Addressing Impingement and Entrainment Issues. Experiences from the USA

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First International Fish Impingement and Entrainment Conference, Liverpool, UK
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Note: Presentation is my opinion based on science and experience and does not necessarily reflect the views of EPRI

1. Regulatory history and current impingement and entrainment rules in the U.S. with comments and critique

2. What do we really know about impingement?

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EPRI

KEY ASPECTS

Nonprofit

Chartered to serve the public benefit, with guidance from an independent advisory council.

Thought Leadership

Systematically and imaginatively looking ahead to identify issues, technology gaps, and broader needs that can be addressed by the electricity sector.

Independent

Objective, scientific research leading to progress in reliability, efficiency, affordability, health, safety, and the environment.

Scientific and Industry Expertise

Provide expertise in technical disciplines that bring answers and solutions to electricity generation, transmission, distribution, and end use.

Collaborative Value

Bring together our members and diverse scientific and technical sectors to shape and drive research and development in the electricity sector.

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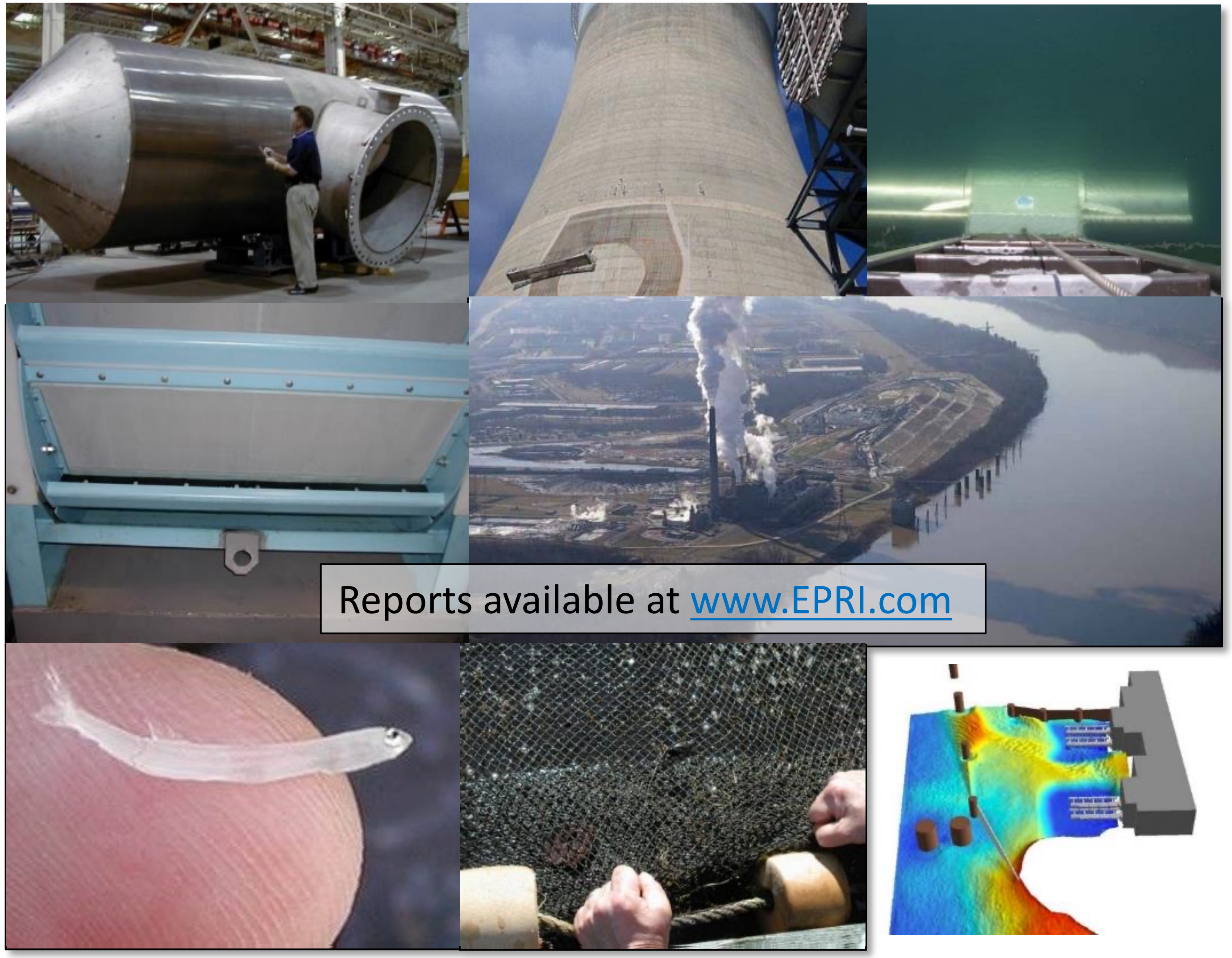
EPRI research

- 100s of Technical Reports on Fish Protection Topics:
  - Hydraulic zone of influence
  - Comprehensive technology manuals
  - Impingement and entrainment databases
  - Closed cycle cooling costs, benefits, environmental impacts
  - Evaluating technology alternatives
  - Traveling screens (Fine-mesh, coarse-mesh)
  - Fish returns
  - Wedgewire screens (narrow-slot)
  - Barrier nets
  - Behavioral deterrents
  - Variable speed drives and flow reduction
  - Impingement and entrainment monitoring
  - Use of DNA for identification
  - Social Costs and benefits
  - Biological modeling (equivalent adults, biomass foregone, lost fisheries yield)
  - Peer review
  - Screen optimization studies
  - Many others!



Reports available at www.EPRI.com

EPRI has done extensive research on fish protection at cooling water intakes

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Fish protection in the U.S.

- Fish protection in U.S. is covered by Section 316(b) of the Clean Water Act
- § 316(b) requires that ***"the location, design, construction, and capacity of cooling water intake structures reflect the best technology available for minimizing adverse environmental impact"***
- The U.S. Environmental Protection Agency (EPA) has the authority to uphold this statue, BUT has delegated that authority to most (but not all) States
- In 2014 EPA issued a new rule for implementing § 316(b) at existing power plants – a culmination of 19 years of rulemaking

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The 2014 § 316(b) existing facility rule

- The Rule addresses impingement and entrainment separately
- Applies to facilities >2 million gallons per day (MGD) [~7,600 m^3/day] [~ 544 Power Plants]
- There are basic reporting requirements for all facilities
- For facilities >125 MGD [~473,000 m^3/day] there are additional studies related to entrainment

Impingement

Juveniles and adults

Entrainment

Eggs and larvae

Rule differentiates impingeable organisms from entrainable organisms by their ability to pass through or be retained by a sieve with maximum opening dimension of 0.56 in.

