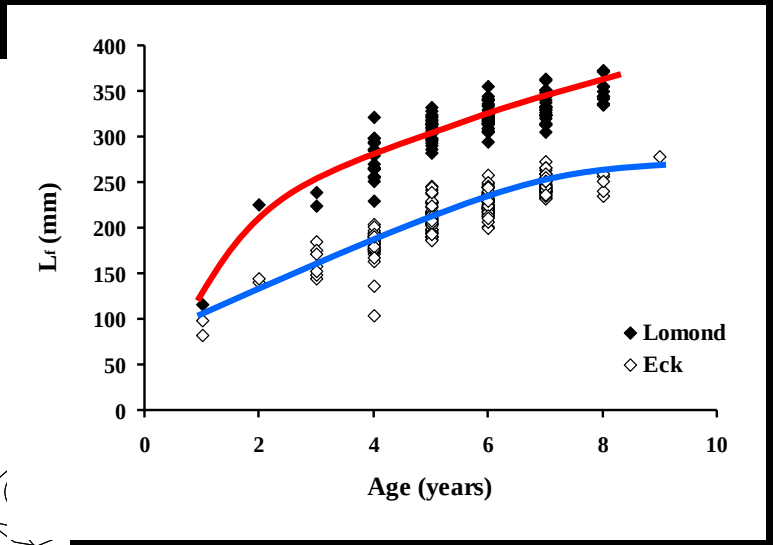
Example 2 Powan *Coregonus lavaretus*

Native: Loch Lomond and Loch Eck



Eck and Lomond: ecological and phenotypic differences

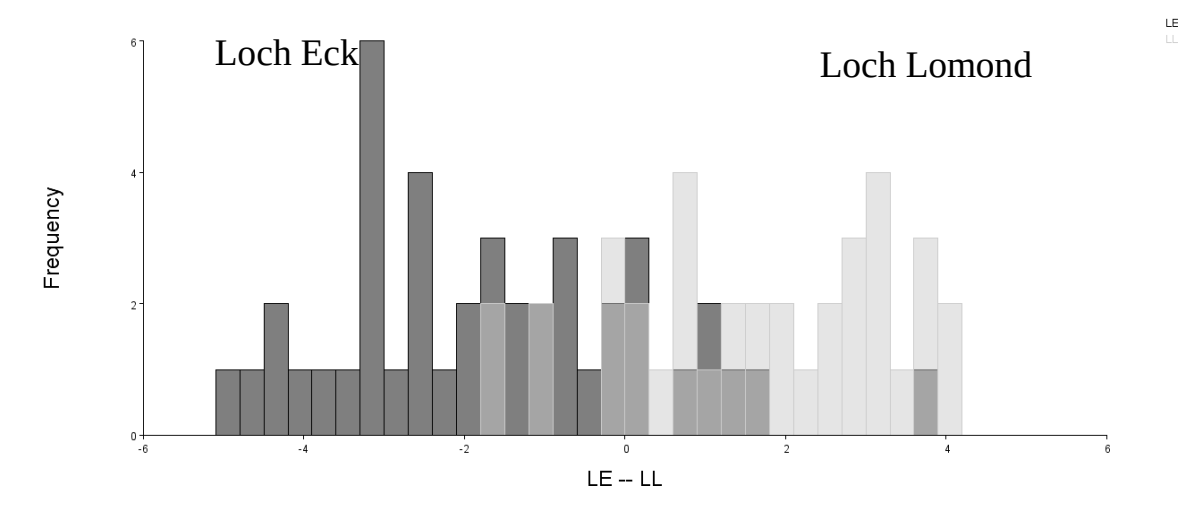




Differences in:

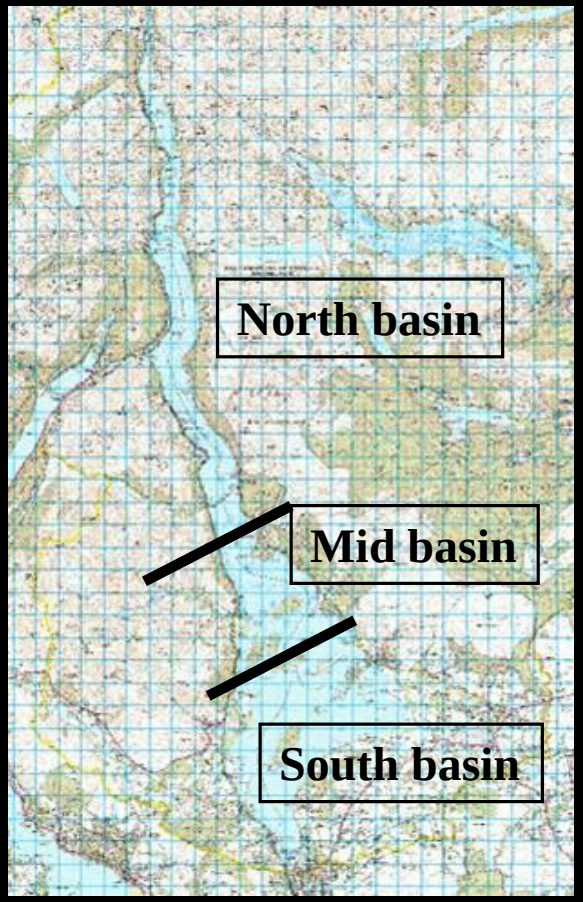
- Phenotype
- Genotype
- Growth rate
- Max size
- Diet / foraging ecology
- C & N Stable isotopes signatures
- Parasite fauna differences

