Fish Guidance Systems

An Introduction to Behavioural Fish Deflection Systems and their use to Control Invasive Fish Species

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Innovative Solutions for Fish Deflection and Protection

Overview of Presentation

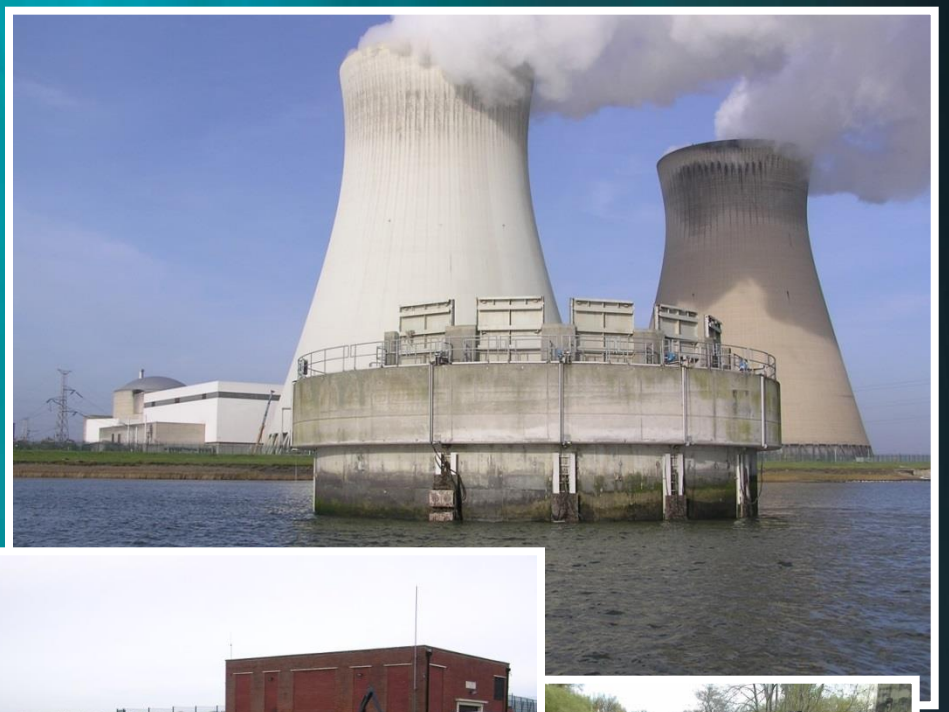
- Introduction to Behavioural Fish Deflection Systems
- Evidence of Performance and Design Considerations
- The use of Behavioural Systems to Control Invasive Fish Species

Introduction

- Fish Guidance Systems Ltd (FGS) established in 1994
- FGS has pioneered the development of acoustic fish deterrent systems
- World leader in supplying behavioural fish deflection systems

Introduction

- Over 100 systems installed in UK / Europe and North America
- Installations range from nuclear power plants to pumping stations and drinking water intakes
- In UK, considered ‘best practice’ for coastal intakes

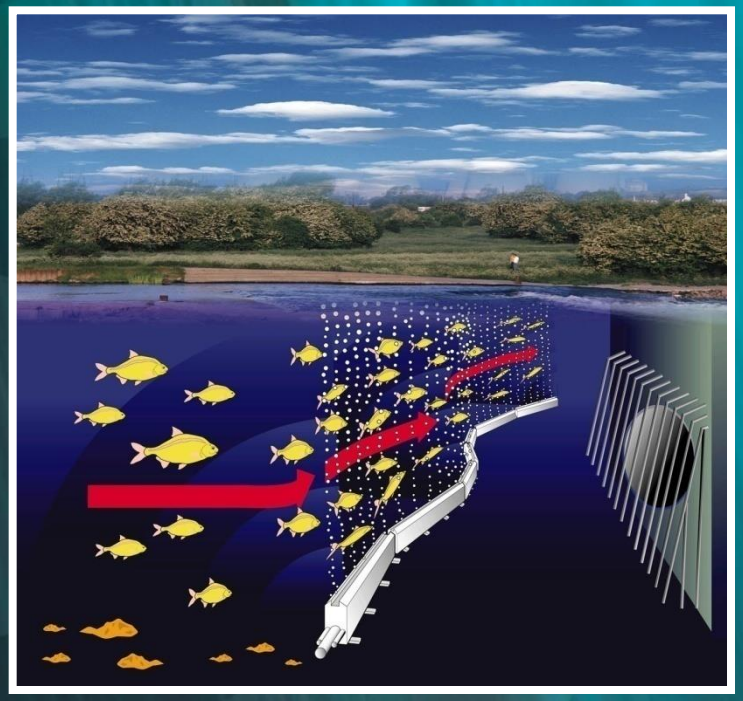


Behavioural Systems

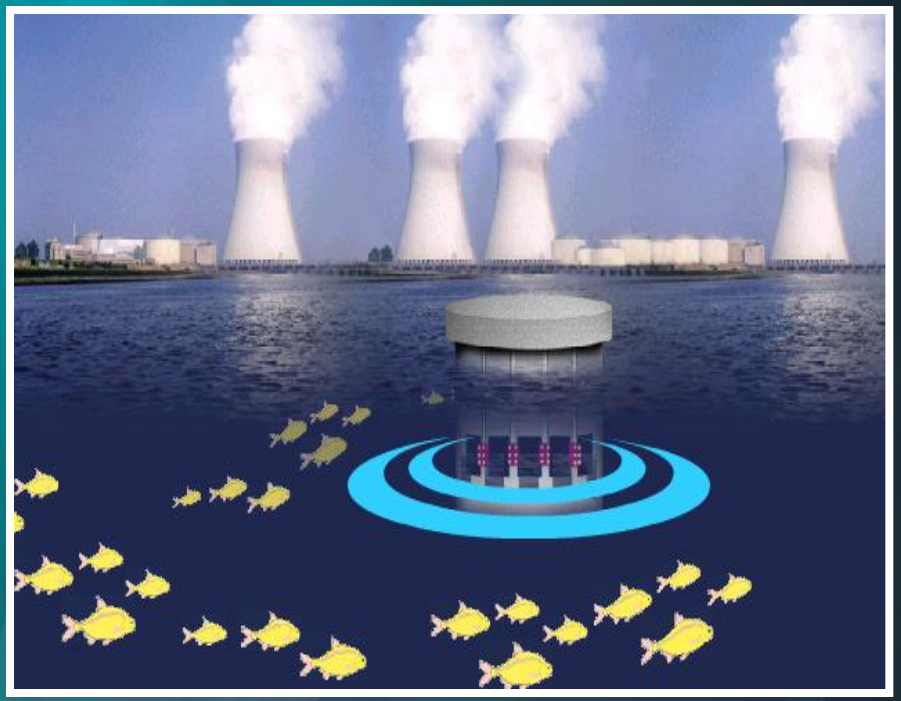
Fish Guidance Systems

Main Systems are based upon acoustic technology

The BioAcoustic Fish Fence (BAFF)



The Sound Projector Array (SPA)



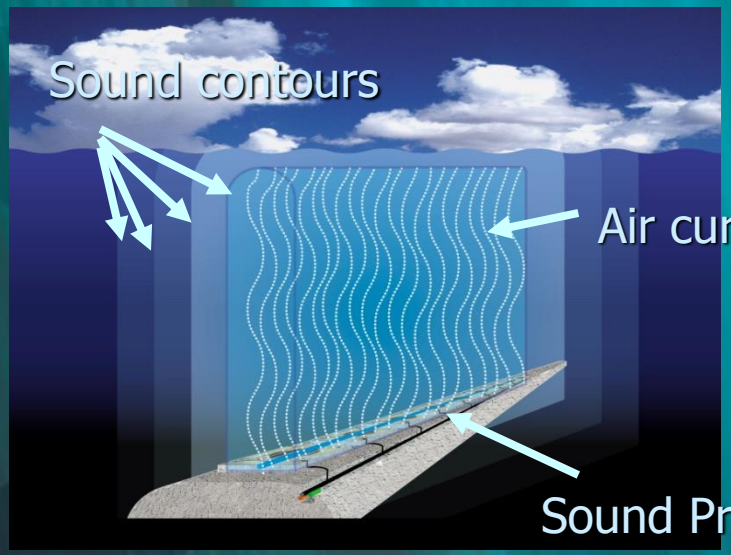
Behavioural Systems

Fish Guidance Systems

Other Systems available are –

- Hybrid System –

The SPA driven BAFF



High Intensity Lights

Behavioural Systems

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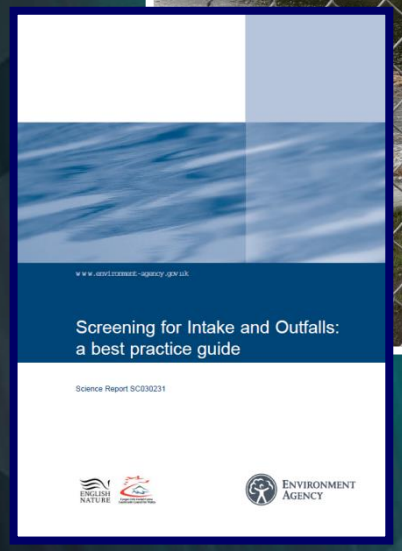