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The 2014 § 316(b) existing facility rule

- Entrainment studies:
  - Entrainment Characterization Study
  - Comprehensive Technical Feasibility and Cost Evaluation Study
  - Benefits Evaluation Study
  - Non-Water Quality and Other Environmental Impacts Study
- Permit writer (Director) must determine the Best Technology Available (BTA) for entrainment based on several factors
  - Almost half (5 of the 11) “must” and “may” factors that Directors can or will consider when making a BTA determination are geared primarily toward closed-cycle cooling

Director Must Consider

- Numbers and types of organisms
- Impact of changes in particulate emissions and other pollutants associated with technology (CCRS only)
- Land availability (Primarily CCRS)
- Remaining useful life of facility and
- Quantified and qualitative social benefits and costs of entrainment technologies

Director May Consider

- Entrainment impacts on waterbody
- Thermal discharge impacts (Primarily CCRS)
- Credit for flow reductions for retired units (last 10 years)
- Impacts on reliability of energy delivery in immediate area (CCRS only)
- Impacts on Water Consumption (CCRS only)
- Availability of alternative water sources

CCRS = Closed Cycle Recirculating Systems

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The 2014 § 316(b) existing facility rule

Impingement Compliance

1. Closed-cycle cooling (or equivalent)
2. ≤ 0.5 ft/sec (15.2 cm/sec) through-screen design velocity
3. ≤ 0.5 ft/sec through-screen actual velocity w/ daily monitoring
4. Existing offshore velocity cap
5. Modified traveling water screen (optimized)
6. System of technologies and/or operational measures (optimized)
7. Impingement mortality performance standard of <24% over 12-month period w/monthly sampling

Exemptions or reduced impingement requirements for "*de minimis*" impingement rates, low capacity utilization (<8%), stocked and managed fisheries

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U.S. Rule – high points

- Recognizes site-specific nature of I&E and doesn't have a one-size-fits-all approach
- Leaves the door open to the development of new technologies
- Considers social costs and benefits
- Gives considerable compliance flexibility to the applicant (and discretion to the permit Director)
- Assumes flow reduction results in commensurate reductions in I&E

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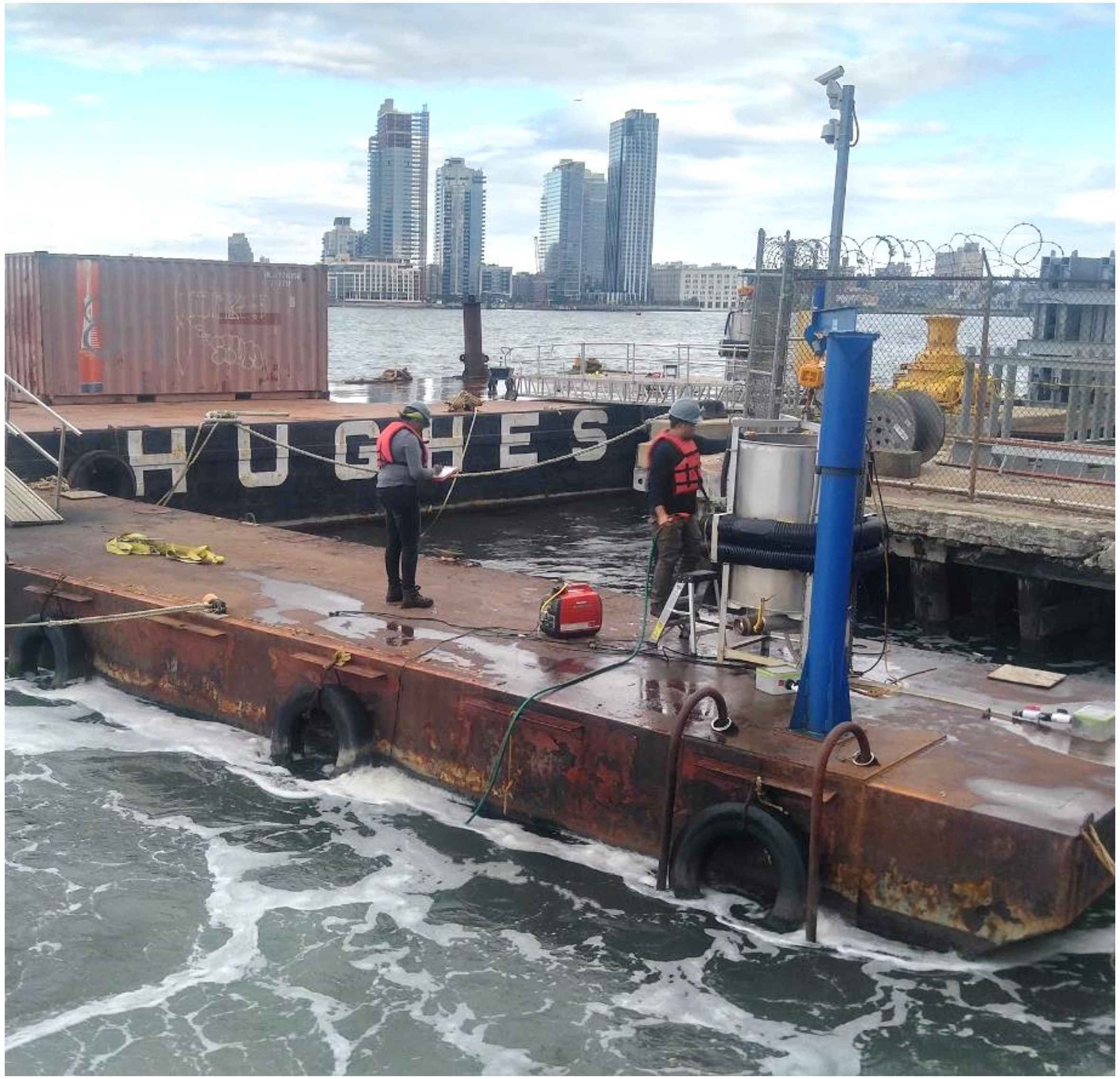
U.S. Rule – lost opportunities

- Excludes restoration or mitigation
- Ignores potential synergies between entrainment and impingement
- Doesn’t look at community or population-level effects. In the Rule, AEI = I&E
- No eye toward cumulative impacts
- 0.5 ft/sec through-screen velocity is overly conservative and approach velocity is probably a better metric



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What Do We Know About Impingement?

