Use of telemetry for rapid barrier assessment

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All URLs listed work as of 14 July 2020 – just copy and past the URL into your browser (checked with Chrome)

AMBER

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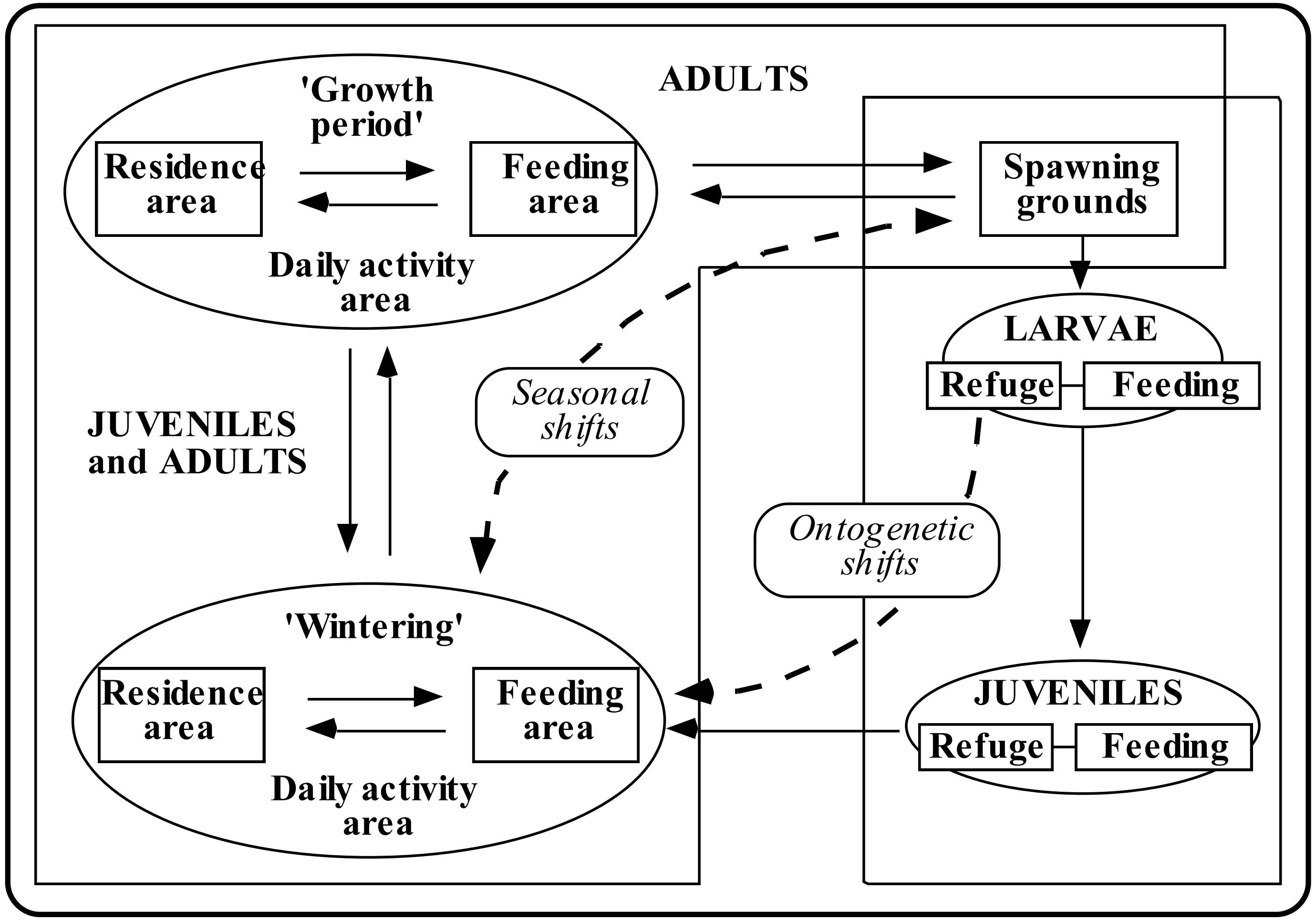
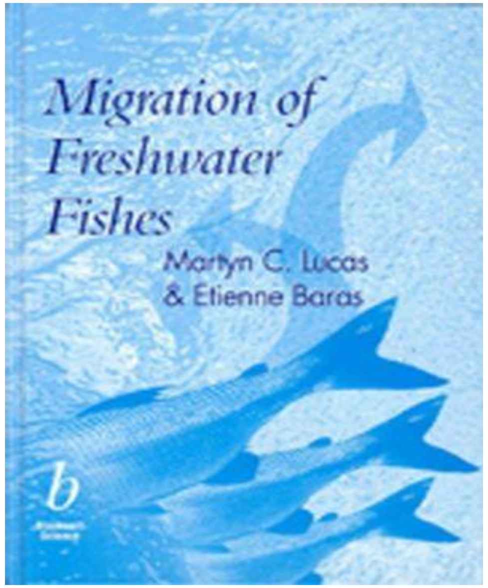
Barrier impacts on fish

Functional Life Units of fishes

- Movements by season and / or life stage key for fitness outcomes





Lucas & Baras (2001)

Sections available by personal request, for non-commercial use!

Diverse and natural habitat conditions → diverse community

The 'Holy Grail' – high natural biodiversity in flowing, non-degraded rivers!

Ray Troll

Barrier being made ‘transparent’ to whole fish-community passage!

Embrey Dam,
Rappahannock River,
Virginia

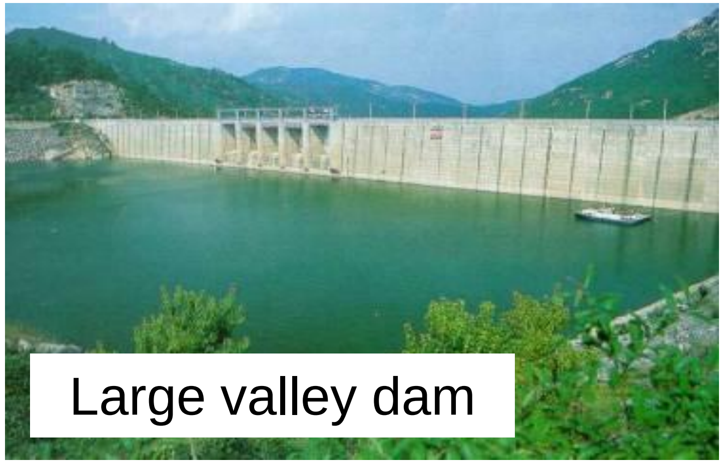
Articles

**What Goes Up,
May Come Down**

Bruce Babbit - *BioScience* special issue on dam removal, 2002

Rapid assessment of barrier passability easier on small structures!

(Whether by AMBER BAT/FishXing/ICE/SNIFFER or telemetry or fish community sampling)



- **Small barriers** are by far **the most abundant river barriers** in most rivers globally, especially in N. America, Oceania & Europe e.g. Jones et al. 2019 (*Sci. Total Env.*)
- Crucial to be able to evaluate passability quickly
- Small barriers - large proportion AMBER/ICE/SNIFFER outputs = **partial passability** (crude)
- Often need **quantitative evidence of passability** to leverage funds for removal/mitigation

A fistful of tags! Why is telemetry “the gold standard”?

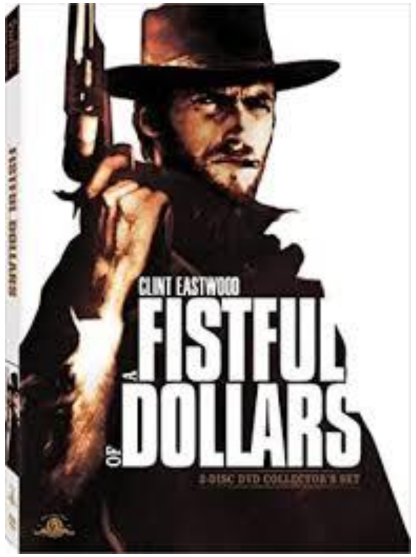
- Enables individual fish ID – #successes/#attempts
- Quantification of no. of approaches to structure per individual
- “ “ number of entries to fishway or bypass per individual
- “ “ passage or fallback per individual
- % approach, % entry, % successful passage + route taken
- Time to passage from first approach (delay)
- Fate of tagged fish (e.g. predation/fisher exploitation)

Ana Silva et al. 2018 The future of fish passage science….
Fish & Fisheries

Forthcoming European Common Standard “CEN” – fish passage evaluation.

“A fistful of tags”

Eva Thorstad
Vs.
Sergio Leone



“For a few PIT tags more”

"A sledgehammer to crack a nut?"

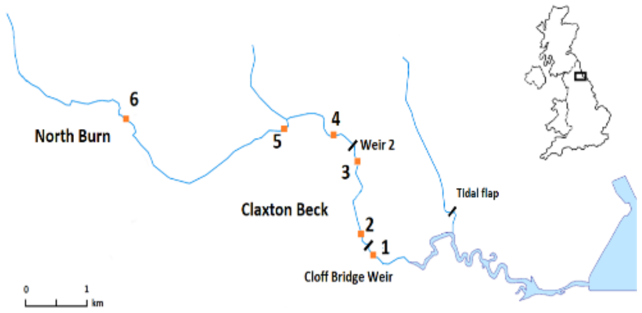
- Telemetry can be expensive & takes some expertise
- Good fish handling is crucial – method assumes no impact, need to be sure or measure impact
- Licences & ethical permissions for tagging
- "Rapid assessment?" Most telemetry studies last months!
- Quickest, cheapest, most flexible option for small structures in streams = **PIT telemetry**

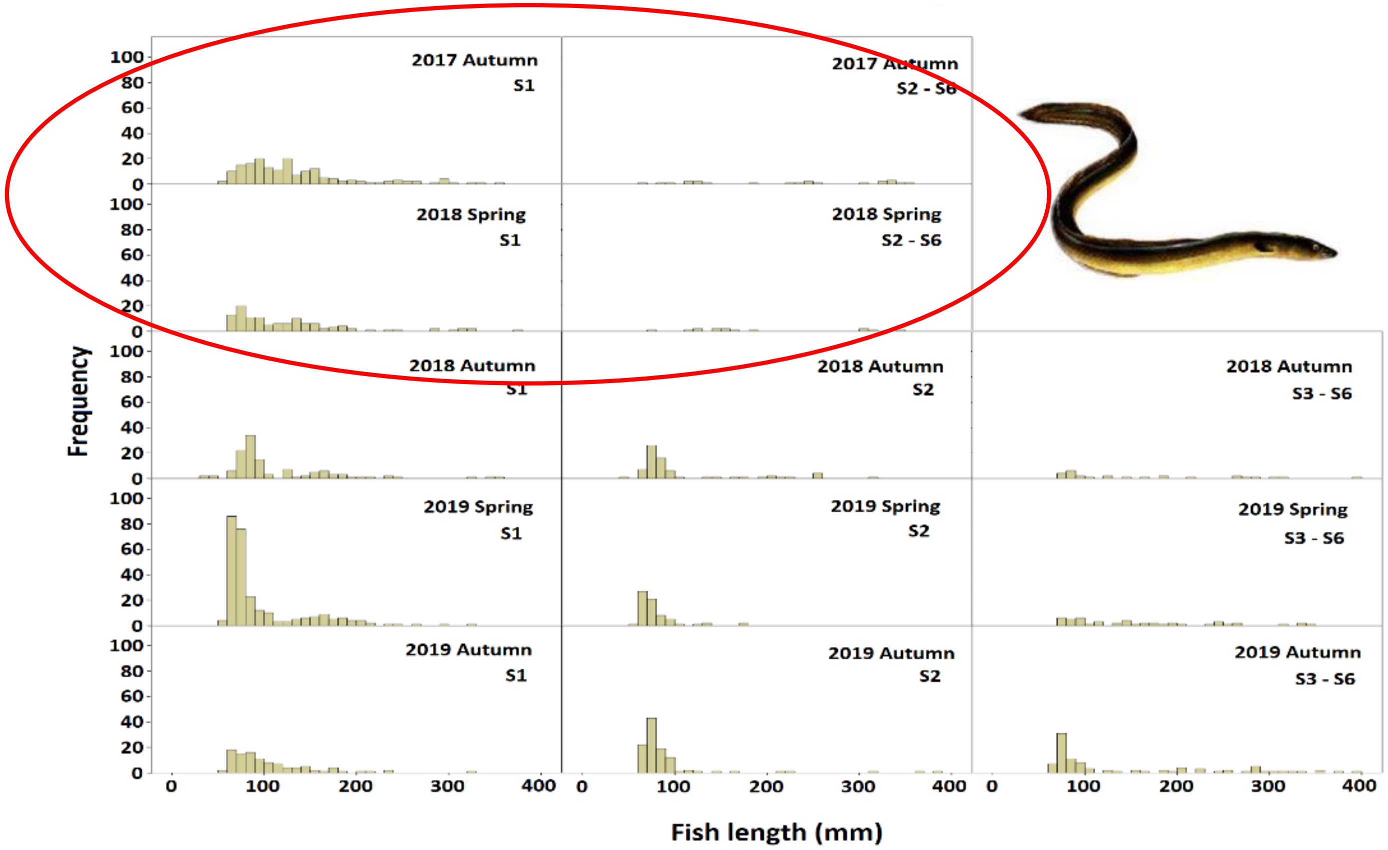
Many help guides e.g. Cooke, Hinch, Lucas, Lutcavage (2012)
***Biotelemetry & Biologging* – ask for copy (non-commercial use)**

Question 1: Is telemetry the right method? Is there an easier or more suitable way?

Sun, Galib & Lucas (in review) –

- Electric fishing upstream of a small weir, suspected of being a barrier, showed abundant eel below but v. few above – inference that it was acting as a barrier (but no behaviour evidence)
- Removal in Spring 2018, gave rapid eel recruitment to entire stream catchment within 17 months.



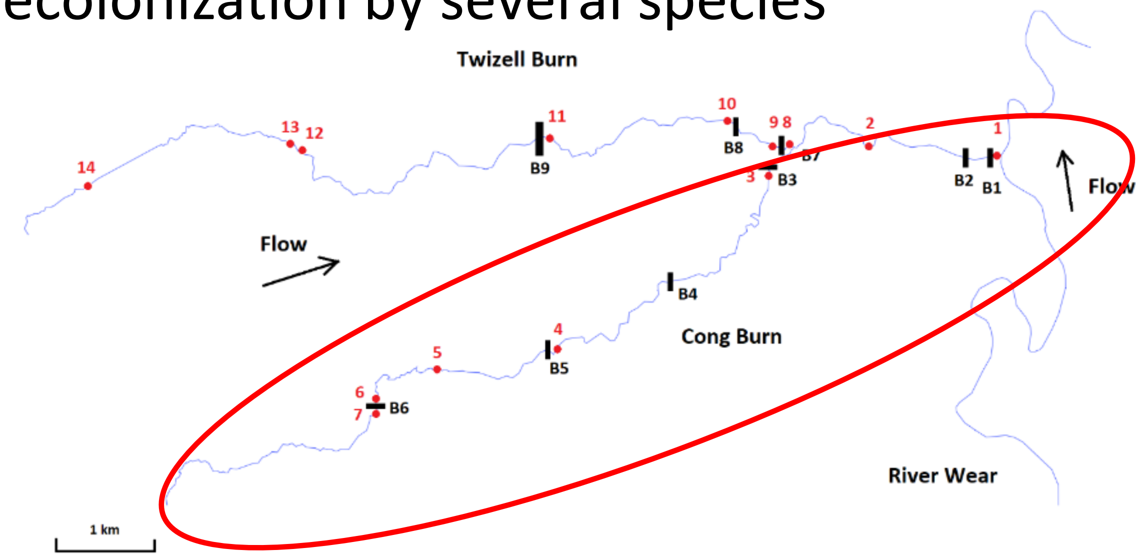


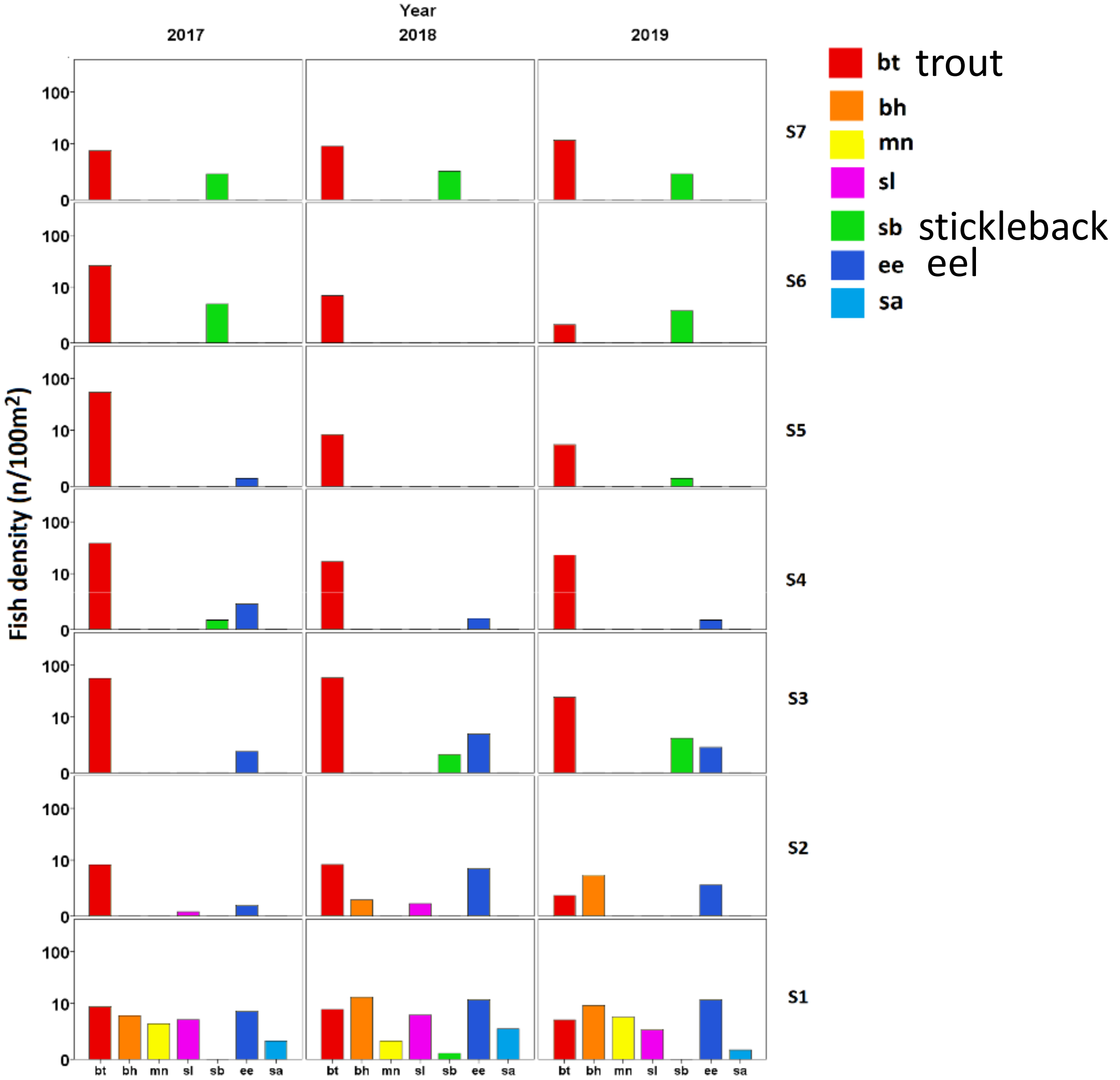
Question 1: Is telemetry the right method? Is there an easier or more suitable way?

Sun et al. unpublished – Whole community electric fishing (usually difficult to sample whole community and all life stages by telemetry).

Cong Burn, NE England

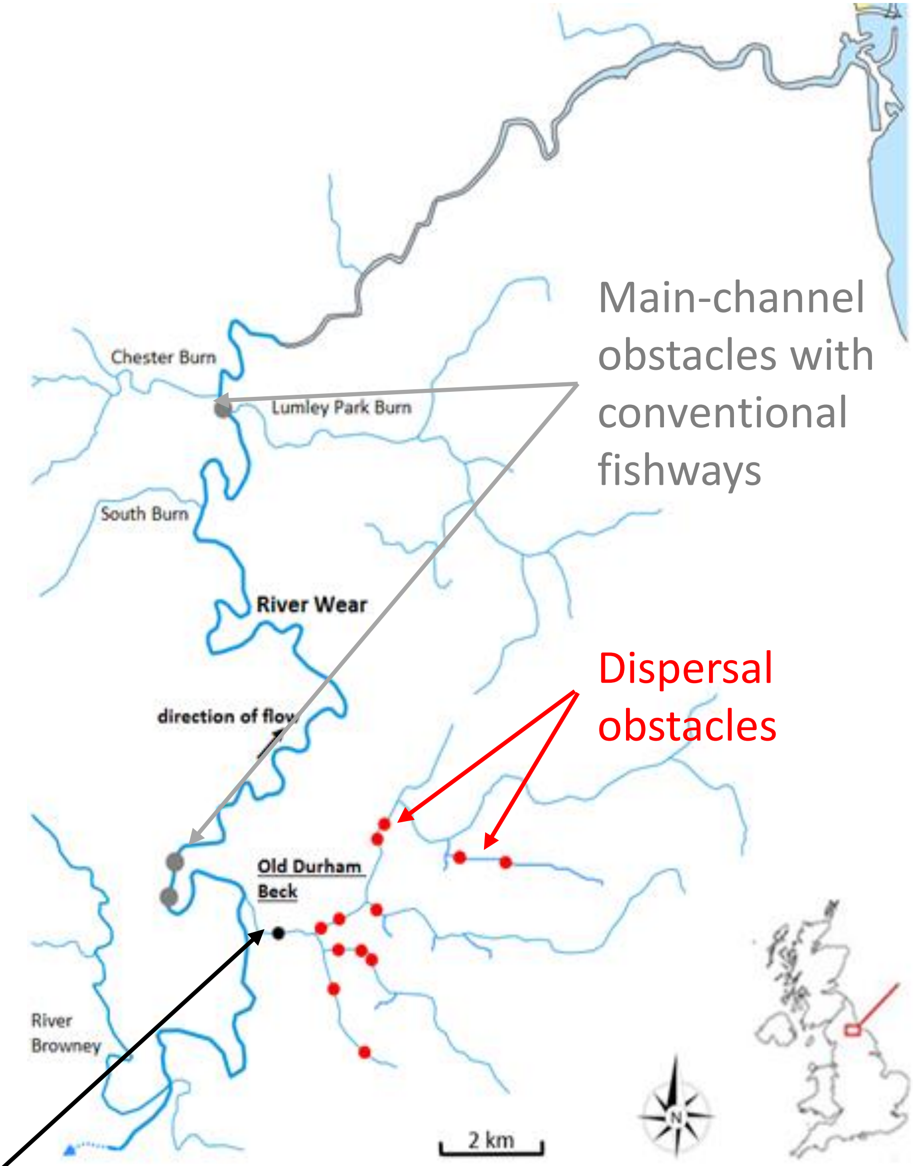
Formerly polluted; barriers have inhibited recolonization by several species





If relying on fish surveying, use sensible sites to evaluate barrier impacts!!

- Old Durham Beck (ODB), trib. of R. Wear, NE England
- Mostly poor fish diversity and abundance
- At least 12 dispersal obstacles
- National agency's single "fish" survey site is downstream of all these stream obstacles, generates a "good" fish community score
- So their cost-benefit assessment says "no impact of barriers, no need to remove/mitigate"



National Agency's sole "Fish" survey site in ODB!

Lucas et al.

From:
www.amber.international
D4.1 - Review of benefits, challenges, and trade-offs in adaptive barrier management (Best Practice Report) – available imminently I believe!

So you still want to do telemetry?

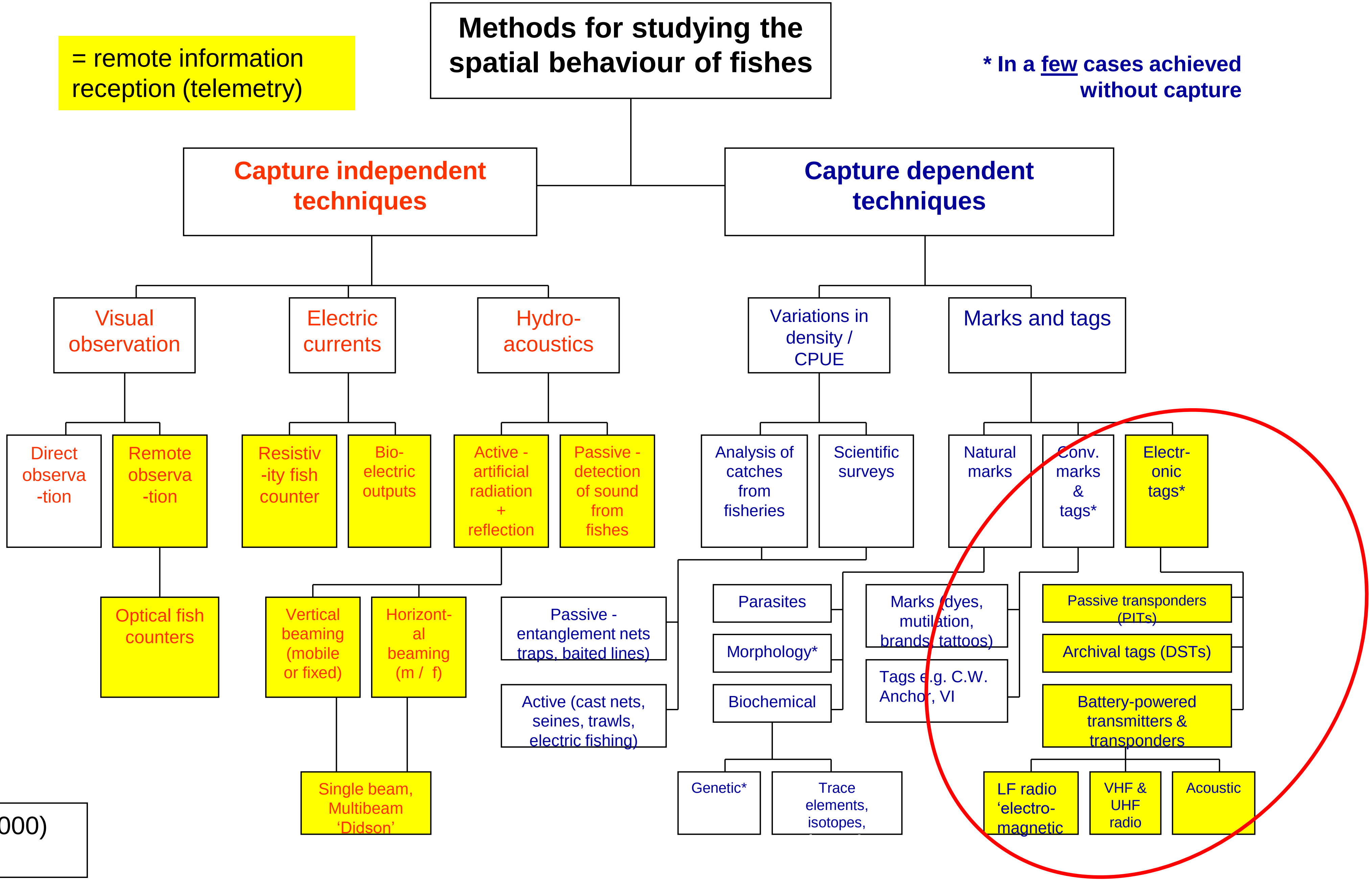
Have you got a tagging license + experience (fish telemetry workshops)? No? collaborate

National, regional legislation – institutional animal care & use committees (*t* = months!)

Have you got the funds? No? Collaborate / central equipment pools (rapid assessment can be quick, so quite cheap, but beware of equipment loss/damage)

Lucas, unpublished. *1001 unconventional uses for telemetry in fish ecology*

Adaptive radiation of methods for studying fish spatial behaviour……….



Lucas & Baras (2000)
Fish & Fisheries

Summary of some telemetry options and comparison of their utility

	Reflected artificial radiation	Radiation from a transmitter		Passive devices	
Method	Hydro-acoustics	VHF radio tagging	Acoustic tagging	Data storage tags (DSTs)	Passive transponder (PIT)
Situation	Little noise or entrained air, few plants. Lakes, rivers, estuaries,sea	Low conductivity (< 500 uS cm^{-1}), shallow. Usually oligotrophic- mesotrophic rivers and lakes	Low noise, little entrained air. Usually lakes and slow-moving rivers	Any aquatic environment, ideally showing heterogeneity	Any environment, so long as fish swims within range of antenna
Location of detector	Fixed station or mobile on a boat	On land or boat or air	In water	On fish, must be downloaded	Across fish's path, or anywhere in range
Range (m)	20-200	20-5000	20-1000	0 (unless tx)	0.1-1.0+
Typical life (days)	No limits	20-600	10-300	100-900	>3000 (or life of fish) if retained
Use in water depths (m)	>1.0	Dependent on conductivity (normally < 5)	Noise dependent (usually 0.5 - 300)	< 1,000 m	Within range (generally < 1)
Minimum fish size (cm)	5	12	12	18	5
Sample size*	No limits	$10 - 10^3$	$10 - 10^3$	$10 - 10^3$	$10^2 - 10^5$
Disadvantages	Poor species and individual ID (except ARIS . DIDSON) High data processing	Lower directionality than acoustics. Poor range in deep/conductive waters. Tagging effects (next 3 columns also). Lacks population scale measurement (next 2 columns also)	Shorter life than equivalent radio tags. Usually requires boat. Sound reflections / noise Fewer tags *cf* radio	Fish must be recaptured unless used with tx. Relies on env. data coverage. Limited spatial resolution	Very low range, data collection limited to antenna position(s)
Value for fish behaviour studies	HIGH where individual ID not needed	HIGH in low conductivity, often noisy, freshwater	HIGH in open water, limited noise	MEDIUM especially sea, estuary, deep lake	HIGH at bypasses/streams and for small fish

PIT (RFID) telemetry for dummies

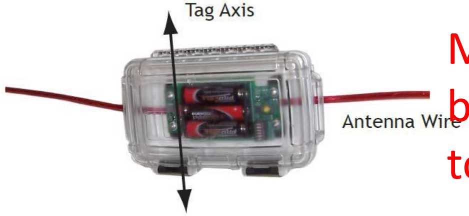
Passive Integrated Transponder (PIT) tag – integrated circuit (ID code), no battery
Radio Frequency Identification (ID) – (low) radio frequency communication to/from tag

- Buy tags, can make own transceivers (‘readers’) & antennas – most buy pre-made
- e.g. Oregon RFID, Biomark   [Many non-wildlife RFID manufacturers (avoid!)]

Tags: 2-3 USD each
Minimum *n* ~100

Hand reader:
300-1000 USD each

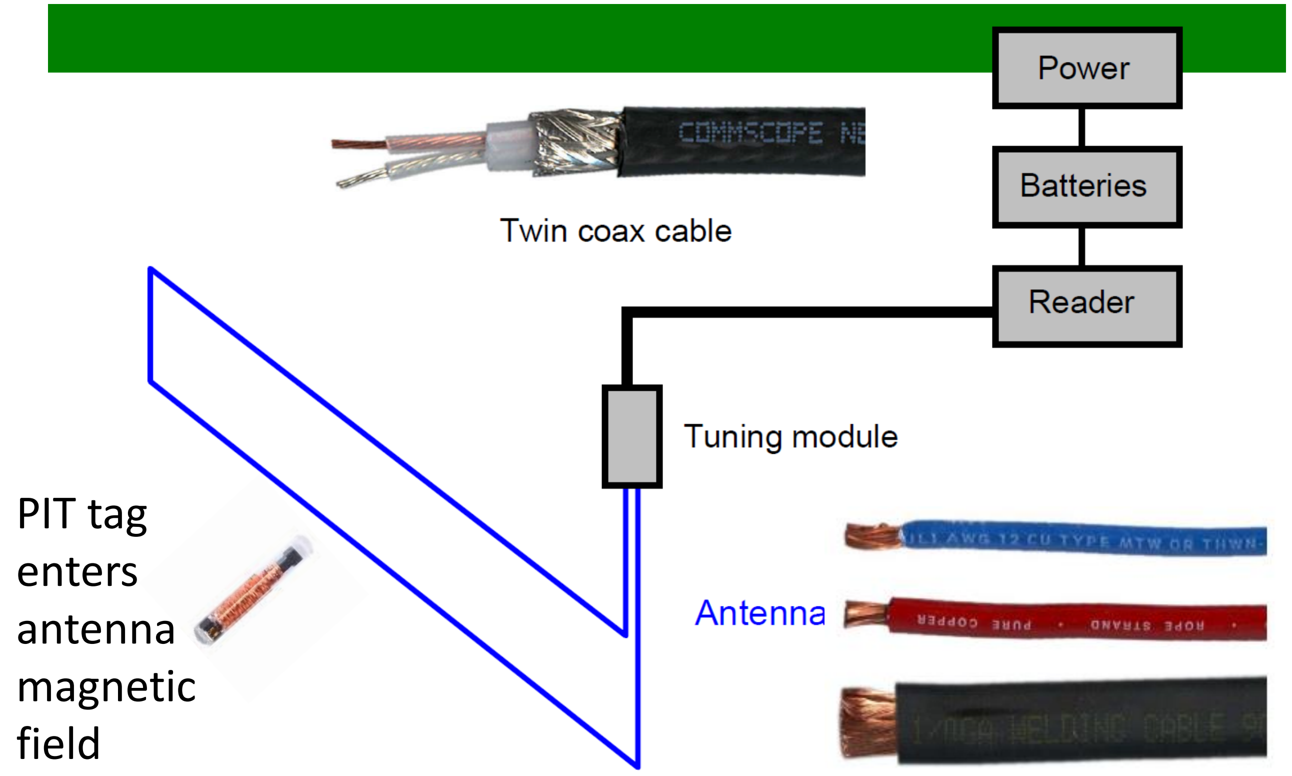
Multi-antenna reader, logger plus tuning boxes ~3000 USD



Marker tags, cables, deep-cycle batteries, storage cabinet, tools ~1000 USD

PIT (RFID) telemetry – basic principles

- DC powered (~12-18 V) reader generates magnetic field from antenna at specific frequency
- PIT tag enters magnetic field, tag circuit charged by Voltage (magnetic induction)
- Charged tag sends signal, received by antenna, decoded by reader, stored on logger

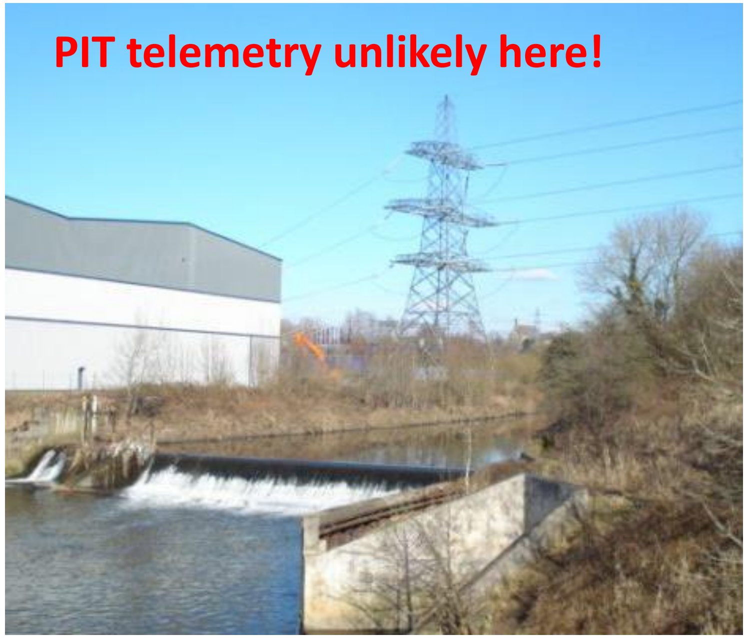


Beware electrical noise!

- **DC supply** (e.g. deep-cycle leisure battery) is 'electrically quiet' – mains AC supply is noisy – RFID circuits are very sensitive to electrical noise!
- If mains supply , then run via **LINEAR transformer battery charger** (old style heavy copper coil charger) through trickle-charged battery
- Aluminium foil-screened Twin Coax signal cable to shield from noise.

PIT telemetry planning – 4 things to watch out for!

Sites near **electricity pylons**, other high voltage cables, or in urban environments can suffer **high electrical noise** and make PIT telemetry v. difficult (low antenna range, difficult to tune)



Supply 12 V, but tuned antenna may be **~250+V** (but usually low current) – cable protection – disconnect power to handle

Don’t garrote **kayakers!** (use flatbed or hinged antennas, not simple pass-through) – if there are large boats, PIT telemetry may not be possible

Beware vandals!

Especially in urban areas -

Trashing gear / solar panels

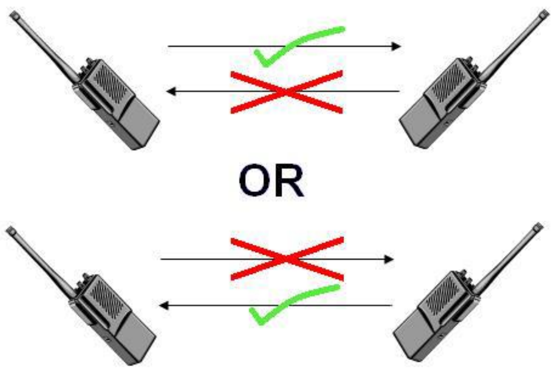
Stealing batteries, copper ant. cable

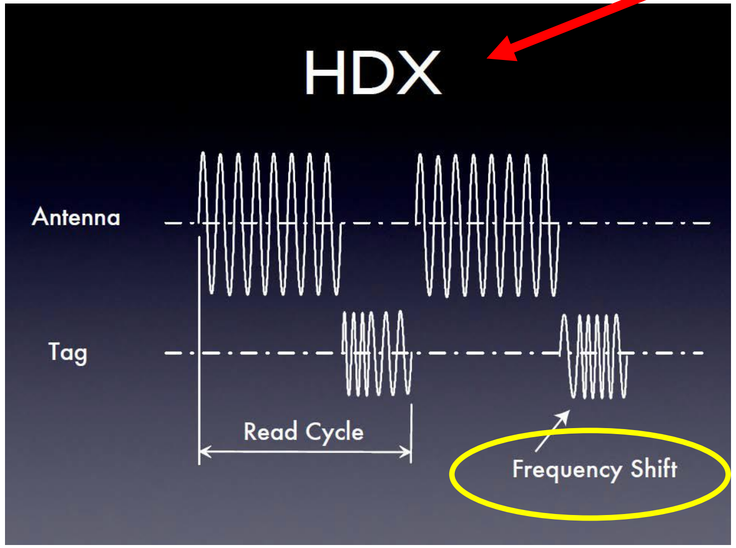
Half duplex vs Full duplex PIT systems

Duplex device – one that can send and receive data

What to use for rapid barrier passage assessment

HDX

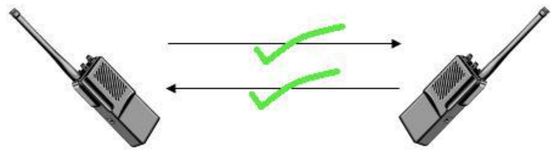


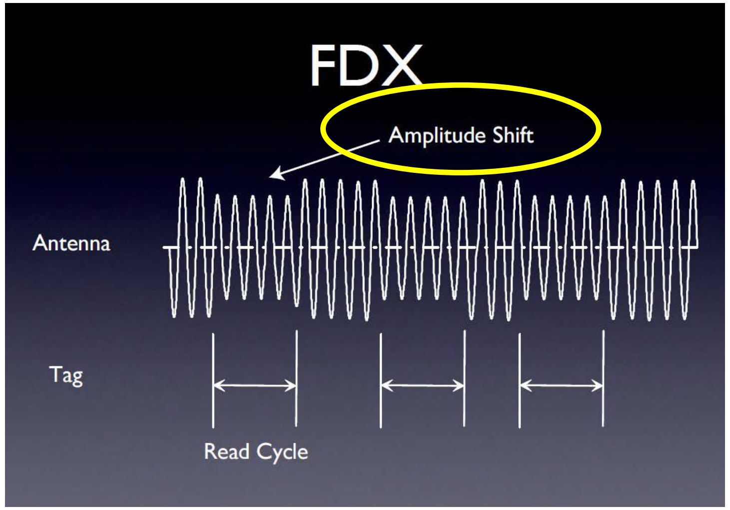


- Tag waits to respond
- Longer read cycles
- Fewer interrogations per second
- In practice, usually < 14 reads/s
- Capacitor stores charge – larger tags
- <u>Less sensitive to 'noise', longer range</u>

Slightly larger fish, slower tag travel, <u>lower-tech demand</u>

FDX





- Tag responds immediately
- Shorter read cycles
- More interrogations per second
- Can be > 25 reads/s
- No capacitor – smaller tags
- More sensitive to 'noise'

Smaller fish, faster tag travel, high-tech demand, lower range

Tommi Linansaari

The right PIT tag

- **Tags are mostly sealed in glass; tag is usually implanted in body cavity by v. simple surgery, or into dorsal muscle (if tag small). Small tags can be injected.**
- **In general, larger PIT tags have more copper windings which gives greater induction within the magnetic field, and so greater range**

  - Smallest tags, maybe only ~0.1 m range

  - Largest tags can give > 1m range in optimal orientation

6 x 1.2 mm FDX

8 x 1.4 mm FDX

11 x 2.1 mm FDX

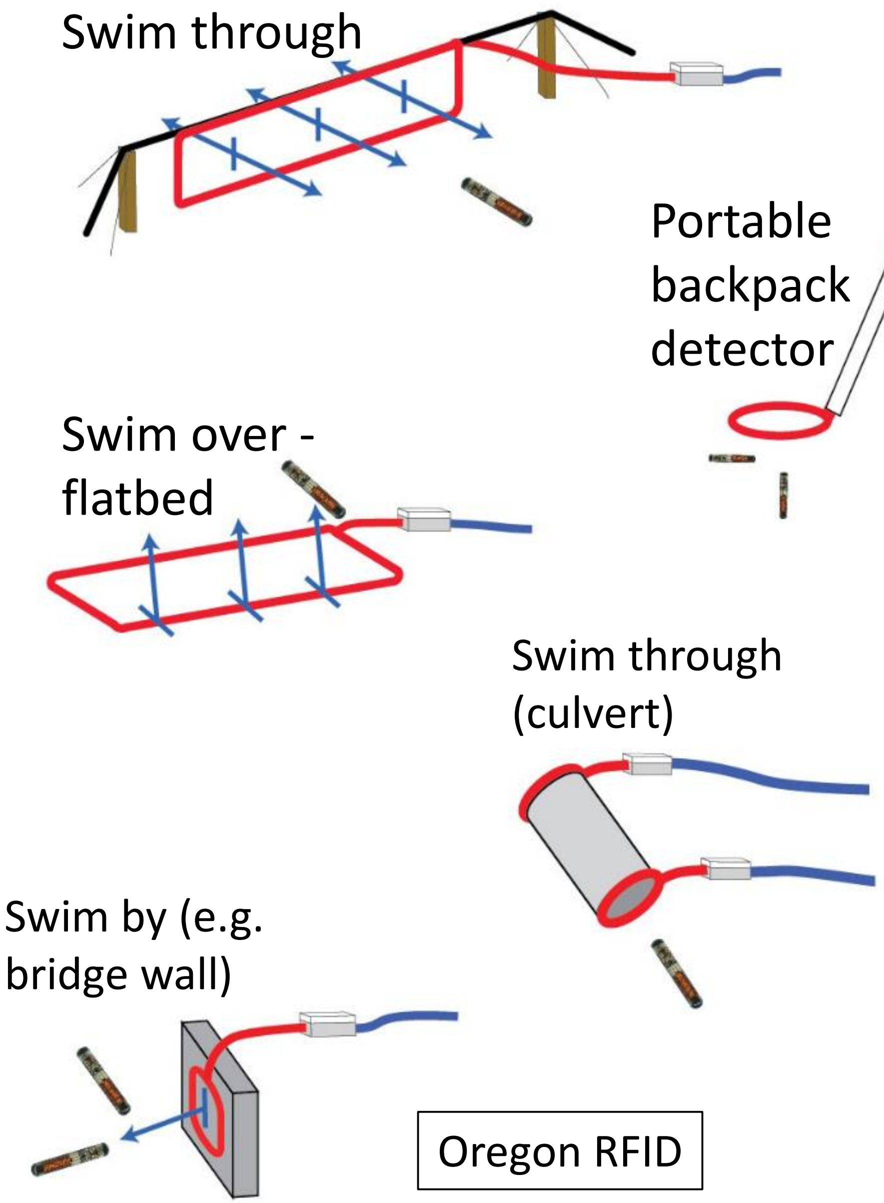
12 x 2.1 mm FDX

12 x 2.1 mm HDX/FDX

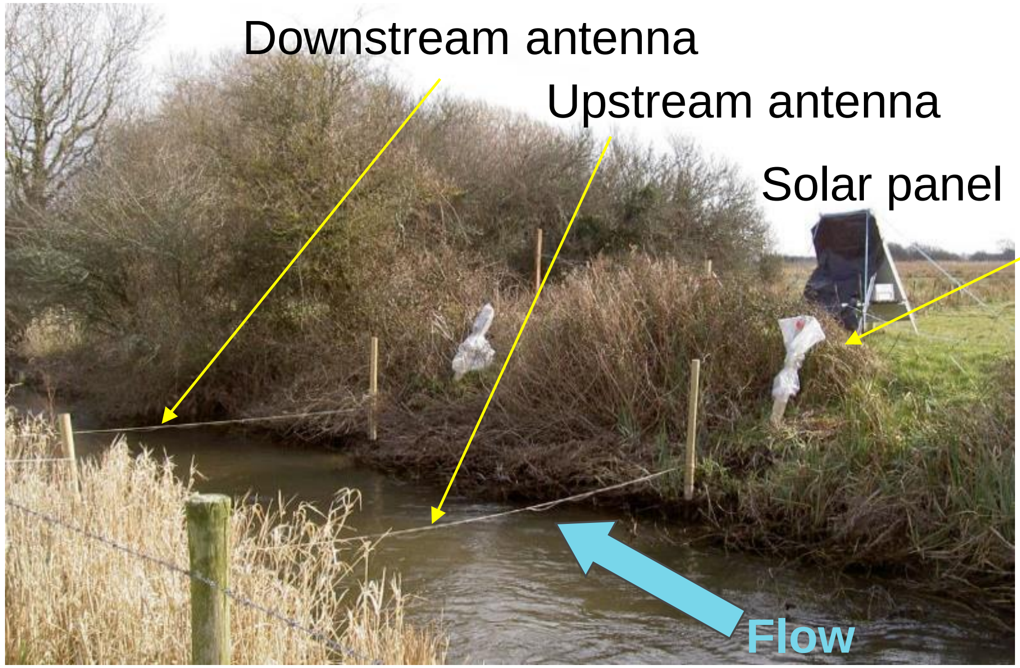
24 x 3.6 mm HDX

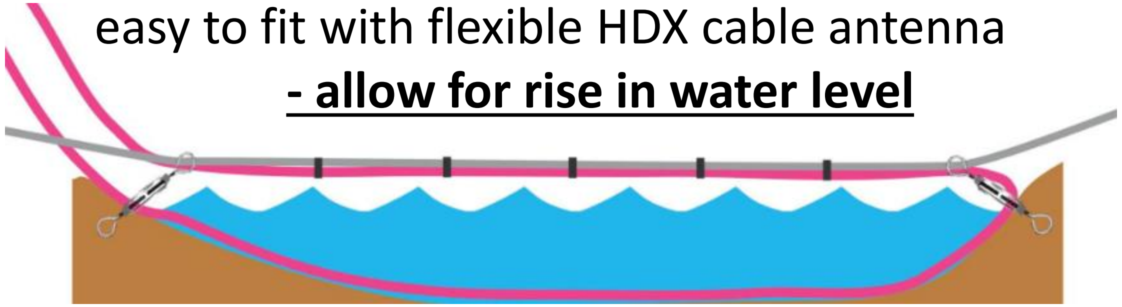
32 x 3.6 mm HDX

A diversity of PIT antenna designs – easy DIY with HDX



Paired HDX PIT antenna cables deployed across stream

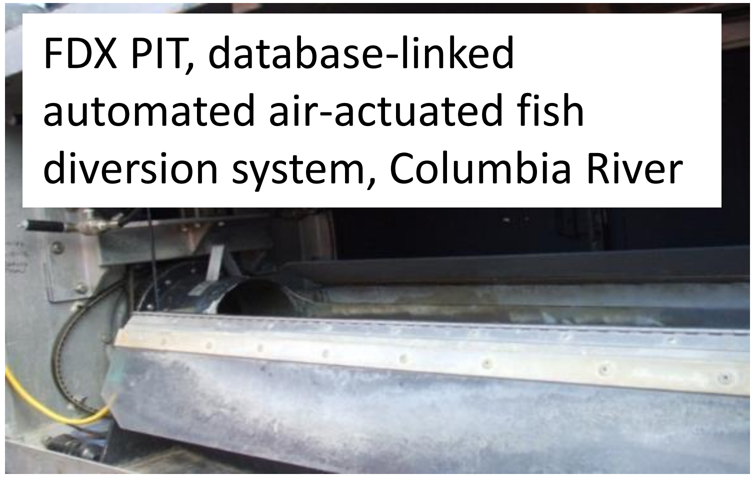




River cross-section, swim-through antenna; easy to fit with flexible HDX cable antenna

<u>- allow for rise in water level</u>

More complicated high-tech PIT antennas (vital for FDX – must not vibrate, often pre-fabricated)



FDX PIT, database-linked automated air-actuated fish diversion system, Columbia River

Designing HDX antennas – everything you want is at this URL!!

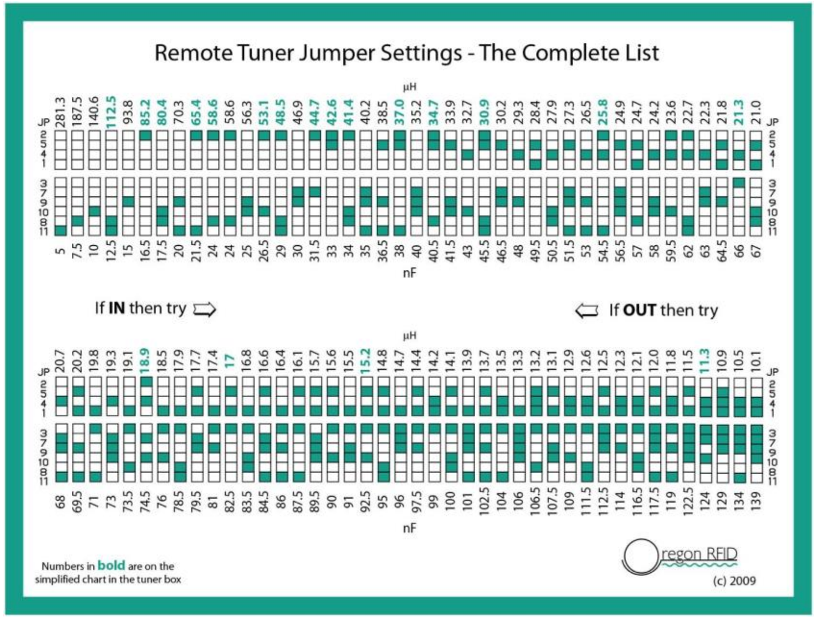
https://www.oregonrfid.com/wp-content/uploads/2018/06/Class-Handout-Antennas.pdf

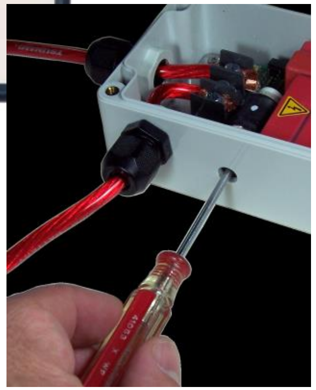
Need to connect tuning capacitors to inductor (antenna loop) to form a resonant circuit

Building antennas - think about:

- Tuning (i.e. inductance – measure with meter) – typically can tune 18-102 uH
- Wire (diameter & length) – insulated multi-copper strand wire
- Number of wire turns and space between turns
- Generally thinner wire & smaller loop = more turns
- Shape and size of antenna, proximity to metal

Auto-tuner (but not always helpful – as cannot deliberately detune in order to only detect in close locality)

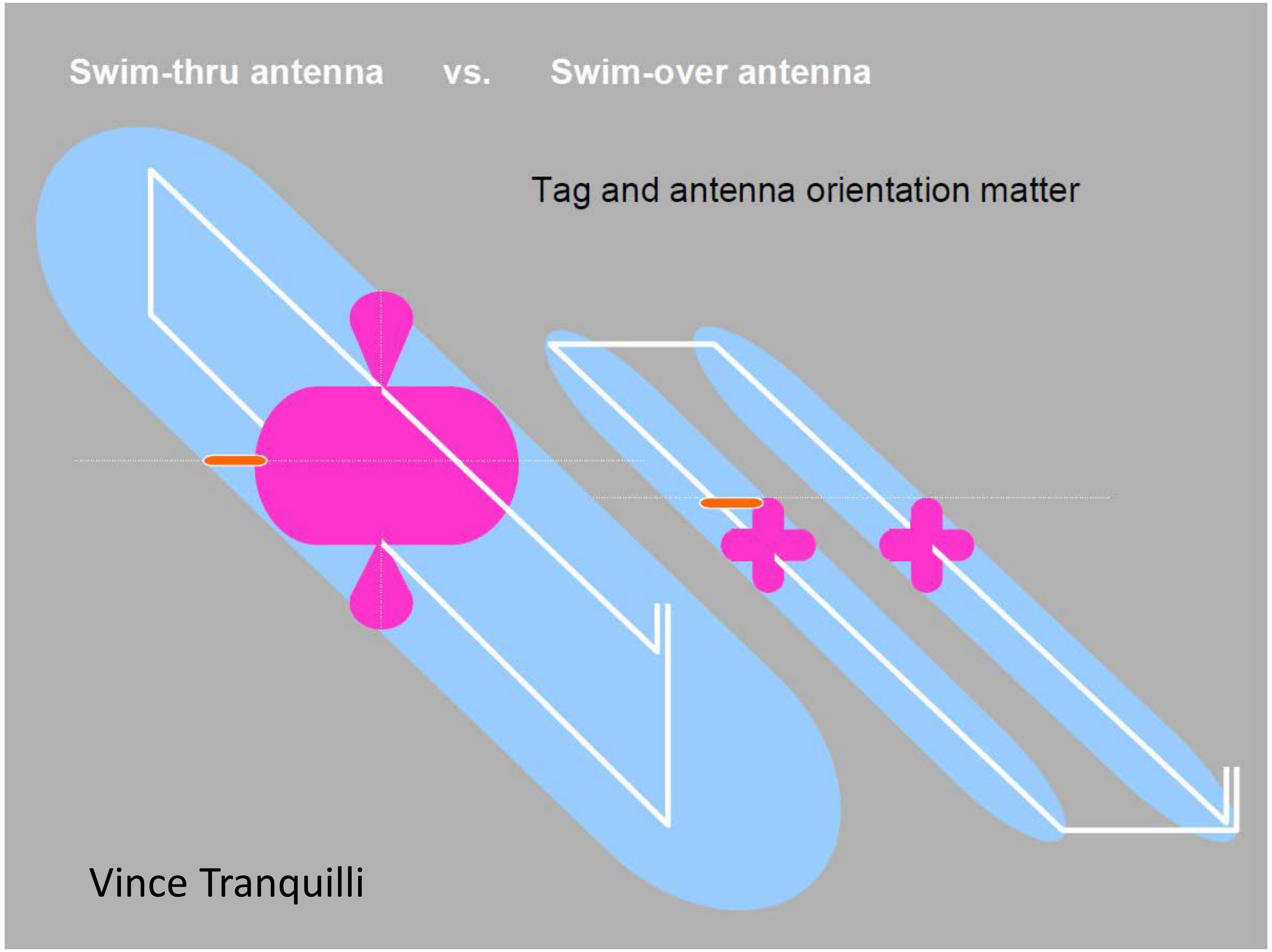


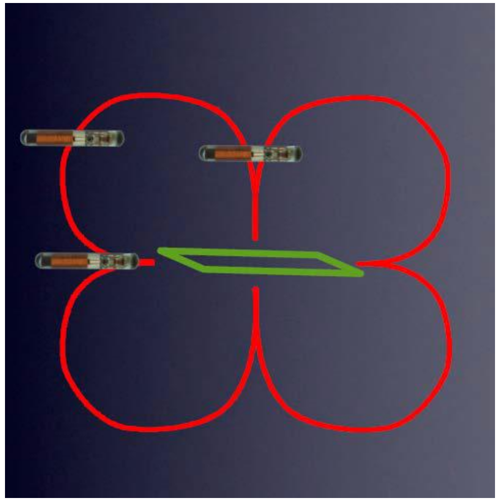


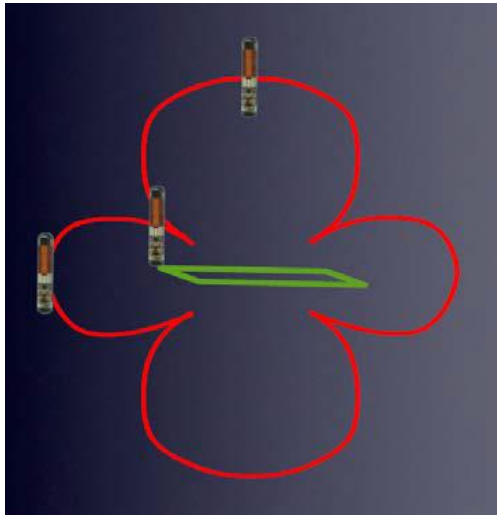
Tag to antenna orientation dramatically affects range

More excellent advice on this URL

https://www.yumpu.com/en/document/read/18471222/a-do-it-yourself-guide-to-full-and-half-duplex-rfid-lessons-



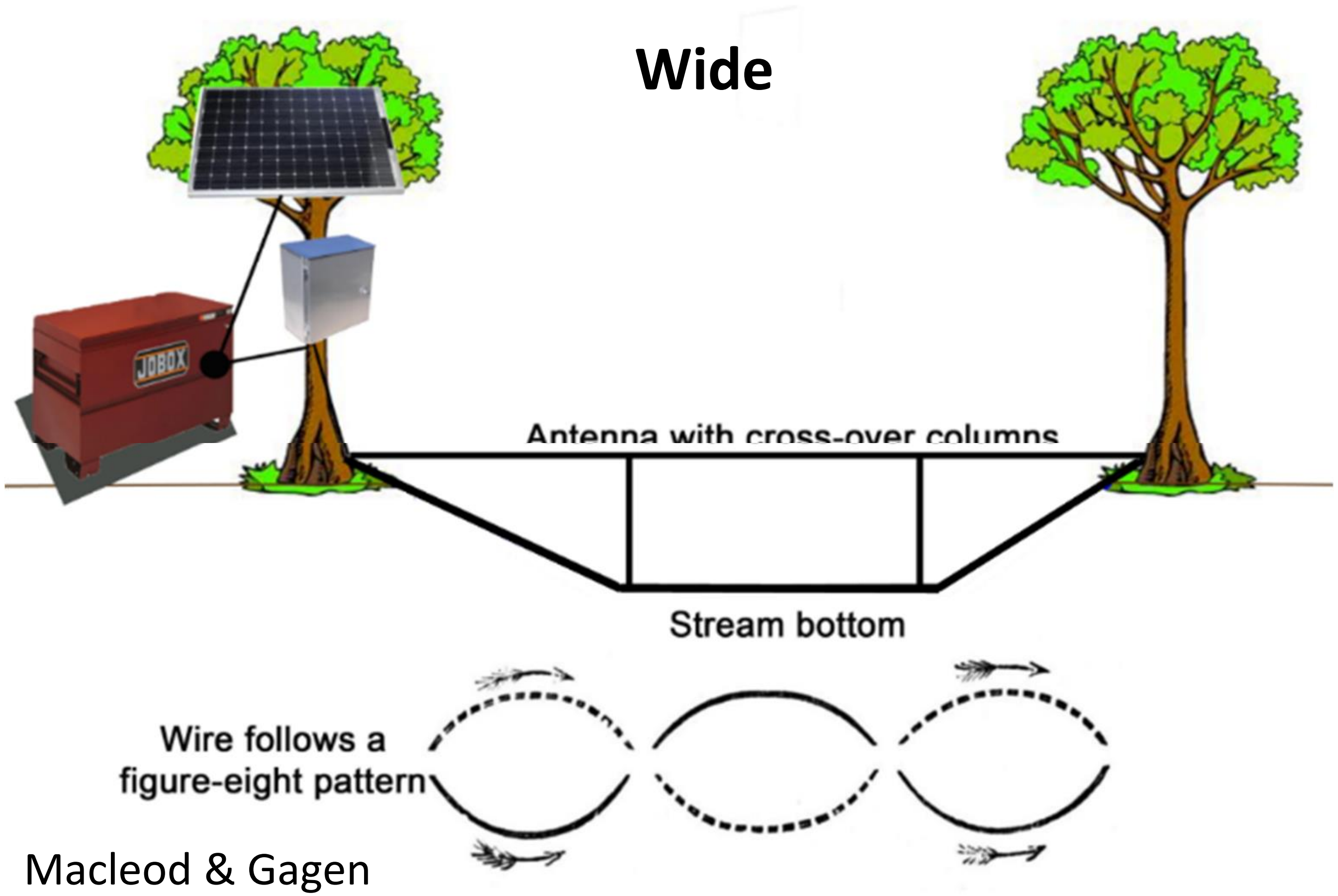




PIT antenna designs for wide and deep channels

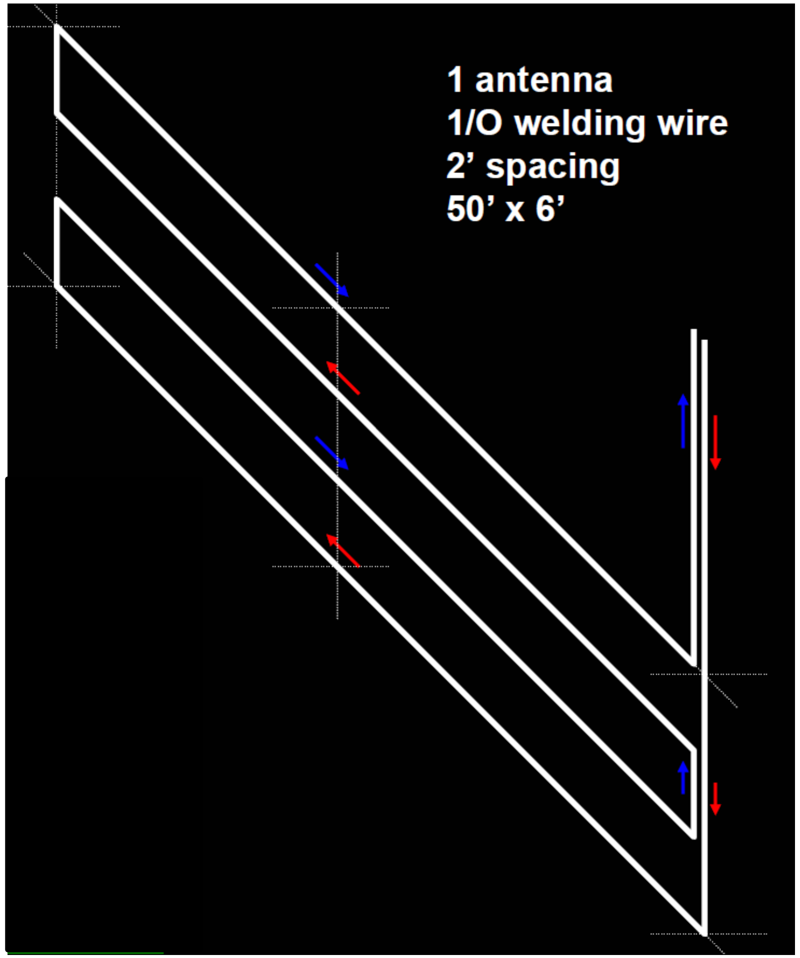
- Typical max. channel dimensions for ‘simple pass through antenna’ 15-m wide x 0.7 m deep
- Up to ~25-m wide x 1-m deep with specialist antennas, ‘welding wire’, & higher voltage
- Up to ~8-m wide x 2.5-m deep with back & forth winding.

Wide



Macleod & Gagen

Deep

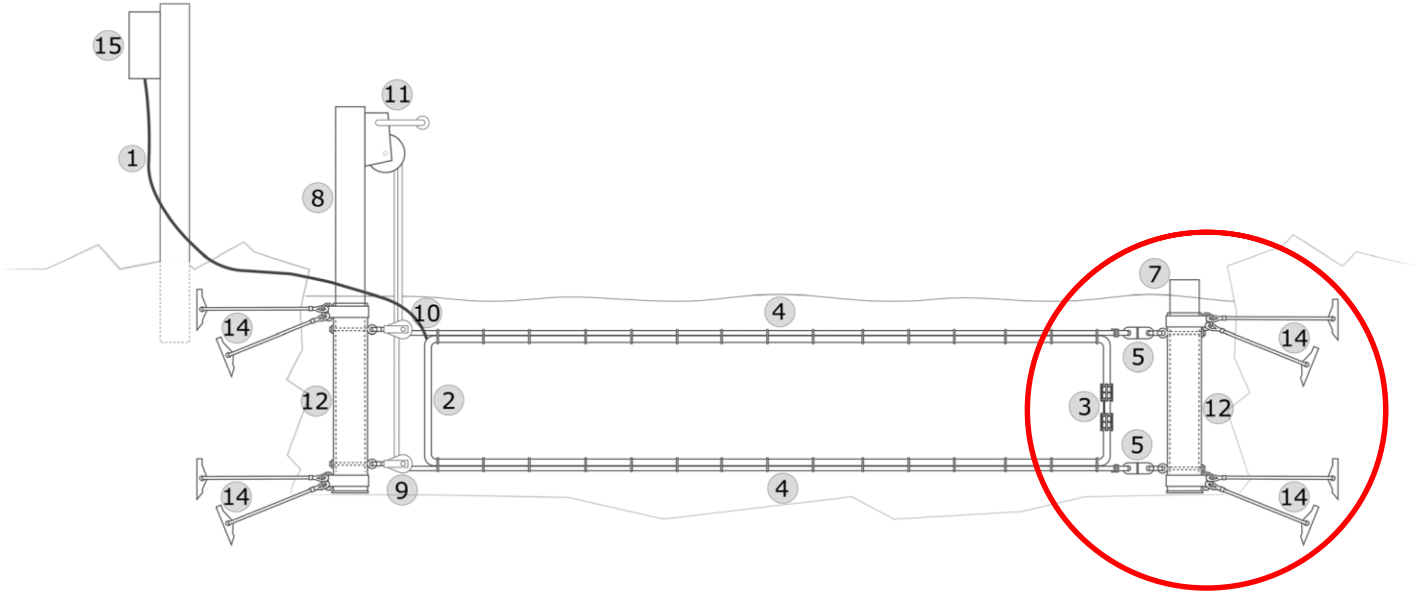


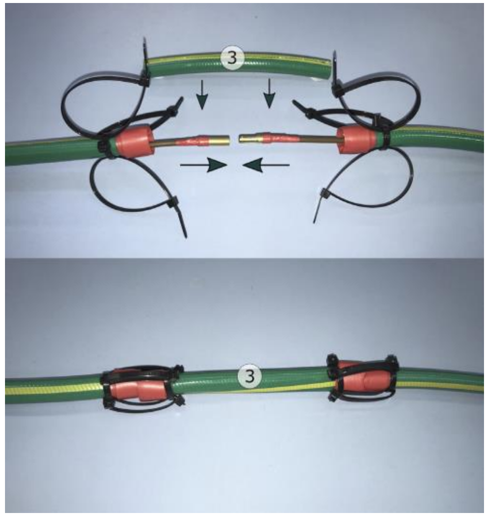
Tranquilli

Debris build-up and breakaway PIT antennas

- **Major problem:** large woody debris during high flows, + ice debris @ "ice out" – strain breaks PIT antenna, damage, data loss
- Especially big problem in 'spate streams'
- Breakaway antenna solution – low-strain breakaway connectors optimized + breakaway plug for PIT antenna wire
- But does not solve problem of (often) many missed fish during high flows (often) favoured for migration

Northwest Fisheries Science Center





Finlay et al 2020 NAJFM

OR hinged buoyant antennas anchored to bed, tend to sit obliquely at elevated flow – less susceptible to LWD

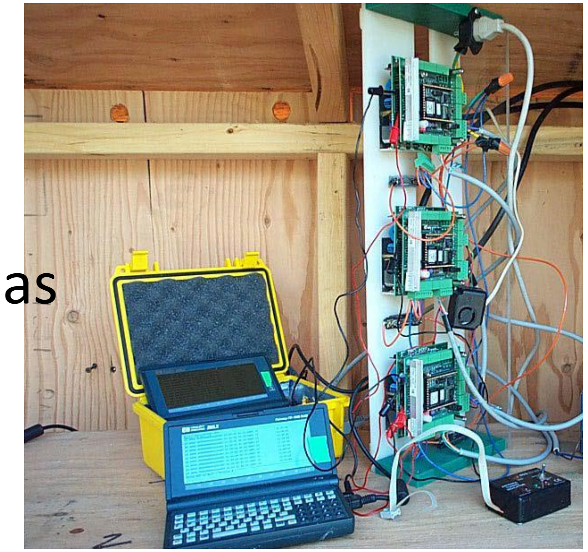
Multiple antennas – generally needed to assess movements+ direction past locations

Multiplexed system

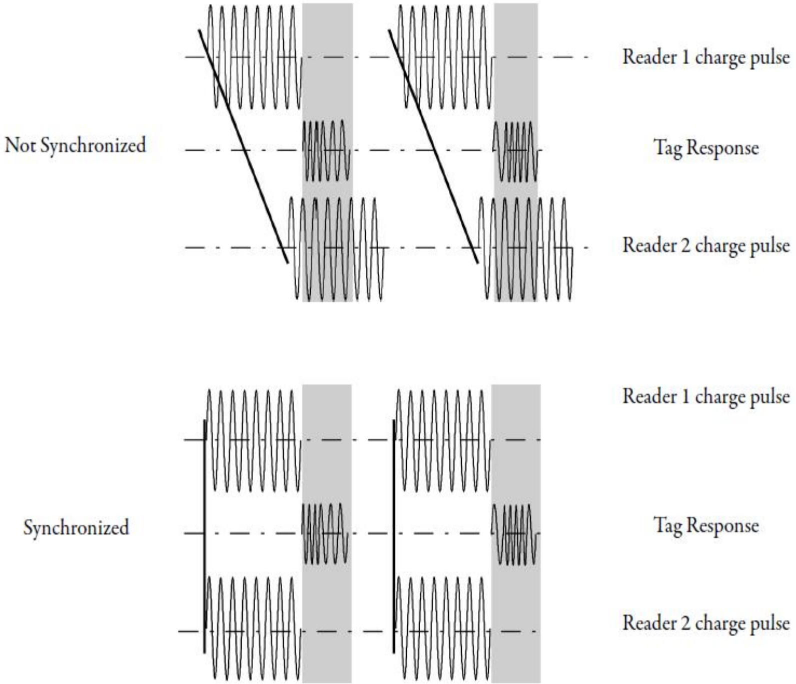
- Up to 4 antennas per reader (can be stacked)
- Reads in cycle, but decreases no. scans per antenna (risks missing fish)
- 1 x power consumption for 4 antennas
- Can use several of these independently, but need to ensure clock times do not drift significantly

Multiple readers - Why?

- All antennas read continuously
- Higher cost (readers & dataloggers)
- 4 x power consumption for 4 antennas
- Need to **synchronize** readers (esp. if antennas close together)
- Battery life – calculate from current drain – typically ~ 0.2-0.5A per field antenna



T. Linansaari



Tag collision

- If multiple tags within range of antenna only one tag detected at a time
- ‘Strongest’ tag normally recorded
- Need to design antenna location well, to minimize fish aggregation
- Loitering “sitter” tagged fish can fill data storage (programme can avoid limit repeat detections until a different tag is recorded)
- Antenna in non-preferable habitat to avoid tags ‘parked’ in field
- Pinpoint and remove “sitter” tagged fish

Tommi Linansaari

What is “rapid assessment” at barriers in telemetry terms?

- Monitoring for how long to get an adequate sample of fish to approach obstacle?
- For upstream passage, displacement of territorial fish downstream can be v. effective
- River-resident brown trout, 70-90% of fish translocated downstream normally attempt
- Of these >80% normally attempt within 48 h for translocation
- <u>Rapid</u> assessment possible at one ‘simple’ site (for trout) within ~4 days
- 1 day set-up & fish capture, 2-3 days monitoring, 1 day dismantling
- But, <u>only for prevailing environmental conditions</u>

Tummers et al. 2016 STOTEN

- Species that are less mobile and less motivated to attempt passage e.g. cottids?

- Comparison to natural seasonal movements over much longer periods?

- ***Both approaches valid – different measures***

Detection efficiency

<u>Every</u> telemetry study requires estimation of detection efficiency @ each antenna / receiver
Regular functionality checks (**marker tags or sentinel tags**)
Range tests under differing environmental conditions
Where multiple cross-river antennas occur, can calculate:
***n1* detected tags / *n2* tags known to pass** (e.g. detected at a site further along channel)

<u>Detection efficiency may be zero if antenna broken</u> (big problem, many fish migrate during high flow events when risk of damage to gear is highest, and gear efficiency may be lowest)

How many fish to tag?

- Depends on objective, but for rapid barrier assessment, aim must be for > 50 fish to attempt (precision of simple % passage estimate)
- No. attempting can be highly variable in a sample – if 10% attempt, ~*n*=500 live,tagged fish

Environmental conditions and barrier characteristics

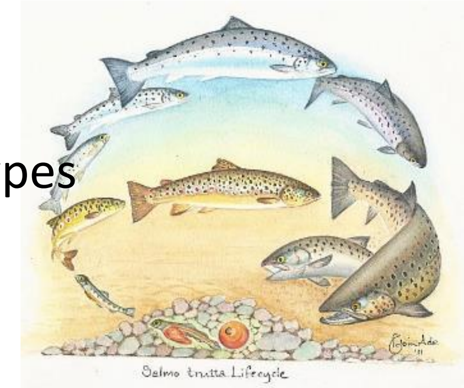
Need recording as accurately as is feasible.

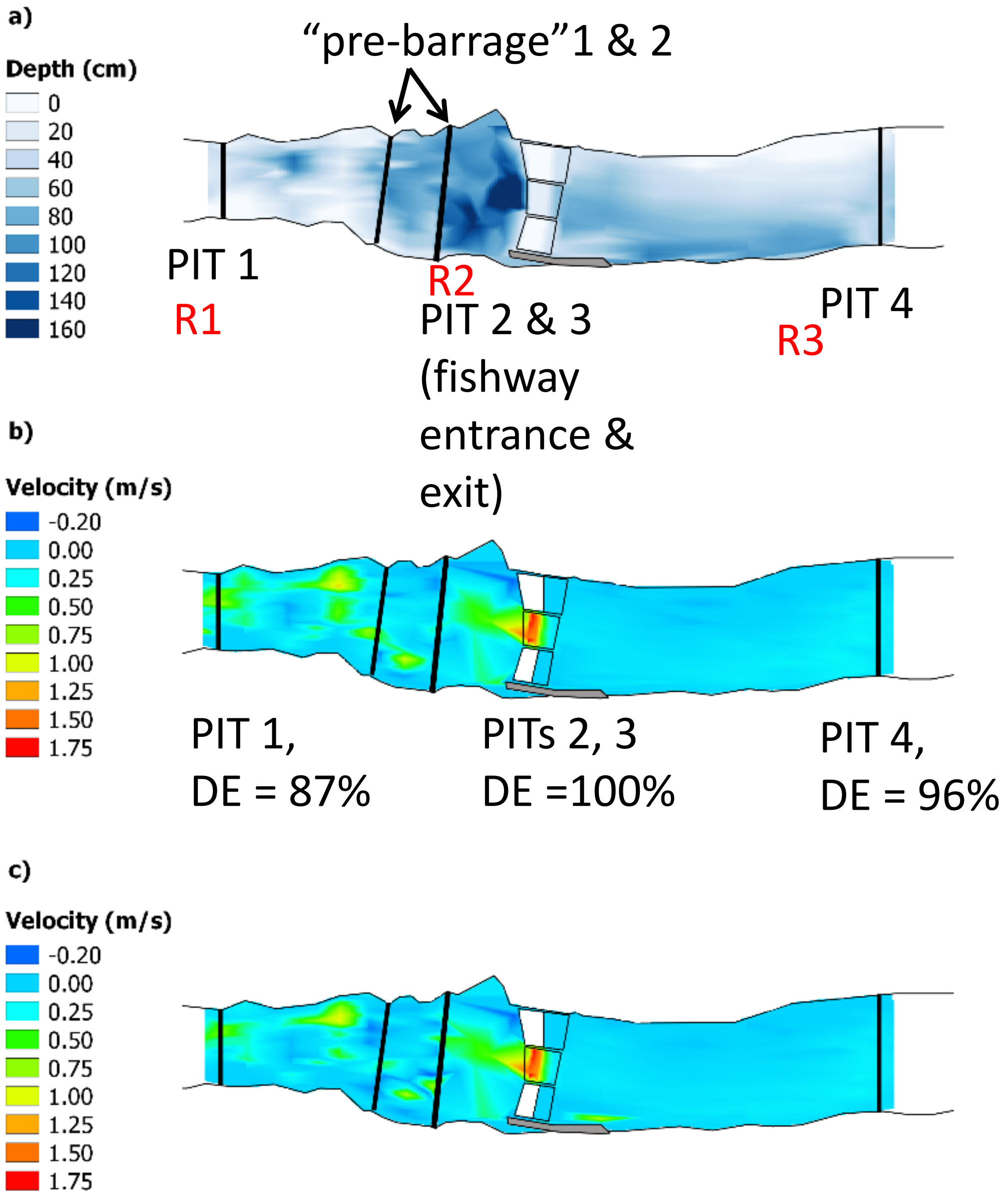
Trout passage at a complex weir and fishway

Study site: Tributary of River Wear

- Compound broad-crest weir
- Larinier Superactive baffle fishway
- X2 prebarrages d/s main weir

PIT telemetry - 160 trout – 3 phenotypes
PIT + radio-telemetry 53 trout – 3 phenotypes
(all wild) tagged ~ 1km d/s
Sept-Dec 2017





Lothian et al. 2020 *J. Env. Man.*

Trout approaching, entering, passing (upstream)

Number of fish detected upstream = **31 (59.6%)**
A: n = 21 (77.8%); P: n = 2 (25.0%); PM: n = 8 (36.4%)

Number of fish traversing weir = **21 (40.4%)**
A: n = 16 (59.3%); P: n = 1 (12.5%); PM: n = 4 (18.2%)

Lar Exit = **10 (76.9%)**
A: n = 5 (83.3%);
P: n = 1 (50.0%);
PM: n = 4 (80.0%)

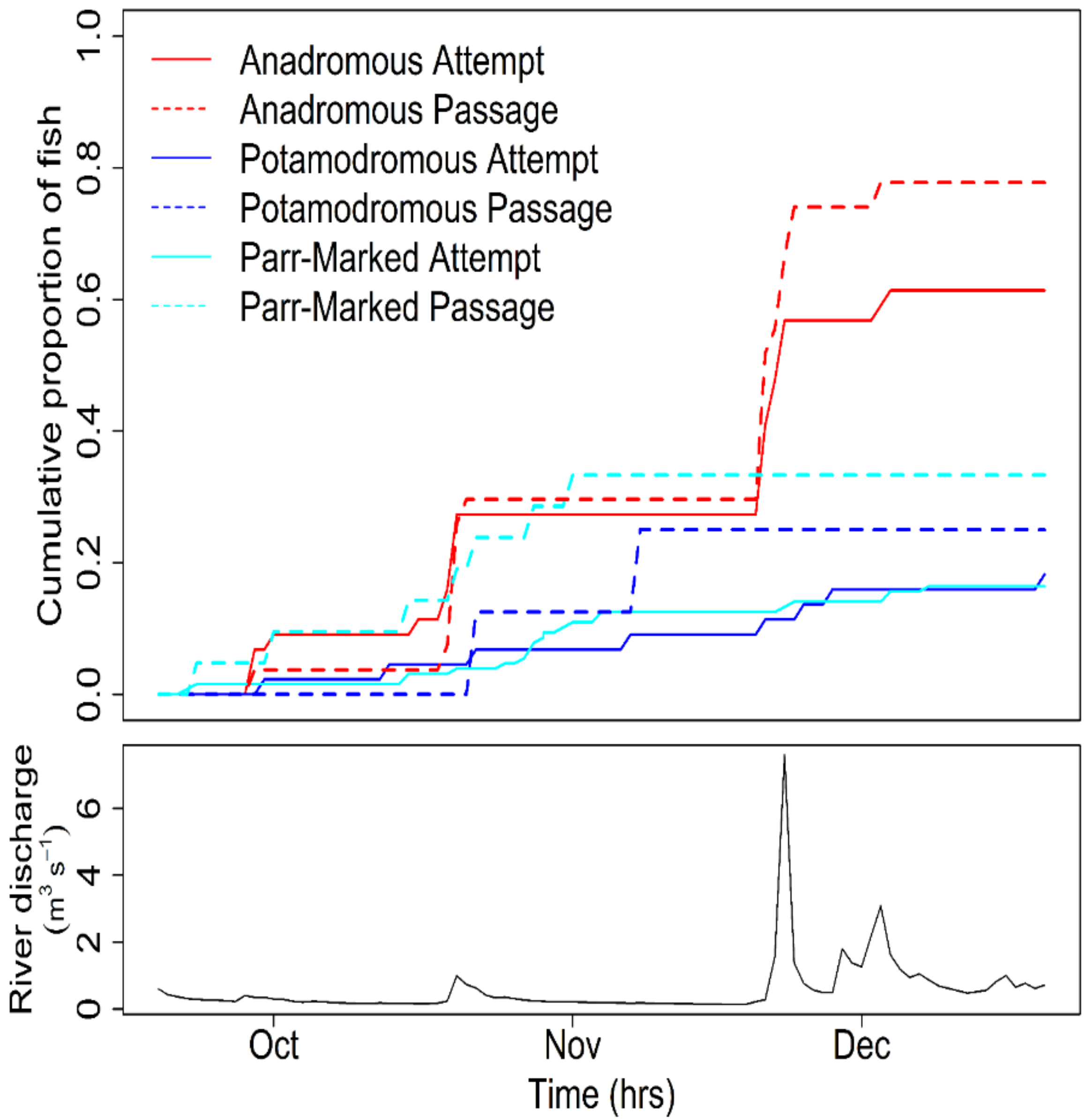
A = Anadromous; P = Potamodromous; PM = Parr-Marked

Lar Enter = **13** **(25.0% attraction)**
A: n = 6 (22.2%);
P: n = 2 (25.0%);
PM: n = 5 (22.7%)

Direction of Flow

Number of fish detected downstream = **52 (of 213)**
A: n = 27; P: n = 8; PM: n = 22

Cumulative proportion detected



- Greater number of attempts at higher flows (GLM: $z_{1,\,92}$ =4.0, $\boldsymbol{p<0.05}$).
- Greater number of successful fish at higher flows (GLM: $z_{1,\,92}$ =4.0, $\boldsymbol{p<0.05}$).

Time to pass structure

Phenotype	Overall Passage	Weir Route	Fishway Route
Anadromous	**96.3 min**	99.4 min	522.7 min
Potamodromous	**299.5 min**	84.6 min	514.4 min
Parr-Marked	**252.7 min**	203.1 min	255.7 min

(Cheap!) Urban waterway reconnection for fishes in London

Fig 3. A) Before, B) during, and C) after installation of baffles on the HGW, and D) position of PIT antennas.

Can **Low-Cost Baffle Solution** at 30%-slope weirs help wild and stocked coarse fish disperse upstream?

PIT telemetry
~240 stocked chub and barbel
~260+ wild chub, roach, dace
March 2017

Lothian *et al.* 2019 *Ecol. Eng.*

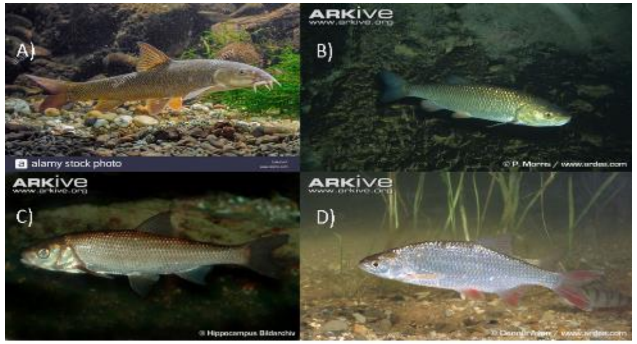


Fig 2. A) **Barbel** (*Barbus barbus*), B) **Chub** (*Squalius cephalus*), C) **Dace** (*Leuciscus leuciscus*), and D) **Roach** (*Rutilus rutilus*).

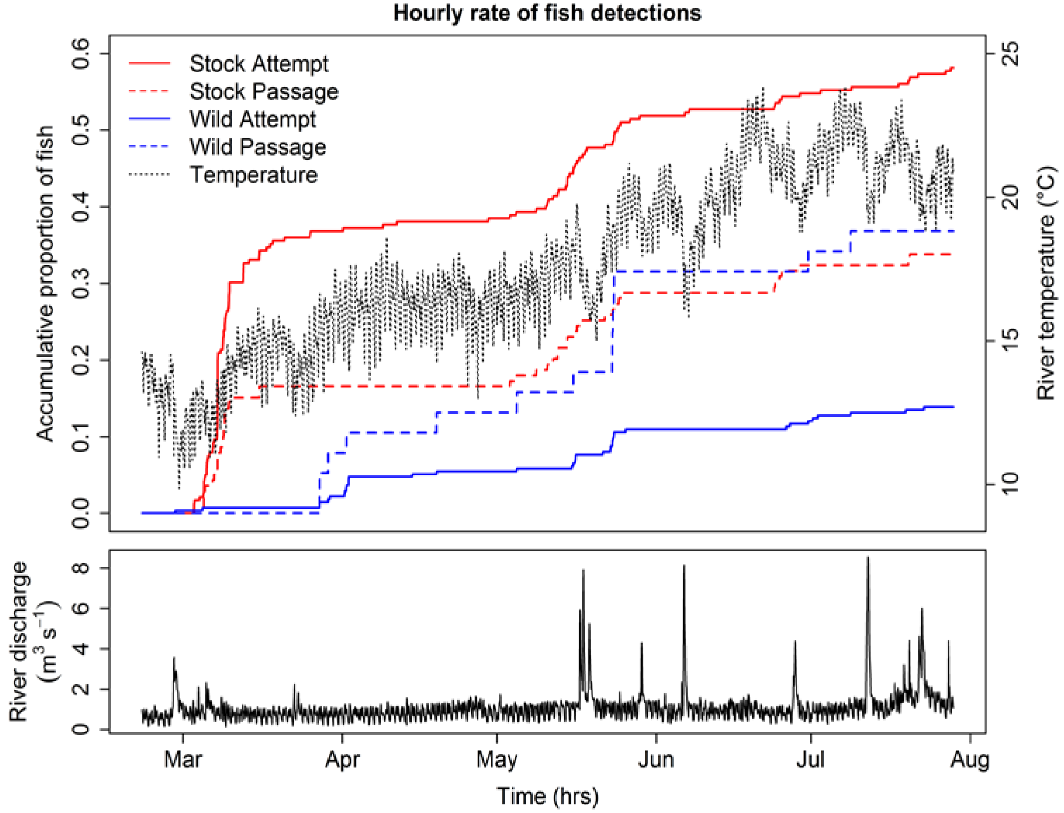
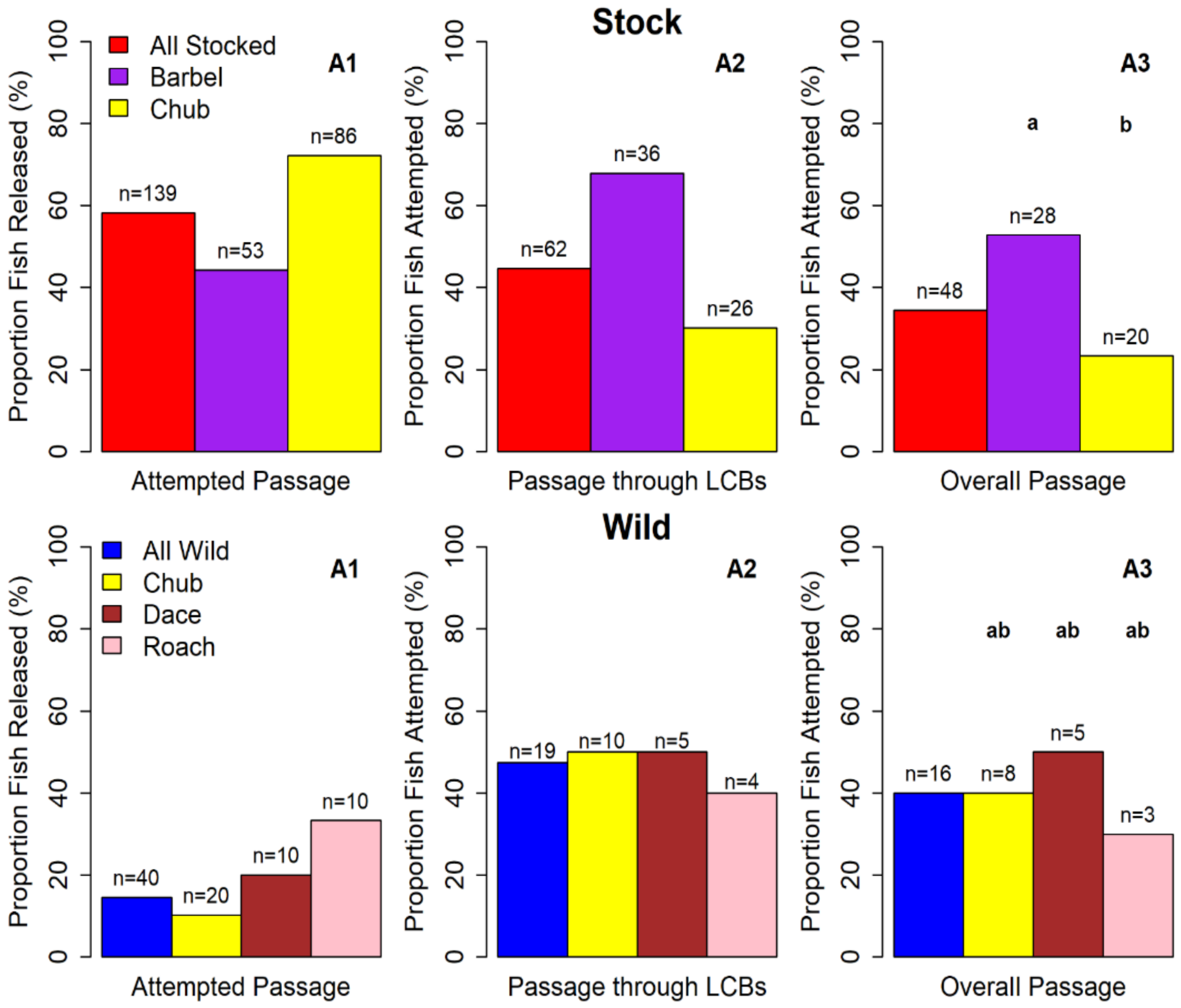


Fig 6. The accumulative proportion of fish released that attempted, and the accumulative proportion of attempting fish that were successful, over time, with hourly river temperature overlaid, and hourly river discharge below.

Overall passage performance

- More stocked fish attempted passage (p<0.001).
- Overall passage success =35.8% (n=64).
- No difference in stocked and wild success (p=0.52).



Lothian et al. (2019) *Ecol. Eng*.

Too much emphasis on passage of main migratory species

- Many previously polluted urban streams now clean enough for fish after wastewater treatment, but recolonisation inhibited by obstacles – so fish community remains poor
- Recolonisation is <u>NOT</u> a migration problem but a <u>DISPERSAL problem</u>
- ALL fish species disperse – not all migrate – <u>need to measure passage of dispersers too</u>
- WHY do we ignore ‘minor’ spp. when they often form main fish biomass in streams?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Evaluating the effectiveness of restoring longitudinal connectivity for stream fish communities: towards a more holistic approach

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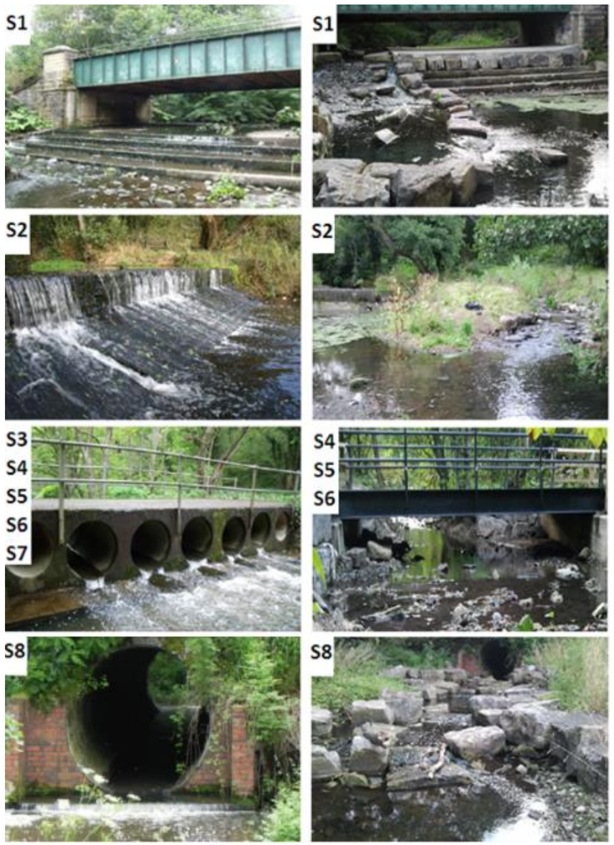
Wilkes, M.A. *et al.* 2018.
Not just a migration problem: Metapopulations, habitat shifts, and gene flow are also important for fishway science and management.
River Research and Applications DOI: 10.1002/rra.3320.

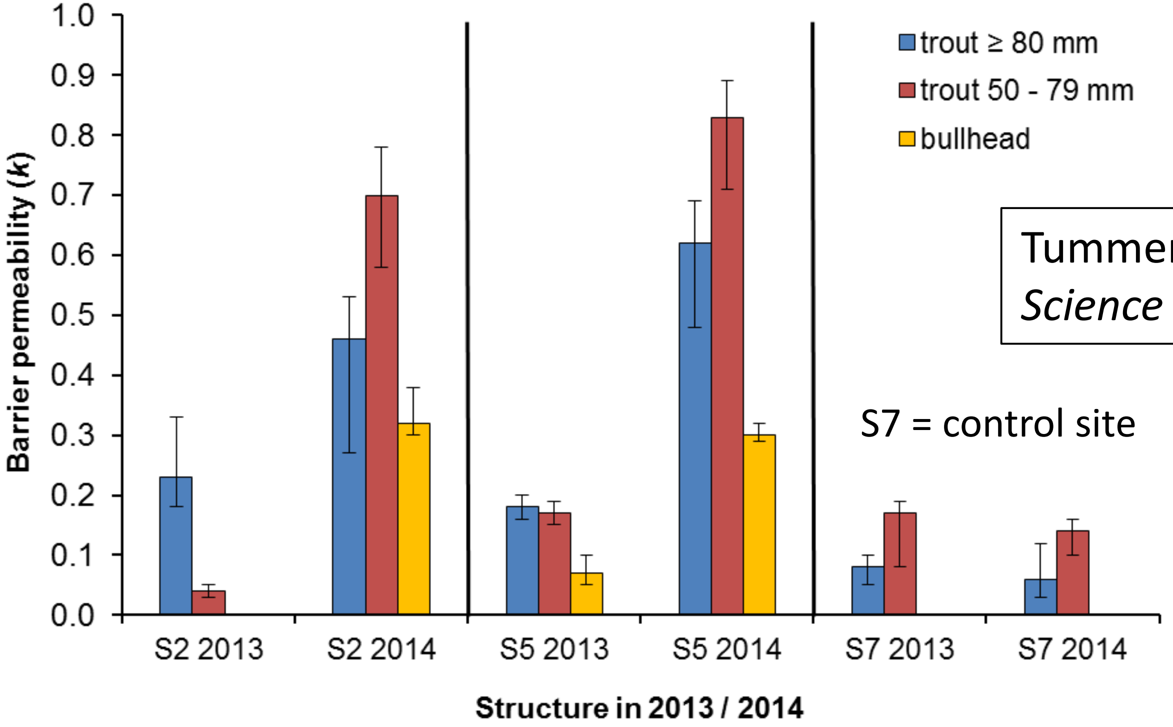
Ensuring dispersal for recolonisation

- How to measure passage of small spp.?
- Long-term PIT telemetry with 8-12 mm tags or– capture-mark-recapture in sections
- CMR (PIT or elastomer) can be used at stream sites with excessive vandalism risk



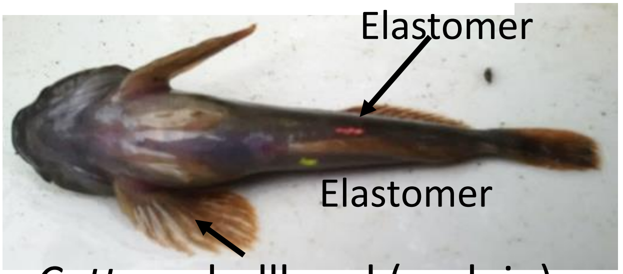
Obstacles (Before)

“Easements” (After)



Tummers *et al.* (2016)
Science Total Environ.

Structured Mark-Recapture
+ Laplace kernel analysis
[Pepino et al 2012]



Cottus – bullhead (sculpin)

Radio-tracking of barbel (*Barbus barbus*), north England

- Showed seasonal migrations – downstream to deeper, slower areas in autumn-winter, upstream to riffles in spring - importance of context (can be lost in rapid assessments)

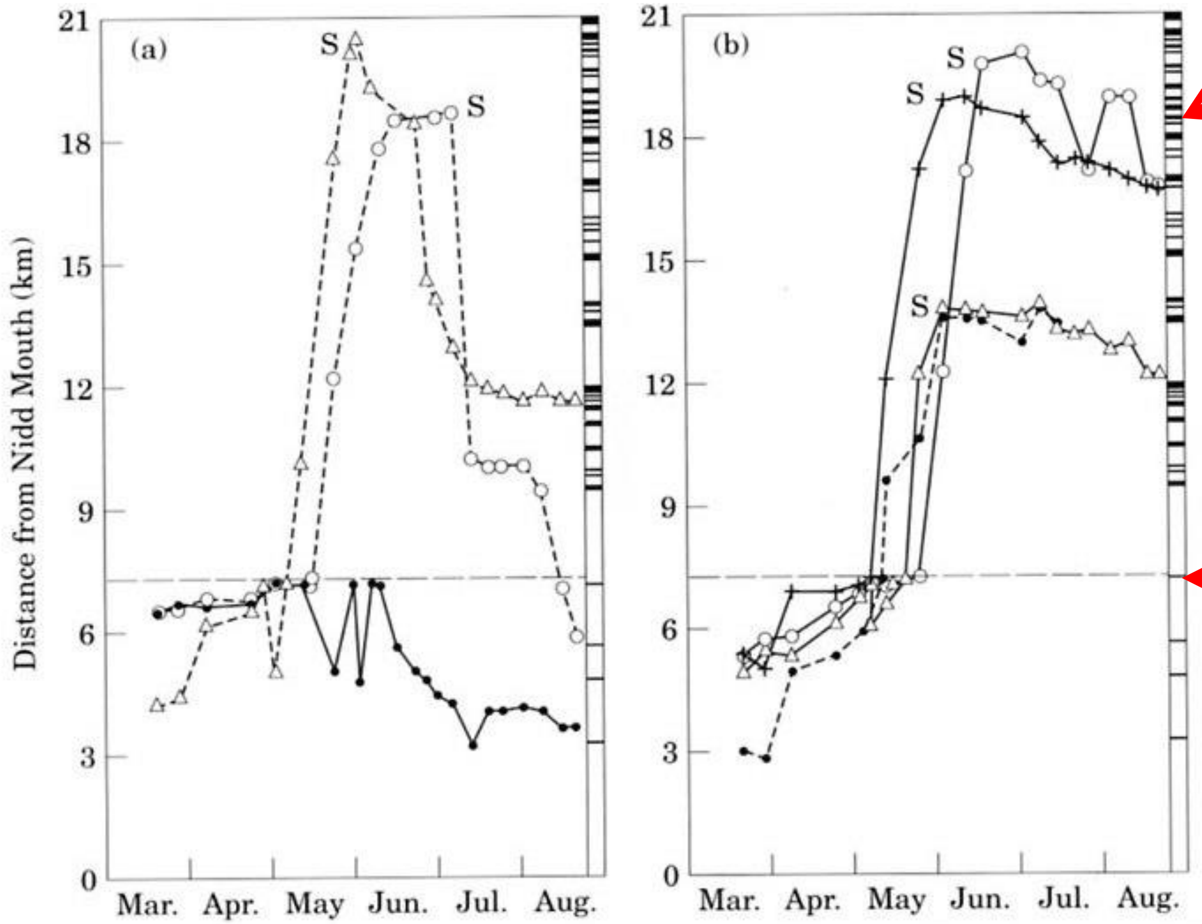


FIG. 4. (a) Example tracks for barbel released below Skip Bridge which were ultimately successful (△, ○) and unsuccessful (●) in passing upstream over Skip Bridge gauging weir. (b) Tracks of other barbel which negotiated the gauging weir. The horizontal dashed line indicates the position of the gauging weir. The bars in the right-hand column of each graph display the distribution of spawning habitat along the stretch of river, while S denotes location of the tagged fish in the presence of spawning/courting conspecifics.

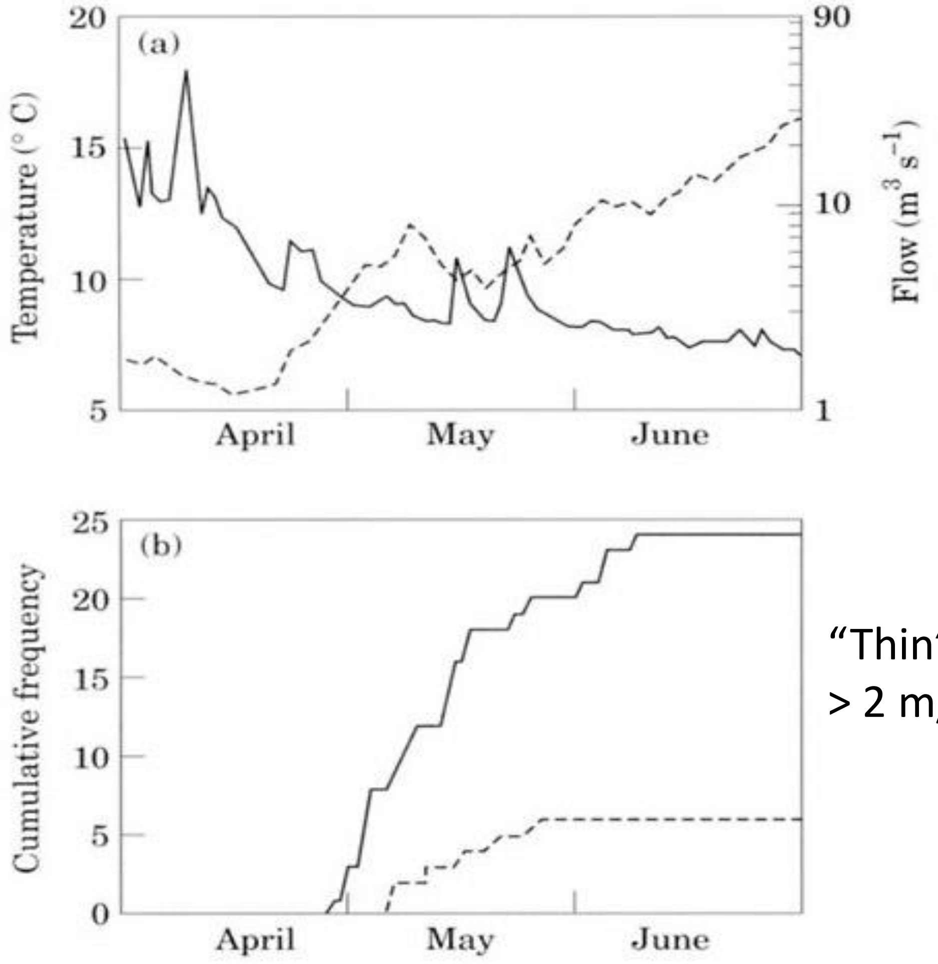
Submerged gravel beds

Lucas & Batley (1996) *J. Applied Ecology*

Lucas & Frear (1997) *J. Fish Biology*

Longitudinal movements – potamodromous fishes

- Temperate potamodromous fishes often spring migrants, temperature inc. often coincide with flow decline, making passage harder (importance of changing environmental conditions – difficult to record in short studies)



(a) Water temperature (– – –) and flow (——) during the main period of study, April–June 1994. (b) Cumulative number of barbel, moving upstream past point A, below the weir (——) and point B, immediately above weir (– – –). Fifteen fish attempted to pass the weir, several times in some cases, hence the final cumulative total exceeds the total number of fish tracked.

"Thin" flow,
> 2 m/s over weir face

Lucas & Batley (1996) *J. Appl. Ecol.*
Lucas & Frear (1997) *J. Fish Biol.*

Difficulties in downstream migration at low-head barriers

- Downstream movement not a problem at open, ‘simple’ low-head barriers, especially for ‘midwater’ fishes like salmonid smolts??

- Little investment for assisting downstream migration at small barriers – often assumed that small barriers will not markedly affect downstream migration

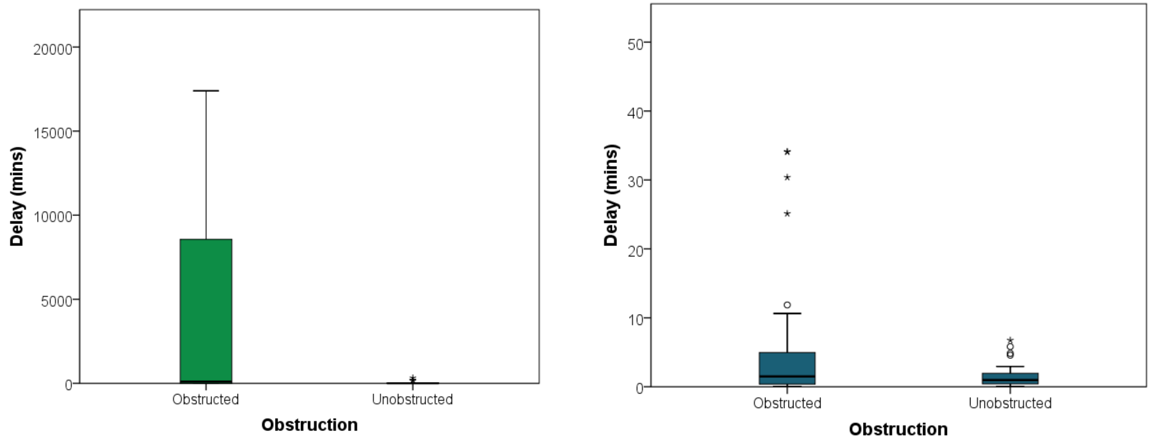
- WRONG!
- Effects of low flows – at barriers vs. open reaches
- Telemetry of downstream migration of sea trout smolts

Philiphaugh weir,

River Tweed system

2010 – low flow

2011 – normal flow



Sig. difference

No sig. difference

(note difference in y-scales on graphs)

Gauld, Campbell & Lucas (2013) *Science of the Total Environ.*

Anadromous river lamprey migration and barriers

EU Habitats and Species Directive – EU-wide part protection, threatened species

- Sea lamprey*
- European river lamprey*
- European brook lamprey

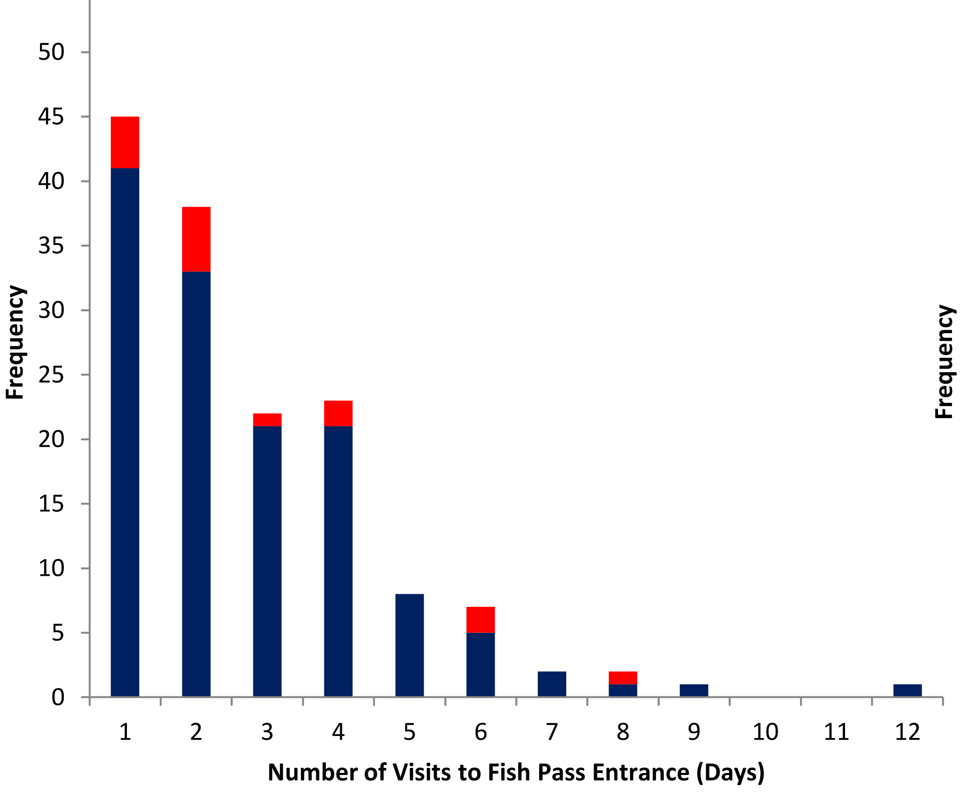
Image: Iain Russon

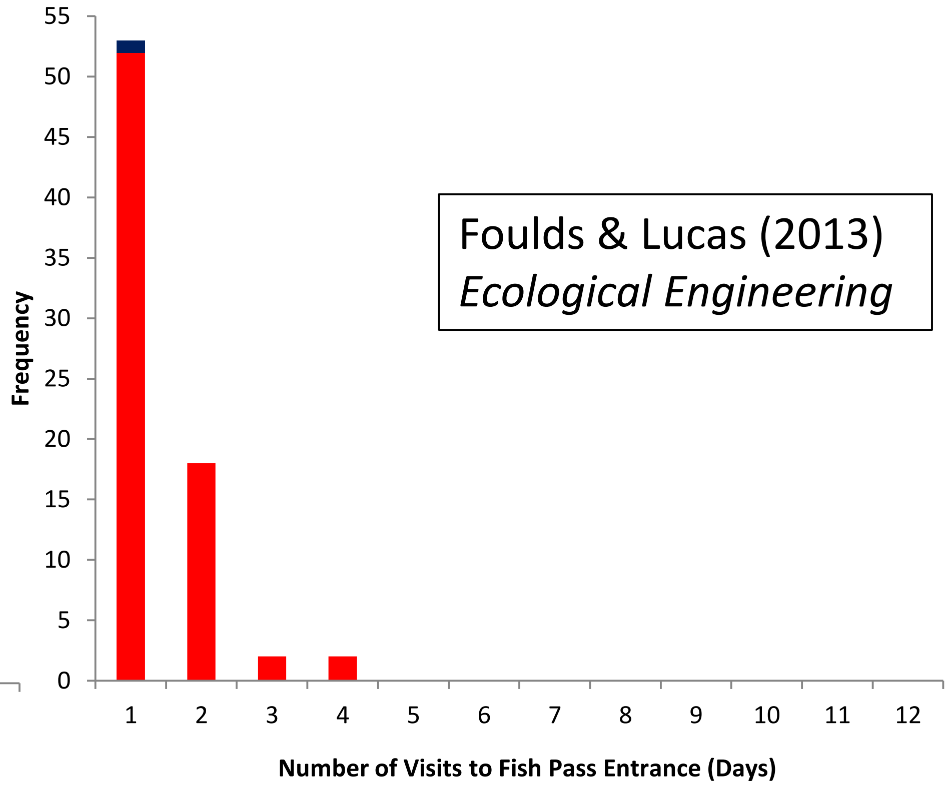
Adult (sexually immature) river lamprey (*Lampetra fluviatilis*) migrating upstream in a river in northern England in winter (at night)

Passage efficiency for river lamprey at two technical fish passes

- 300 river lamprey captured, PIT-tagged, released below fishways (Yorkshire Derwent) & studied over one full migration season (autumn to spring, – but most activity within ~1 week of release + on spates)
- No spawning habitat d/s of Pool & Spill fishway, but spawning habitat at Denil

Fish Pass Design	Entry Efficiency	Passage Efficiency
Denil baffle (u/s)	87%	0%
Pool & Spill (d/s)	47%	5.4%



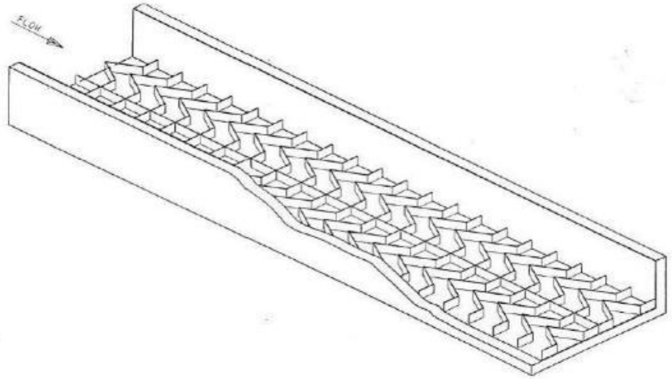


Foulds & Lucas (2013)
Ecological Engineering

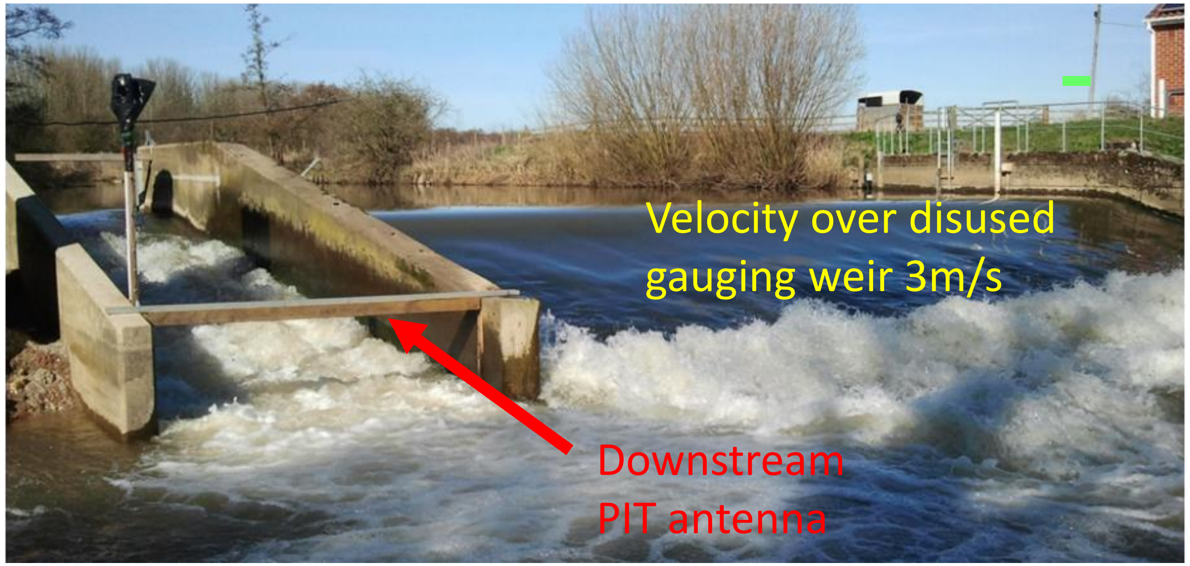
Buttercrambe flow-gauging weir, built 1975

River Derwent, England: UK Natura 2000 site (lamprey = a primary reason)

Installed Larinier superactive baffle fishway in 2014



- Often preferred choice of technical pass in UK at low-head sites for upstream passage of fusiform fishes (originally for salmonids) - cheap
- Lamprey passage efficiency determined by combined PIT and acoustic telemetry



When is a fishway a barrier? When fishway more of a barrier than the dam!

Fishway entry efficiency: 90.7%

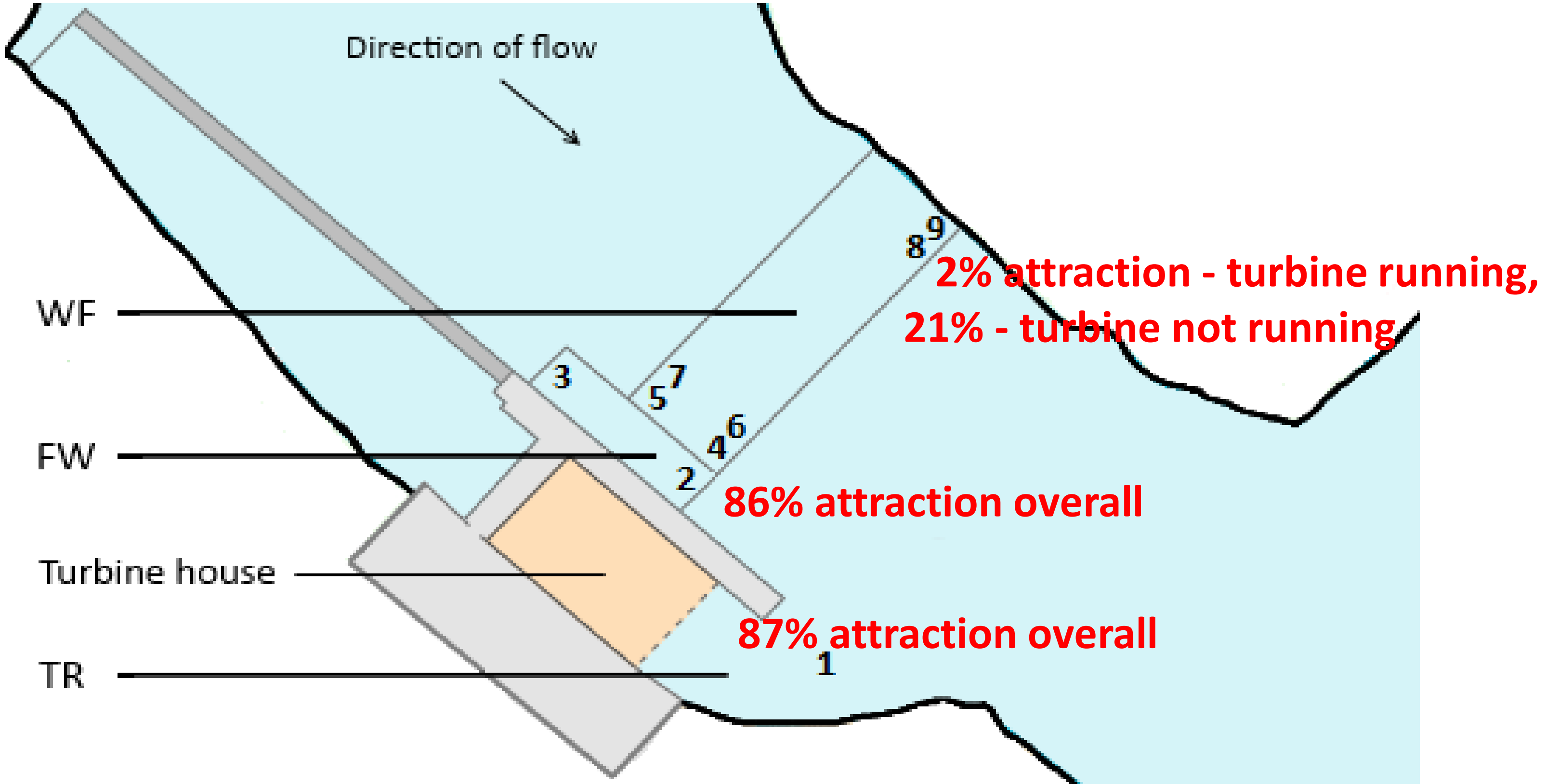
Fishway passage efficiency: 0.3%!!!

Passage over weir directly: 13.8%

Tummers et al (2016) *Ecol. Eng.*

PIT telemetry – Buttercrambe weir, autumn 2017

Multiple PIT antenna array in order to measure attraction efficiency at different localities of weir, fishway, turbine tailrace



Tummers et al 2018 – Ecol. Eng.

Some useful texts:

Cooke, S.J., Hinch, S., Lucas, M.C., Lutcavage, M. (2012) Biotelemetry & biologging. *Fisheries Techniques 3rd ed.*, pp. 819-881.

Silva, A.T., Lucas, M.C**.**, Castro-Santos, T. et al. (2018). The future of fish passage science, engineering, and practice. *Fish and Fisheries* **19**, 340-363. DOI: 10.1111/faf.1258

Lucas, M.C. & Baras, E. (2001). *Migration of Freshwater Fishes*. Blackwell, Oxford, 420 pp.

Tummers, J.S., Hudson, S. & Lucas, M.C. (2016) Evaluating the effectiveness of restoring longitudinal connectivity for stream fish communities…. *Science Total Environ.* **569-570**, 850-860. DOI: 10.1016/j.scitotenv.2016.06.207

See https://sites.google.com/site/ecolabdu/home under Publications tab for copies of some of above (also Researchgate etc)

Cooke, S.J., Hinch, S.G. (2013). Improving the reliability of fishway attraction and passage efficiency. *Ecol. Eng.*, **58**, 123-132.

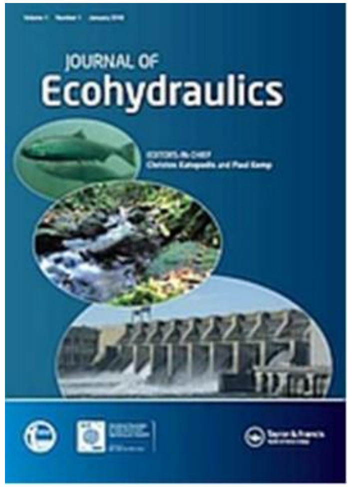
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 689682.

Durham – UNESCO world heritage site, up in the North of England, not far south of "Hadrian's Wall"

Conclusion: ***Most barrier assessment with telemetry is not rapid (!!), but it is informative and can provide robust evidence***

Thanks to Angus Lothian, Rui Sun, Jeroen Tummers, Will Foulds, Niall Gauld etc for doing most of the work!)

And a shameless plug for Journal of Ecohydraulics (Editors: Chris Katopodis & Paul Kemp)



- Keen to receive good-quality papers linking hydraulic and ecological processes.
- All aspects of interaction between river flows and biota / ecological processes
- Ecological aspects of dam/weir removal, aquatic connectivity restoration, fish passage etc are ideal for this journal

AMBER
LET IT FLOW

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