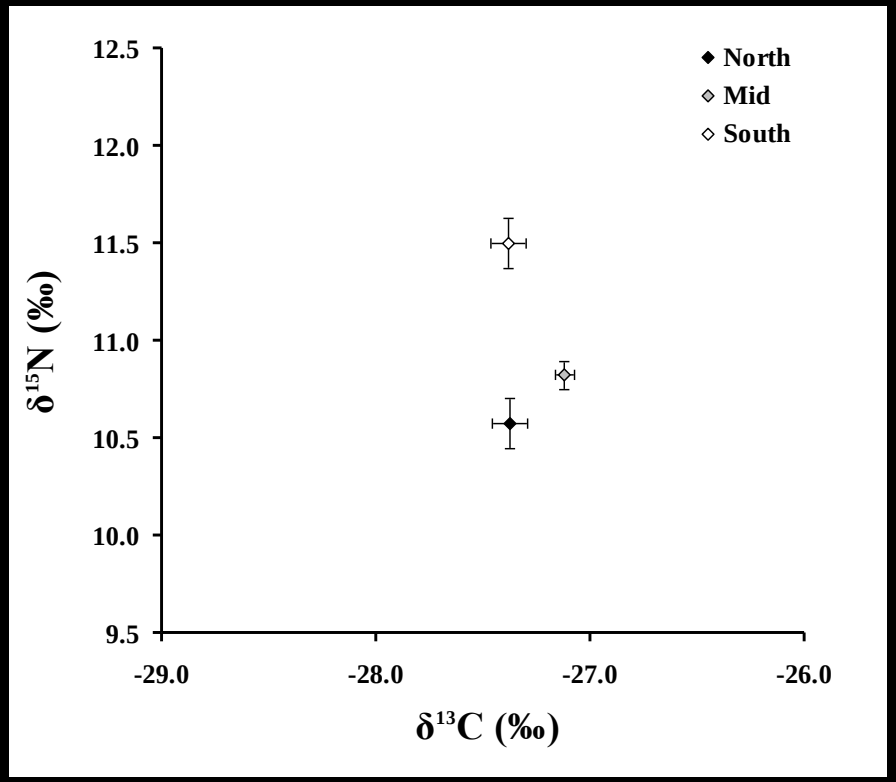
Multivariate measure of body morphology



Reared under identical conditions

Powan from Eck and Lomond – exhibit different morphological phenotypes





Genetic differentiation with gene flow

North basin ⟷ **Mid basin** ⟷ **South basin**

Powan:
Between lochs – highly divergent
Between basins of Lomond – beginning to diverge

River lamprey - Lampetra fluviatilus

John Hume

Brook lamprey
Lampetra planeri

Example 3 - Lamprey

Brook lamprey

River lamprey
– freshwater feeding

River lamprey -

“Body size incompatibility maintains gene pool segregation”

Does it?

River and brook lamprey pairings

- **Flume tank experiments on preference in mating pairs**
- **In vitro fertilisation**
- **Population genetics of wild fish (RADS)**

Results

- Indiscriminate mating choices
- Hybrid offspring viable
- Brook and sea feeding river very considerable genetic overlap
- Almost certainly evolved in situ multiple invasions Species? – no
- Lake feeding - more distinct

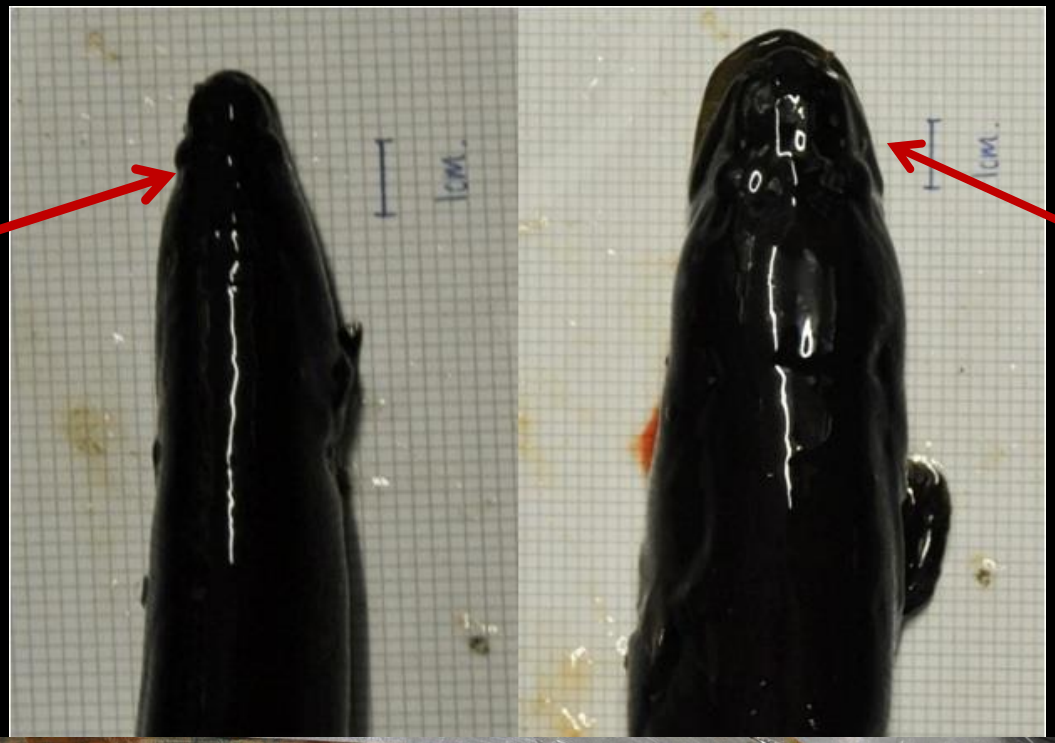
Example 4 European eel (*Anguilla anguilla*)

James Barry

Foraging Ecology

"Individual specialisation in diet is widespread among wild populations"