Spoiler 1: Impingement is episodic and mostly unpredictable

Spoiler 2: A lot of what we know, we've known for ~50 years

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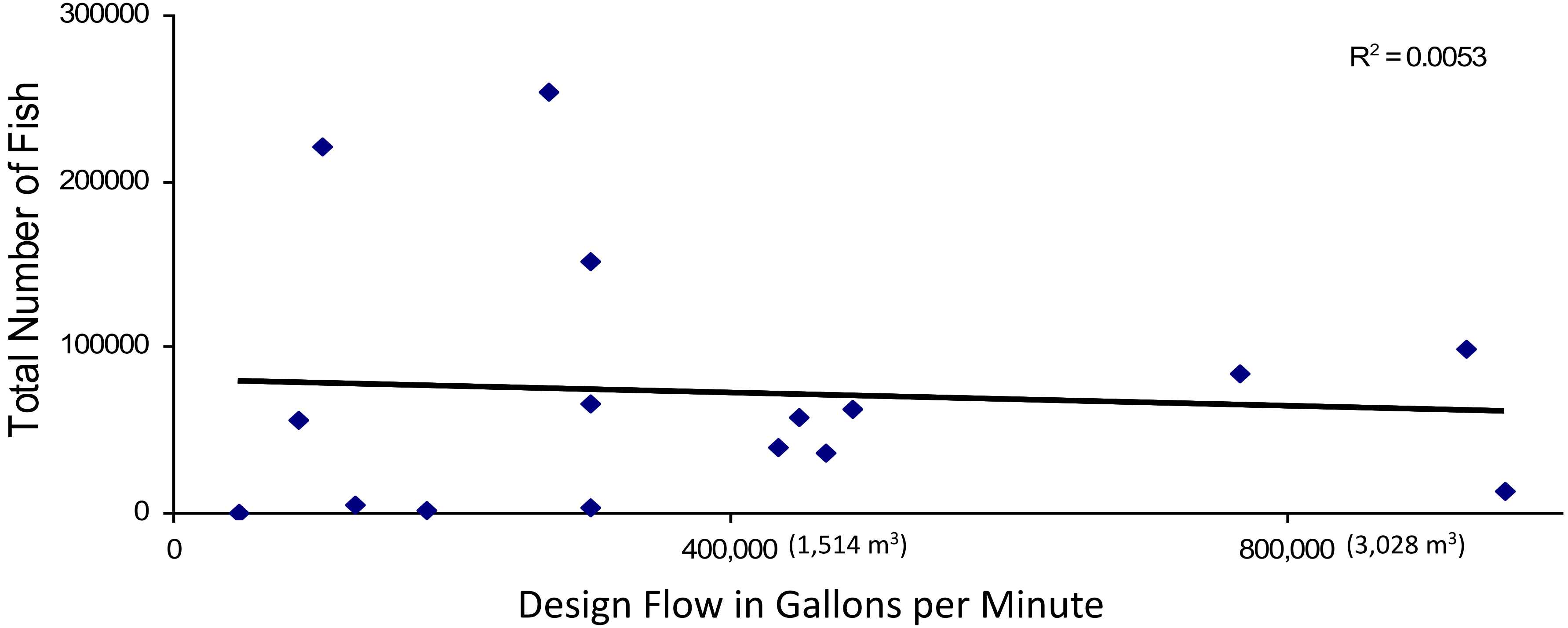
Intake flow versus total number of fish impinged

Data from 16 power plants



Benda & Houtcooper 1976

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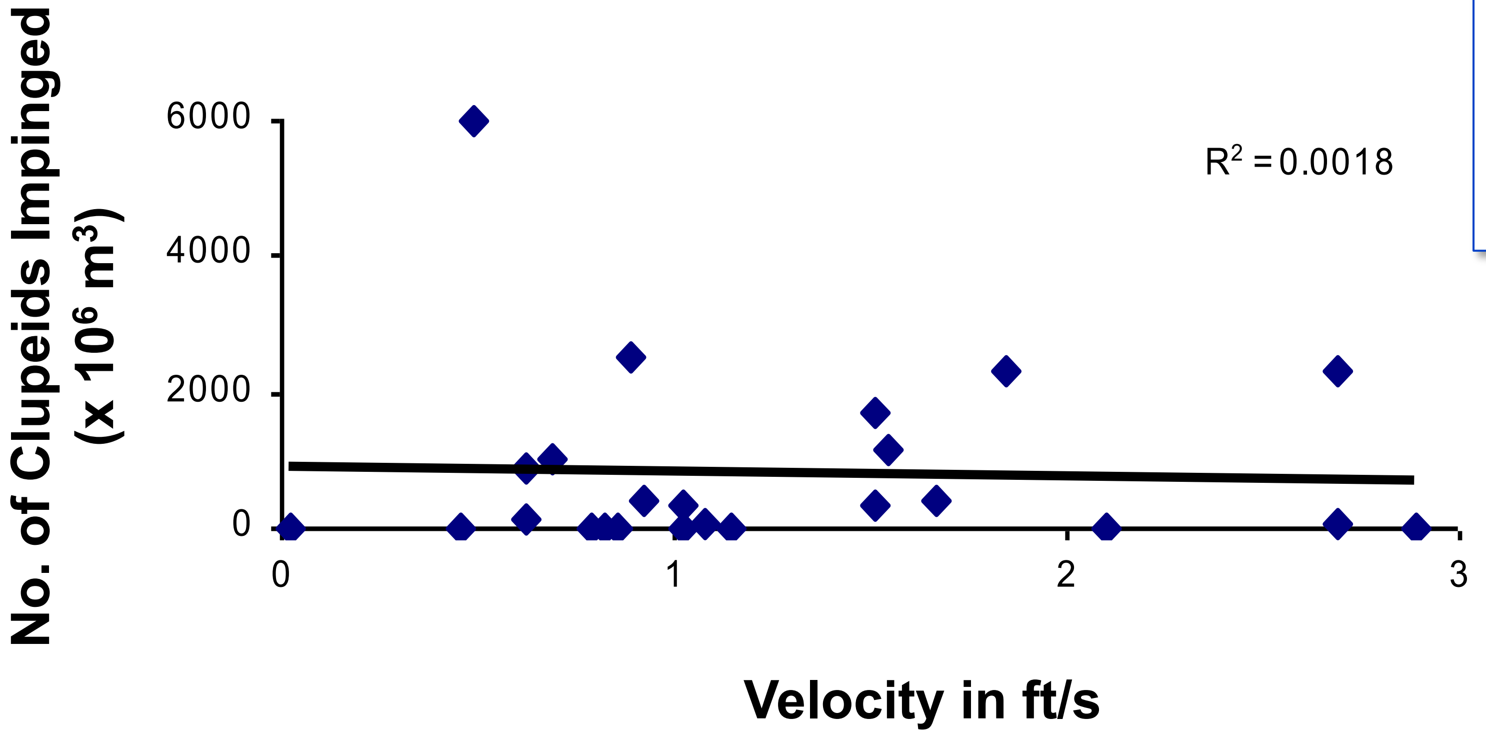
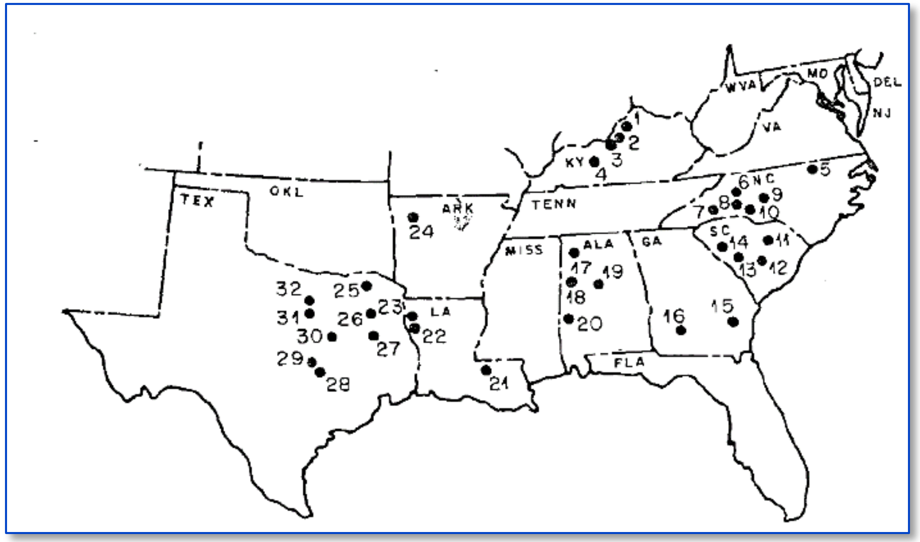
Velocity versus impingement of Clupeids at 24 Southeastern U.S. power plants





