# Exploring the movements of Atlantic Salmon around Scottish coasts, using historical tagging data and a simple agent-based modelling approach

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# Atlantic Salmon, *Salmo salar*

## Anadromous

- Hatch in freshwater, resident for 1-3 years
- Migrate to marine feeding grounds in the North Atlantic for 1-5 years
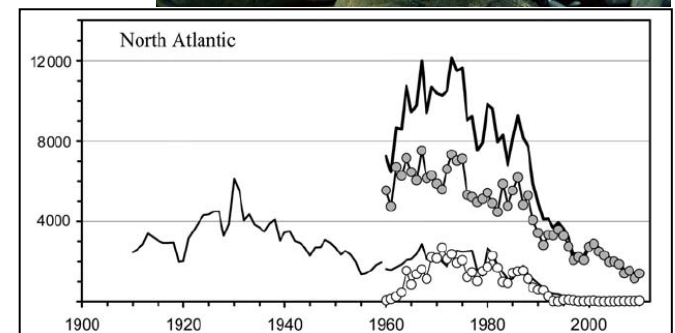- Return to natal rivers to spawn

## Under threat from anthropogenic impacts

- Pollution of freshwater habitats
- Hydropower (rivers) and dams
- Marine fisheries
- *Climate change*

## *Populations are in decline*



Source: Chaput, G. *ICES J. Mar. Sci. (2012) doi:* 10.1093/icesjms/fss013

# Marine Renewables in Scotland

## Scottish Government target:

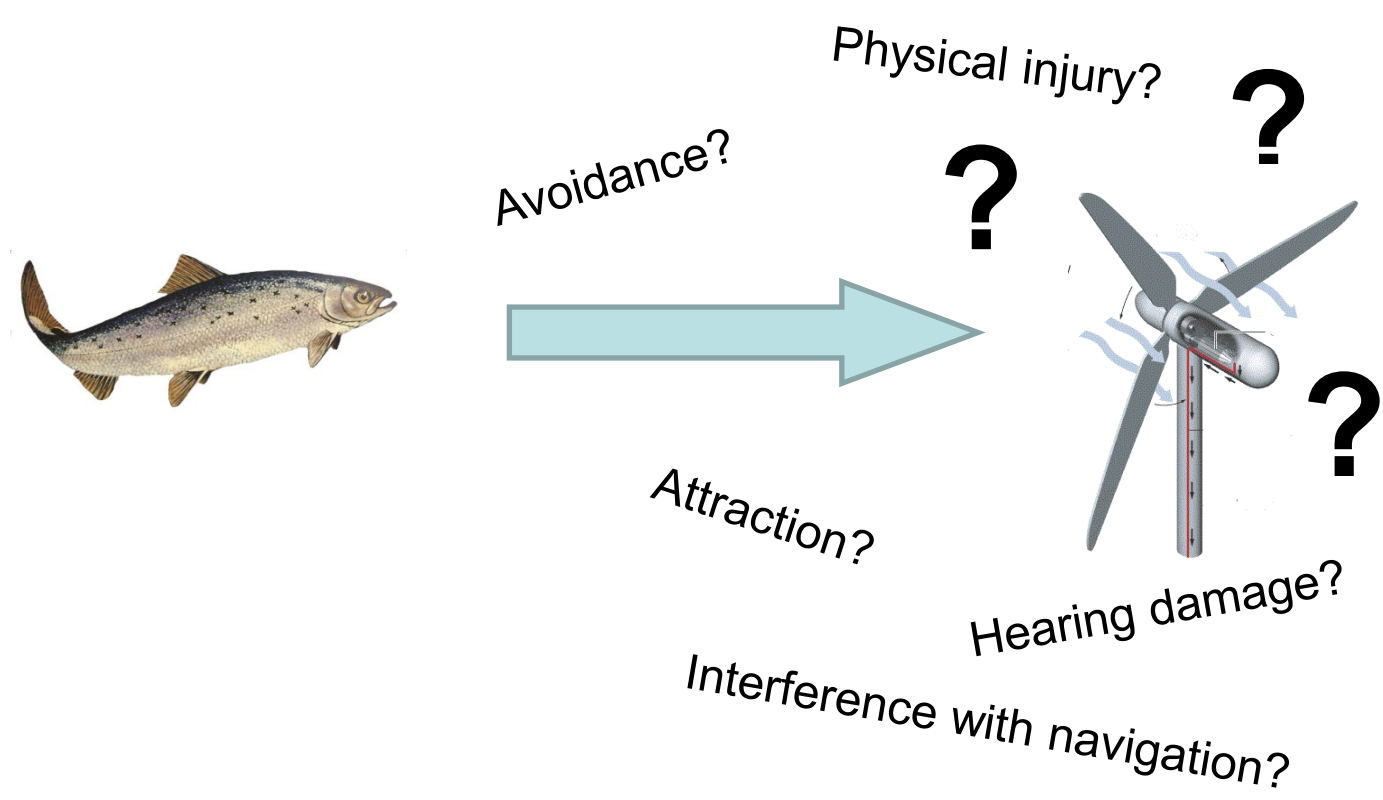*"to meet an equivalent of 100% demand for electricity from renewable energy by 2020"*
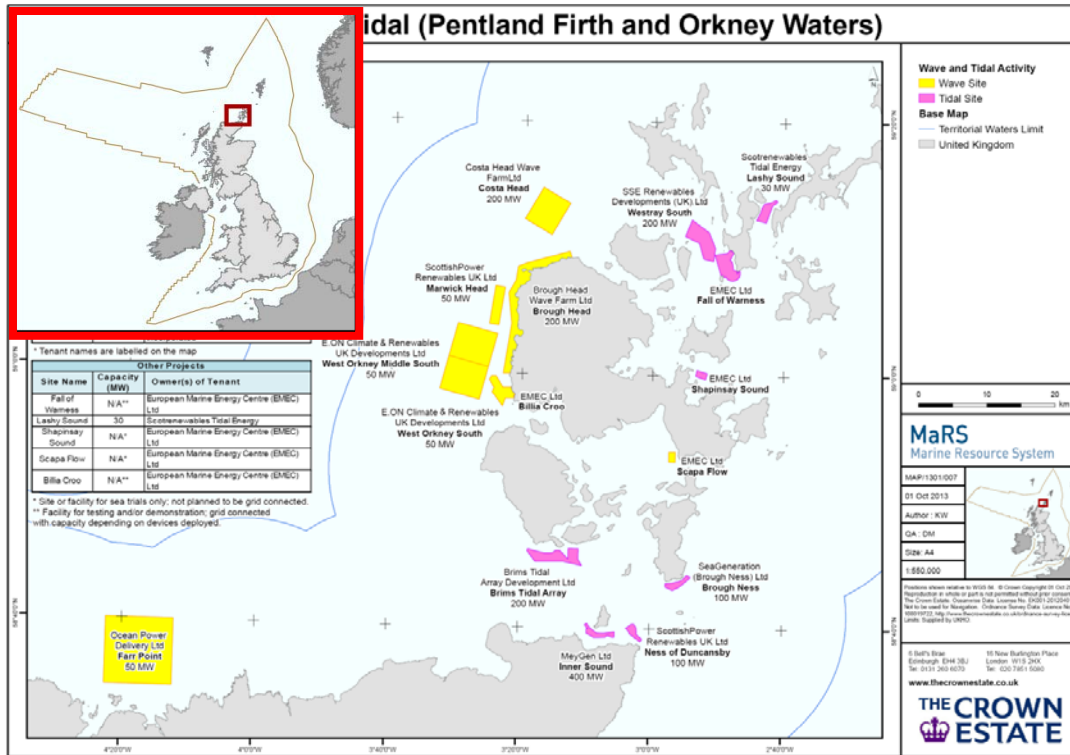
2020 Routemap for Renewable Energy in Scotland
http://www.scotland.gov.uk/Publications/2011/08/04110353/0