Eel head shape

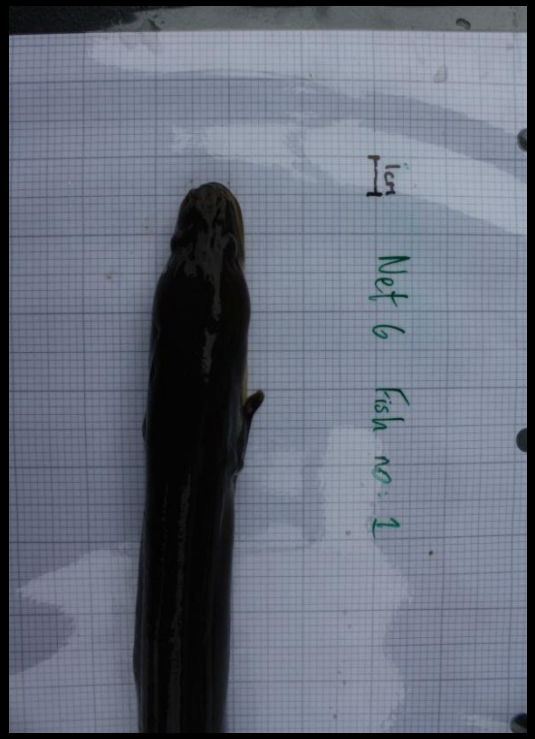


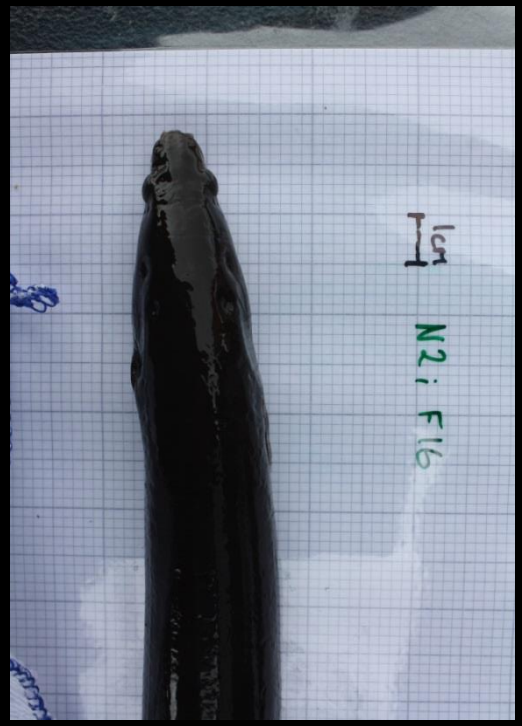
Narrow head
Insect feeder

Broad head
Fish feeder

Loch Lomond:
45% broad head eel
55% narrow head eel
No evidence of genetic structuring across the range

Fitness consequences of individual specialisation





Both eels 475mm, broad head left, narrow head right

Fat content broad = 9.1%, Fat Content narrow = 26.4%

Loch Maree - Wester Ross

Loch Mealt - Isle of Skye

Example 5

Loch Doine - Tross

Loch Builig - Cairngorms

Loch Coulin - Wester Ross

”the most variable vertebrate on earth”? Anders Klemetsen

Cowlyd charr

Coomsaharn charr

Cwellyn charr

Bald mountain charr - Maine

Loch More - Sutherland

What form does this variability take?