Loar et al. 1978

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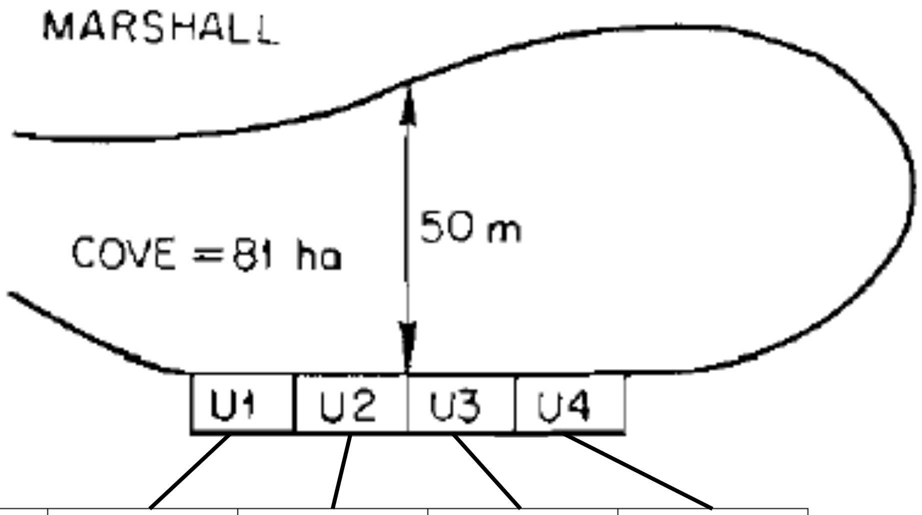
Differences in impingement across units at Marshall Power Plant, Lake Norman, NC



Winter Max Condenser Cooling Water Flow (x 10^6 m^3/day)	5.60	5.60	6.85	6.85
Max Velocity (cm/sec)	19	19	21	21
(ft/sec)	0.6	0.6	0.7	0.7

Total Shad	11,954	85,529	94,190	765,022

Loar et al. 1978

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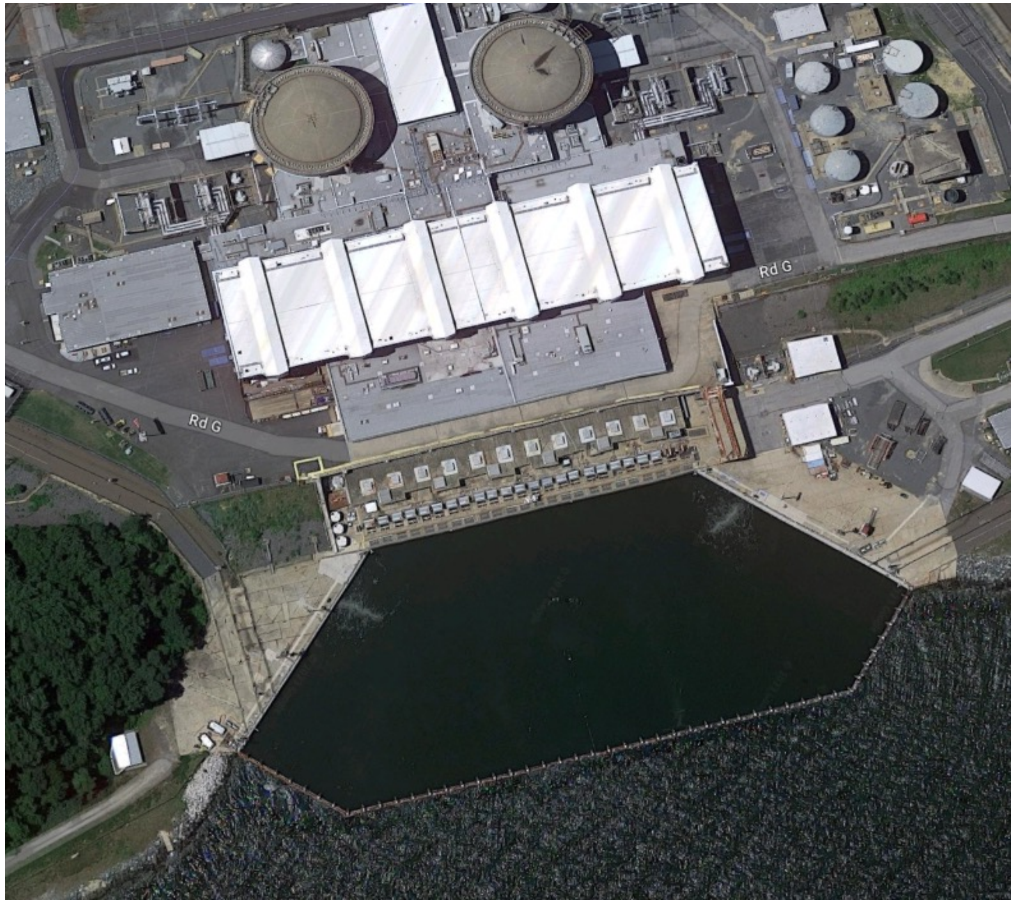
There can be large interannual variability

Year	Total Estimated Impingement
1975	1,765,202
1976	2,223,373
1977	945,579
1978	1,043,776
1979	806,315
1980	1,553,865
1981	1,580,356
1982	836,426
1983	1,846,139
1984	9,671,262
1985	544,897
1986	1,246,150
1987	501,100
1988	864,816
1989	404,566
1990	129,412
1991	264,060
1992	79,081
1993	712,946
1994	149,472
1995	209,988

122x difference



Annual Fin-fish Impingement, Calvert Cliffs (Ringger 2000)

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Fish Health and Condition Play a Role

- Studies conducted at Plant Gorgas (Alabama Power)
- Sampled over three seasons
- Sampled 17 species – presenting data from Gizzard Shad, Threadfin Shad, and Freshwater Drum
- Impinged fish collected and compared to fish electrofished in river near intake

Knight, Terhune, and Garrett 2007

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Fish Health and Condition Play a Role