Environmental implications currently uncertain

# Possible effects on salmon?

Physical injury?

Avoidance?

?

?

Attraction?

?

Hearing damage?

Interference with navigation?

# How likely are fish to encounter arrays?



Source http://www.thecrownestate.co.uk

## Pentland Firth

- Significant tidal and wave energy potential

- Four testing sites (European Marine Energy Centre, Orkney)

- 12 seabed leases granted by Crown Estate

- 4 tidal sites in the Pentland Firth itself

- Consent granted for deployment at one tidal site

# How likely are fish to encounter arrays?

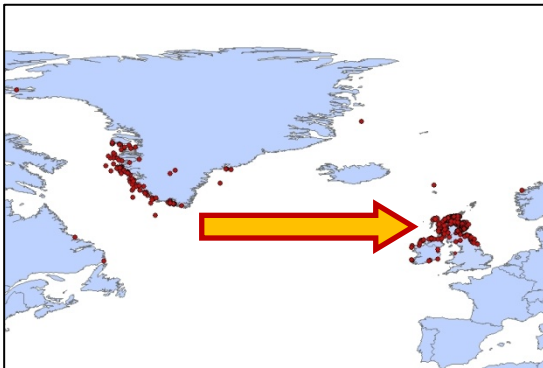How many fish pass through the Pentland Firth (or other areas of interest to the renewables industry)?
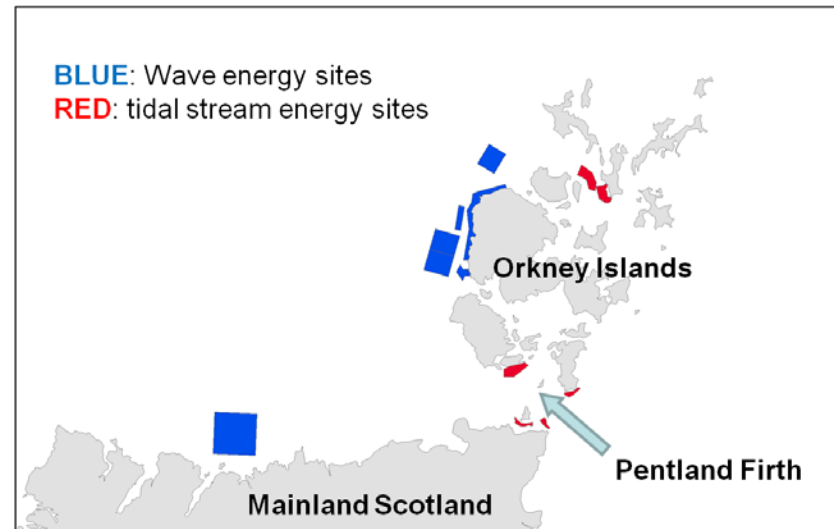
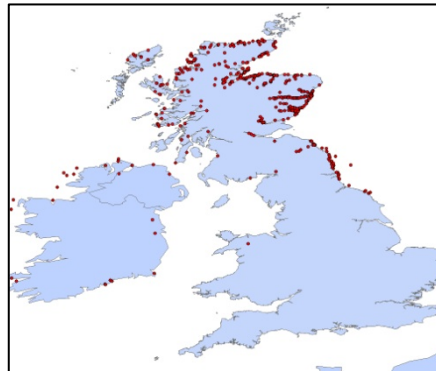How many fish pass through specific array sites?