Loch Coulin

Loch Maree - Wester Ross

Loch Mealt

Loch Builig - Cairngorms

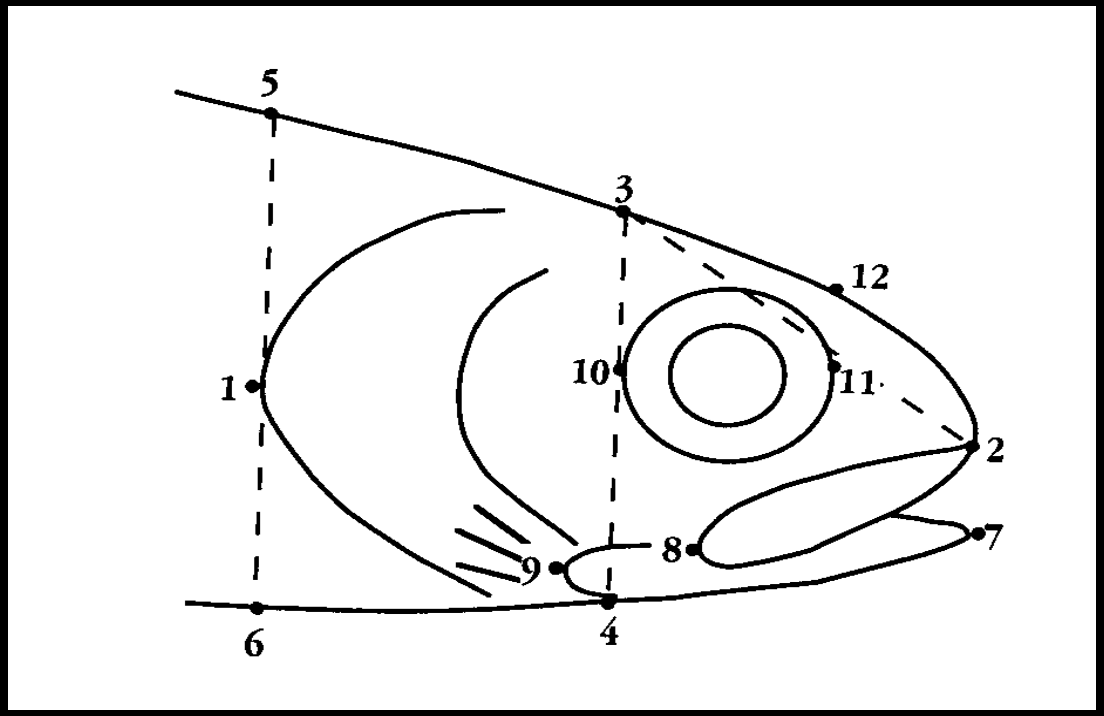
Loch Doine

Loch More - Sutherland

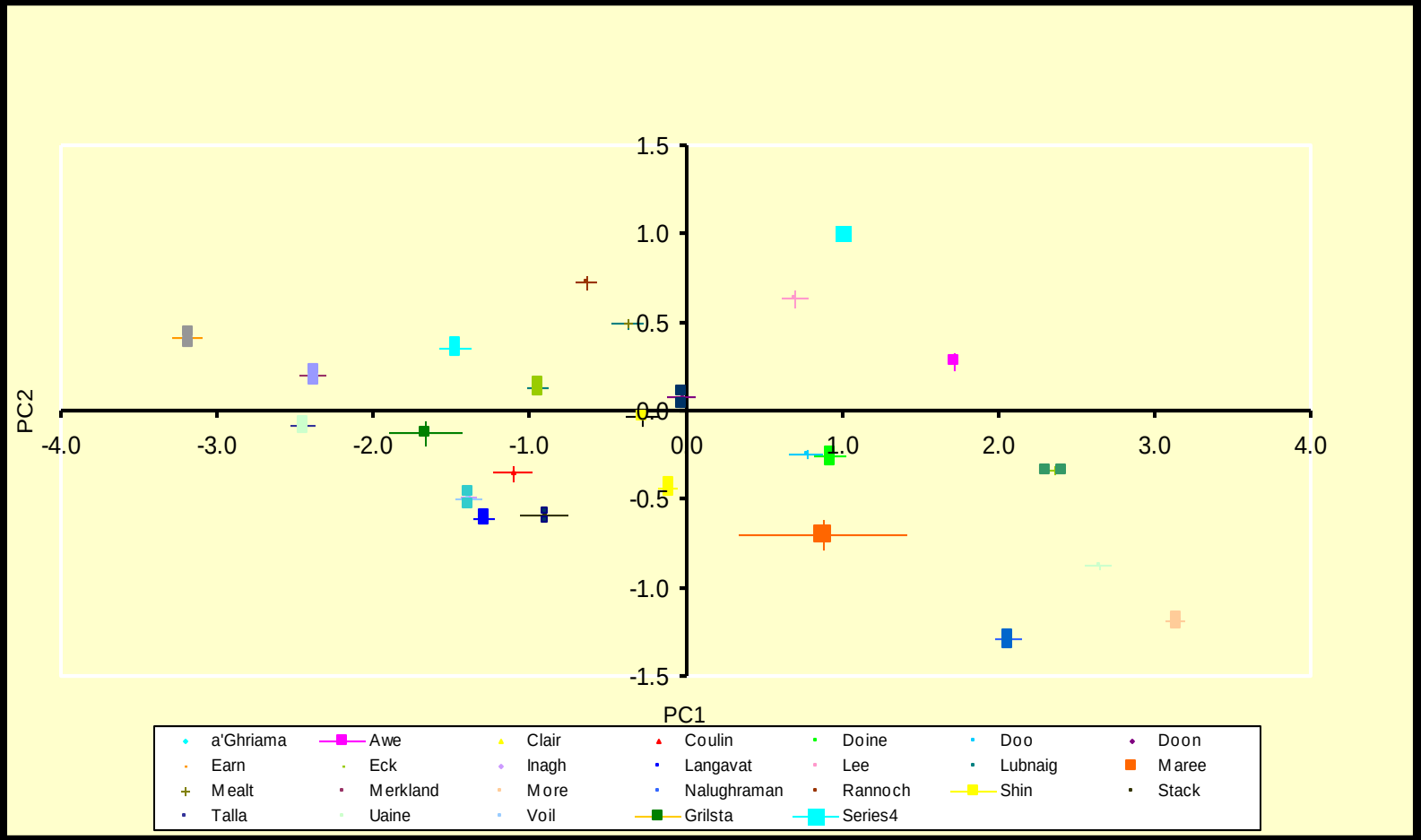
Measuring variation in trophic morphology

10 measures of morphology of feeding

Viperfish – *Chauliodus sp.*



Variability in head shape between populations across Scotland



- Head shape differs between populations
- Degree of head shape variability within differs between populations

Complexity – sympatric morphotypes

Loch Rannoch - Perthshire

Benthivorous

Planktivorous

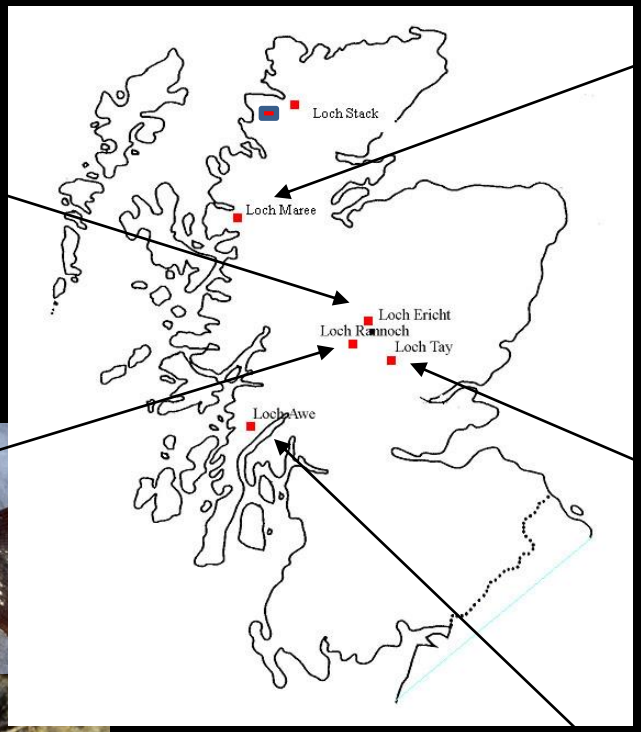
Piscivorous

Phenotypic Differences

Coloration
Head Morphology
Diet
Body shape
Sexual dimorphism
Spawning sites
Mean spawning time
Growth rates
Maximum body size
Age range
Parasite burden
Parasite Fauna
Age at first maturation
Longevity
Reproductive effort
Egg size
Egg mass weight