- Electric barriers
- Require large amounts of energy to operate, especially for small fish
- Costly to run
- Safety issues
- Not recommended in UK Environment Agency Best Practice Guide for screening of intakes

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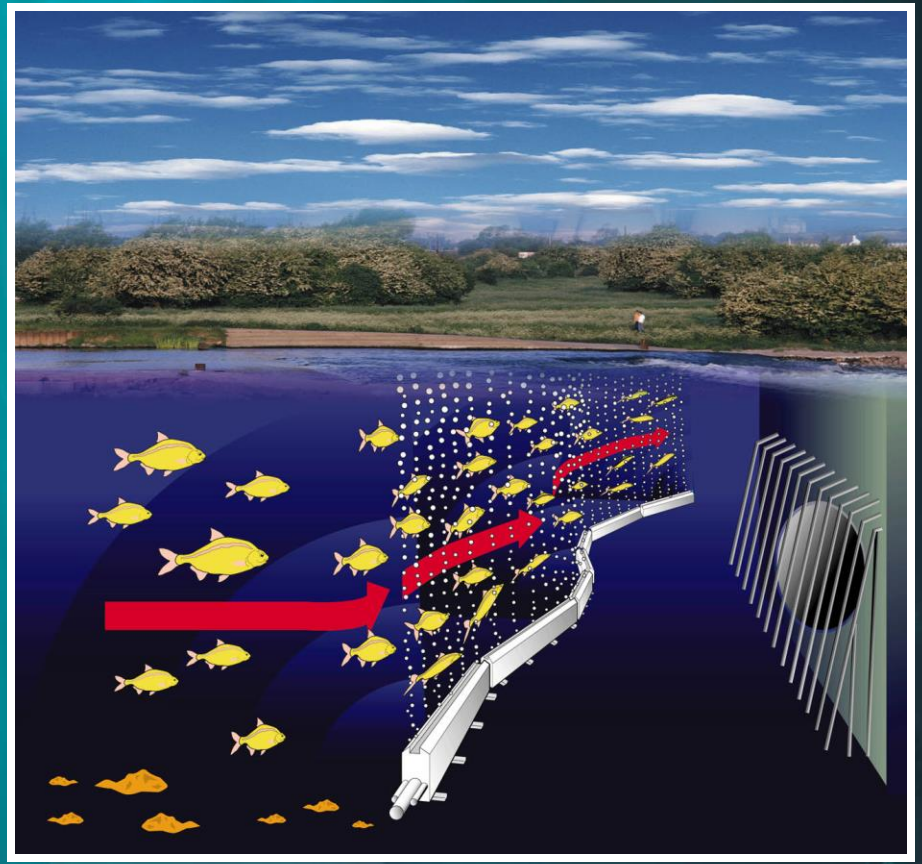
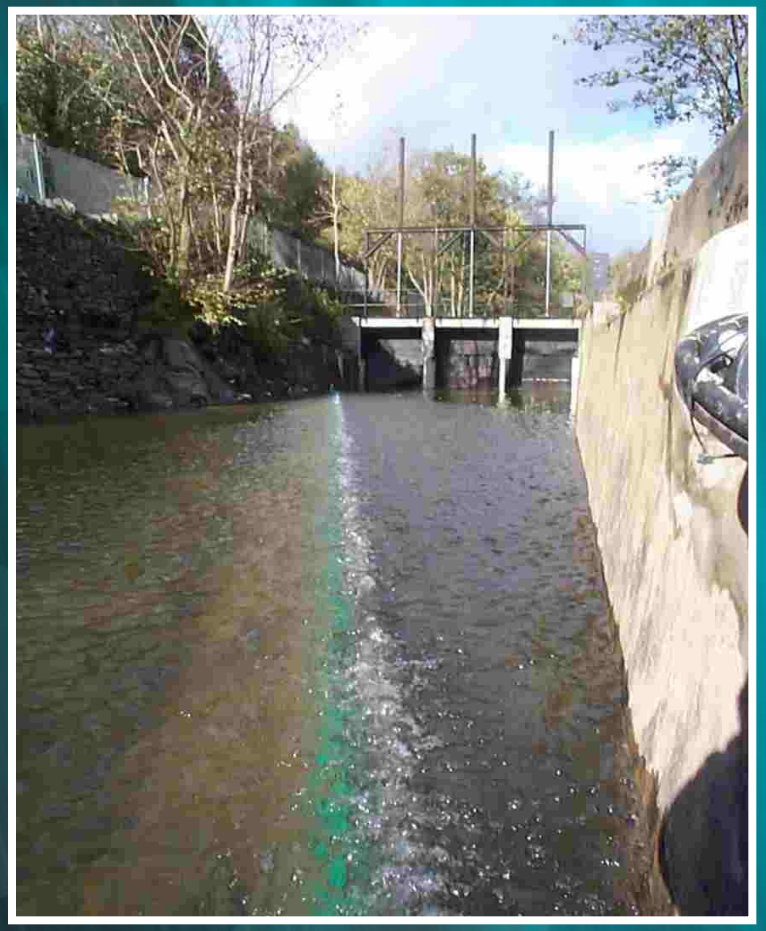
BioAcoustic Fish Fence (BAFF) Systems

The BAFF

- BAFF developed by FGS
- A pneumatic system that introduces sound into a bubble curtain
- Produces a ‘wall of sound’ enabling fish to be guided out of a river / raceway



The BAFF



- Ideally suited to head races for hydro power or irrigation schemes
- Due to natural breakdown of bubble curtain, install when water depth < 4m, but installed successfully in 10m of water

The BAFF

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Typical installation

The BAFF

- 24 BAFF Units
- 58 m long

The BAFF

- BAFF System after re-alignment
- Race drained down, before re-filling

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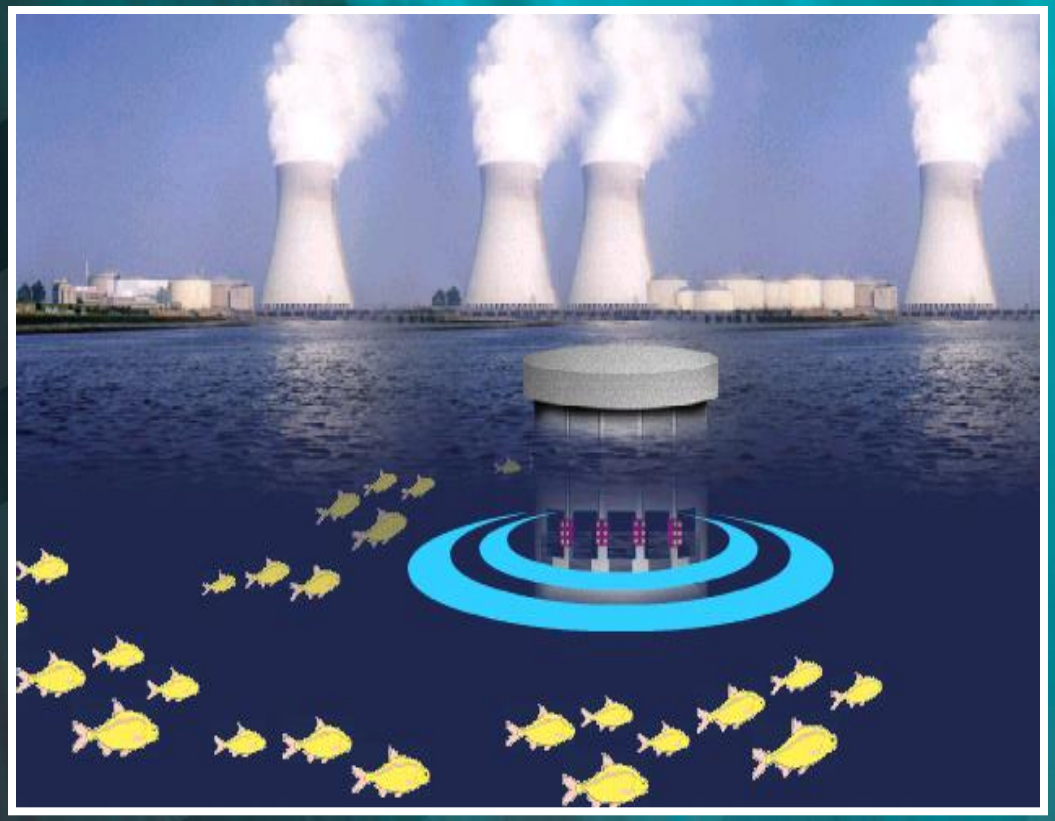
Sound Projector Array (SPA) Systems

‘SPA’ Acoustic Systems

Fish Guidance Systems



- Analogous to an underwater hi-fi system
- Produces a repellent sound gradient in front of intake
- Used to block rather than guide fish
- Suitable for most intake types including retrofit, marine & freshwater

The MkII SPA

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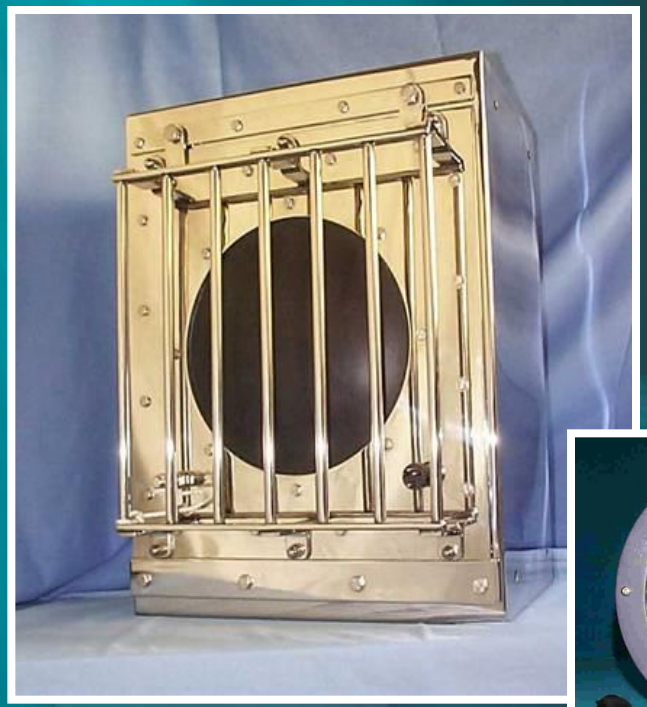
Control Equipment

Sound Projectors



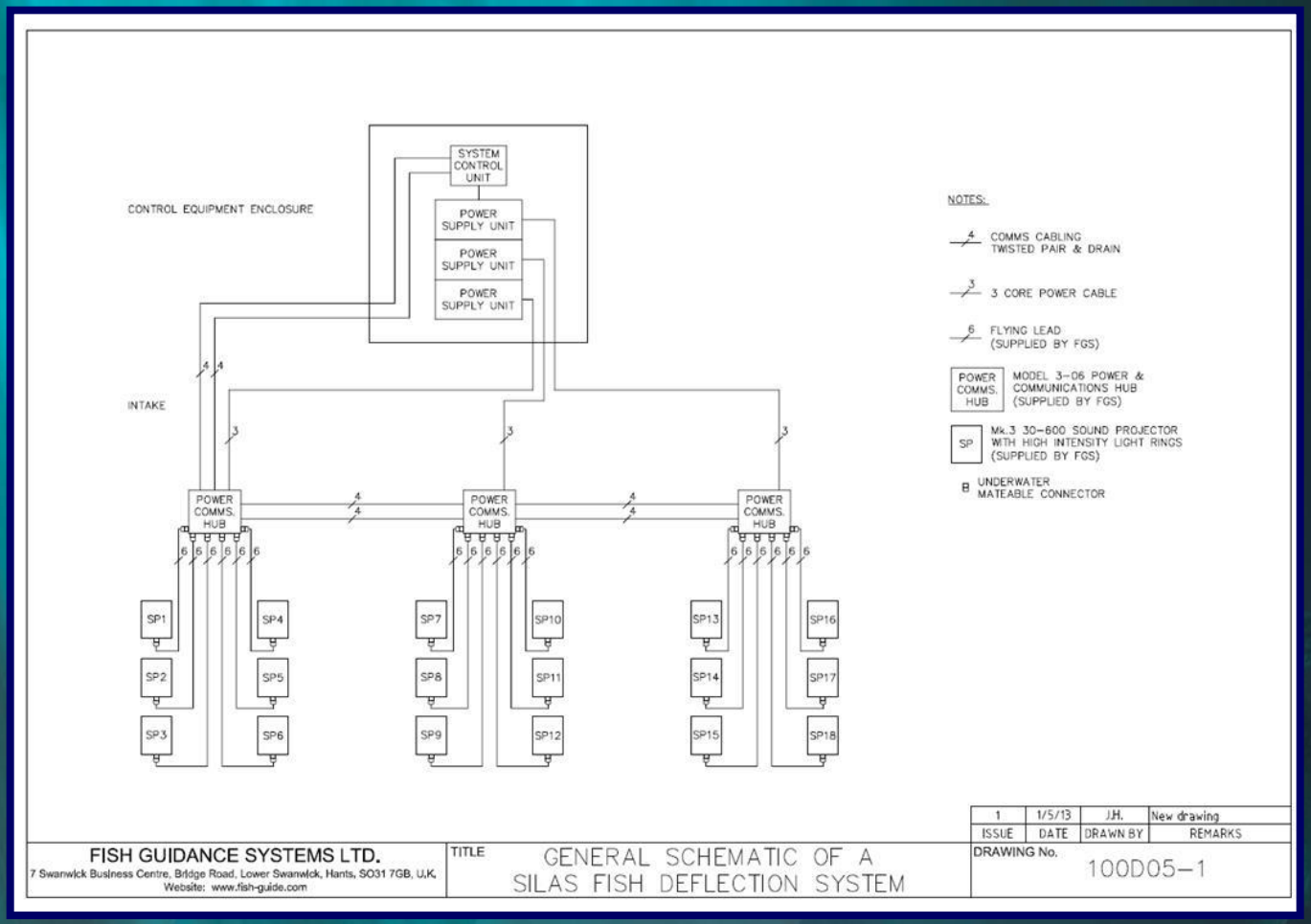
MkIII SPA Systems

- MkIII Sound Projector - most electronics now located within the Sound Projector body
- Designed for easy maintenance
- Reduces cabling in systems
- Reduces size of Control Equipment
- Built in diagnostics
- Can be monitored remotely (when internet access available)

MkIII SPA Systems

Fish Guidance Systems

General Schematic of MkIII System



SILAS Systems

- SILAS – Synchronised Intense Light And Sound
- Combined acoustic and light stimulus to enhance deflection efficiencies
- Can be incorporated into BAFF and SPA systems
- SILAS M designed for smaller Municipal intakes
- Most systems now use SILAS technology

Maintenance Requirements

Fish Guidance Systems

Maintenance of Sound Projectors

- Needed due to natural deterioration of seals underwater and replacement of mechanical components
- Recommended every 12 months

Maintenance of High Intensity Lights

- Require routine cleaning – frequency dependent upon local conditions

Maintenance of other components

- Limited – Control Equipment PSUs every 3-5 yrs.
- Service program based upon site operation

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Hybrid – SPA driven BAFF Systems

SPA Driven BAFF

- The SPA driven BAFF generates sound using Sound Projectors that are acoustically coupled to the bubble sheet.
- Enables selected deflection signals to be incorporated into system
- Combines a guiding wall of sound/bubbles with far-field audibility

SPA Driven BAFF

- Main systems installed in California
- Head of Old River 2009-2011
- Georgiana Slough 2010-2011
- Installed to deflect Chinook Salmon and keep smolt in main rivers

SPA Driven BAFF

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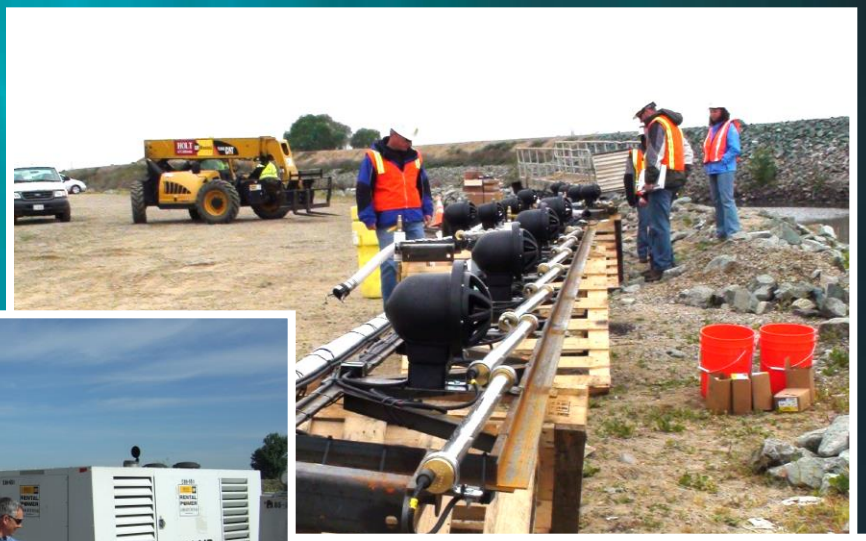
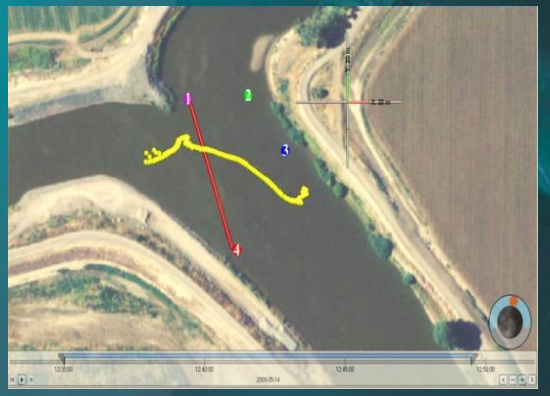
- Both systems multi-stimulus (SILAS) barriers, using sound, high intensity lights and bubbles
- Head of Old River 110m long
- Georgiana Slough 192m long
- Both systems only installed for Chinook migration in the spring



SPA Driven BAFF

- Both systems evaluated to determine overall efficiency
- Georgiana Slough up to 90% deflection
- Head of Old River up to 81% deflection
- Final decision on installation due this spring (2015)

System ON



System OFF

Images courtesy of HTI

Fish Guidance Systems

Evidence of Performance and Design Considerations

Are all the Fish Diverted?

- No behavioural system is 100% effective, but 100% deflection has been noted at some sites for particular fish species
- Under optimal conditions in excess of 90% deflection has been achieved
- This is exceptionally high for a behavioural barrier

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Fish Sensitivity to Sound

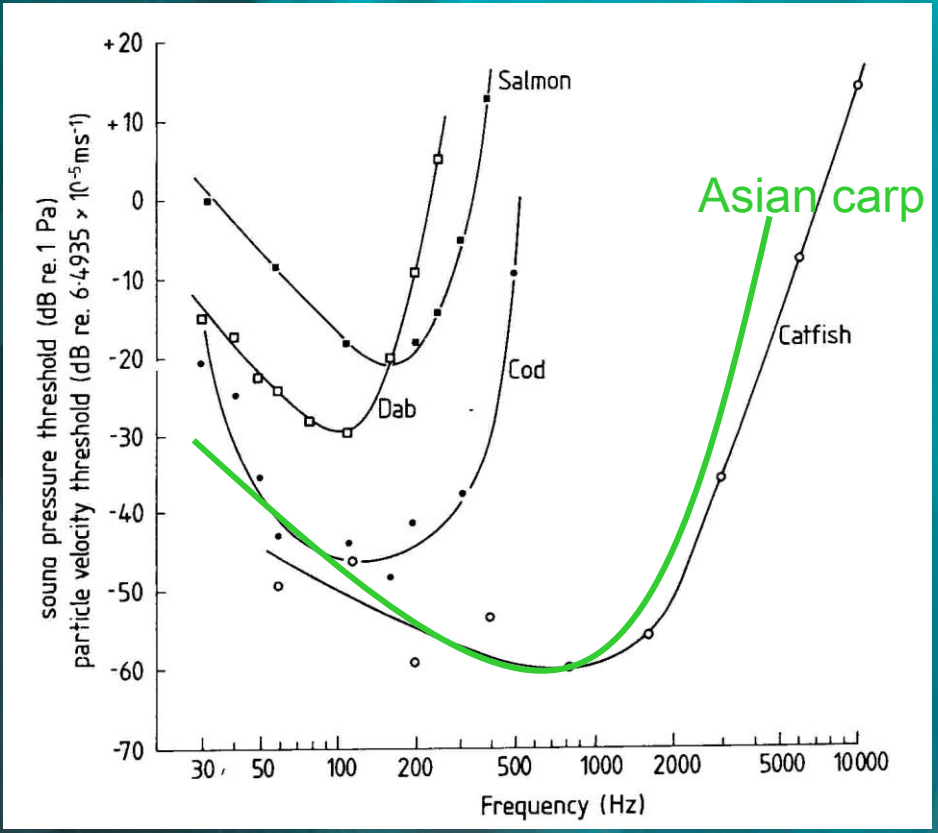
How do fish React?

- The video shows the typical reaction of koi carp to an acoustic stimulus
- The fish move away to a position where they are comfortable with the level of sound

Fish Hearing

- High Sensitivity: 'hearing specialists': clupeids, cyprinids (carp family), catfish etc.
- Moderate sensitivity: most roundfish e.g. cod
- Low sensitivity: bottom fish and those without swimbladder

Fish Hearing



- Most fish are sensitive to sounds less than 3000Hz
- Audiograms can be measured using Acoustic Brainstem Response (ABR) technique
- Frequency composition of signal can be adjusted as necessary

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Acoustic Barrier Efficiencies for Cyprinids

Expected Deflection Efficiencies

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FISH GUIDANCE SYSTEMS LTD (FGS) - PERFORMANCE EFFICIENCIES OF ACOUSTIC SYSTEMS

There continues to be a steady improvement in the screening efficiency of FGS acoustic systems resulting from improvements in the design of acoustic installations and the introduction of new improved equipment (e.g. Doel and Hartlepool). Acoustic systems are used either to **deflect** fish away from a water intake (e.g. cooling water, pumping station, etc) or to **guide** fish away from an intake towards a fish pass or by-wash, which is more difficult to achieve. Each site has a unique range of site conditions affecting performance efficiencies. Key variables include the species and size of fish, background noise, hydraulic conditions (e.g. intake velocities, attraction flow to the fish pass) and acoustic design. FGS have obtained independent scientific results from the following 6 installations.

No.	Project / Objective	Site Conditions	Acoustic Installation	Deflection Efficiencies %
1	**Doel Nuclear Power Station** Deflect estuarine fish away from cooling water intake	Tidal estuary 2,000 MW power station Offshore intakes 3 & 4	Installed 1997 20 off FGS Mk II 30-600 sound projectors 1 off FGS Signal Generator (1 signal) 18 off FGS Model 400 Amplifiers	Overall reduction - 80% Herring *(Clupea harengus)* - 98% Sprat *(Sprattus sprattus)* - 97% Bass *(Dicentrarchus labrax)* - 89% Gobies *(Gobidae)* – 75% * Nov. 1999 trial
2	**Hartlepool Nuclear Power Station** Deflect estuarine fish away from cooling water intake	Tidal estuary 1,200 MW power station Eight onshore intakes and four pumps Intake flow 34 m^3/sec	Trial 1995 12 off FGS Mk I 30-600 sound projectors 1 off FGS Signal Generator (1 signal) 12 off FGS Model 400 Amplifiers	Overall reduction - 56% Sprat *(Sprattus sprattus)* - 60% Herring *(Clupea harengus)* - 80%
3	**Foss Barrier Pumping Station** Deflect coarse fish away from pumps prior to and during operation	Freshwater Flood relief pumping station Intake flow 32 m^3/sec	Installed 1994 6 off FGS Mk I 30-600 sound projectors 1 off FGS Signal Generator (1 signal) 6 off FGS Model 400 Amplifiers	Overall reduction - 80% Roach *(Rutilus rutilus)* 68% Bleak *(Alburnus alburnus)* 72% Dace *(Leuciscus leuciscus)* 76% Chub *(Leuciscus cephalus)* - 88% Perch *(Perca fluviatilis)* -56% Bream *(Abramis brama)* -74%
4	**Institute of Freshwater Ecology** Guide salmon and sea trout smolt into by-wash and through fish counters	Freshwater River flow - 75 % By-wash flow - 25%	Installed 1995 24 m long BAFF (10 units) 1 off BAFF control unit 1 off air blower	Salmon smolt *(Salmo salar)*- 88% Sea trout smolt *(Salmo trutta)* - 88%
5	**Farmoor Water Treatment Works Pumping Station** Deflect juvenile coarse fish juveniles away from water intake	Freshwater 4 intakes Max. intake flow 2.7 m^3/sec Intake flow 1.5 m^3/sec during trial River flow 3.6 m^3/sec during trial	Installed 1998 8 FGS Mk II 15-100 sound projectors 1 FGS 1-08 Signal Generator 1 FGS Model 400 Amplifier	Overall coarse fish reductions - 80%
6	**Blantyre Hydro Station** Guide salmon and sea trout smolt towards fish pass.	Freshwater 575 kW hydro station Intake flow - 95% Fish pass flow - 5%	Trial 1996 24m long BAFF (SPA driven) 1 air blower	Salmon smolt *(Salmo salar)* - 74% Sea trout smolt *(Salmo trutta)* -74% Coarse fish - 92%

FGS Reference: Efficiencies of FGS Systems 01-01

Foss Barrier Pumping Station

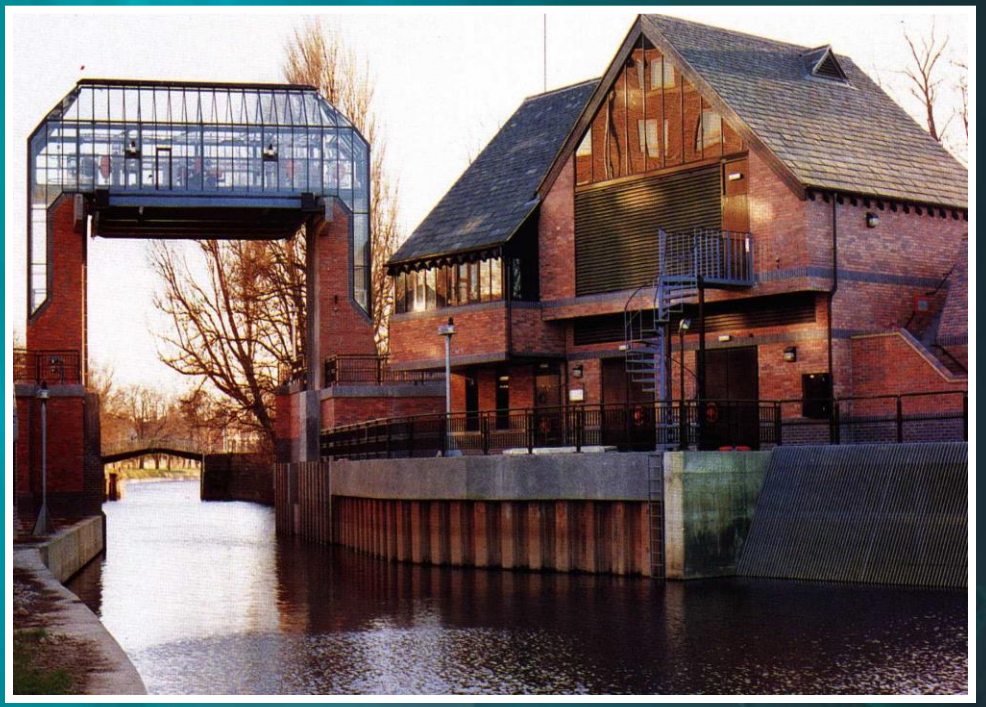
Fish Guidance Systems

- SPA System
- Installed 1994
- Freshwater
- Deflects coarse fish away from pumps prior to operation
- System comprises

  6 MkI 30-600 Sound Projectors

  6 Model 400 amplifiers

  1 FGS signal generator (1 signal)



Foss Barrier - Results

- Overall Reduction 80%

Bleak *(Alburnus alburnus)*	72%
Bream *(Abramis brama)*	74%
Chub *(Leuciscus cephalus)*	88%
Dace *(Leuciscus leuciscus)*	76%
Roach *(Rutilus rutilus)*	68%
Perch *(Perca fluviatilis)*	56%

Design Requirements

Fish Guidance Systems

Design elements for a system include

- Identification of key fish species and species characteristics (inc. size, maximum swimming speed and seasonal variations)
- Signal selection for key fish species
- System Selection
- Sound Projector location
- Hydraulic & Acoustic (PrISM) modelling to optimise Sound Projector position and layout
- Design of Sound Projector deployment system
- Other Considerations

Other Considerations

Fish Guidance Systems

Location of Control Equipment / compressor

Requirement for air conditioning

Cable / Pipe routes between Control Equipment and Sound Projectors

Length of cable runs and potential voltage drop

Power backup in event of power cuts

Redundancy built into the system

Spare Components and availability

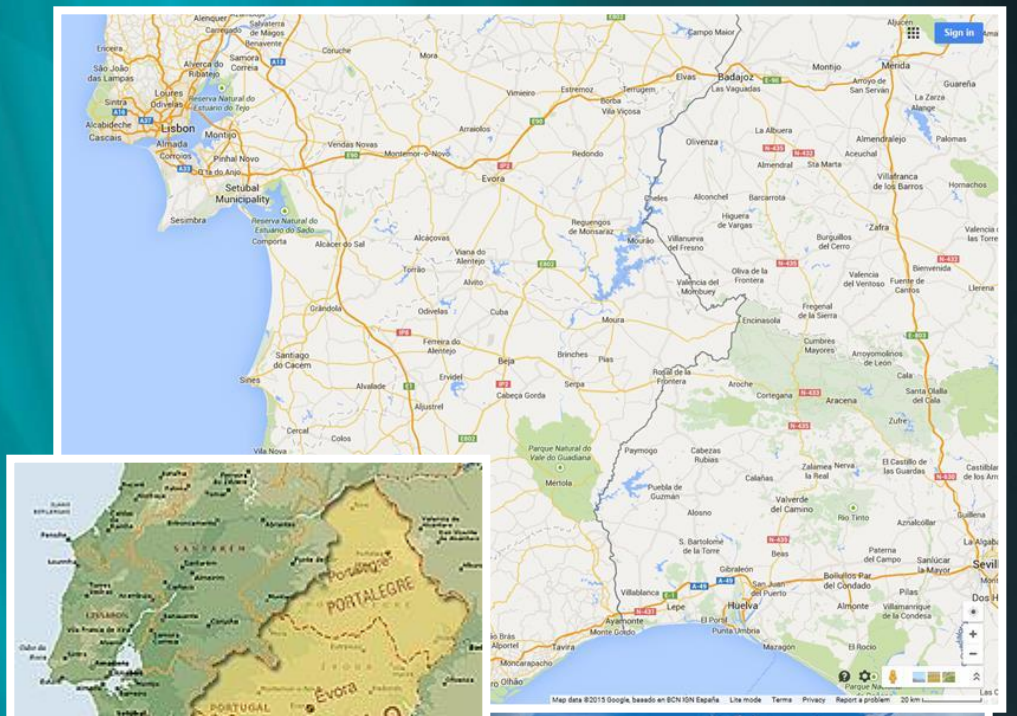
Fish Guidance Systems

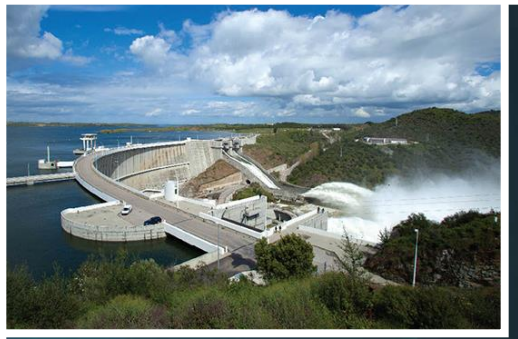
Use of AFDs to Control Invasive Fish Species

Alqueva Project

Fish Guidance Systems

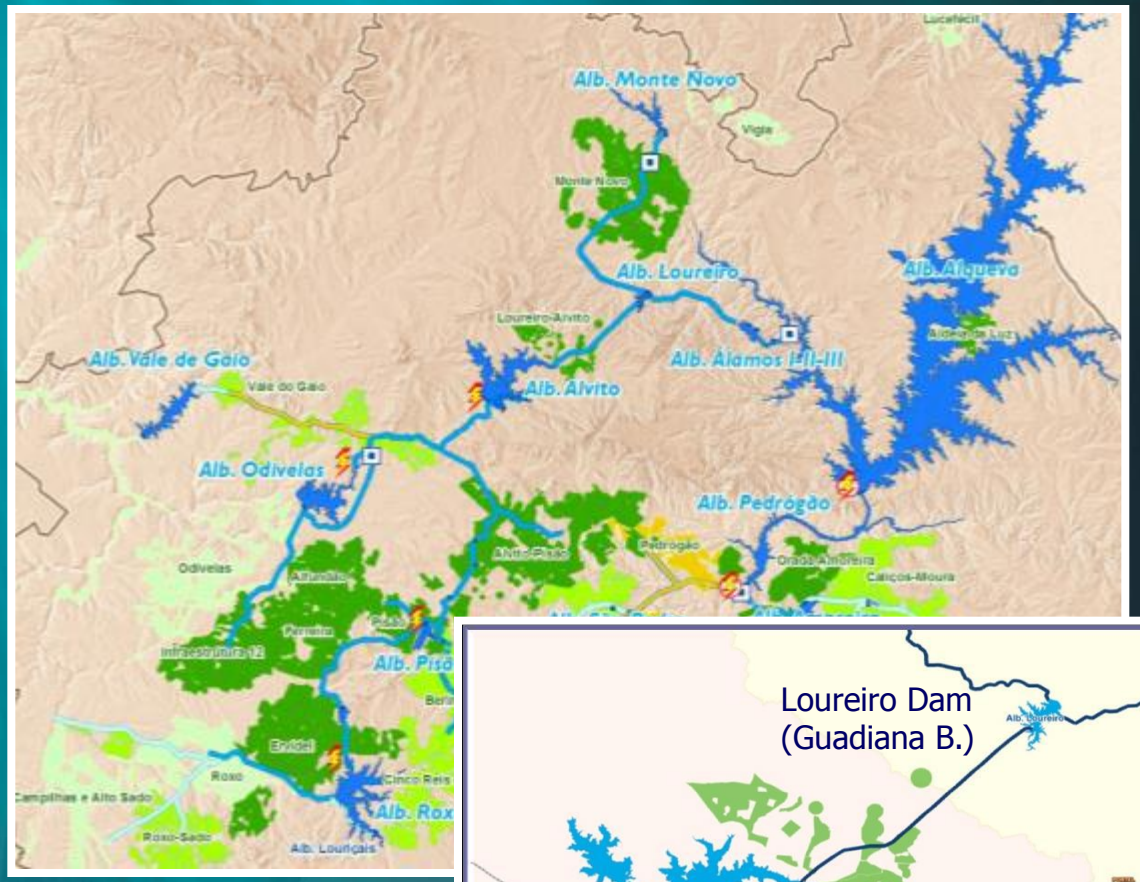
- Major irrigation and hydro power Scheme in Alentejo, Southern Portugal
- Flooded area – 250 km^2
- Largest man made lake in Europe
- Irrigates 120,000 hectares





Alqueva Project

- Project includes transfer from Loureiro Reservoir, Guadiana catchment to Sado catchment
- 11 km link between reservoirs



Alqueva Project

Fish Guidance Systems

- Concern over transfer of cyprinid fish not present in Sado catchment
- Loureiro intake designed to minimise fish entrainment
- For additional protection EDIA requested FGS to install acoustic Fish Deflection System

Alqueva Project

Fish Guidance Systems

- PrISM modelling to determine acoustic field
- Minimum system should be 12 FGS MkII 30-600 Sound Projectors
- Deployment system designed for additional projectors, if needed
- System installed 2006

Fish Guidance Systems

Asian Carp

Asian Carp

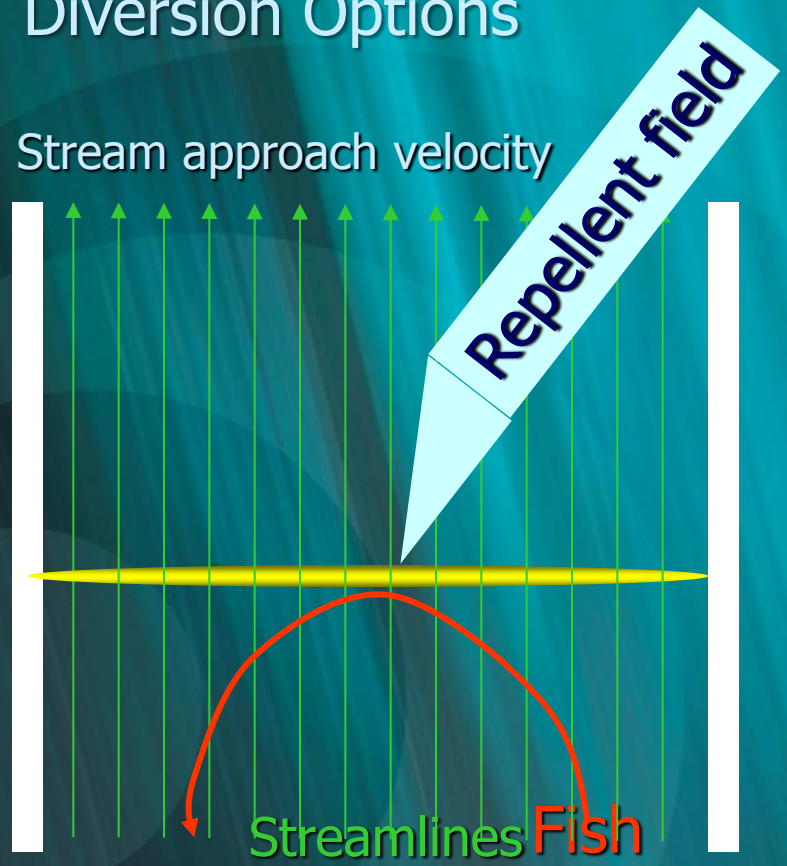
Fish Guidance Systems

- Related to common carp
- Imported into USA by catfish farmers in 1970s
- Present in Mississippi River and Chicago Sanitation Canal, which connects Mississippi to Lake Michigan
- Voracious feeders and prolific spawners
- US EPA: ”significant risk to the Great Lakes ecosystem”

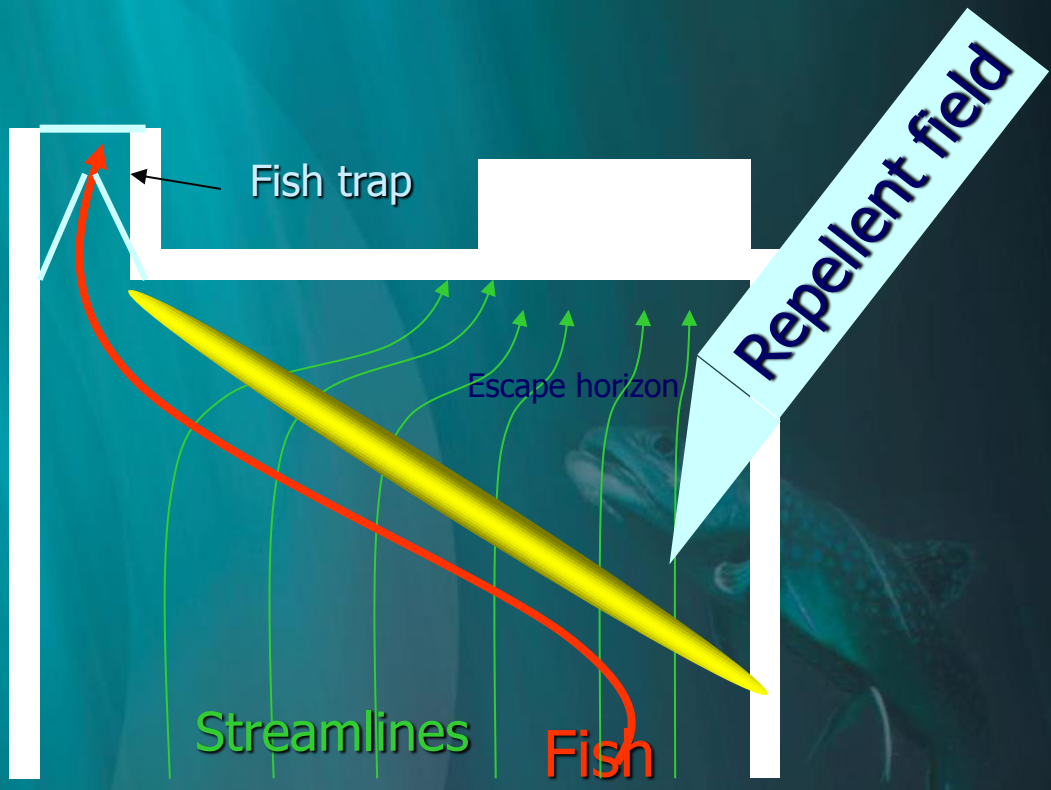
Asian Carp

Fish Guidance Systems

- Diversion Options



Blocking



Deflection /Trapping

Asian Carp

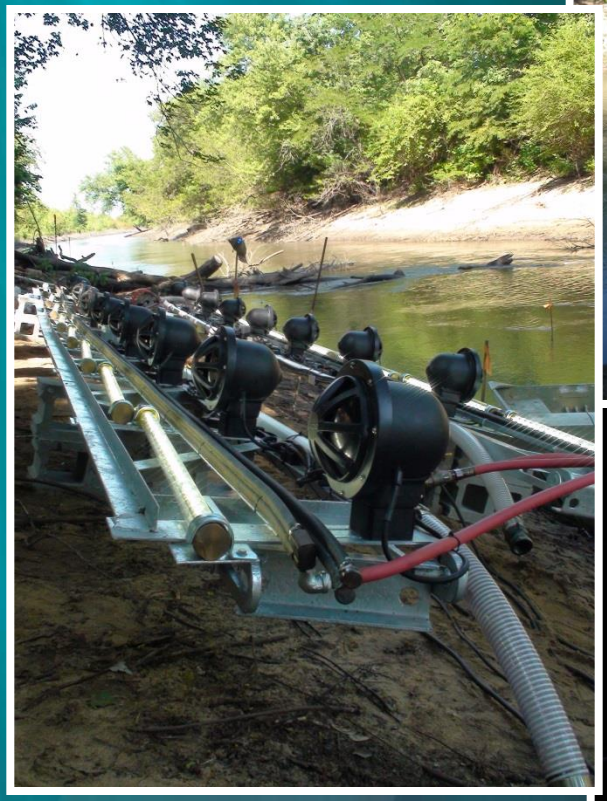
Fish Guidance Systems

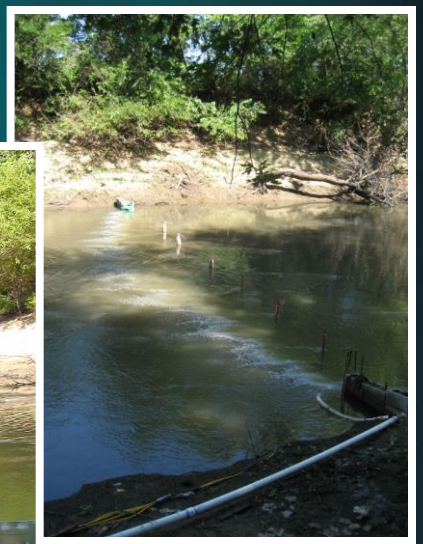
- FGS systems evaluated by Illinois Natural History Survey (INHS)
- First evaluation 2003
- BAFF installed in hatchery raceway
- Initial results demonstrated 57% deflection efficiency for silver carp
- Signal changed – resulted in 95% deflection efficiency

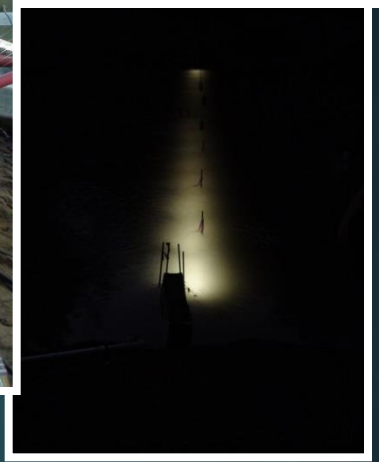
Asian Carp

Fish Guidance Systems

- Later INHS trials 2009-2010 at Quiver Creek Research Station
- 16m BAFF with SILAS technology located across channel
- Upstream dam blocking fish movement
- Flow 0.4-0.8 m/s

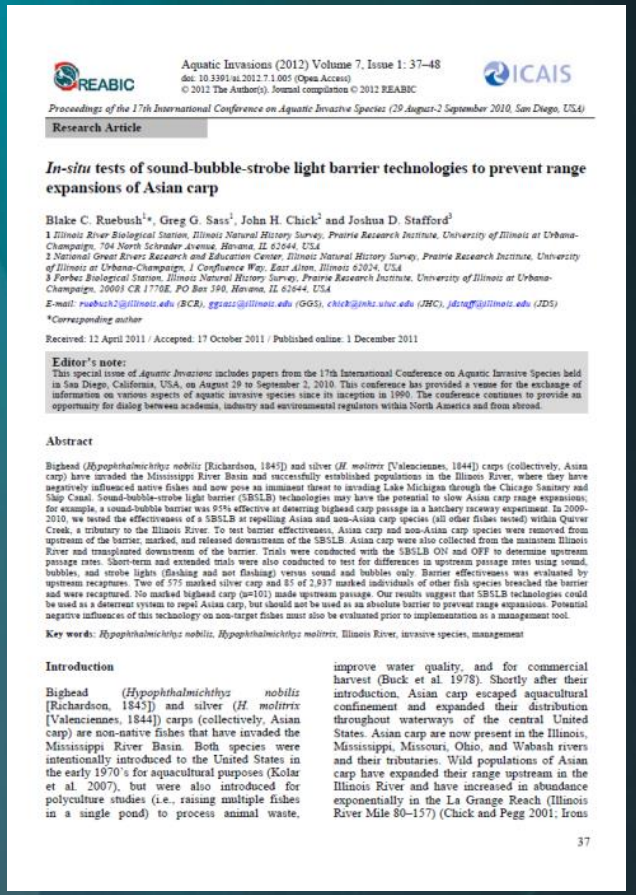






Asian Carp

- System evaluated by electrofishing 200m between barrier and dam
- Monitored fish movement back into cleared area
- Results indicated
- 100% effective for silver carp (2009)
- 99.7% effective for silver carp (2010)
- 100% efficient for bighead carp (2010)
- All non-Asian carp species – 97% deflection efficiency
- Largemouth Bass - 97.8% effective
- Channel catfish – 100% effective



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ICAIS
Proceedings of the 17th International Conference on Aquatic Invasive Species (29 August-2 September 2010, San Diego, USA)
Research Article

In-situ tests of sound-bubble-strobe light barrier technologies to prevent range expansions of Asian carp

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Editor's note:
This special issue of *Aquatic Invasions* includes papers from the 17th International Conference on Aquatic Invasive Species held in San Diego, California, USA, on August 29 to September 2, 2010. This conference has provided a venue for the exchange of information on various aspects of aquatic invasive species since its inception in 1990. The conference continues to provide an opportunity for dialog between academia, industry and environmental regulators within North America and from abroad.

Abstract

Bighead (*Hypophthalmichthys nobilis* [Richardson, 1845]) and silver (*H. molitrix* [Valenciennes, 1844]) carps (collectively, Asian carp) have invaded the Mississippi River Basin and successfully established populations in the Illinois River, where they have negatively influenced native fishes and now pose an imminent threat to invading Lake Michigan through the Chicago Sanitary and Ship Canal. Sound-bubble-strobe light barrier (SBSLB) technologies may have the potential to slow Asian carp range expansions; for example, a sound-bubble barrier was 95% effective at deterring bighead carp passage in a hatchery raceway experiment. In 2009-2010, we tested the effectiveness of a SBSLB at repelling Asian and non-Asian carp species (all other fishes tested) within Quiver Creek, a tributary to the Illinois River. To test barrier effectiveness, Asian carp and non-Asian carp species were removed from upstream of the barrier, marked, and released downstream of the SBSLB. Asian carp were also collected from the mainstem Illinois River and transplanted downstream of the barrier. Trials were conducted with the SBSLB ON and OFF to determine upstream passage rates. Short-term and extended trials were also conducted to test for differences in upstream passage rates using sound, bubbles, and strobe lights (flashing and not flashing) versus sound and bubbles only. Barrier effectiveness was evaluated by upstream recaptures. Two of 575 marked silver carp and 85 of 2,937 marked individuals of other fish species breached the barrier and were recaptured. No marked bighead carp (n=101) made upstream passage. Our results suggest that SBSLB technologies could be used as a deterrent system to repel Asian carp, but should not be used as an absolute barrier to prevent range expansions. Potential negative influences of this technology on non-target fishes must also be evaluated prior to implementation as a management tool.

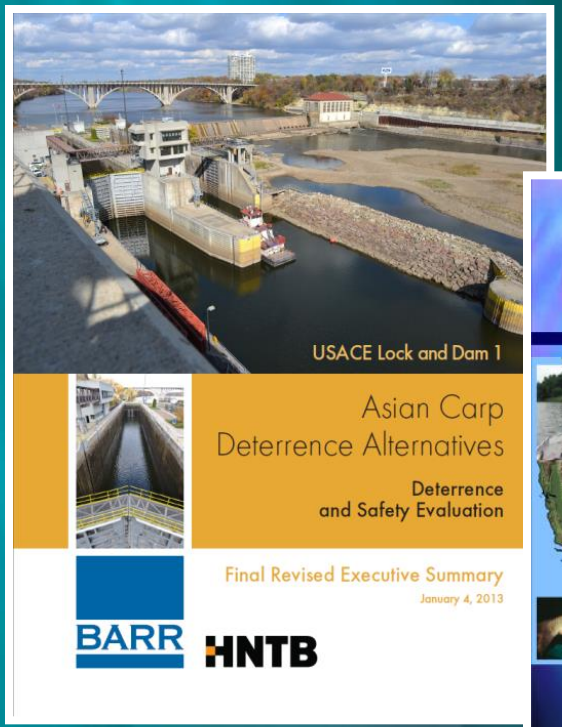
Key words: *Hypophthalmichthys nobilis, Hypophthalmichthys molitrix*, Illinois River, invasive species, management

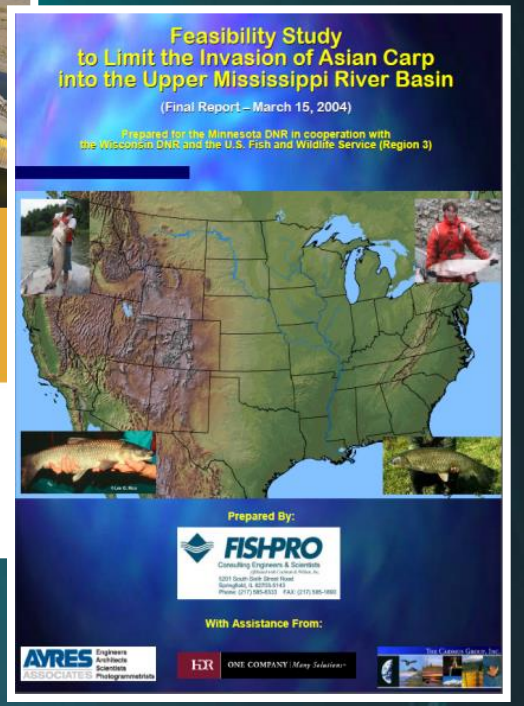
Introduction

Bighead (*Hypophthalmichthys nobilis* [Richardson, 1843]) and silver (*H. molitrix* [Valenciennes, 1844]) carps (collectively, Asian carp) are non-native fishes that have invaded the Mississippi River Basin. Both species were intentionally introduced to the United States in the early 1970's for aquacultural purposes (Kolar et al. 2007), but were also introduced for polyculture studies (i.e., raising multiple fishes in a single pond) to process animal waste, improve water quality, and for commercial harvest (Buck et al. 1978). Shortly after their introduction, Asian carp escaped aquacultural confinement and expanded their distribution throughout waterways of the central United States. Asian carp are now present in the Illinois, Mississippi, Missouri, Ohio, and Wabash rivers and their tributaries. Wild populations of Asian carp have expanded their range upstream in the Illinois River and have increased in abundance exponentially in the La Grange Reach (Illinois River Mile 80–157) (Chick and Pegg 2001; Irons

Asian Carp

- Behavioural barriers reviewed in two separate independent reviews
- FGS BAFF system recommended as best available technology in both reports

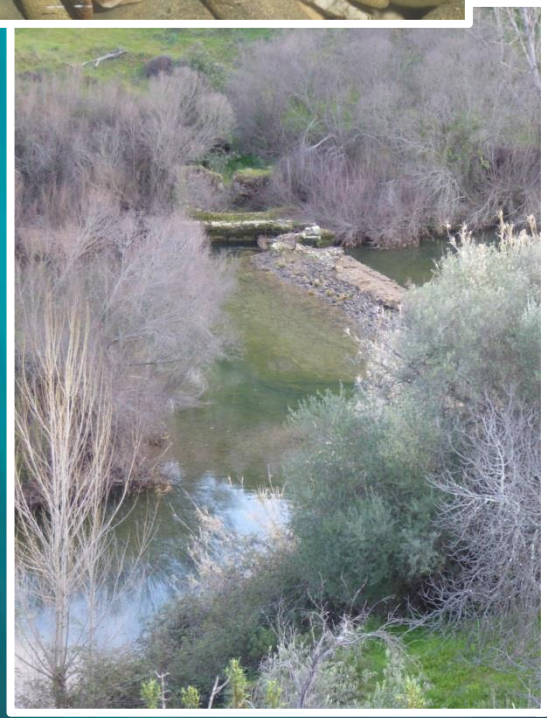


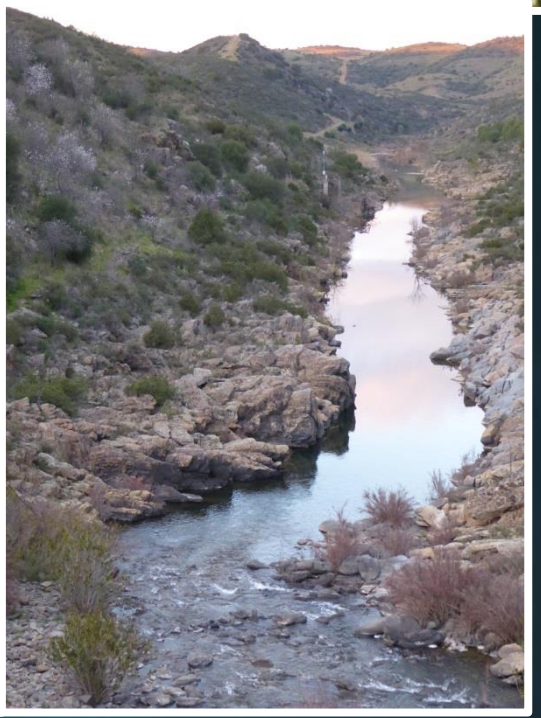


Saramugo (*Anaecypris hispanica*) Protection

Fish Guidance Systems

- Number of exotic species entering rivers, threatening Saramugo
- Main aim to prevent bleak (*Alburnus alburnus*) entering Vascão River
- Number of possible sites for barrier





Conclusions

- Number of behavioural systems available
- Acoustic based system most suitable for cyprinids
- Cyprinids very sensitive to sound, with deflection efficiencies 80%+ with some species demonstrating up to 100%
- System selection dependant upon application
- Requirement to block movement of bleak to protect the Saramugo
- Number of sites where barrier could be installed

Fish Guidance Systems

Any Questions?