# Return migration of adult salmon

## Three phases

| OCEANIC | COASTAL | RIVER |
|---------|---------|-------|



**OCEANIC**

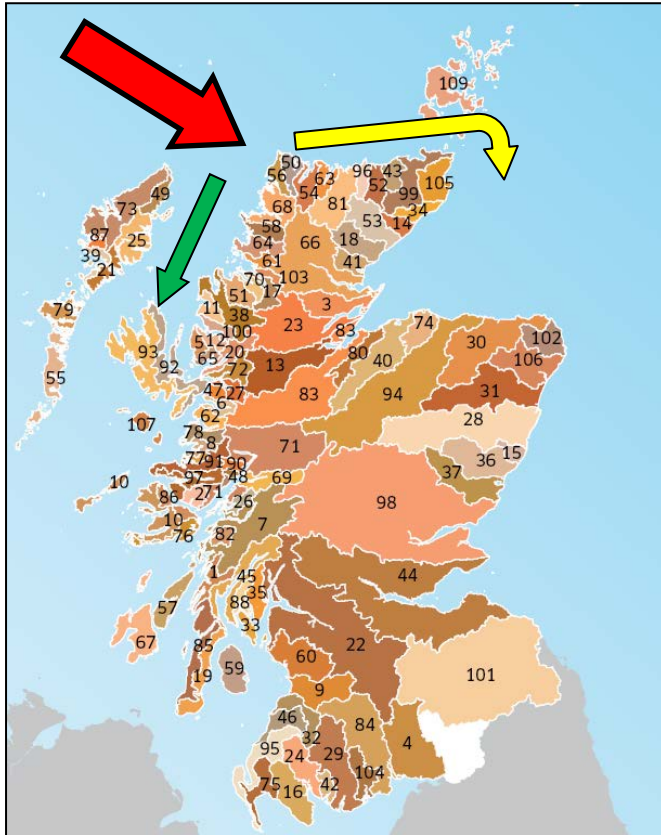Return from distant waters to UK coastal seas

**COASTAL**

Movement around Scottish/UK coasts as fish seek home rivers

**RIVER**

Fish move up their home rivers in search of spawning sites

# An agent-based 'cellular' model



Scotland is divided into 109 Fishery Districts

- Catch and effort statistics recorded

- Fish caught in

    - Coastal 'fixed engine' net fisheries

    - Rivers by 'net and coble' and 'rod and line'

**Assumption: once fish arrive at the coast, they follow the coast, passing through each district in sequence as they search for their home river.**

Image source: http://www.scotland.gov.uk/Publications/2012/09/5760
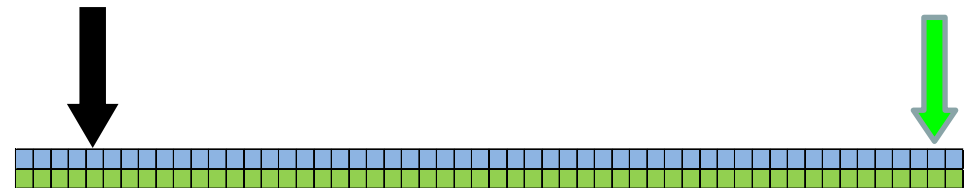
# An agent-based 'cellular' model



This allows us to represent the coastal waters as a linear series of 'cells' (blue cells in the model 'world' below).

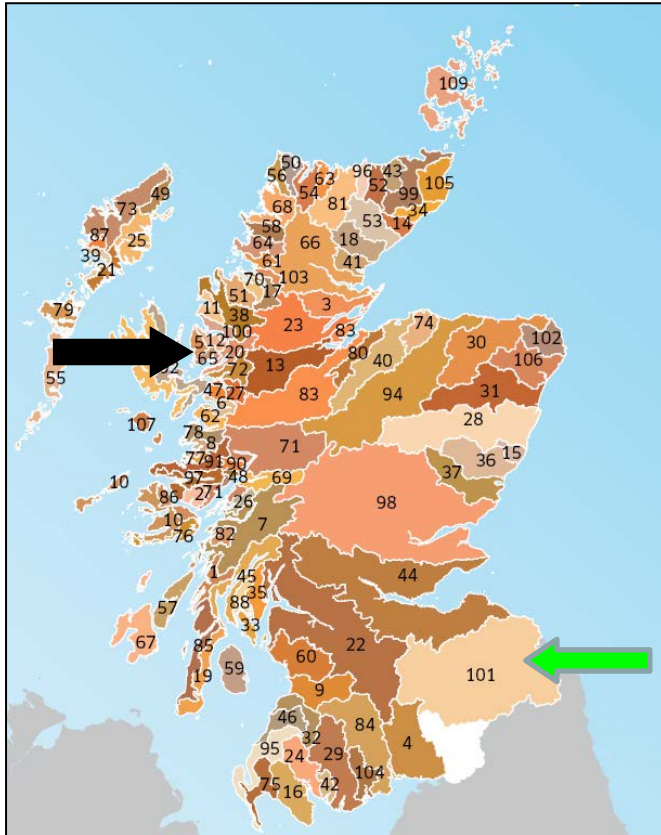The rivers of each district can also be represented as a parallel series of cells (green cells).
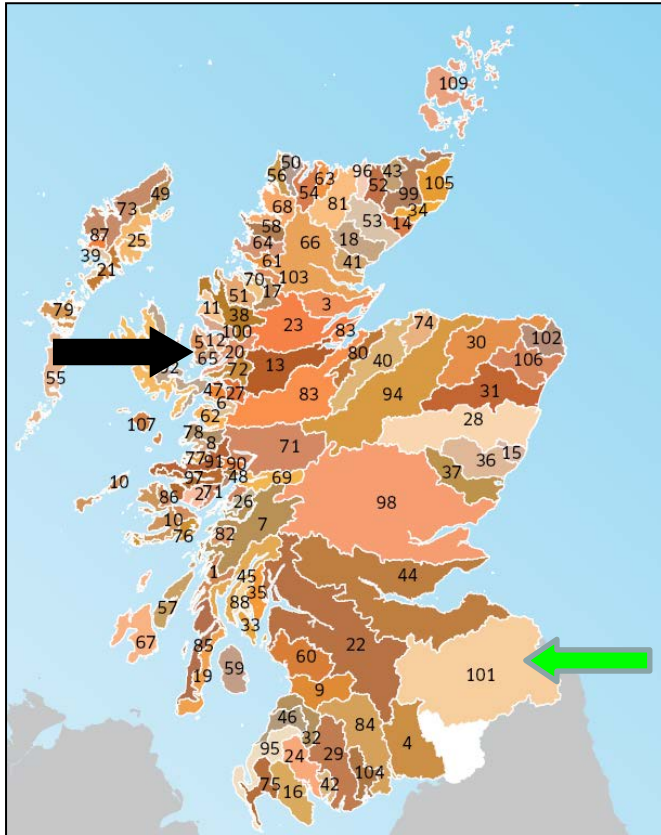
**Kishorn district, 65**                    **Tweed district, 101**