Sympatric Polymorphism Scotland

Loch Eright



Loch Marie

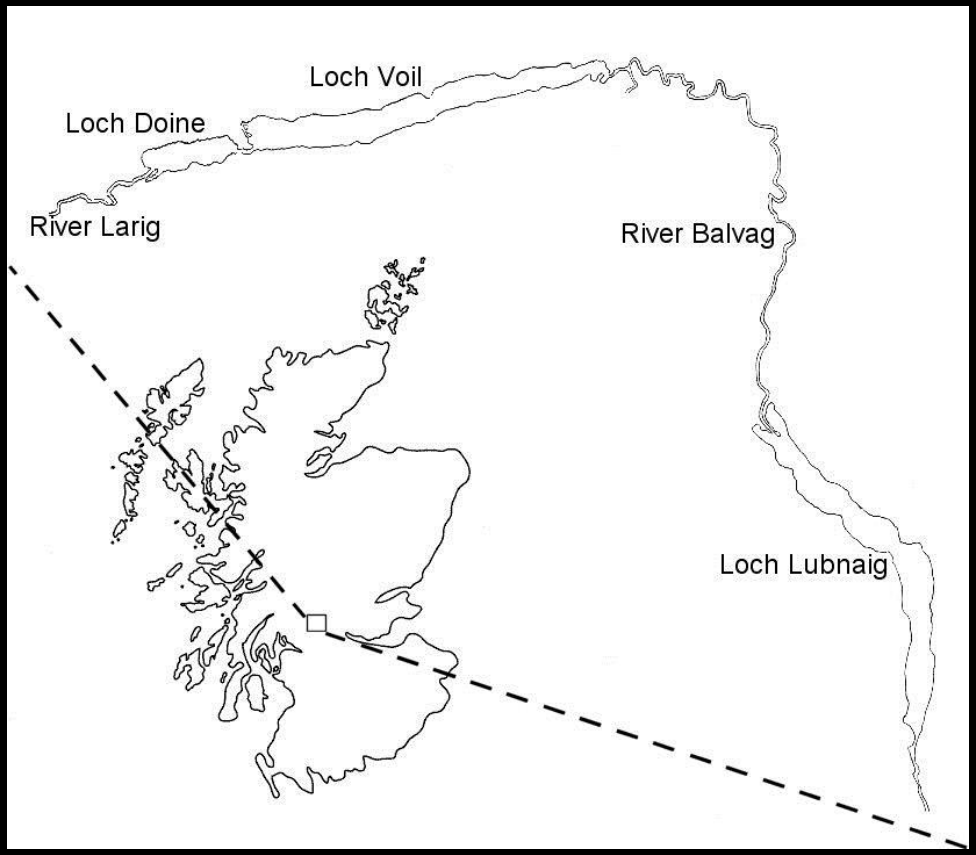
Loch Tay

Loch Rannoch

Loch Awe

Trossachs lochs charr show polymorphisms

proximate mechanisms maintain divergence

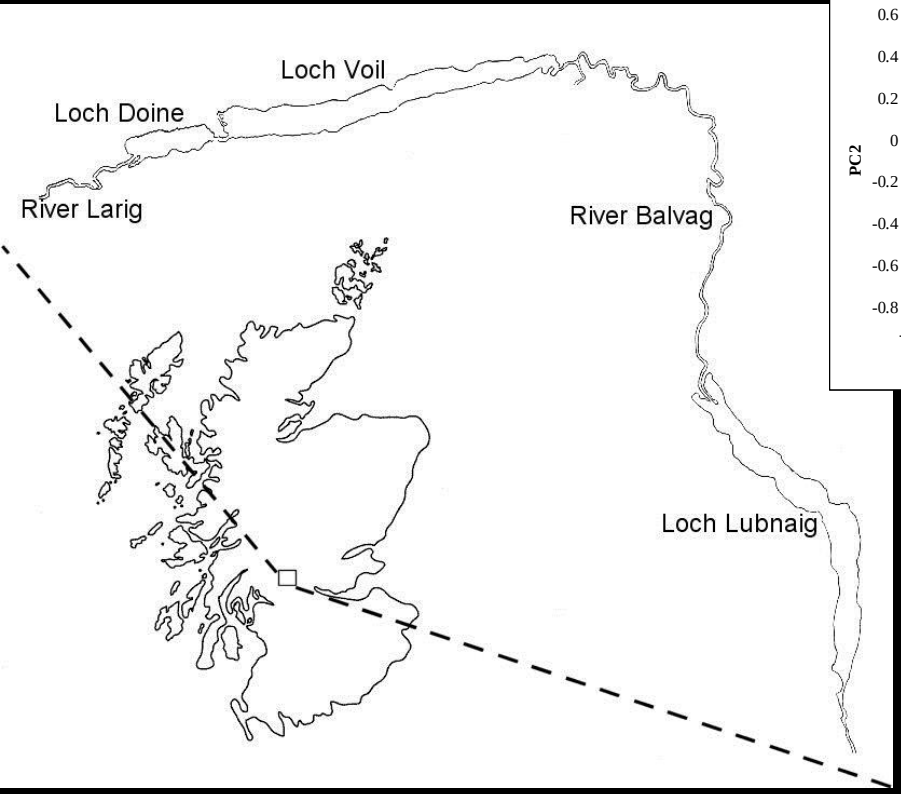


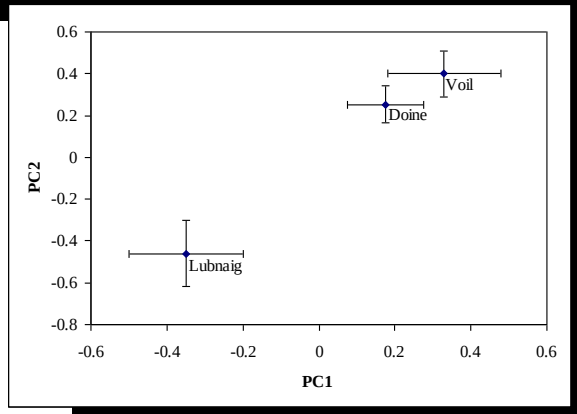
Loch Doine

Trossachs charr

F_{ST} R_{ST}	Doine	Voil	Lubnaig
Doine		-0.005	0.155*
Voil	-0.003		0.111*
Lubnaig	0.060*	0.034*	