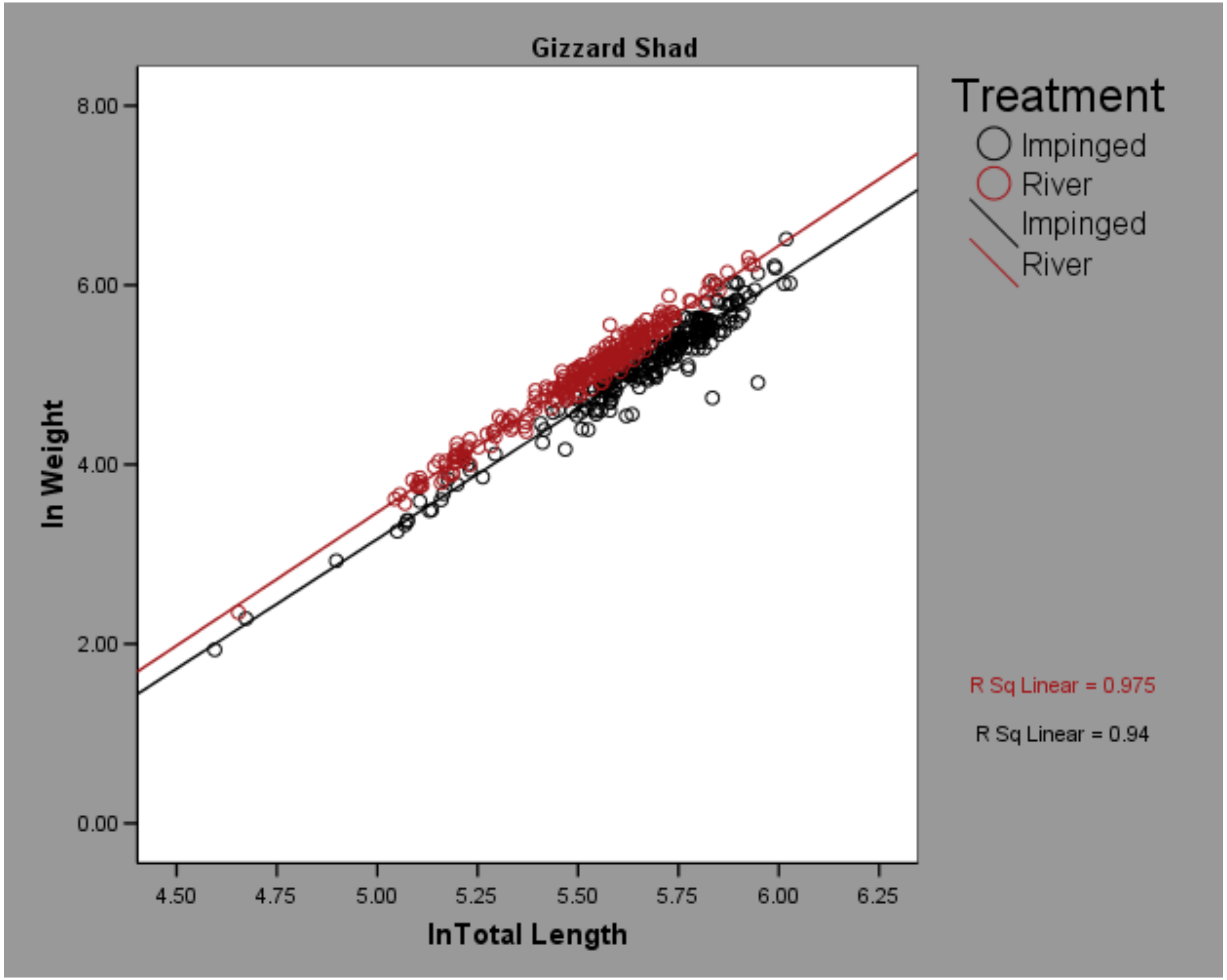
Lnwgt= -11.29+2.89*lnLen

R-Square=0.94

Lnwgt= -11.33+2.96*lnLen

R-Square=0.97

P<0.000



Knight, Terhune, and Garrett 2007

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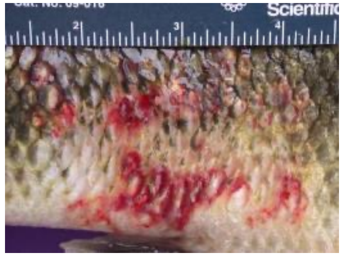
Fish Health and Condition Play a Role

- Conclusions
  - River fish tend to be in better health than those impinged
  - The intake environment may be acting as a selective predator selecting for sicker/weaker fish
  - The intake and canal could be a collection area for a population of fish with higher disease prevalence

Species	Fish (n)	External Lesions	Parasite	Bacteria
Gizzard Shad	Imp (124) River (150)	11.3% 2.0% P=0.001	57.3% 38.0% P=0.001	79.8% 26.0% P<0.000
Threadfin Shad	Imp (98) River (71)	9.2% 0.0% P=0.006	12.2% 15.5% P=0.349	60.2% 19.7% P<0.000
Freshwater Drum	Imp (139) River (35)	7.6% 0.0% P=0.206	87.3% 34.8% P<0.000	64.6% 30.4% P=0.004
All Species Combined	Imp (301) River (244)	9.6% 1.2% P<0.000	50.5% 31.1% P<0.000	69.4% 24.6% P<0.000



Knight, Terhune, and Garrett 2007

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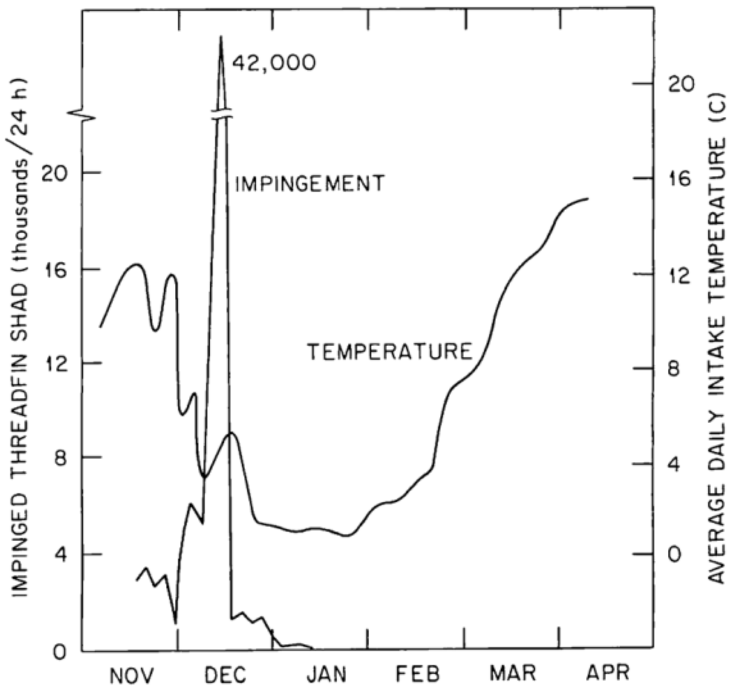
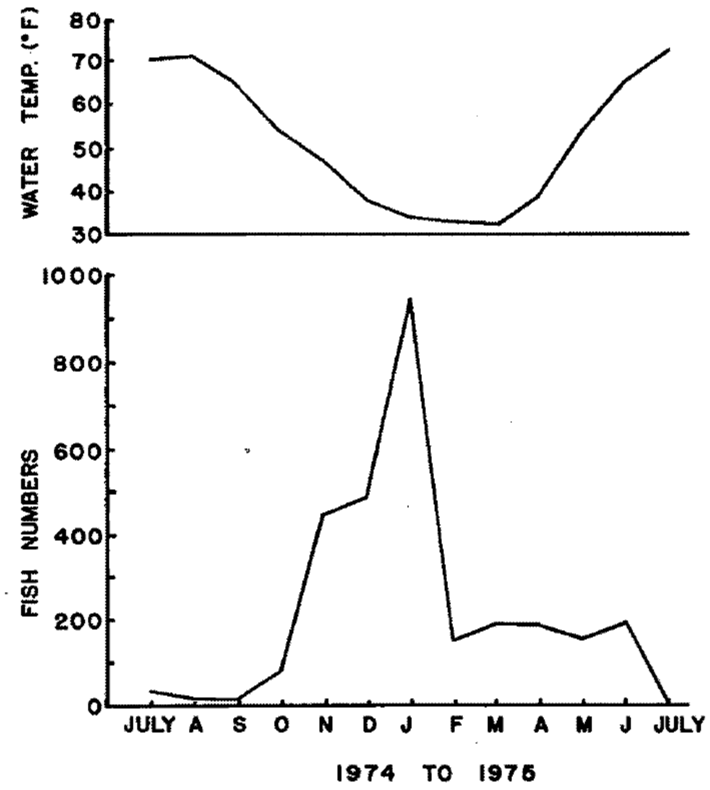
Temperature

In the U.S. shad are particularly susceptible to cold shock



Impingement of threadfin shad at Kingston Steam Plant and water temperatures at the intake canal from November 1976 through April 1977. (McGee et al. 1978)



Relationship between impingement of fish (No. per million gallons per month) and water temperature at C.R. Huntley Power Plant from July 1974 to July 1975. (Lifton and Storr 1978)

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Temperature

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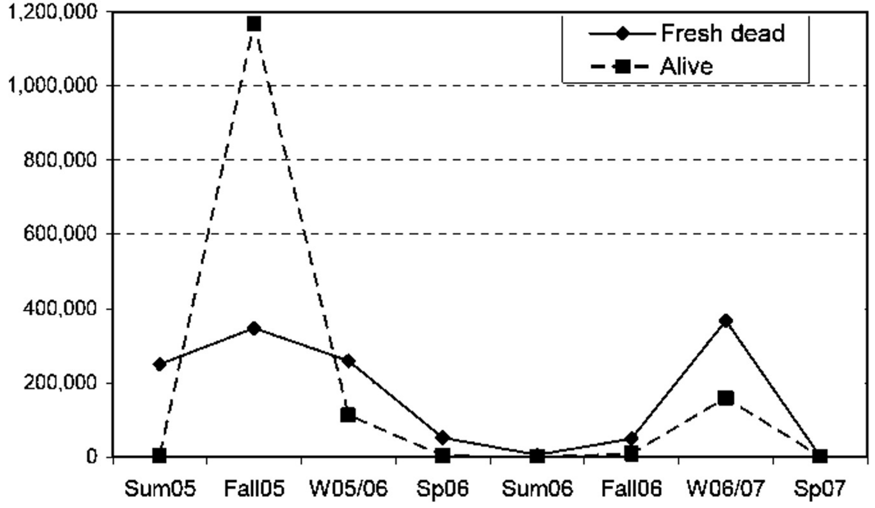

Total number of impinged fish (alive and fresh dead) per season at 15 intake structures on the Ohio River
(*NOTE: the impingement data for fall 2005 included almost 1.1 million live but moribund threadfin shad collected at one power plant in a single day of sampling*)

EPRI 2008

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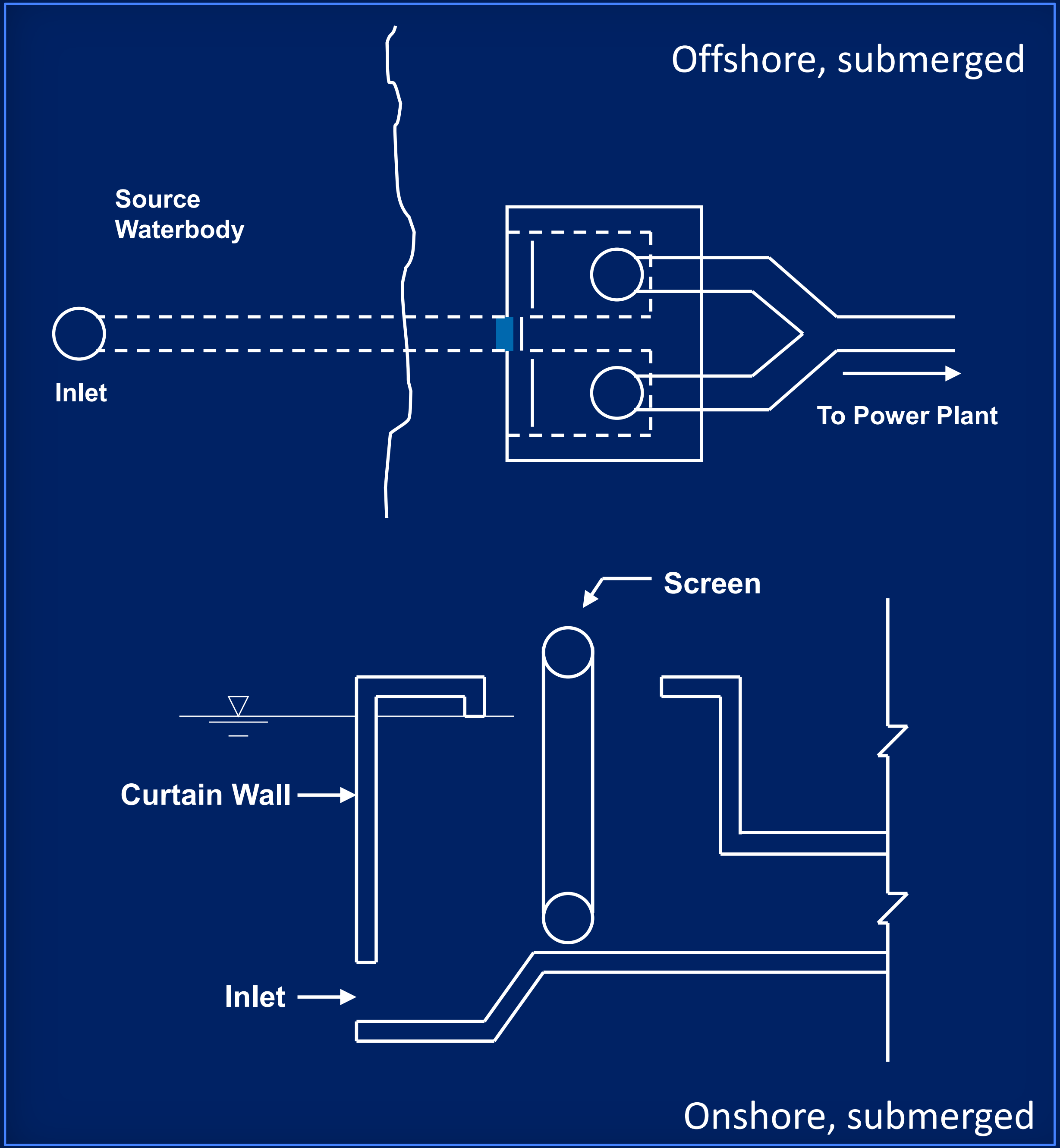
Other factors impacting impingement

- Intake location and orientation
  - Offshore, submerged
  - Shoreline, submerged
  - Shoreline, surface
- Design features
  - Canals
  - Jetties
  - Breakwaters
  - Embayments
  - Characteristics of screening systems
- Water quality
  - Temperature
  - Turbidity
  - Salinity
- Debris loading



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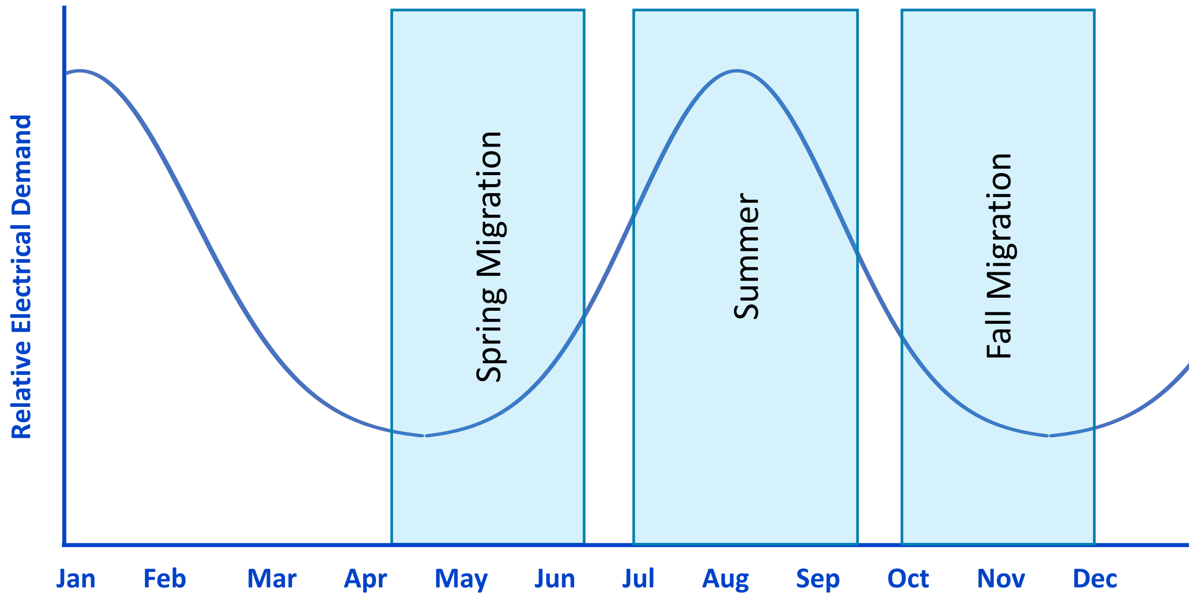
Other factors impacting impingement

- Intake location relative to fish concentrations
  - Juvenile nursery areas
  - Migration pathways
  - Overwintering areas
- Seasonal occurrence
- Vertical distribution and movements



Modified from Dey 2001: UWAG/USEPA Workshop

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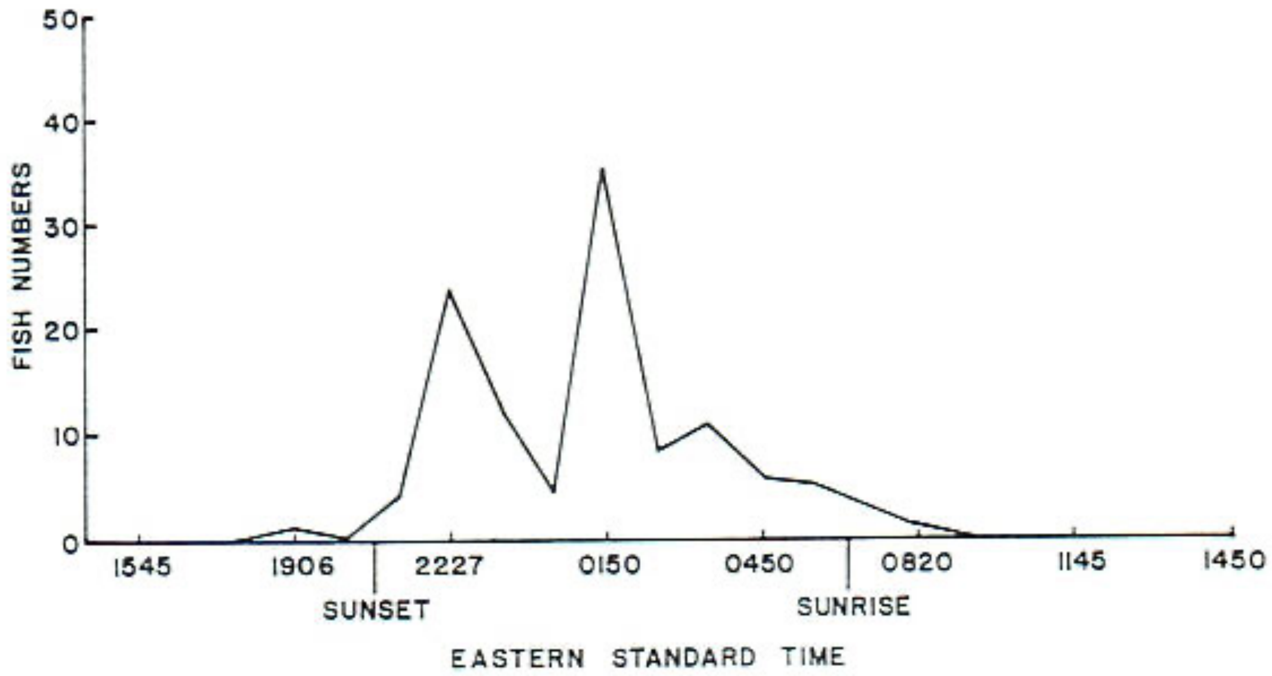
Other factors impacting impingement

- Cross-sectional distribution
  - Habitat preference
  - On-shore vs offshore
- Swimming ability
  - Avoidance
  - Highly species-specific
  - Function of size (growth rate)
  - Function of water temperature
- Physiological stress
  - Spawning
  - High temperature
  - Low dissolved oxygen



Rainbow smelt – C.R. Huntley Plant – Niagara River
(Lifton and Storr 1978)

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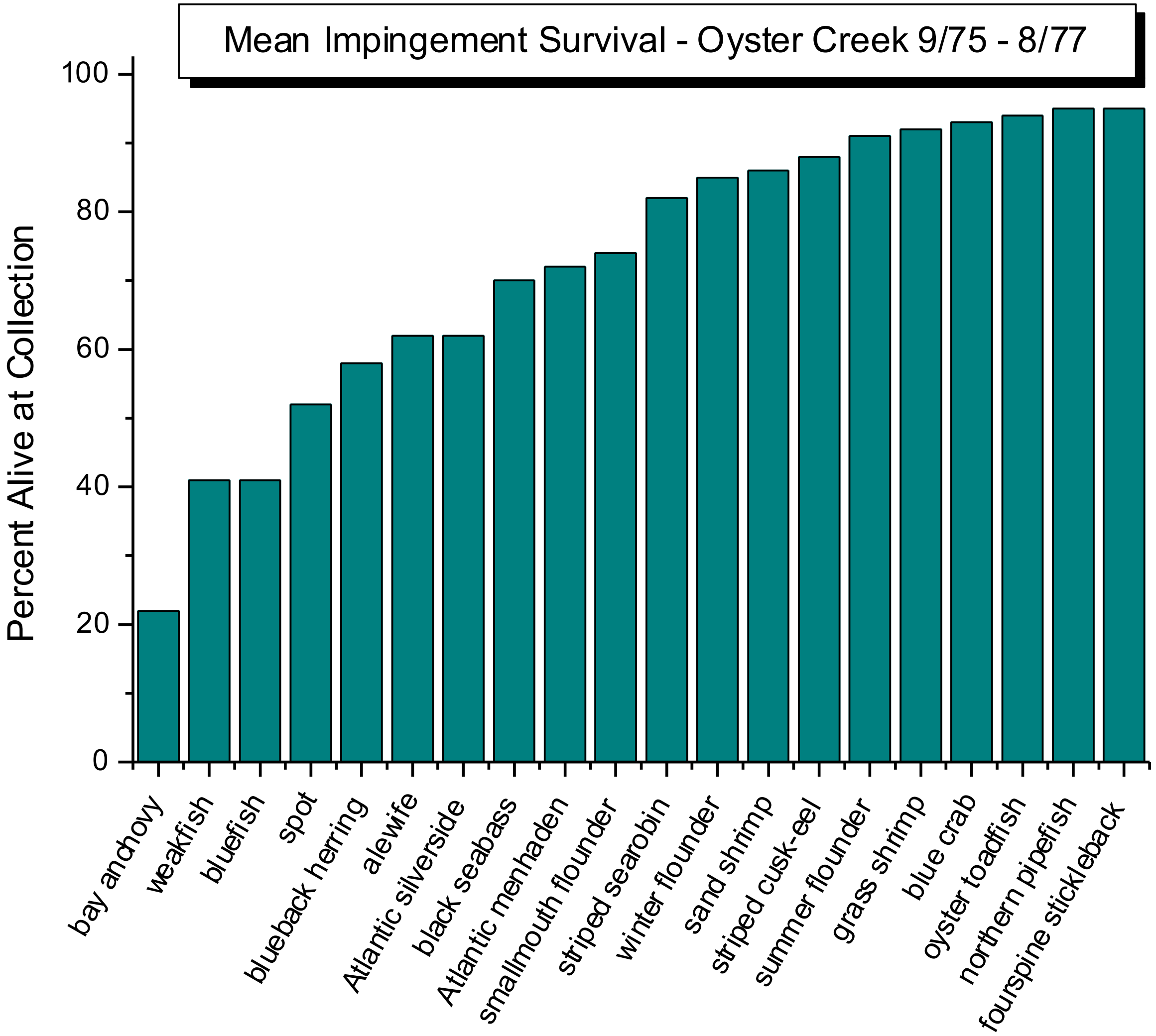
Species survival is highly species-specific

Some species are more fragile and susceptible to impingement mortality



Dey 2001: UWAG/USEPA Workshop

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Impacts from I&E are Relatively Small

“…any impacts caused by impingement and entrainment are small compared to other impacts on fish populations and communities, including overfishing, habitat destruction, pollution, and invasive species.

The available scientific evidence does not support a conclusion that reducing entrainment and impingement mortality via regulation of cooling water intakes will result in measurable improvements in recreational or commercial fish populations.”

– Larry Barnthouse

(2013; Impacts of entrainment and impingement on fish populations: A review of the scientific evidence)

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A path forward

- Should we invest in reducing impingement and entrainment?
- Fish and fisheries are valuable:
  - Commercial and recreational fisheries value
  - Ecosystem services
  - Genetic diversity
  - Non-use benefits
- Global climate change and cumulative impacts
- We should take a close look at opportunities to reduce impacts to fisheries – and make incremental changes when, where, and how we can

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References

- Barnthouse, L. W. 2013. Impacts of entrainment and impingement on fish populations: a review of the scientific evidence. Environmental Science and Policy 31: 149-156
- Benda, R. S. and W. C. Houtcooper. 1976. Impingement studies at 16 Electrogenerating plants in Michigan. in L. D. Jensen, editor. Fourth national workshop on entrainment and impingement. EA Communications, Melville, New York.
- EPRI 2008. The role of temperature and nutritional status in impingement of Clupeid fish species. EPRI, Palo Alto, CA 1014020
- Knight, C., T.S. Terhune, and W. E. Garrett. 2007. Health Evaluations of Impinged Fishes at Steam Generating Power Plants. American Fisheries Society Annual Meeting.
- Lifton, W. S. and J. F. Storr. 1978. The Effect of Environmental Variables on Fish Impingement. in L. D. Jensen, editor. Fourth national workshop on entrainment and impingement. EA Communications, Melville, New York.
- Loar, J. M., J. S. Griffith, and K. D. Kumar. 1978. An analysis of factors influencing the impingement of threadfin shad at power plants in the southeastern United States. in L. D. Jensen, editor. Fourth national workshop on entrainment and impingement. EA Communications, Melville, New York.
- McGee, M. V., J. S. Griffith, and R. B. McLean. 1978. Aspects of the winter predator-prey relationship between sauger and threadfin shad in Watts Bar Reservoir, Tennessee. Environmental Sciences Division Publication No. 1192.
- Rinnger 2000. Investigations of impingement of aquatic organisms at the Calvert Cliffs Nuclear Power Plant, 1975-1995. Environmental Science and Policy 3(Supplement 1): 261-273.

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