Coloured arrows indicate corresponding locations on map and model 'world'

# An agent-based 'cellular' model



Model coded using NetLogo.

- 'Fish' can be placed in the coastal water of one (or more) district, and given a 'home river' ID.

- 'Home river' IDs represent the district in which the fish hatched

- These IDs are assigned on the basis of the productivity of the rivers of each district (ie. Larger river systems contribute more to the population of model fish).
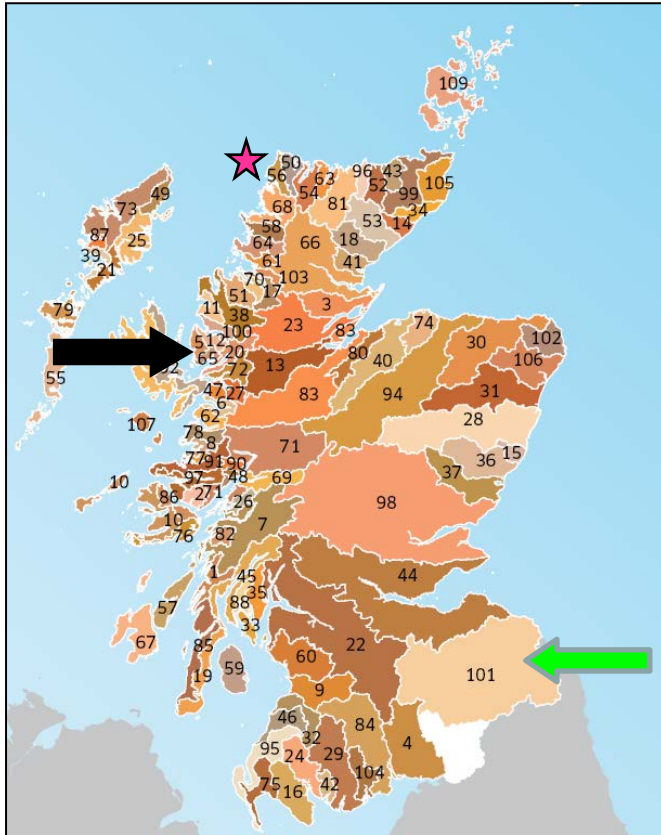
# An agent-based 'cellular' model
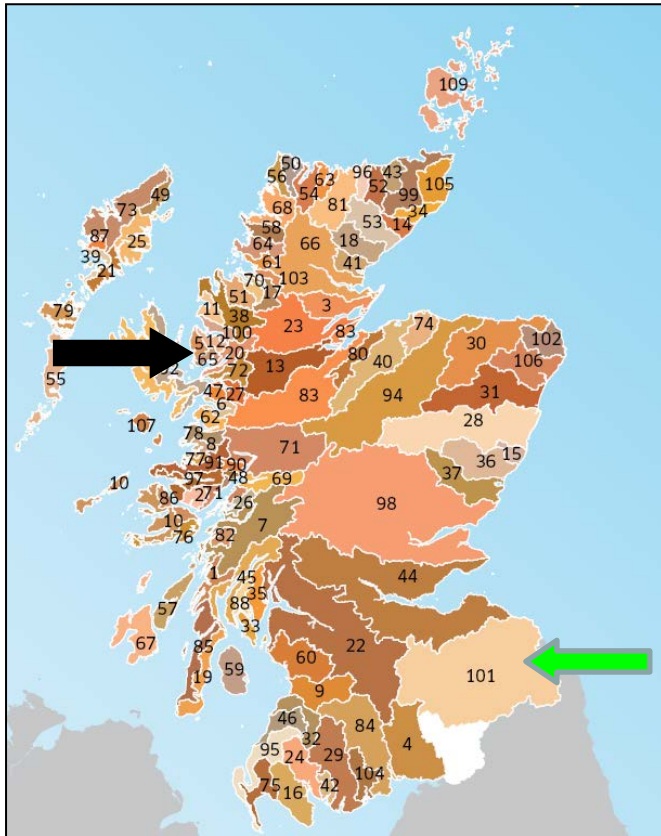


At each time step:

- If fish are in the coastal waters of their home river, they may enter it (50% chance)
- Otherwise, fish move towards their home river (15% chance), or randomly.