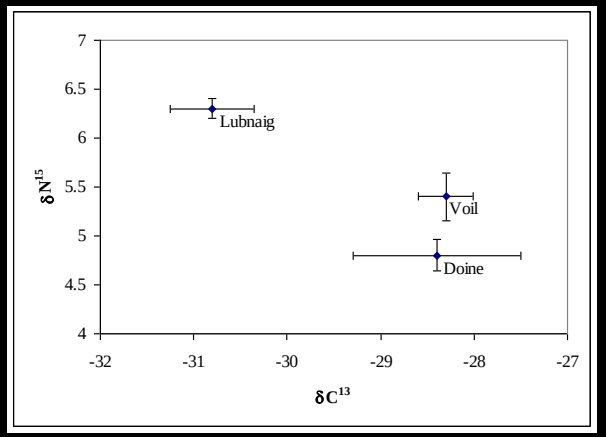
Discrete genetic variation

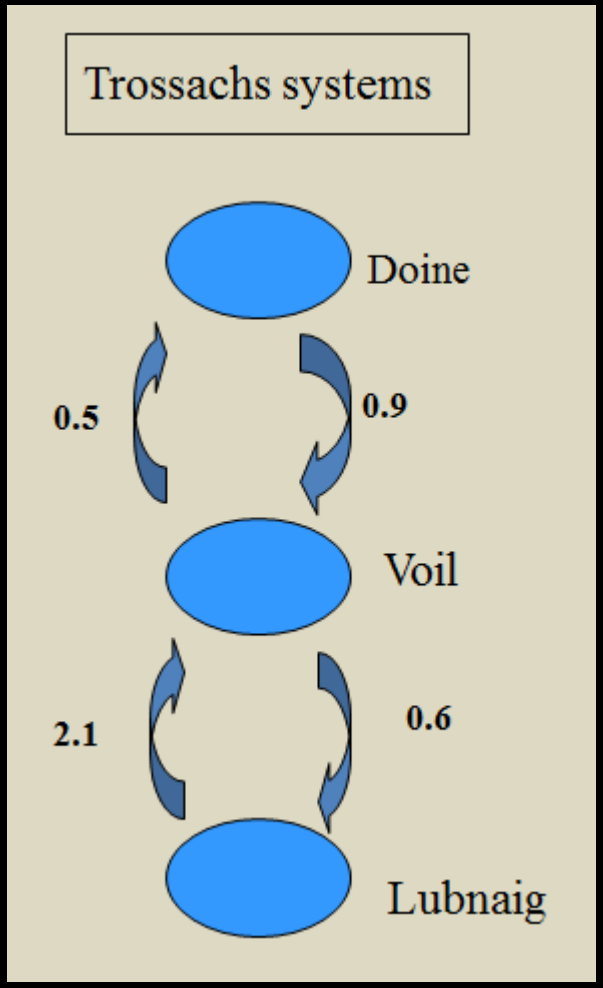




Discrete variation in shape

Discrete variation
in feeding ecology





Gene flow – between charr populations up and down 3 lochs

Loch Shin

Loch Bulig

Loch Shin

Loch Earn

Loch Coulin

Loch Clare

Loch More

Loch Mealt

small ground finch

medium ground finch

large ground finch

sharp-beaked ground finch

cactus finch

large cactus finch

small tree finch

large tree finch?

vegetarian finch

woodpecker finch

warbler finch

“Darwins finches in Scotland ??”

Is this any of this important?

Conservation, science and management implications

1) Evolutionary Model: to explore evolutionary process
2) Cultural importance
3) Species status - uncertain
4) **Hidden diversity**

5) most sub-specific units have no statutory protection –

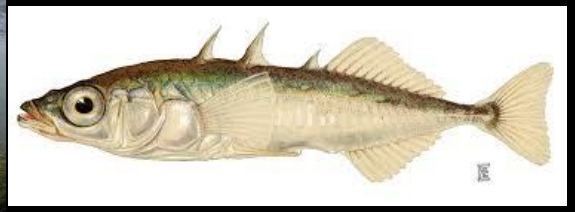
Arctic charr

Site	Year	Mechanism
Loch Achray	1970's	Acidification
Loch Dungeon	1960's	Acidification
Loch Grannoch	1900s	Acidification
Loch Heldal	Late 20th century	Unknown
Loch Venachar	1970's ?	Acidification
Loch Leven	1837	Drainage
St Mary's Loch	ca 1750s	Uncertain
Loch Katrine	Mid 20th century	Acidification

Loch Venachar

Loch Katrine

- 16 known extinctions in Scotland
- 50 in Ireland

The concept of “species” dominates legislation, policy & interventions

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We are failing to take into account:

- significant biodiversity
- the mechanisms that give rise to biodiversity

As a result may be failing to protect much of our natural heritage

Conservation Importance :

- Almost no recognition of diversity below species level
- No account taken of different management needs different forms
- Little consideration of the need to conserve the processes that leads to this emerging biodiversity

Loch Lee charr

Loch Earn charr

One further complication of intra-specific structuring

IUCN and *Salvelinus*

The IUCN Red List of Threatened Species™ 2012.1

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Home > Salvelinus alpinus (Arctic Charr, Charr)