- Additionally, at each time step, fish in coastal waters have a fixed probability of being captured in coastal net fisheries

First runs:

- 141 fish released from Inchard district
- Model runs until all fish:
  - are captured by a coastal fishery, *OR*
  - successfully return to their home river
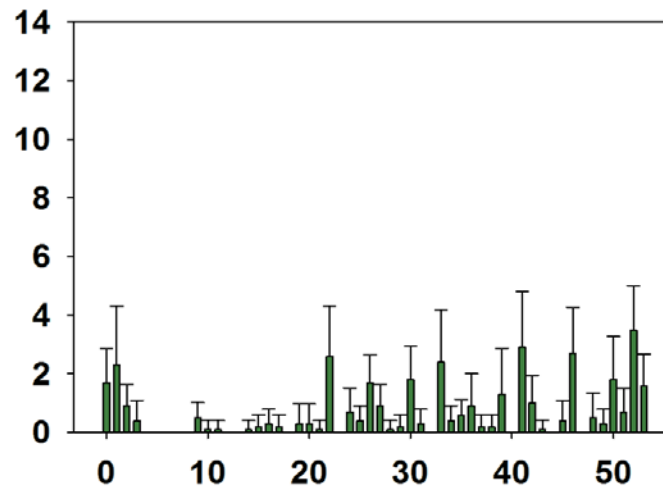- Final positions of all fish recorded
- Repeated 10 times

**Inchard district, 56**
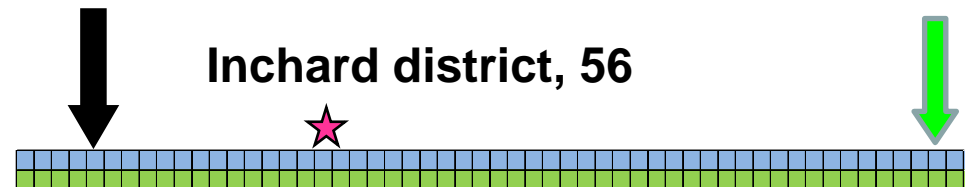
# Model output

**COASTAL FISHERIES CATCH**

*Note – all x-axes labels are sequential cell numbers – these do not correspond to district numbers on the map*
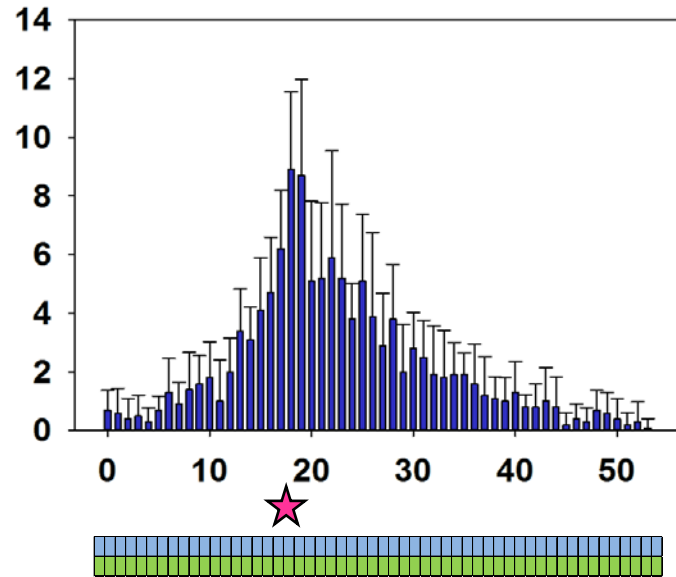
**FISH RETURNING TO RIVERS**

# Real data: Historical fish tagging experiments

## Fish tagging experiments in Scotland

- Early 20$^{th}$ Century (even late 19$^{th}$ century) up to 1970s
- Work initially conducted by Inspector of Salmon Fisheries for Scotland
  - W.L. Calderwood
  - W. J. M. Menzies
- Tag-recapture exercise
  - Fish caught in coastal netting stations
  - Tagged, released
  - Recaptured by coastal fisheries, river nets and anglers
- Couldn't be repeated today (not enough coastal fishing effort)

# Real data: Historical fish tagging experiments
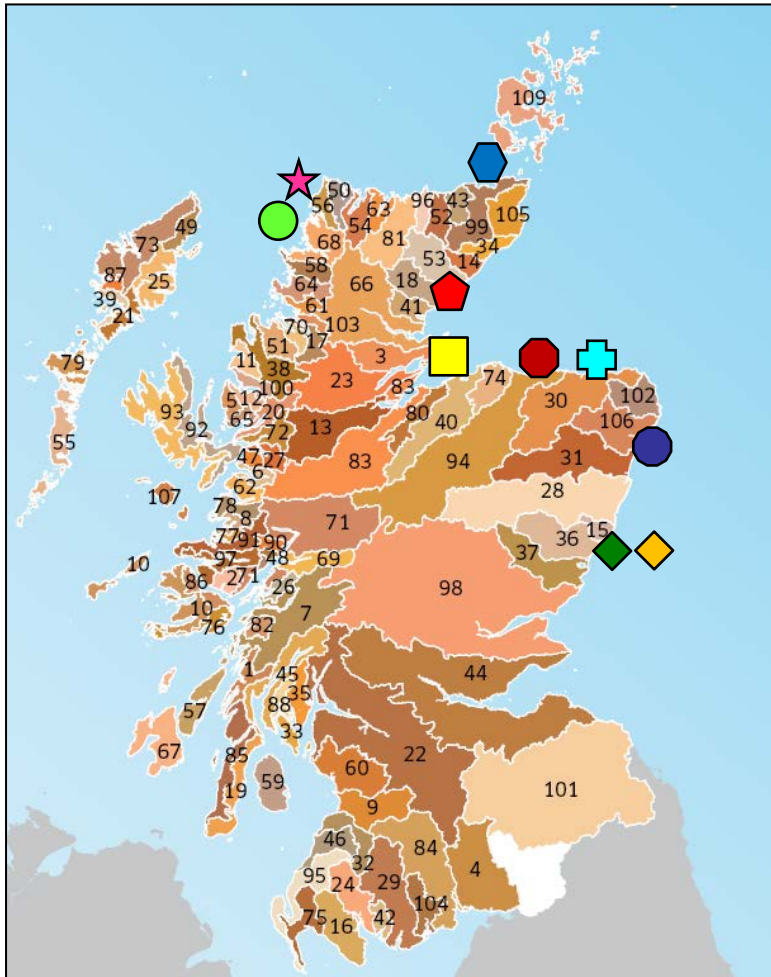


## Fish tagging experiments in Scotland

- 🟨 1914 – Learnie station
- ⬟ 1915 – Kintradwell
- ⬡ 1920 – Thurso
- ★ 1936 – Loch Inchard
- 🟢 1937 – Raffin
- 🔵 1952 – Altens
- ◆ 1954-55 – Rockhall
- ◇ 1977-78 – Rockhall
- ✚ 1978-80 – Macduff
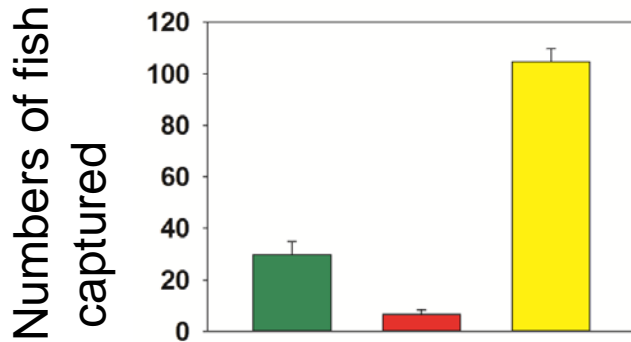- ⬡ 1981-83 – Buckpool & Boar's Head

## Summarised by Malcolm et al. 2010:

Review of migratory routes and behaviour of Atlantic salmon, sea trout and European eel in Scotland's coastal environment: implications for the development of marine renewables
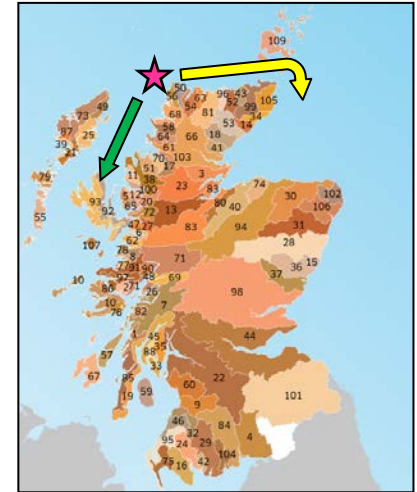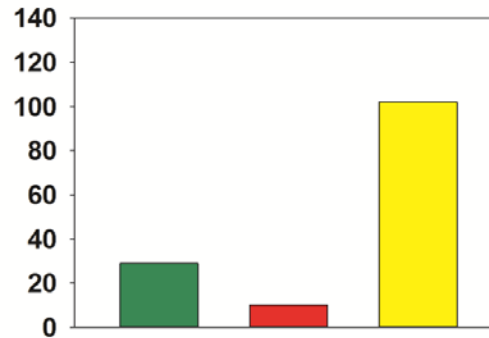
# Model vs data