VIEW MAP

Salvelinus alpinus

NOT EVALUATED	DATA DEFICIENT	LEAST CONCERN	NEAR THREATENED	VULNERABLE	ENDANGERED	CRITICALLY ENDANGERED	EXTINCT IN THE WILD	EXTINCT
NE	DD	LC	NT	VU	EN	CR	EW	EX

Summary | Classification Schemes | Images & External Links | Bibliography | Full Account

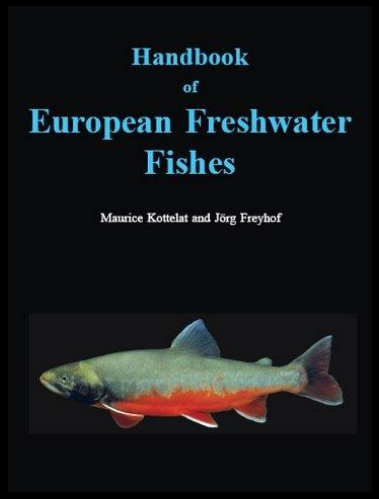
Taxonomy
Assessment Information
Geographic Range
Population
Habitat and Ecology
Threats
Conservation Actions

View Printer Friendly

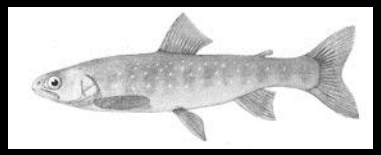
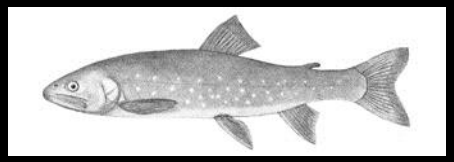
Taxonomy [top]

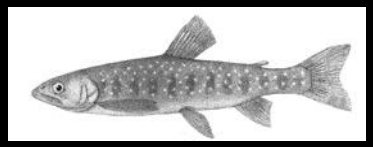
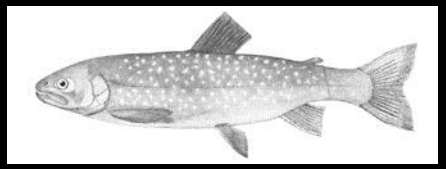
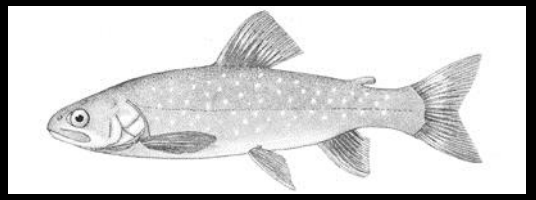
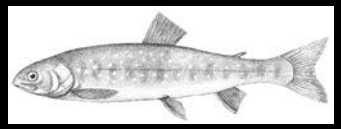
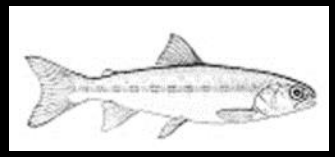
Kingdom	Phylum	Class	Order	Family
ANIMALIA	CHORDATA	ACTINOPTERYGII	SALMONIFORMES	SALMONIDAE

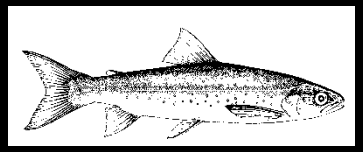
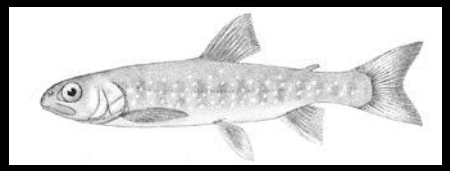
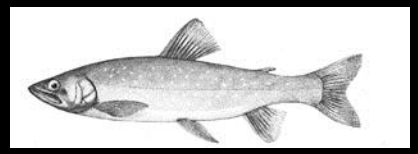
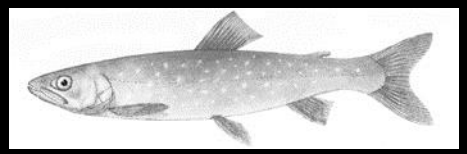
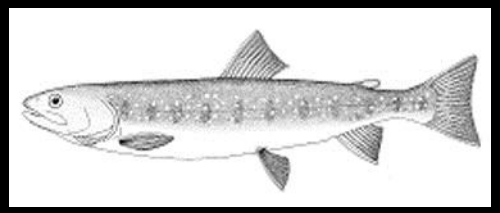
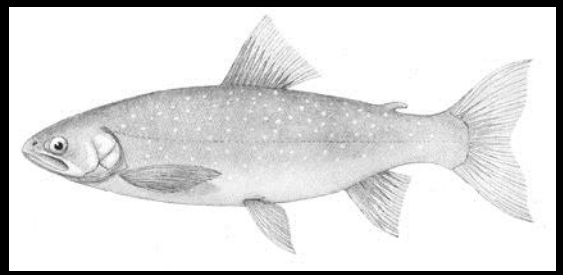
Scientific Name:	*Salvelinus alpinus*
Species Authority:	(Linnaeus, 1758)

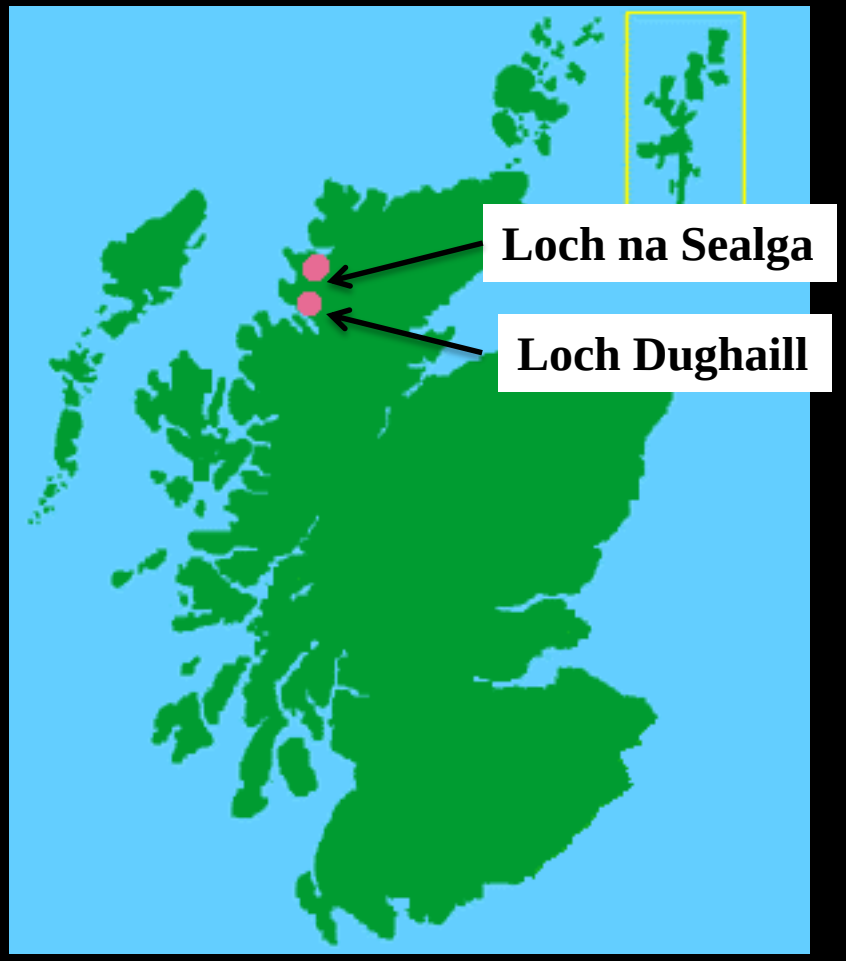


1908 – 15 species (Regan); 2006 – 1; 2008 – 16?:

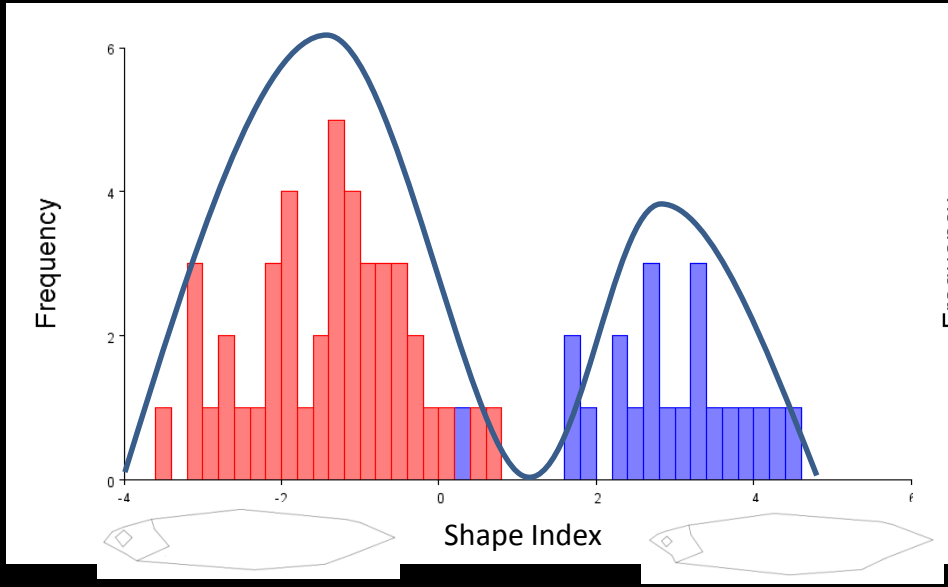



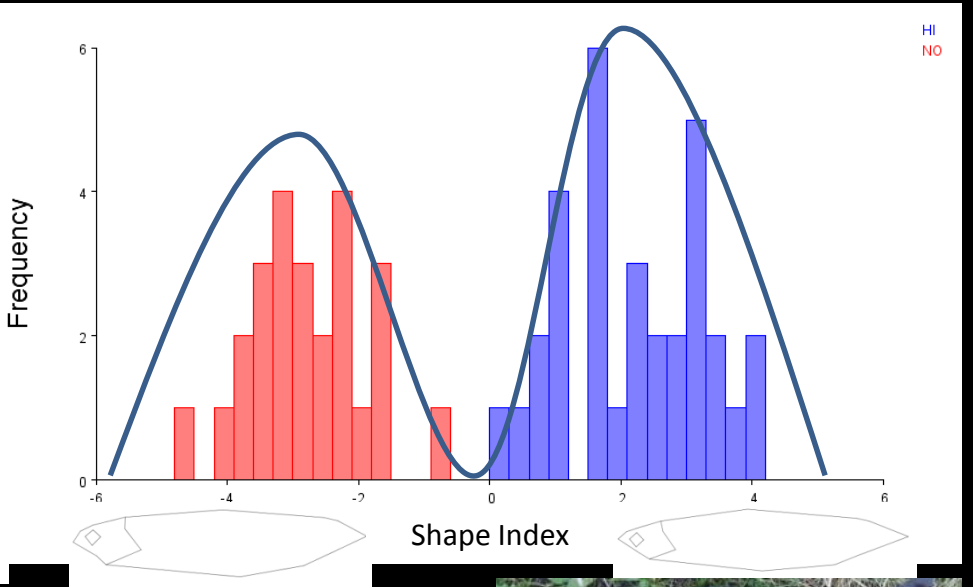







Loch na Sealga
Loch Dughaill

na Sealga and Dughaill





N= 43 : 21

Procrustes distances among groups:
P = < 0.0001

N= 25 : 32

Procrustes distances among groups:
P = < 0.0001