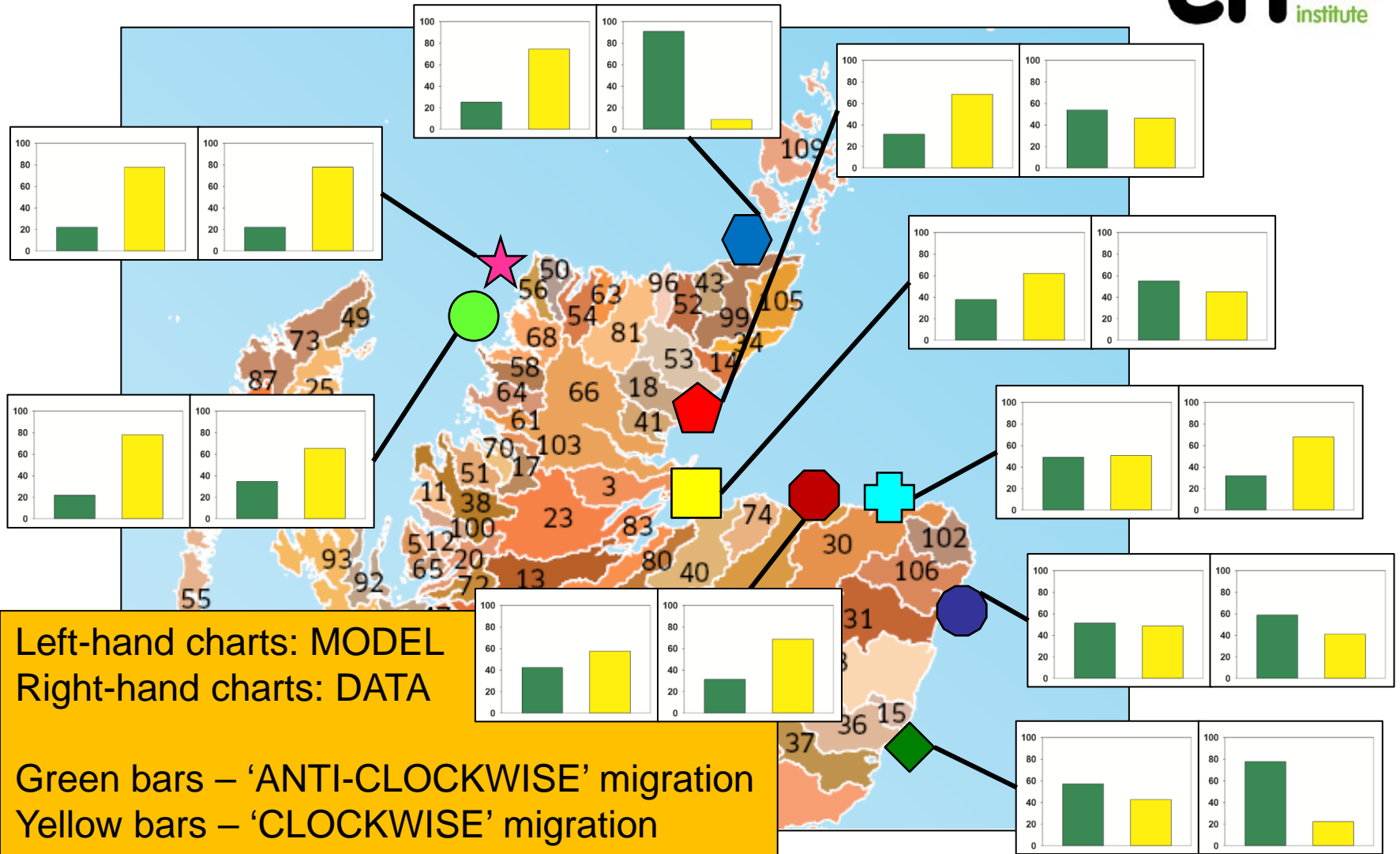Loch Inchard 1936 data

## MODEL OUTPUT

## ACTUAL DATA

Numbers of fish captured



LEFT BARS - NUMBERS OF FISH RECAPTURED WEST/SOUTH OF INCHARD
CENTRE BARS - NUMBERS OF FISH RECAPTURED AT INCHARD
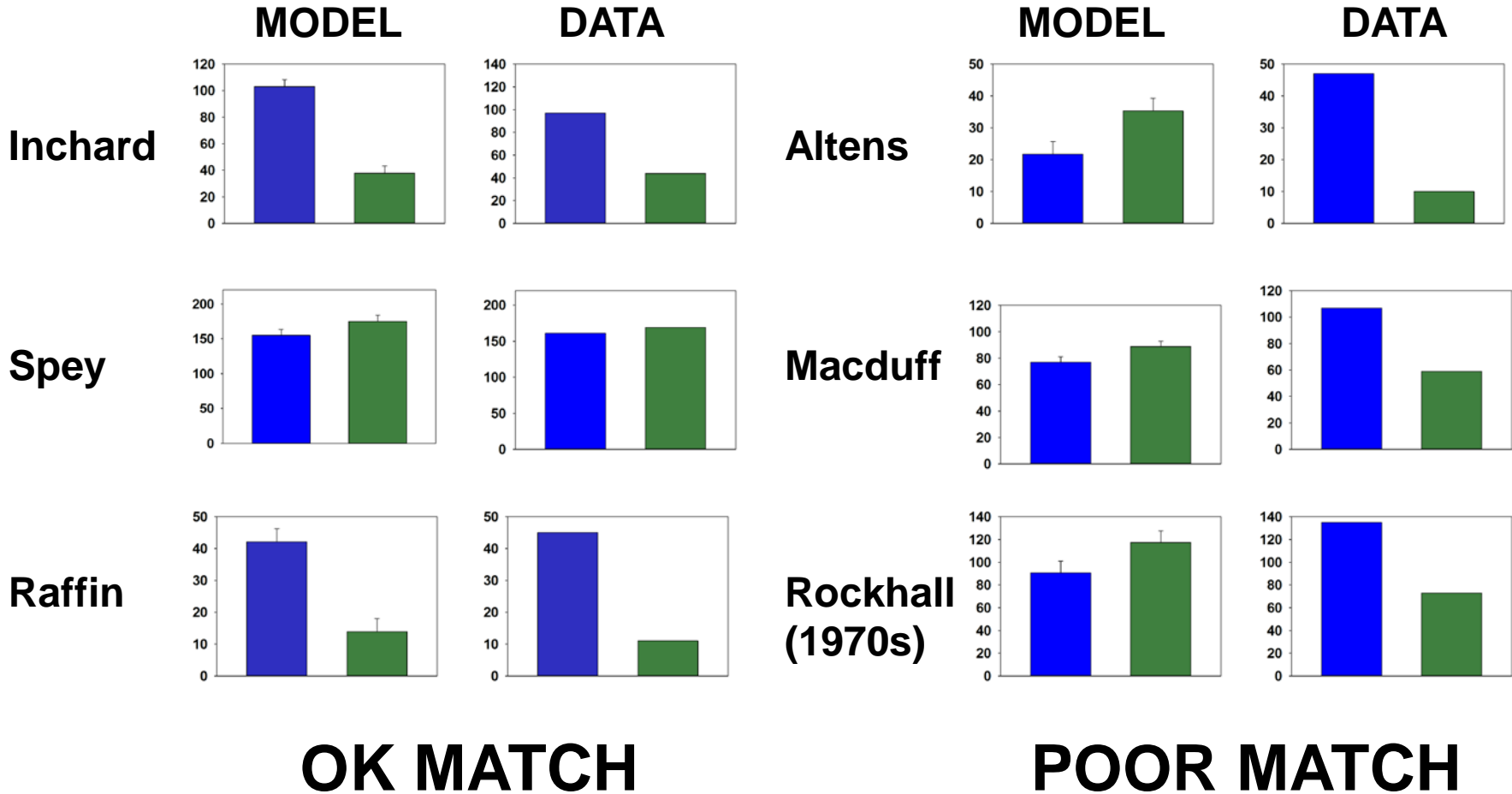RIGHT BARS - NUMBERS OF FISH RECAPTURED NORTH/EAST OF INCHARD

# Model versus additional real data



Left-hand charts: MODEL
Right-hand charts: DATA

Green bars – 'ANTI-CLOCKWISE' migration
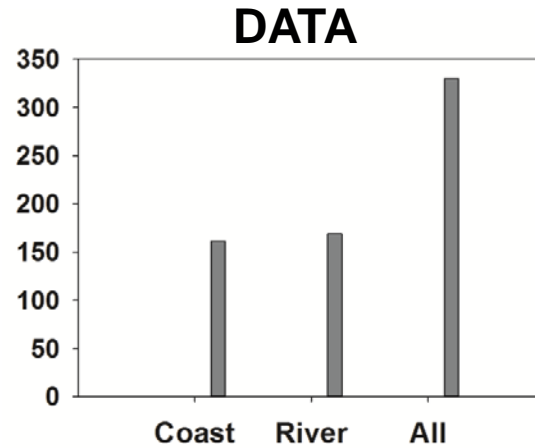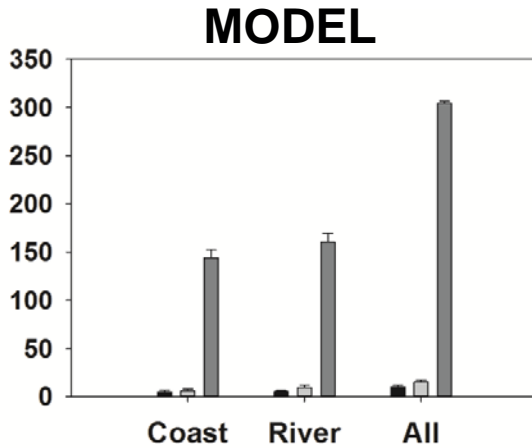Yellow bars – 'CLOCKWISE' migration

# More data: coastal versus river recaptures

Blue bars (left) coastal recaptures, Green bars (right) river returns



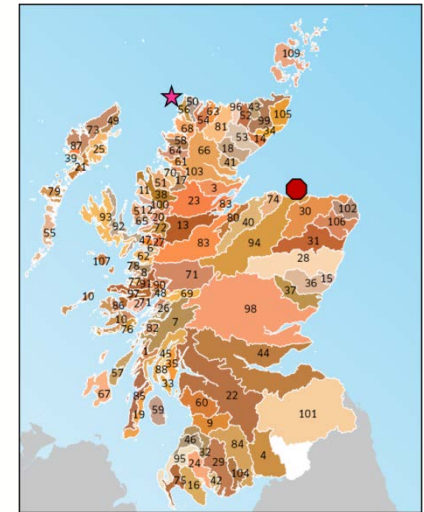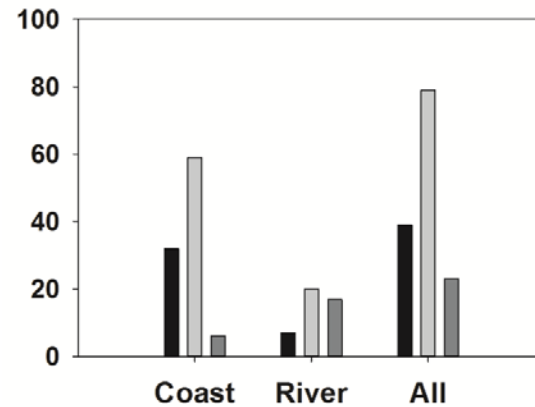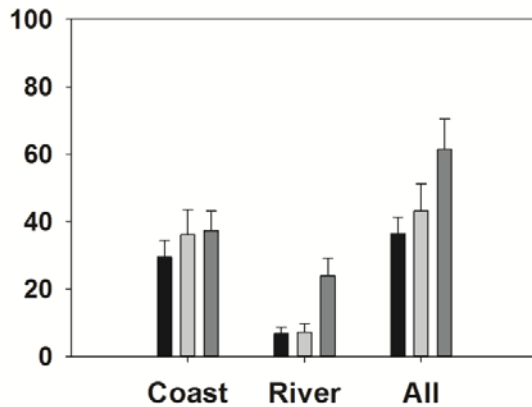**MODEL**     **DATA**     **MODEL**     **DATA**

Inchard     Altens

Spey     Macduff

Raffin     Rockhall (1970s)

## OK MATCH     POOR MATCH

# Further model-data comparisons

**MODEL**

**DATA**

**SPEY**

**INCHARD**



Left bars (black) – West Coast recaptures
Centre bars (light grey) – North Coast recaptures
Right bars (dark grey) – East Coast recaptures

# Conclusions

A simple ABM can represent some features of the coastal migration of returning adult salmon in Scotland.
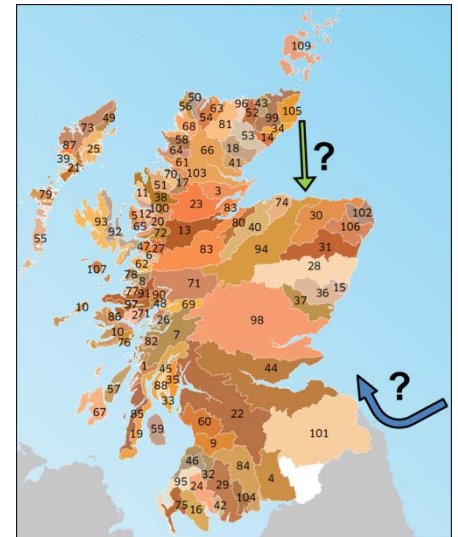
Other features are currently not well reproduced.

Problems with model assumptions?

- Composition of fish wrong at start?
- Simple linear passage too simple?
- Need alternate starting points?

Problems with underlying data?

- Uniform coastal fishing effort is not realistic
- Use of recent fishing data for river productivity

**But the model can be modified to explore the alternatives!**

# Thank you for your attention!

**Presentation can be viewed and downloaded at**

www.slideshare.net/andrewjguerin

## Thanks to: