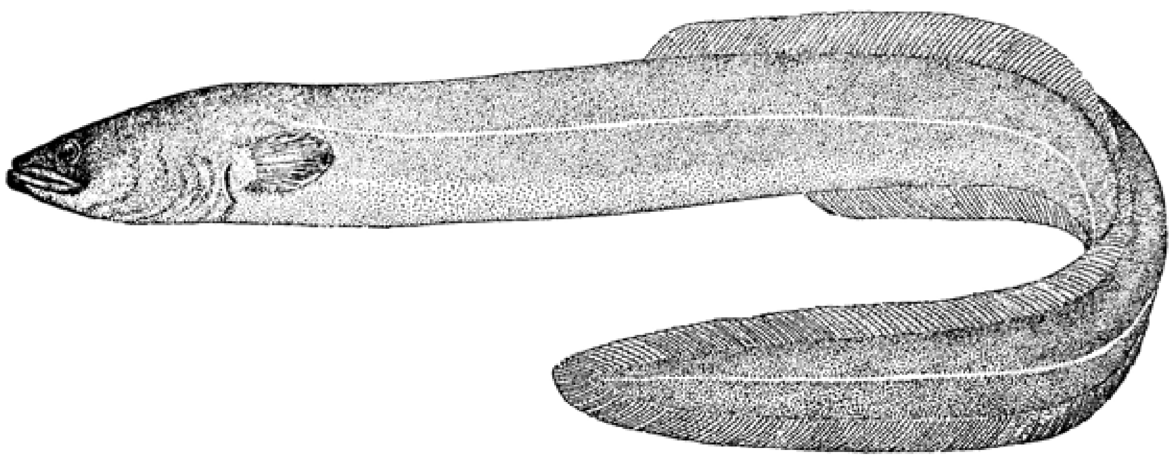
Technical workshop aimed at investigating methods for providing safe downstream passage for the American eel (*Anguilla rostrata*) past hydroelectric facilities on the St. Lawrence River



February 15 to 18, 2005
NAV CANADA Training Institute and Conference Centre, Cornwall, Ontario

Acknowledgements:

The organizing committee would like to acknowledge the contributions of the following to the agencies (in alphabetic order) to the development of this workshop:

- Electric Power Research Institute
- Environment Canada
- Great Lake Fisheries Commission
- Fisheries and Ocean Canada
- Ministère des Ressources naturelles, de la Faune et des Parcs du Quebec Hydro-Québec
- Ontario Commercial Fisheries' Association
- Ontario Ministry of Natural Resources
- Ontario Power Generation

The organizing committee would also like to acknowledge the efforts of all of the presenters and participants to the workshop.

The drawing of the eel used in this document is reproduced from 'Freshwater Fishes of Canada' with the permission of Dr. W.B. Scott.

Technical workshop aimed at investigating methods for providing safe downstream passage for the American Eel (*Anguilla rostrata*) past hydroelectric facilities on the St. Lawrence River.

1. Brian Eltz - USGS
2. Heather Lutz - GLFC
3. Kevin Reid - OCFA
4. François Travade – Electricite de France
5. Rob MacGregor - OMNR
6. Ben Rizzo, USFWS
7. Steve Patch, USFWS
8. Dawn Dittman - USGS
9. Maarten Bruijs - KEMA
10. Steve Lapan - NYSDEC
11. Richard Verdon – Hydro Québec
12. Thomas Tatham - NYPA
13. Don Meisner - ESSA
14. Ron Threader – OPG
15. Jon Truebe – Lakeside Engineers
16. Max Stanfield – DFO
17. Greg Pope - OPG
18. Lucien Marcogliese – Independent Contractor
19. Peter Meisenheimer - OCFA
20. Kipp Powell - Devine Tarbell & Assoc.
21. Sandra Dosser - OMNR
22. Larry Miller - USFWS
23. Serge Tremblay - Ressources Naturelles et Faune Québec
24. Melissa Grader – USFWS
25. Brian Knights - University of Westminster
26. Alex Haro - USGS
27. Margaret Yu - OPG
28. Cindy LaVean, NYPA
29. Leah Brown - USGS
30. Denis Desrochers - Milieu Inc
31. Gail Wippelhauser – MDIFW
32. David Marmorek - ESSA
33. Pierre Dumont - Ressources Naturelles et Faune Québec
34. Carole Fleury - Milieu Inc
35. Terry Euston - Normandeau Associates
36. Marget Davis - ESSA
37. Kipp Powell - Devine Tarbell & Associates, Inc.
38. Jean-Maurice Coutu - DFO
39. Scott Ault - Kleinschmidt Assoc.
40. Julie Sbeghen – Hydro Québec
41. John Tammadge - OPG
42. Steve Amaral - Alden Research Lab
43. Jacques Boubee – NIWA Inc.
44. Eric Truebe – Lakeside Engineers
45. Valérie Tremblay – U. du Québec à Rimouski
46. Thomas Pratt – DFO
47. Dave Stanley – Stantec Consultants
48. Bill Richkus - Versar
49. Richard VanIngen – DFO
50. Rob Caldwell - Environment Canada
51. Kevin McGrath - NYPA
52. Doug Royer - Normandeau Associates
53. Guy Verreault - Ressources Naturelles et Faune Québec
54. Dan Parker - NYPA
55. Mike Hreben - Kleinschmidt
56. James Snyder - St. Regis Mohawk Tribe
57. Vic Cairns - DFO
58. John Casselman - OMNR
59. John Freidhoff – Buffalo State College
60. Alan Fairbanks - NYSDEC
61. Alastair Mathers - OMNR
62. Colin Lake – OMNR

USGS – United States Geologic Survey; **GLFC** – Great Lakes Fisheries Commission; **OCFA** – Ontario Commercial Fisheries' Association; **OMNR** – Ontario Ministry of Natural Resources; **USFWS** – United States Fish and Wildlife Service; **NYSDEC** – New York State Department of Environmental Conservation; **NYPA** – New York Power Authority; **OPG** – Ontario Power Generation; **DFO** – Fisheries and Oceans Canada; **MDIFW** – Maine Department of Interior Fish and Wildlife; **NIWA Inc**. - National Institute of Water & Atmospheric Research Inc.

Group photo by Kevin McGrath

Cornwall, Ontario, Canada. February 15 – 18, 2005.

Agenda Tuesday, February 15:

Time	Topic
5:15 to 7:15 PM	Dinner
7:30 PM	*'Meet and Greet'* Reception

Agenda Wednesday, February 16:

Time	Topic	Speaker	LINKS
1. INTRODUCTION			
8:30 AM	Welcome from Steering Committee and introduction of ESSA	Rob MacGregor (OMNR) and Serge Tremblay (Faune Québec)	Presentation
8:40 AM	Introductions of participants and housekeeping	ESSA	
8:55 AM	Workshop Scope & Objectives	ESSA	
9:05 AM	Overview of St. Lawrence River, Geography, Hydrology and General Water Management	David Fay (Environment Canada)	Presentation Abstract
9:40 AM	The Dramatic Decline of the American Eel with Special Reference to the St. Lawrence River-Lake Ontario System	John Casselman (Ontario Ministry of Natural Resources)	Presentation Abstract
10:00 AM	Break		
10:15 AM	Estimation of American eel escapement from Upper St. Lawrence River and Lake Ontario.	Guy Verrault (Faune Québec)	Presentation Abstract
10:30 AM	Beauharnois GS Technical Description, Operations, and Turbine Mortality Study	Ginette Vaillancourt (Hydro Québec)	
10:50 AM	Eel Survival Study at Beauharnois Power Dam (1994)	Richard Verdon (Hydro Québec)	Presentation Abstract
11:00 AM	Bus to R.H. Saunders Hydroelectric Dam for lunch, tour and presentations		
11:30 AM	Moses/Saunders Generating Station (including Long Sault Spillway, Iroquois Dam and Eisenhower Lock) Technical Description and Operations.	Mike Boutilier (Ontario Power Generation)	Presentation
11:55 AM	American eel (Anguilla rostrata) Entrainment Survival Study at the St. Lawrence-FDR Power Project on the St. Lawrence River	Kevin McGrath (New York Power Authority)	Presentation Abstract
12:05 PM	Lunch and tour	Ron Threader (Ontario Power Generation)	

Agenda Wednesday, February 16 (continued):

Time	Topic	Speaker	LINKS
2. EEL BEHAVIOUR RELATED TO DOWNSTREAM PASSAGE			
1:15 PM	Seasonal Migration Patterns of Downstream Migrating American eel (*Anguilla rostrata*) in the St. Lawrence River.	Kevin McGrath (New York Power Authority)	Presentation Abstract
1:20 PM	Movement Patterns of Downstream Migrating American Eels in the Upper St. Lawrence River.	Kevin McGrath (New York Power Authority)	Presentation Abstract
1:40 PM	Downstream Migrating Eel Telemetry Study at Beauharnois Power Dam (2000).	Richard Verdon (Hydro Québec)	Presentation Abstract
2:00 PM	Three-dimensional behavior of migrant silver-phase American eels (*Anguilla rostrata*) encountering and passing downstream of a small hydroelectric facility	Leah Brown (United States Geological Survey)	Presentation Abstract
2:20 PM	Downstream passage of migrating silver-phase American eels at a hydroelectric dam	Brian Eltz (United States Geological Survey)	Presentation Abstract
2:35 PM	Management of Silver Eel: Human Impact on Downstream Migrating Eel in the River Meuse.	Maarten Bruijs (KEMA Consulting Services - Netherlands)	Presentation Abstract
3:00 PM	Break		
3:15 PM	Break-Out Group #1 Discussion of uncertainties and research priorities about eel behaviour during downstream migration in areas away from the influence of hydro electric dams.	ESSA	
3:15 PM	Break-Out Group #2 Discussion of uncertainties and research priorities about eel behaviour during downstream migration adjacent to hydro electric dams.	ESSA	
3:15 PM	Break-Out Group #3 Discussion of uncertainties and research priorities about eel behaviour during downstream migration adjacent to hydro electric dams.	ESSA	

Agenda Thursday, February 17:

Time	Topic	Speaker	LINKS
8:00 AM	Presentation of break-out session #1 to 3	ESSA	
3. EEL PROTECTION / MITIGATION			
8:30 AM	Review of Research and Technology on Passage and Protection of Downstream Migrating Eels and Current EPRI Eel Research Projects	Bill Richkus (Versar Inc.)	Presentation Abstract
9:00 AM	Summary of attempts to reduce mortality of eels as they migrate downstream in rivers in Maine.	Gail Wippelhauser (Maine Department of Inland Fisheries and Wildlife)	Presentation Abstract
9:15 AM	Simulation of Migration, Passage, and Mortality of American Eels at Hydroelectric Dams	Alex Haro (United States Geological Survey)	Presentation Abstract
9:30AM	Evaluation of Angled Bar Racks and Louvers for Guiding Eels at Hydro Projects	Steve Amaral (Alden Research Lab)	Presentation Abstract
9:45 AM	Biological Evaluation of a New Turbine Designed to Minimize Fish Injury and Mortality.	Steve Amaral (Alden Research Lab)	Presentation Abstract
10:00 AM	Break (reminder to look at posters in Room A210)		
10:15 AM	The Use of Mechanically Generated Current in Downstream Catadromous-Eel Passage	Jon Truebe (Lakeside Engineers)	Presentation Abstract
10:20 AM	Eel protection devices and operations at the Rimouski River hydroelectric power plant: a Win/Win approach that works.	Guy Verrault (Faune Québec)	Presentation Abstract
10:35 AM	Evaluation of bypasses to protect eel migrating downstream at small hydroelectric facilities in France	Francois Travade (Electricity de France)	Presentation Abstract
11:05 AM	Status of Protection Measures for Downstream Migrant Eels in New Zealand.	Jacques Boubee (New Zealand National Institute of Water and Atmospheric Research Inc.)	Presentation Abstract
11:35 AM	Avoidance of artificial light by downstream migrating American eel (*Anguilla rostrata*) in the St. Lawrence River	Kevin McGrath (New York Power Authority)	Presentation Abstract
11:55 AM	Sampling Efforts for Downstream Migrating American eel (*Anguilla rostrata*) in Lake St. Lawrence, St. Lawrence River.	Kevin McGrath (New York Power Authority)	Presentation Abstract

Agenda Thursday, February 17 (continued):

Time	Topic	Speaker	LINKS
12:00 PM	Lunch		
1:00 PM	Eel Light Avoidance Study conducted at Les Cèdres Intake Canal (2004)	Richard Verdon (Hydro Québec)	Presentation Abstract
1:20 PM	Break-Out Group 4 -Reducing eel mortality during passage through the power stations (e.g. fish-friendly turbines, alteration of generation schedules etc.)	ESSA	
1:20 PM	Break-Out Group 5 – Reducing eel mortality by excluding/directing eel away from turbines (e.g. lights, louvers, screens etc.)	ESSA	
1:20 PM	Break-Out Group 6 - Reducing eel mortality by diversion around the power stations (e.g. bypass, channels, trap/transport, etc.)	ESSA	
2:00 to 3:30PM	Break (15 minutes)		
4:20 PM	Presentation of break-out session #4	ESSA	
4:40 PM	Presentation of break-out session #5	ESSA	
5:00 PM	Presentation of break-out session #6	ESSA	

Agenda Friday, February 18:

Time	Topic	Speaker	LINKS
8:00 AM	American eel stocking (*Anguilla rostrata*) in the Upper Richelieu River and Lake Champlain: a fisherman-scientist-manager partnership.	Pierre Dumont (Faune Québec)	Presentation Abstract
8:20 AM	A critical review of 'biological' compensation approaches.	Brian Knights (University of Westminster)	Presentation Abstract
8:50 AM	Managing in the face of uncertainty.	David Marmorek (ESSA - Vancouver)	
9:50 AM	Break		
10:05 AM	Group Discussion - Other alternatives for improving escapement & a process for making recommendations	ESSA	
11:35 AM	Wrap-up of workshop	ESSA	
12:20 PM	Lunch		
1:20 PM	Steering Committee meeting (review of workshop for committee members)	ESSA / MacGregor / Tremblay	

Abstracts

(Listed in alphabetic order based on the last name of the corresponding author):

Biological Evaluation of a New Turbine Designed to Minimize Fish Injury and Mortality

Amaral, Stephen V.[1], Thomas C. Cook, and George E. Hecker
Alden Research Laboratory, Inc., 30 Shrewsbury Street, Holden, MA 01520, USA
Tel: 508-829-6000 (x 415); Email: amaral@aldenlab.com

Link To Presentation

A biological evaluation of a new hydro-turbine specifically designed to minimize injury and mortality of entrained fish was conducted with eight species, including two size groups of American eel (mean lengths of 249 and 431 mm). The new turbine was developed by Alden Research Laboratory, Inc., and Concepts NREC as part of the U.S. Department of Energy's Advanced Hydro Turbine Program. The ability of the new turbine to safely pass fish was evaluated by comparing survival and injury rates of test groups released upstream (treatment) and downstream (control) of the turbine. To isolate turbine-related mortality and injury from experimental effects, treatment and control fish were subjected to the same marking, introduction, and recovery methods. Immediate turbine passage survival (1 hr post-passage) for both size groups of American eel was 100%. Total passage survival (immediate and 96-hr survival combined) was 99.6% for the smaller size group and 98.3% for the larger fish. The percent of eels that were injured during turbine passage (i.e., adjusted for control fish injury rates) was less than 6% for both size groups. The predominant injury type was bruising, which was likely caused by contact with the runner blades. The results of the Alden/Concepts NREC turbine biological evaluation demonstrate that the new turbine design has considerable potential to significantly reduce mortality and injury of American eels entrained at hydro projects.

Evaluation of Angled Bar Racks and Louvers for Guiding Eels at Hydro Projects

Amaral, Stephen V.[1], Jonathan Black, and Douglas A. Dixon
1: Alden Research Laboratory, Inc., 30 Shrewsbury Street, Holden, MA 01520, USA
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Link To Presentation

We evaluated the ability of silver American eels to guide along various configurations of angled bar racks (25- and 50-mm clear spacing) and louvers (50-mm clear spacing) in a laboratory flume. Guidance tests were conducted with the bar racks and louvers angled at 45 and 15 degrees to the approach flow at velocities of 0.3 m/s to 0.9 m/s. A full-depth bypass was used for all tests. Guidance efficiency was calculated by dividing the number of fish recovered from the bypass by the total number recovered downstream (bypass and entrainment combined). Mean guidance efficiency with the 45-degree, 25-mm bar rack ranged from a low of 56.8% at 0.6 m/s to a high of 65.9% at 0.9 m/s. During tests with the 45-degree, 50-mm bar rack, mean guidance efficiency decreased from 72.7% at 0.3 m/s to 54.5% at 0.9 m/s. Mean guidance efficiency of the 45-degree louver ranged from a low of 34.9% at 0.3 m/s to a high of 61.9% at 0.6 m/s. Fish guidance efficiency was considerably higher for tests with the 15-degree structures, exceeding 88% at all velocities during tests with a solid bottom overlay placed over the lower 30 cm of each

structure. During tests without the overlay in place and at a velocity of 0.6 m/s, guidance efficiency decreased to 83.3 and 60.7% for the bar racks and louvers, respectively. The estimated guidance efficiencies indicate that angled bar racks and louvers have potential for diverting American eels away from hydro intakes, particularly if a shallow angle is employed (e.g., 15 degrees to the approach flow). However, we believe our estimates of guidance efficiency are higher than would be experienced at an actual intake due to the full depth bypass and the short length of each rack configuration that we evaluated.

Status of Protection Measures for Downstream Migrant Eels in New Zealand.

Link To Presentation

Boubée, Jacques and Erica Williams, National Institute of Water & Atmospheric Research, P.O. Box 11-115 Hamilton, New Zealand
Email: j.boubee@niwa.co.nz

About 61% of the 40,000 GWh of electricity consumed annually in New Zealand is from hydro generation. Such a high dependency on hydro-electricity has affected the distribution of the two main eels species present: the shortfin eel (*Anguilla australis)* and the longfin eel *(A. diefenbachii).* Lonfins, which tend to penetrate further inland than shortfins, have been the most affected, especially the highly fecund, large females. Although in the last decade significant progress has been made in restoring eel populations upstream of dams by elver transfer and/or the construction of elver ladders and lifts, downstream passage for sexually mature eels remains a key issue. To address this, catch and transfer operations, barrier nets, spillway openings and installation of bypasses are being tested and monitored by tracking the movement of eels implanted with PITs, radio and acoustic transponders. Barrier nets have proven difficult to operate in large rivers, especially where the load of drifting plant material is high. Some success has been obtained by passing eels over spillways, and by installing small diameter bypasses. However, until means of fully protecting intakes to prevent entrainment and impingement of migrant eels are devised, these measures will remain only partially effective. To address this, trials with behavioural barriers are being made. Lights barriers have not proved useful, as in many New Zealand catchments, migrations tend to occur during high flows when the water is turbid. Tests with electricity, fine screening and possibly sound are being planned and based on results will be installed on the intakes of new stations.

Three-dimensional behavior of migrant silver-phase American eels (*Anguilla rostrata*) encountering and passing downstream of a small hydroelectric facility

Link To Presentation

Brown, Leah, Alex Haro, and Ted Castro-Santos, S. O. Conte Anadromous Fish Research Center, Biological Resource Discipline, U. S. Geological Survey, P.O. Box 796, Turners Falls, MA 01376, USA
(413) 863-3805, Email : leah_brown@usgs.gov

During the fall of 2002 and 2003, we investigated the behavioral movements of downstream migrant eels, as they approached, encountered, and passed downstream of a small hydroelectric facility (Cabot Station) on the Connecticut River (Massachusetts, USA, 198-rkm). Using three-dimensional acoustic telemetry, we monitored the movement and passage of 50 telemetered eels within the forebay (the first 100 m of area located directly upstream of the dam). Forty-six out of the total 50 eels released 1.5 km upstream of Cabot

Station were detected within the forebay. Preliminary results have shown that eels occupied a variety of depths throughout the entire forebay; however, the greatest proportion of time was spent near the bottom. In the zone 10 m immediately upstream of the trash racks, eels occupied the middle and upper column more frequently and displayed a significant increase in the rate of turning. The increase in surface orientation and elevated rate of turning is likely due to the amplified amount of vertical and horizontal searching behavior we observed in this area. In addition to the vertical and horizontal movements observed at or near the trash racks, other trends were observed, including quick, upstream “sprint-like” movement (once eels encountered the trash racks), circular movements that often covered the entire forebay as well as small areas directly upstream of the trash racks, and repeated movements upstream and downstream through the trash racks. Overall, the amount of time each eel spent within the forebay was extremely variable; median forebay residence time was 14.1 min (range 1.0 min to 19.3 h). While some eels passed downstream of the dam on their first attempt, more than half of the eels were observed swimming back upstream after encountering the trash racks and re-entered the forebay up to 10 additional times before passing downstream of the dam. Ninety-six percent (44 out of 46) of the passage events occurred through the turbines, while only two of the passage events occurred at the surface bypass. Downstream passage through the surface bypass was observed under two conditions; first, when no turbine units were operating and the surface bypass was the only location where flow occurred and second, when only one turbine unit, near the area of the surface bypass, was operating at low operational flows. While flow and forebay residence times were not significantly correlated, eels tended to be attracted to zones of predominant flows; usually the turbine intakes under normal operating conditions.

Management of Silver Eel: Human Impact on Downstream Migrating Eel in the River Meuse

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Link To Presentation

Human impact on the downstream migrating silver eel in European inland waters is caused by commercial fisheries and by the cumulative mortality of eel passing the turbines of a series of hydropower stations. These human activities are widespread in many European rivers and might have detrimental effects on the population level of the European eel. Therefore, it is important to know to what extent damage to eel caused by hydropower stations as well as the impact of withdrawal of eel by commercial fisheries.

The ‘European Silver Eel Project’ was performed in the period 2001-2002. The aim was to investigate the impact of commercial eel fisheries and hydropower stations on downstream migration of silver eel in the river Meuse and to evaluate the applicability of the Migromat®, an early warning system to detect downstream migration events. The early warning of migration enables turbine management, i.e. to close down the turbines during short periods with peak migration of silver eel and to offer them a save passage over the weirs. These goals have been achieved by the monitoring of downstream migration of silver eel by means of telemetry, eel catches by commercial fisheries and assessment of mortality due to turbine passage at a hydroelectric power station. The combined results provide a scientific basis for further development of technical measures and management actions in order to reach the ‘silver eel escapement targets’ set out in the management plan under development by the European Commission.

The Dramatic Decline of the American Eel with Special Reference to the St. Lawrence River-Lake Ontario System

Casselman, John M., Ontario Ministry of Natural Resources, Aquatic Research and Development Section, Glenora Fisheries Station, R.R. 4, Picton, Ontario K0K 2T0 Email: John.Casselman@MNR.GOV.ON.CA

Link To Presentation

The dramatic decline of the American eel in the St. Lawrence River-Lake Ontario (SLRLO) system is a severe example of recent declines in freshwater eels. Particularly disconcerting, recruitment to this once large, distant stock has virtually ceased. Decreased abundance and loss of recruitment at extremities of the range are strong evidence of universal decline of this panmictic species and forewarn continued, accelerated species and resource declines. The extent of this decline has caused scientists (CSEWoG) to recommend 50% reduction in anthropogenic mortality to reduce risk of widespread population collapse of this panmictic species and encourage increased escapement and recruitment. All attempts should be made to increase escapement and survival of this large-bodied stock, since it is diminishing 23% yearly. This stock, on a weight basis, may provide more than a quarter of overall fecundity of the species, which may both drive overall recruitment and provide necessary reproductive capacity to sustain its own distant recruitment. Multiple factors interact to put eels in this precarious state; these are poorly understood and generally unquantified. However, fishing and turbine mortality are obviously involved. Modelling indicates yellow eel fisheries of upper SLRLO, with an estimated annual exploitation rate of 5%, account for an overall accumulated mortality (25%), about equal to that of combined turbine mortality (22%) during emigration. Since some commercial fisheries have been closed, turbine mortality should be more specifically addressed. The present challenge of the precautionary approach is to reduce mortality now rather than waiting to see what happens or depending upon others.

American eel stocking (*Anguilla rostrata*) in the Upper Richelieu River and Lake Champlain: a fisherman-scientist-manager partnership.

Dumont, Pierre[1], Guy Verreault[2], Georges-Henri Lizotte[3] and André Dallaire[4]

Link To Presentation

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In Europe and Asia, eel stocking is seen as an interesting action to rapidly increase local population in a specific growth habitat facing poor natural recruitment. In North America, this practice has been limited to a few experimental trials and has never been used as a way to compensate low recruitment. In 1999, faced to a dramatic decline of landings and recruitment, and supported by the positive conclusions of a risk analysis, the Association des pêcheurs d'anguilles et de poissons d'eau douce du Québec (APAPEDQ), a

commercial fishermen Union, in cooperation with Faune Québec fisheries managers, initiated a first eel transfer: 40 000 elvers from the Bay of Fundy (New Brunswick, Canada) were stocked in Lake Morin (400 ha) in an eel-free watershed located in south eastern Québec. A four year monitoring showed that eel is well established and grows very fast. Males, generally very rare in the St. Lawrence watershed freshwaters, represented 27% of the sample.

In 2003, encouraged by these results, the APAPEDQ turned his attention on a larger system, free of turbines and considered as a very good eel pasture. For at least 150 years, the Richelieu River supported significant commercial eel fisheries. Between 1920 and 1980, annual landings averaged 34.6 metric tons. A sharp and constant decline since 1981 (from 72.9 to 4.7 tons) and a significant increase in eel size (from 890 to 1017 m between 1987 and 1997) pointed to a decline in recruitment in the Lake Champlain watershed, a large (1140 km2), deep and narrow oligotrophic lake bordering New York and Vermont States and extending into Québec. The fishery closed in 1998. This enhanced decline has been at least partly related to the rebuilding, in the 1960s, of two old cribwork dams. In 1997 in Chambly and in 2001 in Saint-Ours, eel ladders were retrofitted to enhance eel recruitment. The efficiency of these ladders is high. However, as observed elsewhere in the Upper St. Lawrence watershed, the number of small eel (TL averaging 35-40 cm) ascending the river is very low. Except for the first two years of operation, it never exceeded 3500 eels while, to support annual historical landings of silver eel (circa 35 t), many hundred thousand would be required each year.

According to the new National Code on Introductions and Transfers of Aquatic Organisms in Canada, a risk analysis was performed and submitted to the evaluation of an expert committee. The project, based on a ten-year annual transfer of 0.5 to 1 million elvers (marked with oxytetracycline), was accepted but conditions were imposed to prevent the introduction of diseases and parasites, particularly the nematode Anguillicola crassus, recently introduced in North America. The project also received the support of the United States federal and states agencies involved in Lake Champlain fisheries management. In spring 2004, the project was interrupted, histological signs suggestive of viral disease being observed on a sample collected one week before the transfer. Supplemental studies performed in summer 2004 (viral isolation and transmission electron microscopy evaluation of diseased tissues) could not support the hypothesis of viral infection, thus allowing for a new trial in 2005, submitted to the same preliminary health tests prior to translocation. Future monitoring will include exhaustive biological (growth, sex ratio) and pathological examination of all eel recaptured, the repeat of capture-recapture experiments made in the 1970s and 1980s in three bays of Lake Champlain and the measure of stocked eels contribution to the migrating silver phase run.

Downstream Passage of Migrating Silver-Phase American eel *Anguilla rostrata* at a Hydroelectric Dam

Eltz, B., A. Haro, and T. Castro-Santos, S.O. Conte Anadromous Fish Research Center, Biological Resource Discipline, U.S. Geological Survey, P.O. Box 796, Turners Falls, MA 01376, USA, Email: beltz@forwild.umass.edu

Link To Presentation

Over the past two decades, a decline in the population of the American eel has been observed in North America. Hydroelectric facilities are believed to be one of the contributing factors to the eel population decline because they impair downstream movement during reproductive migration. During the fall of 2004, a radio telemetry study of eel movement and passage was conducted at a small (2MW) hydroelectric facility, Rainbow Dam (12.9-rkm), on the Farmington River in Windsor, Connecticut. Antennas were also installed in the fishway and downstream bypass to record eels tagged with passive integrated transponder (PIT) tags. A total of thirty eels were surgically tagged with both radio and PIT tags and released 6.4 km upstream of the Rainbow Dam in batches throughout the migratory period. Downstream movements of 29 out of 30 eels were detected at the dam; routes of passage and residence time were examined. Eels frequently made several attempts to pass the dam and although the time of passage was variable, the majority of eel movement occurred at night. Twenty-four eels passed the dam during high flow events caused by rain and fifty-nine percent of all eels were last detected in the 5-13 meter range before passing. All telemetered eels passed via the turbines.

Overview of St. Lawrence River, Geography, Hydrology and General Water Management

Fay, David, P.Eng. Manager, Great Lakes - St. Lawrence Regulation Office, Environment Canada, 111 Water Street East, Cornwall, Ontario K6H 6S2
Email: David.Fay@ec.gc.ca

Link To Presentation

The geography and hydrology of Lake Ontario and the upper St. Lawrence River downstream to Montreal is reviewed. The review includes hydraulic features (such as dams and locks), the temporal variation of flows in the system and the effects that regulation has had on these flows. An outline of the governance of water management in the St. Lawrence River is presented.

Simulation of Migration, Passage, and Mortality of American Eels at Hydroelectric Dams

Haro, Alex, S. O. Conte Anadromous Fish Research Center, Biological Resources Division, U. S. Geological Survey, P.O. Box 796, Turners Falls, MA, USA; (413) 863-3806; fax (413) 863-9810; Alex_Haro@usgs.gov

Link To Presentation

Simulations of operational modifications at a hypothetical hydroelectric project to mitigate eel turbine and spill-induced mortality were performed using six years of weir catch data from a small Maine stream. The results indicated that simulated mortality of the entire run decreased with increasing spill flow, and also decreased significantly when turbine operation was suspended on days with significant rainfall. Suspending turbine operation on dates encompassing 25 to 75% of the cumulative eel catch caused a

reduction in simulated eel mortality of two-thirds to one-half relative to normal operation. Simulated mortality was further halved when limits on hydro project operation were set using a combination of rainfall events and eel run timing factors. As a strategy for consistently reducing run mortality on an annual basis, suspending generation for a 7-day period during the most probable time of peak downstream movement was as unreliable as normal project operation, and was less than half as reliable as limiting hydro project operations on dates encompassing 25 to 75% of the cumulative eel catch (~ 30 days). The simulations might provide guidance for modification of hydroelectric project operations as a mitigative tool for downstream passage of eels. However, implicit assumptions of the simulation model need further testing or quantification, including spill mortality, universality of environmental cues for migration, details of run timing (especially in larger river environments), and route selection (spill vs. turbines) of downstream migrant eels.

A critical review of ‘biological’ compensation approaches

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Critical review of biological and financial cost-benefits of 'biological' means of compensating for losses of silver eels to turbines, utilizing European and other experiences: (a) upstream trapping and downstream transport and release, the practicalities, costs and risks: (b) stocking: quantifying how many (female) eels are needed: seed stock, types, sources, quantities and costs: locating suitable (under-utilized) waters for stocking: methods and densities (to produce females): (c) risk assessments with respect to time scales and effects on source and stocked habitats and on local and regional populations and on the species: (d) baseline and monitoring data requirements.

Movement Patterns of Downstream Migrating American Eels in the Upper St. Lawrence River.

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One hundred fifty two downstream migrating American eels (*Anguilla rostrata*) were tagged with internal ultrasonic depth sensitive transmitters and released 20 km upstream of the St. Lawrence-FDR Power Project on the St. Lawrence River near Massena, NY. The movement of 62 eels was monitored with 38 remote receivers extending from the Power Dam to 5 km upstream of the Dam. The telemetry system was designed to provide the most accurate positioning data within the last 500 m upstream of the Dam. Data were analyzed with a software package that enabled evaluation of eel movements in 3-dimensions relative to depth and bottom topography. Most (75%) movement occurred at night. Most eels were sedentary in daylight hours, remaining in the bottom substrates and vegetation. All eels demonstrated a pronounced up and down movement pattern in the water column when migrating. Overall, while migrating in upstream open water areas, eels spent approximately 50 % of their time in the top 5 m, 75% in the upper 10 m, however 25% of the time was spent at depths greater than 10m. Eels when actively moving were averaging speeds of 0.2 to 0.4 m/s faster than the water current speed. Eels were generally in the upper portion of the water column as they approached the Dam (300 m upstream), however they were evenly distributed across the River and within the water column 50 m upstream of the Dam and as they passed through the Dam. Movement in the last 50 m prior to passing the Dam was relatively quick with 92% spending less than 21 min and 67% spending less than 6 min before passing the Dam. In the last 50 m, eels generally exhibited one of three types of behaviors: direct movement through the Dam (34%), limited lateral movement and depth related exploration (55%) and more extensive lateral movement and depth exploration (11%).

Avoidance of artificial light by downstream migrating American eel (*Anguilla rostrata*) in the St. Lawrence River

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A proof-of-concept study was conducted to determine if downstream migrating American eels avoid artificial light. The study was conducted from July through September 2002 on the St. Lawrence River near Waddington, NY. A 90-m long, surface to bottom, "wall-of-light" was created by suspending eighty-four 1000-W halogen lamps from a platform in approximately 10 m water depth. Light intensity was approximately 3500 lux at 1 m, 175 lux at 10 m, and 2 lux at 40 m from the platform. The light platform was set 30 degrees to the River current, which was 0.6 m/s. Estimates of effectiveness were obtained by netting downstream from the platform. Control and treatment conditions were created by randomly alternating nights with lights off and lights on. No other conditions were varied. Additionally, movement patterns were documented for eels observed in the light field.

A total of 258 eels were collected during 53 nights of sampling. Probability of avoidance was estimated to be 78% based upon net results; the 90% confidence intervals ranged from 66% to 92%. Qualitative visual data, based upon 111 observed eels, showed 85% avoidance of the light array.

Seasonal Migration Patterns of Downstream Migrating American eel (*Anguilla rostrata*) in the St. Lawrence River.

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Six standardized systematic boat surveys for dead or injured eels were conducted in the tailwaters of the Moses-Saunders Power Dam from 1999 to 2004. The surveys were conducted twice a week from mid-June through early October. The purpose of the surveys was to document the seasonal outmigration pattern of American eel and to provide a relative measure of the number of downstream migrants.

The seasonal outmigration pattern over the six years has been relatively consistent. Eels migrate from mid-June through the end of September, with most of the movement occurring from early July through mid-September. The migration pattern is seasonally broad with no distinct peak. Outmigration further downstream in the Kamouraska region of Quebec is later (primarily October) and more concentrated/peaked.

The average number of eels collected per day of sampling effort has been similar, although somewhat variable over the past five years: 2000 (14.8), 2001 (17.8), 2002 (13.8), 2003 (11.7) and 2004 (11.1). The number of eels collected in 1999 (39.4 eels/day) was noticeably higher than during other survey years. Although the sampling method in 1999 was very similar to the method used in the subsequent survey years, we are uncertain as to whether this higher rate in 1999 is a sampling artifact or represents higher numbers of migrating eels. The average length of eels has been relatively similar in the last five years ranging from 98.0 cm (2001) to 100.5 cm (2004). In 1999 the average length was 94.3 cm, slightly less than the past five years.

American eel (*Anguilla rostrata*) Entrainment Survival Study at the St. Lawrence-FDR Power Project on the St. Lawrence River

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An entrainment survival study was conducted on downstream migrating American eel at the Robert Moses Power Dam on the St. Lawrence River in August and September 1997. A total of 240 eels were introduced into a turbine at two release depths while 134 eels were released into the turbine discharge as controls. The turbine was operating within its normal range.

Test specimens came from the Richelieu River; about 125 kilometers downstream and ranged in length from 81 to 114 cm (mean 102 cm). A balloon tagging technique was used to recover eels after turbine passage. Eels were tagged with uninflated balloons. A catalyst inflated the balloons after turbine passage, buoying the eels to the surface. The eels were netted by crews in boats and examined to determine the extent of injury. Eels that survived turbine passage were held for 88 hour to determine latent mortality.

Recapture rates were high, 86% for treatment specimens and 95% for control specimens. Average recapture time was less than 12 minutes.

The 88-hour survival was estimated at 73.5 to 75.0% (confidence intervals of 67.9 to 80.3%). The primary sources of injury and mortality were attributed to mechanical causes resulting from blade strikes or direct contact with other structural components during turbine passage.

Sampling Efforts for Downstream Migrating American eel (*Anguilla rostrata*) in Lake St. Lawrence, St. Lawrence River

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Various sampling techniques using trawl nets and stownets have been utilized to collect downstream migrating American eels in Lake St. Lawrence. Trawling utilized nets (9.2m width x 7.0m height x 33.5m length) towed behind large vessels (24m length, 500hp) equipped with hydraulic net drums. Stownetting also utilized a trawl type net (12m width x 6m height x 30.2m length) however the nets were anchored and fished in the current. Stownets required a large tending vessel equipped with a hydraulic net drum.

Trawling was conducted in the middle to the top portion of the water column while stownetting was primarily conducted in the top portion of water column. Trawling was limited to large deep areas due to vessel maneuverability and potential net snagging, while stownetting did not have similar limitations. Trawl sampling was discontinuous (i.e. frequent deployment and retrieval), while stownetting was nearly continuous. It was felt that stownetting was less stressful on collected eels due to the lower collection velocities (approximately 0.6 m/s vs. 2.0 m/s). Both gears were susceptible to clogging with floating debris/vegetation, particularly when fished close to the surface.

In 2000 an intensive trawling effort (73 fishing nights - 389 tows) resulted in the capture of 155 eels. Slightly greater than 1% of the River flow was sampled while the net was in the water (342 hours). The cost for this effort was $165,000. In 2002 a large scale stownetting effort (3 stownets fished 28 nights) resulted in the capture of 159 eels. Slightly greater than 2% of the River flow was sampled while the net was in the water (536 hours). The cost for this effort was $295,000.

Review of Research and Technology on Passage and Protection of Downstream Migrating Eels and Current EPRI Eel Research Projects

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EPRI funded Versar, Inc. to conduct two major literature reviews on eels, one in 1999 addressing stock status and downstream migratory behavior of eels, and the second in 2001 assessing means of safely passing eels past hydroelectric projects during their spawning outmigration. These reviews synthesized research conducted on numerous catadromous eel species throughout the world and conducted over decades. Existing literature on silver eel migration documented some distinctive temporal patterns of migration from small streams and rivers and a number of environmental cues (e.g., precipitation, rainfall,

freshets, moon phase) that, individually or in concert, triggered seasonal migration pulses. Migration patterns in large rivers, such as the St. Lawrence, appeared less coherent and unrelated to environmental cures. These past studies serve as a foundation for much of the research currently on-going, as reported earlier. Categories of eel protection technologies reviewed included behavioral barriers (light, sound, water jets and air bubbles, and electrical fields), mechanical barriers (angled bar racks, louvers and screens), bypass facilities and induced flows, altered generation schedule, and trap and transport. Of these technologies, light and infrasound appeared to offer the greatest potential for diverting or directing downstream migrating eels. Accurate prediction of migration patterns could provide a basis for modifying hydroelectric facility operations (e.g., short-term turbine shutdown) as a means of protecting downstream migrants. Each of the most promising technologies has subsequently been demonstrated to have potential for field application. However, site- and facility-specific characteristics are likely to have a dominant impact on which technology is most feasible, cost-effective and successful for safely passing eels downstream. EPRI has continued to fund research into eel passage in an effort to develop cost-effective means of enhancing protection for a fisheries stock that appears to be in decline throughout North America.

Evaluation of bypasses to protect eel migrating downstream at small hydroelectric facilities in France.

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Efficiencies of bypasses for downstream migrating European eels (*Anguilla anguilla)* were evaluated at two different hydroelectric power plant in the southwest of France. At the small plant of Halsou (turbined discharge: 30 m3/s, trashrack length: 20 m; height: 3 m), on the Nive River, two types of bypasses, a surface and a bottom sluice, were tested during three years (1999-2001). At the larger power plant of Baigts (turbined discharge : 90 m3/s, trashrack length: 40 m; height: 5.5 m) on the Gave de Pau River, we have tested in 2004 a surface bypass. These devices, similar to those designed for salmon smolts in France, are using the repulsive effect of trashracks to momentarily prevent fish from entrainment in the turbines and guide them to a nearby bypass in which the flow represents a small percentage of the turbined discharge (2% to 2.5%). The bar-spacing of the trashrack was 3 cm on both plants. The tests were conducted by radiotracking at both plants, and at Halsou, by trapping naturally migrating silver eels after their passage through either bypass.

At Halsou 74 individuals were radiotracked and a total of 637 eels were trapped during the three-year study. Total efficiency for both bypasses, evaluated on the basis of downstream movement of radio-tagged eels, ranged from 56% to 64% but varied according to the years (72% to 90% in 2000, and 40% in 2001). The precise efficiency of each separate bypass could not be calculated by trapping, however, preferred passage through the bottom bypass was confirmed by telemetry, as 3 to 4 times eels transited through the bottom bypass compared to the surface one. The eels displayed foraging behaviour in the forebay with frequent displacement interrupted by long resting periods in zones with low current. The repulsive effect of the trashrack, located in front of the turbine intake, seemed to increase with increasing turbined discharge.

At Baigts, 40 individuals were radiotracked. The results were less positive than those obtained at Halsou : only 18% of the eels passed through the surface bypass, 60% by the turbines and 22% partly over the spillways during floods and by the attraction flow of the fishway. The analysis of the behaviour of eels in front of the trashrack is under progress, but similarly to Halsou, we observed large individuals differences, some eels passed very quickly (several minutes) through the trashrack and others many several incursions over several days before eventually crossing.

These experimental studies have shown that a downstream migration device composed of a bypass with a discharge of 2% to 3% of the turbined discharge located near a trashrack with 3 cm bar spacing could be partially efficient for adult eels and that a bottom bypass was preferable to a surface bypass. The efficiency of such a device is only partial (18% to 60%) and not sufficient for most power plants given the high mortality induced by the passage into the turbines. Efficiency could be improved by reducing the bar spacing of the trashrack (close to 2 cm) which would block the majority of downstream migrants (90% of the migrating eels of the river Nive). This solution requires a low water velocity in front of the trashrack (< 0.5 m/s) to prevent eel impingement on the trashrack and resulting mortalities. This solution needs to be tested by on-site experiments at hydroelectric power plants of various sizes and configurations.

The Use of Mechanically Generated Current in Downstream Catadromous-Eel Passage

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Recent work with salmon smolts might have an application in the collection and diversion of downstream migrating eels around hydroelectric plants. A 15 hp propeller, acting like a fan in the water, creates a current in still water of 0.1m/s in a 27 meter diameter plume about 150 meters long. At the center of that plume (in a 9 meter diameter) the velocity is 0.3m/sec and reaches 80 meters. These currents reach the threshold for deterring and guiding eels. Therefore, the generated current could divert eels to fyke net collection areas that are removed from confusing currents near the powerhouse intake. By taking into account the Coriolis force when deploying propellers and traps, multiple collection efforts can be made with limited energy requirements. Another application of mechanically generated currents is to create a current perpendicular to existing bar racks that would divert eels to a bypass system, thereby eliminating the extensive civil works associated with installing louvers.

Eel Survival Study at Beauharnois Power Dam (1994)

Link To Presentation

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The Beauharnois Generating Station (BGS) is equipped with 26 Francis turbines and 10 propeller turbines. In 1994, 222 eels were injected in turbine intakes (Francis: n = 122, Av. Length: 881 mm; Propeller: n = 100, Av. Length: 897 mm) and recovered in tailwater to asses survival rate after passage through turbine. Recovered eels were kept in tanks for 48 hours and examined by a veterinarian for injuries. Recovery rate was 96 % and 95 % for propeller and Francis turbines respectively. Survival rate after 48 hours was 76.1 % (C.I. 95% between 68 % and 84 %) for propeller turbine, and 84.2 % (C.I. 95% between 77 % and 92 %) for Francis turbine. Cut eels were associated only with propeller turbine. With the hypothesis that outmigrating eels are distributed randomly as they pass through turbines, overall survival rate at BGS is 82.0 %.

Downstream Migrating Eel Telemetry Study at Beauharnois Power Dam (2000)

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During the summer of 2000, the New York Power Authority tagged 167 adult eels with acoustic tags and released them 20 km upstream of the Moses-Saunders Power Dam (MSPD). Monitoring of these eels at the Beauharnois-Les Cèdres Complex showed that none were detected at the Les Cèdres Power Dam nor at the St. Timothée Dam. However, 26 (15.6% of the tagged fish) were detected in the forebay of the Beauharnois Power Dam (BPD). The individuals took, on average, 8.2 days (average speed 0.43 km/h) to travel from the MSPD to the BPD, located 85 km downstream. The majority of the eels approached the Dam at night (85% between 8:00 PM and 5:00 AM). In the forebay, the exploratory behavior of the eels was rather limited. Slightly more than half (14/26, 53.8%) of the eels moved downstream in a corridor less than 250 m wide, while one eel moved across the full width of the forebay. The movements of the eels in the water column were on average at 10.5 m (S = 5.7 m). With receivers covering about 300 m upstream of the dam, the fish were detected in the forebay for a period of 31 minutes, on average. From the last signal received, the eels would have crossed the power houses 1, 2 and 3 of the BPD in these proportions: 23.1%, 50.0% and 26.9%. This is not different from random passage. The average depth of the eels when the last signal was detected is 8.5 m (S = 5.1 m). However, eels can be entrained through the entire depth of the turbine intake. In 1994, the survival rate of the downstream migrating eels at the BPD was 84.2% for

the eels that went through the Francis type turbines (power houses 1 and 2) and 76.1% for the fish that went through the propeller turbines (power house 3). Applying those rates to the 19 eels that presumably went through power houses 1 and 2 and to the 7 eels that crossed through power house 3 of the dam, results in an overall survival rate of the downstream migrants of about 82.0%.

Eel Light Avoidance Study conducted at Les Cèdres Intake Canal (2004)

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In 2004, Hydro-Quebec conducted a study in the Les Cèdres Generating Station intake canal to assess the potential of an underwater laser light (40 watts, 532 nm) to guide eels over long distance in the St. Lawrence River. Results indicated that because of suspended particulate matter in the canal, laser light is scattered on a short distance and does not offer great potential to guide eels downstream from Lake St. Francis
.
Two incandescent lights (12 000 Watts each) were then mounted above the water surface with a 32º angle. During a 30-day period, lights were on half of the days. From September 10 to October 1st, 210 eels (av. Length: 940.3 mm) were tagged with acoustic tags surgically implanted and released 1.6 km upstream of the light zone. Of the tagged eels, 136 were detected and 40 passages were recorded in the light zone. Results indicate that partial avoidance (33.3%) occurs above 100 lux. Results also suggest that efficient light barrier in the St. Lawrence would need a dense array of high intensity lights.

Estimation of American eel escapement from Upper St. Lawrence River and Lake Ontario.

Link To Presentation

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American eel stock from Upper St. Lawrence River and Lake Ontario (USLRLO) is almost exclusively composed of large fecund females. This stock that historically represented a large proportion of the seaward migrating silver eels in this watershed, is successively exposed to three major sources of mortality: two large hydroelectric complex (Moses-Saunders and Beauharnois-Les Cèdres) and a commercial fishery in the estuary. Estimates of mortality rates caused by these three factors and the number of migrating eels in the estuary were combined with geographic origin of the catch. These data allowed the first evaluation of eel escapement from USLRLO. In 1996 and 1997, less than half a million

eels were estimated to have left this sector. In the first 500-km between Lake Ontario and the lower Estuary, eels were subjected to an estimated cumulative mortality of 53%, three quarters of these losses were caused by fish passage through turbines. Impact of recent decreasing abundance and increasing length of eels in the USLRLO on the previous estimates are discussed.

Eel protection devices and operations at the Rimouski River hydroelectric power plant: a Win/Win approach that works.

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The effectiveness of a downstream passage device installed at a small hydropower station was surveyed in the Rimouski River from 1994 to 2004. The devices tested for mitigating mortality from turbine passage during the downstream migration were an underwater lights system (1997) and a fine mesh inclined screen (1997 and 1998), in conjunction with a bypass system. The underwater light device has a very low efficiency, while the fine grid inclined screen can reach 100 % efficiency when it is adequately fitted. Problem associated with leaves and debris clogging the screen in the headrace channel was solved using an air compressor system. Moreover, strong involvement from the power plant managers was the key factor for an effective protection of migrating silver eel on that river.

Summary of attempts to reduce mortality of eels as they migrate downstream in rivers in Maine

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Maine has more than 100 FERC-licensed hydropower projects. The projects have rated capacities ranging from 15-76,600 KW, however, many of them are small (median rated capacity = 1500 KW). Approximately 80% of the projects are located in existing or historical habitat for American eel. Medway, licensed in 1999, was the first Maine project that contained a license article requiring downstream passage for American eel. Since then, downstream passage for American eels has been achieved at 11 projects, and is anticipated at 18 projects within five years. Passage measures have been achieved through the standard relicensing process, the APEA process, and via negotiated settlement (although not solely for eels). Downstream passage measures for eels fall into five categories: dam removal, shutdown, turbine exclusion with bypass, turbine exclusion with bypass and limited shutdown if necessary, and bypass alone. In most cases, dam removals are the result of requirements for upstream anadromous fish passage. Shutdowns for recently licensed projects range from 8 weeks (for eel) to several months (for juvenile alewife and American eel). Site-specific field studies may reduce the shutdown period. Turbine exclusion is by bar racks or punch plate with 1" spacing. Bypasses or gates are surface opening, vertical slots, or bottom opening. With one exception, no effective testing has been conducted to date.

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Meisner, Don	ESSA	dmeisner@essa.com		
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Tremblay, Serge	**Faune et des Parcs Quebec**	**serge.tremblay@fapaq.gouv.qc.ca**	**(418) 521-3875 poste 4495**	**Québec City, Québec**

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(Workshop organizing committee members are identified in bold)

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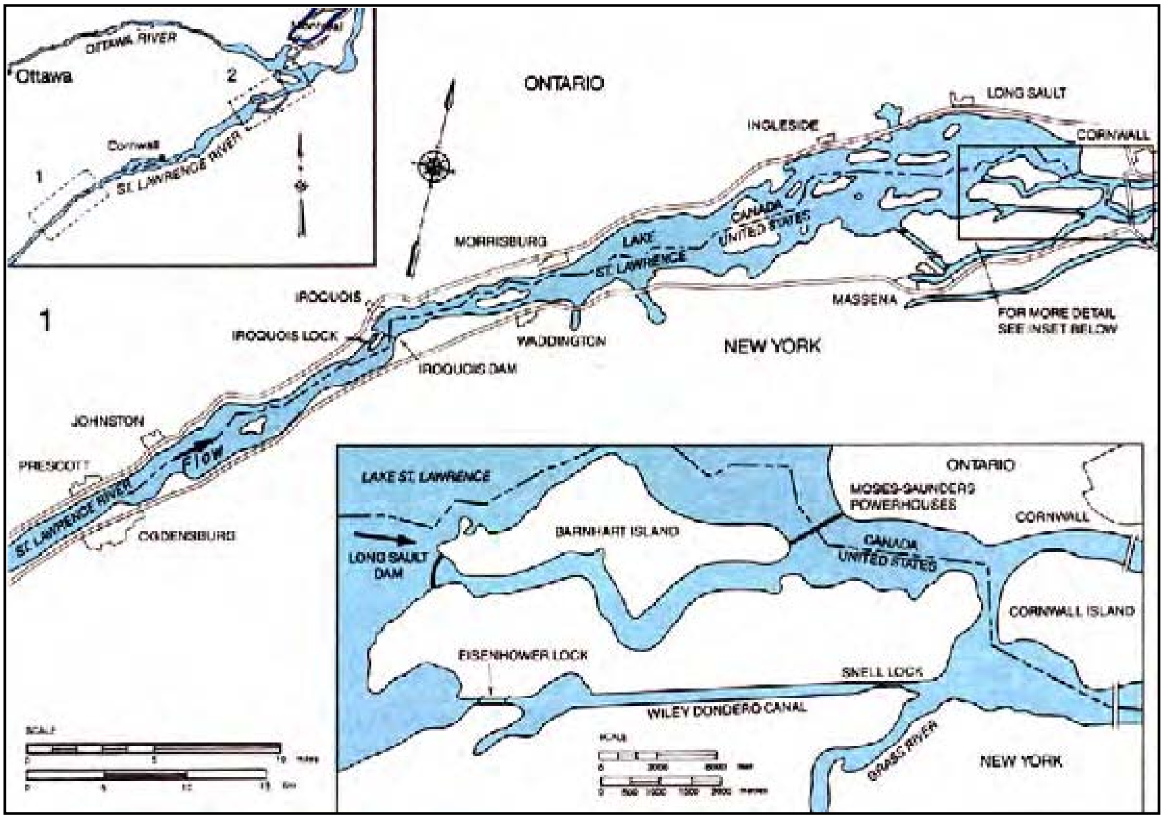
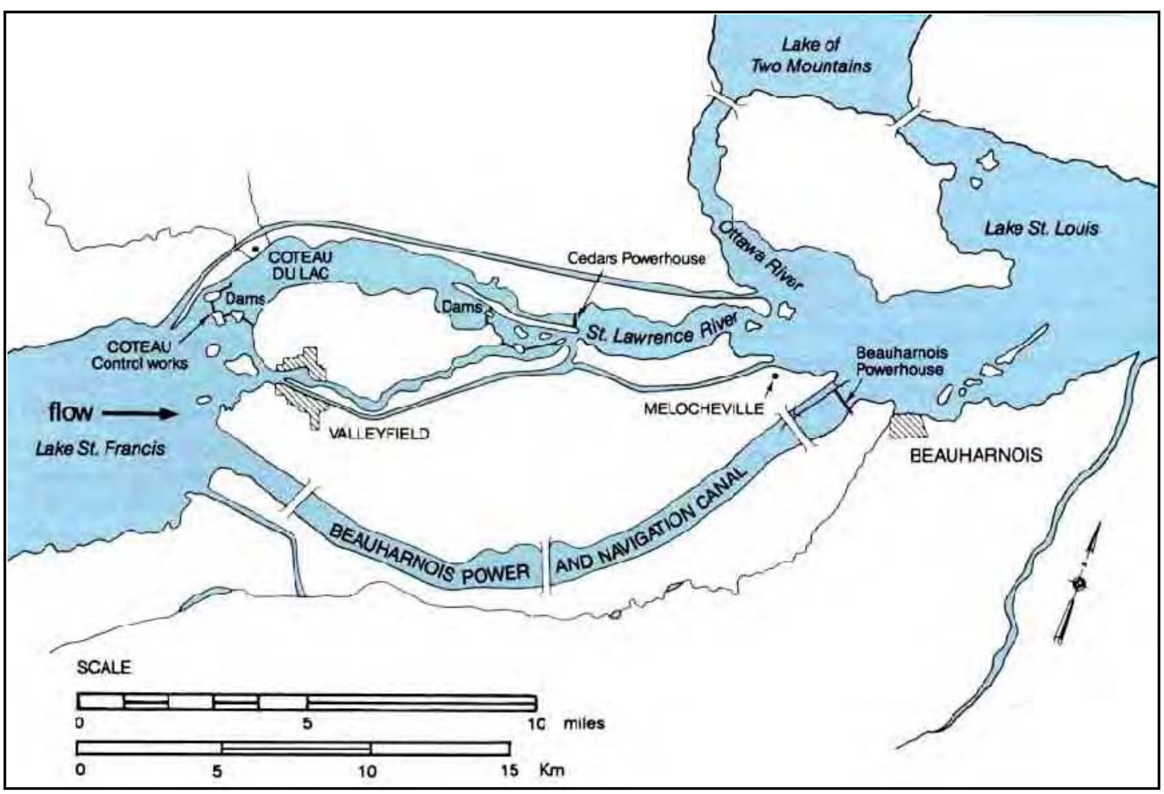
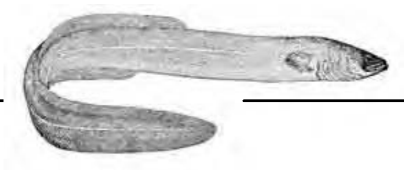
Maps of the Upper St. Lawrence River:







Workshop on safe downstream passage of eel in the St. Lawrence River

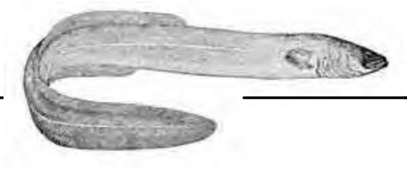
Presentations

Presentations given at the workshop were divided into three general areas:

1. **Introduction**
2. **Eel behaviour related to downstream passage**
3. **Eel protection / mitigation**

(click on the section you would like to view)

Workshop photos by Kevin McGrath



Workshop on safe downstream passage of eel in the St. Lawrence River

1. Introduction

Welcome from Steering Committee and introduction of ESSA – Rob MacGregor (OMNR) and Serge Tremblay (Faune Québec)

Overview of St. Lawrence River, Geography, Hydrology and General Water Management - David Fay (Environment Canada)

The Dramatic Decline of the American Eel with Special Reference to the St. Lawrence River- Lake Ontario System - John Casselman (Ontario Ministry of Natural Resources)

Estimation of American eel escapement from Upper St. Lawrence River and Lake Ontario - Guy Verrault (Faune Québec)

Eel Survival Study at Beauharnois Power Dam (1994) – Richard Verdon (Hydro Québec)

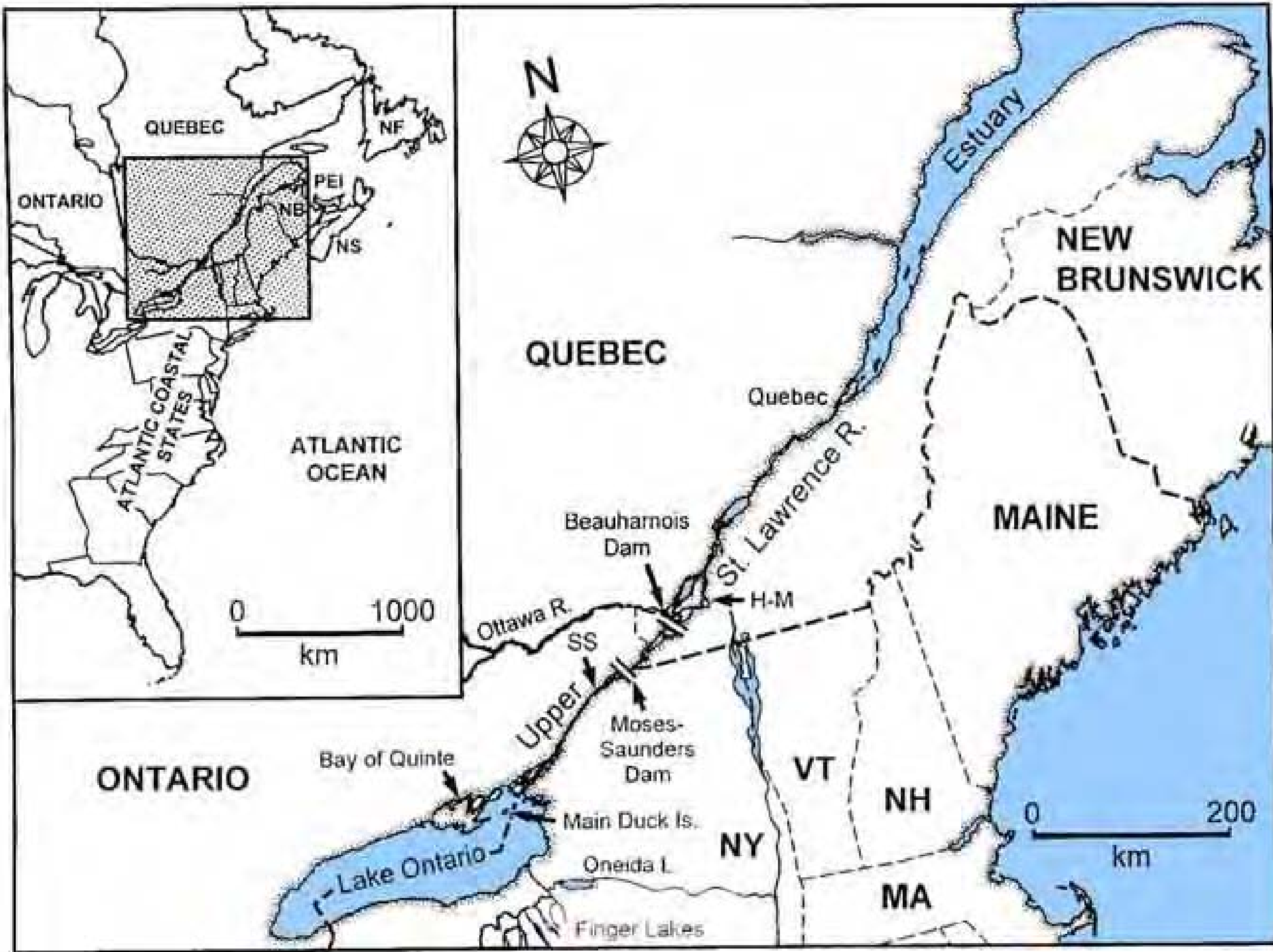
Moses/Saunders Generating Station (including Long Sault Spillway, Iroquois Dam and Eisenhower Lock) Technical Description and Operations – Mike Boutilier (Ontario Power Generation)

American eel (*Anguilla rostrata*) Entrainment Survival Study at the St. Lawrence-FDR Power Project on the St. Lawrence River – Kevin McGrath (New York Power Authority)

Workshop photos by Kevin McGrath

Downstream Passage Workshop

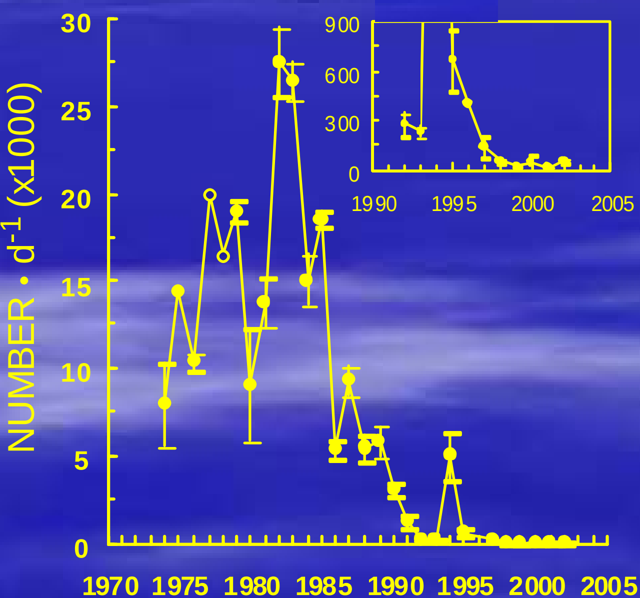
Canadian Eel Steering Committee


QUEBEC
NF
ONTARIO
PEI
NB
NS
ATLANTIC COASTAL STATES
ATLANTIC OCEAN
0
1000
km
N
Estuary
NEW BRUNSWICK
QUEBEC
Quebec
St. Lawrence R.
MAINE
Beauharnois Dam
H-M
Ottawa R.
SS
Upper
Moses-Saunders Dam
Bay of Quinte
ONTARIO
VT
NH
Main Duck Is.
NY
Lake Ontario
Oneida L.
MA
Finger Lakes
0
200
km

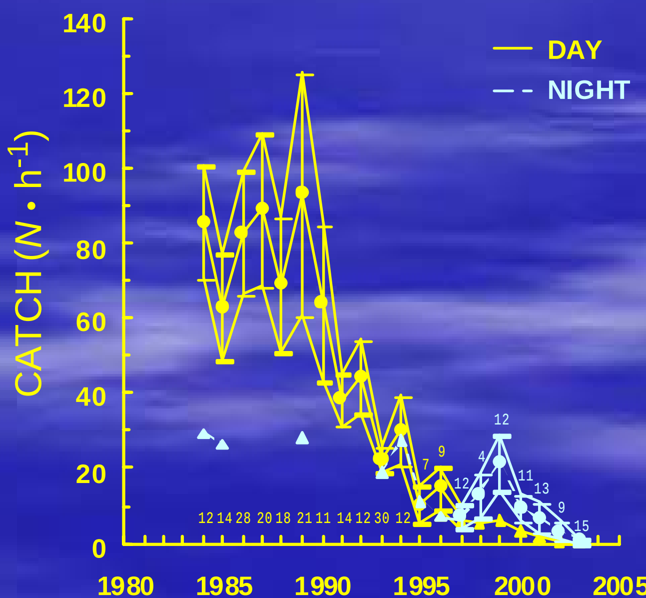
Ladder Index and Commercial electrofishing, Lake Ontario

- Eel ladder index confirms that recruitment of juvenile eels to upper St. Lawrence River – Lake Ontario has virtually ceased
- Commercial catches reflect this decline with a lag equal to age of catch. Commercial electrofishing catches eels 5 yr later (see peaks 1994, 1999)

Eel ladder recruitment



Commercial electrofishing index



Significant Issue

- American eel provided significant socio-economic benefits
- Rich part of local heritage and culture
- Virtually all large, highly fecund females that were important to overall spawning biomass
- Significant part of biodiversity
- Steep declines in Lower St Lawrence
- Eels appear to be at risk of extirpation in the Upper St Lawrence/ Lake Ontario

Structure

- Canadian Eel Working Group (CEWG)
  - 4 Sub groups: Management, Science, Inter-jurisdictional, Habitat
  - Recommended 50% reduction in human-induced mortality of American eel
- Canadian Eel Steering Committee Relating to Passage and Associated Habitat Issues in the St. Lawrence River
  - Reports to CEWG Science SG
  - Focus on mortality of eels at two dams: Moses-Saunders and Beauharnois on St. Lawrence River
  - Key objective is to evaluate means of improving downstream passage/reduce mortality of eels at these facilities
  - Partnership approach among government agencies, hydro facilities and stakeholders
  - This workshop is attempting to address only one of numerous factors affecting American eel survival.

Steering Committee Objectives

- Identify priority areas of interest and concern relating to improving eel passage, mitigating turbine mortality and associated habitat issues at dams
- Identify information, science and management needs and oversee data collection, science and mitigation/enhancement projects,
- Oversee activities of Task Groups and review and approve their work plans,
- Provide information and make recommendations to the Canadian Eel Working Group to improve eel passage and mitigate turbine mortality and associated habitat issues
- Seek additional funding opportunities,
- Review and recommend the implementation of relevant legislation where required,
- Develop communications strategies

No Small Task!

Overview of R.H. Saunders Hydroelectric Dam

First Step

Workshop

Next Steps

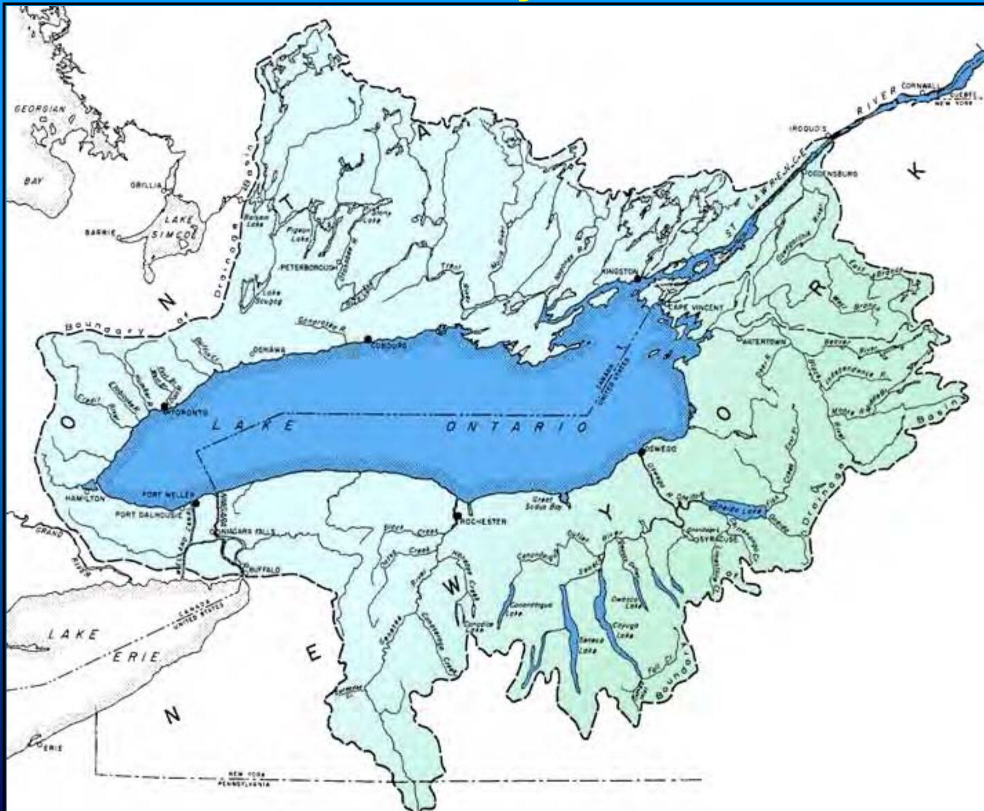
- Steering Committee Meeting
- Identify best bets to move forward
- Develop a process to make decisions
- Implementation

Lake Ontario - St Lawrence River Water Management

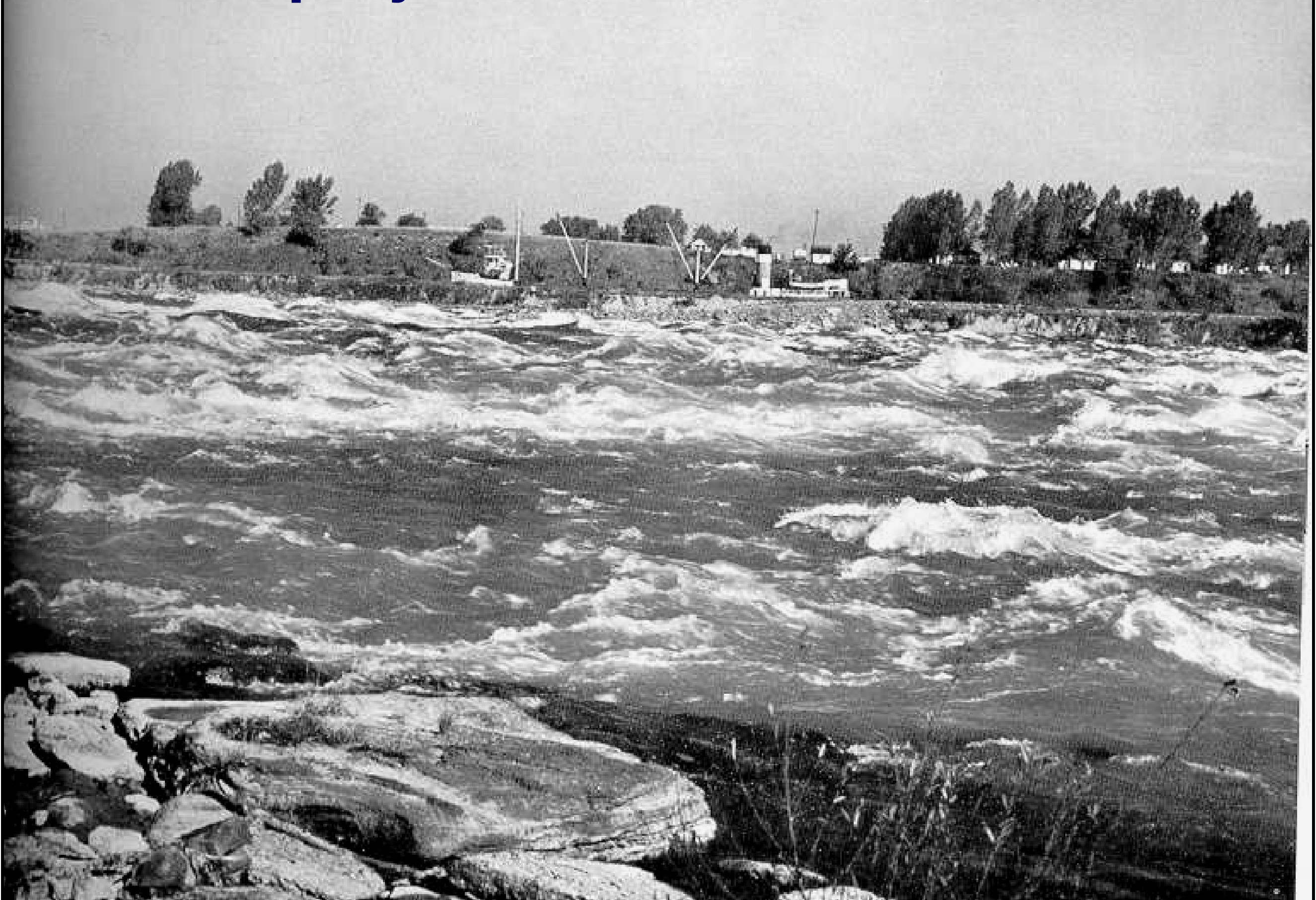
David Fay
Environment Canada


Great Lakes - St. Lawrence River
Drainage Basin
CANADA
U.S.A.
Thunder Bay
Marathon
Duluth
Marquette
Lake Superior
Sault Ste. Marie
Sudbury
Parry Sound
Georgian Bay
Owen Sound
Lake Huron
Petoskey
Traverse City
Green Bay
Lake Michigan
Bay City
Saginaw
Flint
Milwaukee
Grand Rapids
Chicago
Toledo
Detroit
Windsor
Sarnia
London
Hamilton
Toronto
Lake Erie
Cleveland
Erie
Buffalo
Niagara Falls
Rochester
Syracuse
Oswego
Lake Ontario
Trenton
Kingston
Massena
Cornwall
Montréal
Trois Rivières
N
50 0 50 100 Kilometers
50 0 50 Miles

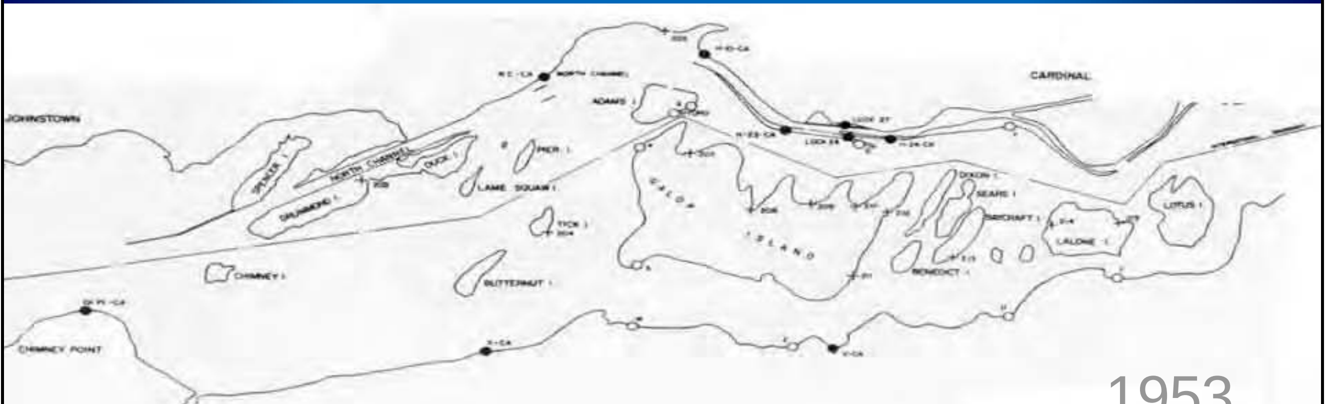
Lake Ontario-St. Lawrence River System



Pre-project - *International Rapids Section*



Lake Ontario Pre-project Outlet



1953

1960

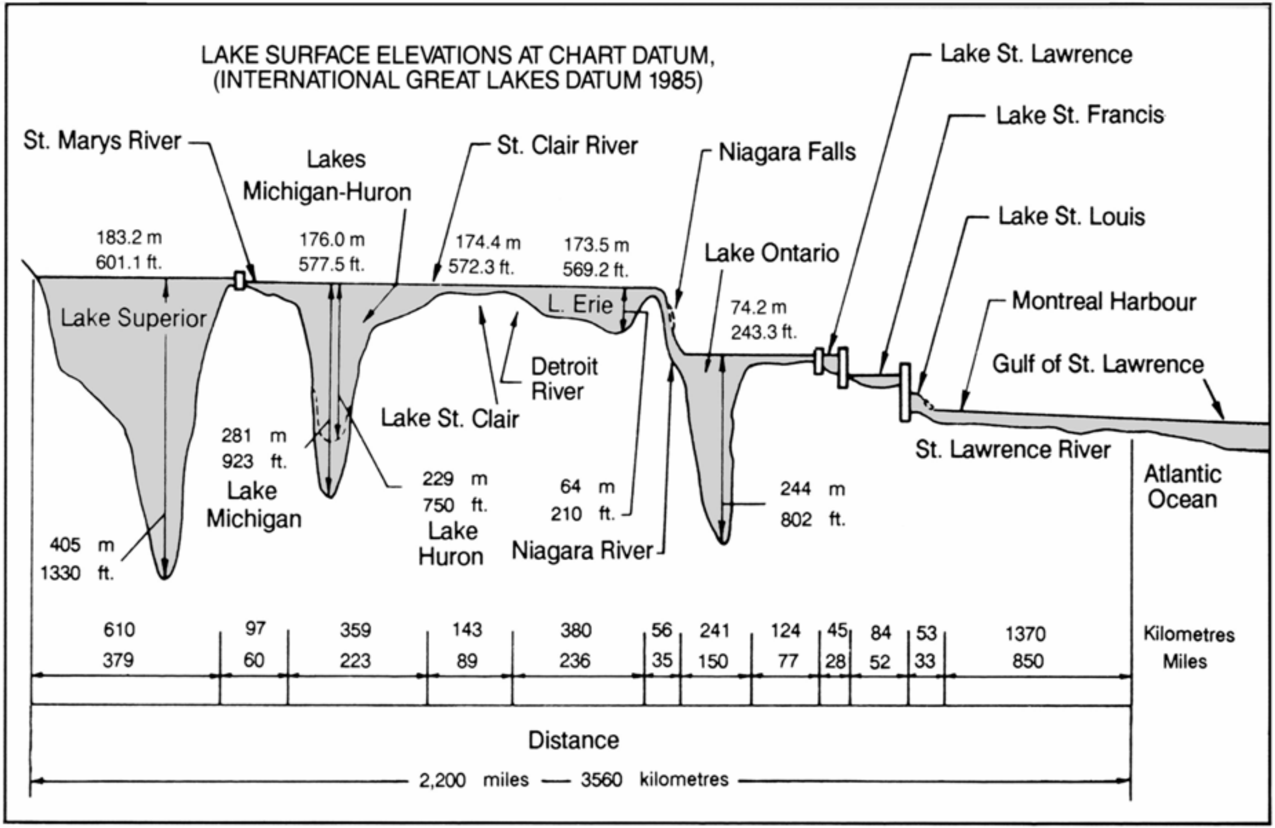
Lake Ontario Outflow Regulation History

1909 Boundary Waters Treaty

- Creates International Joint Commission with power to:
- approve uses, obstructions, diversions
- conduct studies, make recommendations to governments
- act as arbitrator

Hydropower Development in International Reach of St. Lawrence River

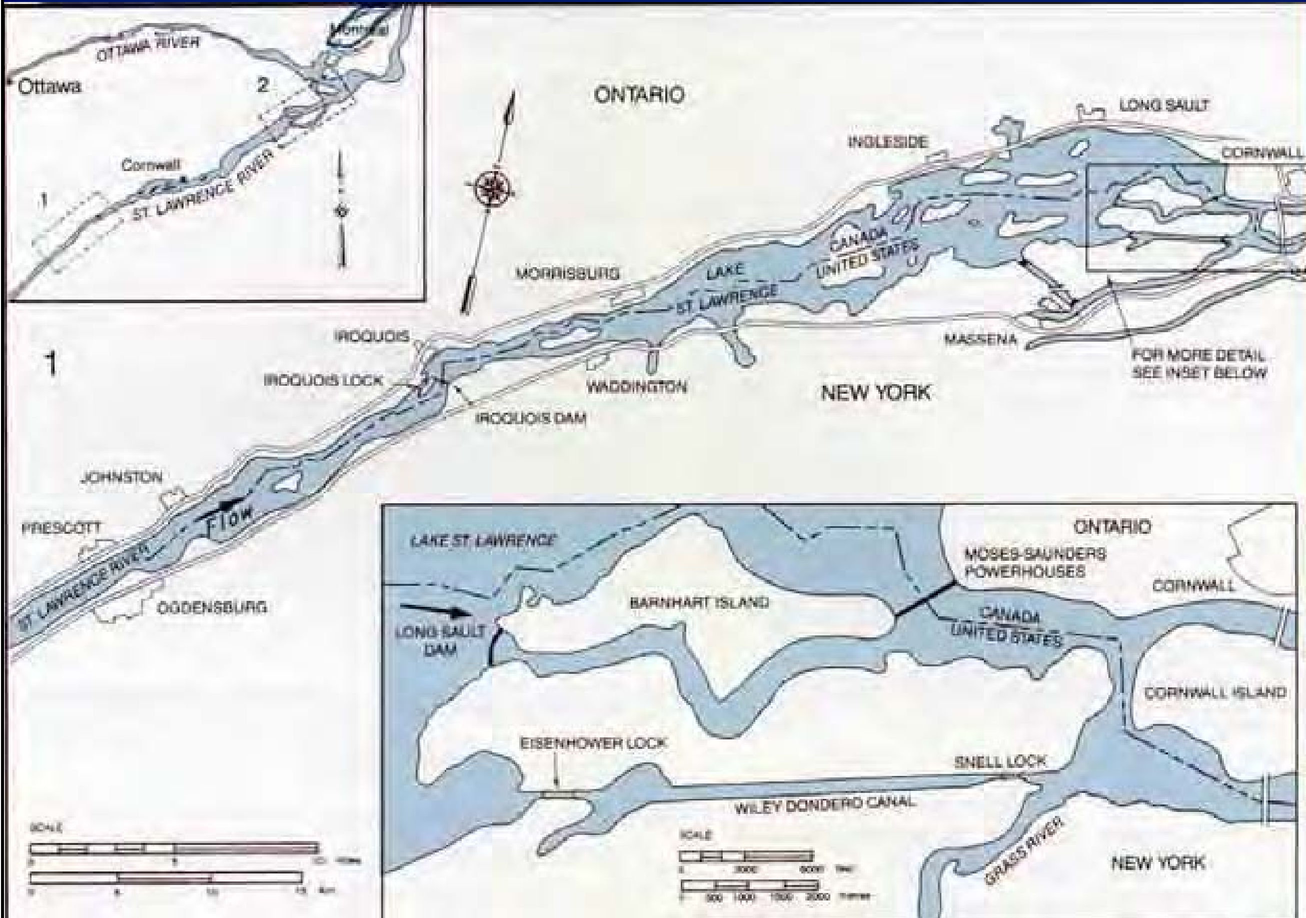
- Required IJC Approval
- Order of Approval (1952) and Supplementary Order (1956)
- designed to allow simultaneous Seaway expansion
- International St. Lawrence River Board of Control oversees operations
- construction completed in 1958
- operated by New York Power Authority and Ontario Power Generation



LAKE SURFACE ELEVATIONS AT CHART DATUM,
(INTERNATIONAL GREAT LAKES DATUM 1985)
St. Marys River
Lakes Michigan-Huron
St. Clair River
Niagara Falls
Lake St. Lawrence
Lake St. Francis
Lake St. Louis
Montreal Harbour
Gulf of St. Lawrence
Lake Ontario
183.2 m
601.1 ft.
176.0 m
577.5 ft.
174.4 m
572.3 ft.
173.5 m
569.2 ft.
74.2 m
243.3 ft.
Lake Superior
L. Erie
Detroit River
Lake St. Clair
281 m
923 ft.
Lake Michigan
229 m
750 ft.
Lake Huron
64 m
210 ft.
Niagara River
244 m
802 ft.
405 m
1330 ft.
St. Lawrence River
Atlantic Ocean
610 379
97 60
359 223
143 89
380 236
56 35
241 150
124 77
45 28
84 52
53 33
1370 850
Kilometres
Miles
Distance
2,200 miles — 3560 kilometres

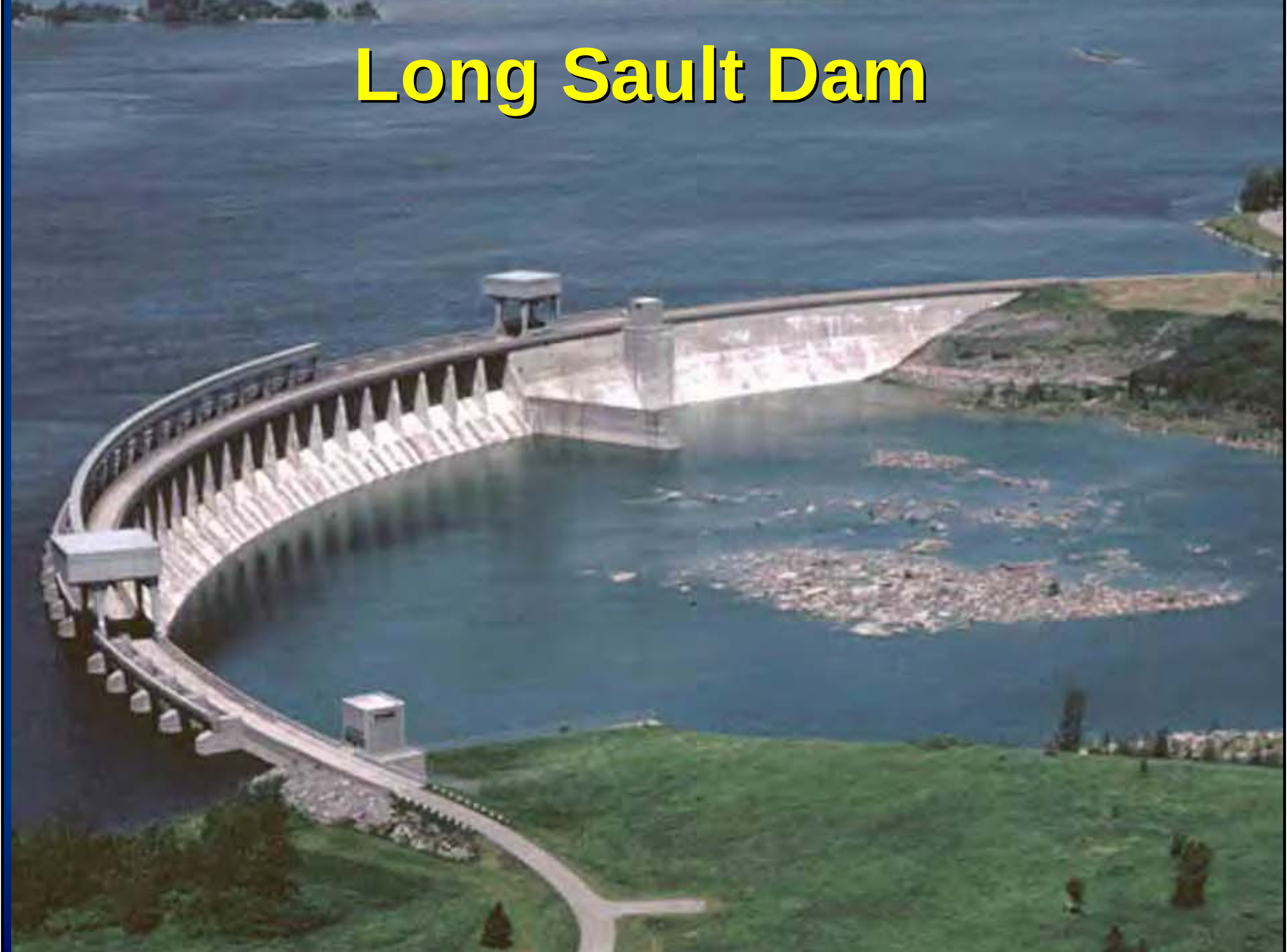
Control Works under IJC Jurisdiction

- Channel enlargements in international reach
  - increase flow capacity and for Seaway expansion
- Iroquois Dam
  - ice management, limit high levels of Lake St. Lawrence
- Moses-Saunders hydropower dam
  - main structure regulating Lake Ontario outflows
- Long Sault Dam - used as spillway
- Ice Booms - ice management in international reach

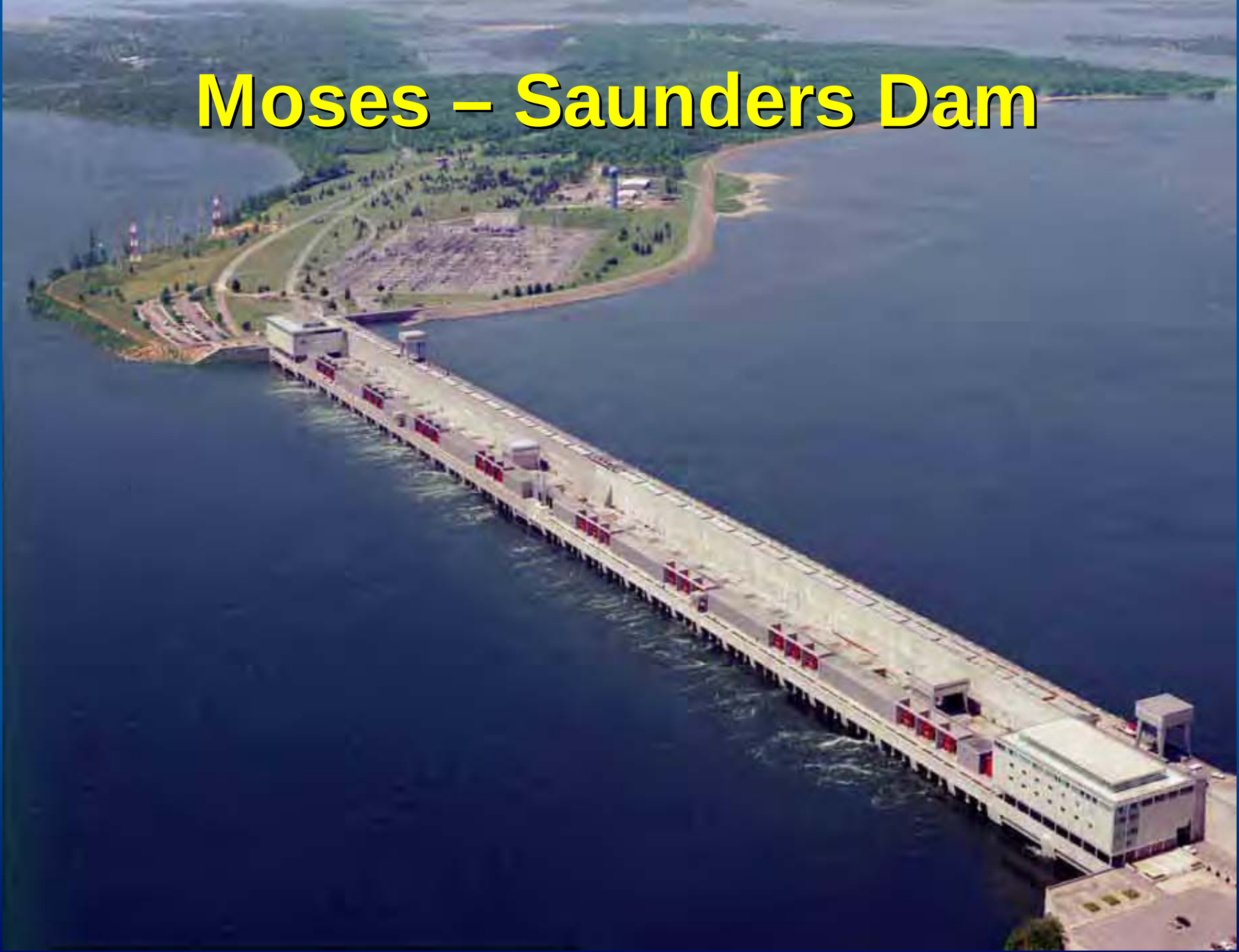


OTTAWA RIVER
Ottawa
2
Cornwall
1
ST. LAWRENCE RIVER
ONTARIO
LONG SAULT
INGLESIDE
CORNWALL
CANADA
UNITED STATES
LAKE
ST LAWRENCE
MORRISBURG
IROQUOIS
MASSENA
FOR MORE DETAIL SEE INSET BELOW
1
IROQUOIS LOCK
WADDINGTON
NEW YORK
IROQUOIS DAM
JOHNSTON
Flow
PRESCOTT
ST LAWRENCE RIVER
OGDENSBURG
ONTARIO
LAKE ST LAWRENCE
MOSES-SAUNDERS POWERHOUSES
CORNWALL
BARNHART ISLAND
CANADA
UNITED STATES
LONG SAULT DAM
CORNWALL ISLAND
EISENHOWER LOCK
SNELL LOCK
WILEY DONDERO CANAL
GRASS RIVER
NEW YORK
SCALE
SCALE

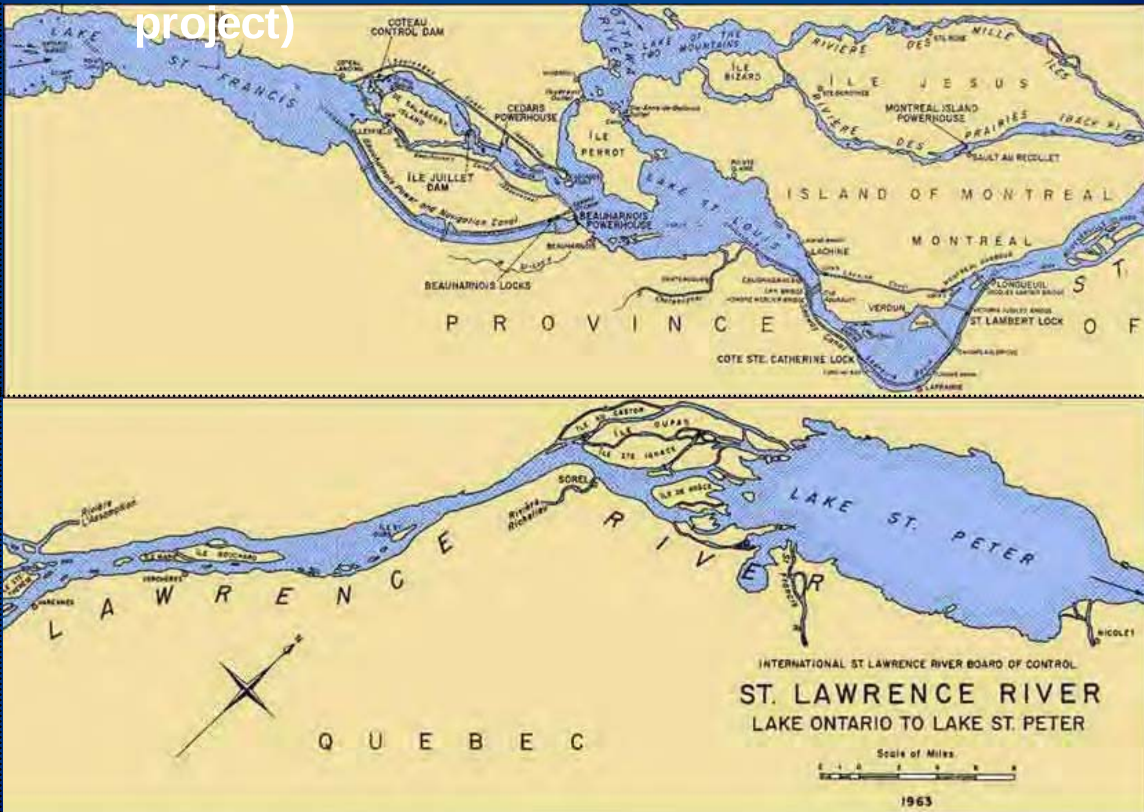
Iroquois Dam and Lock


Long Sault Dam

Moses – Saunders Dam



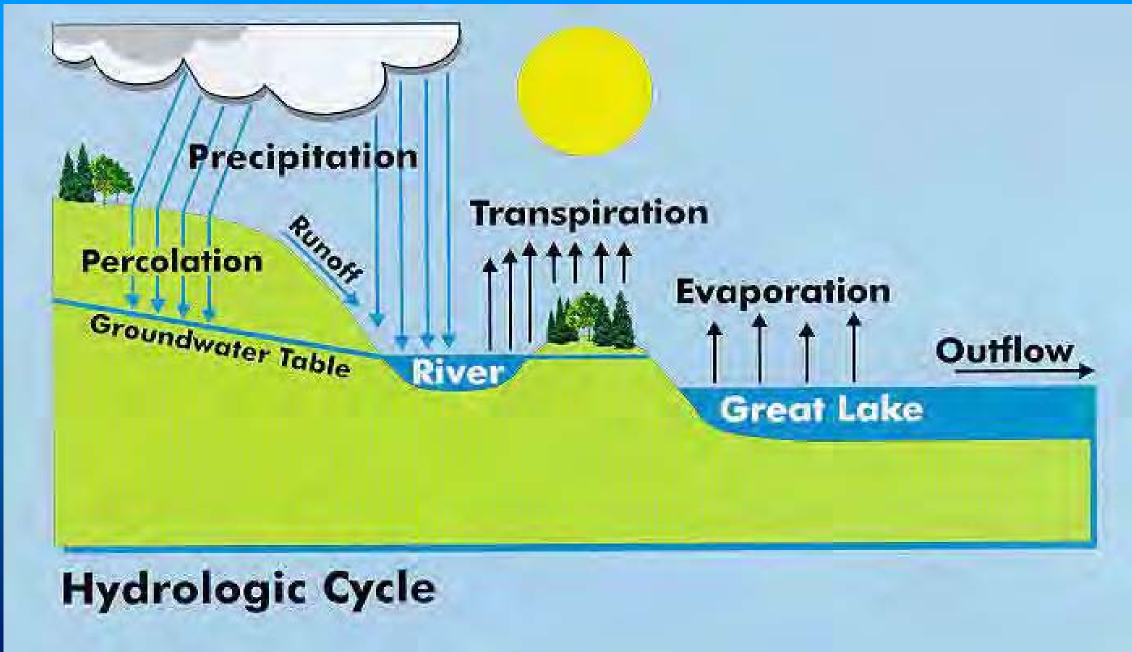
St. Lawrence River (downstream of project)



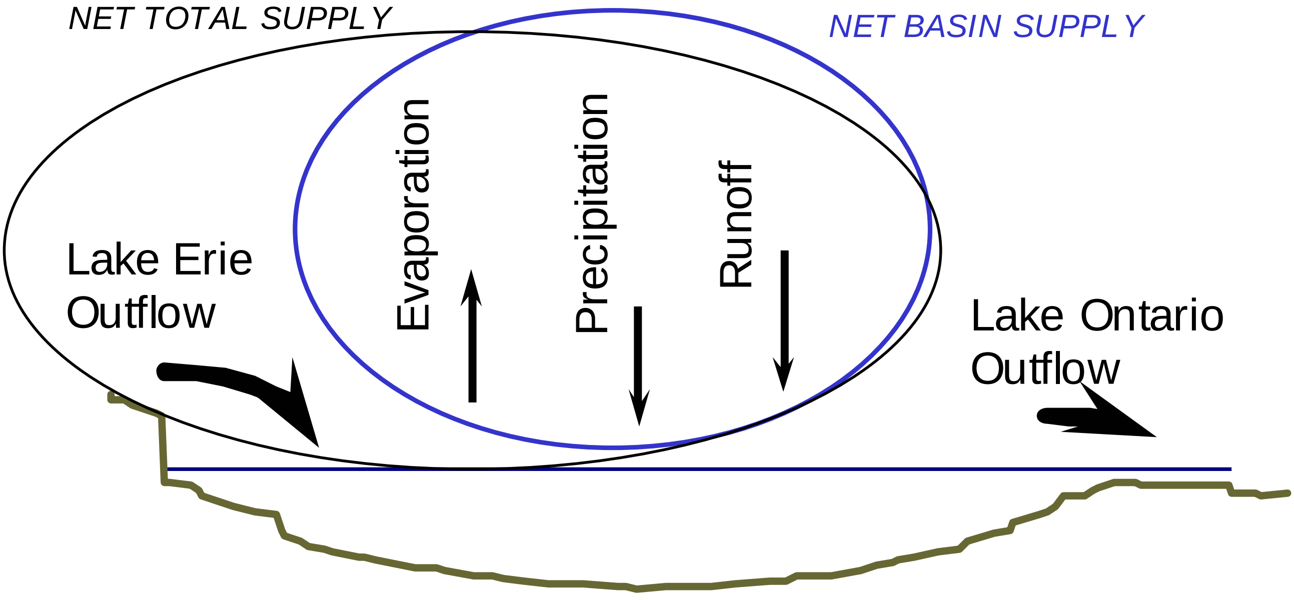
Beauharnois Dam

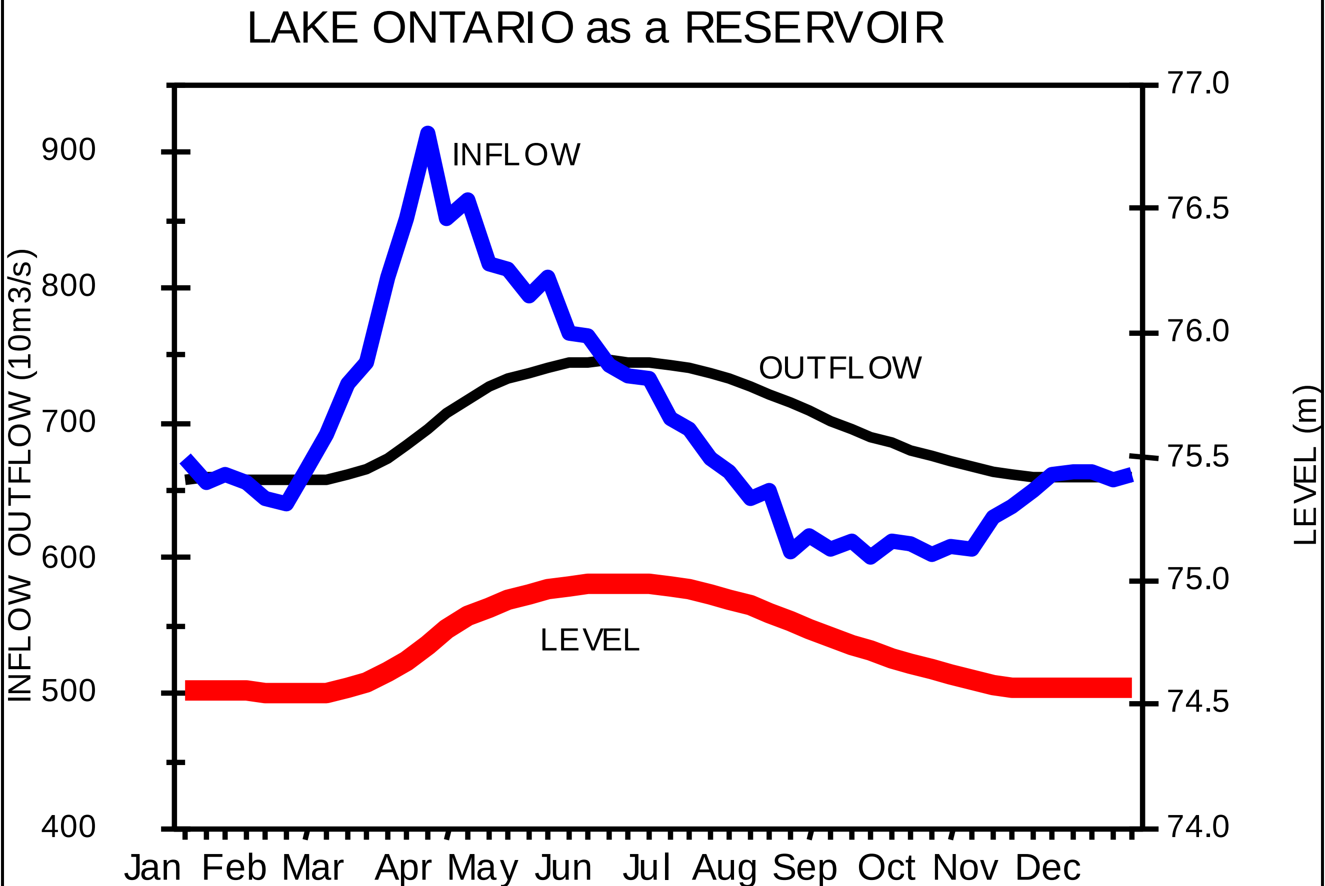
Les Cedres Dam

Hydrologic Cycle

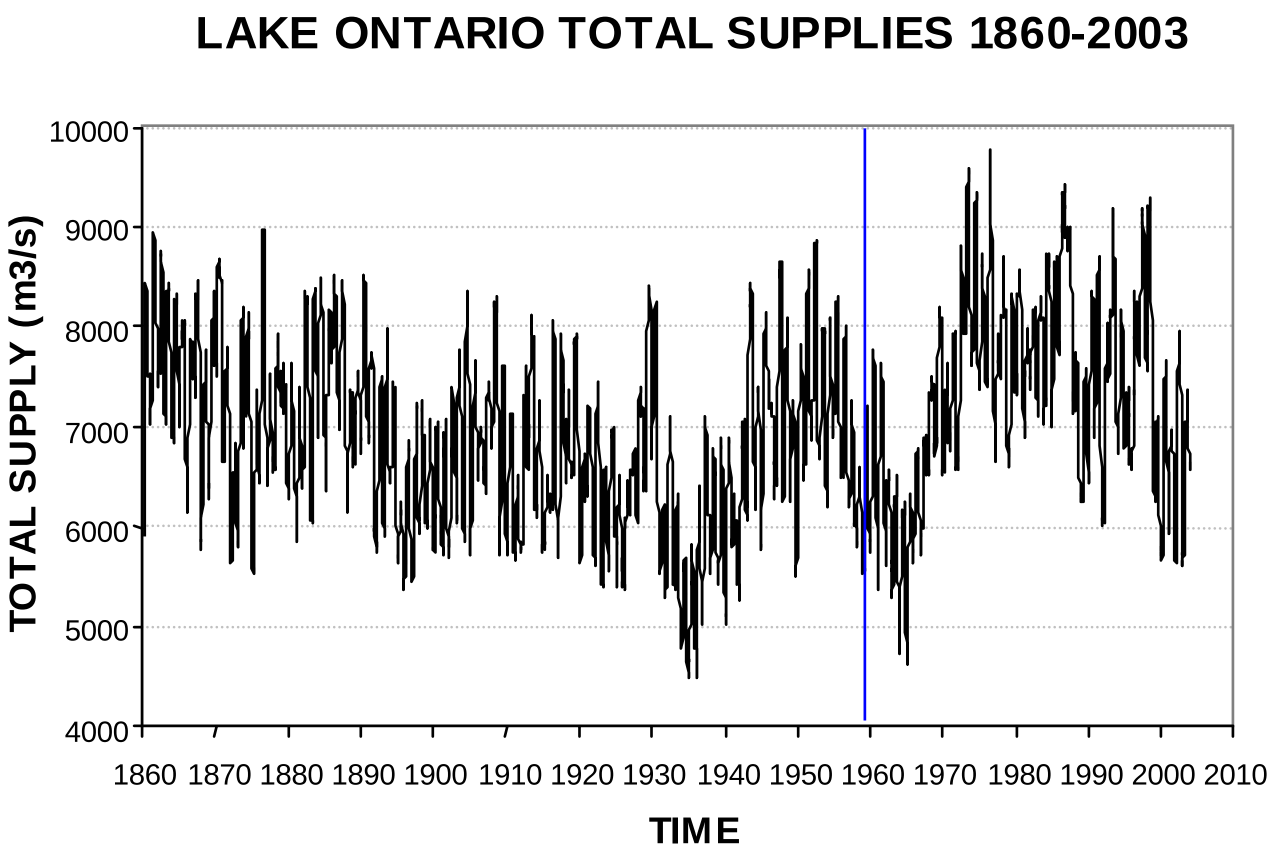


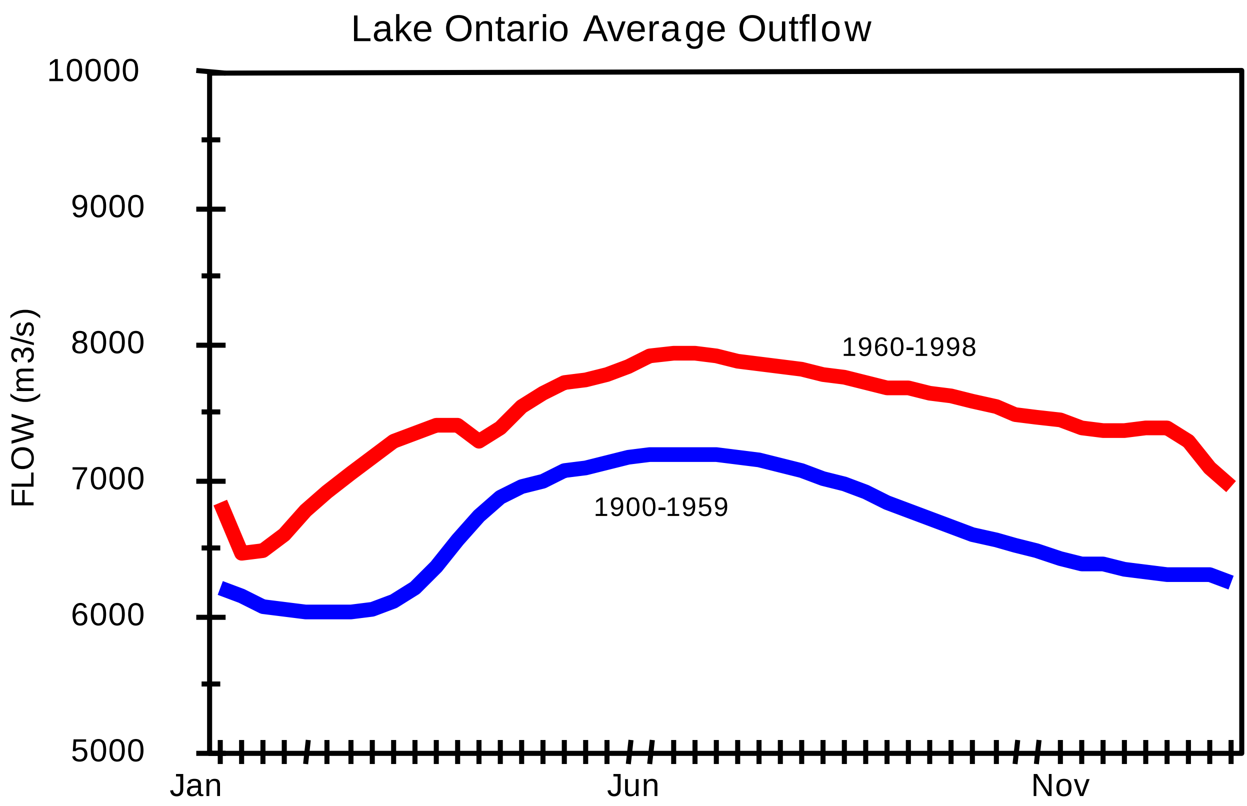
Lake Ontario Water Supplies

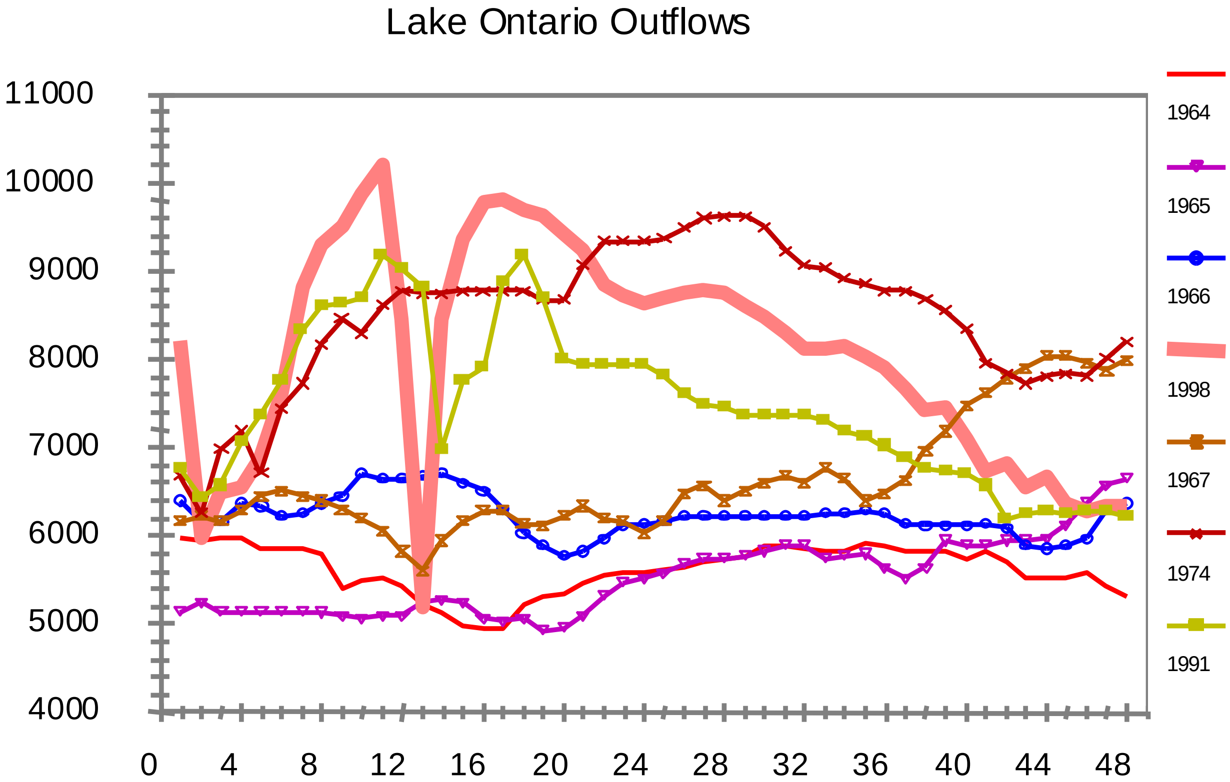


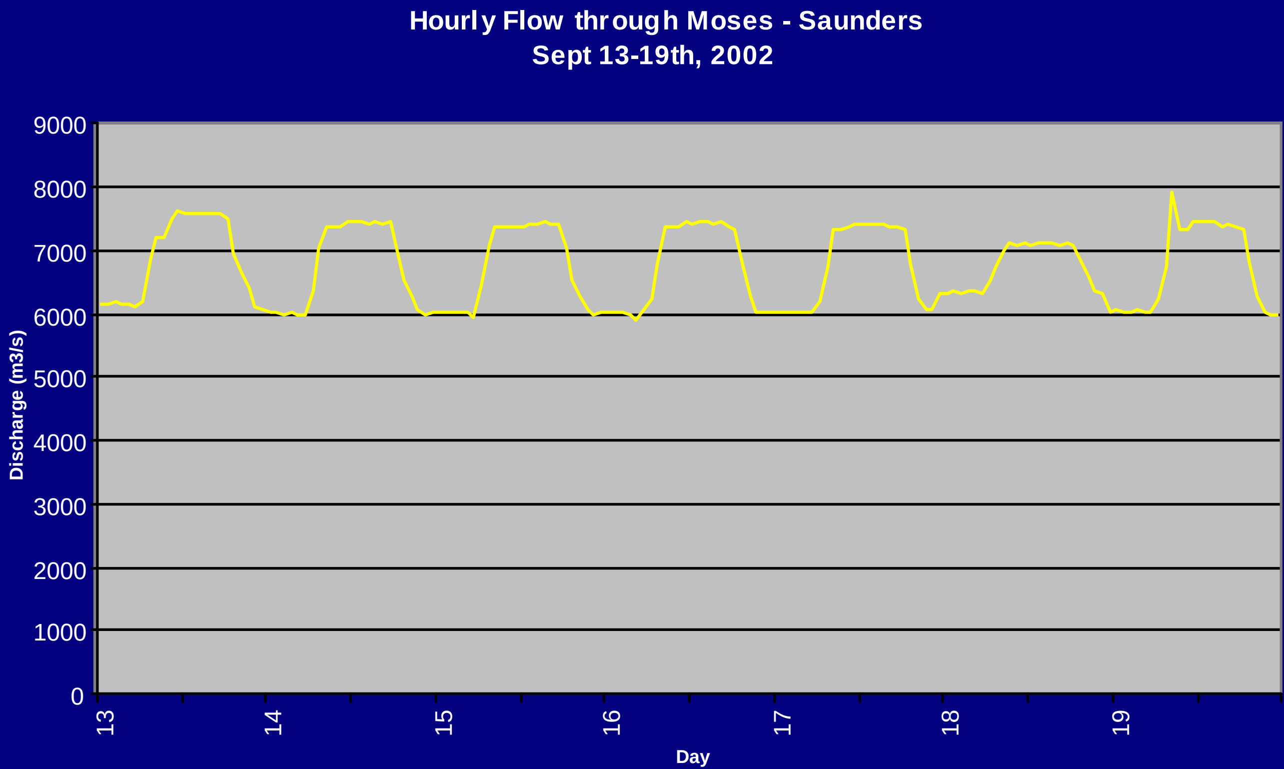


LAKE ONTARIO as a RESERVOIR
INFLOW
OUTFLOW
LEVEL
INFLOW OUTFLOW (10m3/s)
LEVEL (m)
900
800
700
600
500
400
77.0
76.5
76.0
75.5
75.0
74.5
74.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


LAKE ONTARIO TOTAL SUPPLIES 1860-2003
TOTAL SUPPLY (m3/s)
10000
9000
8000
7000
6000
5000
4000
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
TIME


Lake Ontario Average Outflow
FLOW (m3/s)
10000
9000
8000
7000
6000
5000
1960-1998
1900-1959
Jan
Jun
Nov


Lake Ontario Outflows
11000
10000
9000
8000
7000
6000
5000
4000
0
4
8
12
16
20
24
28
32
36
40
44
48
1964
1965
1966
1998
1967
1974
1991


Hourly Flow through Moses - Saunders
Sept 13-19th, 2002
Discharge (m3/s)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
13
14
15
16
17
18
19
Day


QUESTIONS?

The Dramatic Decline of the American Eel With Special Reference to the St. Lawrence River – Lake Ontario System

John M. Casselman

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and
Department of Biology, Queen's University
Kingston, Ontario K7L 3N6

February 2005

Background

- American eels have been a long-valued and heavily used resource across the extensive eastern North American range.
- Since the mid-1980s, eel catches have declined across most of the range, and more dramatically in the 1990s.
- Dramatic decreases in abundance and loss of recruitment in the St. Lawrence River - Lake Ontario (SLR-LO) stock forewarn the possibility of widespread population declines.

Objectives

To review:

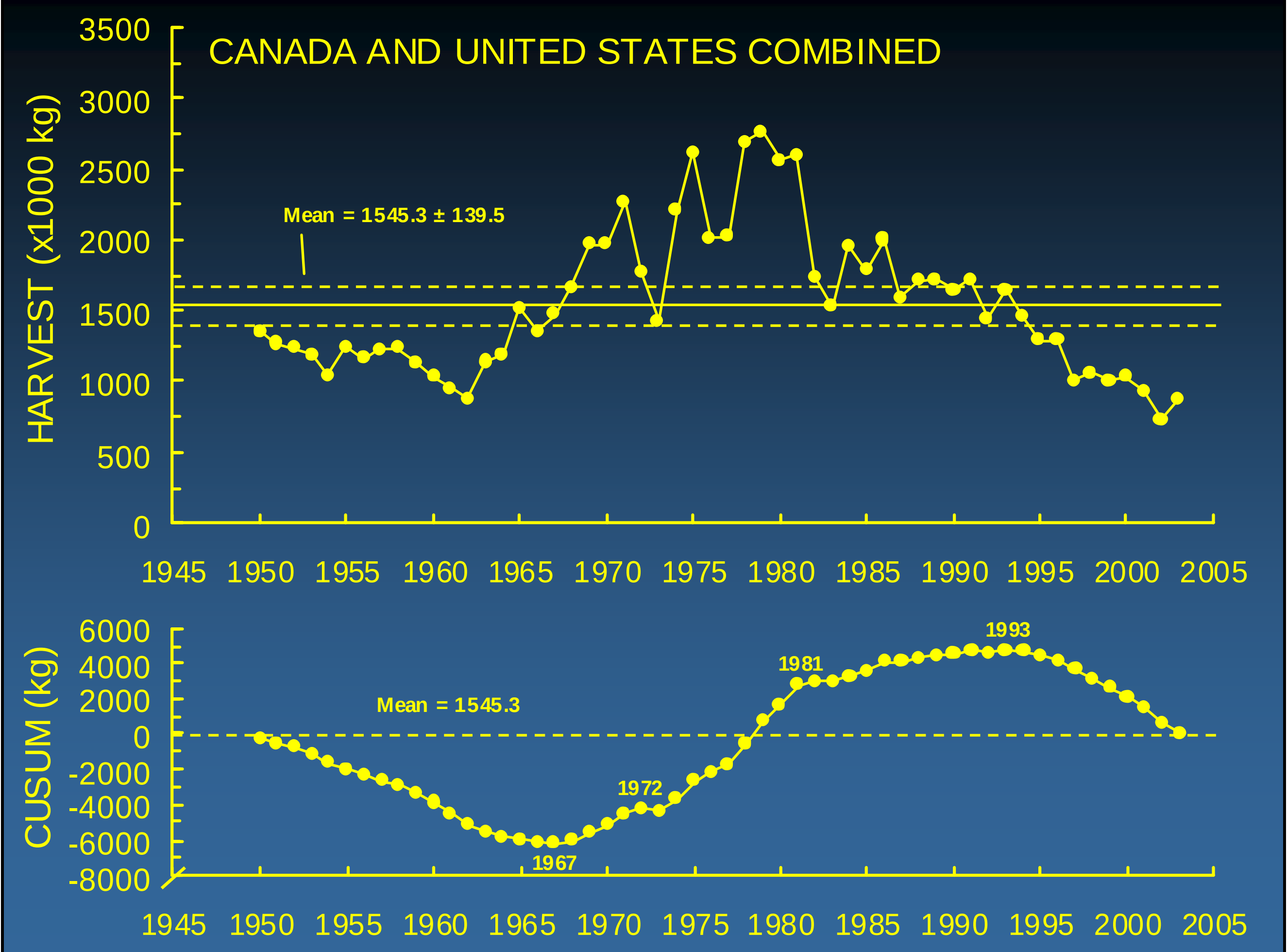
- **commercial harvest and trends across the range, emphasizing the past 50 years and the St. Lawrence River – Lake Ontario stock**

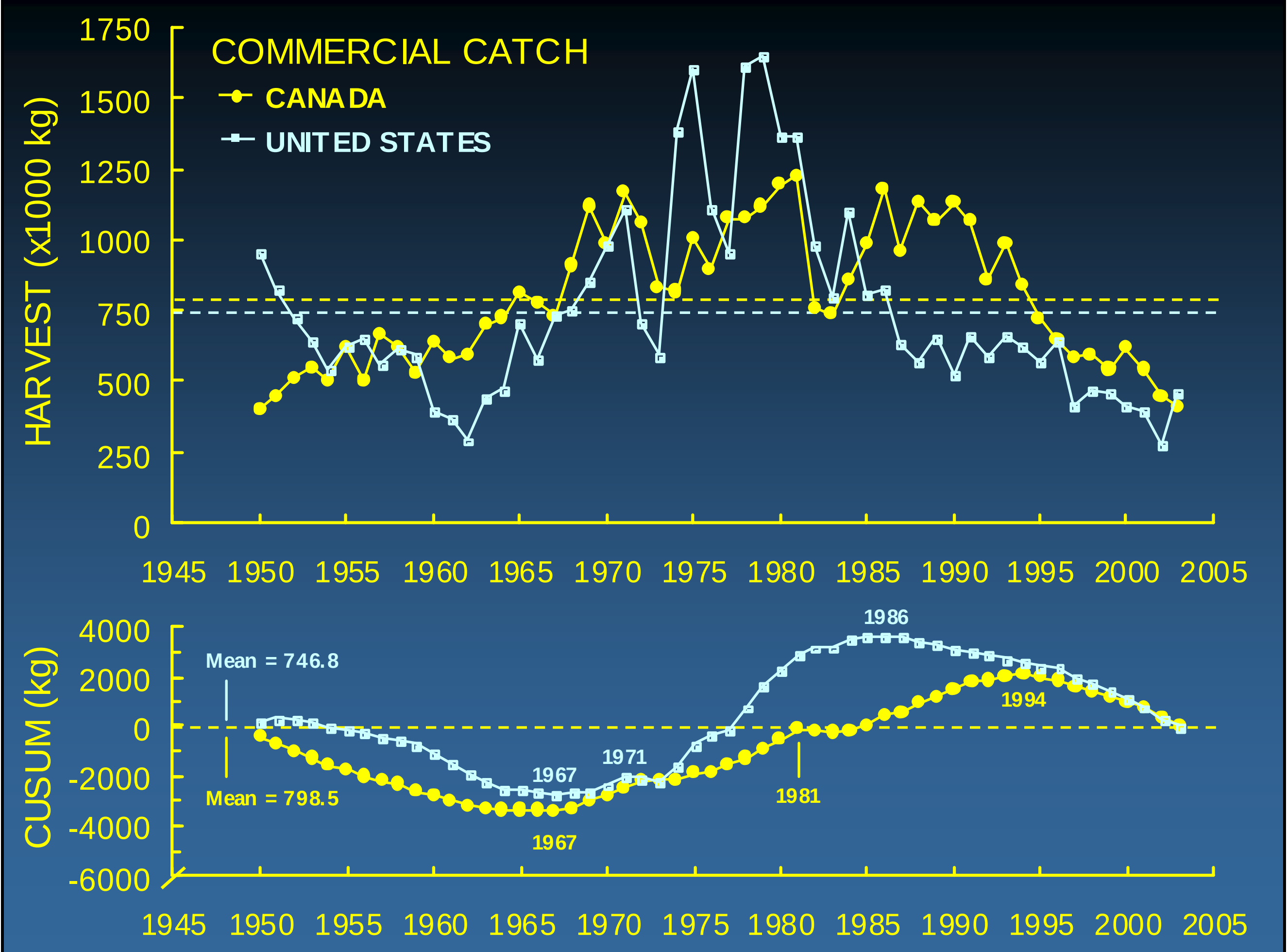
- **scientific indices and trends, emphasizing those that are long-term and fishery-independent**

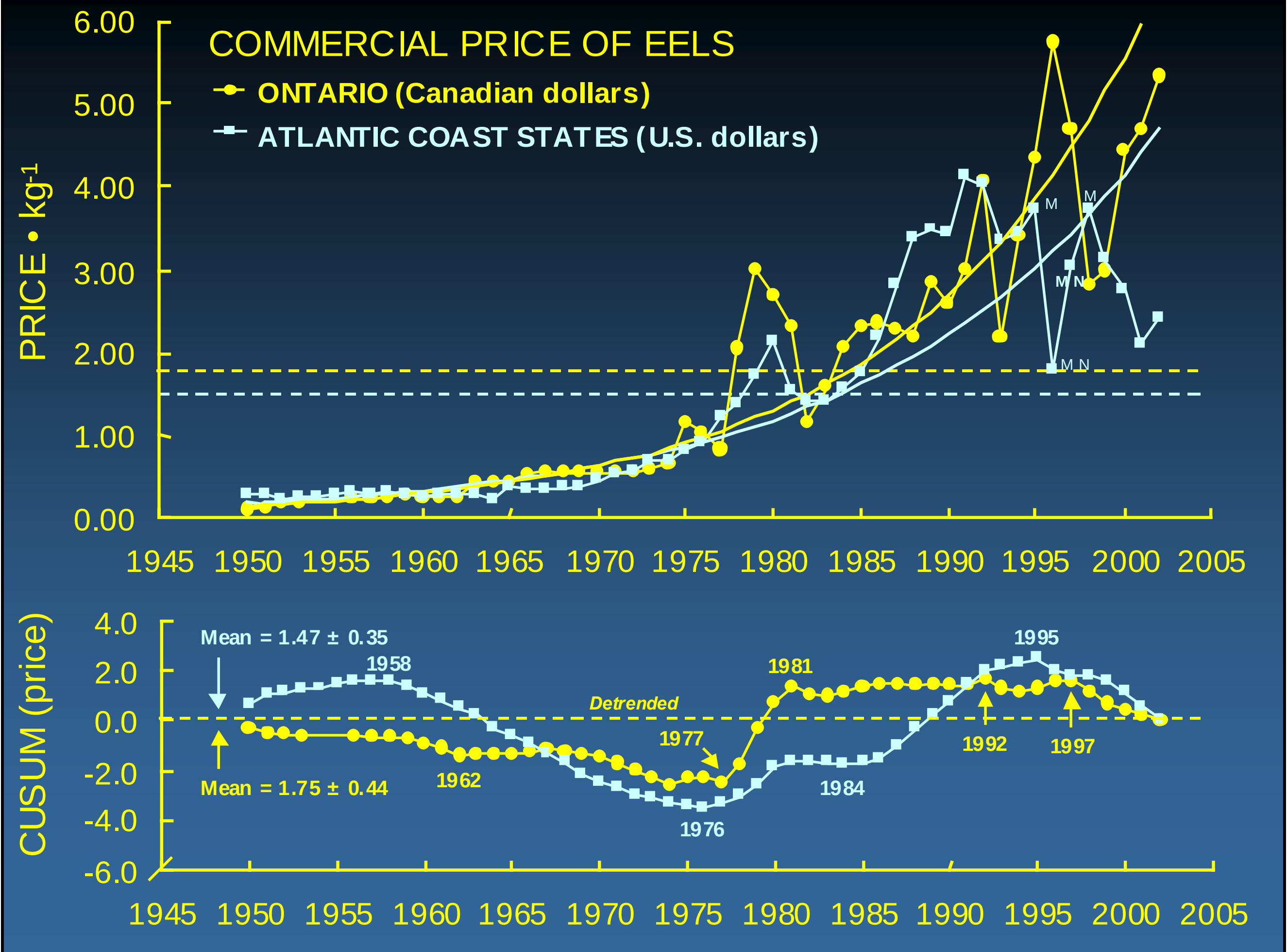
- **declines in recruitment, possible factors, and special considerations**

AMERICAN EEL DYNAMICS AND ABUNDANCE

A valuable historic resource in unprecedented decline


CANADA AND UNITED STATES COMBINED
HARVEST (x1000 kg)
Mean = 1545.3 ± 139.5
3500
3000
2500
2000
1500
1000
500
0
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
CUSUM (kg)
Mean = 1545.3
1967
1972
1981
1993
6000
4000
2000
0
-2000
-4000
-6000
-8000
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005

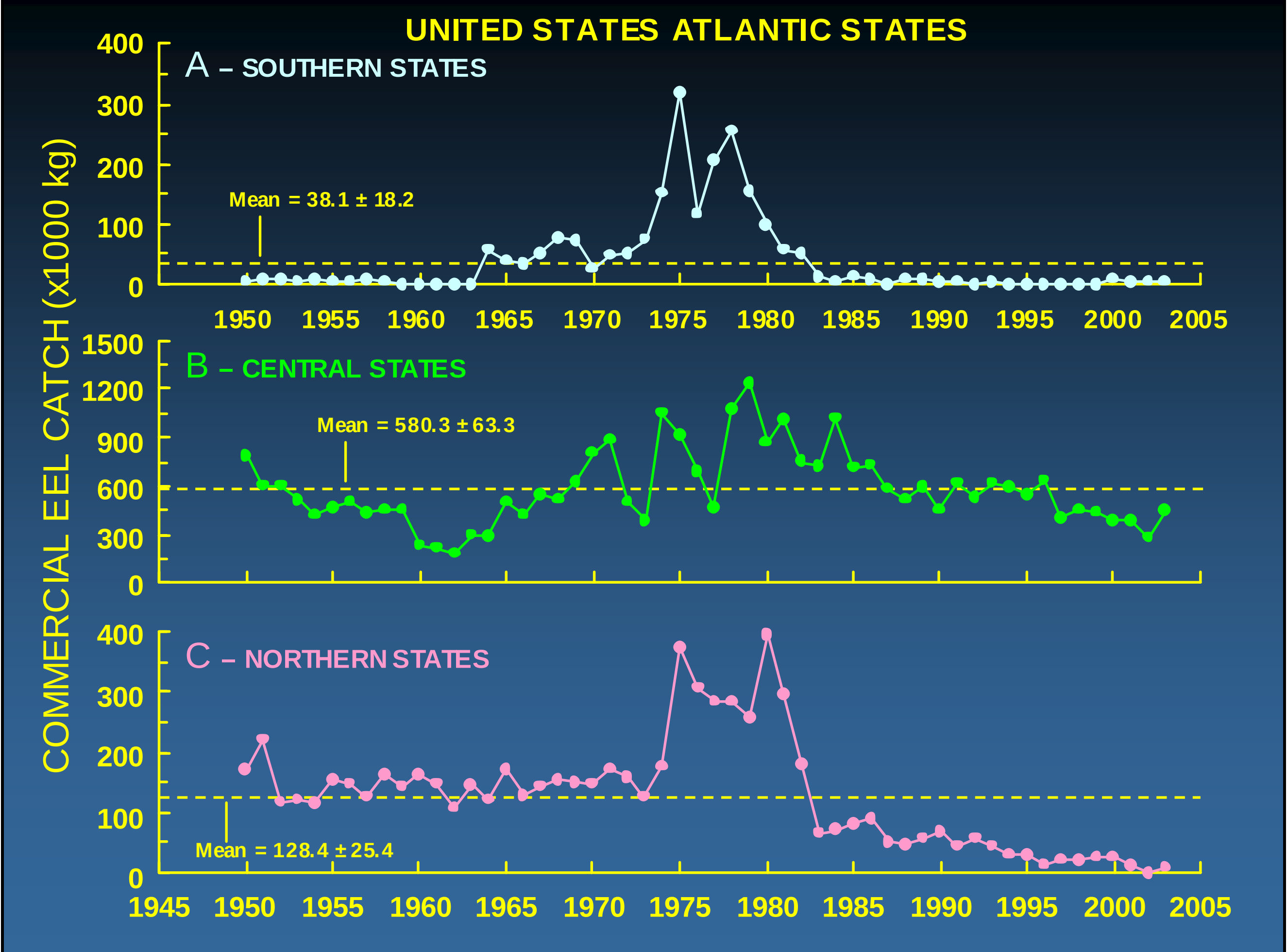

COMMERCIAL CATCH
CANADA
UNITED STATES
HARVEST (x1000 kg)
1750
1500
1250
1000
750
500
250
0
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
CUSUM (kg)
4000
2000
0
-2000
-4000
-6000
Mean = 746.8
Mean = 798.5
1967
1971
1967
1981
1986
1994

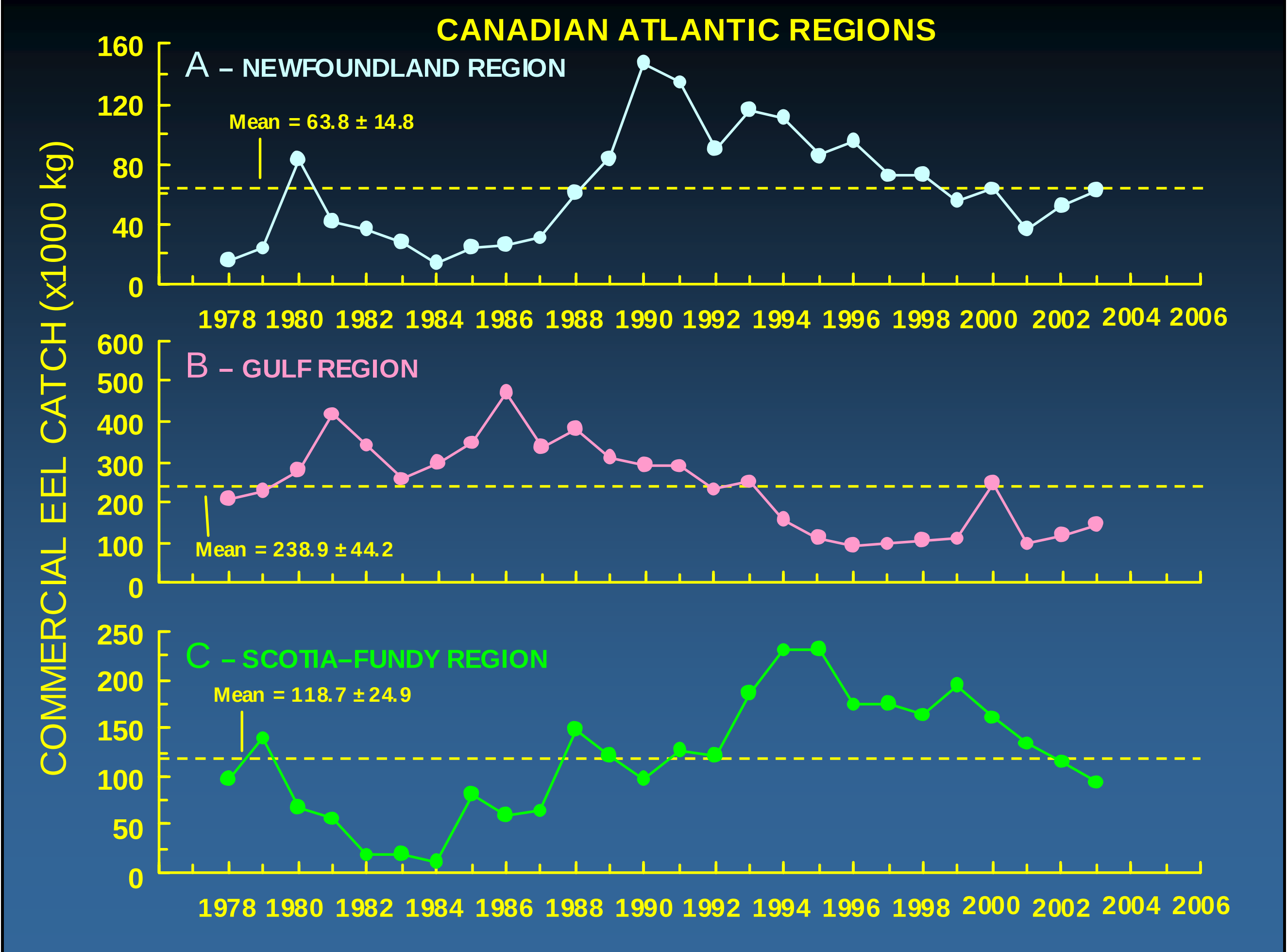


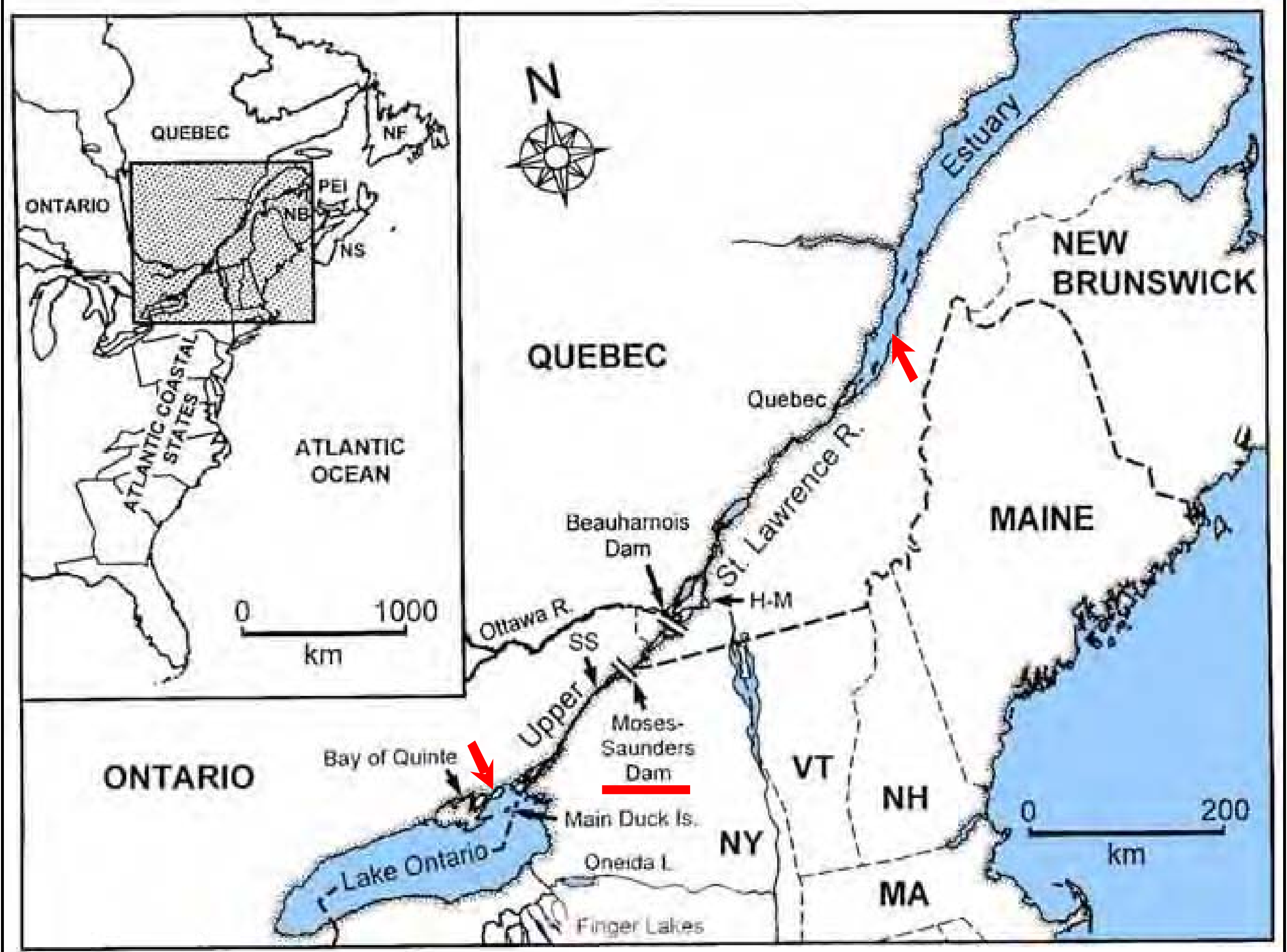
COMMERCIAL PRICE OF EELS
ONTARIO (Canadian dollars)
ATLANTIC COAST STATES (U.S. dollars)
PRICE • kg-1
6.00
5.00
4.00
3.00
2.00
1.00
0.00
M
M
M N
M N
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
CUSUM (price)
4.0
2.0
0.0
-2.0
-4.0
-6.0
Mean = 1.47 ± 0.35
Mean = 1.75 ± 0.44
1958
1962
Detrended
1977
1976
1981
1984
1992
1995
1997

American Eel Harvest by Region

1. Southern States
2. Central States
3. Northern States
4. Scotia–Fundy Region
5. Gulf Region
6. Newfoundland Region
7. Lower St. Lawrence River
8. Upper St. Lawrence River and Lake Ontario


UNITED STATES ATLANTIC STATES
COMMERCIAL EEL CATCH (x1000 kg)
A – SOUTHERN STATES
Mean = 38.1 ± 18.2
B – CENTRAL STATES
Mean = 580.3 ± 63.3
C – NORTHERN STATES
Mean = 128.4 ± 25.4
400
300
200
100
0
1500
1200
900
600
300
0
400
300
200
100
0
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005

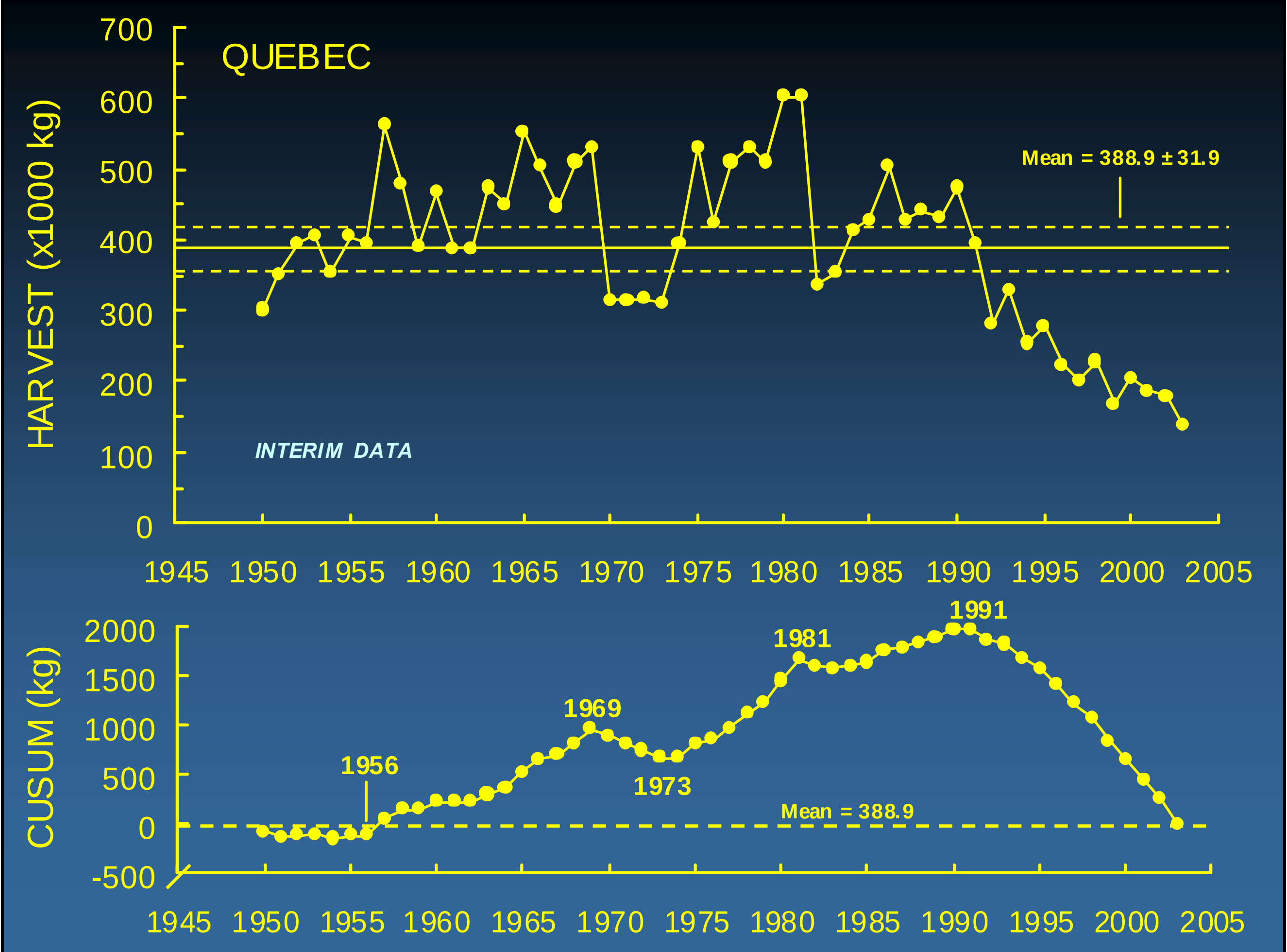

CANADIAN ATLANTIC REGIONS
COMMERCIAL EEL CATCH (x1000 kg)
A – NEWFOUNDLAND REGION
Mean = 63.8 ± 14.8
0
40
80
120
160
B – GULF REGION
Mean = 238.9 ± 44.2
0
100
200
300
400
500
600
C – SCOTIA–FUNDY REGION
Mean = 118.7 ± 24.9
0
50
100
150
200
250
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006



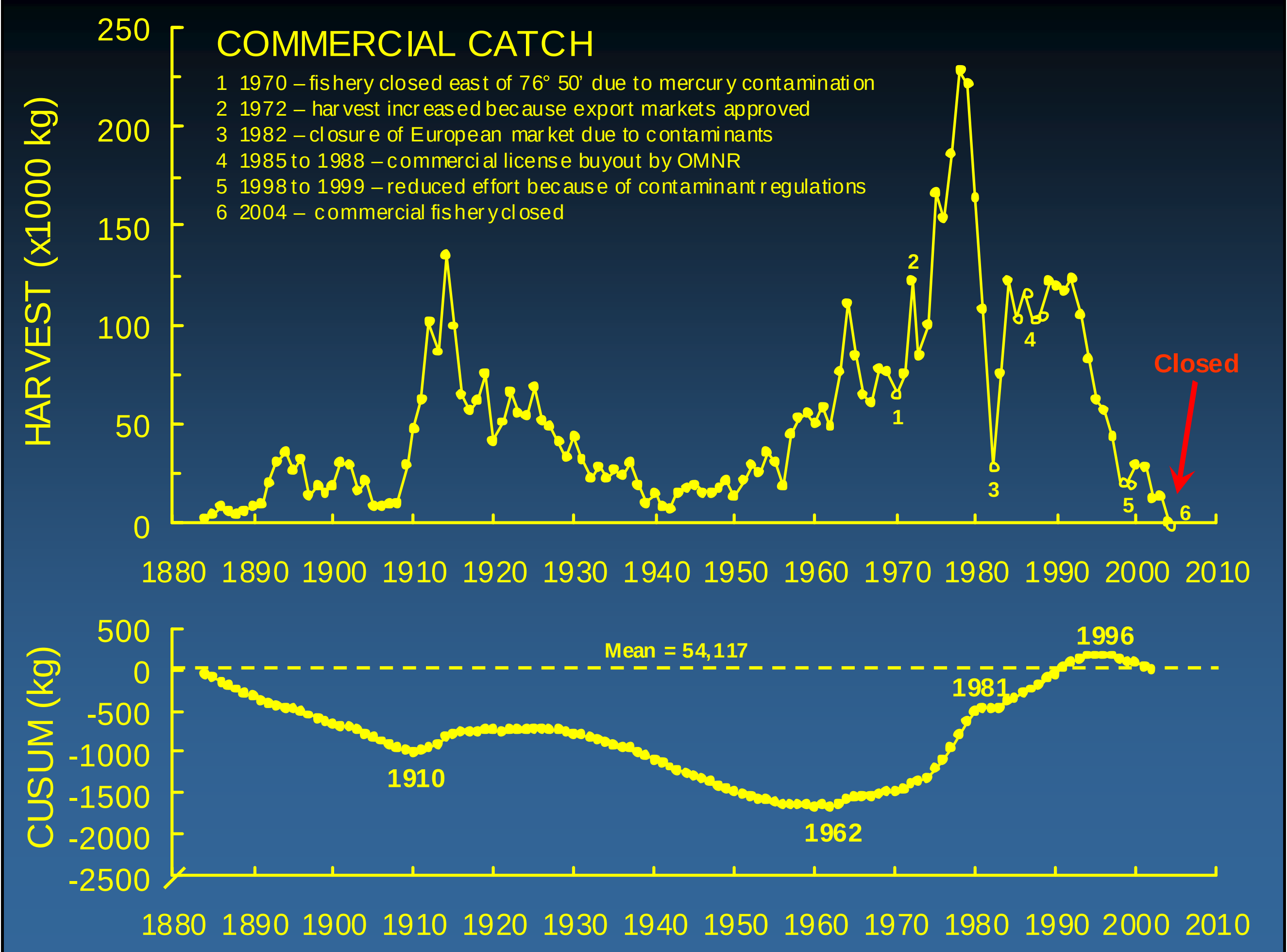
QUEBEC
NF
ONTARIO
PEI
NB
NS
ATLANTIC COASTAL STATES
ATLANTIC OCEAN
0
1000
km
N
Estuary
NEW BRUNSWICK
QUEBEC
Quebec
St. Lawrence R.
MAINE
Beauharnois Dam
H-M
Ottawa R.
SS
Upper
Moses-Saunders Dam
Bay of Quinte
ONTARIO
Main Duck Is.
Lake Ontario
Oneida L.
Finger Lakes
NY
VT
NH
MA
0
200
km

Tidal Eel Weir

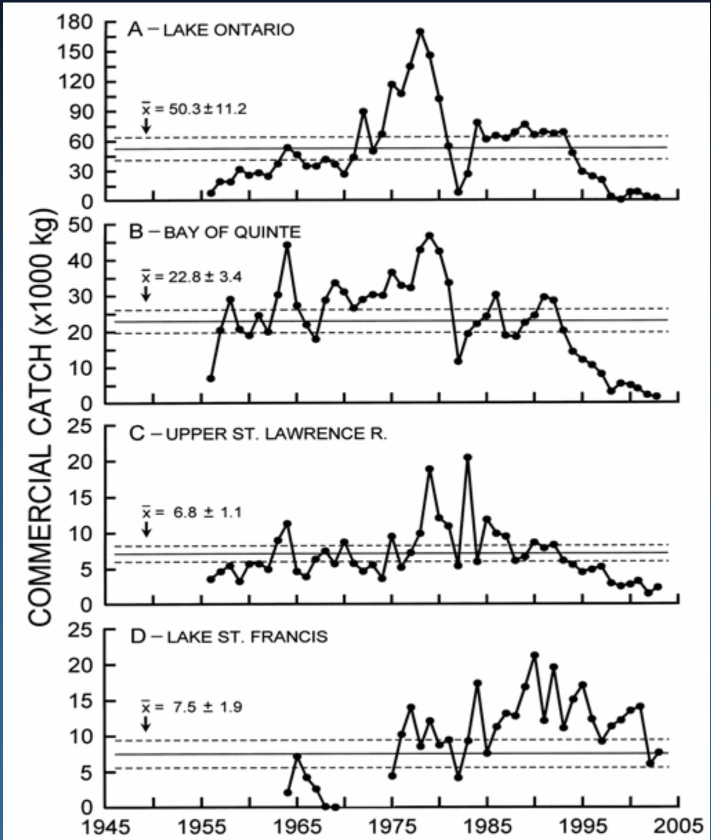
Lower St. Lawrence River



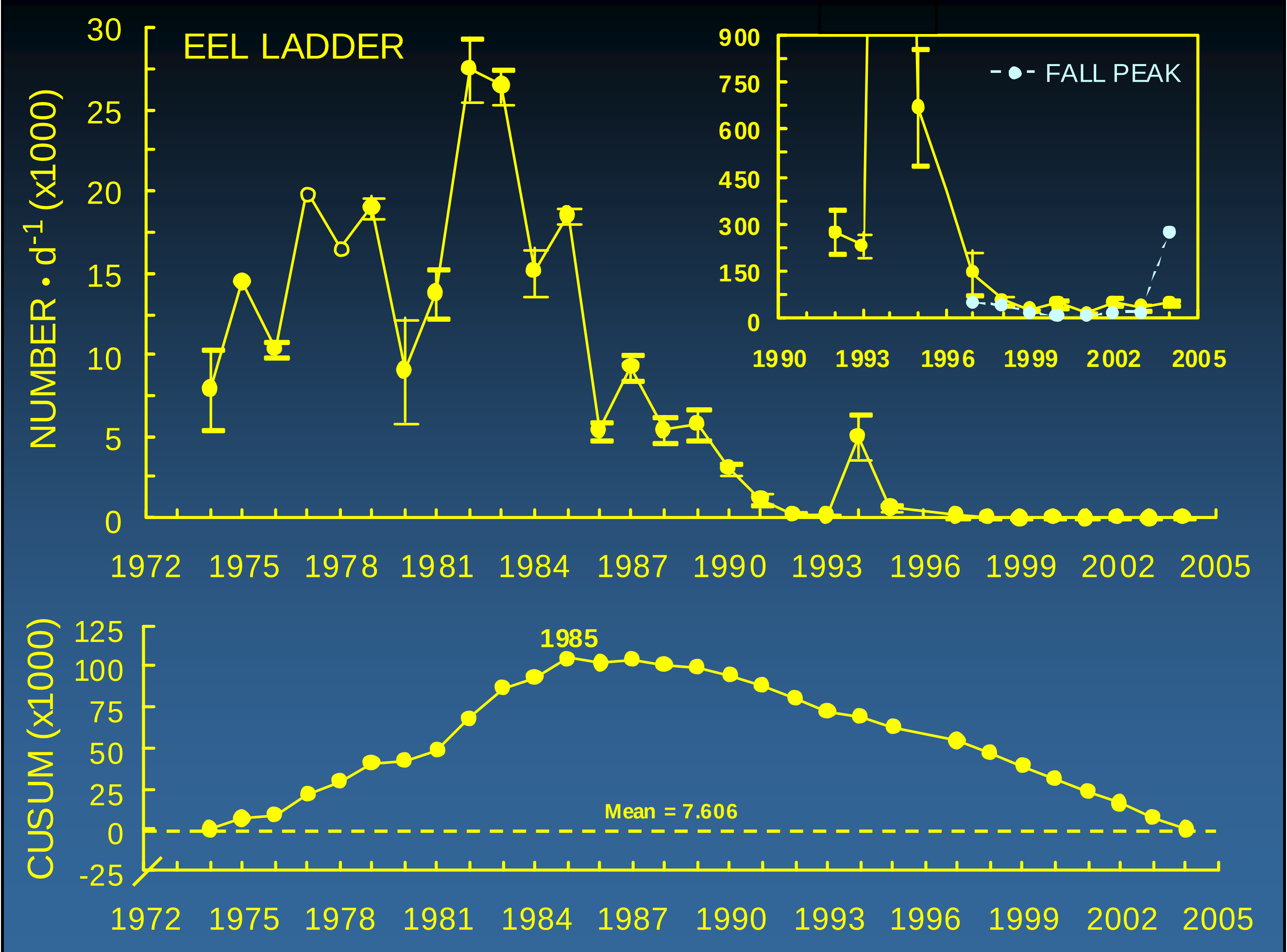
QUEBEC
HARVEST (x1000 kg)
700
600
500
400
300
200
100
0
Mean = 388.9 ± 31.9
INTERIM DATA
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
CUSUM (kg)
2000
1500
1000
500
0
-500
1956
1969
1973
1981
1991
Mean = 388.9
1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005


COMMERCIAL CATCH
1 1970 – fishery closed east of 76° 50' due to mercury contamination
2 1972 – harvest increased because export markets approved
3 1982 – closure of European market due to contaminants
4 1985 to 1988 – commercial license buyout by OMNR
5 1998 to 1999 – reduced effort because of contaminant regulations
6 2004 – commercial fishery closed
HARVEST (x1000 kg)
250
200
150
100
50
0
1
2
3
4
5
6
Closed
1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010
CUSUM (kg)
500
0
-500
-1000
-1500
-2000
-2500
Mean = 54,117
1910
1962
1981
1996
1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010

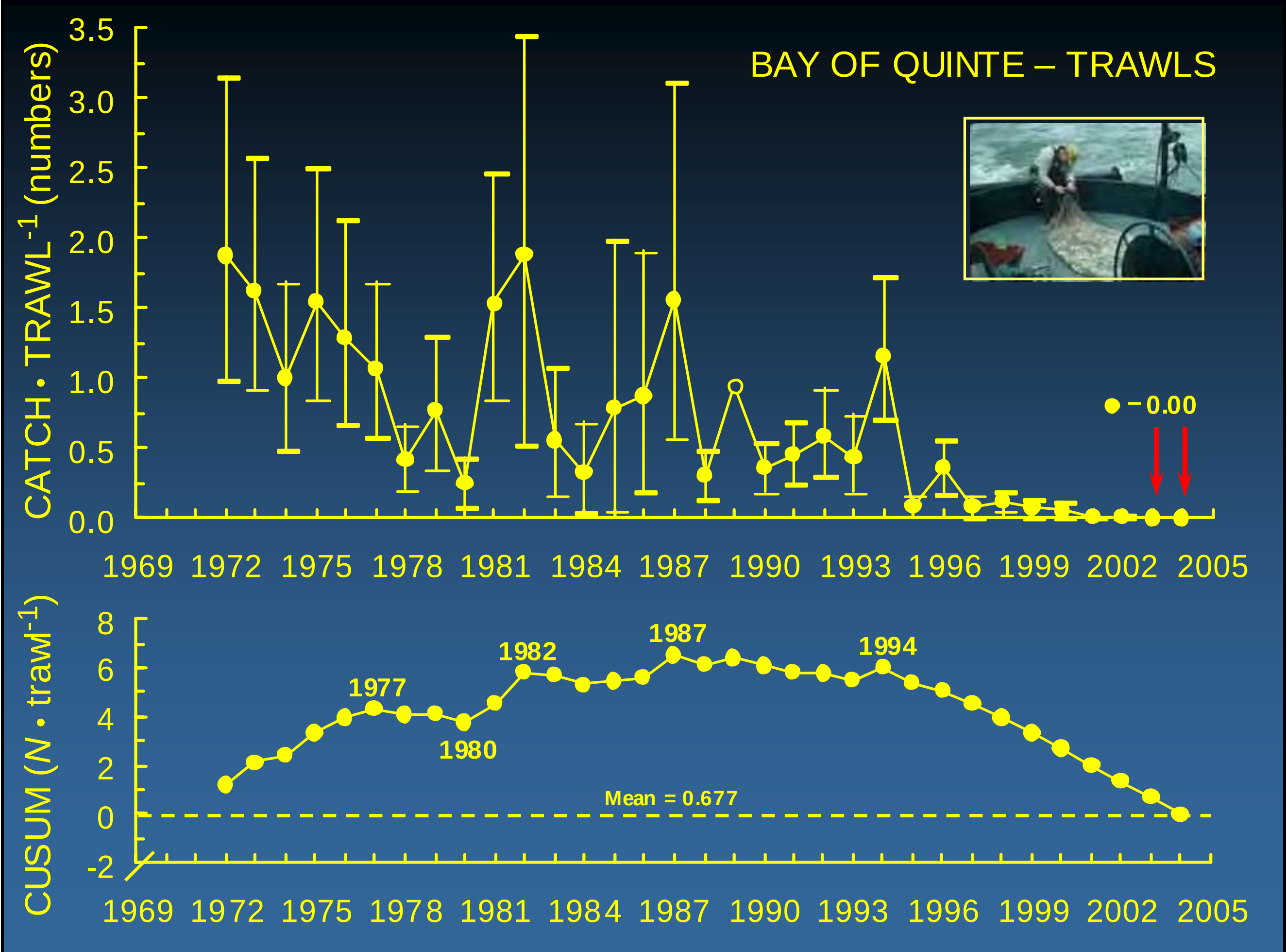
Lake Ontario-Upper St. Lawrence River Harvest by Area



Moses Saunders Dam and Eel Ladder, Upper St. Lawrence River



EEL LADDER
NUMBER • d-1 (x1000)
30
25
20
15
10
5
0
1972
1975
1978
1981
1984
1987
1990
1993
1996
1999
2002
2005
FALL PEAK
900
750
600
450
300
150
0
1990
1993
1996
1999
2002
2005
CUSUM (x1000)
125
100
75
50
25
0
-25
1985
Mean = 7.606
1972
1975
1978
1981
1984
1987
1990
1993
1996
1999
2002
2005



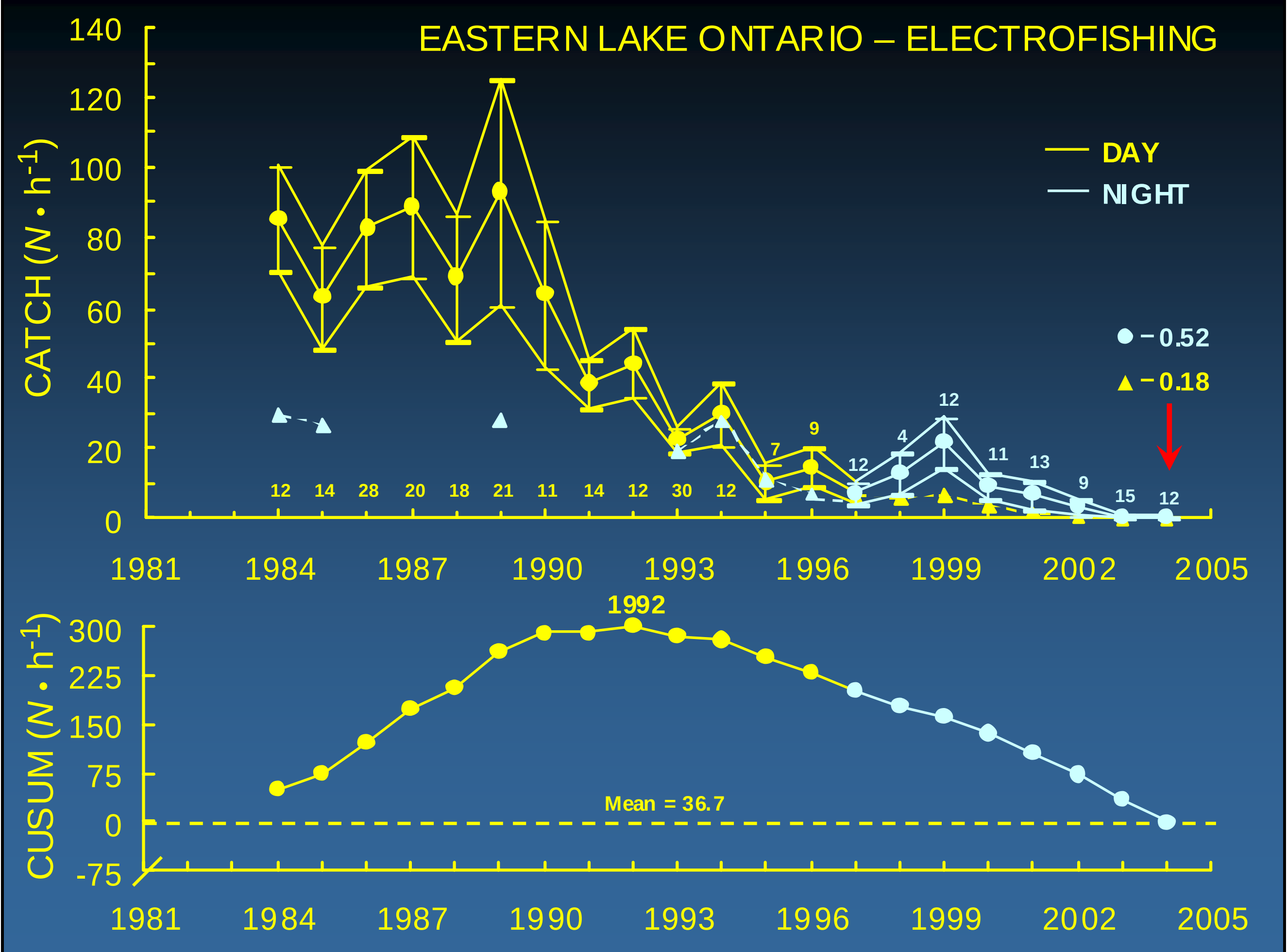
BAY OF QUINTE – TRAWLS
CATCH • TRAWL-1 (numbers)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
– 0.00
1969 1972 1975 1978 1981 1984 1987 1990 1993 1996 1999 2002 2005
CUSUM (N • trawl-1)
8
6
4
2
0
-2
1977
1980
1982
1987
1994
Mean = 0.677
1969 1972 1975 1978 1981 1984 1987 1990 1993 1996 1999 2002 2005

Commercial Electrofishing

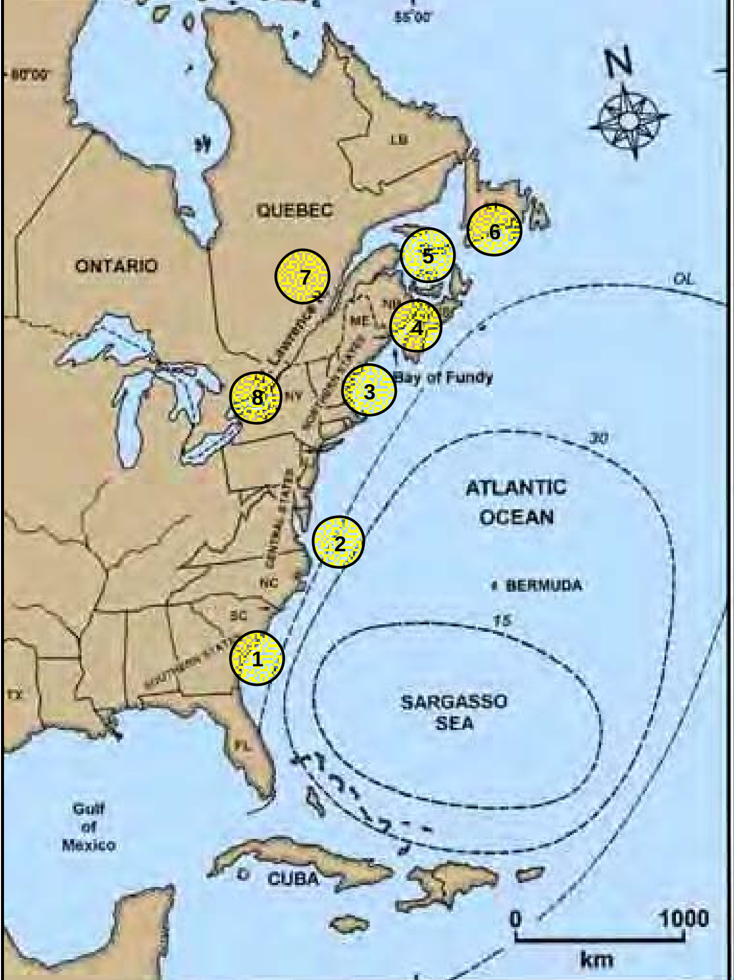
Main Duck Island

Eastern Lake Ontario

2003



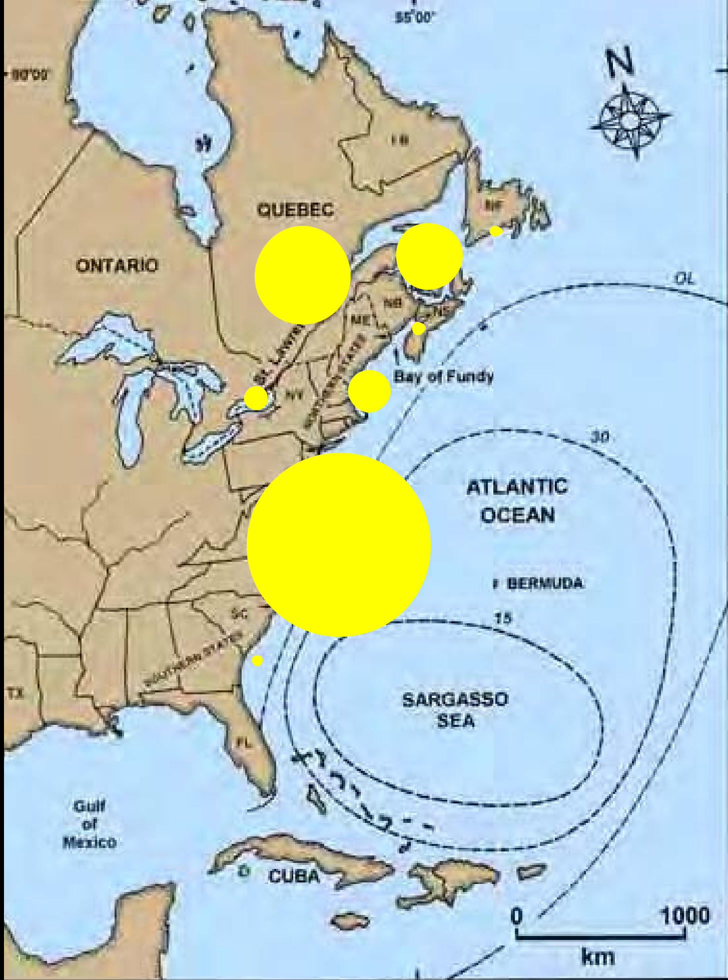
EASTERN LAKE ONTARIO – ELECTROFISHING
CATCH (N • h-1)
DAY
NIGHT
0.52
0.18
12 14 28 20 18 21 11 14 12 30 12 7 9 12 4 12 11 13 9 15 12
1981 1984 1987 1990 1993 1996 1999 2002 2005
CUSUM (N • h-1)
1992
Mean = 36.7



American Eel Harvest

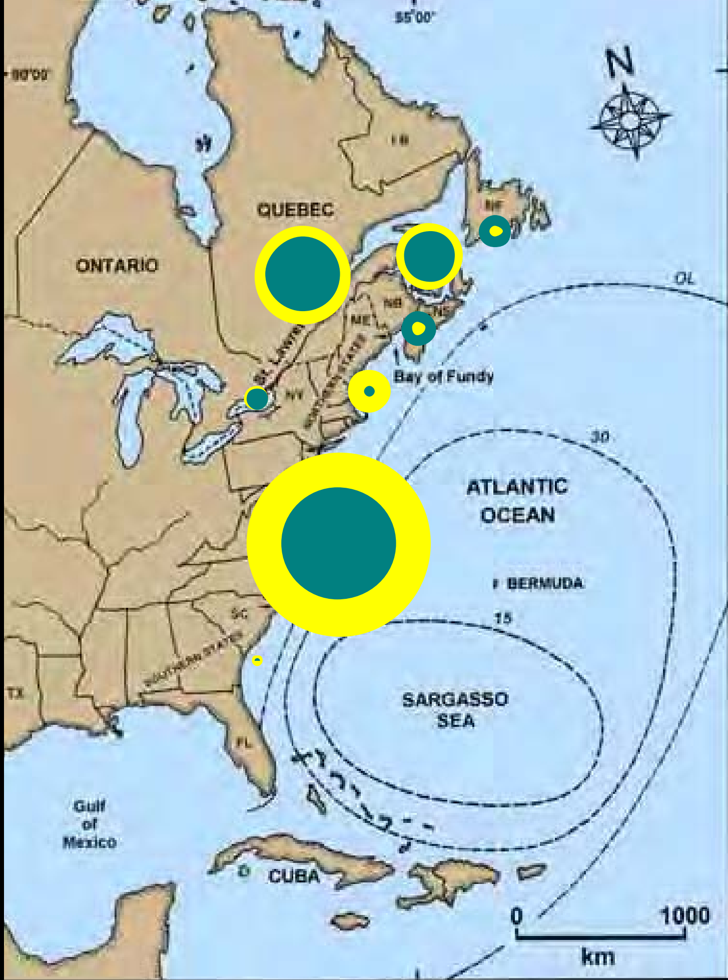
Regions

1. Southern States
2. Central States
3. Northern States
4. Scotia–Fundy Region
5. Gulf Region
6. Newfoundland Region
7. Lower St. Lawrence River
8. Upper St. Lawrence River and Lake Ontario



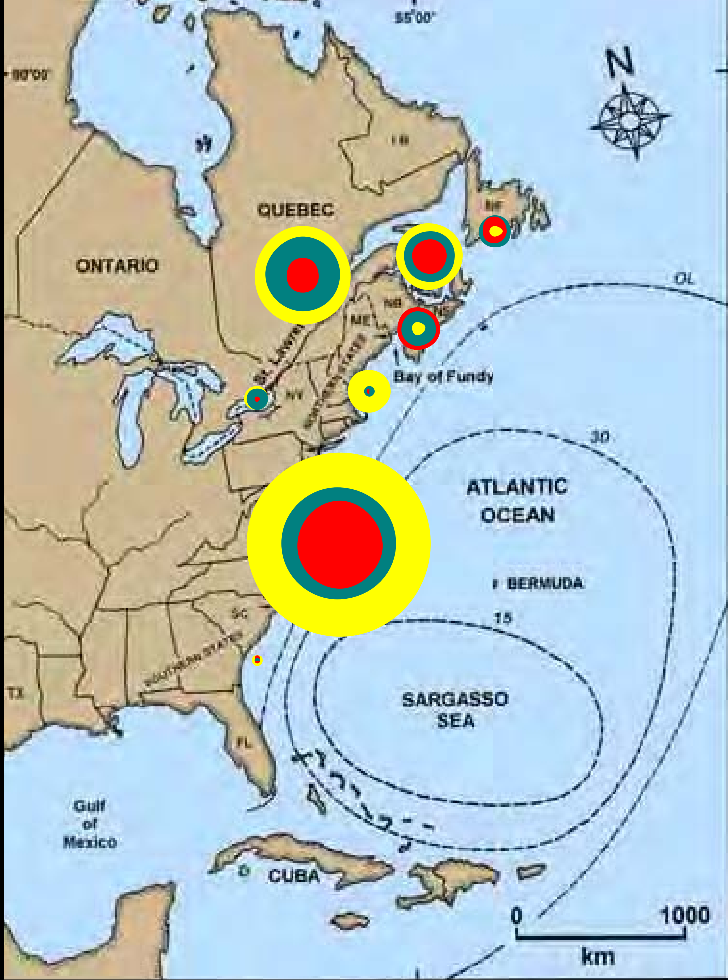
Mean Harvest 1980 to 1984 (x1000 kg)

Southern States	17.6
Central States	876.7
Northern States	201.4
Newfoundland Region	31.4
Gulf Region	318.0
Scotia–Fundy Region	34.2
Lower St. Lawrence River	461.9
Upper St. Lawrence River and Lake Ontario	117.5
Total	2,058.7



Mean Harvest 1990 to 1994 (x1000 kg)

Region	Mean harvest
Southern States	1.3
Central States	537.2
Northern States	48.6
Newfoundland Region	87.3
Gulf Region	244.4
Scotia–Fundy Region	152.4
Lower St. Lawrence River	347.7
Upper St. Lawrence River and Lake Ontario	109.3
Total	1,528.2

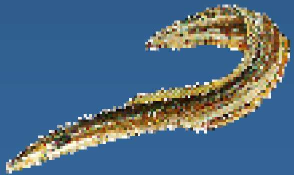


Mean Harvest 1998 to 2001 (x1000 kg)

Southern States	2.7
Central States	409.7
Northern States	20.4
Newfoundland Region	63.7
Gulf Region	164.5
Scotia–Fundy Region	172.7
Lower St. Lawrence River	164.5
Upper St. Lawrence River and Lake Ontario	25.0
Total	1023.2

Possible Factors Causing Recent Declines

- **Alteration and loss of habitat *(1)***
- **Barriers to migration *(2)***
- **Changes in oceanic conditions *(8)***
- **Exploitation of all life stages *(4)***
- **Hydroelectric turbine mortality *(5)***
- **Productivity and food web changes *(6)***
- **Parasitism *(7)***
- **Sargasso weed harvest *(9)***
- **Toxicity of contaminants *(3)***

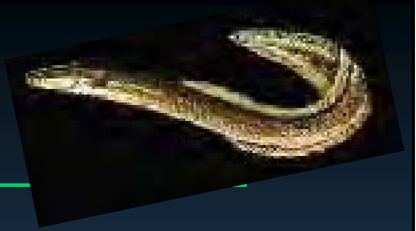


( ) Order of historical impact

Model estimates of cumulative fishing, mortality, and exploitation rates (%) for a cohort of eels ascending the ladder in the early 1980s and subjected to various levels of yellow eel annual exploitation rates (%). Assuming that harvested yellow eels range in age from 14 to 22, that peak escapement occurs at 20 years of age, and that downstream turbine mortality at Moses Saunders = 26.5%, at Beauharnois = 17.8%, and that the estuary commercial fisheries exploitation rate = 21.5%.

	Upper St. Lawrence River – Lake Ontario exploitation rate (%)				
Stage and Aspect	1	2	5	7.5	10
Yellow eel fisheries	5.7	11.2	25.4	36.5	45.6
Turbine mortality (combined)	30.1	28.0	22.3	18.2	15.8
Moses Saunders	20.1	18.7	14.9	12.2	9.9
Beauharnois	10.0	9.3	7.4	6.0	4.9
Estuary fisheries	9.9	9.2	7.3	6.0	4.9
Escapement	36.2	33.7	27.3	21.9	17.7
Natural Mortality	18.1	17.9	17.7	17.4	16.0

Special considerations



- No doubt multiple factors are involved in these declines; these are difficult to assess because the species is panmictic, life history is extremely variable, and spawning eludes us
- These numerous factors no doubt combine and interact to put eels in the present precarious state; nevertheless, human-induced fishing and emigration mortality must be involved

- **Fisheries are being closed, harvest reductions are proposed; it is logical to now address, in a concerted way, safer downstream passage**

- **For the upper SLR-LO stock, action is urgently needed since eel abundance is now diminishing, primarily related to escapement, at an annual rate of 23%**

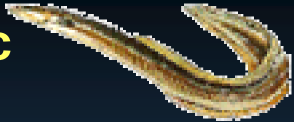
- **Fecundity of the large-bodied SLR-LO eel stock may provide more than 25% of the reproductive capacity of the species**

- **The fecundity of this stock may not only drive overall recruitment of the species but may be needed to sustain its own distant recruitment**

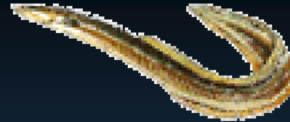
- **Some minor increases in recruitment and harvest in some parts of the range in recent years may be explained by oceanic influences**

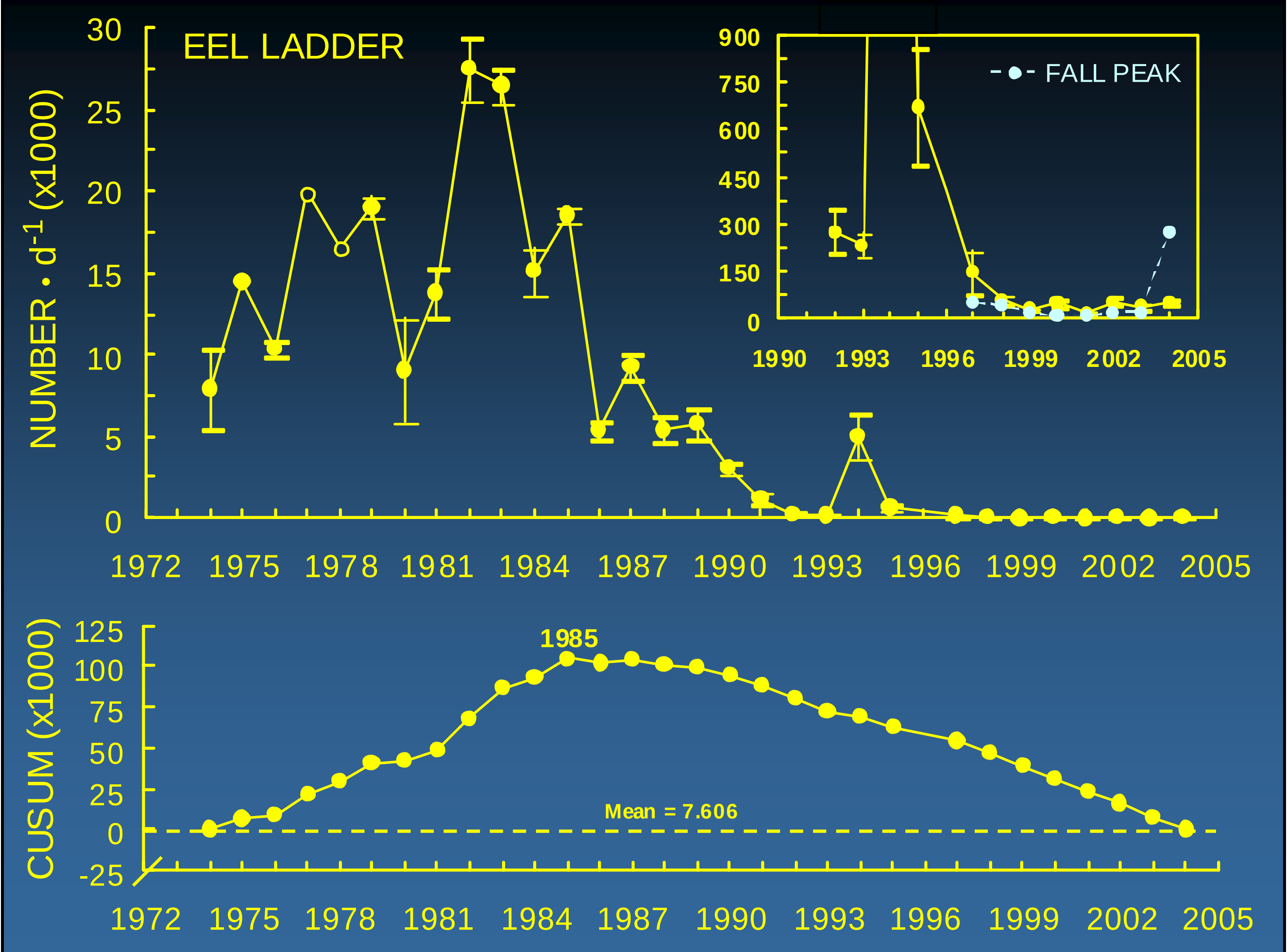
Let's look at this

Eel Recruitment and the North Atlantic Oscillation Index

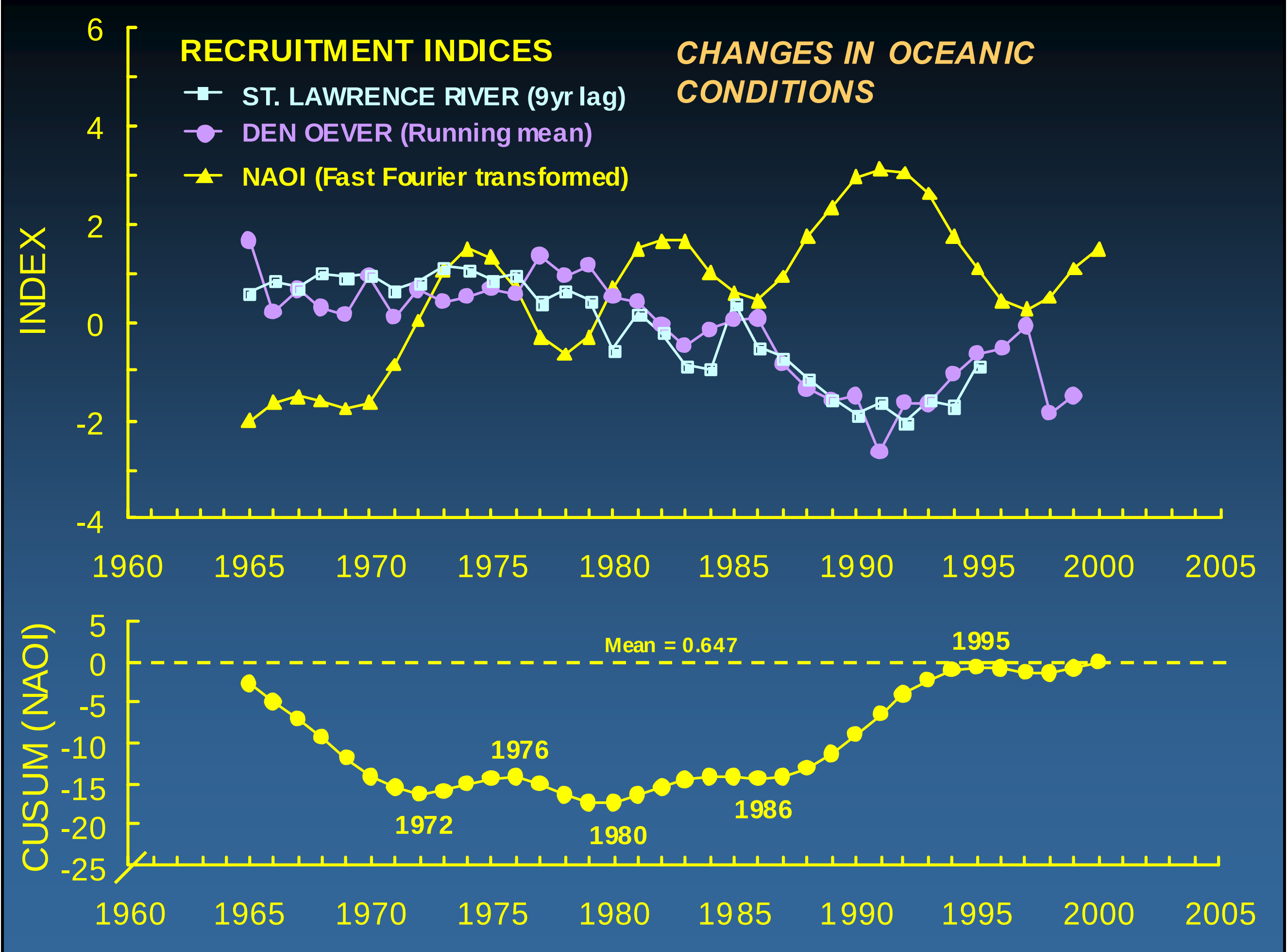


North Atlantic Oceanic Currents

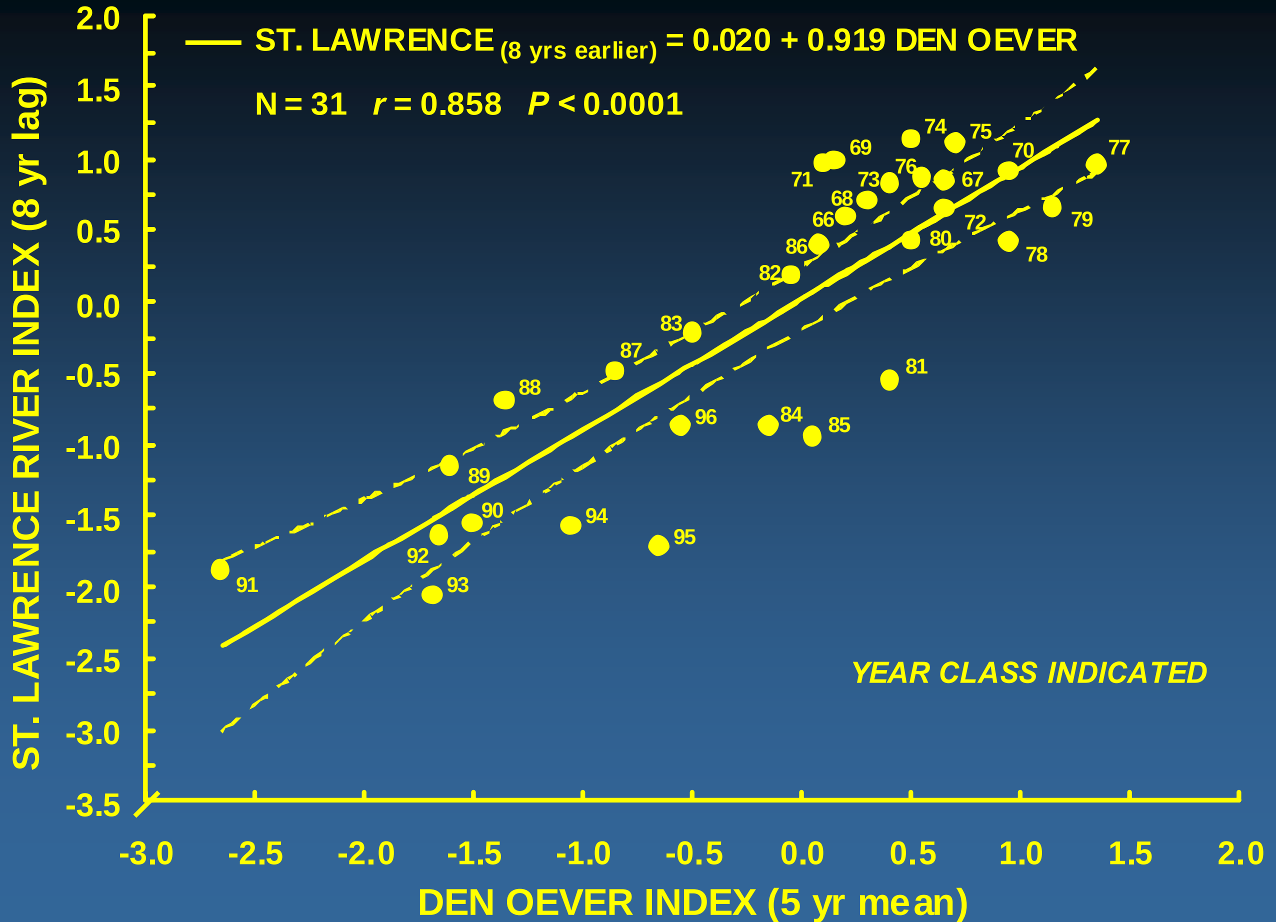




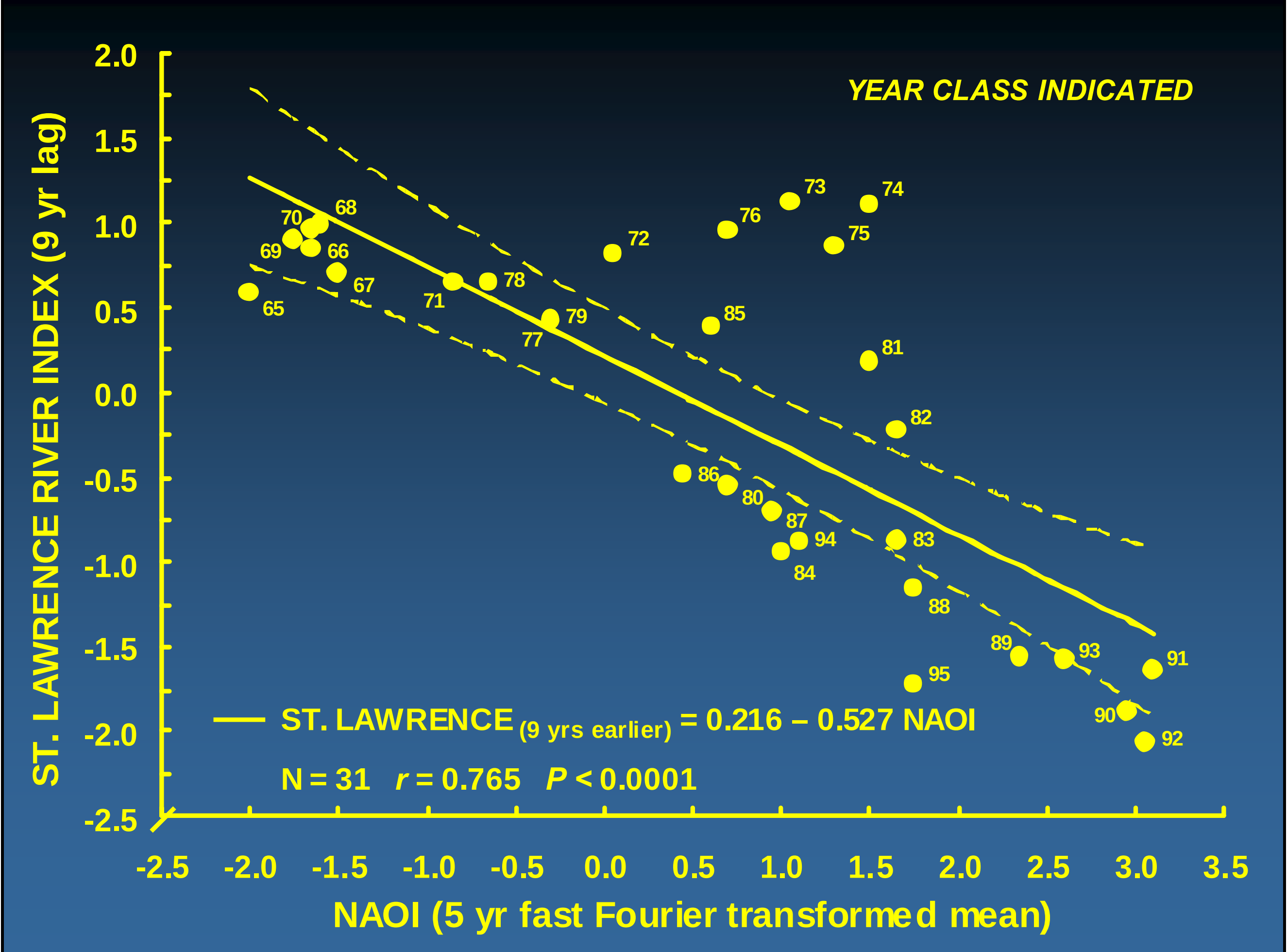
EEL LADDER
NUMBER • d-1 (x1000)
30
25
20
15
10
5
0
1972
1975
1978
1981
1984
1987
1990
1993
1996
1999
2002
2005
900
750
600
450
300
150
0
FALL PEAK
CUSUM (x1000)
125
100
75
50
25
0
-25
1985
Mean = 7.606



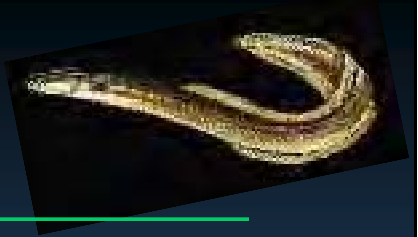
RECRUITMENT INDICES
ST. LAWRENCE RIVER (9yr lag)
DEN OEVER (Running mean)
NAOI (Fast Fourier transformed)
CHANGES IN OCEANIC CONDITIONS
INDEX
6
4
2
0
-2
-4
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
CUSUM (NAOI)
5
0
-5
-10
-15
-20
-25
Mean = 0.647
1995
1976
1972
1980
1986
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005



ST. LAWRENCE (8 yrs earlier) = 0.020 + 0.919 DEN OEVER
N = 31 r = 0.858 P < 0.0001
YEAR CLASS INDICATED
ST. LAWRENCE RIVER INDEX (8 yr lag)
DEN OEVER INDEX (5 yr mean)
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
-3.0
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
74
75
69
71
70
77
76
73
67
68
66
72
79
80
86
78
82
83
87
81
88
96
84
85
89
90
94
95
92
91
93


YEAR CLASS INDICATED
ST. LAWRENCE RIVER INDEX (9 yr lag)
NAOI (5 yr fast Fourier transformed mean)
ST. LAWRENCE (9 yrs earlier) = 0.216 – 0.527 NAOI
N = 31 r = 0.765 P < 0.0001
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95

Regardless of Oceanic Effect



The question is:

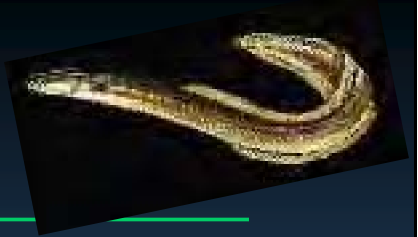
What can we do now to try to make a difference?

The direct and immediate approach would be to:

Find out whether increased escapement results in increased recruitment

Nevertheless . . .

In Conclusion



- Loss of recruitment at the extremities of the range are strong evidence of a universal decline in this panmictic species and forewarn continued and accelerated species and resource declines if recruitment does not increase
- Reproductive capacity of the large-bodied, highly fecund SLR-LO stock may be important in maintaining overall species recruitment, particularly at the extremity of the range.

- **Science working groups have recommended an immediate 50% reduction in anthropogenic mortality to reduce risk of widespread population collapse**

- **The immediate challenge of this precautionary approach is *how to reduce human-induced mortality to increase escapement and enhance recruitment***

Because . . .

"If we don't act, who will?"

"If we don't act now, when?"

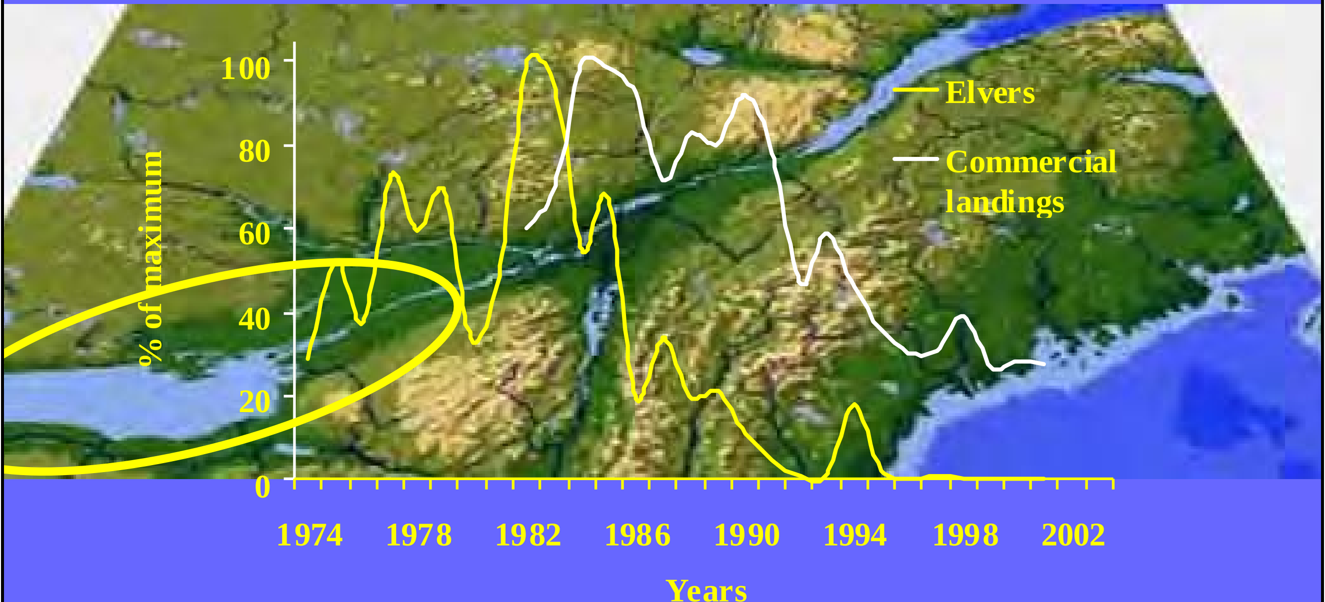
What can we recommend?

Thank you

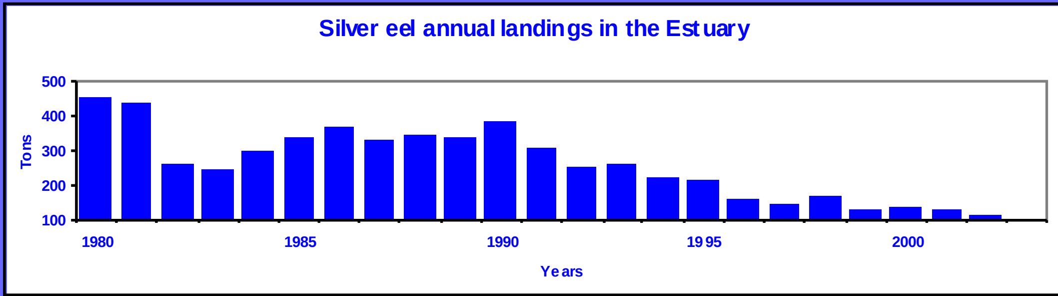
Estimation of American eel escapement from Upper St. Lawrence River and Lake Ontario

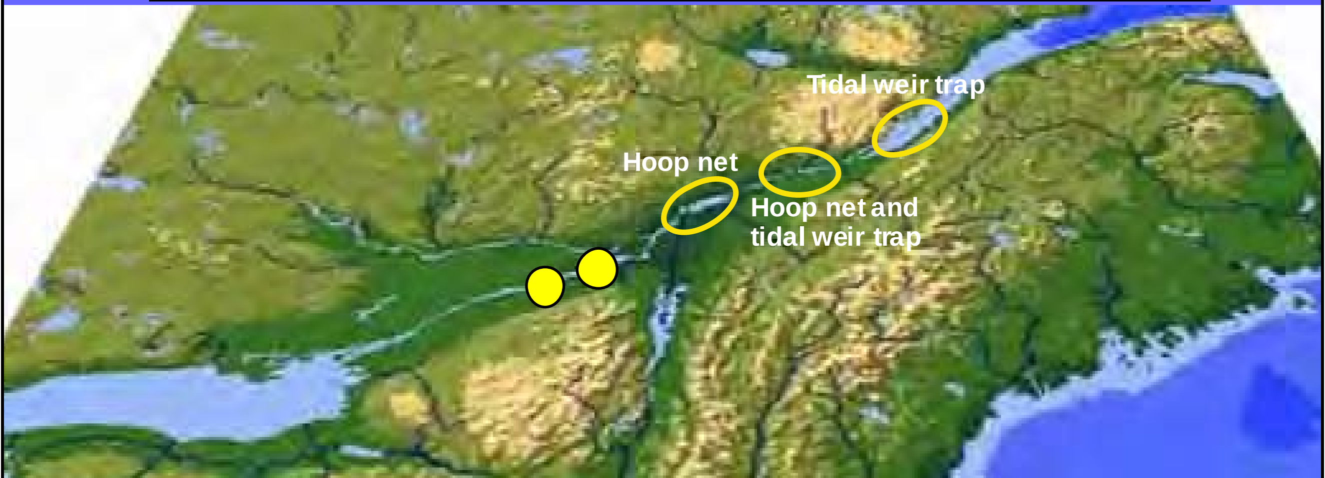
Guy Verreault and Pierre Dumont
Faune Québec





% of maximum
100
80
60
40
20
0
1974
1978
1982
1986
1990
1994
1998
2002
Years
Elvers
Commercial landings


Silver eel annual landings in the Estuary
Tons
500
400
300
200
100
1980
1985
1990
1995
2000
Years

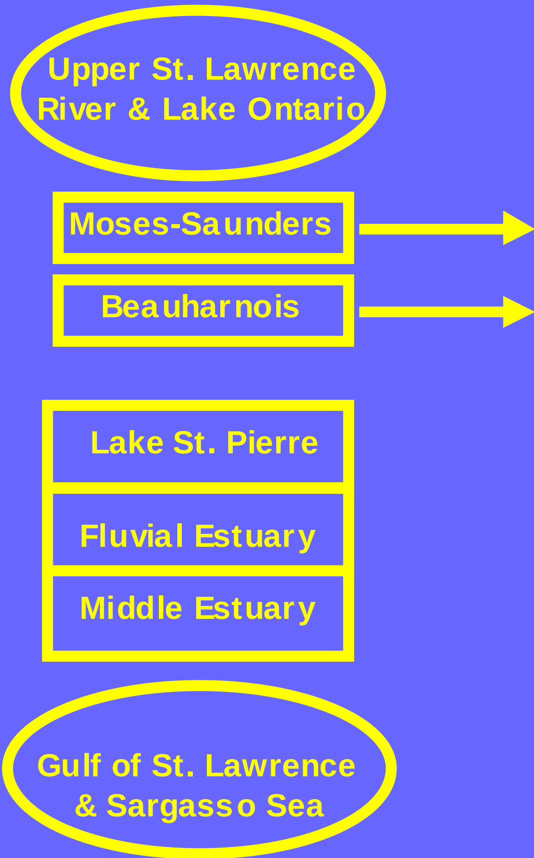

Tidal weir trap
Hoop net
Hoop net and tidal weir trap

The Model


Upper St. Lawrence River & Lake Ontario
Moses-Saunders
Beauharnois
Lake St. Pierre
Fluvial Estuary
Middle Estuary
Gulf of St. Lawrence & Sargasso Sea

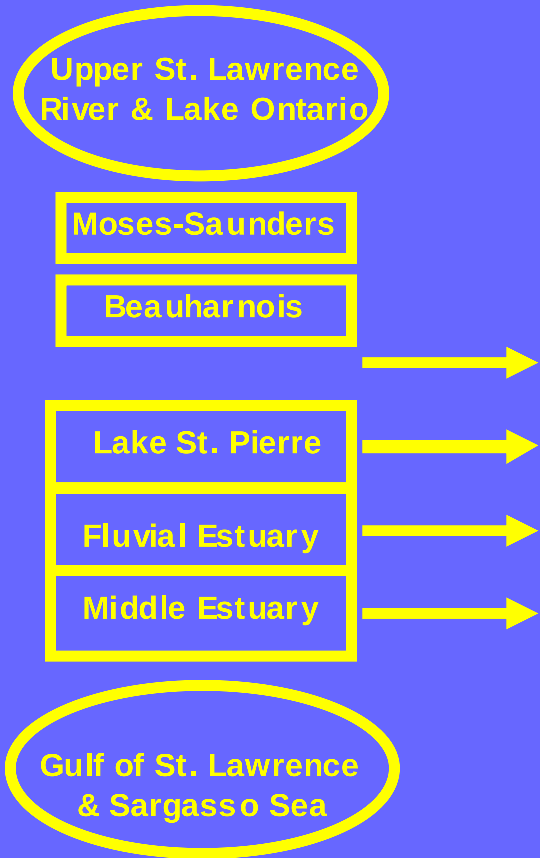
The model considers:

1. Eel passage
2. Commercial landings
3. % migrants in landings
4. % originating from Lake Ontario
5. Turbine survival rates



% of water flow diverted through turbines

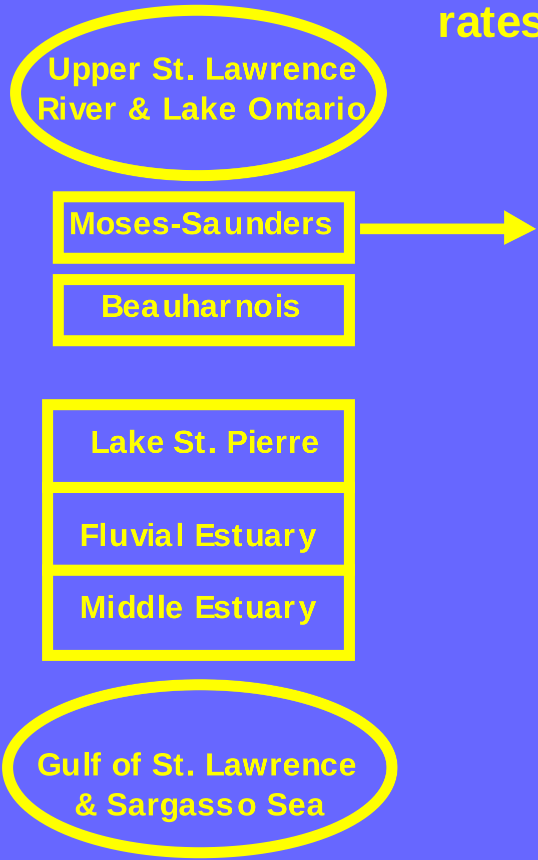
Water flow is directed to eel migration on a 1:1 basis



Non significant harvest of silver eel upstream Lake St. Pierre

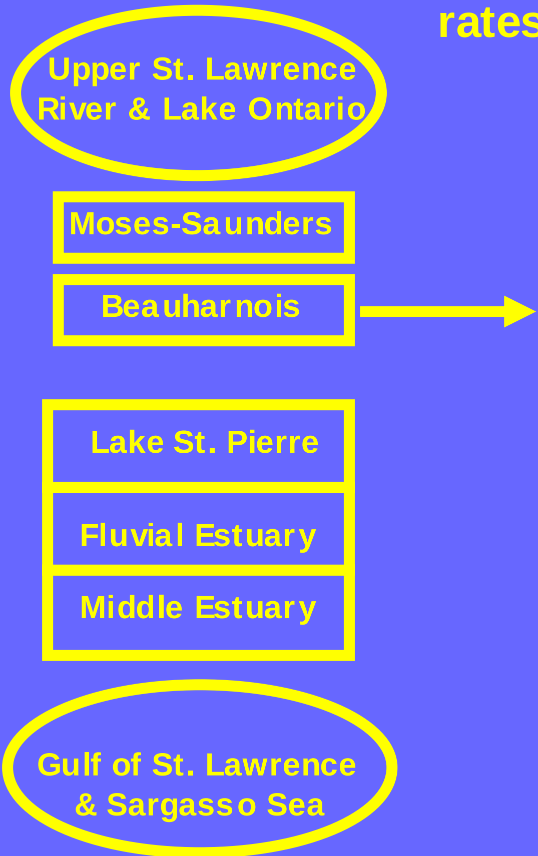
% of silver eels originating from Lake Ontario and numbers landed

River flow diverted through turbine and survival rates at the Moses-Saunders Complex



Mean water flow: 7075 m^3/s
diverted to turbines: > 99.7%
Eel survival rates : 73.6%

River flow diverted through turbine and survival rates at the Beauharnois Complex



Mean water flow: 7600 m^3/s
diverted to turbines: > 99.4%
Eel survival rates : 82.3%

Percentage of eel originating from Lake Ontario

Upper St. Lawrence River & Lake Ontario

Moses-Saunders

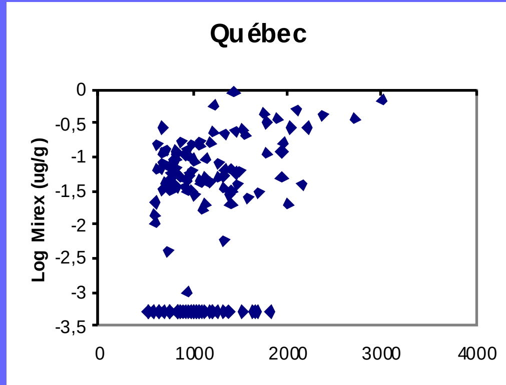
Beauharnois

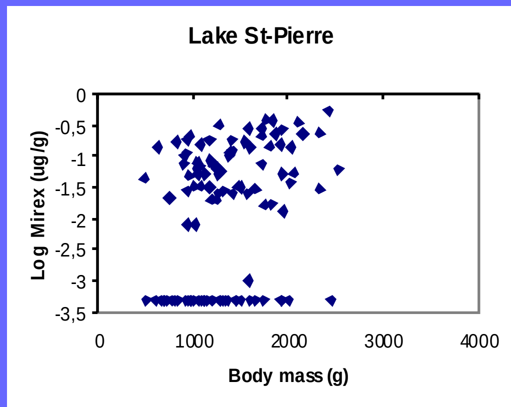
Lake St. Pierre

Fluvial Estuary

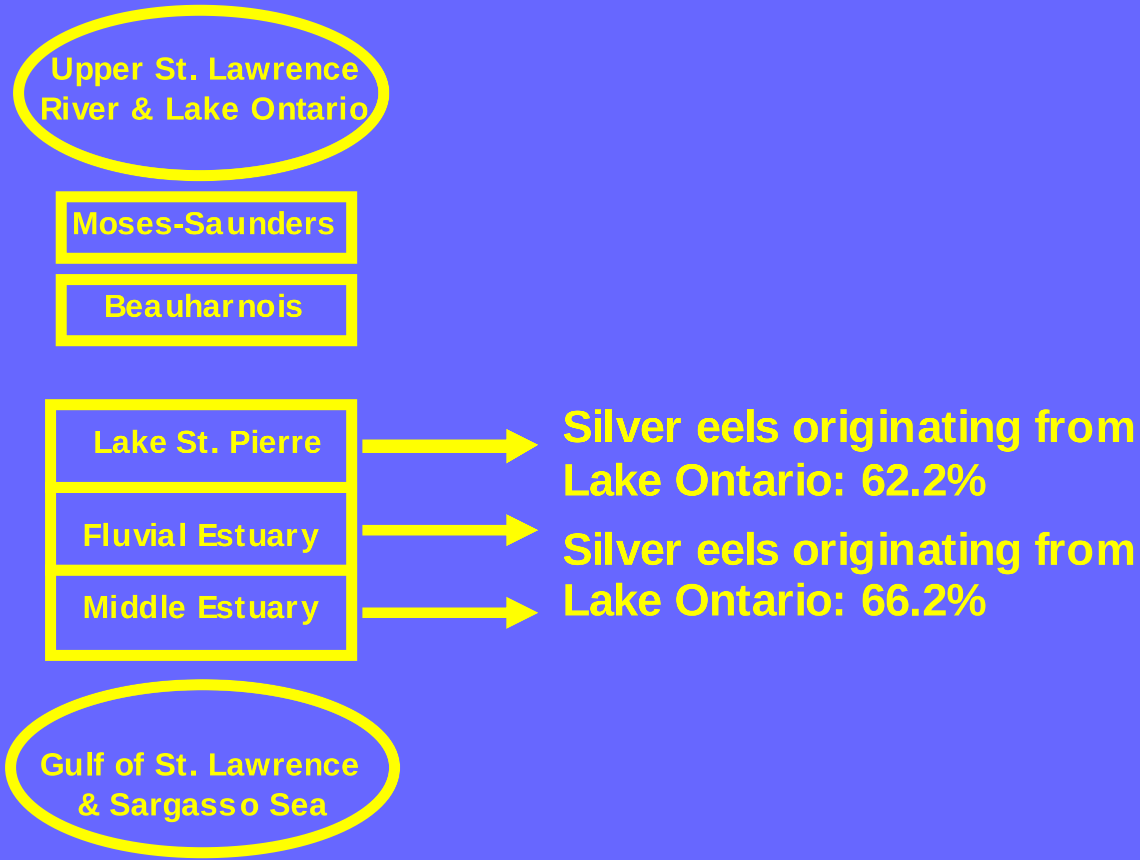
Middle Estuary

Gulf of St. Lawrence & Sargasso Sea





Percentage of eel originating from Lake Ontario



With population size estimates in the Middle Estuary and number of landed eels in the fisheries, some boxes could be filled with numbers

Abundance estimates in 1996 and 1997

Upper St. Lawrence River & Lake Ontario

Moses-Saunders

Beauharnois

Lake St. Pierre

Fluvial Estuary

Middle Estuary

Gulf of St. Lawrence & Sargasso Sea

Number of eels migrating In the Middle Estuary: 488,000 ~ 397,000

Silver eel numbers landed in the fisheries in 1996 and 1997

Upper St. Lawrence River & Lake Ontario

Moses-Saunders

Beauharnois

Lake St. Pierre → Landed silver eels 1666 ~ 1598

Fluvial Estuary → Landed silver eels 18,386 ~ 21,987

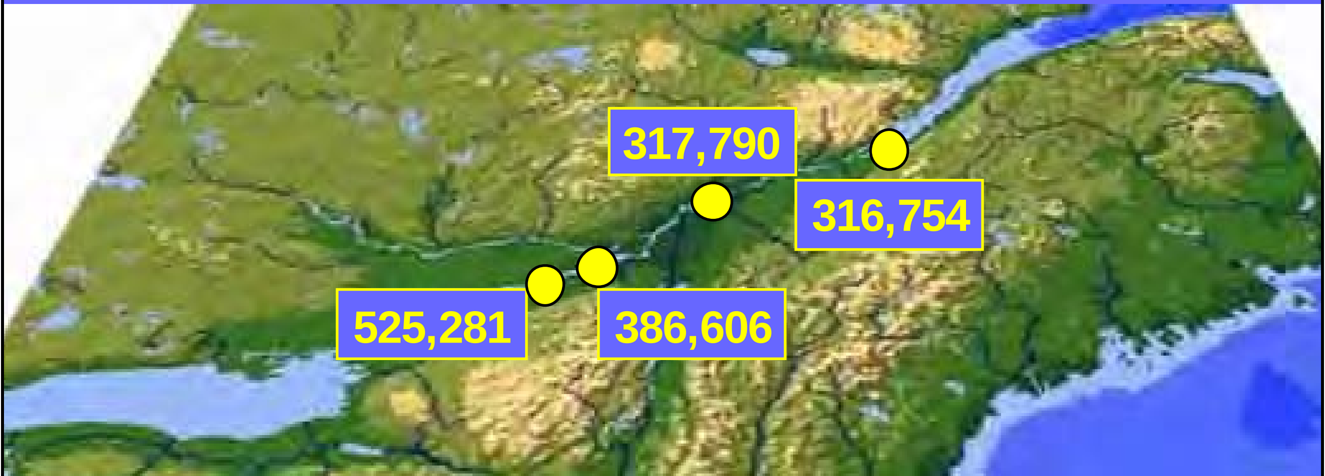
Middle Estuary → Landed silver eels 85,580~ 93,017

Gulf of St. Lawrence & Sargasso Sea

Back calculations for the estimation of escapement from the Upper St. Lawrence River & Lake Ontario

1996 Lake Ontario *escapement* =

$$\{(N_{QUE} + L_{QUE}) * P_{Lake\ Ontario} + (L_{LSP} * P_{Lake\ Ontario})\} * 1 / S_B * 1 / S_{MS}$$



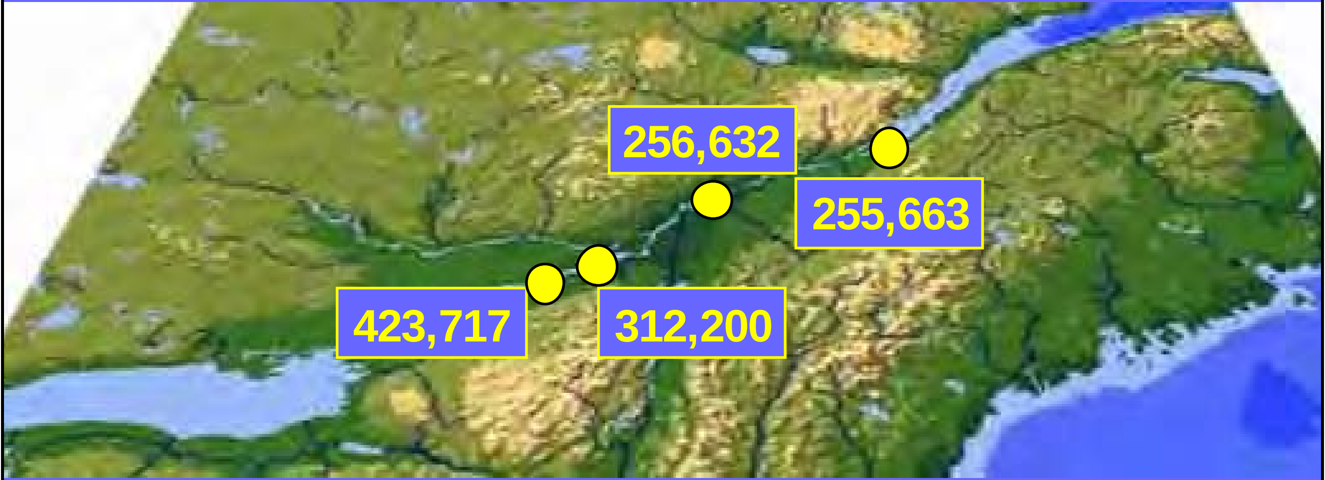
Lake Ontario *escapement* ^{1996} =

{(460,084 + 18,396) * 66.2% + (1666 * 62.2%)} * 1 / 82.2% * 1 / 73.6%

Back calculations for the estimation of escapement from the Upper St. Lawrence River & Lake Ontario

1997 Lake Ontario *escapement* =

$$\{(N_{QUE} + L_{QUE}) * P_{Lake\ Ontario} + (L_{LSP} * P_{Lake\ Ontario})\} * 1 / S_B * 1 / S_{MS}$$



Lake Ontario *escapement* [1997] =

$$\{(364{,}211 + 21{,}987) * 66.2\% + (1598 * 62.2\%)\} * 1 / 82.2\% * 1 / 73.6\%$$

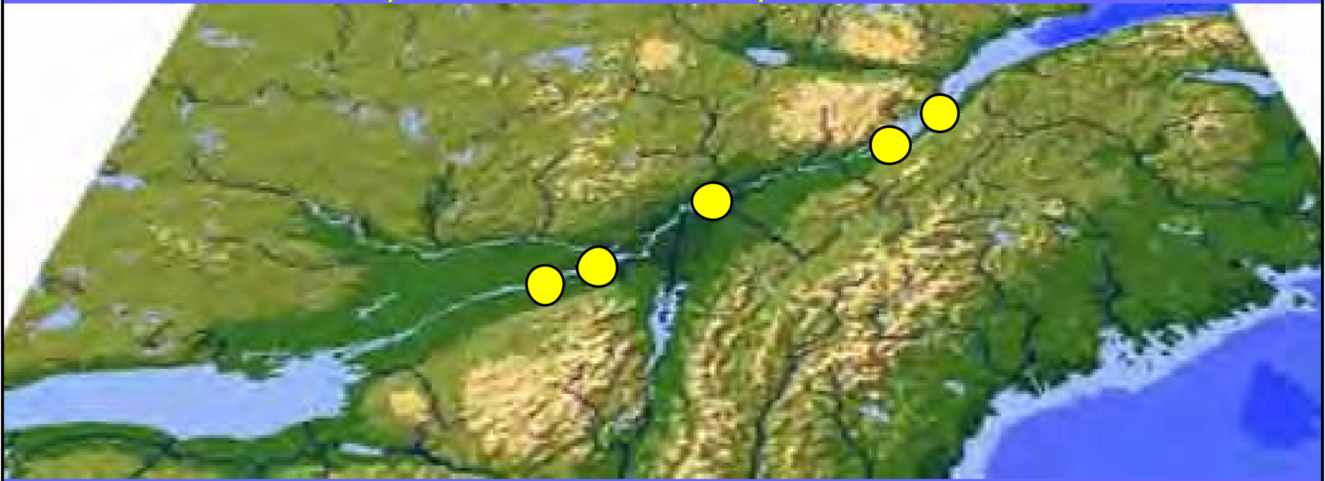
About 500,000 migrating eels left Lake Ontario in 1996 & 1997

Each year, 39.5% died after turbine passage

207,500 in 1996, and 167,400 in 1997

In 1996 & 1997, 22% died in the fisheries

69,900 in 1996 and 56,460 in 1997



Overall mortality rate estimated at 53%

Turbine passage is responsible for three-quarters of this loss

Recent changes since 1996-1997

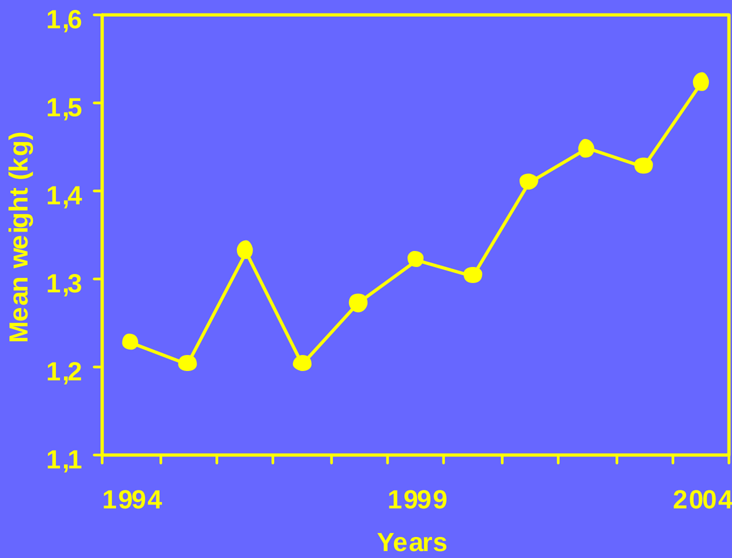
Eel ladder Index still declining

Lesser % in the estuarine fisheries
Lesser numbers impacted by turbines

Eels are bigger…and longer

Mortality rates could be higher

Annual mean weight of silver eel in the Estuary



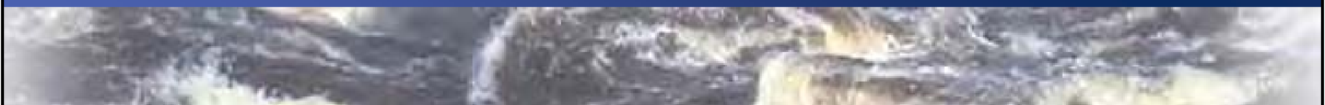
 

Hydro Québec Production

Une division d'Hydro-Québec

Eel Survival Study at Beauharnois Power Dam (1994)

Richard Verdon
Hydro-Québec
and
Denis Desrochers
Milieu Inc.



STUDY OBJECTIVE

- Determine the survival rate of outmigrating eels as they pass through Francis and propeller turbines

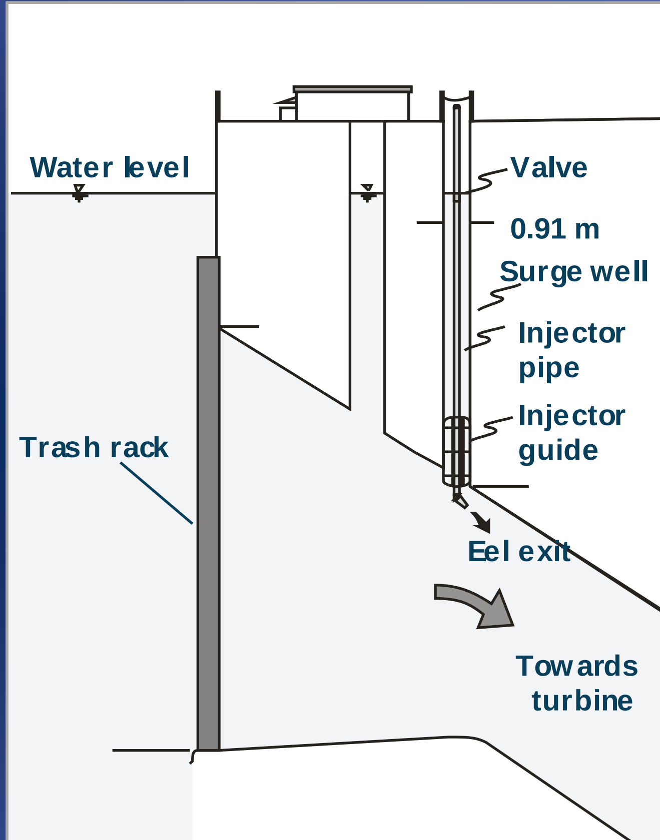
Turbine characteristics

	Turbine #19	Turbine #33
Turbine type	Francis	Propeller
Nameplate rating (MW)	40	54.7
Rated discharge capacity (m^3/s)	198	265
Speed (RPM)	75	94.7
Runner diameter (m)	5.44	6.39
Stay vanes		
number	12	24
opening at entrance (cm)	205	125
Wicket gates		
number	24	24
max. opening at entrance (cm)	87	109
Runner		
number of blades	13	6
diameter at half blade heigth (cm)	471	439
opening at half blade heigth (cm)	113	229

Methodology

- **Outmigrating eels purchased from commercial fishermen**
- **Eels were tagged with a float attached to the tail**
- **Tagged eels (n = 222) were injected in turbines**
  - **Francis: n = 122, Av. Length: 881 mm**
  - **Propeller: n = 100, Av. Length: 897 mm**
- **Injected eels recovered in tailwater**
- **Recovered eels kept in tanks for 48 hours and examined for external and internal injuries by a veterinarian**

Injection system





Recovery Rate

	Propeller		Francis		Total	
Injected						
Average Length (mm)	881		897		888	
	nb		nb		nb	
	122		100		222	

Recovery	nb	%	nb	%	nb	%
With eel	117	95,9	95	95,0	212	95,5
Without eel (float only)	4	3,3	2	2,0	6	2,7
Not recovered	1	0,8	3	3,0	4	1,8

Survival estimates

	Propeller		Francis	
	n	%	n	%
Recovered	117	100	95	100
Immediate survival	90	76.9	90	94.7
24 hr survival	90	76.9	82	86.3
48 hr survival	89	**76.1**	80	**84.2**
C.I. (95%)		68.3		76.7
		83.9		91.7

Type of injuries

	Propeller		Francis	
	nb	% (n=117)	nb	% (n=95)
Cut	**17**	14,5	**0**	0,0
Internal injuries only	**8**	6,8	**14**	14,7
Internal and minor external	**3**	2,6	**1**	1,1

	Propeller		Francis	
	nb	%	nb	%
With injuries	**28**	23,9	**15**	15,8
Without injuries	**89**	76,1	**80**	84,2
Total	**117**	100	**95**	100

Uncertainties

- **Condition of unrecovered eels is unknown** (<5 %)
- **Effect of handling in unknown (probably minimal)**
- **Effect of float on turbine mortality is unknown**
  - Might affect behavior
  - Might increase strike probability

CONCLUSIONS

- **Survival rate is higher for Francis (84.2%) than for propeller turbine (76.1%)**
- **Cut eels were observed only on propeller turbines**
- **With the hypothesis that outmigrating eels are distributed randomly as they pass through turbines, overall survival rate for Beauharnois GS is 82.0 %**

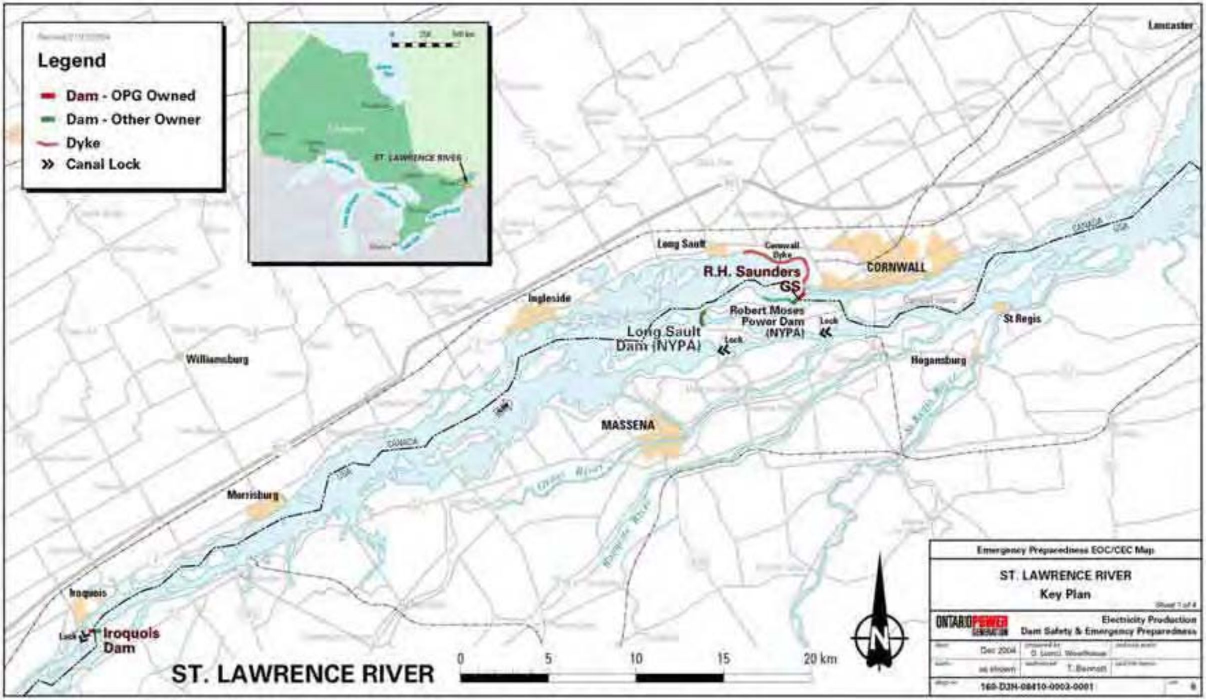
SAUNDERS/MOSES TECHNICAL PRESENTATION

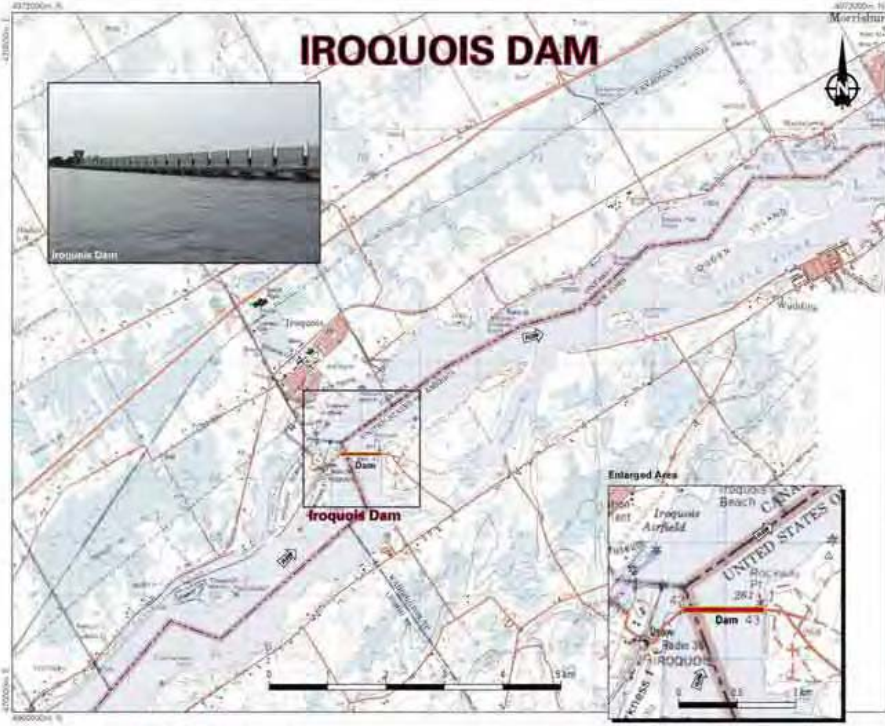
by

Michael Boutilier

ONTARIO POWER GENERATION

February 2005


Legend
Dam - OPG Owned
Dam - Other Owner
Dyke
Canal Lock
ST. LAWRENCE RIVER
Lancaster
Long Sault
Cornwall Dyke
R.H. Saunders GS
CORNWALL
Ingleside
Robert Moses Power Dam (NYPA)
Lock
Long Sault Dam (NYPA)
St Regis
Williamsburg
Hogansburg
MASSENA
Morrisburg
Iroquois
Lock
Iroquois Dam
ST. LAWRENCE RIVER
0
5
10
15
20 km
Emergency Preparedness EOC/CEC Map
ST. LAWRENCE RIVER
Key Plan
Electricity Production
Dam Safety & Emergency Preparedness
Dec 2004
160-D3H-08410-0003-0001



Item		Iroquois Dam
Flow (cms)	Time Lag to Next Dam (hrs)	
	Rate of Rise (Daily Stoppage/1 cm)	
	Total Flow - Remote Op. Sluicegates	
	Total Flow - Local Operated Sluicegates	
	Total Flow - Local Operated Log Sluices	
	Total Flow through Generators	
Elevations (meters)	Minimum Earth Dam Crest Elevation	
	Concrete Dam Crest Elevation	
	Emergency response WL3	
	Emergency response WL2	
	Abs. Max. Elevation (Emerg. Response WL1)	
	Spillway Elevation	
	Operating Max. Elevation (m)	
	Operating Min. Elevation (m)	
	T-Dam Min. Elevation	
Physical	# Generating Units	
	# Sluice Gates	
	# Stop Log Sluices	
	# Stop Logs per Sluice	
	Spillway Length (m)	
	Log Lifter Type	
	Backup Power for Sluices	
	# Gates with Deicing System	
	Hrs to strip 1 Log Sluice	
	Hrs to strip ? Sluices	
Dam Safety	Flood ICC	
	Sunny Day ICC	
	IDF Q (cms)	
	IDF HWL (m)	
	IDF Freeboard	
	# Gates Required	
	# Log Sluices Required	
Access	Log OP Crew Base	
	Access via Road	
	Road Hrs: Base-Dam	
	Other Access	
	Heli Hrs: Base-Dam	

Emergency Preparedness EOC/CEC Map

ST. LAWRENCE RIVER

Iroquois Dam

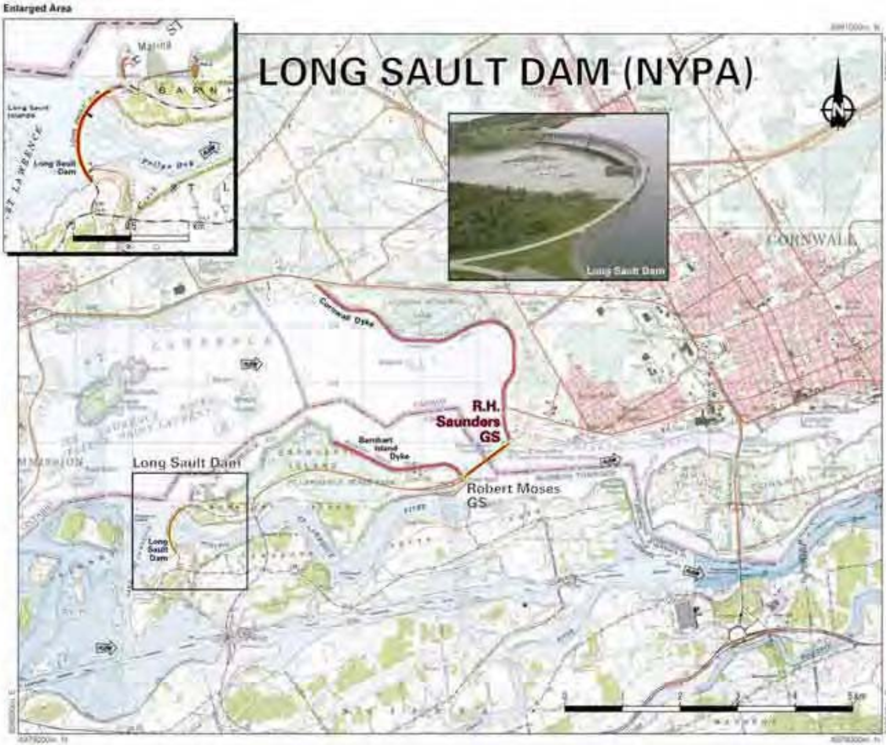
Sheet 8 of 8

ONTARIO POWER GENERATION

Electricity Production

Dam Safety & Emergency Preparedness

date	Dec 2004	prepared by D. Lewis Woodhouse	
scale	1: 50,000	authorized	T. Bennett
drawing no.	160-D3H-08410-0003-0003	rev.	0



Item		Long Sault Dam
Flow (cms)	Time Lag to next Dam (hrs)	8 hrs
	Rate of Rise (Daily Storage/1 cm)	28.3 cm
	Total Flow - Remote Operated Sluicegates	N/A
	Total Flow - Local Operated Sluicegates	22,092 cms
	Total Flow - Local Operated Log Sluices	N/A
	Total Flow through Generators	N/A
Elevations (meters)	Min. Earth Dam Crest Elevation	N/A
	Concrete Dam Crest Elevation	66.14 m
	Emergency Response WL3	N/A
	Emergency Response WL2	N/A
	Abs. Max Elevation (Emerg. Response WL1)	N/A
	Spillwall Elevation	N/A
	Operating Max Elevation (m)	N/A
	Operating Min Elevation (m)	72.5 m
	T-Dam Min. Elev.	
Physical	# Generating Units	N/A
	# Sluice Gates	30
	# Stop Log Sluices	N/A
	# Stop Logs per Sluice	N/A
	Spillwall Length (m)	549 m
	# Log Lifter and Type	N/A
	Backup Power for Sluices	Diesel brake
	# Gates with De-icing System	18
	Hrs to strip one Log Sluice (Summer/Winter)	N/A
	Hrs to strip Log Sluices for IDF Q (Sum/Win)	N/A
Dam Safety	Flood ICC	
	Sunny Day ICC	
	IDF Q (cms)	
	IDF HWL (m)	
	IDF Freeboard	
	# Gates Req'd to pass IDF Q	
	# Log Sluices Req'd to pass IDF Q	N/A
Access	Log Op Crew Base	N/A
	Access via Road	3 hrs
	Road Hrs. Base-Dam	3 hrs
	Other Access	
	Heli Hrs. Base-Dam	

Emergency Preparedness EOC/CEC Map

ST. LAWRENCE RIVER
Long Sault Dam (NYPA)

ONTARIO POWER GENERATION
Electricity Production
Dam Safety & Emergency Preparedness

Dec 2006	D. Lowe / Woodhouse	
1:50,000	T. Bennett	
160-D3H-08410-0003-0004		0

Item		R.H. Saunders GS
	Time Lag to next Dam (hrs)	8 hrs
	Rate of Rise (Daily Storage/1 cm)	28.3 cm
	Total Flow - Remote Op. Sluicegates	22,092 cms
	Total Flow - Local Operated Sluicegates	N/A
	Total Flow - Local Operated Log Sluices	N/A
	Total Flow through Generators	8,010 cms
	Min. Earth Dam Crest Elevation	77.57 m
	Concrete Dam Crest Elevation	78.03 m
	Emergency Response WL3	75.84 m
	Emergency Response WL2	75.54 m
	Abs. Max Elevation (Emerg. Response WL1)	74.48 m
	Spillwall Elevation	N/A
	Operating Max Elevation (m)	74.02 m
	Operating Min Elevation (m)	72.50 m
	T.Dam Min. Elev	74.98 m
Physical	# Generating Units	16
	# Sluice Gates	N/A
	# Stop Log Sluices	N/A
	# Stop Logs per Sluice	N/A
	Spillwall Length (m)	N/A
	# Log Lifter and type	N/A
	Backup Power for Sluices	N/A
	# Gates with De-icing System	N/A
	Hrs to strip one Log Sluice (Summer/Winter)	N/A
	Hrs to strip Log Sluices for IDF Q (Sum/Win)	N/A
Dam Safety	Flood ICC	
	Sunny Day ICC	
	IDF Q (cms)	
	IDF HWL (m)	
	IDF Freeboard	
	# Gates Req'd to pass IDF Q	
	# Log Sluices Req'd to pass IDF Q	
Access	Log Op Crew Base	N/A
	Access via Road	5 min
	Road Hrs Base-Dam	5 min
	Other Access	
	Heli Hrs Base-Dam	

Emergency Preparedness EOC/CEC Map

ST. LAWRENCE RIVER
R.H. Saunders GS

ONTARIO POWER GENERATION

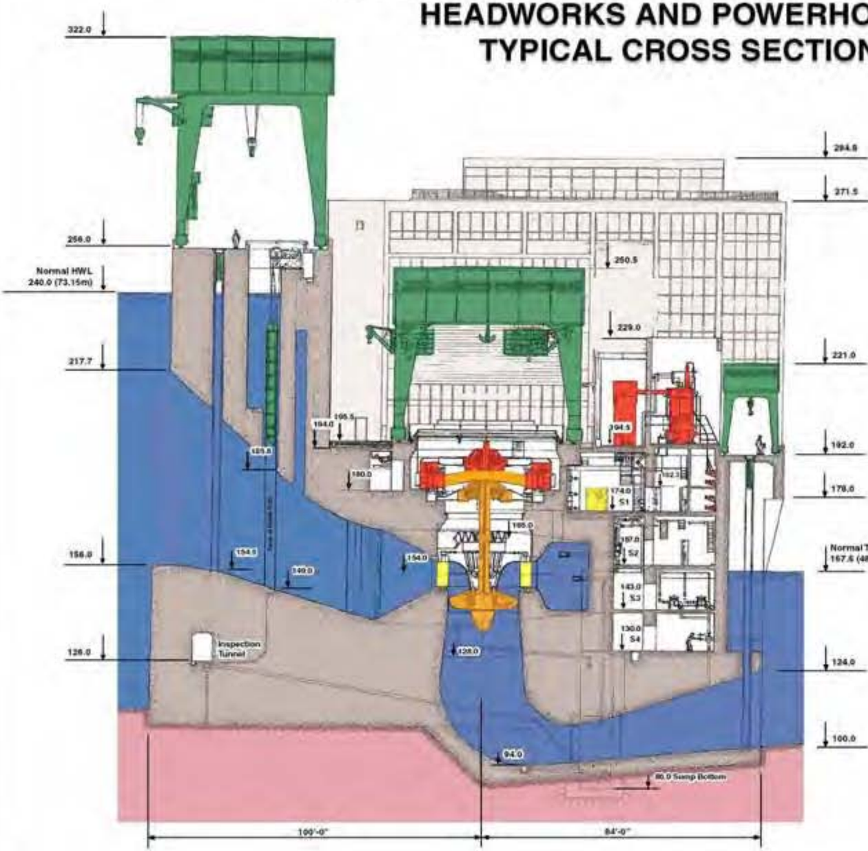
Electricity Production
Dam Safety & Emergency Preparedness

Dec 2004	B. Lam / L. Woodhouse	
1:50,000	T. Bennett	
160-D3H-08410-0003-0002		0

32 Units x 69 MVA
Structure Length: 1 km
Runners: Propeller Type
Capacity: 2,000 MW
Turbine Flow Capacity: 300cms

Head: 82 ft (25 m)
In-service Dates: 1958 & 1959
Average Flow: 7300 cms
Generation: 13.8 kV/230 kV
Trash Racks: Removed in early '60's

ROBERT H. SAUNDERS GENERATING STATION
HEADWORKS AND POWERHOUSE
TYPICAL CROSS SECTION



DATA

Location of Site	St. Lawrence R.-2 miles west of Cornwall
No. of Units Installed	Sixteen
Rated Head	81 Feet
Discharge per Unit	9,500 CFS (Max.)
Headwater Level	240.0 Feet Ultimate
Tailwater Level	157.5 Feet Normal
Turbine Capacity	88,000 BHP (Rated)
Turbine Speed	94.7 RPM
Turbine Manufacturer	English Electric Co. of Can. Ltd.
Turbine Type	Propeller
Runner Blade Material	Stainless Steel Casting
Runner Throat Diam	21 Feet
Runner No. of Blades	6
Speed Ring No. of Vanes	24
No. of Wicket Gates	24
Generator Capacity	69 MVA
Generator Manufacturer	8-Canadian General Electric Co. Ltd. 8-Canadian Westinghouse Co. Ltd.
Governor Manufacture	Woodward Governor Co.
Transformer Capacity	100 MVA
Transformer Manufacturer	ABB and Ferranti - Packard
Headgate Opening	17 x 37 Feet Hoist Capacity 120 tons
Headgate Manufacturer	Dominion Bridge Co. Ltd.
Gantry Headworks	90 Tons and 2-15 Ton Jib Crane
Gantry Powerhouse	300 Tons and 2-15 Ton Jib Cranes
Gantry Tailrace	15 Tons
Gantry Manufacturer	Dominion Bridge Co. Ltd.
Cranes Erection Bay Overhead	2-80 Tons & 2-15 Ton Aux.
Crane Manufacturer	Dominion Bridge Co. Ltd.
Transformer Transfer Truck Capacity	110.5 Tons
Transformer Transfer Truck Manufacturer	Dominion Bridge Co. Ltd.
Erection Bay Door	60'-6" W x 58'-0" H
Erection Bay Door Manufacturer	Richards-Wilcox Canadian Co.

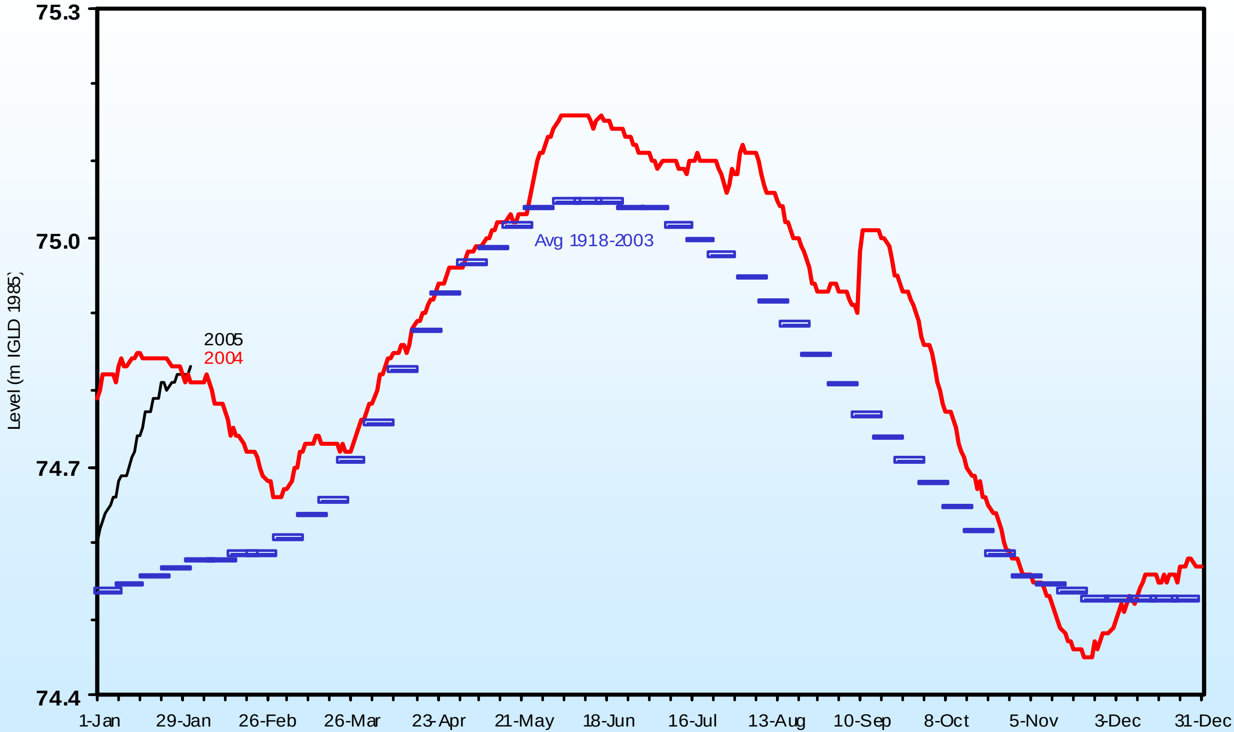
ONTARIO POWER GENERATION

TURBINE RUNNERS

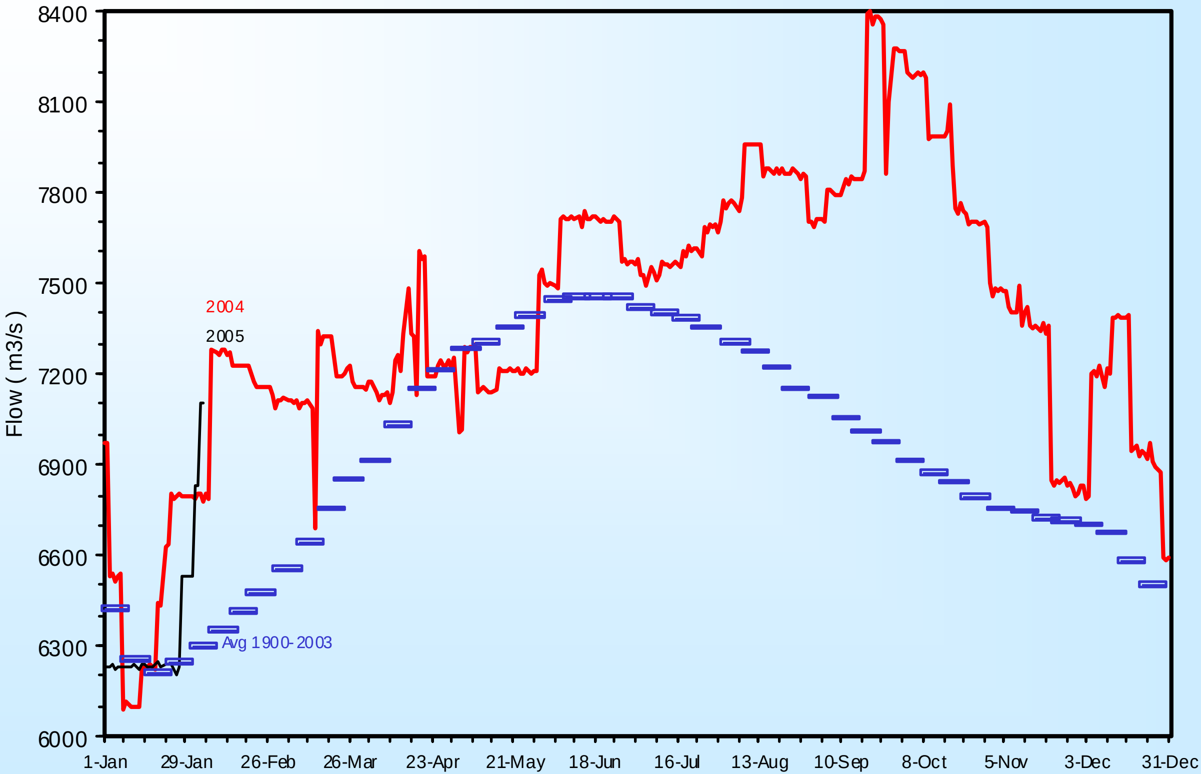
RUNNER REPLACEMENT PROGRAM

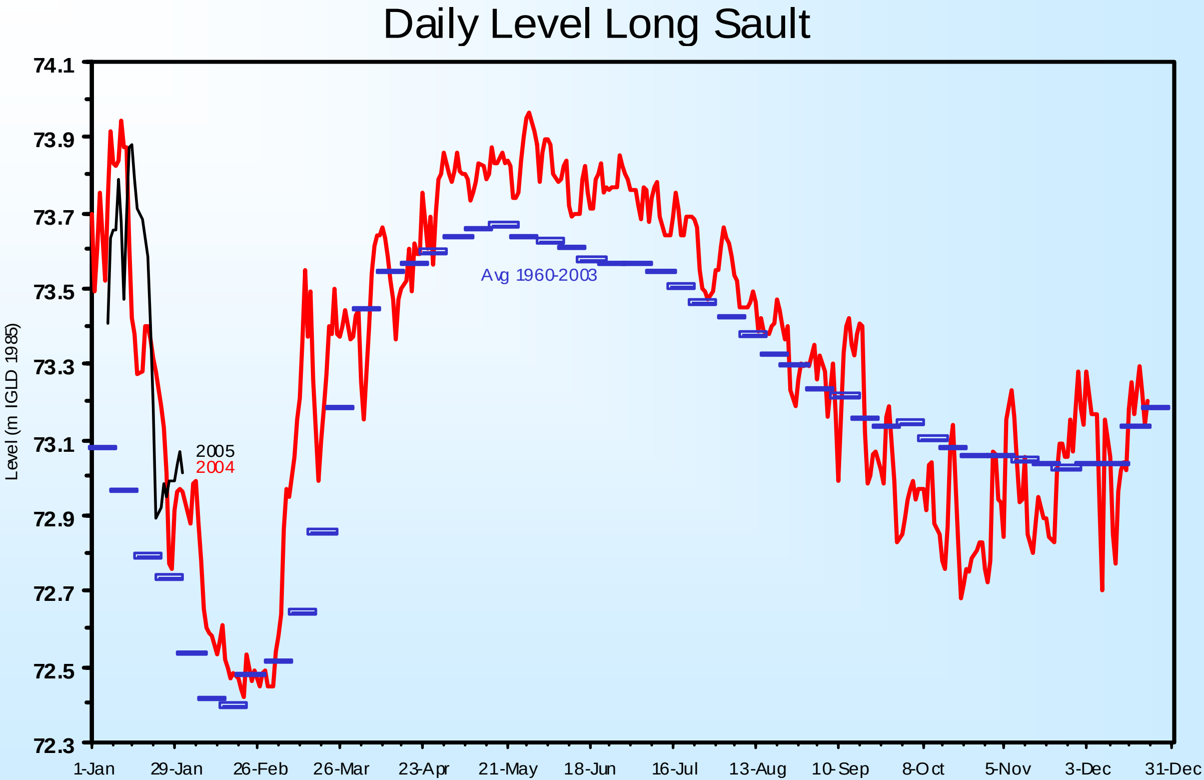
- Propeller type – 6 blade, 21 ft. dia.
- Increase generator efficiency
- Increase unit output: 57 MW ⟶ 67 MW
- New stainless steel blades
- Manufacturer – Sulzer Hydro
- Runner Replacement Program 1992 – 2002 (14 of 16 units)

Lake Ontario Level



Lake Ontario Outflow





Daily Level Long Sault
Level (m IGLD 1985)
74.1
73.9
73.7
73.5
73.3
73.1
72.9
72.7
72.5
72.3
1-Jan
29-Jan
26-Feb
26-Mar
23-Apr
21-May
18-Jun
16-Jul
13-Aug
10-Sep
8-Oct
5-Nov
3-Dec
31-Dec
2005
2004
Avg 1960-2003

STEWARDSHIP ACTIVITIES

- Eel ladder installation and maintenance
- Lake St. Lawrence elevation monitoring and control
- Debris removal – 400 tons removed in 2004
- Oil detection and containment system installed
- Emergency Preparedness and Response Plan

  - Dam, Spill, Fire and Medical

  - Work with stakeholders in exercising Response Plan

STEWARDSHIP ACTIVITIES

- Public Safety Campaign – Stay Clear, Stay Safe
- Ice Management Program and Boom Installation
- Work closely with navigation on Seaway opening and closing
- Maintain navigable passage for recreational boaters at Iroquois Dam

GREAT LAKES REGULATORY AGENCIES

INTERNATION JOINT COMMISSION (IJC)

- The IJC is an independent bi-national organization
- Established by the Boundary Waters Treaty of 1909
- Canadian Section has 3 members

  (Co-chair is Commissioner Herb Gray)
- US Section has 3 members

  (Co-chair is Commissioner Dennis Schornack)

- IJC calls their respective Boards before them twice a year.

- The Boards report on the progress of their actions related to the international boundary waters.

- The Spring appearance takes place in Washington D.C. and the Fall appearance takes place in Ottawa.

OPG INTERESTS

- There are 18 “Boards” reporting to the IJC.
- OPG has interest or involvement with the following Boards:

✓ International Lake of the Woods Control Board
✓ International Lake Superior Board of Control
✓ International Niagara Board of Control
✓ International St. Lawrence River Board of Control

INTERNATION ST. LAWRENCE RIVER BOARD OF CONTROL

The Board consists of:

- Five members from Canada
  (Co-chair is Mr Jacques Lorquet – Coast Guard)
- Five members from United States
  (Co-chair is Brigadier General Bruce Berwick)
- Also, each section has one Regulation Representative

  - Environment Canada (Canadian Section)
  - Army Corps of Engineers (US Section)

- The International St. Lawrence River Board of Control (ISLRBC) was established by the IJC in its 1952 Order of Approval.

- Main role – to ensure that outflows from Lake Ontario and flows in the St. Lawrence meet the requirements of the IJC's orders.

- The ISLRBC develops regulation plans (weekly) and conducts special studies as requested by the IJC.

- Hold monthly conference calls and meet quarterly in addition to the bi-yearly appearances to the IJC.

OPERATIONS ADVISORY GROUP (OAG)

- The OAG was created to advise the Board Regulation Representatives on the day-to- day operations.
- The group assists in implementing Board Strategies.
- They make recommendations with regard to river conditions, outflow, peaking and ponding operations and Plan 58-D.

The OAG consists of the following representatives:

- Ontario Power Generation
- St. Lawrence Seaway Management Corporation (Canadian)
- St. Lawrence Seaway Development Corporation (United States)
- New York Power Authority
- Canadian Coast Guard
- Hydro Quebec

- The OAG finalizes and confirms the St. Lawrence River flow for the coming week via conference call.
- The OAG members attend the Board meetings and appear before the IJC in an advisory capacity to the Board.

Estimation of Survival of American Eel after Passage Through a Turbine at the St. Lawrence-FDR Power Project, New York 1997

Presented by Kevin McGrath

New York Power Authority

Collaborators

Normandeau Associates

Kleinschmidt

John Skalski – U. of Washington

American Eel Workshop
February 2005
Cornwall, Ontario, Canada

Test Specimens

- Specimens from Richelieu River, 125 km downstream
- Length ---- 81 to 114 cm (mean 102 cm)

Methods

- 240 eels released through turbine at two depths
- 134 eels released in turbine discharge as controls
- Balloon tagging technique
  - Uninflated upon release
  - Catalyst inflates balloon, time controlled
  - Eels are buoyed to surface in tailrace
- Live eels were held for 88-hour latent survival estimates

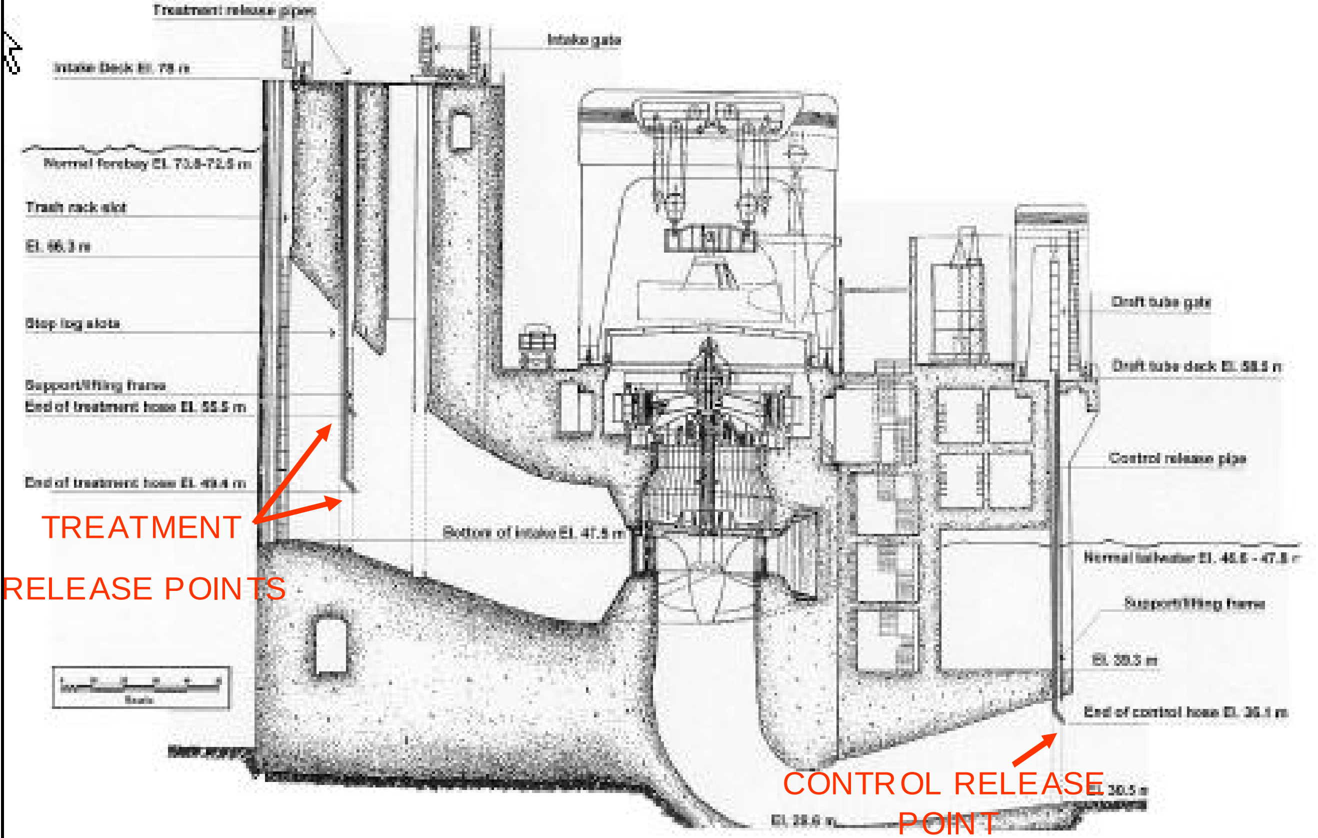


Figure 2.3-1. Typical cross-section of a turbine at the Robert Moses Power Dam (St. Lawrence-FDR Power Project) showing the flow path and position of the treatment and control release pipes for introducing balloon tagged eels.

Results

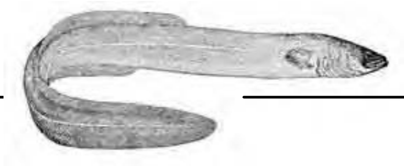
- 86% of treatment specimens recovered
- 95% of control specimens recovered
- Mean collection time was less than 12 minutes

Survival Estimates

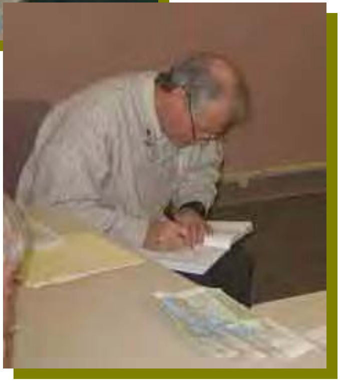
Estimated Survival Probabilities of American eel in passage through Turbine Unit 28 at the St. Lawrence-FDR Power Project		
	Survival Estimate %	Ninety percent confidence interval
ح 88 hour [1]	73.5	67.9 – 79.0
ح 88 hour [2]	75.0	69.6 – 80.3

1 Survival calculation assumes noncaptured eels classified alive at 1 hr via radio telemetry

2 Survival calculation assumes noncaptured eels classified alive at 1 hr would be alive at 88 hr



2. Eel behaviour related to downstream passage



Seasonal Migration Patterns of Downstream Migrating American eel (*Anguilla rostrata*) in the St. Lawrence River - Kevin McGrath (New York Power Authority)

Movement Patterns of Downstream Migrating American Eels in the Upper St. Lawrence River - Kevin McGrath (New York Power Authority)

Downstream Migrating Eel Telemetry Study at Beauharnois Power Dam (2000) - Richard Verdon (Hydro Québec)

Three-dimensional behavior of migrant silver-phase American eels (*Anguilla rostrata*) encountering and passing downstream of a small hydroelectric facility - Leah Brown (United States Geological Survey)

Downstream passage of migrating silver-phase American eels at a hydroelectric dam - Brian Eltz (United States Geological Survey)

Management of Silver Eel: Human Impact on Downstream Migrating Eel in the River Meuse - Maarten Bruijs (KEMA Consulting Services - Netherlands)

Workshop photos by Kevin McGrath

St. Lawrence-FDR Power Project

Moses-Saunders Power Dam

Seasonal Migration Patterns 1999-2004

Presented by Kevin McGrath

New York Power Authority

Collaborators

Riveredge Associates

Kleinschmidt

Milieu, inc.

John Skalski – U. of Washington

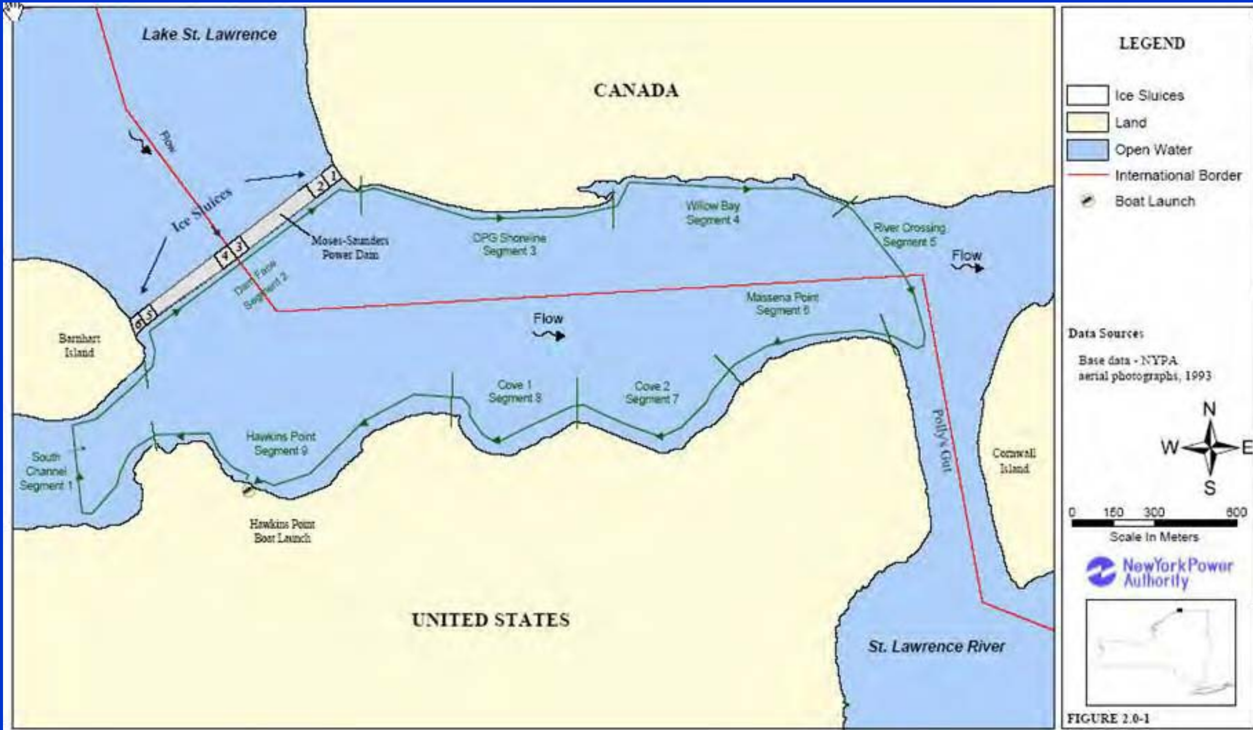
American Eel Workshop

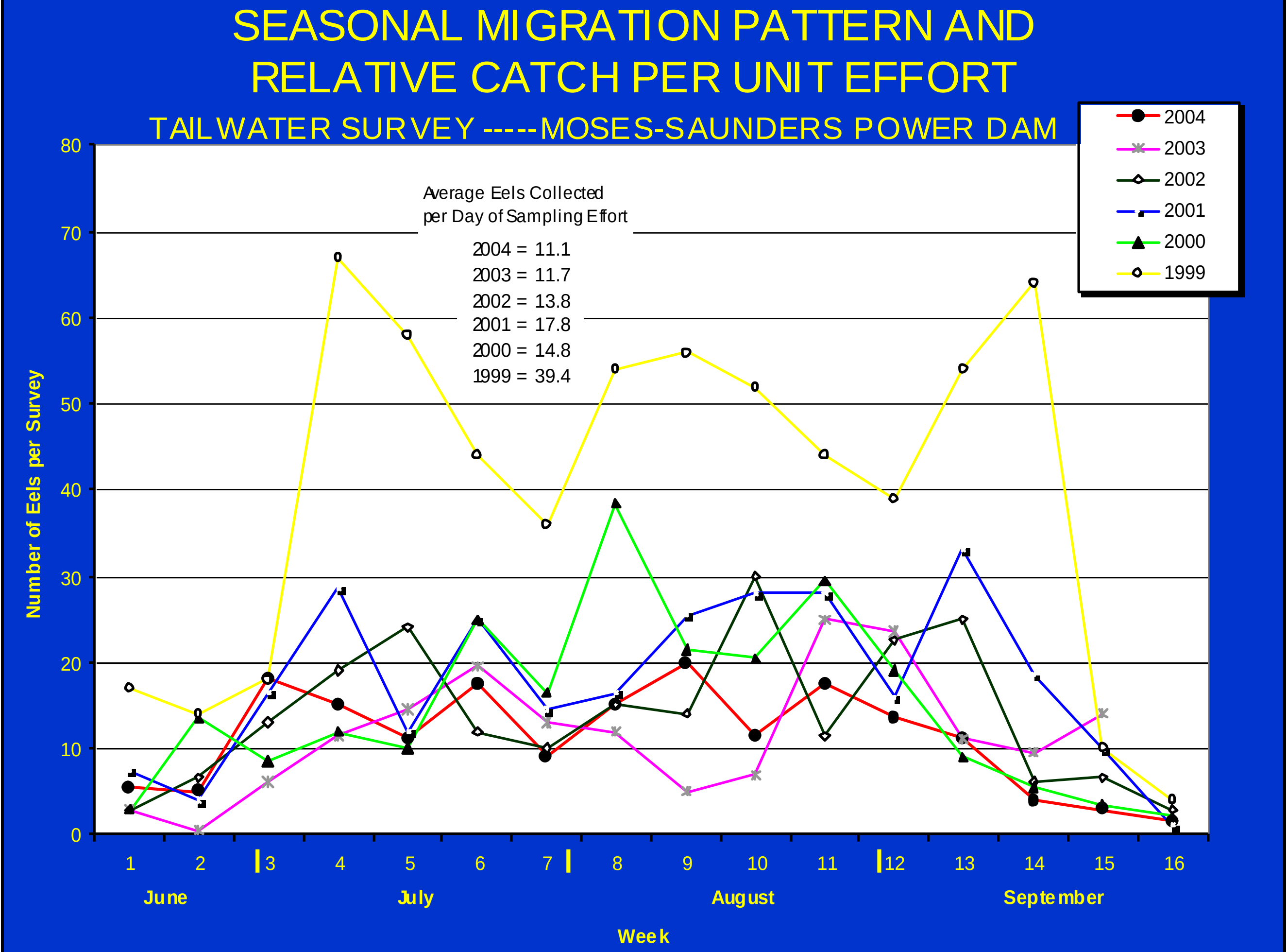
February 2005

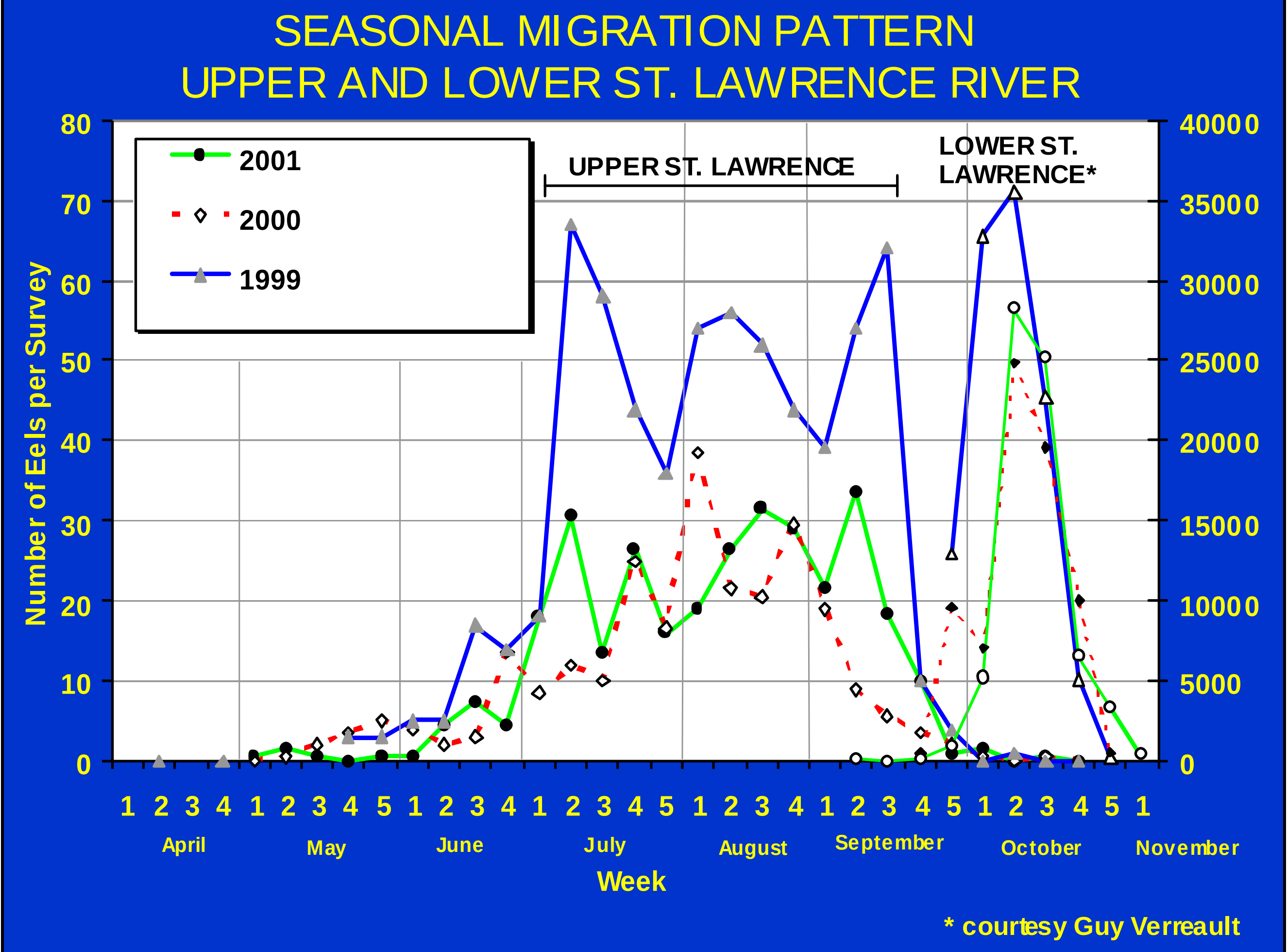
Cornwall, Ontario, Canada

SURVEY ROUTE

Surveys conducted twice per week from mid-June through September

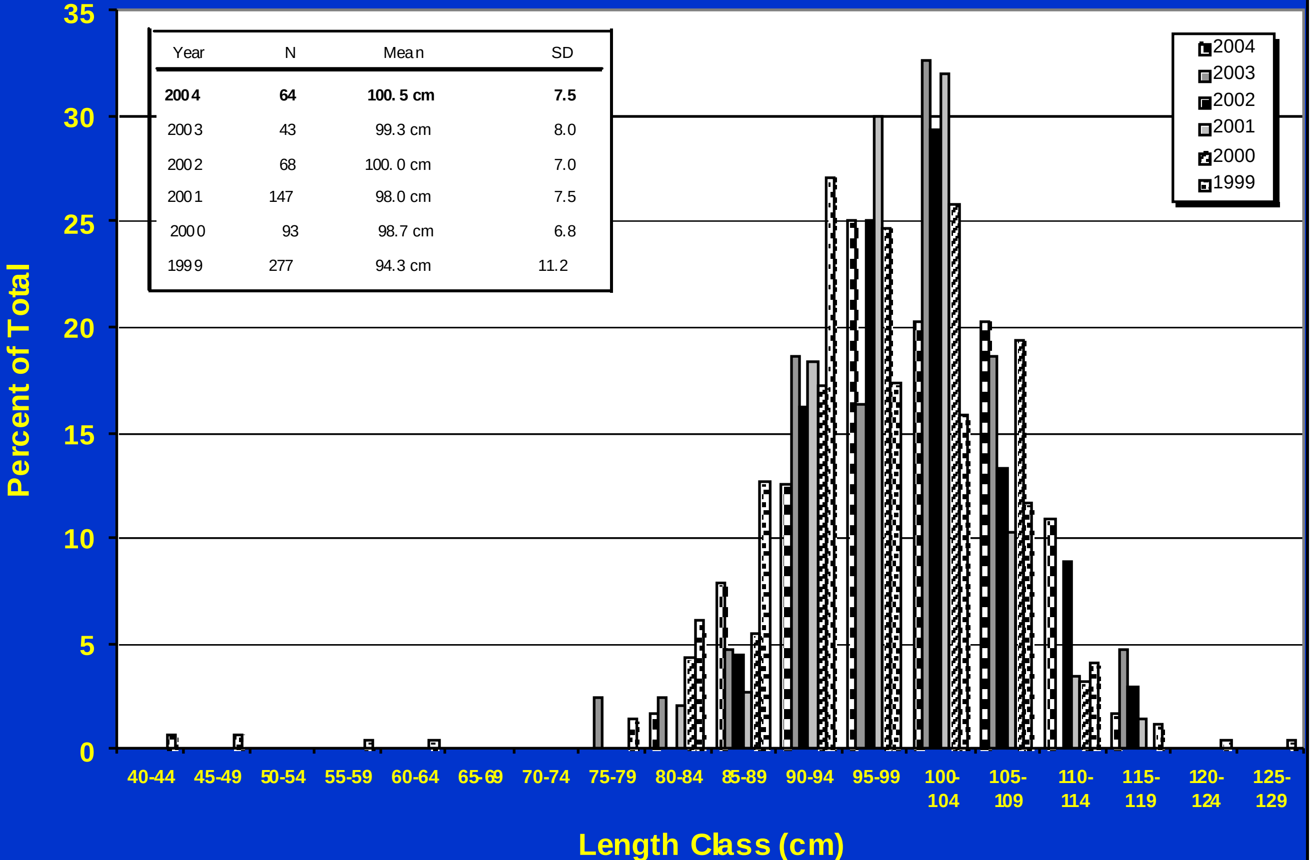



SEASONAL MIGRATION PATTERN AND
RELATIVE CATCH PER UNIT EFFORT
TAILWATER SURVEY -----MOSES-SAUNDERS POWER DAM
Average Eels Collected
per Day of Sampling Effort
2004 = 11.1
2003 = 11.7
2002 = 13.8
2001 = 17.8
2000 = 14.8
1999 = 39.4
2004
2003
2002
2001
2000
1999
Number of Eels per Survey
0
10
20
30
40
50
60
70
80
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
June
July
August
September
Week



SEASONAL MIGRATION PATTERN
UPPER AND LOWER ST. LAWRENCE RIVER
2001
2000
1999
UPPER ST. LAWRENCE
LOWER ST. LAWRENCE*
Number of Eels per Survey
80
70
60
50
40
30
20
10
0
40000
35000
30000
25000
20000
15000
10000
5000
0
1 2 3 4 1 2 3 4 5 1 2 3 4 1 2 3 4 5 1 2 3 4 1 2 3 4 5 1 2 3 4 5 1
April
May
June
July
August
September
October
November
Week
* courtesy Guy Verreault

LENGTH FREQUENCY DISTRIBUTION OF TAILWATER EELS



Year	N	Mean	SD
2004	**64**	**100.5 cm**	**7.5**
2003	43	99.3 cm	8.0
2002	68	100.0 cm	7.0
2001	147	98.0 cm	7.5
2000	93	98.7 cm	6.8
1999	277	94.3 cm	11.2

AMERICAN EEL TELEMETRY STUDY
ST. LAWRENCE RIVER

ST. LAWRENCE-FDR POWER PROJECT

Summer/Fall, 2000

Presented by Kevin McGrath

New York Power Authority

American Eel Workshop
February 2005
Cornwall, Ontario, Canada

MAJOR CONTRIBUTORS

Kleinschmidt Assoc.

Planning/Management and Report Preparation

Scott Ault -- Joe Dembeck -- Mike Hreben

Vemco

Telemetry

Fred Voegeli -- Greg McKinnon

Baird Associates

Software Analytical Tools

Kevin MacIntosh -- Derek Williamson -- Don Zimmer

Stantec Consulting (formerly Beak Associates)

Field Management and Report Preparation

David Stanley -- Geoff Burchill

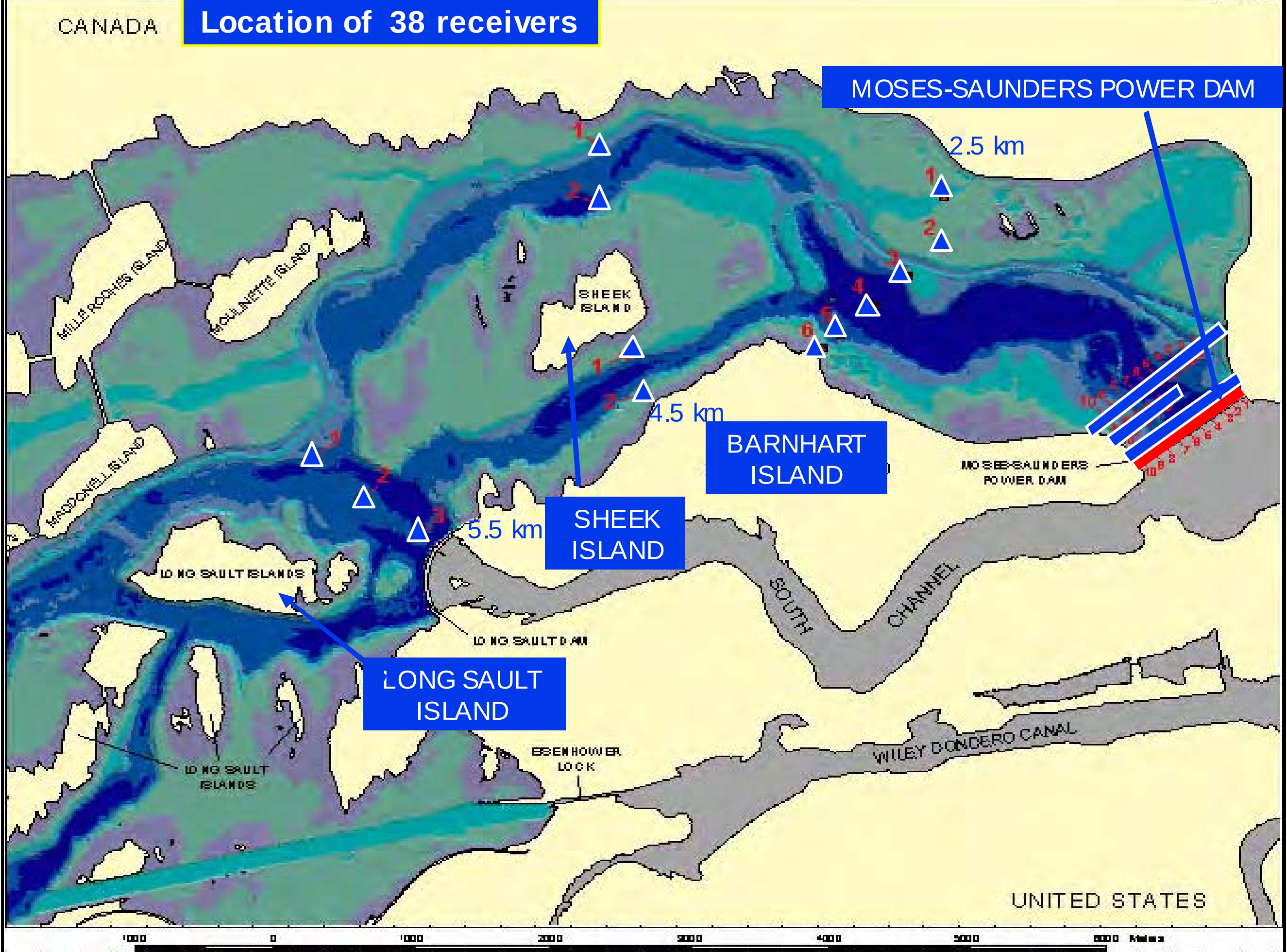
<u>Objective</u>:

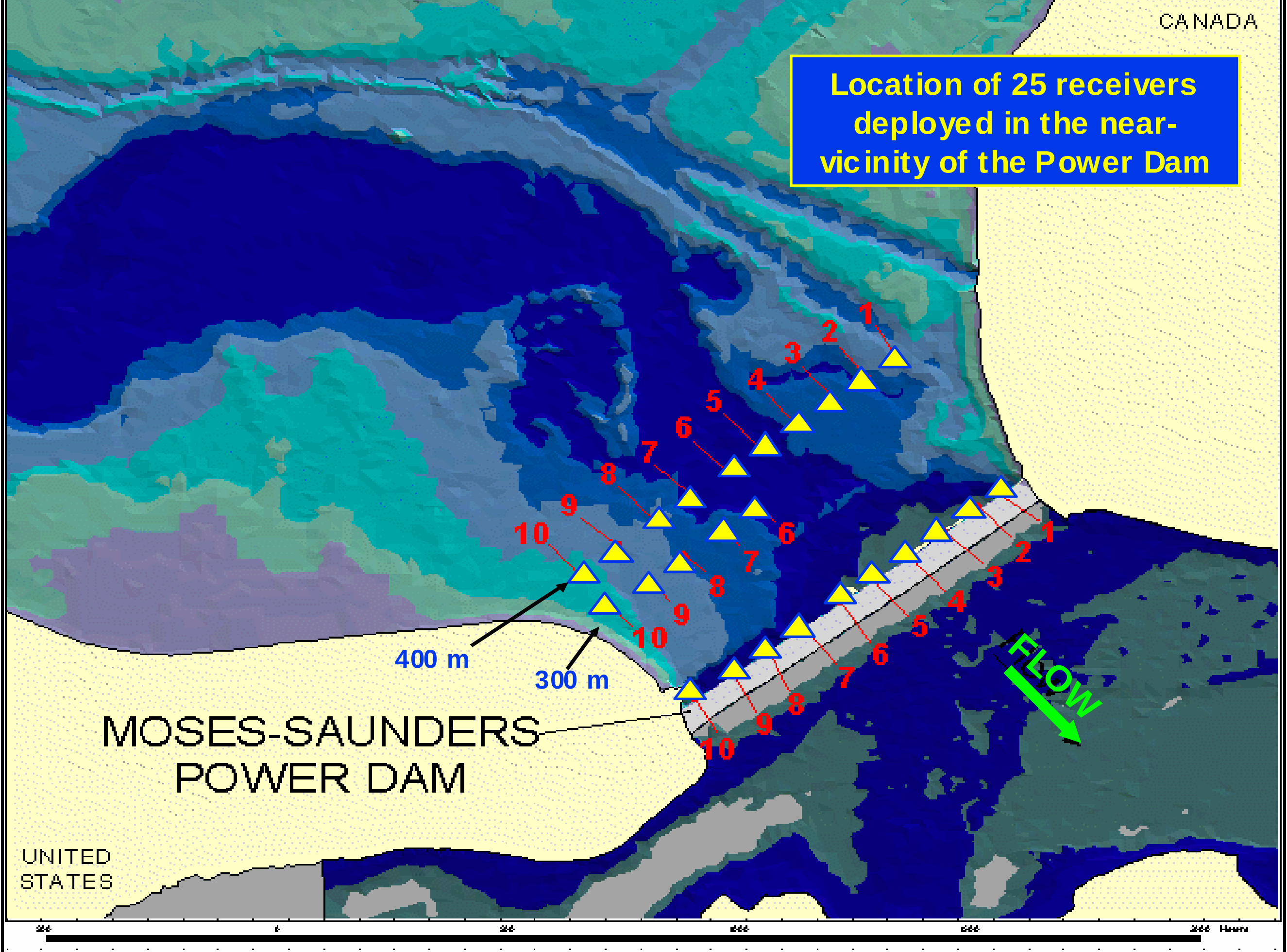
To gather information on downstream migrating eel movement patterns above and in the near-vicinity of the Moses-Saunders Power Dam

August 2000 CM 19880001.fb8 (08-17-00)


LAKE ST. LAWRENCE
FLOW
FLOW
MOSES-SAUNDERS
POWER DAM
TAILWATER
FLOW


Approximately
0.8 to 1.1 meter
in length
All female


Location of 38 receivers
CANADA
MOSES-SAUNDERS POWER DAM
2.5 km
MILLE ROCHES ISLAND
MOULINETTE ISLAND
SHEEK ISLAND
4.5 km
BARNHART ISLAND
MOSES-SAUNDERS POWER DAM
MACDONELL ISLAND
5.5 km
SHEEK ISLAND
LONG SAULT ISLANDS
SOUTH CHANNEL
LONG SAULT DAM
LONG SAULT ISLAND
EISENHOWER LOCK
WILEY DONDERO CANAL
LONG SAULT ISLANDS
UNITED STATES
1000 0 1000 2000 3000 4000 5000 6000 Meters



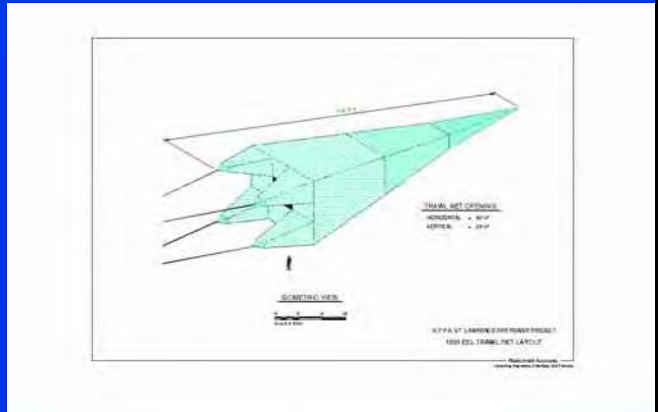
CANADA
Location of 25 receivers deployed in the near-vicinity of the Power Dam
1
2
3
4
5
6
7
8
9
10
400 m
300 m
MOSES-SAUNDERS POWER DAM
FLOW
UNITED STATES

RECEIVERS

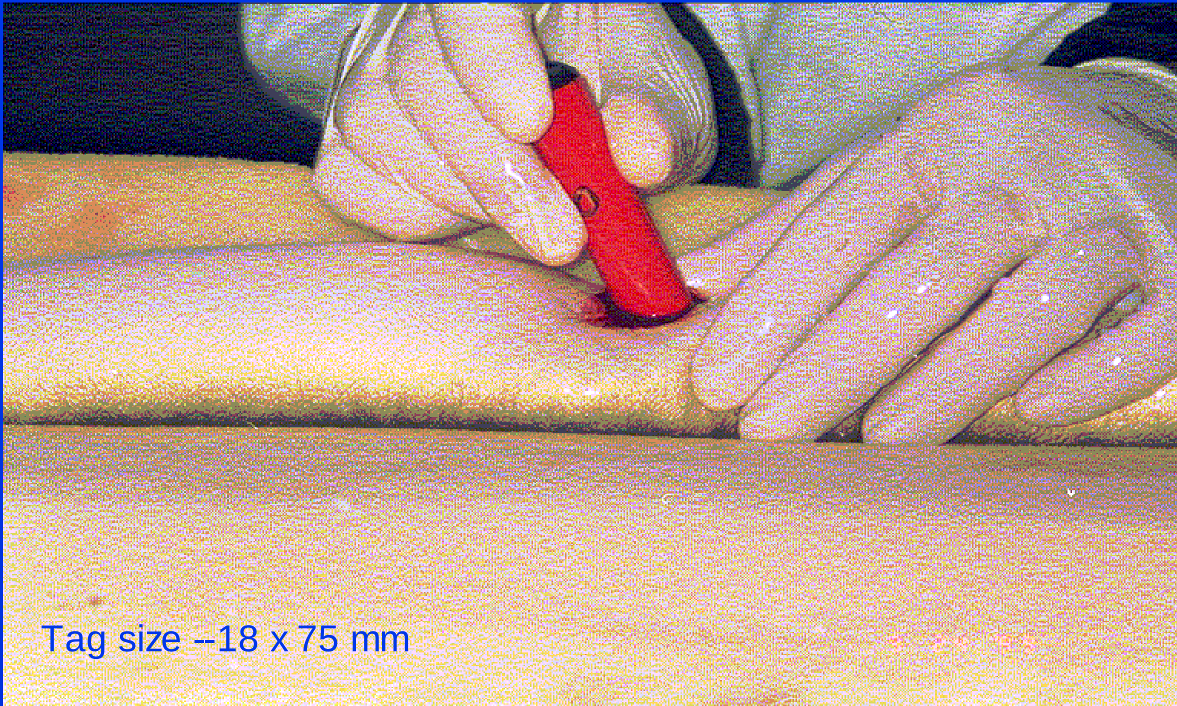
- Self Contained -- 200 kHz
- 63.5 cm x 10.2 cm -- 7 kg
- Stainless Steel Case -- 25 Day Battery Life

Collection of Eels

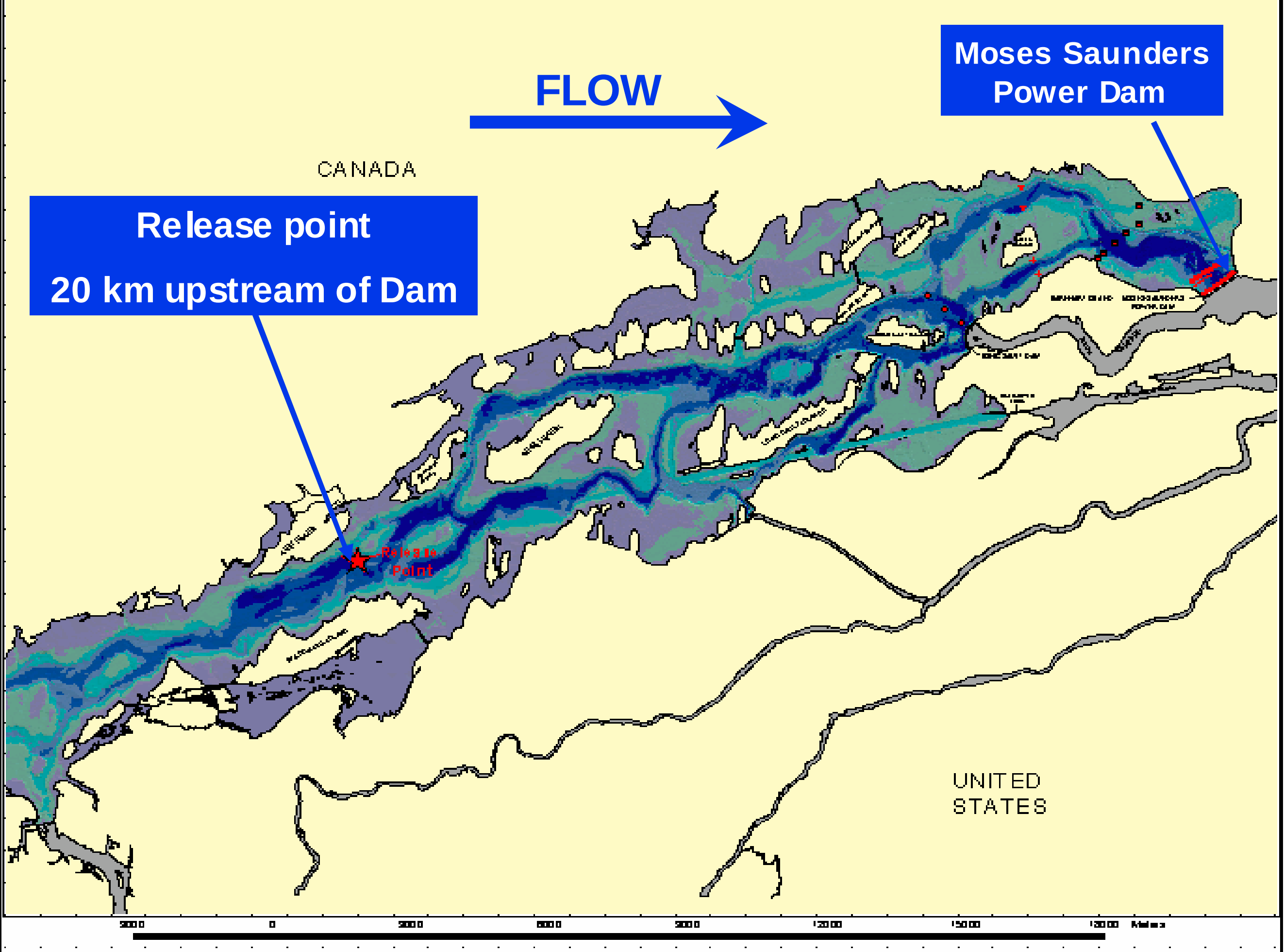
- Trawling
  - Net - French mid-water trawl,
    33 m length,
    mouth 7 m by 9 m



- Vessel -- Andrea Marie
  - 25 m length,
    500 hp



Surgical Implantation of a Transmitter in the Coelomic Cavity of an Adult American Eel.


FLOW
Moses Saunders Power Dam
CANADA
Release point
20 km upstream of Dam
Release Point
UNITED STATES

Results

- 152 eels were tagged and released
- 62 eels passed through the Power Dam

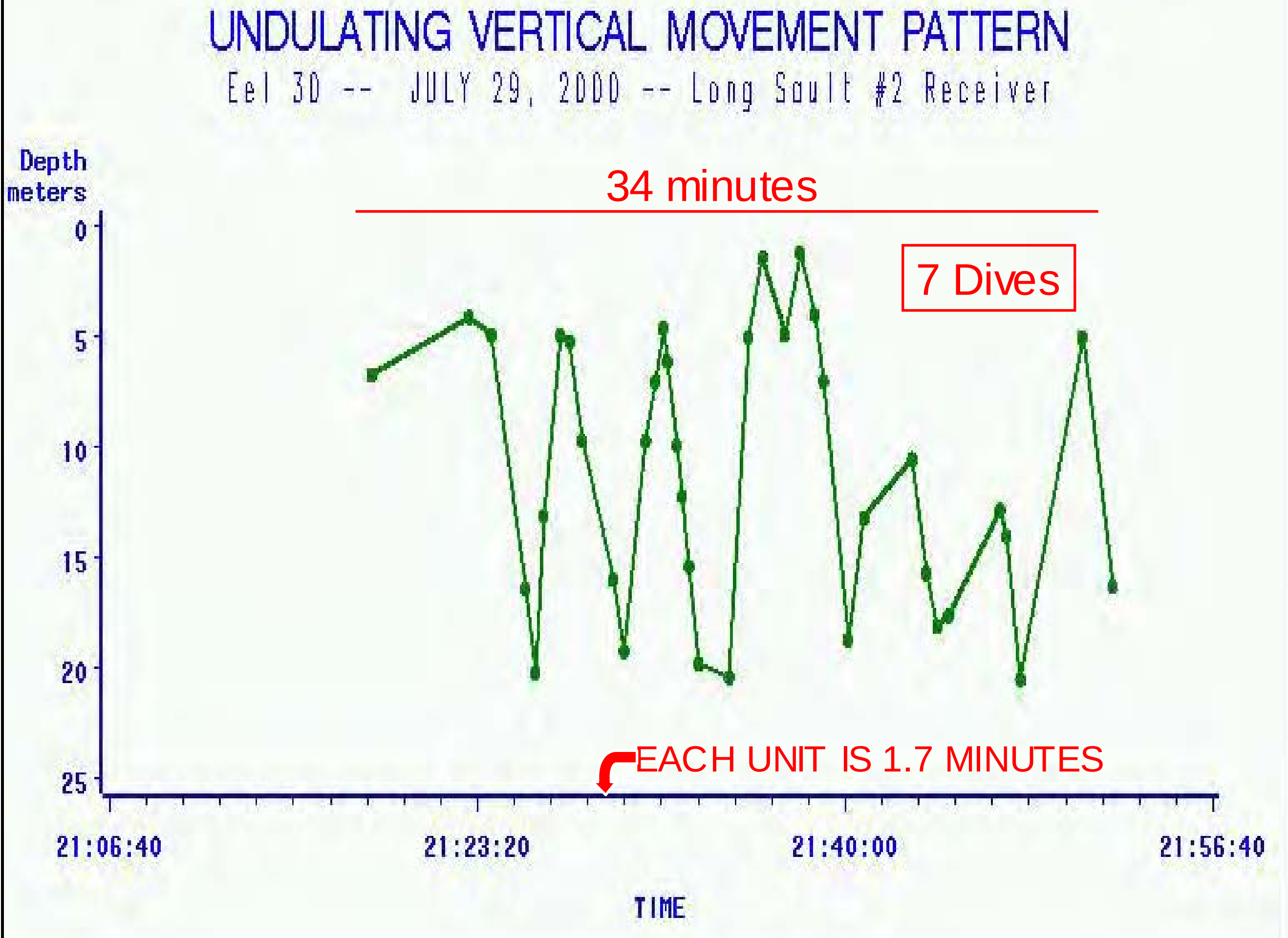
Number of LSL tagged eels detected at receiver arrays in the Study Area. Total number of eels detected at each array was 62 except at the Long Sault (LS) array.

Speed of Movement

- Actively migrating eels averaged between 0.6 and 0.8 m/s while water velocities in these regions were approximately 0.2 to 0.4 m/s

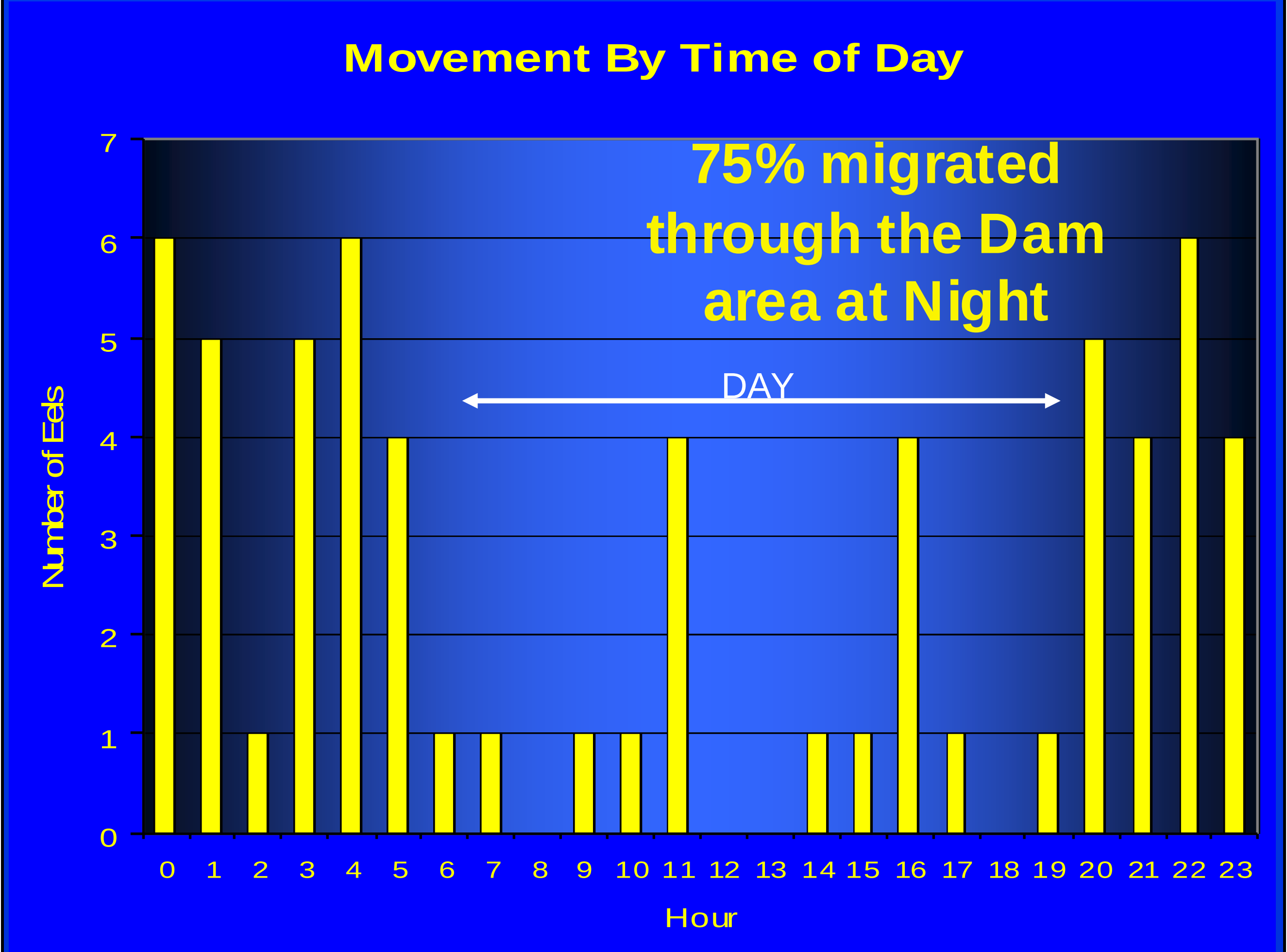
- Migration between the Moses-Saunders Power Dam and the Beauharnois Dam, approximately 85 km downstream, took on average 8.2 days with an average speed of 0.12 m/s. The minimum travel time was 0.9 days (1.13 m/s) and the maximum travel time was 31 days (0.03 m/s).*

*data courtesy of Richard Verdon, Hydro-Quebec


UNDULATING VERTICAL MOVEMENT PATTERN
Eel 30 -- JULY 29, 2000 -- Long Sault #2 Receiver
Depth meters
34 minutes
7 Dives
0
5
10
15
20
25
EACH UNIT IS 1.7 MINUTES
21:06:40
21:23:20
21:40:00
21:56:40
TIME

Depth of travel for actively migrating American eels in areas upstream of Moses-Saunders Power Dam

Depth Strata (m)	Number of Observations	Percent	Cumulative Number of Observations	Cumulative Percent
0 - 1	509	13.8	509	13.8
1 - 2	387	10.5	896	24.3
2 - 3	352	9.6	1248	33.9
3 - 4	345	9.4	1593	43.3
4 - 5	313	8.5	1906	51.8
5 - 6	240	6.5	2146	58.3
6 - 7	223	6.1	2369	64.3
7 - 8	185	5.0	2554	69.3
8 - 9	133	3.6	2687	73.0
9 - 10	142	3.9	2829	76.8
10 - 15	412	11.3	3241	88.0
15 - 20	286	7.7	3527	95.8
20 - 25	146	3.9	3673	99.7
> 25	10	0.2	3683	100



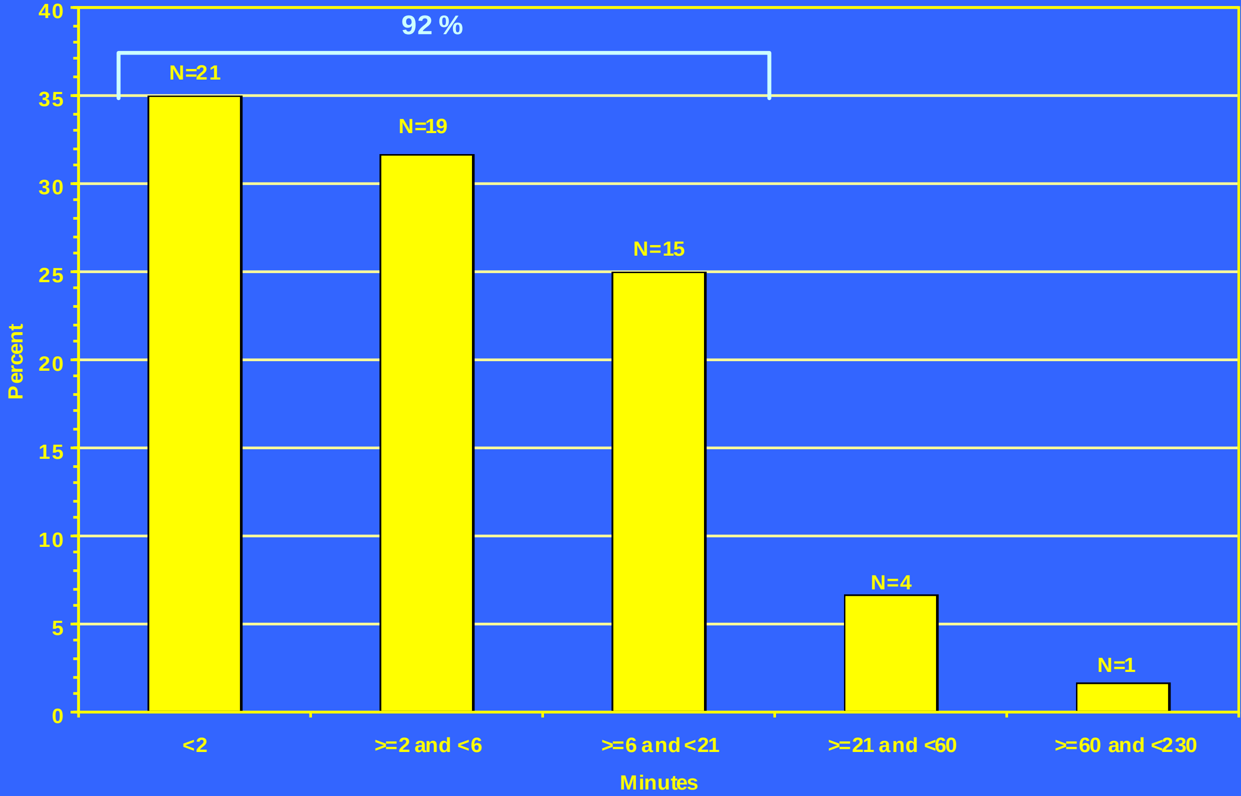
Movement By Time of Day
75% migrated through the Dam area at Night
DAY
Number of Eels
0
1
2
3
4
5
6
7
Hour
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23

Approach and Time at the Dam

- For the most part eels approached the Dam directly then passed relatively quickly
- 35% passed in less than 2 minutes
- 92% passed in less than 21 minutes

Amount of Time Within 50m of Power Dam

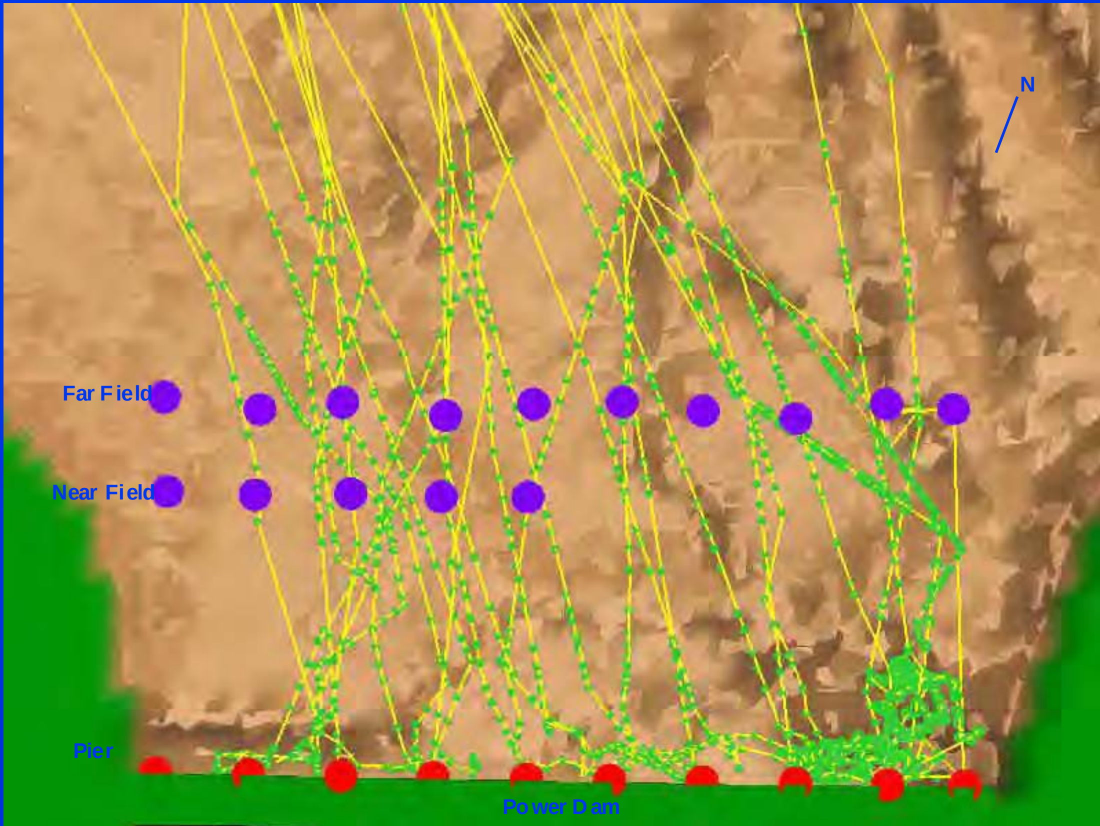
Time Could Not Be Estimated for 2 out of the 62 Eels

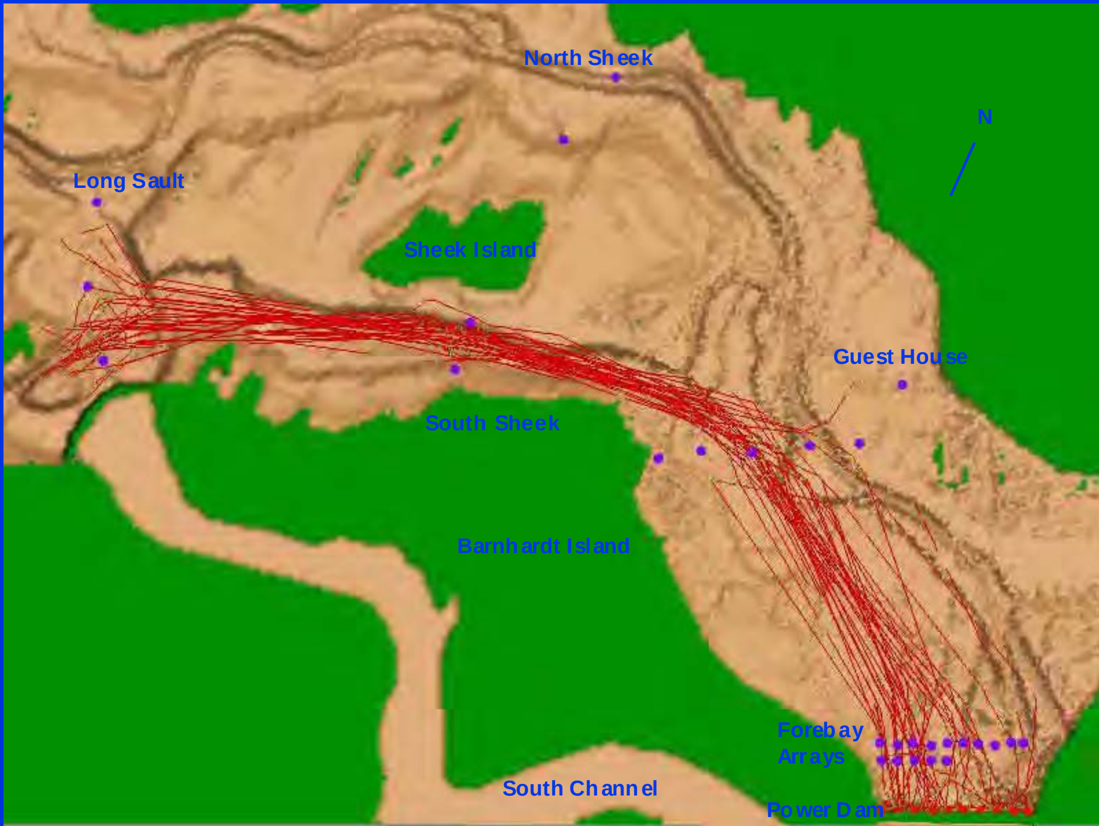


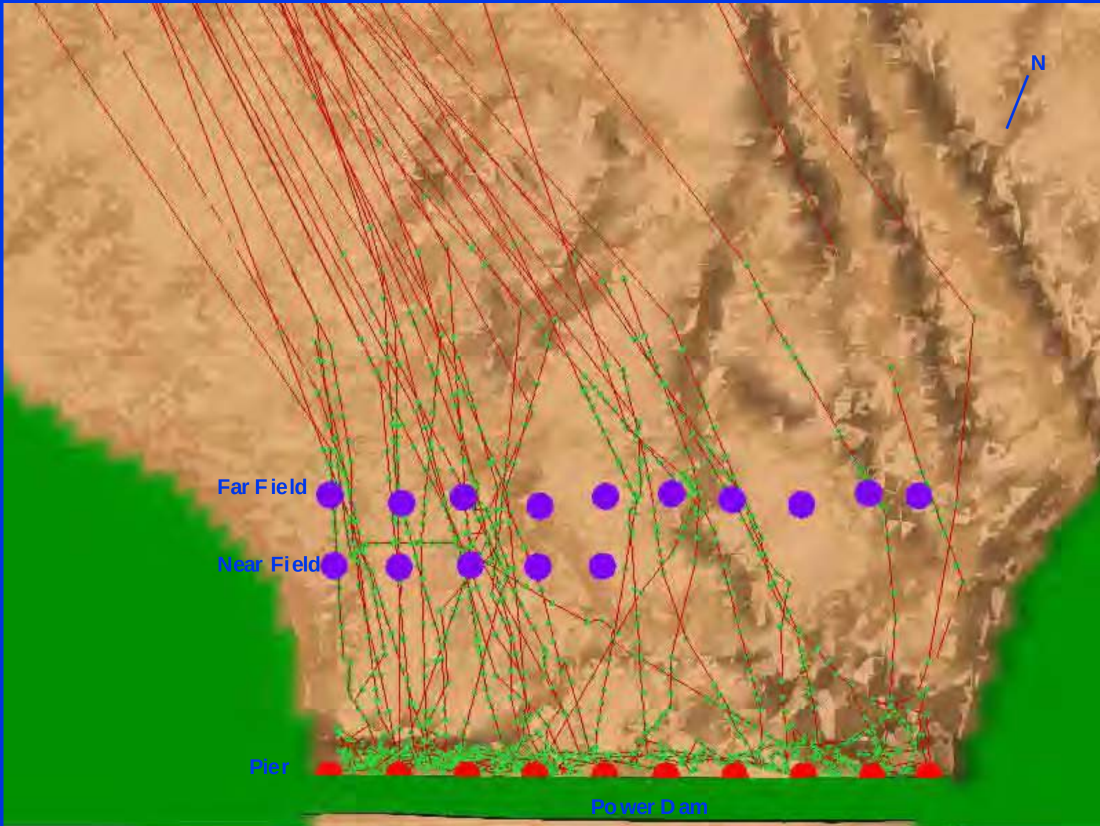
Movement Patterns

- Eels don't seem to be entrained in the classic sense, eel paths demonstrate that they swim and alter their paths in front of intakes
- Most vertical and lateral movement was very near the Dam--primarily within 100 m
- Flow velocities in this region are approximately 0.5 m/s

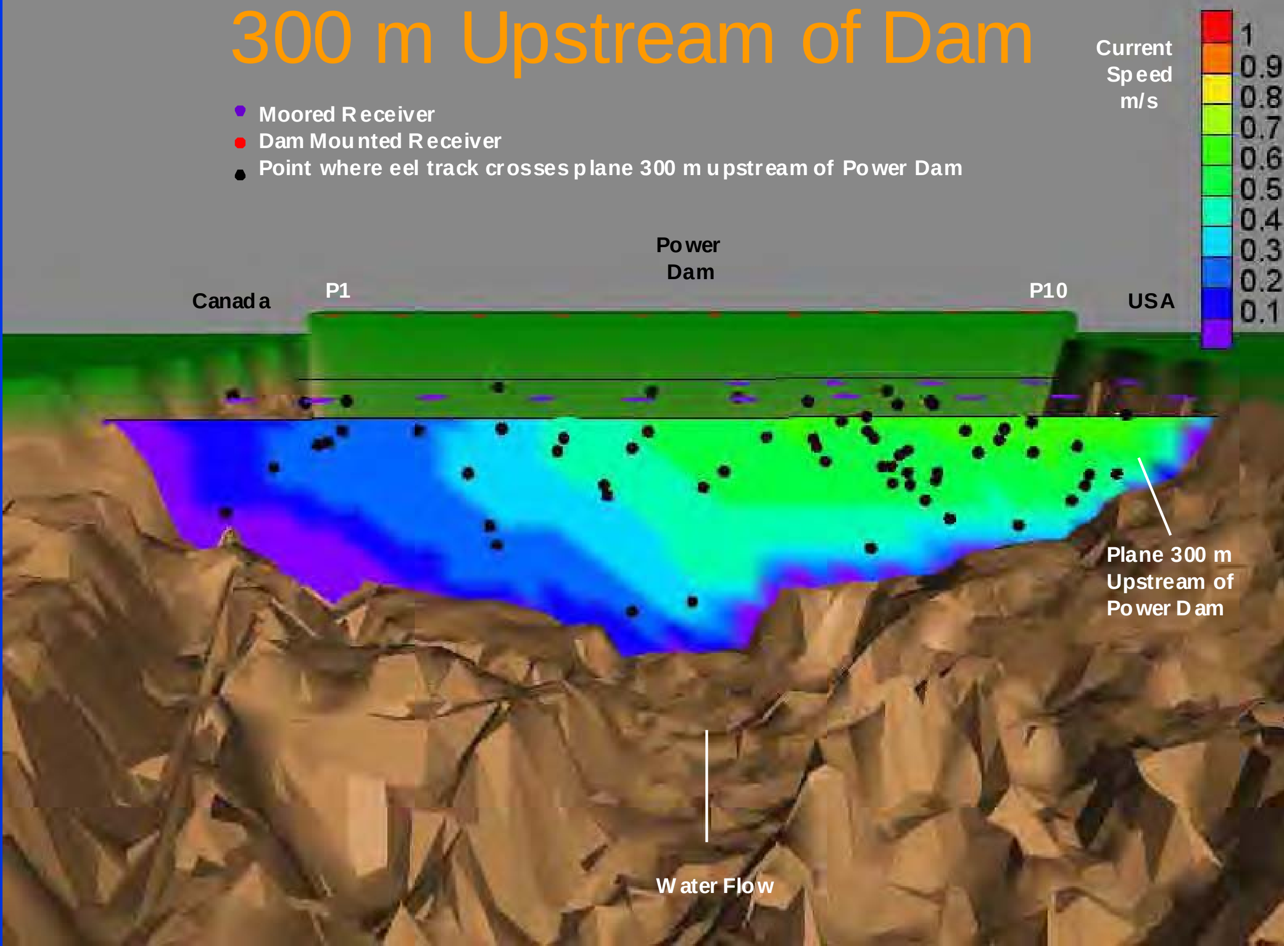

North Sheek
N
Long Sault
Sheek Island
Guest House
South Sheek
Barnhardt Island
Forebay
Arrays
South Channel
Power Dam


N
Far Field
Near Field
Pier
Power Dam

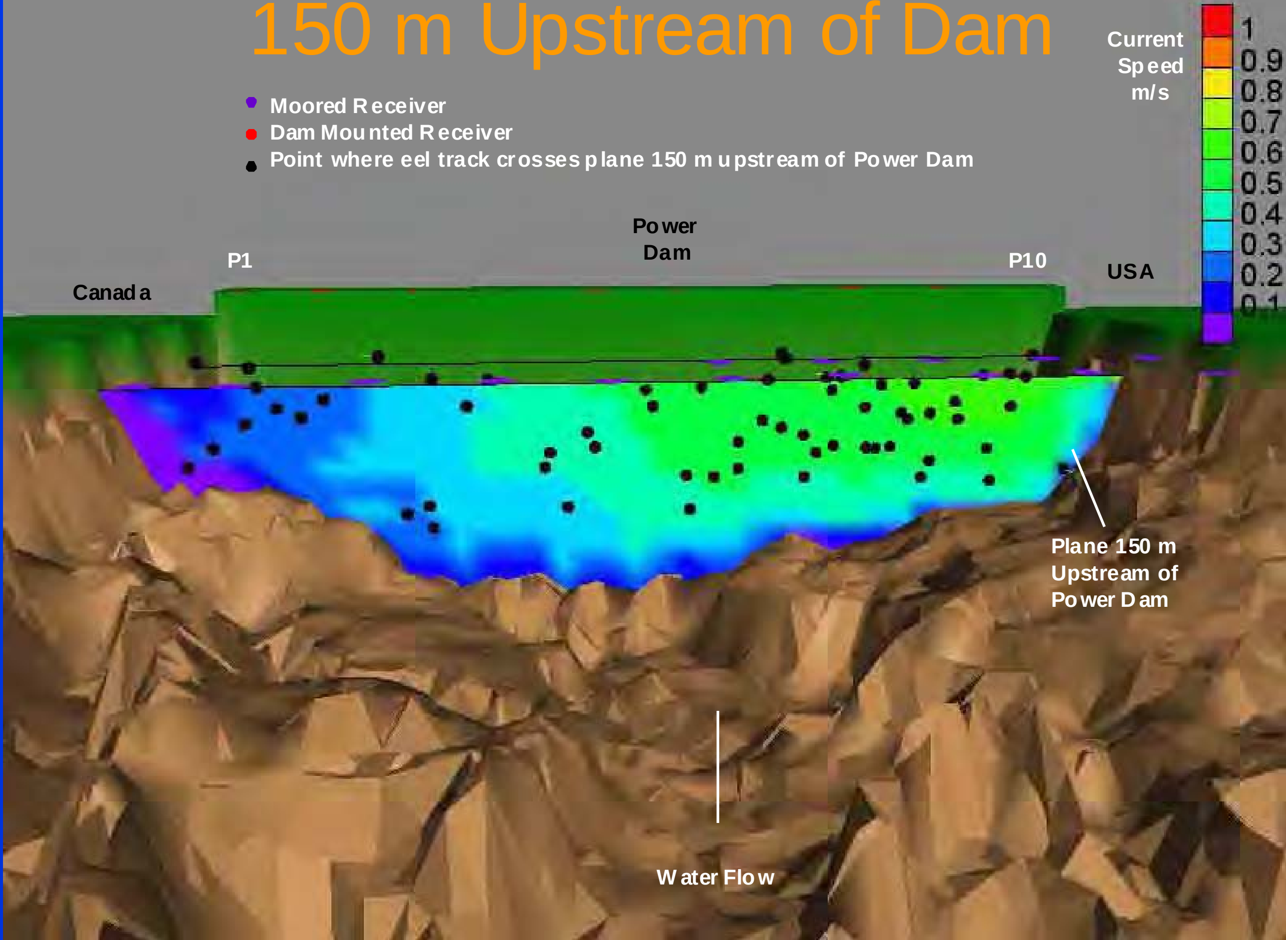

North Sheek
N
Long Sault
Sheek Island
Guest House
South Sheek
Barnhardt Island
Forebay
Arrays
South Channel
Power Dam


N
Far Field
Near Field
Pier
Power Dam

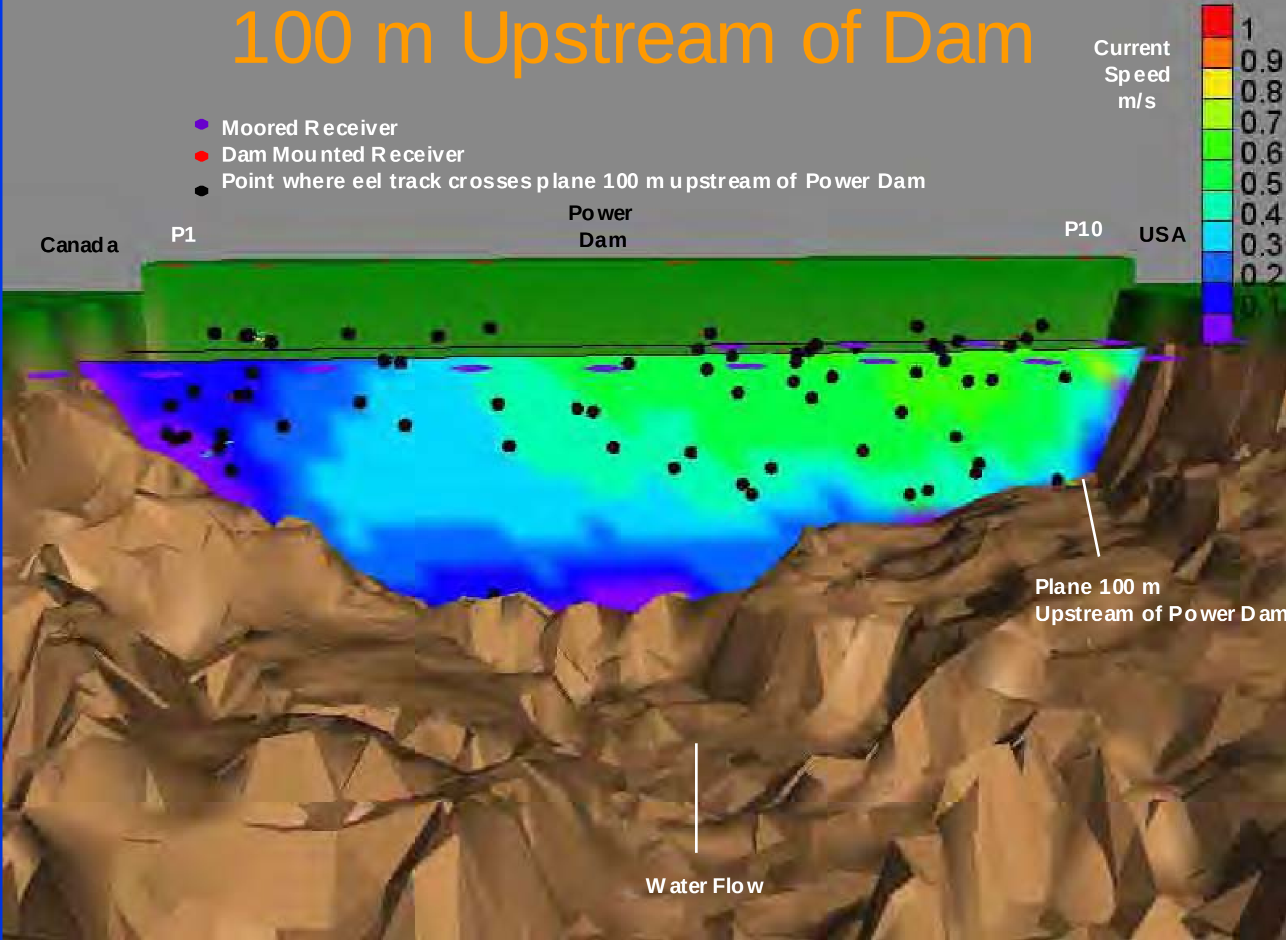
300 m Upstream of Dam



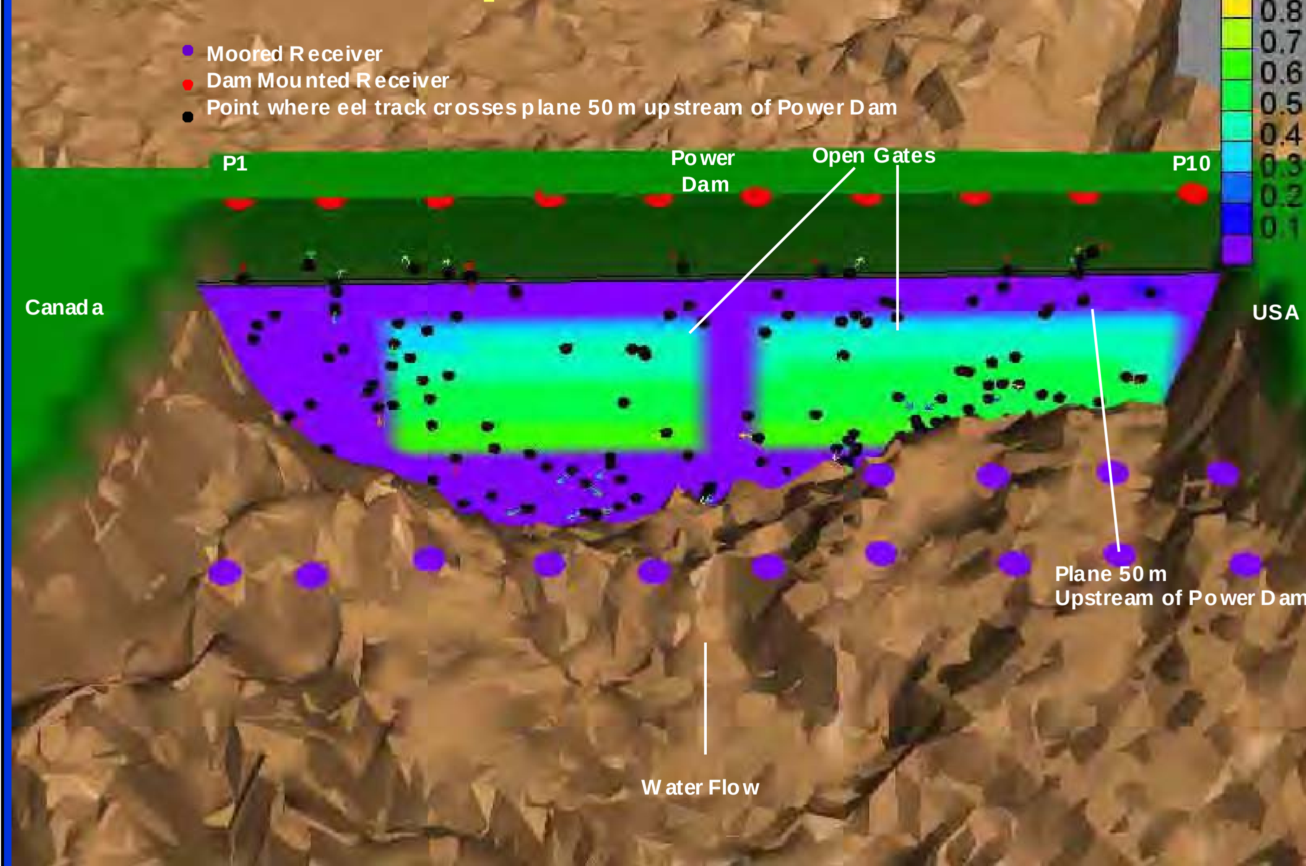
150 m Upstream of Dam

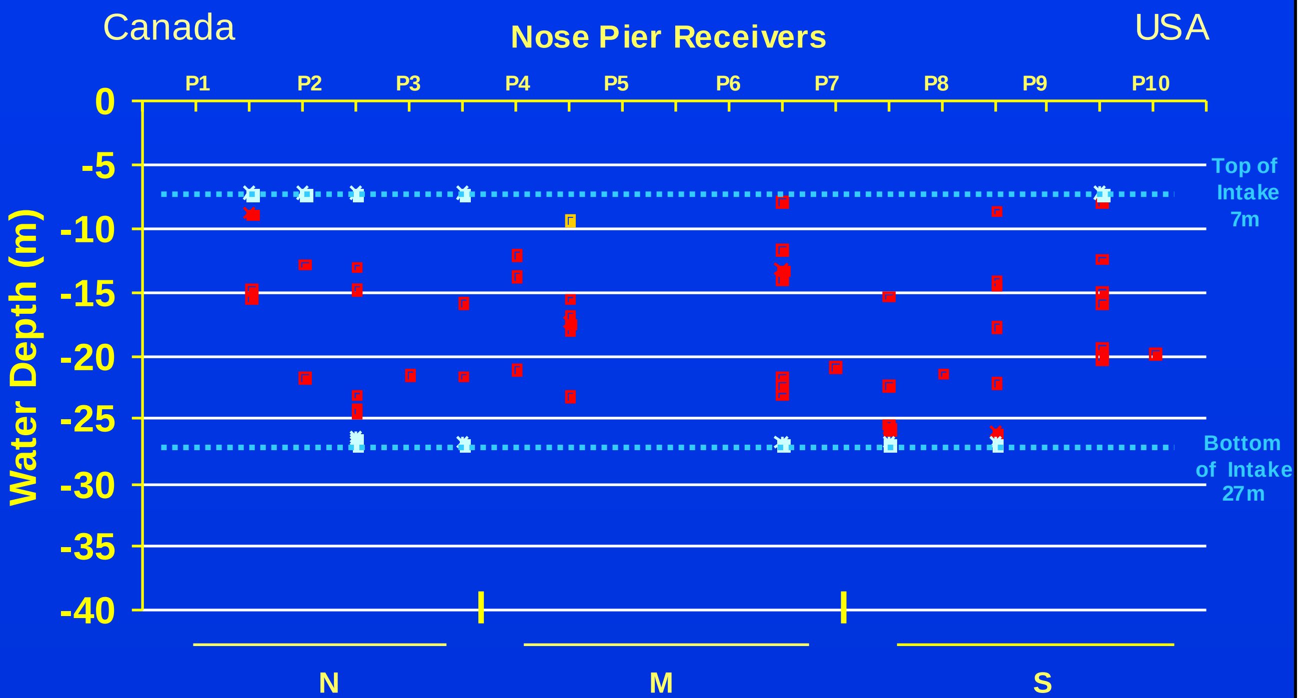


100 m Upstream of Dam



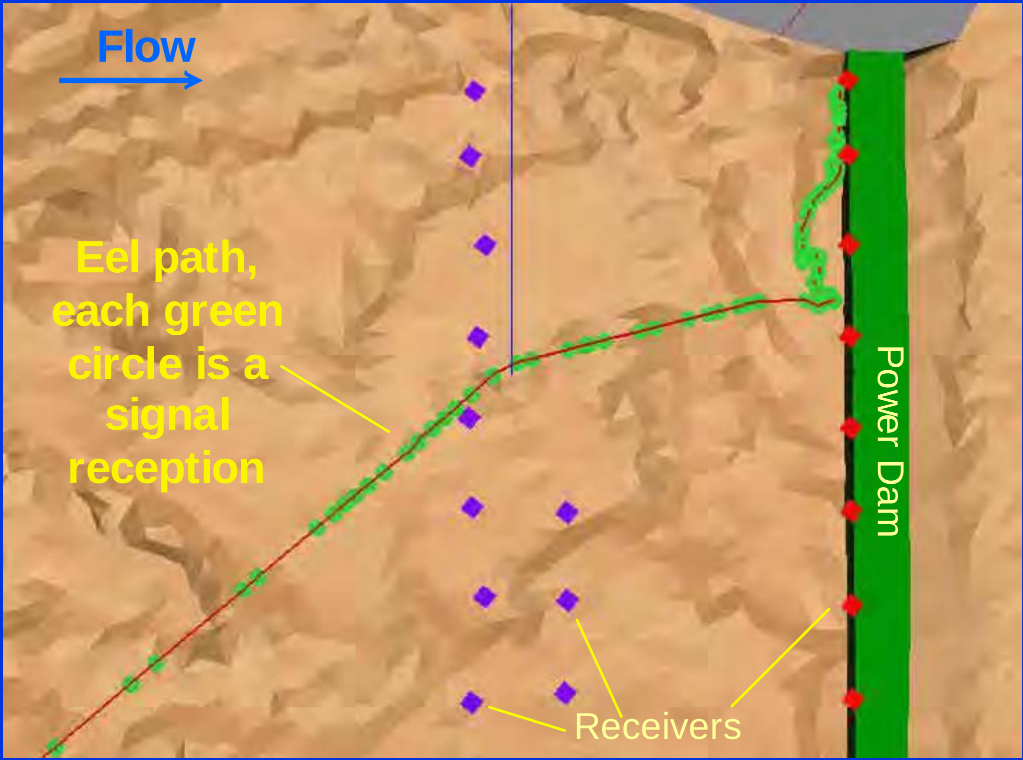
50 m Upstream of Dam



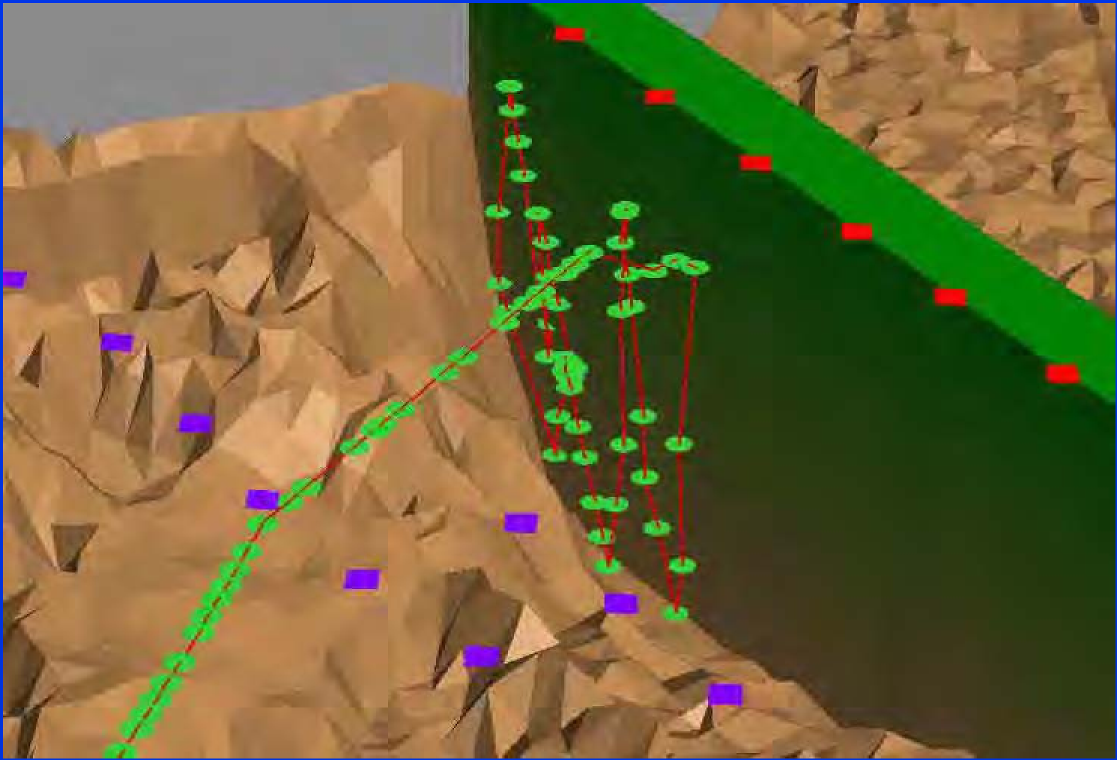


Estimated point of entry into intakes of the 62 eels at the Moses-Saunders Power Dam. Red squares are locations at point of last detection. Light blue squares and yellow squares are locations last detection point was moved to bring it into area of intakes.

Eel 87 Behavior at the Power Dam - Plan View

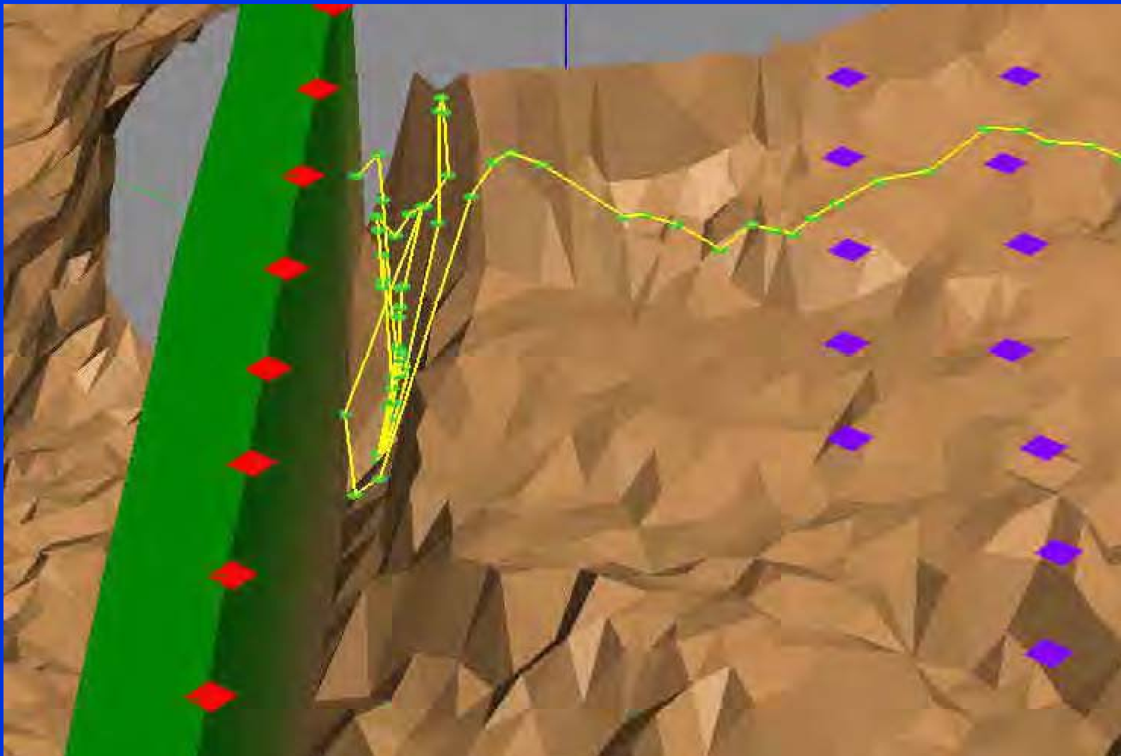


Eel 87 Behavior at the Power Dam - Side View Looking Northeast



Eel 140 Behavior at the Power Dam - Plan View

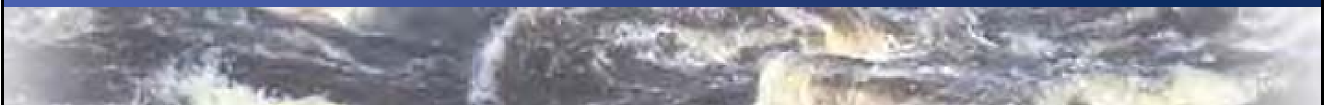
Eel 140 Behavior at the Power Dam - Side View Looking Southeast



Une division d'Hydro-Québec

Downstream Migrating Eel Telemetry Study at Beauharnois Power Dam (2000)

Richard Verdon
Hydro-Québec
and
Denis Desrochers
Milieu Inc.

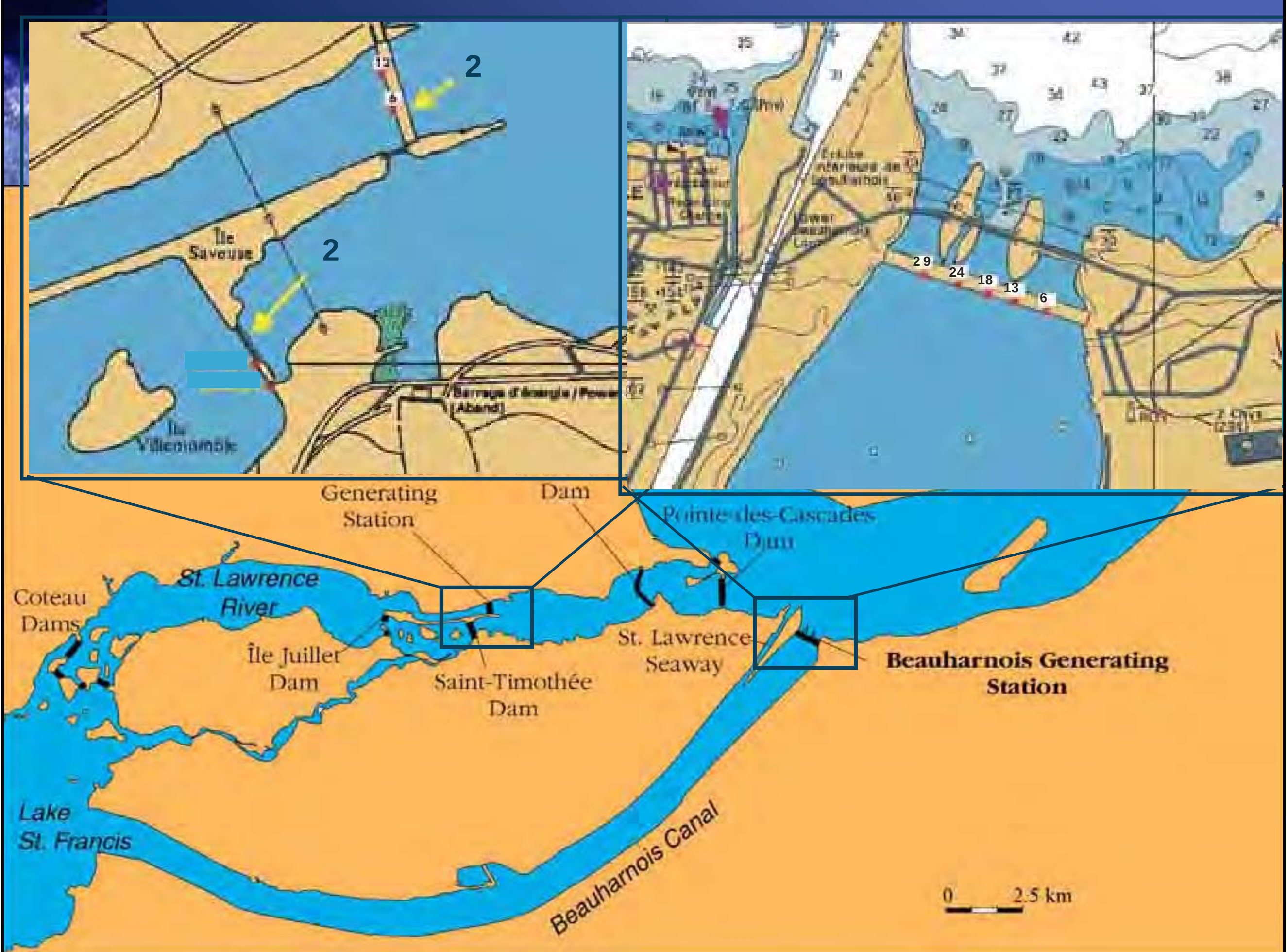


STUDY OBJECTIVES

- Determine the preferential migration route between:
  - The Beauharnois Canal
  - The St.Lawrence River
    - Les Cèdres Canal
    - St-Timothée Dam
- Describe the behaviour of migratory eels as they approach the dams
- Determine the distribution of migratory eels between the two types of turbines as they pass the Beauharnois GS

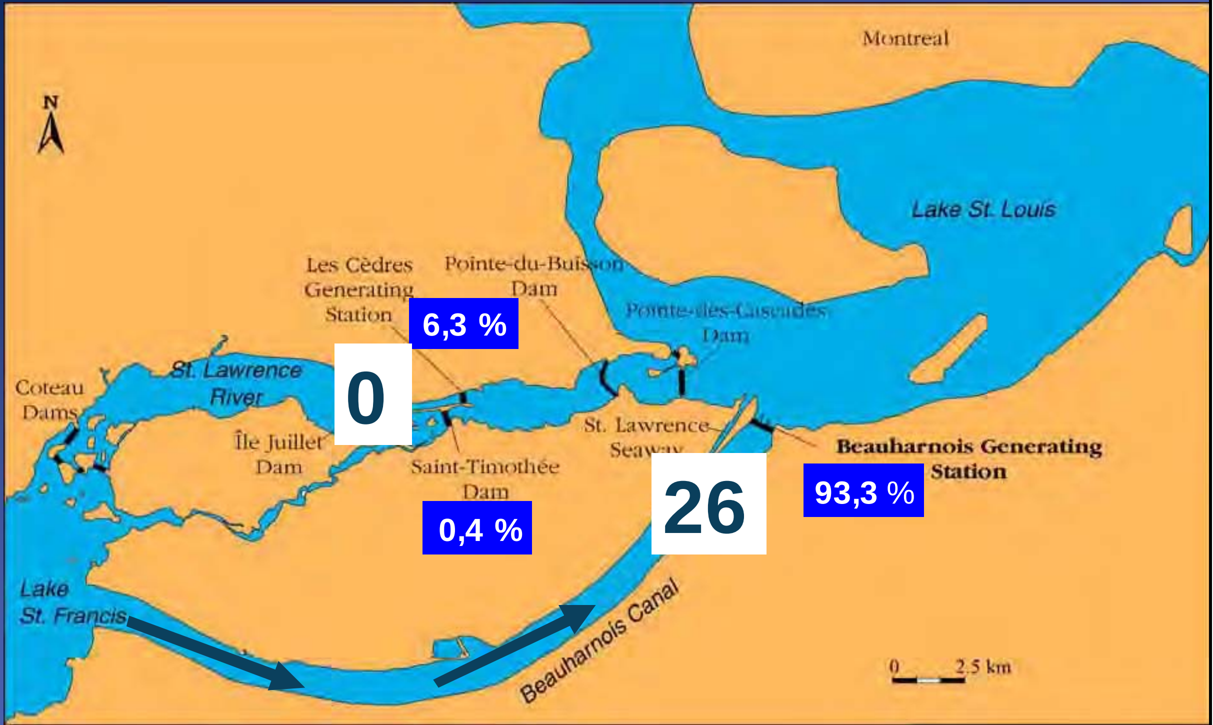
Methodology

- Eels (n = 167) were internally tagged with acoustic tags by New York Power Auhtority and released in Lake St. Lawrence 20 km upstream of Moses-Saunders Power Dam
- Eels were monitored using acoustic receivers mounted on the face of dams in the Beauharnois region
- Number and location of receivers to cover the full span of the river

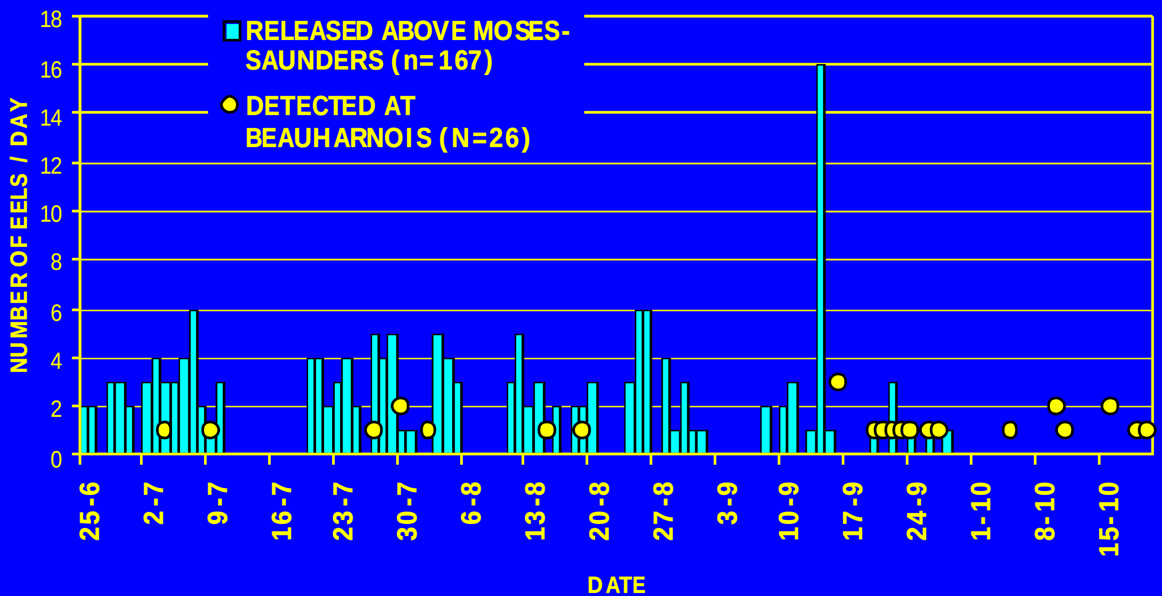

2
2
Île Savoyse
Île Villemomble
Barrage d'Beauharnois / Power (Aband)
29
24
18
13
6
Generating Station
Dam
Pointe-des-Cascades Dam
St. Lawrence River
Coteau Dams
Île Juillet Dam
Saint-Timothée Dam
St. Lawrence Seaway
Beauharnois Generating Station
Lake St. Francis
Beauharnois Canal
0
2.5 km


Receivers were monted on the dam face
Montréal
Moses-Saunders Power Dam
Lake St. Francis
St. Louis
Cornwall
Massena
Beauharnois Power Dam
Lake Champlain
167 tagged eels
18 mm
75 mm
73 detected
26 detected
Vemco VR25 200 kHz

Detected eels
Beauharnois region



NUMBER OF EELS RELEASED ABOVE MOSES-SAUNDERS AND DETECTED AT BEAUHARNOIS



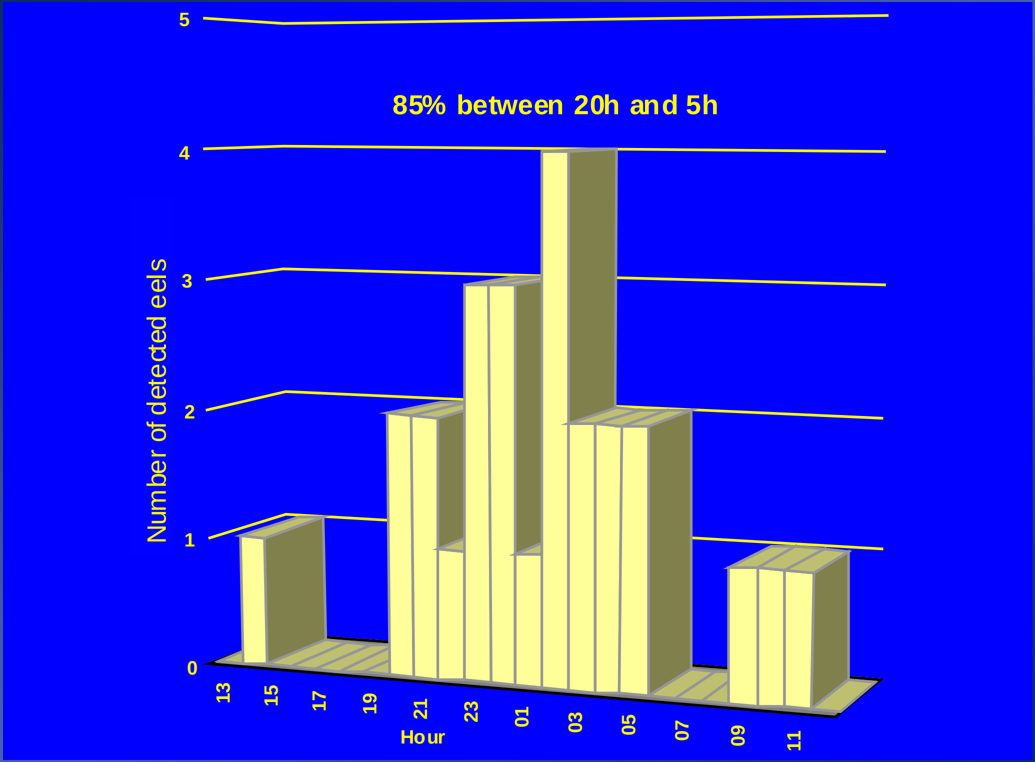
DETECTION OF TAGGED EELS AT BEAUHARNOIS IN RELATION TO PERIOD OF RELEASE

	RELEASED ABOVE MOSES-SAUNDERS	DETECTED AT BEAUHARNOIS	
RELEASED BEFORE SEPT. 1	135	12	8.9 %
RELEASED AFTER AUGUST 31	32	14	43.8 %
TOTAL	167	26	15.6 %

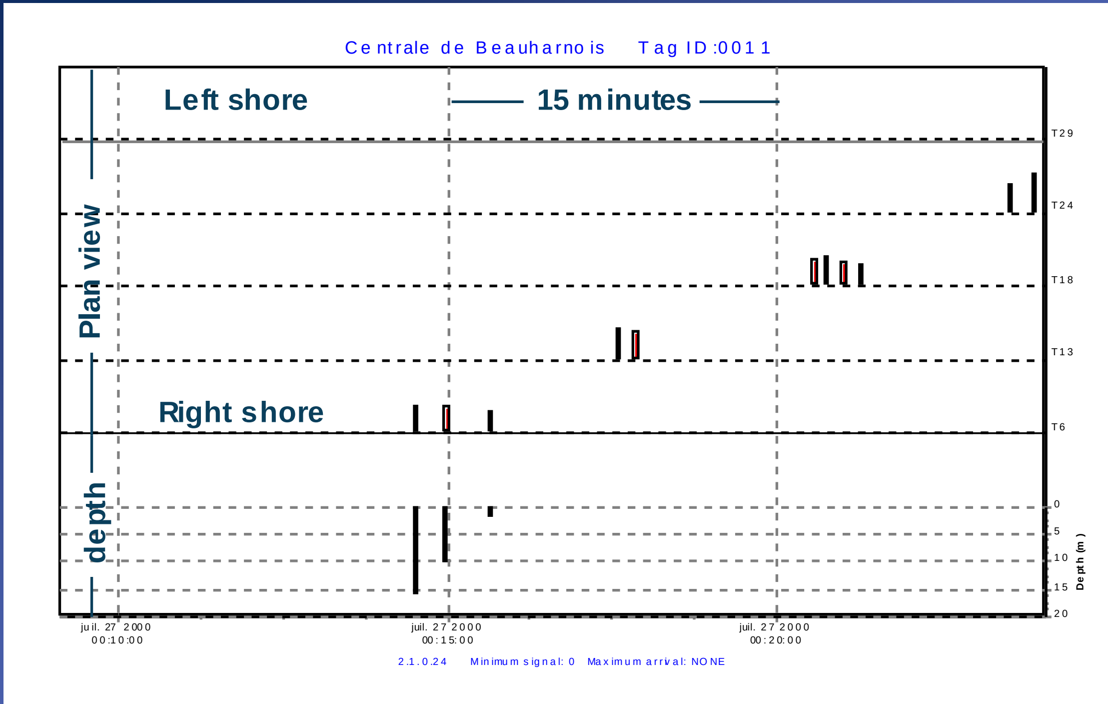
Migration time and speed of detected eels at Beauharnois GS (N = 26)

	Lake St.Lawr. -> Beauharn.		M-S -> Beauharnois	
	Distance = 105 km		Distance = 85 km	
	Days	Km/h	Days	Km/h
Average	**18,3**	**0,24**	**8,2**	**0,43**
s.d.	9,1	0,48	8,1	0,44
Min	2,8	1,54	0,9	4,08
Max	**34,9**	0,13	31,0	0,11

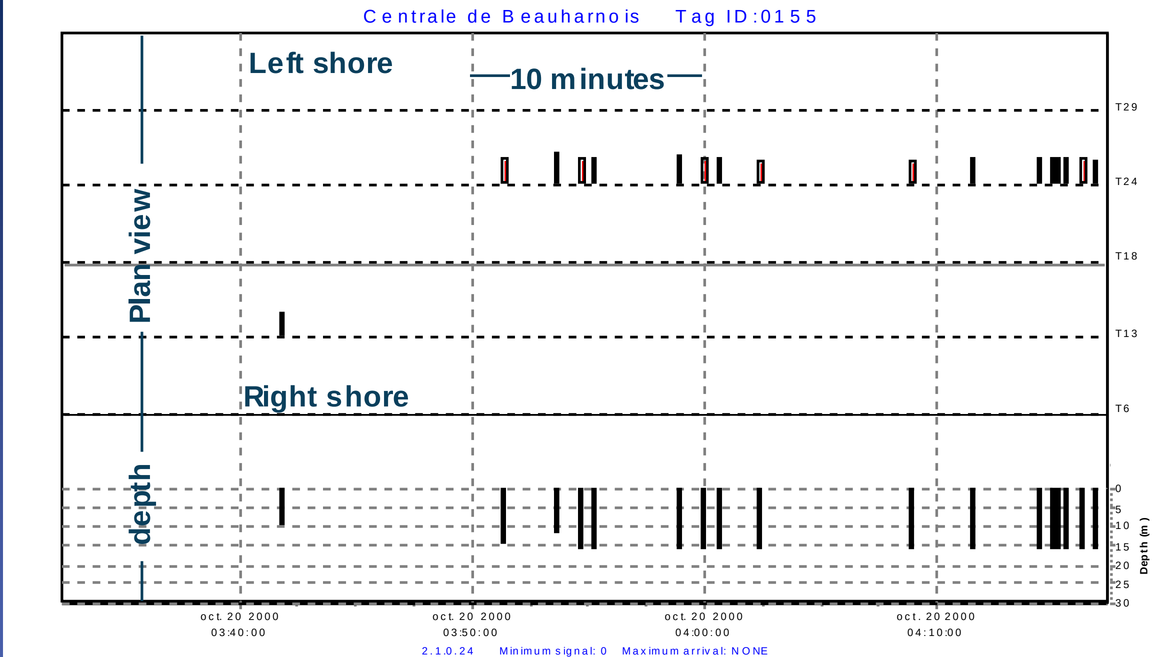
Time of arrival in the Beauharnois GS forebay



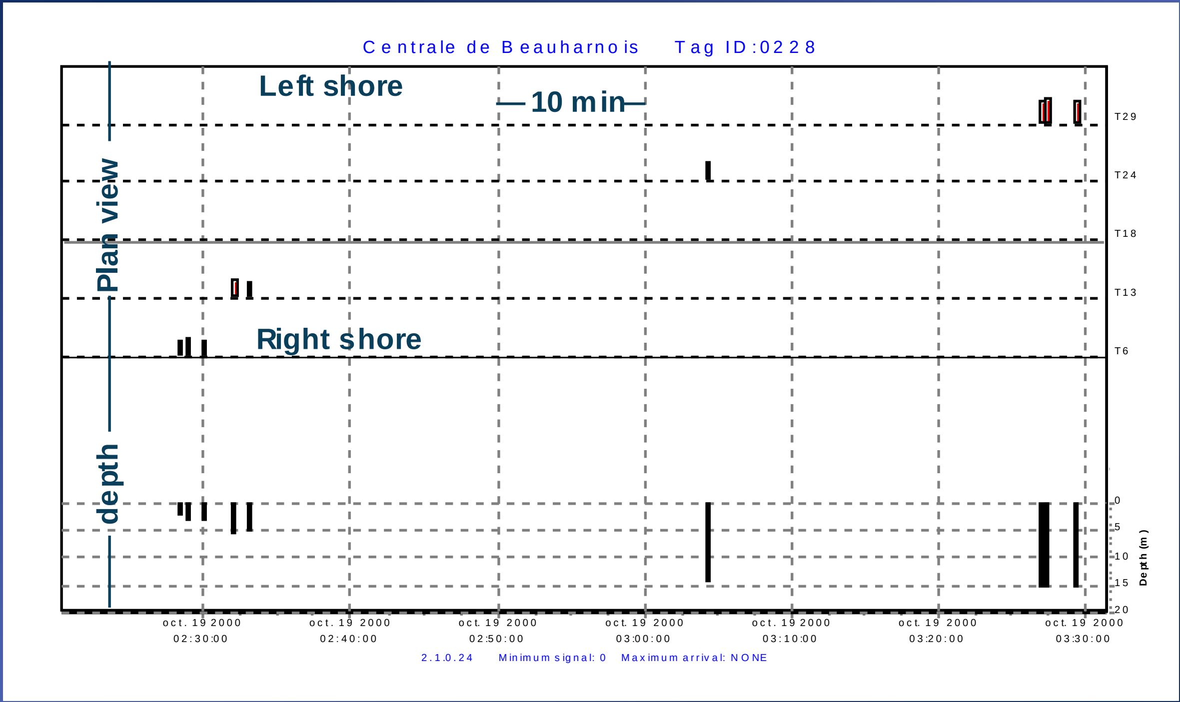
Example 1: Movement from right to left and from bottom to surface



Example 2: Movement towards unit 24 ~ Constant depth



Example 3: Movement from right to left and from surface to bottom



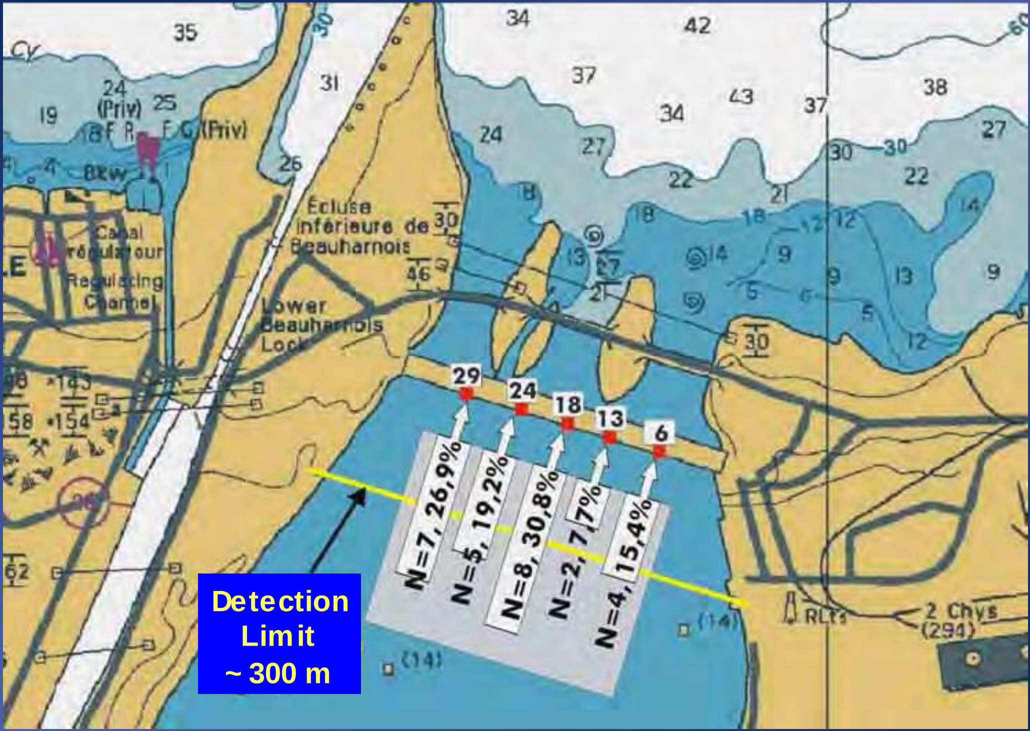
Approaching the Station

- Average depth of signals: 10.5 m ,

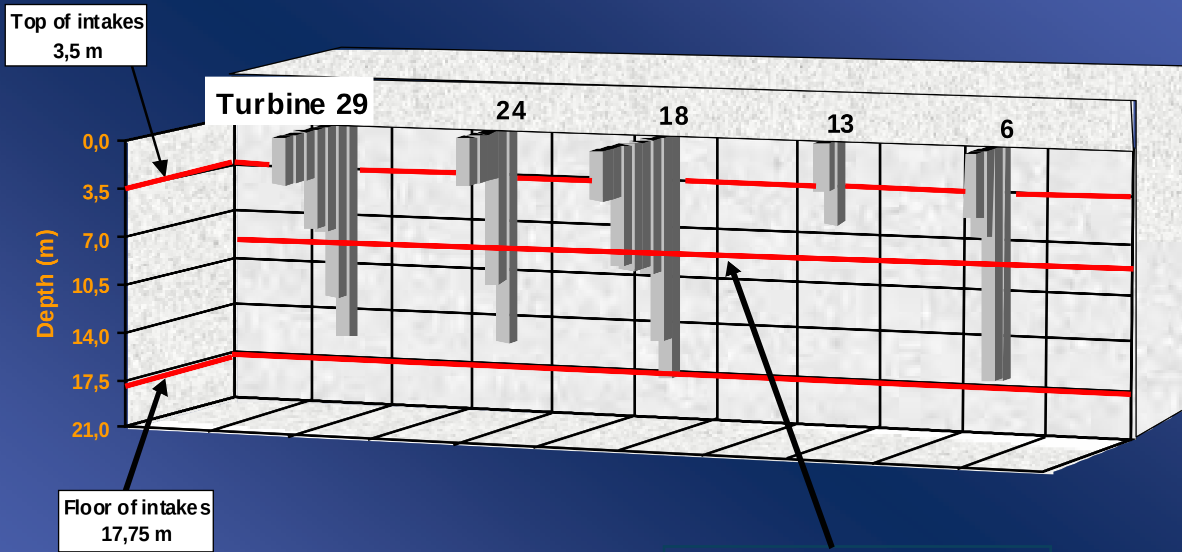
  range : 0 to 17.6 m
- Little exploratory behavior: 54% of eels were detected by only one or two receivers
- No distinct pattern: movements occur in all directions and all depth
- Movement is rapid: average presence time is 31 min. (range 1.5 min – 2.25 hre)

Last signal

Beauharnois Generating Station



Depth of last signal
Beauharnois Generating Station



CONCLUSIONS

- **Preferential migration route is the Beauharnois Canal**
- **Average migration time between Moses-Saunders and Beauharnois for detected eels is 8.2 days, average speed: 0.43 km/hr**
- **Most of migrants (85%) detected at night**
- **Approaching the Station:**
  - Movement is rapid
  - No distinct movement pattern
  - Little exploratory behaviour

CONCLUSIONS (cont'd)

- **Turbine passage:**
  - Passage occurs at all depth
  - Detection of last signal is more frequent at power house no 2, but conform to random entrainment among the three power houses ($p>0,05$)
  - With the hypothesis of random entrainment, 48 hr survival rate for Beauharnois GS is 82.0 %

Many thanks to:

- **K. McGrath, from NYPA, for providing all information on tagged eels released upstream of Moses-Saunders Power Dam**
- **Staff from Milieu, Les Cèdres GS and Beauharnois GS**

Three-dimensional behavior of migrant silver-phase American eels encountering and passing downstream of a small hydroelectric facility

Leah Brown,* Alex Haro, & Theodore Castro-Santos

S. O. Conte Anadromous Fish Research Center, U. S. Geological Survey

One Migratory Way, Turners Falls, MA 01376 USA

Safer Downstream Eel Passage

- Hydroelectric facilities impact downstream migrants
  - Downstream migration delays
  - Impingement & suffocation
  - Turbine induced mortality

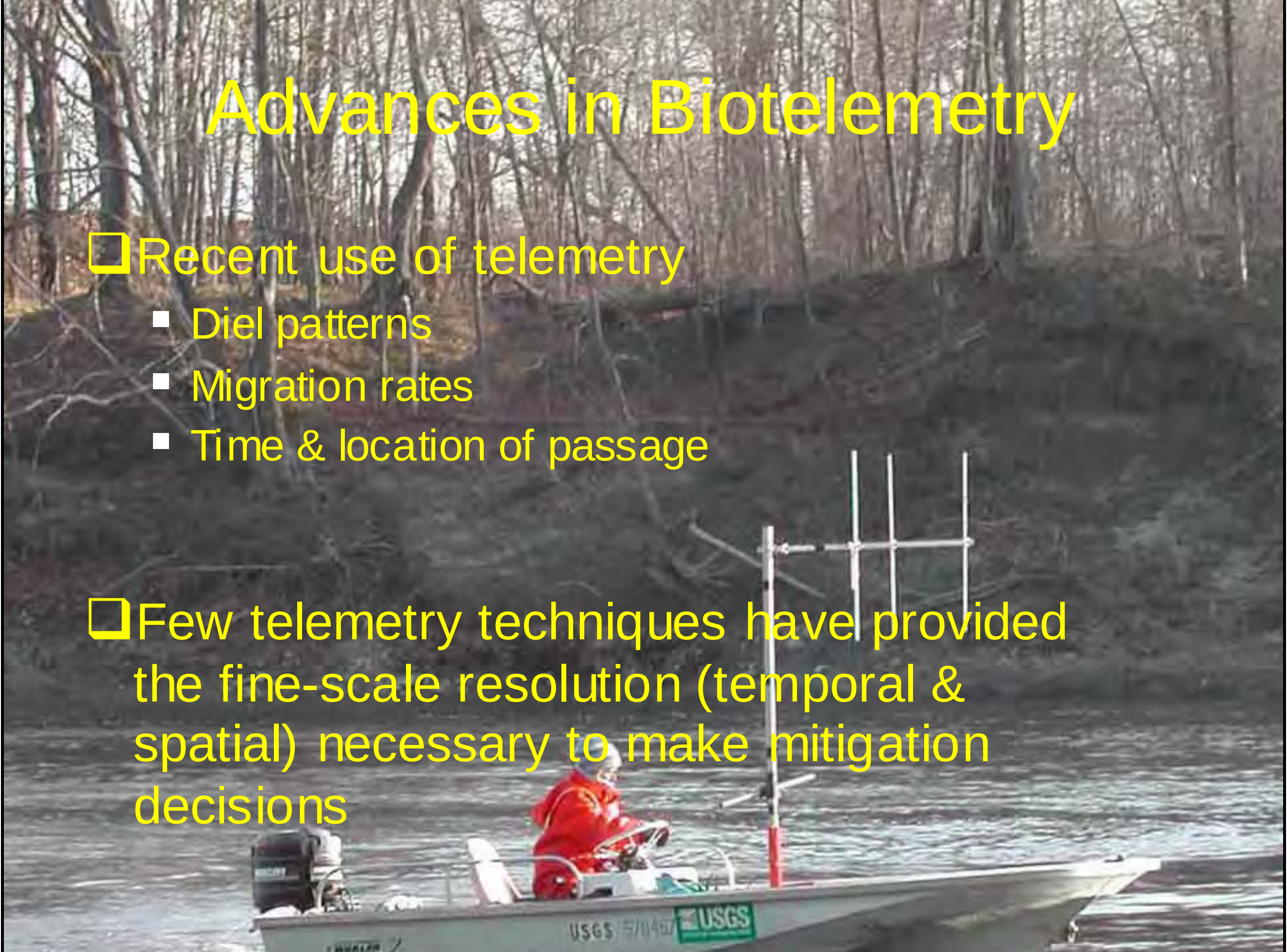
- Turbine mortality estimates have ranged from 6 to 37% and higher (EPRI 2001)
  - Eel size
  - Turbine type & specifications

USGS

Advances in Biotelemetry

- Recent use of telemetry
  - Diel patterns
  - Migration rates
  - Time & location of passage

- Few telemetry techniques have provided the fine-scale resolution (temporal & spatial) necessary to make mitigation decisions



Few studies have attempted to characterize and quantify the downstream behavior of eels at dams…

- How do eels react to obstructions?
- How does their behavior change when they encounter a hydroelectric facility?
- Can we manipulate their behavior to attract to safer passage routes …*like other downstream migrant fishes?*

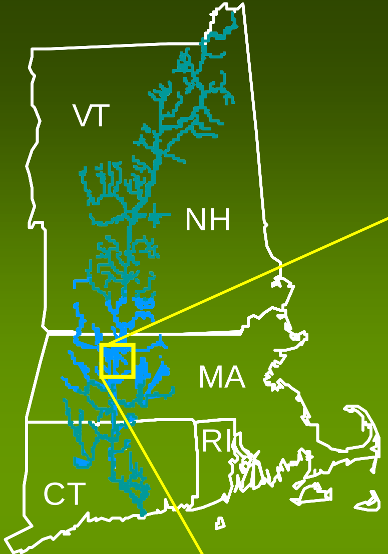
Research Objectives

Using 3D telemetry,

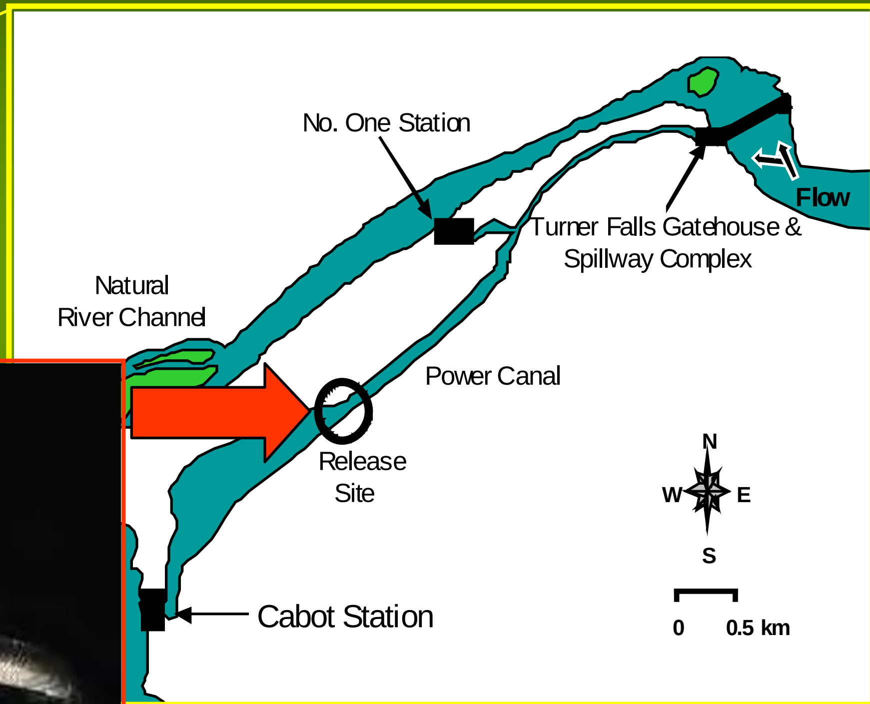
- Increase the resolution of information collected at Cabot Station (Haro et al. 2000)
  - Forebay residence times
  - Number of passage attempts
  - Time & location of passage
- Characterize the fine-scale movement of migrants as they encounter & pass at a hydroelectric facility
- Examine the environmental & operating conditions during passage

USGS

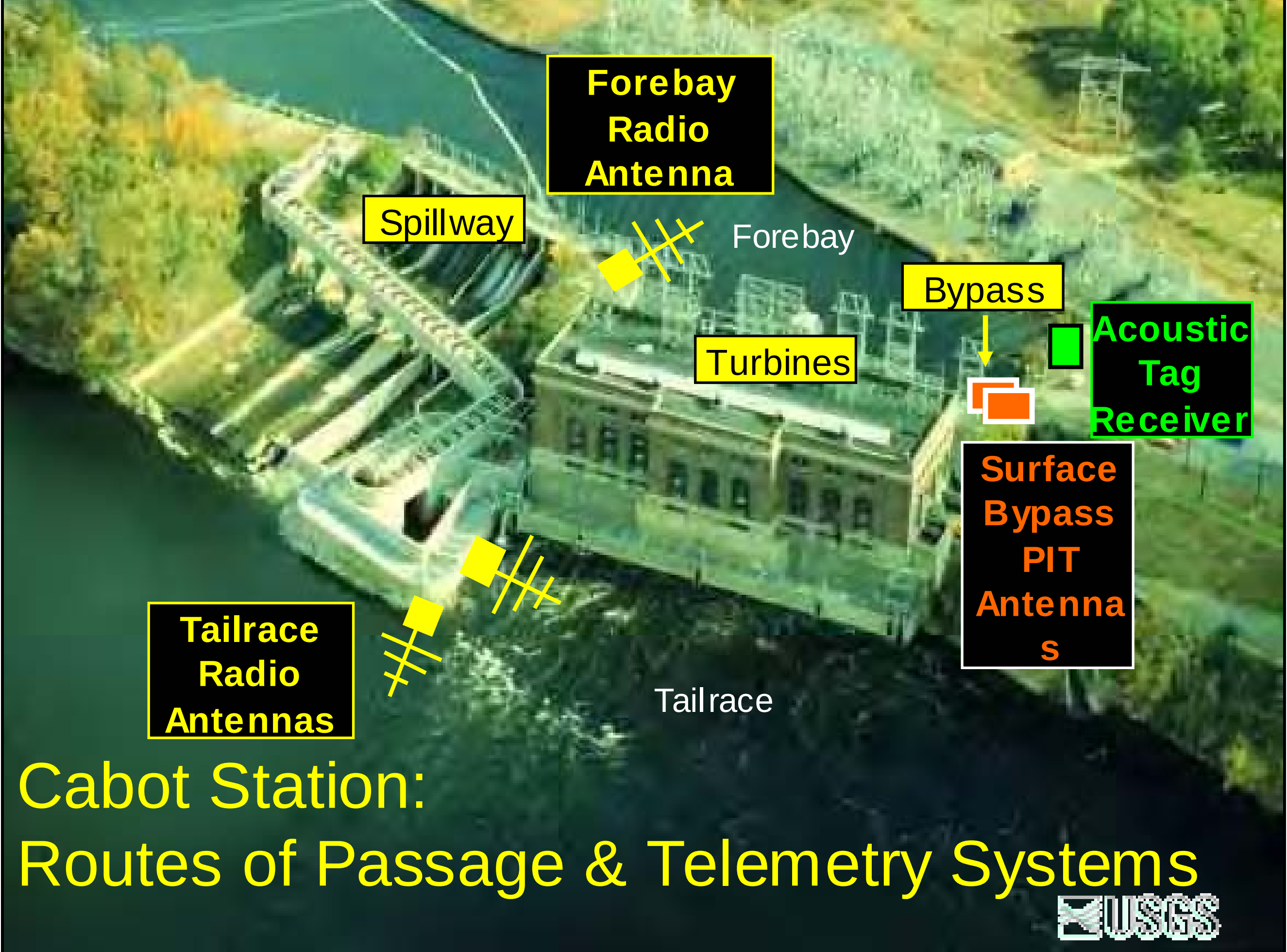
Study Site



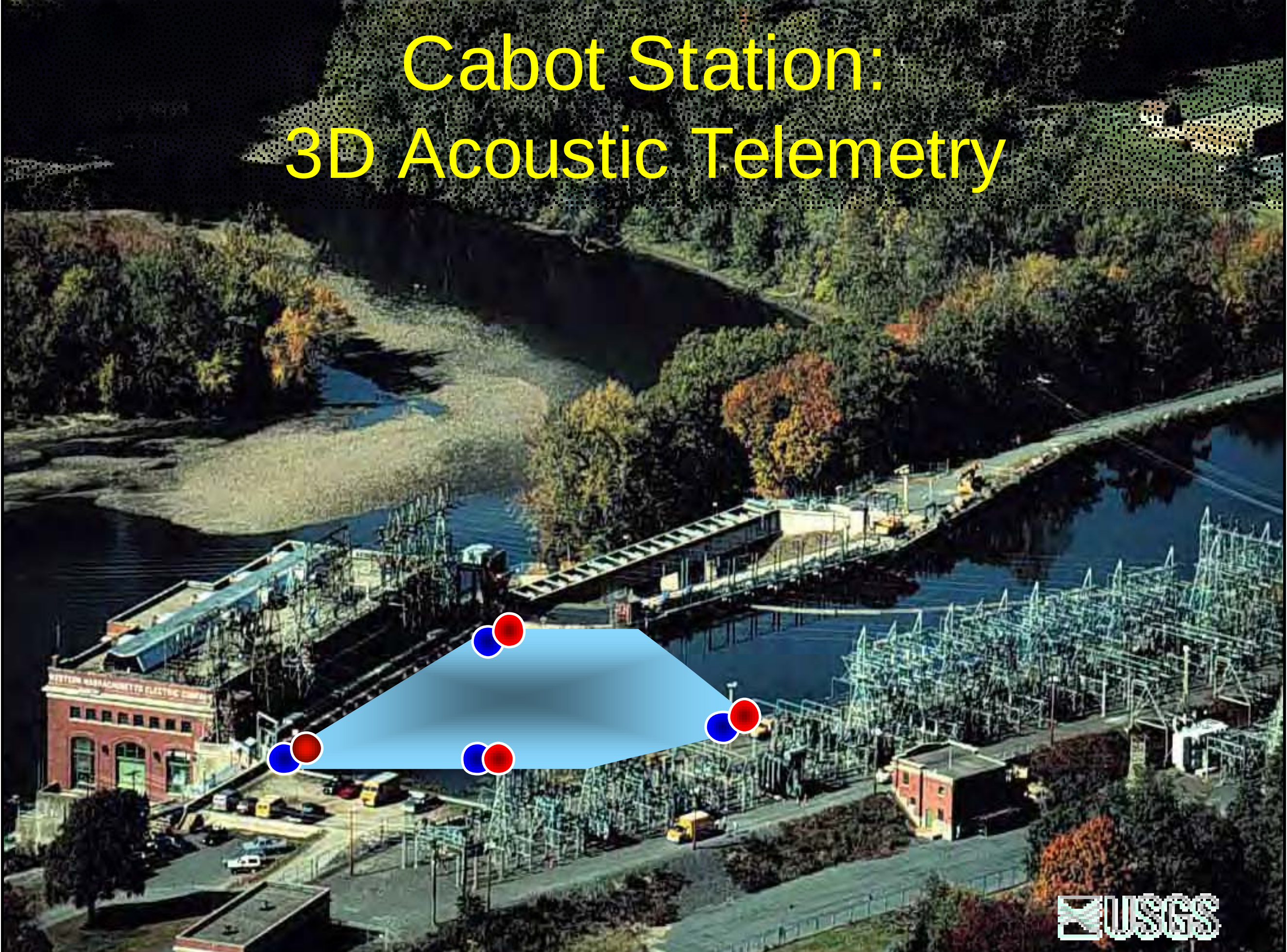
VT
NH
MA
RI
CT



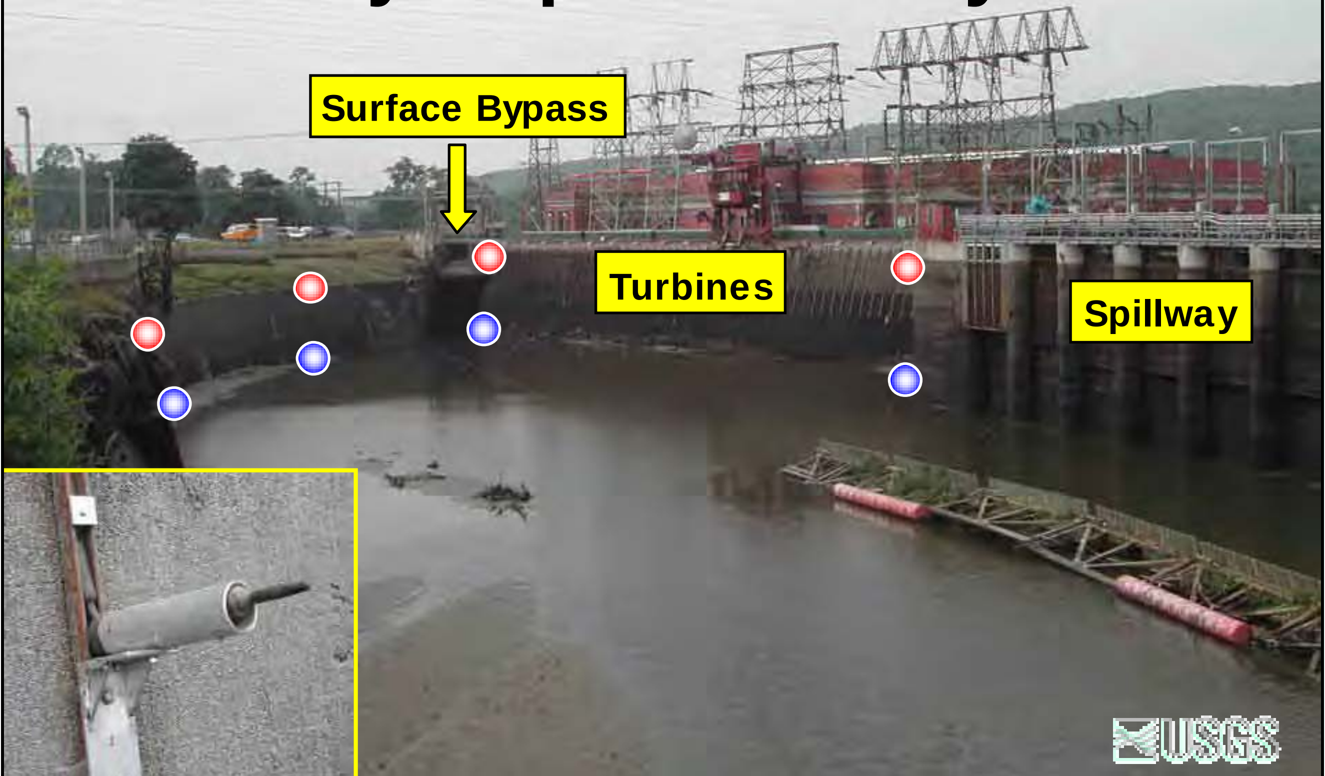
No. One Station
Turner Falls Gatehouse &
Spillway Complex
Flow
Natural
River Channel
Power Canal
Release
Site
Cabot Station
N
W
E
S
0
0.5 km


Forebay Radio Antenna
Spillway
Forebay
Bypass
Turbines
Acoustic Tag Receiver
Surface Bypass PIT Antenna
s
Tailrace Radio Antennas
Tailrace
Cabot Station:
Routes of Passage & Telemetry Systems
USGS

Cabot Station:
3D Acoustic Telemetry



Cabot Station Forebay & Hydrophone Array



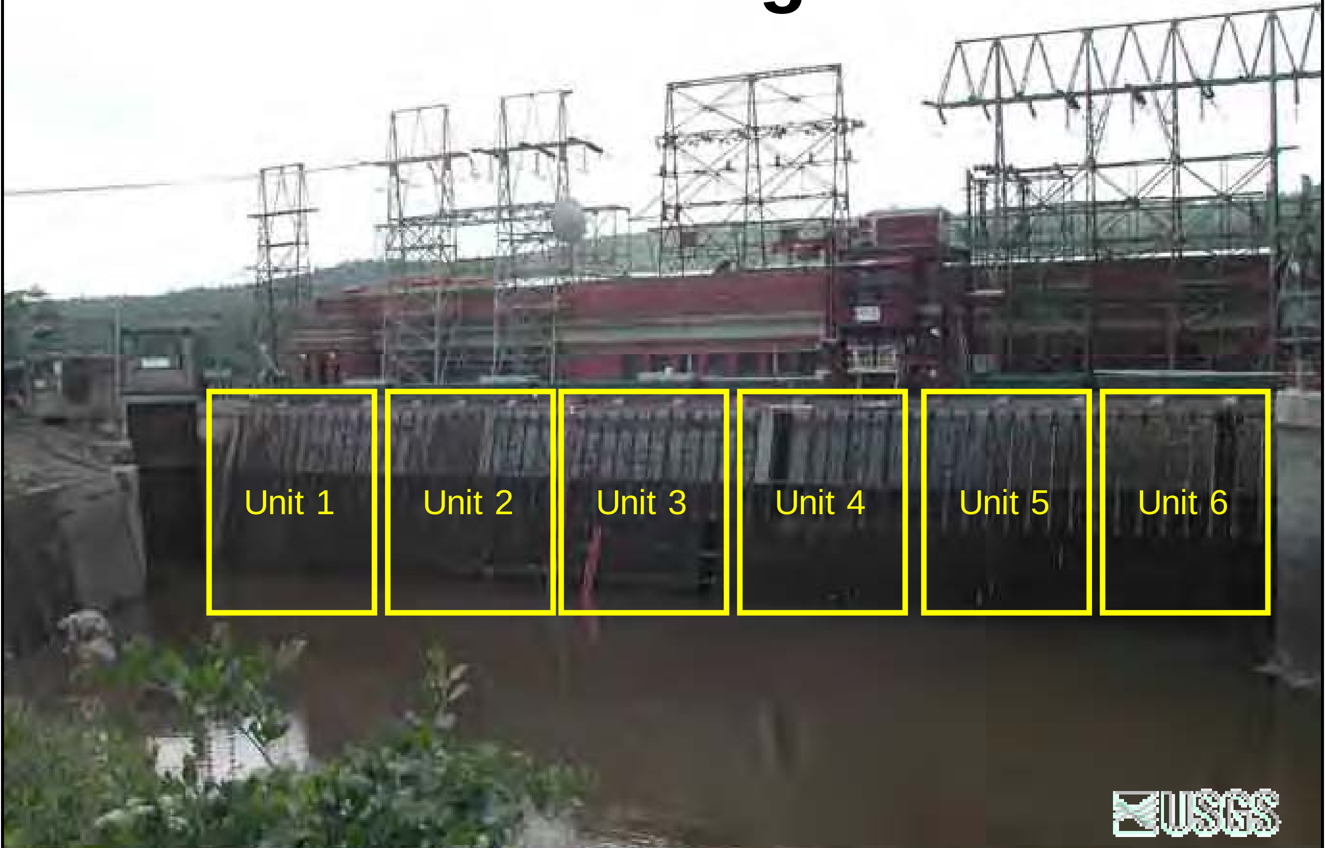
Fish Collection, Tagging, & Release

- Collection site:
  - Hadley Station (Holyoke, MA) surface bypass (2002 & 2003)
  - Sebasticook River, ME (2003)

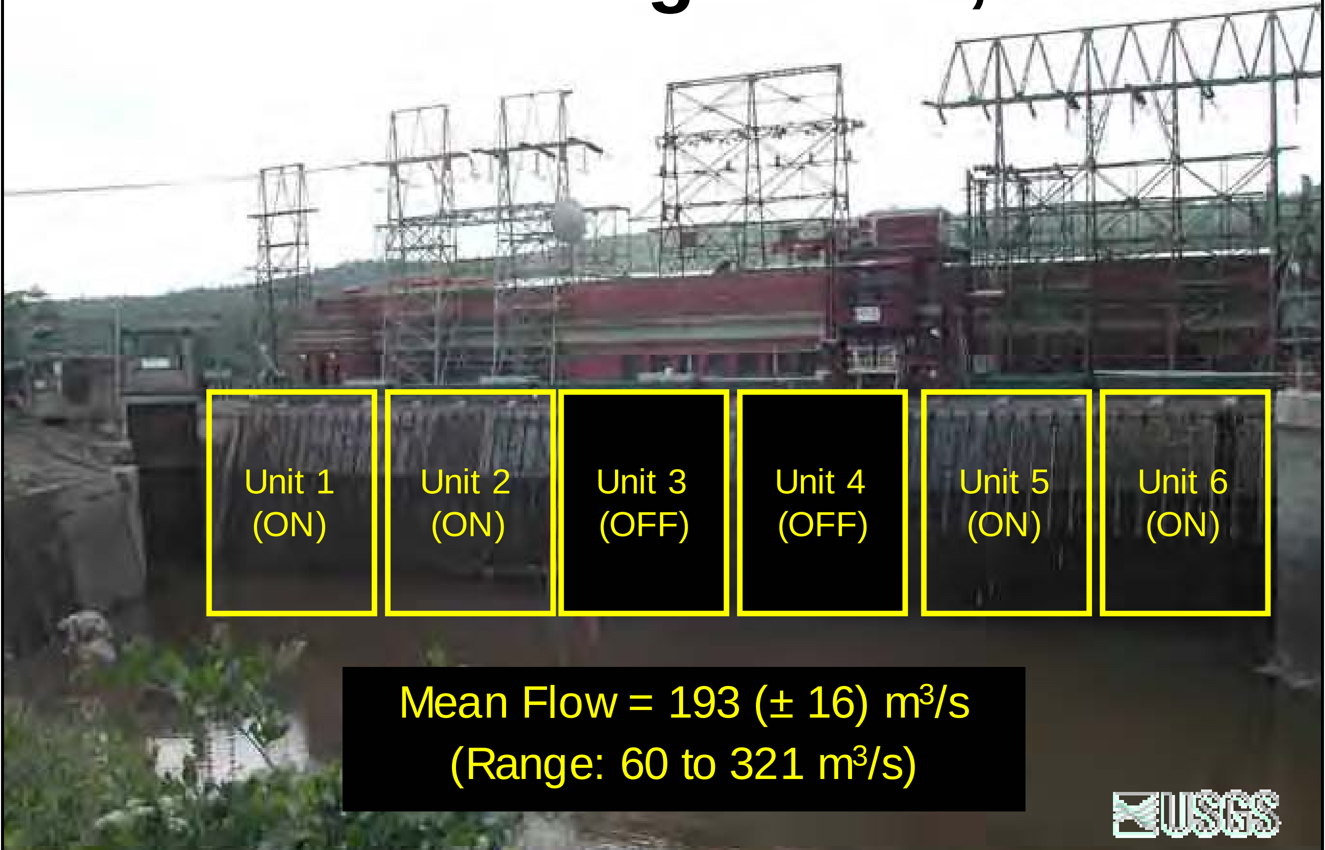
- Tagging:
  - Anesthetized & transmitters surgically implanted
  - Recovery period (48 h)

- Released 1.5 km upstream of Cabot Station
  - 2002: 4 Oct – 1 Nov (n = 20)
  - 2003: 11 Oct – 26 Oct (n = 30)

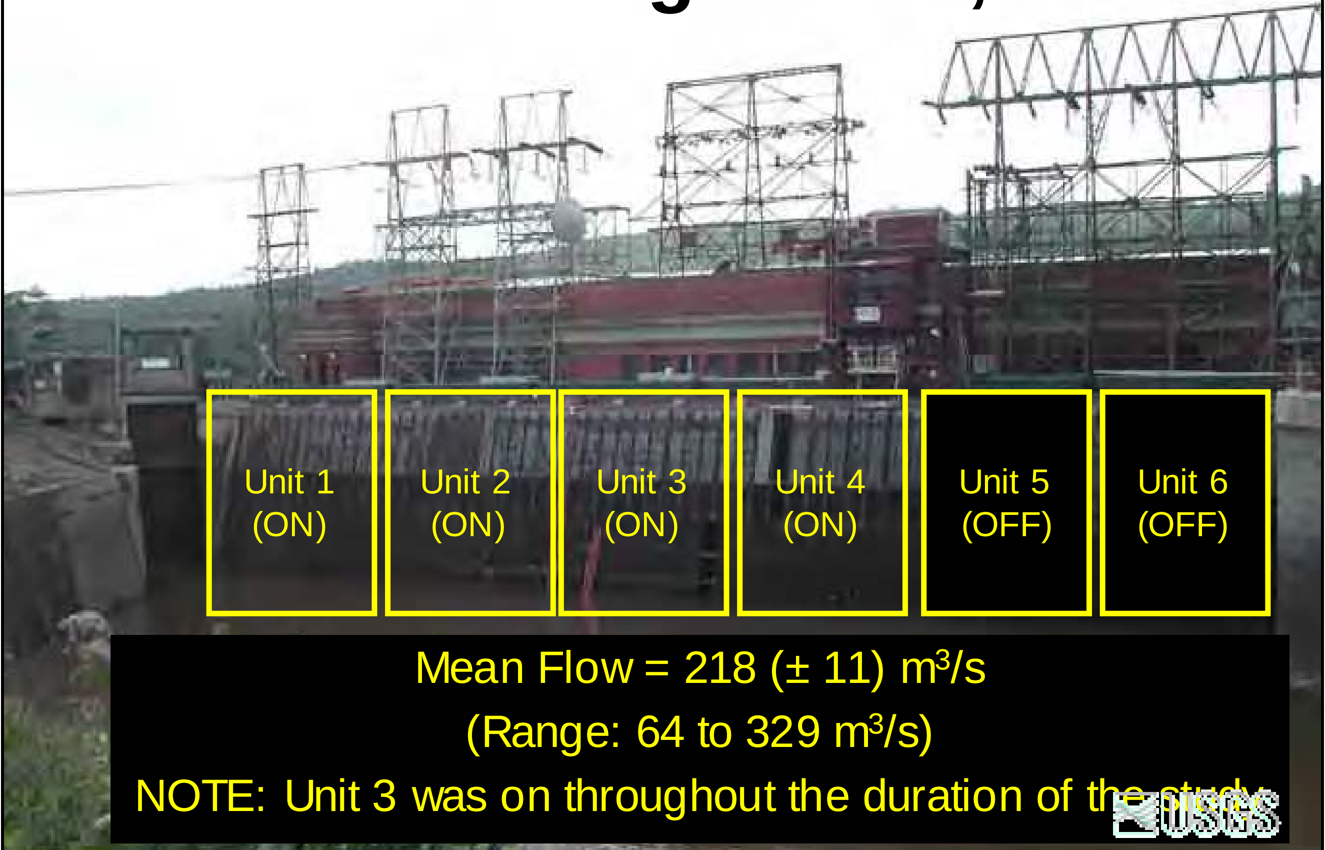
Turbine Configuration



Turbine Configuration, 2002



Turbine Configuration, 2003



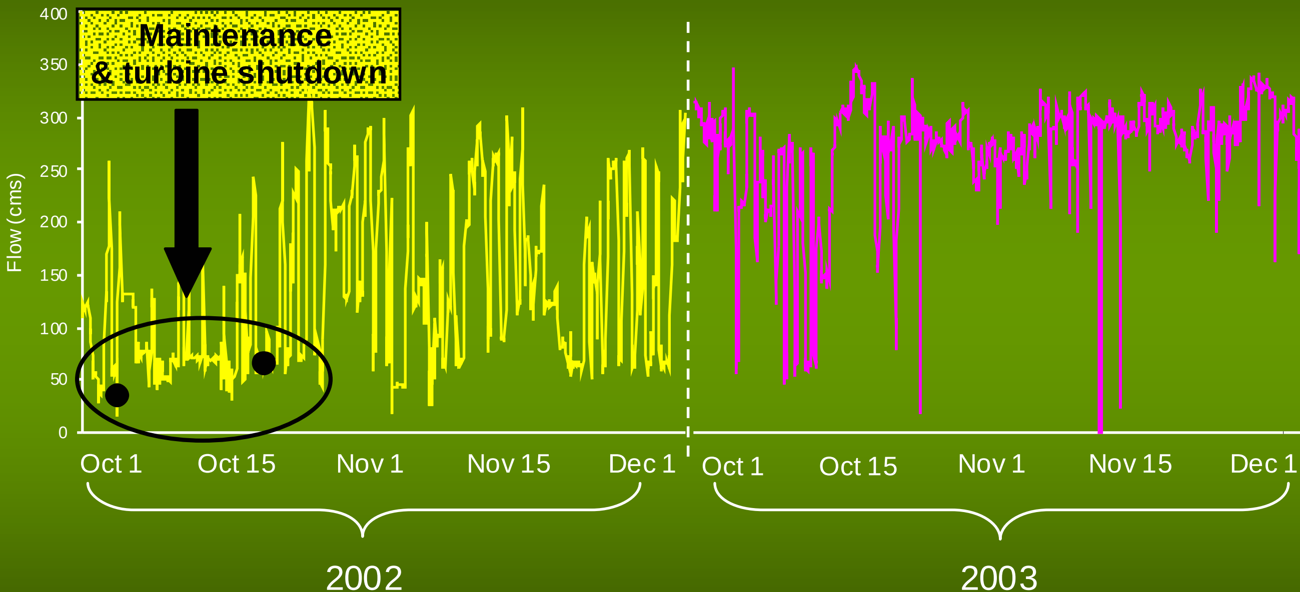
Results

- 46 out of 50 eels were detected (at least once, in the forebay)
  - Majority of detections were at dusk and before midnight
- Over ½ of the eels (52%) made multiple attempts to pass (range of attempts: 1 to 11)
- Forebay residence times were variable
  - 2002: median = 9.6 min (range: 1.4 to 2 h)
  - 2003: median = 22.9 min (range: 1 min to 19 h)

    **Significant differences between years (Kruskal-Wallis, p = 0.025)*
- Majority of eels exit at the turbines

Forebay Exit Locations

Hourly Canal Flow



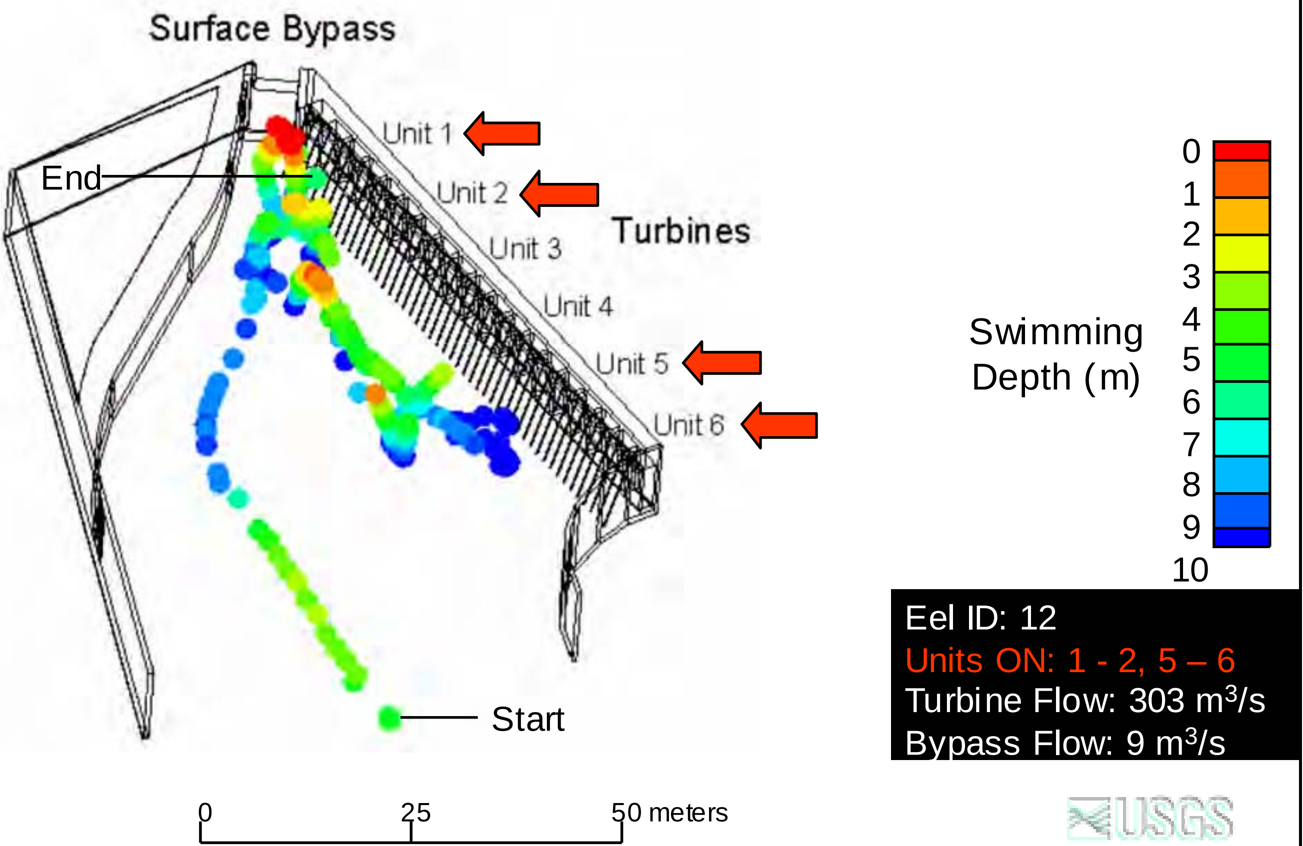
There were no significant differences in flow conditions experienced by eels, within residence times between years, but in 2002 there were periods of turbine shutdown.

Trends in Movement

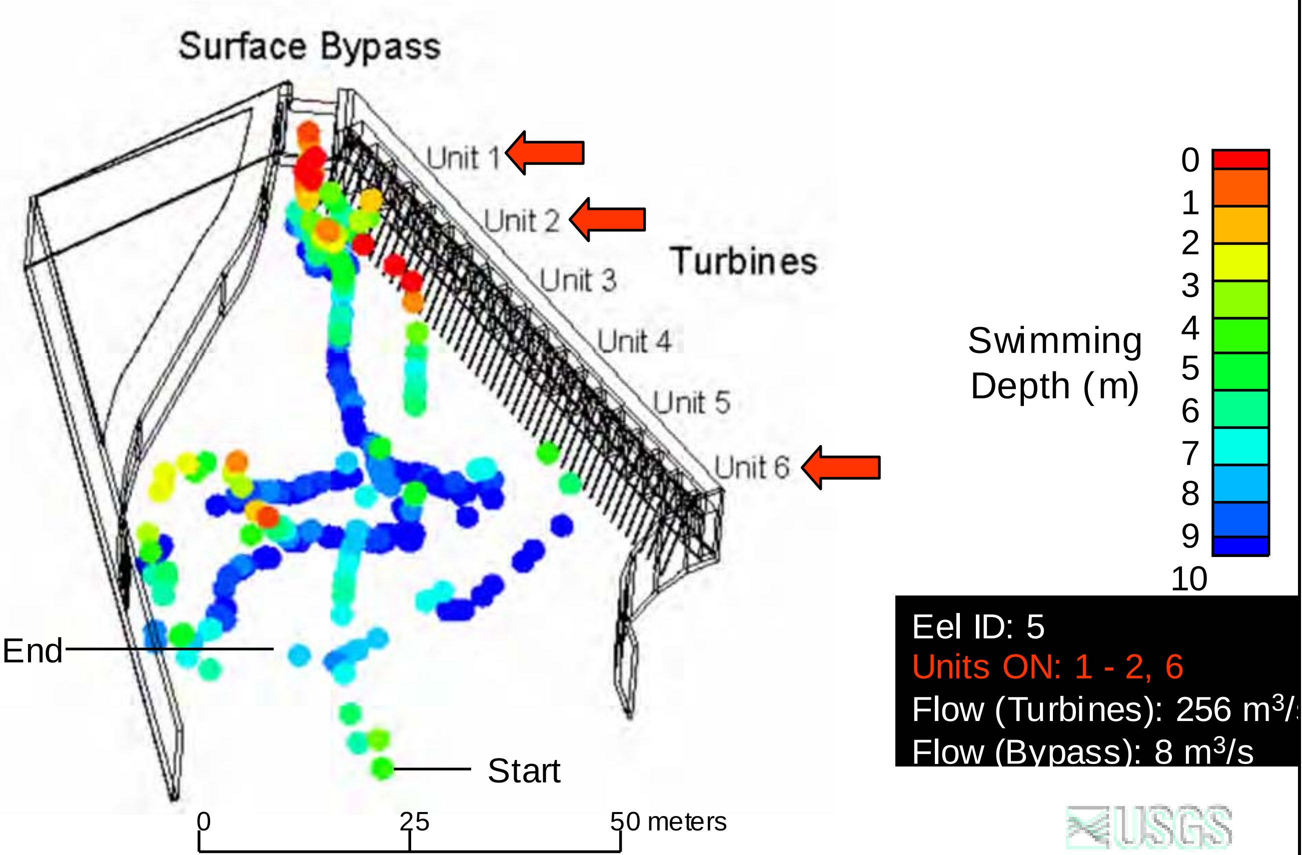
Trends in behavioral movements of eels included:

- Passage directly through the trash racks when first encountered
- Encountered the trash racks, turned, and swam back upstream
- Encountered the trash racks & began moving vertically and/or horizontally just upstream of the trash racks
- Swimming through the trash racks, upstream & downstream during low flow conditions
- Looping in front of the trash racks or throughout the forebay
- Upstream movement (returning at a later time and/or date to either pass or continue searching)

Horizontal & Vertical Excursions & Looping



… Multiple Attempts to Pass

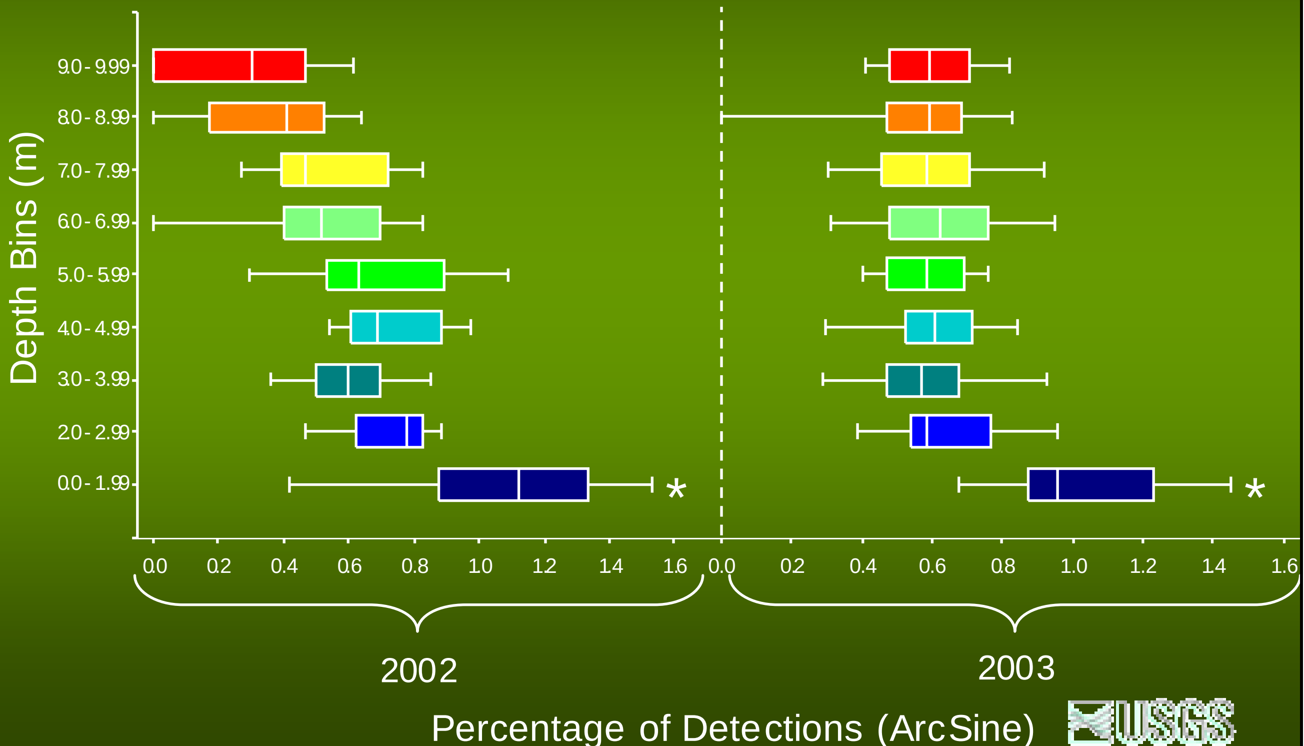


Pre-Passage Behavior

How do you quantify behavior?

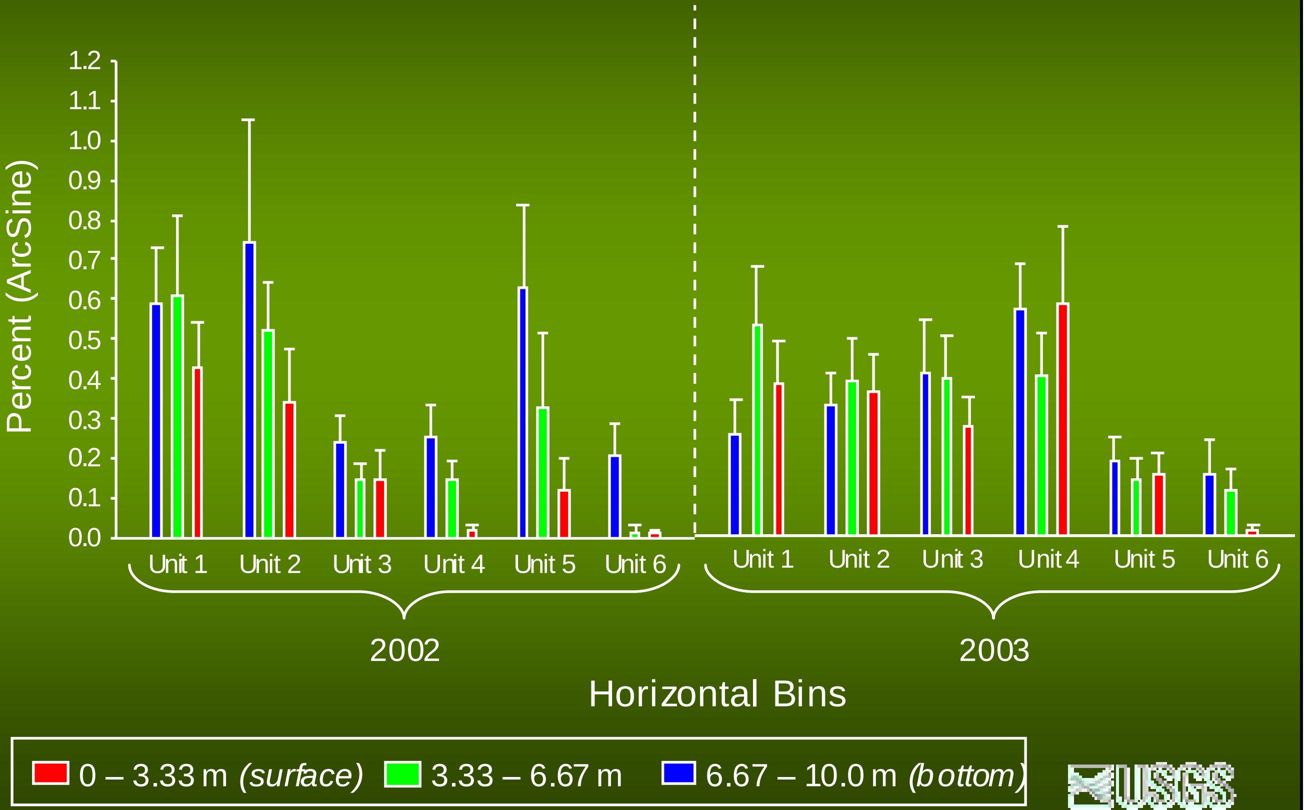
- What is the depth distribution of eels within the forebay and at the trash racks?
- How long do fish spend in the forebay before they pass or give up and swim back upstream?
- Where/how much are they searching?
- Are environmental and operational conditions influencing passage?

Forebay Depth Distribution

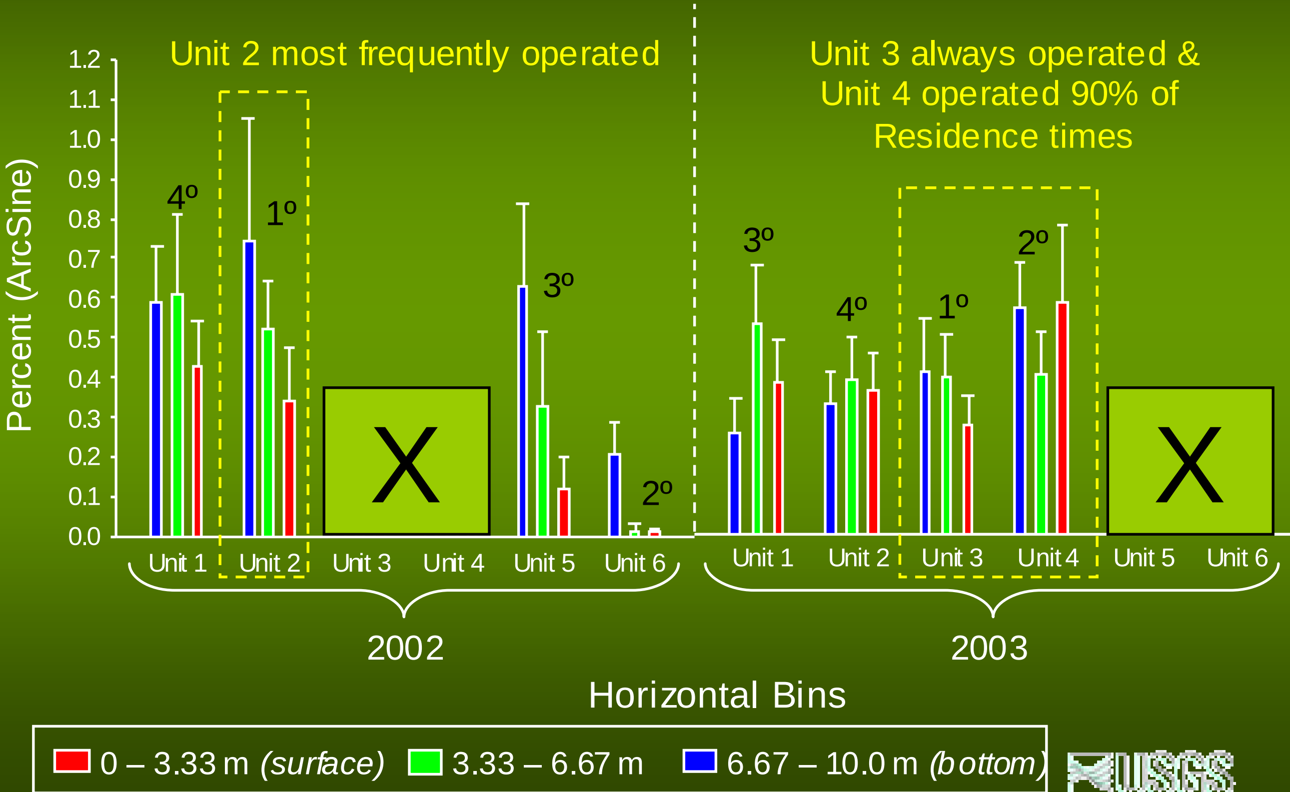


USGS

Trash Rack Depth Distribution



Trash Rack Depth Distribution



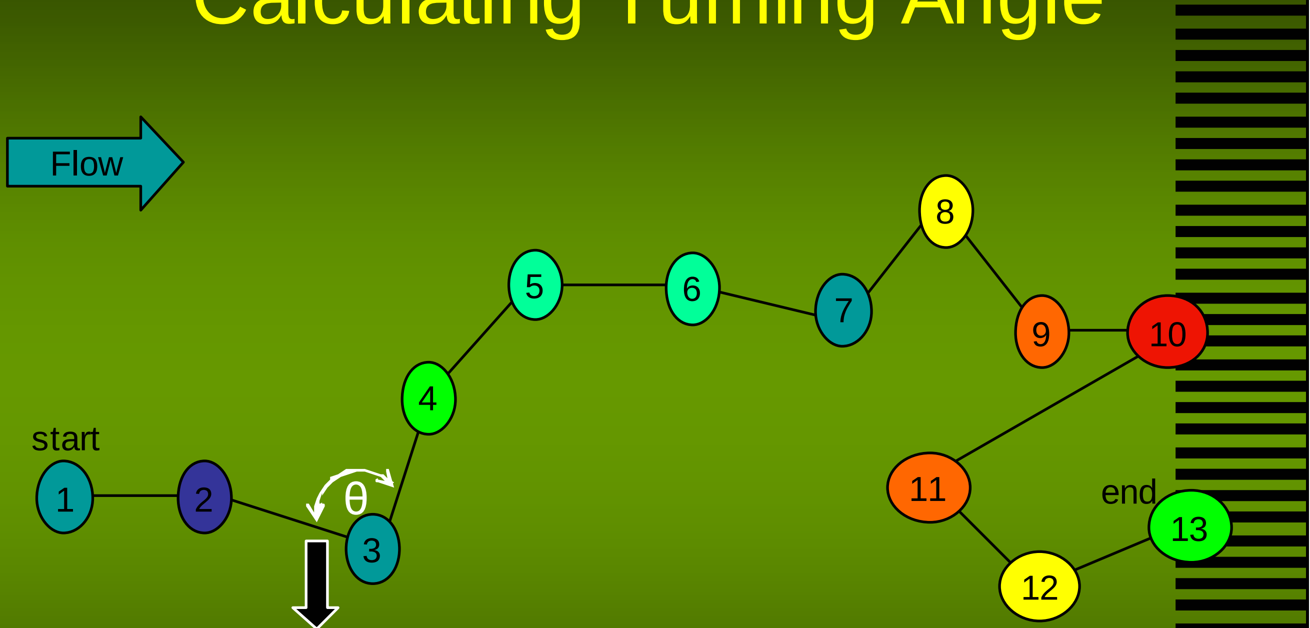
Residence Times: Time to Pass vs. Time to Quit

- Time to Pass: No effect of environmental or operational conditions

- Time to Quit: Significant effect of operational conditions
  - In 2002, when unit 5 was on, rate of quitting increased & the residence times increased by 20X
  - In 2003, when unit 1 was on, they quit 12X faster than when it was off (decreasing residence times)

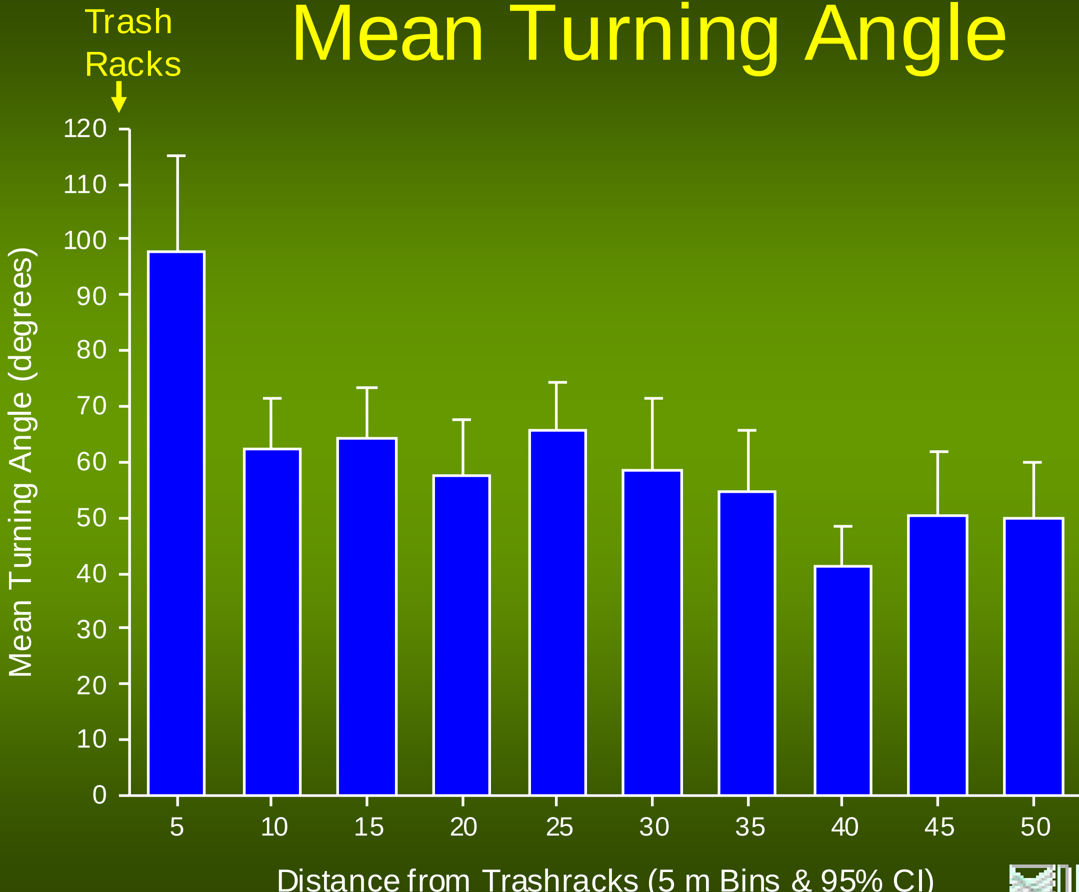
USGS

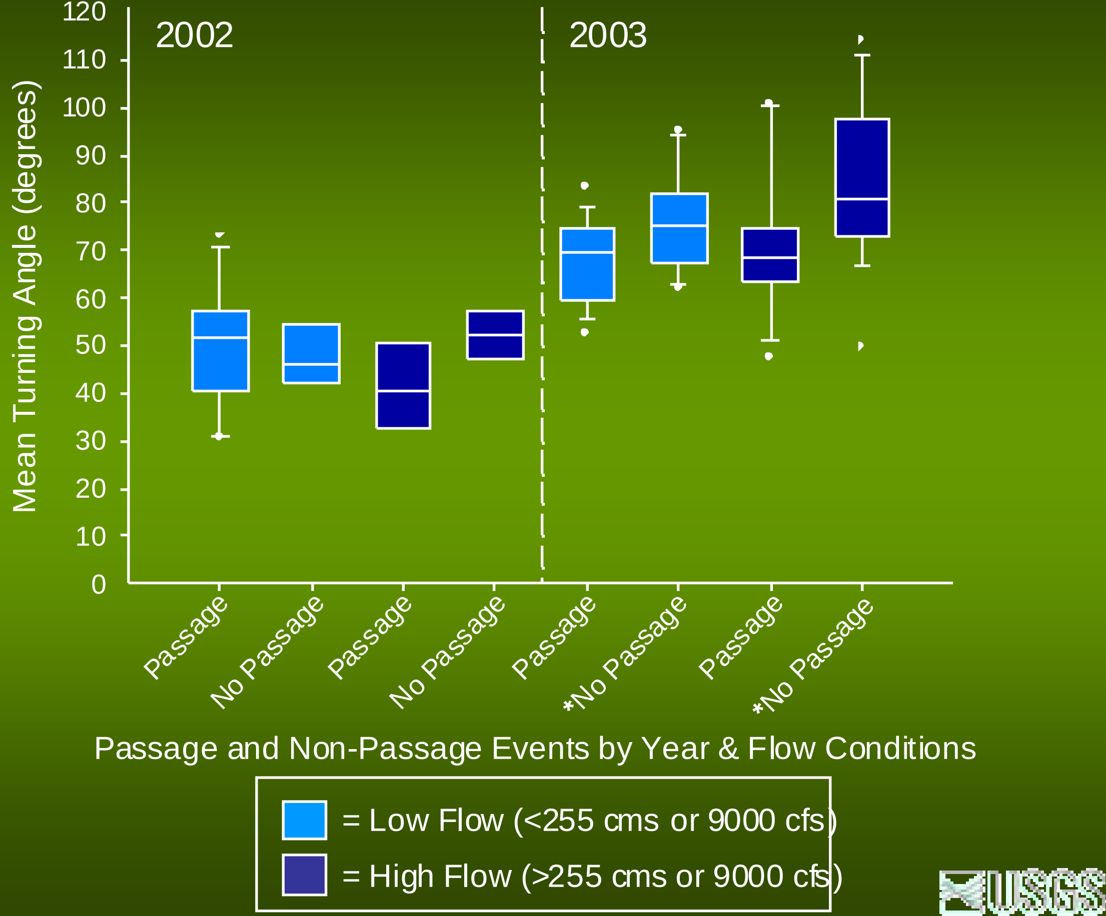
Calculating Turning Angle



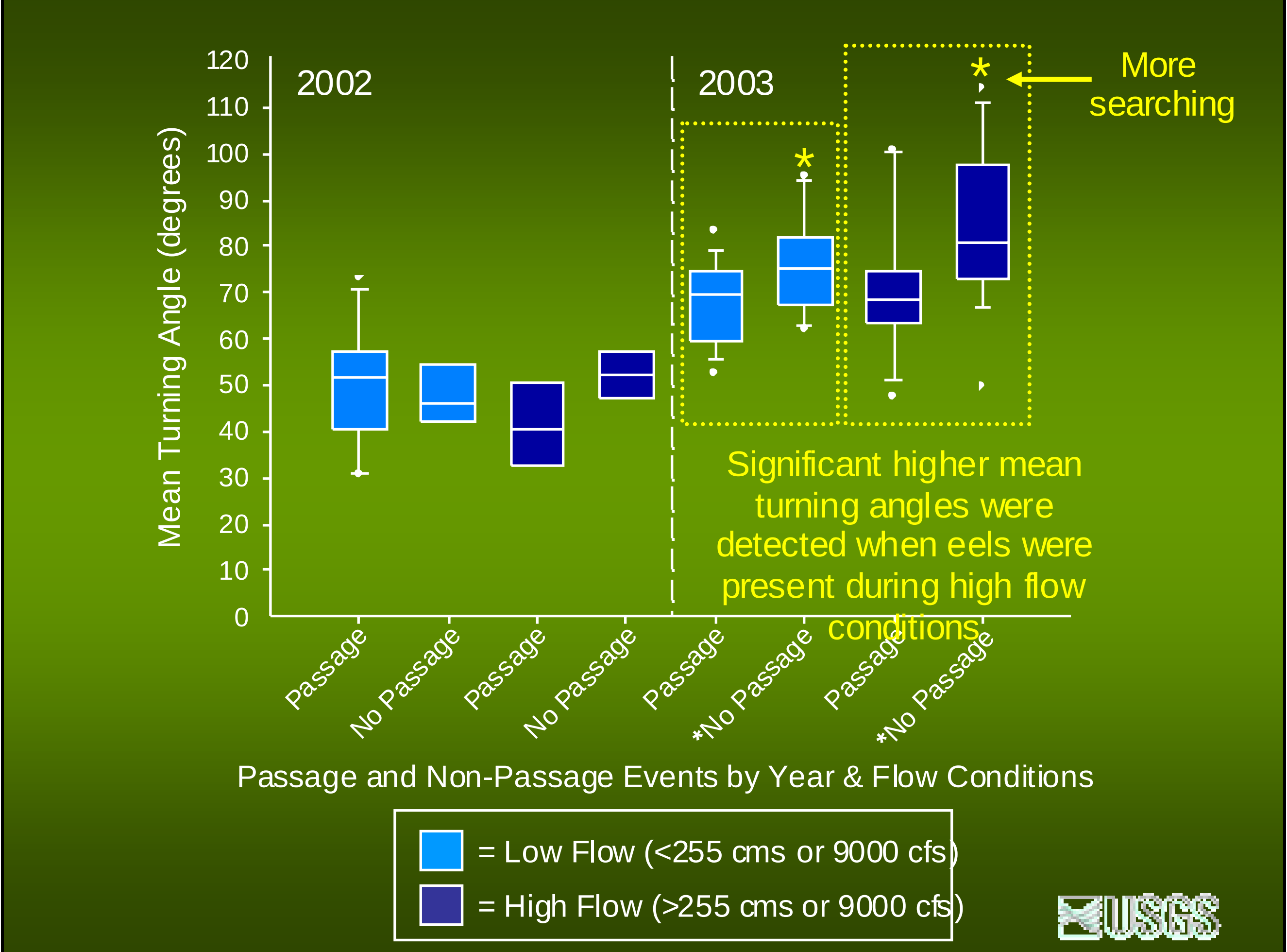
$$\theta = \arccos\left(\frac{((\Delta Pos\ X)^2 - (\Delta Pos\ Y)^2 - (\Delta Pos\ Z)^2)}{-2\,((\Delta Pos\ X)*(\Delta Pos\ Y))} \right)$$

Mean Turning Angle





Mean Turning Angle (degrees)
0
10
20
30
40
50
60
70
80
90
100
110
120
2002
2003
Passage
No Passage
Passage
No Passage
Passage
*No Passage
Passage
*No Passage
Passage and Non-Passage Events by Year & Flow Conditions
= Low Flow (<255 cms or 9000 cfs)
= High Flow (>255 cms or 9000 cfs)
USGS



Mean Turning Angle (degrees)
120
110
100
90
80
70
60
50
40
30
20
10
0
2002
2003
*
*
More searching
Significant higher mean turning angles were detected when eels were present during high flow conditions
Passage
No Passage
Passage
No Passage
Passage
*No Passage
Passage
*No Passage
Passage and Non-Passage Events by Year & Flow Conditions
= Low Flow (<255 cms or 9000 cfs)
= High Flow (>255 cms or 9000 cfs)
USGS

Mean Turning Angle & Results of General Linear Models

- Environmental variables (flow, precipitation, temperature, & moon phase): No significant relationships

- Turbine configurations: Significant relationship
  - In 2002, when unit 2 was on, eels had a higher mean turning angle ($p = 0.0063$ & $R^2 = 0.36$)
  - In 2003, when unit 1 & 3 were on, eels had a higher mean turning angle ($p < .0001$ & $R^2 = 0.58$)

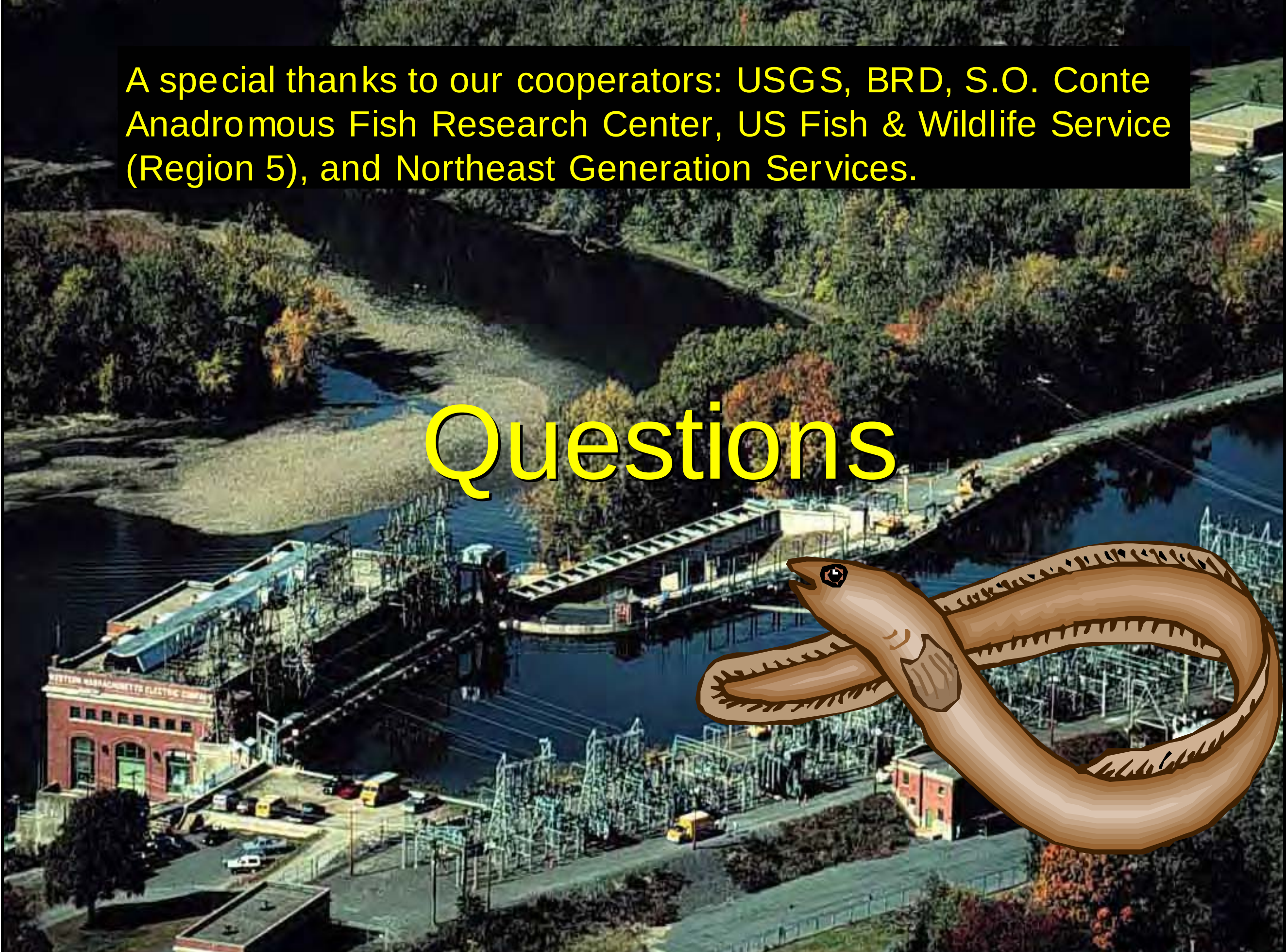
USGS

Conclusions

- Eels are using the turbines as their primary route of passage
- Eels are not being effectively guided to the surface bypass
- Eels will use the surface bypass when it is the only route of passage or perhaps when station generation is minimized

Conclusions

- Passage is being heavily influenced by flow and turbine configuration
- More searching appears to occur when unit generation is split
- Increasing flows at bypasses and/or altering unit generation may have potential to increase safer downstream passage for migrant eels


A special thanks to our cooperators: USGS, BRD, S.O. Conte Anadromous Fish Research Center, US Fish & Wildlife Service (Region 5), and Northeast Generation Services.
Questions

Downstream Migratory Behavior of Silver-phase American Eels (*Anguilla rostrata*) at a Small Hydroelectric Facility

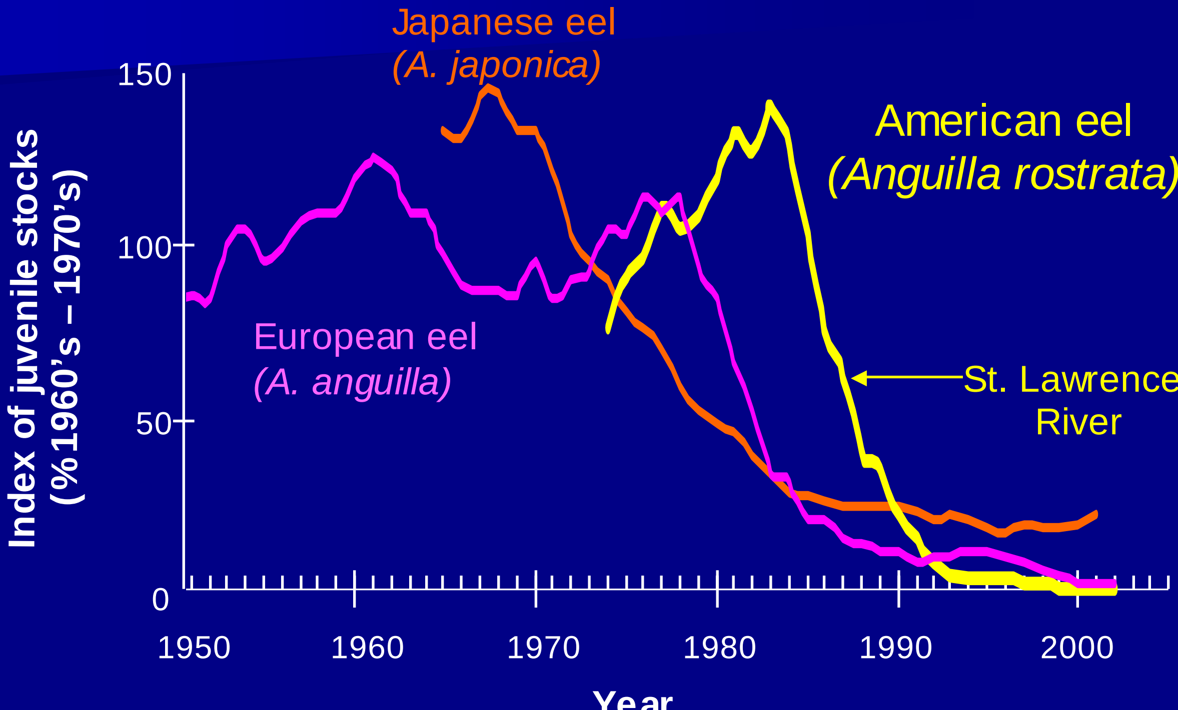
Brian Eltz,* Alex Haro’ & Ted Castro Santos’

*University of Massachusetts Amherst

‘S.O. Conte Anadromous Fish Research Center, U.S. Geological Survey

One Migratory Way, Turners Falls, MA 01376

Population Status



Data from International Eel Symposium, Quebec City AFS Annual Meeting, August 2003

Factors Contributing to the Decline of American Eels

1. Barriers to migration
2. Habitat loss and alteration
3. Hydro turbine mortality
4. Oceanic conditions
5. Over-fishing
6. Parasitism
7. Pollution

Background:

- Little is currently known about the behavior of downstream migrants at hydroelectric facilities
- Previous studies show that downstream migrants utilize turbines for passage
- Eels exhibit a variety of responses to hydro- electric facilities
    1. Vertical excursions
    2. Avoidance behavior
    3. Multiple passage attempts

Study Objectives:

- Determine the total number of silver eels passing through the Rainbow Dam fishway and downstream bypass
- Determine relationships between downstream migration timing and magnitude and environmental variables
- Compare the extent of the eels' attraction to the fishway and bypass

Study Site

Rainbow Dam

Windsor, Connecticut


YOU
ARE
HERE
X

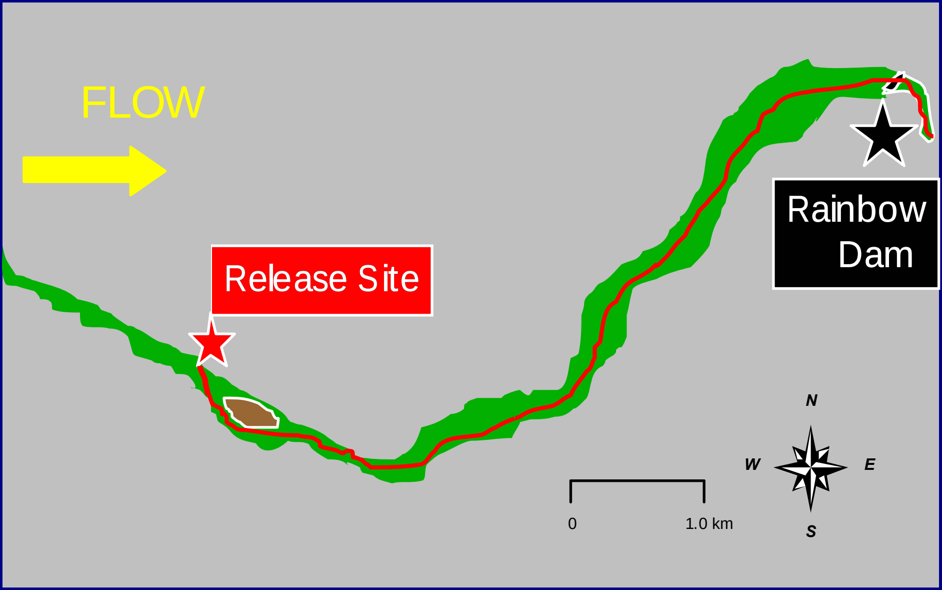
Methods: Video Taping

- 2001 & 2002, 580 & 1622 silver eels respectively in fishway
- Bypass & fishway in 2003
- Analyze environmental variables
- PIT tagged 70 fish
- Radio telemetry in 2004

Methods: Fish Capture

- Fyke Nets
- Rainbow downstream bypass sampler
- Holyoke downstream bypass sampler

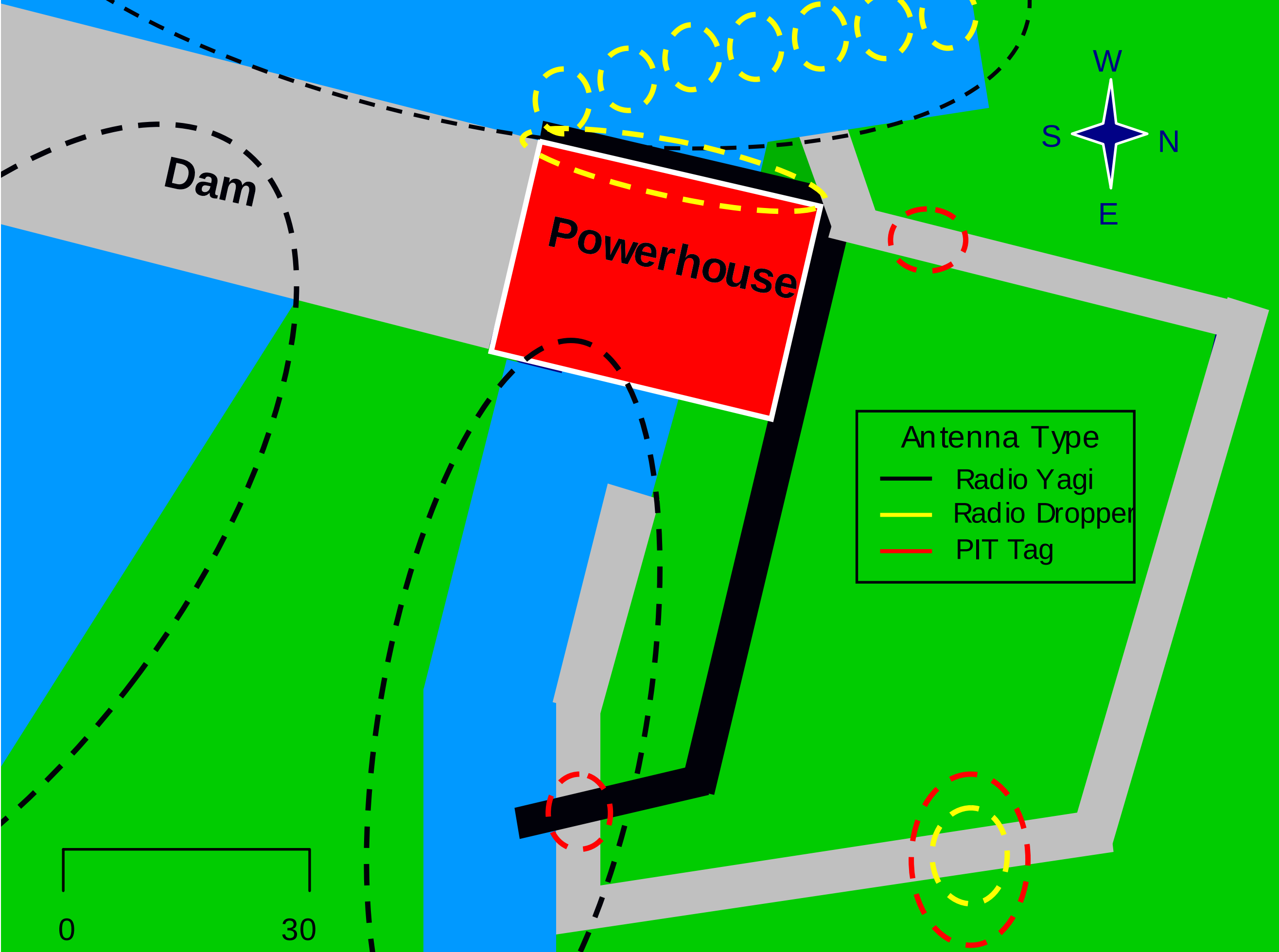
Release Site



Methods: Monitoring

- Continuous 24-hour data collection & mobile tracking; PIT tag
- Hourly hydroelectric generation
- Daily environmental variables



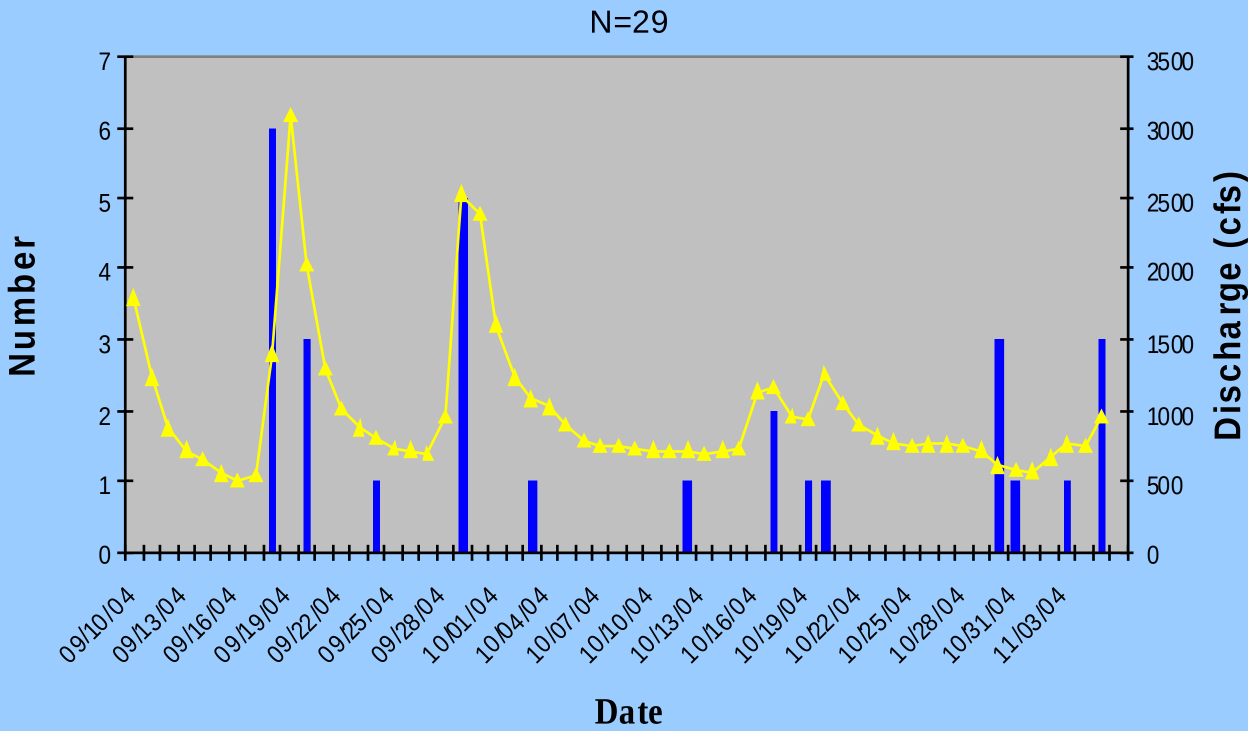



Dam
Powerhouse
W
S
N
E
Antenna Type
Radio Yagi
Radio Dropper
PIT Tag
0
30

Results:
Where Did They Go?

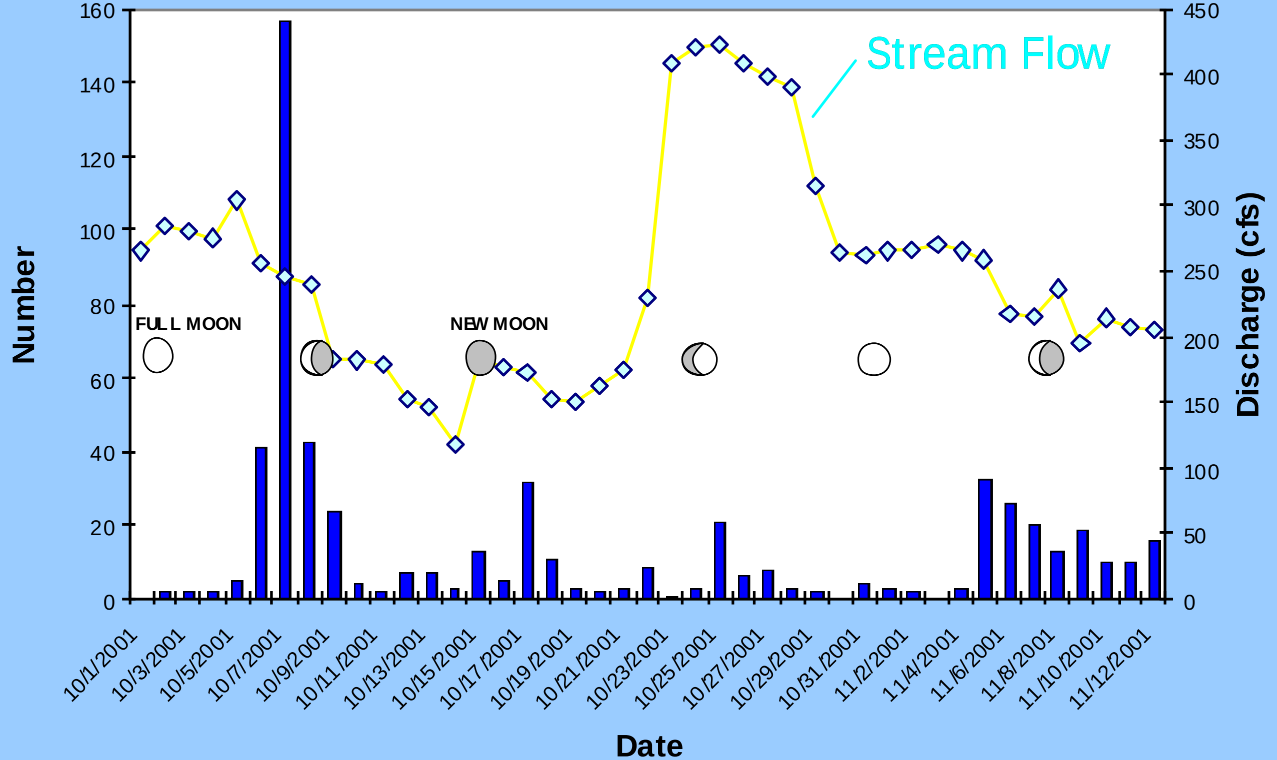
All 29 eels passed through the turbines

Passage of Radio Tagged Eels at Rainbow Dam 2004

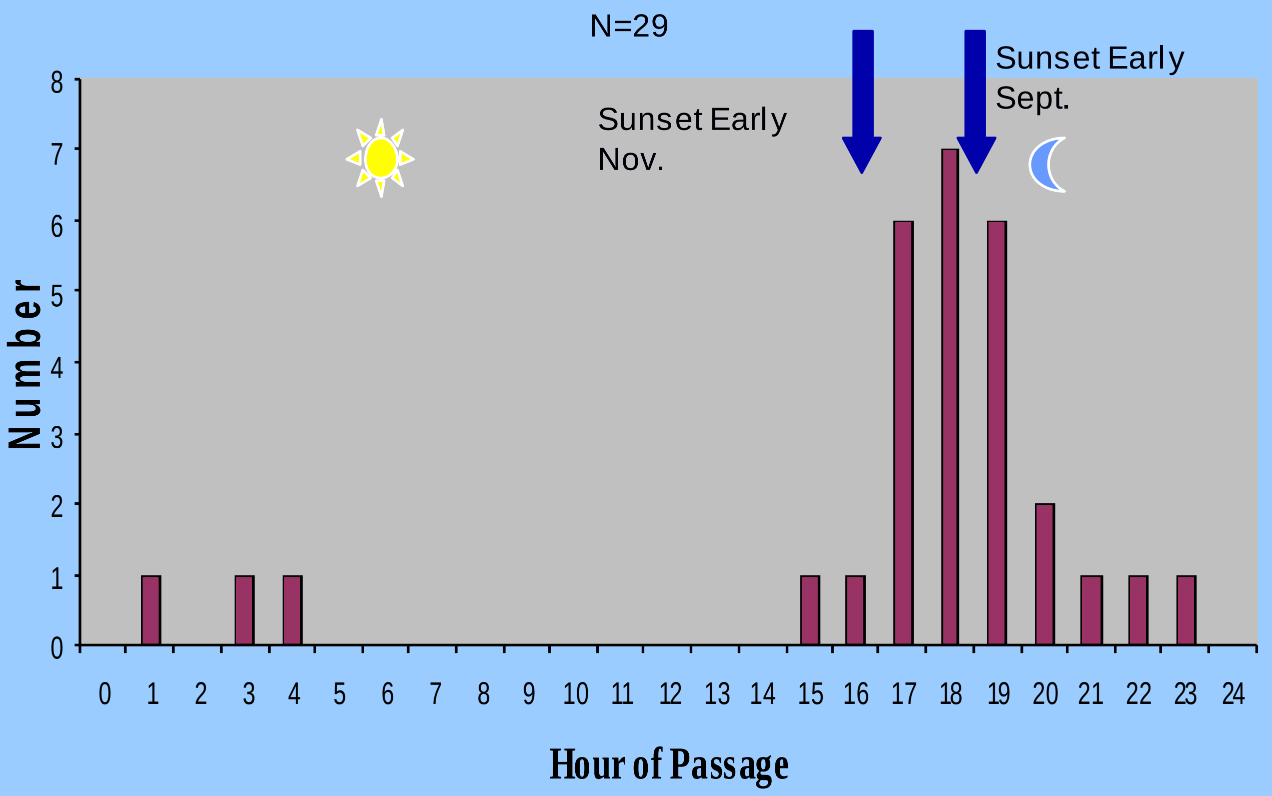


Passage of Video Taped Eels through the Fishway 2001

N = 580

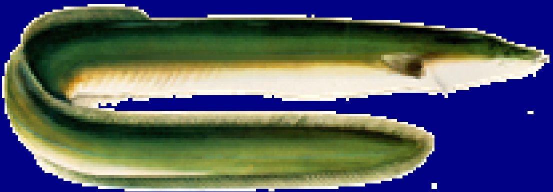


Time of Passage Events



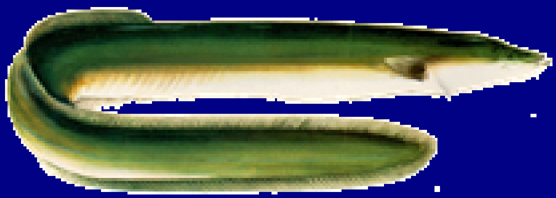
Other Observed Patterns:

- Temperature ranged from 10.5°C and 18.5°C
- Median time of 3.5 days for eels to reach forebay
- Median time of 2 days for eels to pass after entering forebay
- Multiple presences were detected

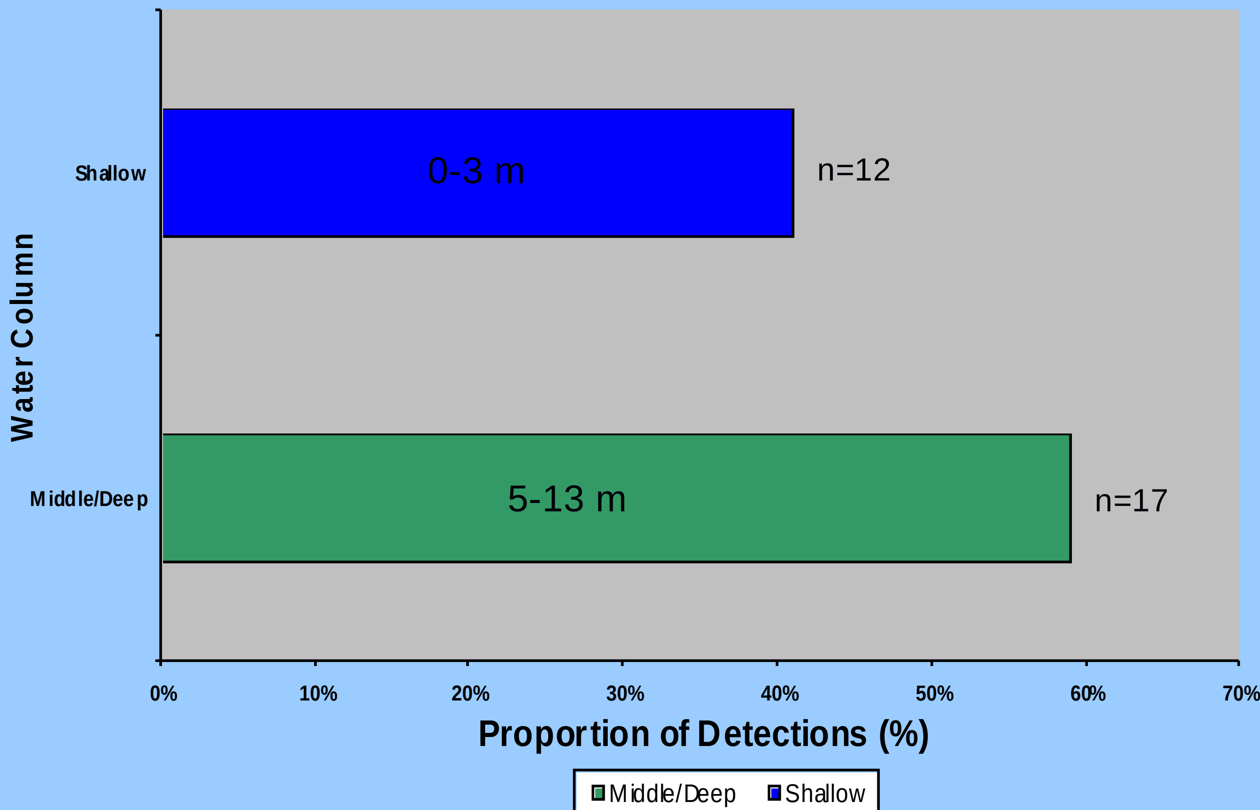


Other Observed Patterns:

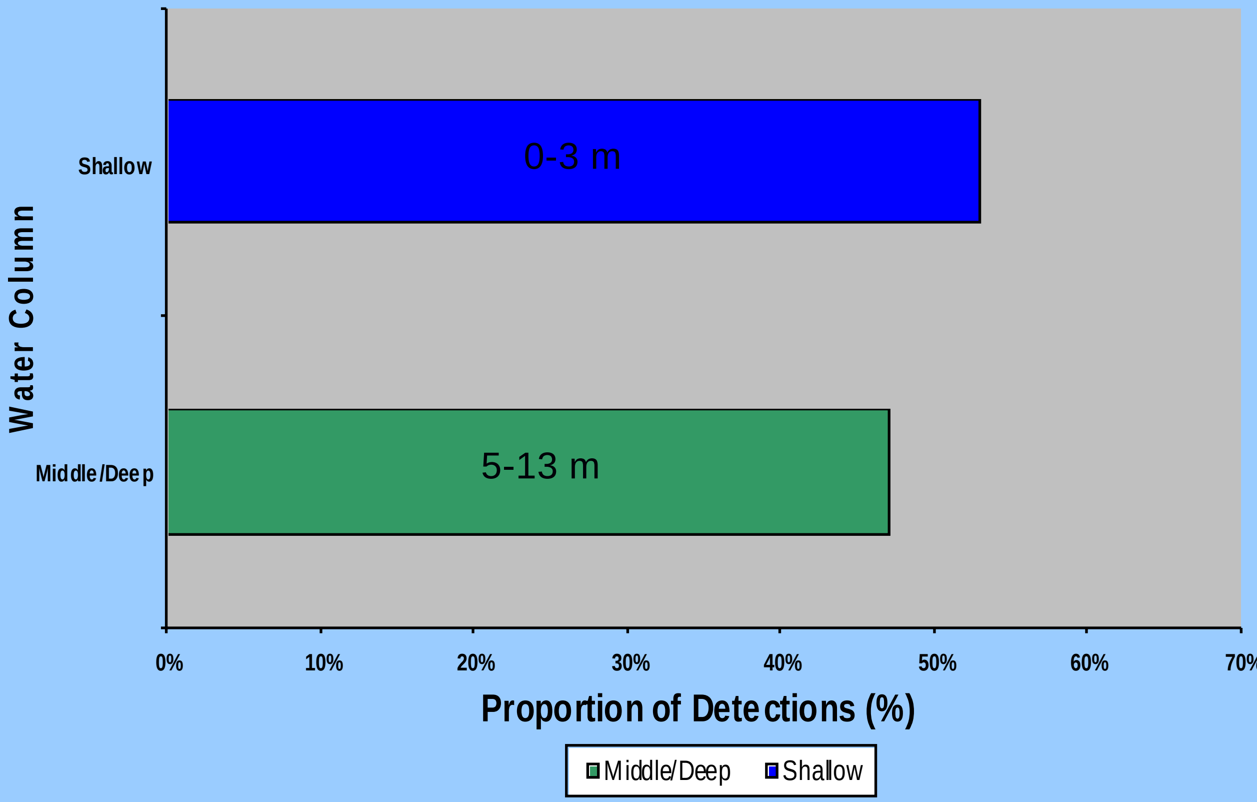
- Median presence time was ~3 minutes
- Median time between presences was ~2.5 hours
- Depth at final detection varied
- Majority of detections occurred in the upper water column



Depth at Final Detection



Distribution of Detections



Conclusions:

- The majority of eels exit through the turbines
- Behavior is highly variable
- The majority of passage occurred in the evening
- Eels made multiple attempts to pass
- Eel passage is influenced by flow

Management Solutions?

- Decrease evening generation?
- Open flood gates or allow spill?
- Alter surface bypass?
- Construct bottom or deep bypass?

What's Next?

- Survival analysis/ event-time analysis
- View remaining video tapes
- Analyzing environmental variables & hydroelectric generation

Acknowledgements

- **Cooperators**

  -U.S. Geological Survey, BRD, S.O Conte Anadromous Fish Research Center (CARFC)
  -Electric Power Research Institute (EPRI)
  -CT Department of Environmental Protection
  -Northeast Utilities Service Company
  -Stanley Works, FRPC

- **Special Thanks...**

  -Co-authors: Alex Haro & Ted Castro-Santos
  -Steve Gephard & Francis Juanes
  -UMass Volunteers!
  -Friends & Family!


Thank You!

KEMA

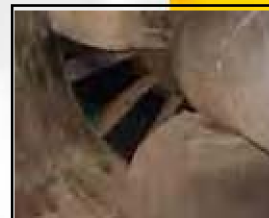
Management of silver eel: human impact on downstream migrating silver eel in the river Meuse

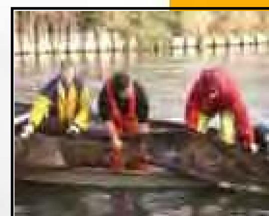
Impact assessment of hydropower plants and commercial fisheries

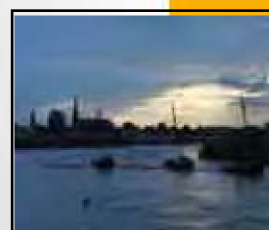
By Maarten C.M. Bruijs M.Sc. & Rolf H. Hadderingh M.Sc.

February 16, 2005 Technical Workshop Eel Passage

KEMA POWER GENERATION & SUSTAINABLES







EU-project Silver Eel

Partners: - KEMA Power Generation & Sustainables (Netherlands)
- Netherlands Institute of Fisheries Research (Netherlands)
- Floecksmühle (Germany)
- Institute for Applied Ecology (Germany)

Period: April 2001 - April 2003

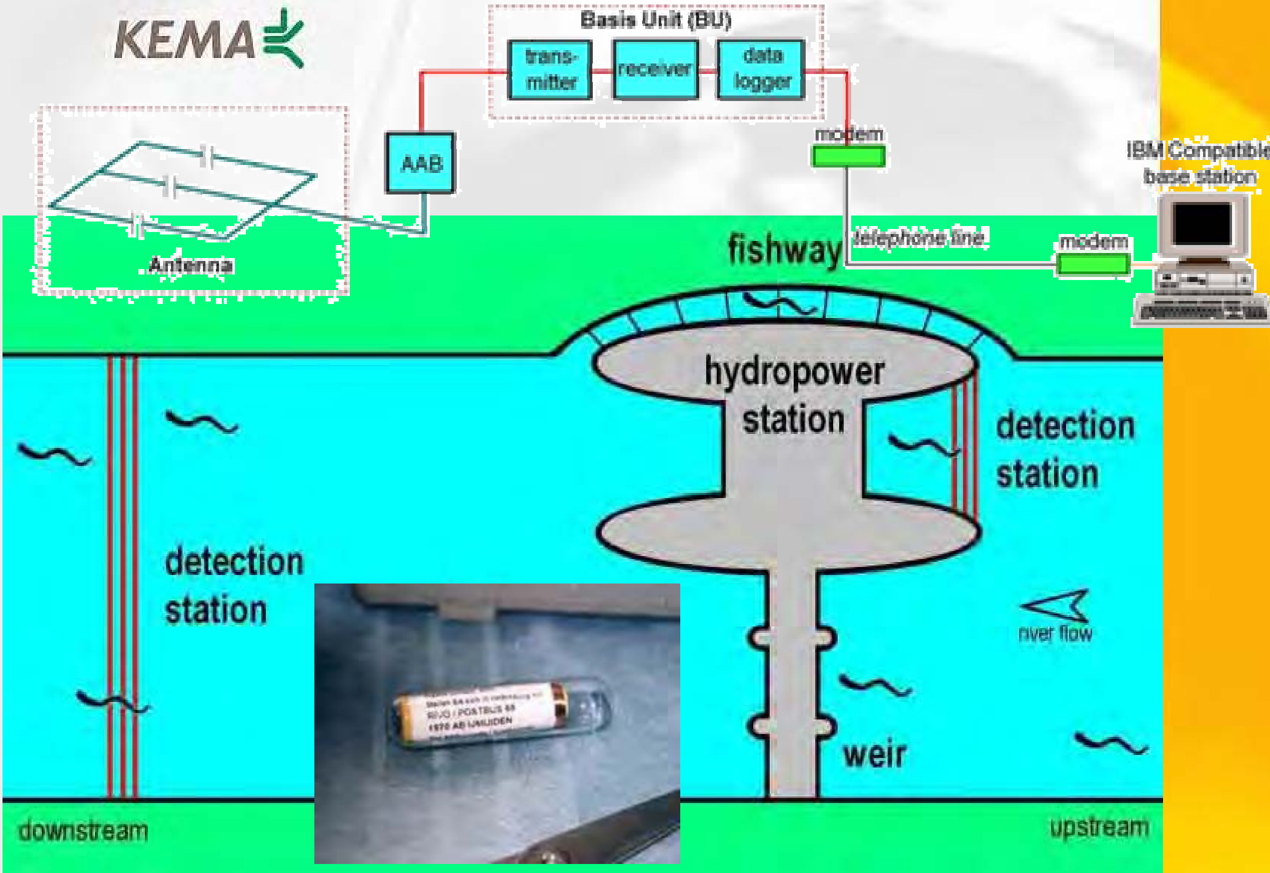
EU Program: Quality of Life Management of Living Resources EU Contract Q5RS-2000-3114

KEMA

Research objectives 'EU SILVER EEL'

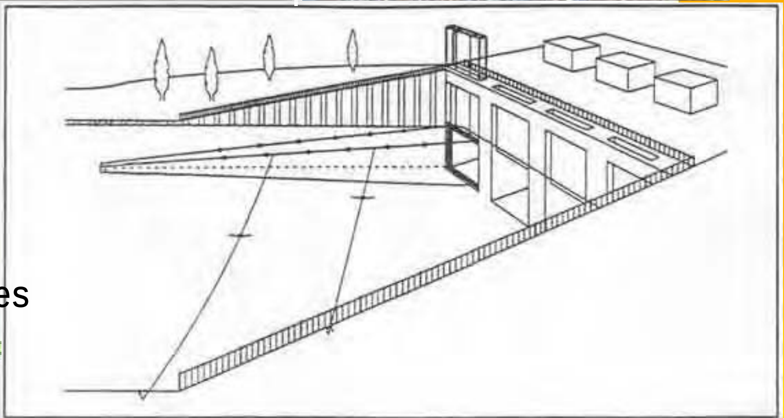
- To assess the impact by hydropower stations in the river Meuse
  - monitoring turbine passage / mortality assessment
  - monitoring downstream migration by telemetry
- To assess the impact of eel fisheries on the eel population in the river Meuse by monitoring silver eel catches
- To test the Migromat® early warning system
- To develop a turbine management system to protect silver eels

Main Goal: to contribute to a sustainable eel fishery and a sustainable production of electricity by hydropower in European waters


KEMA
Basis Unit (BU)
trans-
mitter
receiver
data
logger
AAB
modem
IBM Compatible
base station
Antenna
fishway
telephone line
modem
hydropower
station
detection
station
detection
station
river flow
weir
downstream
upstream

KEMA

Monitoring turbine passage at Linne



Linne Hydropower station:
- 10 MW
- 4 horizontal Kaplan turbines

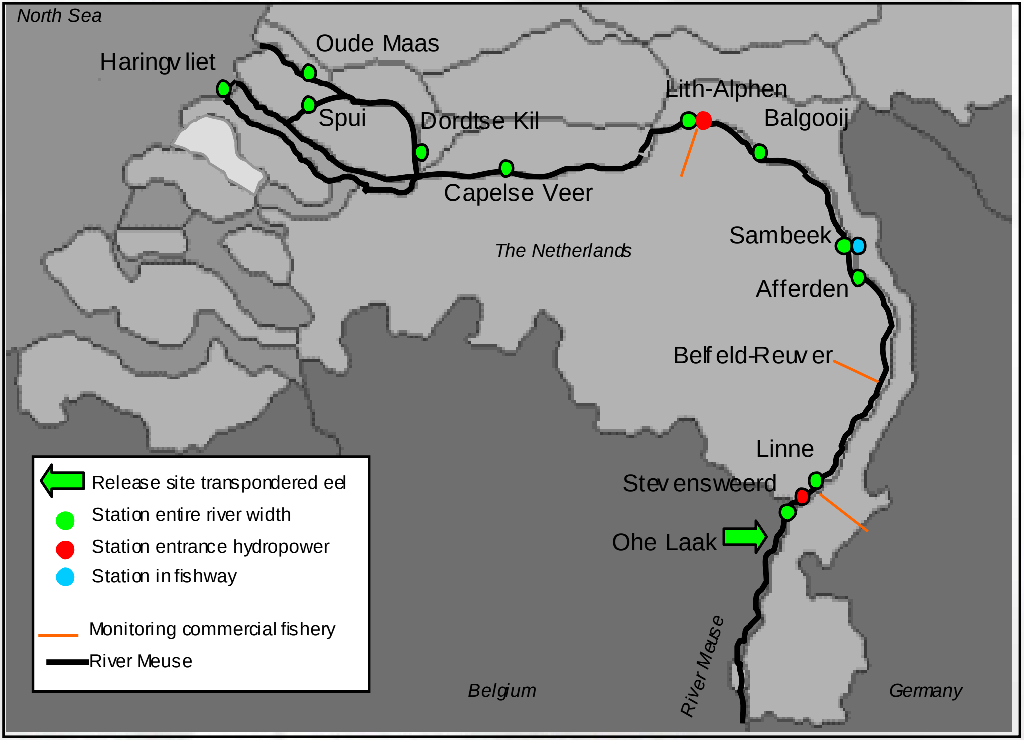
Monitoring commercial eel fisheries

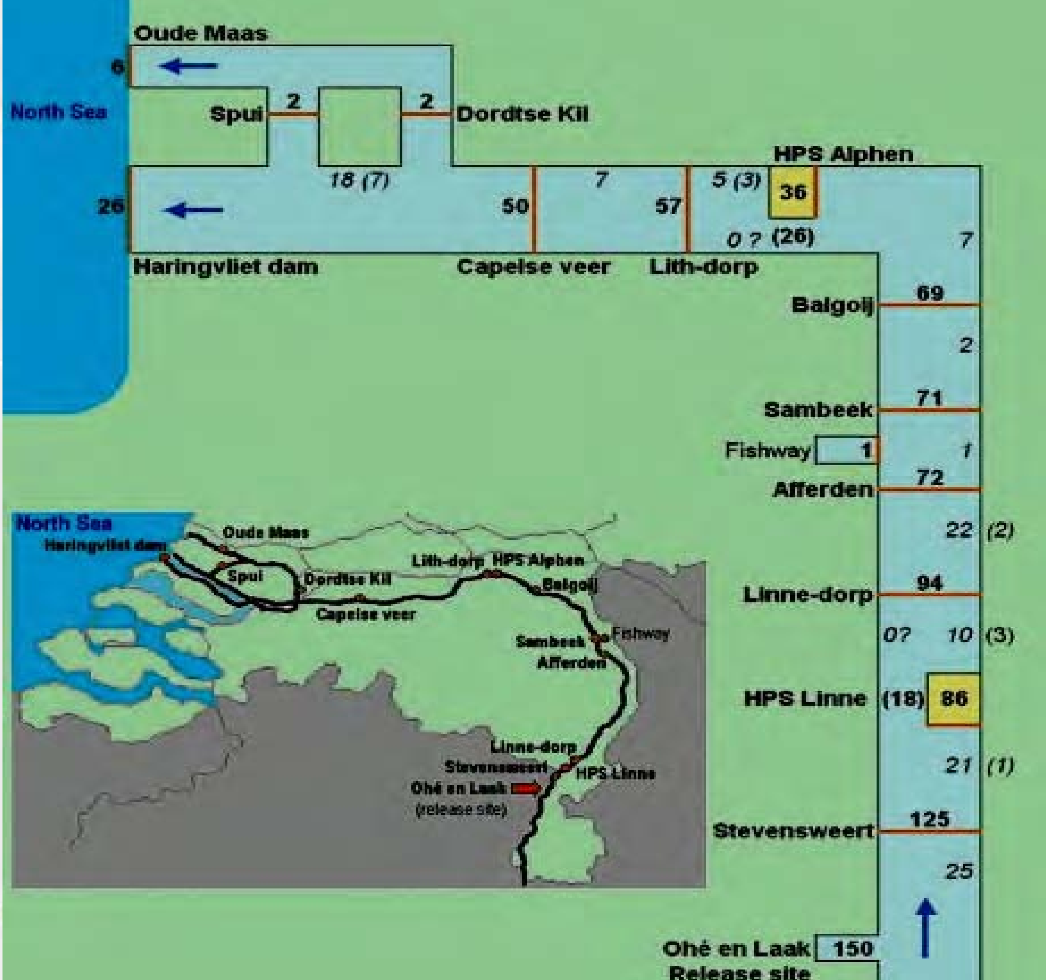
KEMA POWER GENERATION & SUSTAINABLES

KEMA

Migromat®

KEMA


North Sea
Oude Maas
Haringvliet
Spui
Dordtse Kil
Lith-Alphen
Balgooij
Capelse Veer
The Netherlands
Sambeek
Afferden
Belfeld-Reuver
Linne
Stevensweerd
Ohe Laak
Release site transpondered eel
Station entire river width
Station entrance hydropower
Station in fishway
Monitoring commercial fishery
River Meuse
Belgium
River Meuse
Germany


Oude Maas
6
North Sea
Spui
2
2
Dordtse Kil
18 (7)
HPS Alphen
26
50
7
57
5 (3)
36
0 ?
(26)
7
Haringvliet dam
Capelse veer
Lith-dorp
Balgoij
69
2
Sambeek
71
Fishway
1
1
Afferden
72
22
(2)
Linne-dorp
94
0?
10
(3)
HPS Linne
(18)
86
21
(1)
Stevensweert
125
25
Ohé en Laak
150
Release site
North Sea
Haringvliet dam
Oude Maas
Spui
Dordtse Kil
Lith-dorp
HPS Alphen
Balgoij
Capelse veer
Sambeek
Fishway
Afferden
Linne-dorp
HPS Linne
Ohé en Laak
(release site)

Observations

Migration and behaviour

- highest eel migration activity between sunset and midnight
- migration activity / events related to increase of river flow
- migration during limited number of nights
- 50% of eel show clear hesitation to pass the trash rack, 25% turns into upstream direction

KEMA

Conclusions

- The Nedap Trail System® has been shown to be an appropriate system to monitor downstream migration
- During limited number of nights, passage of about 70% of total number of transpondered silver eel
- Within the Dutch section of the river Meuse, each individual silver eel has a chance of at least 30% and probably about 40% to reach the North sea

KEMA

Conclusions

- The impact of the combined mortality by the two hydropower stations (HP) is smaller than the combined mortality by the commercial fisheries (F):
  - F-mortality is up to a factor 2 higher than HP-mortality
    - HP-mortality (max 16%) is likely an overestimation
    - F-mortality (min 22%) is likely an underestimation
- Reducing eel fisheries catches results directly in higher number of silver eel reaching the North sea

  → Action Plan set by the European Commission

Conclusions

- Migromat®-warnings correspond to the observed migration events
- the results of the monitoring experiments verify that the Migromat® system accurately registers the pre-migratory restlessness of eels, predicting the downstream migration events
- the prediction of the Migromat®, enables an eel-friendly turbine management of hydropower facilities
- application of the Migromat® during the migration season 2002/03 would have reduced the mortality by hydropower with max 69.4%

Basis for Early Warning

- European eels migrate downstream during 10 to 20 nights (September till December)
- Trigger(s) to start migration are not known
- Captured eels in tanks show increasing activity (restlessness) before start of migration events in the river

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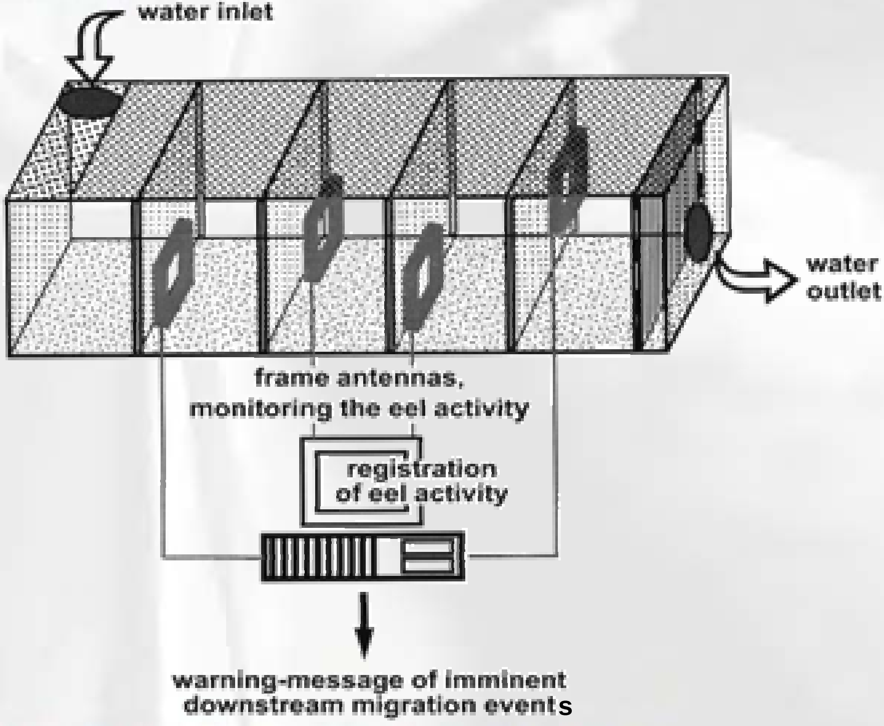
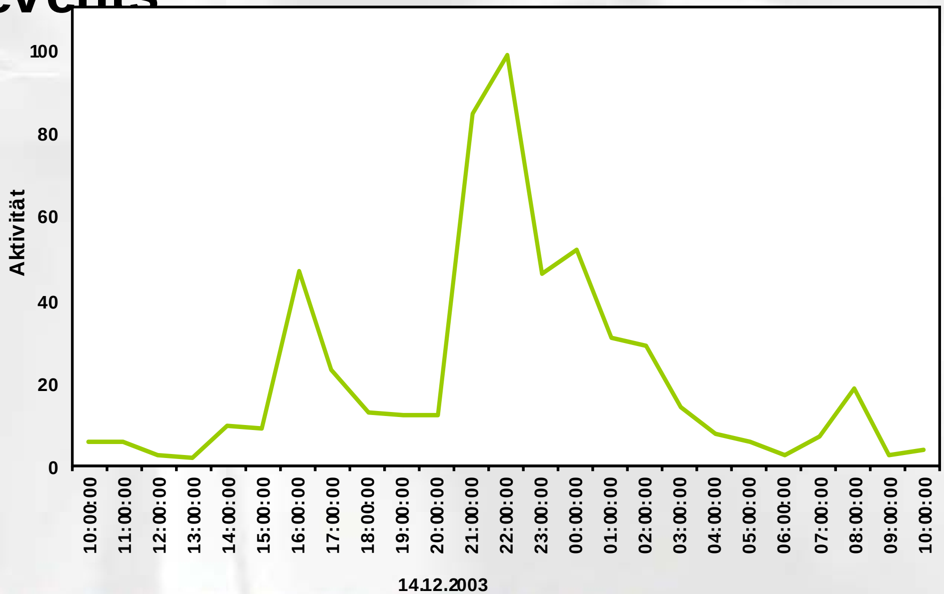
Migromat®

- by the Institute for Applied Ecology & Floecksmühle Consultants
- 4 years of test cases:
  - river Lahn (G) 1999 - 2000
  - river Meuse (1+2) (NL) 2001 - 2003
  - first full operational commercial installation at the river Fulda (Germany) in 2003

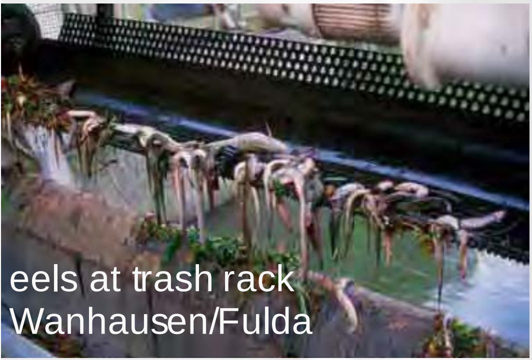


water inlet
water outlet
frame antennas, monitoring the eel activity
registration of eel activity
warning-message of imminent downstream migration events

Migromat®: daily activity migration events



Evaluation of Migromat® alarms



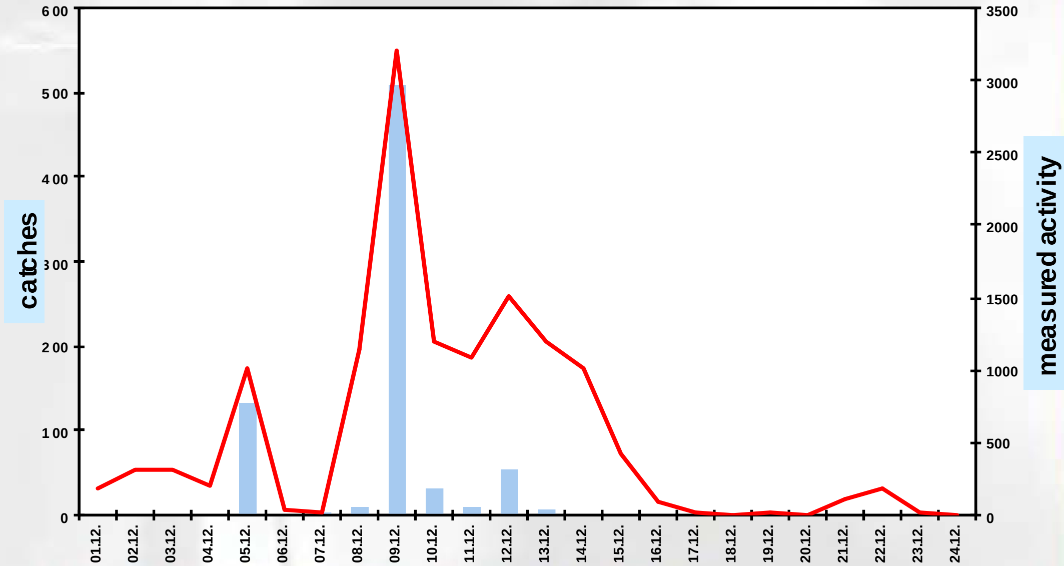
eels at trash rack
Wanhausen/Fulda

eel trap at Dorlar/Lahn

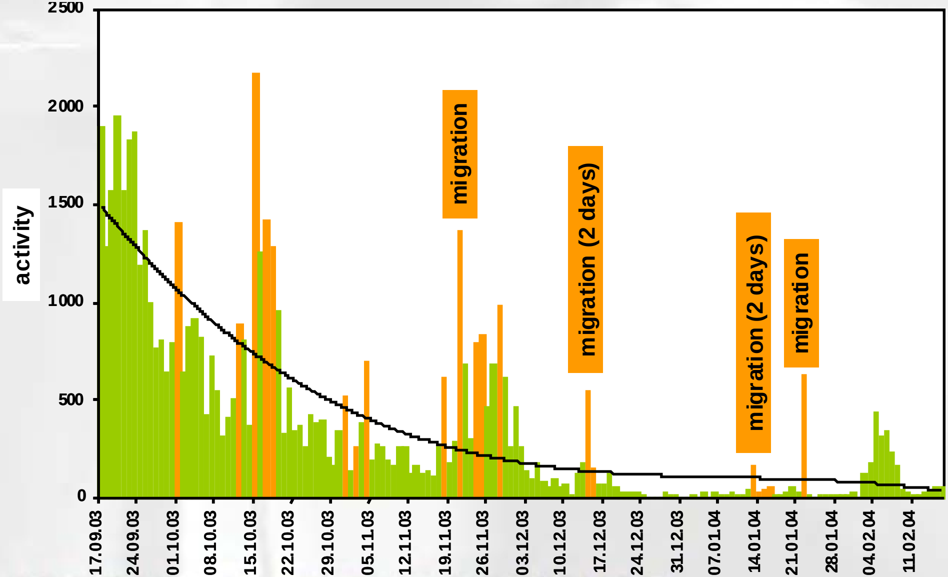
commercial fisheries
river Meuse

active transponders in
river Meuse

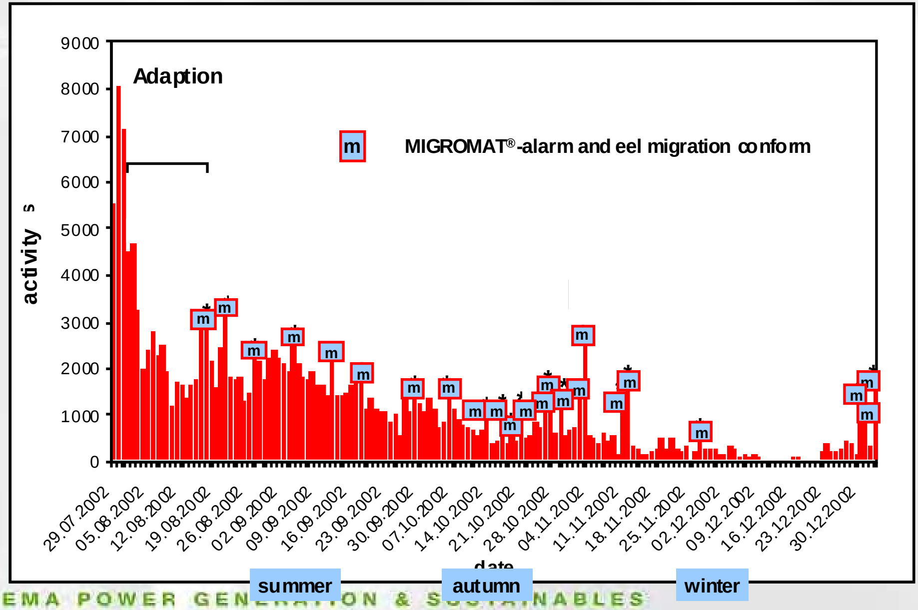
Migromat® River Lahn - Eel activity and catches (Eel Trap) - 1999/00



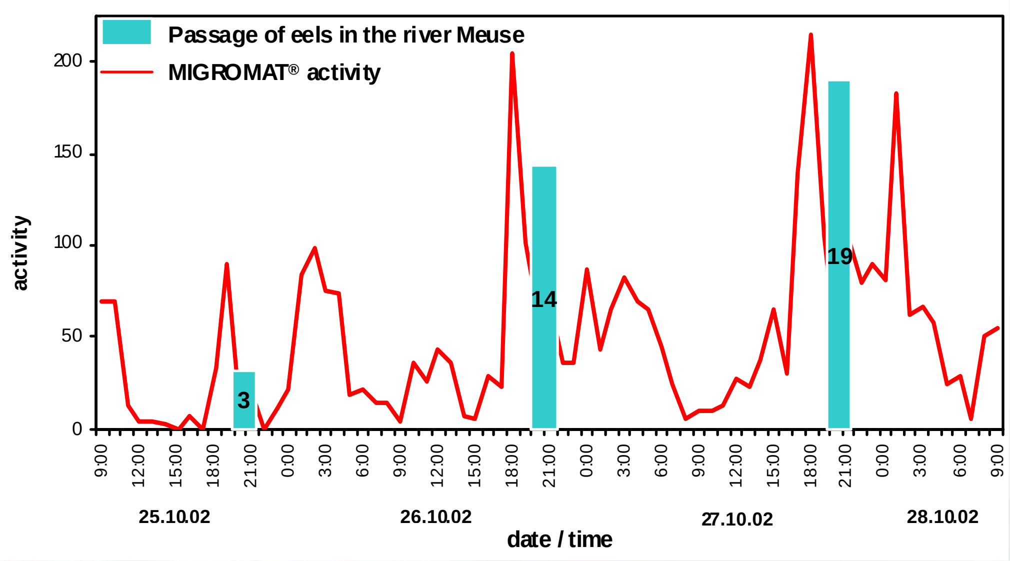
Migromat® at River Fulda – Alarms & Migration of Eels



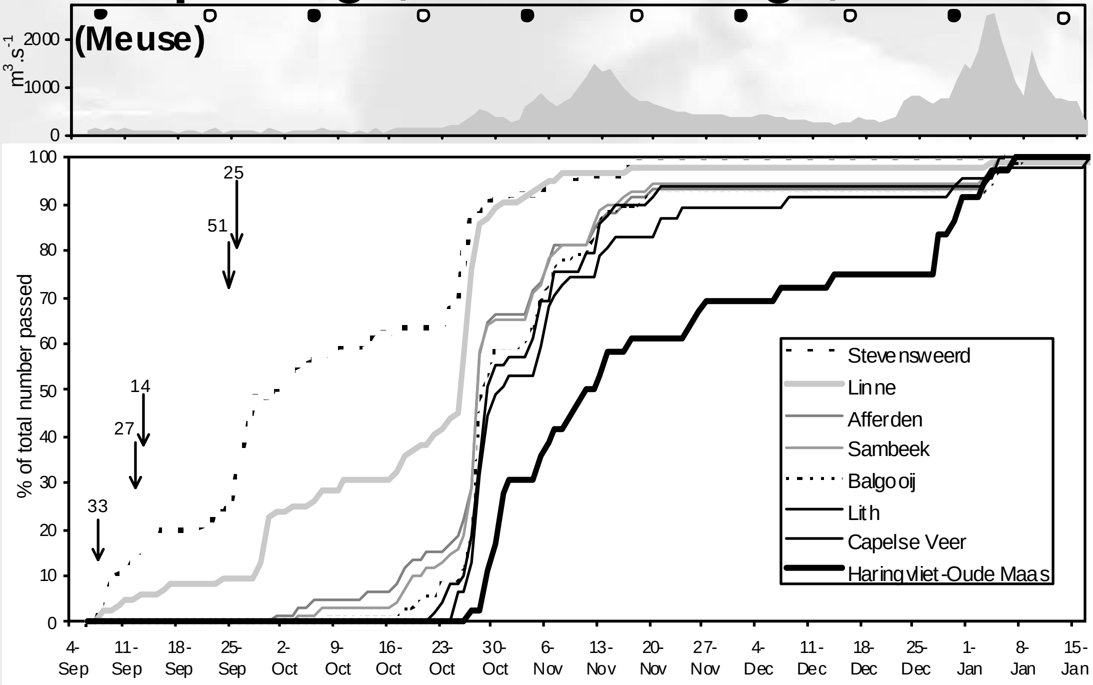
Migromat® River Meuse - Eel Activity - 2002/03



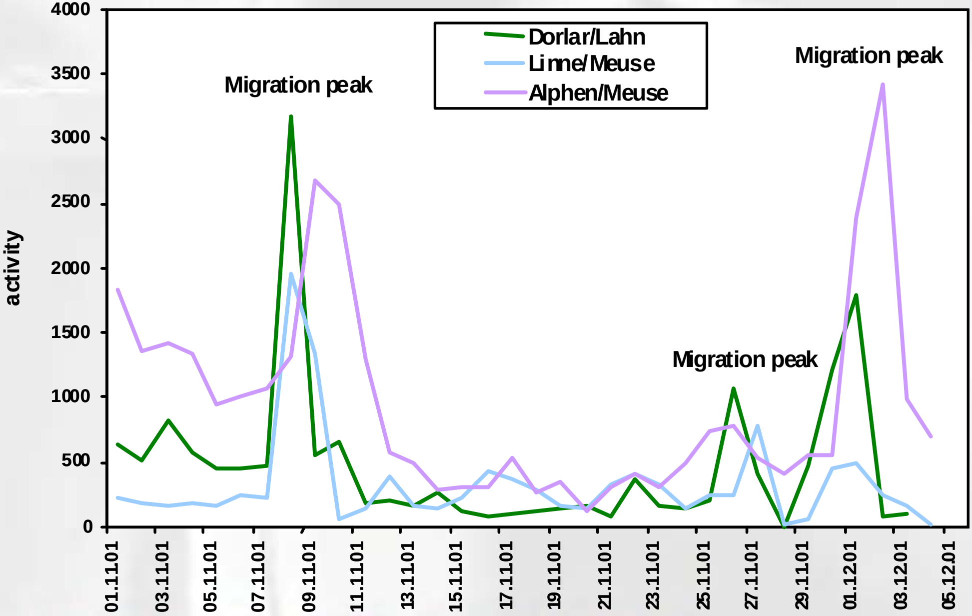
Migromat® River Meuse - Eel Activity and passage of Eels - Oct 25 - 27, 2002



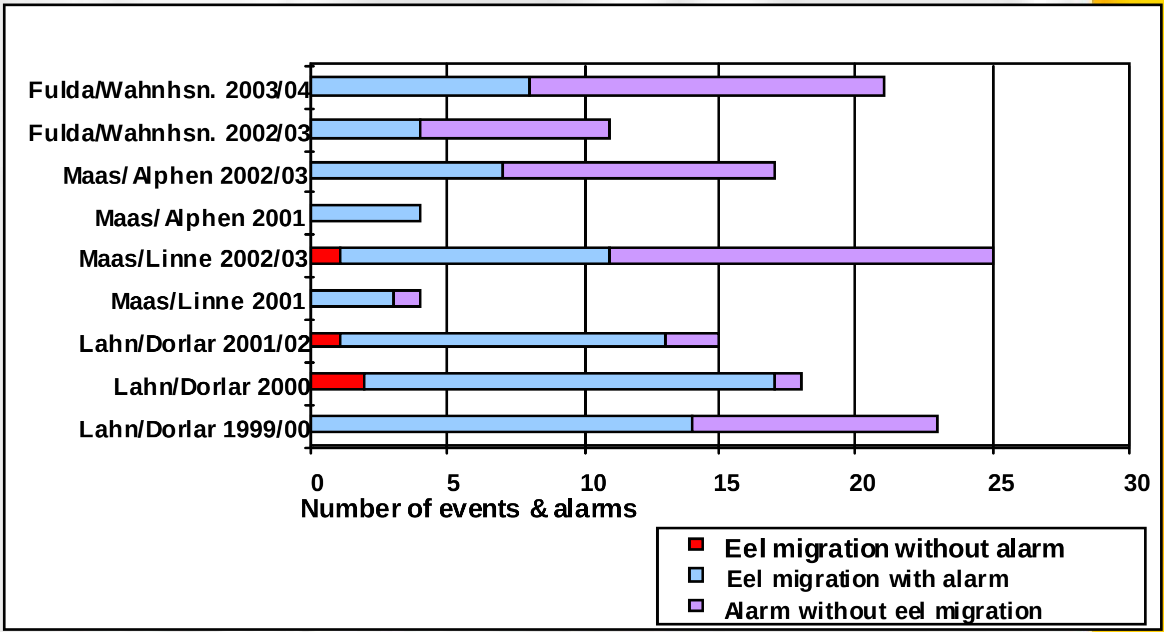
Eel passage, river discharge, moon (Meuse)



Migromat® activity at rivers Meuse & Lahn



Reliability of Migromat® prognosis



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Application of Migromat®

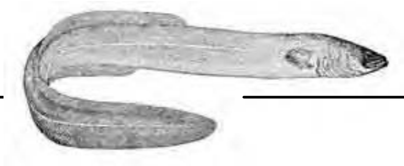
In case of alarm given by Migromat® Installation:

- Shut down of turbine
  ➔ 100 % bypass of flow and eels over weir
- Reduction of turbine discharge and approach velocity at screen
  ➔ eels can use bypass
- Optimised operation of a number of turbines
  ➔ only turbines with max. discharge and (or) minimum mortality of eels in operation.

Acknowledgements EU SILVER EEL

- European Commission, Directorate-General Fisheries
- ESSENT Energy
- NUON Renewable Energy Projects
- Directorate-General of Public Works and Water Management
- Dutch Ministry of Economic Affairs
- Dutch Ministry of Agriculture, Nature Management & Food quality

Questions?



3. Eel protection / mitigation

Review of Research and Technology on Passage and Protection of Downstream Migrating Eels and Current EPRI Eel Research - Bill Richkus (Versar Inc.)

Summary of attempts to reduce mortality of eels as they migrate downstream in rivers in Maine - Gail Wippelhauser (Maine Dept. of Inland Fisheries and Wildlife)

Simulation of Migration, Passage, and Mortality of American Eels at Hydroelectric Dams - Alex Haro (United States Geological Survey)

Evaluation of Angled Bar Racks and Louvers for Guiding Eels at Hydro Projects - Steve Amaral (Alden Research Lab)

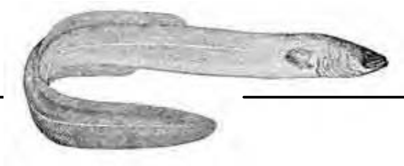
Biological Evaluation of a New Turbine Designed to Minimize Fish Injury and Mortality - Steve Amaral (Alden Research Lab)

The Use of Mechanically Generated Current in Downstream Catadromous-Eel Passage - Jon Truebe (Lakeside Engineers)

Eel protection devices and operations at the Rimouski River hydroelectric power plant: a Win/Win approach that works - Guy Verrault (Faune Québec)

Workshop photos by Kevin McGrath

Continued…



3. Eel protection / mitigation (continued)

Evaluation of bypasses to protect eel migrating downstream at small hydroelectric facilities in France - Francois Travade (Electricity de France)

Status of Protection Measures for Downstream Migrant Eels in New Zealand - Jacques Boubee (New Zealand National Institute of Water and Atmospheric Research Inc.)

Avoidance of artificial light by downstream migrating American eel (*Anguilla rostrata*) in the St. Lawrence River - Kevin McGrath (New York Power Authority)

Sampling Efforts for Downstream Migrating American eel (*Anguilla rostrata*) in Lake St. Lawrence - Kevin McGrath (New York Power Authority)

Eel Light Avoidance Study conducted at Les Cèdres Intake Canal (2004) - Richard Verdon (Hydro Québec)

American eel stocking (*Anguilla rostrata*) in the Upper Richelieu River and Lake Champlain: a fisherman-scientist-manager partnership - Guy Verreault, Pierre Dumont (Faune Québec)

A critical review of 'biological' compensation approaches - Brian Knights (University of Westminster)

Workshop photos by Kevin McGrath

Review of Research and Technology on Passage and Protection of Downstream Migrating Eels

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EPRI-Funded Reviews

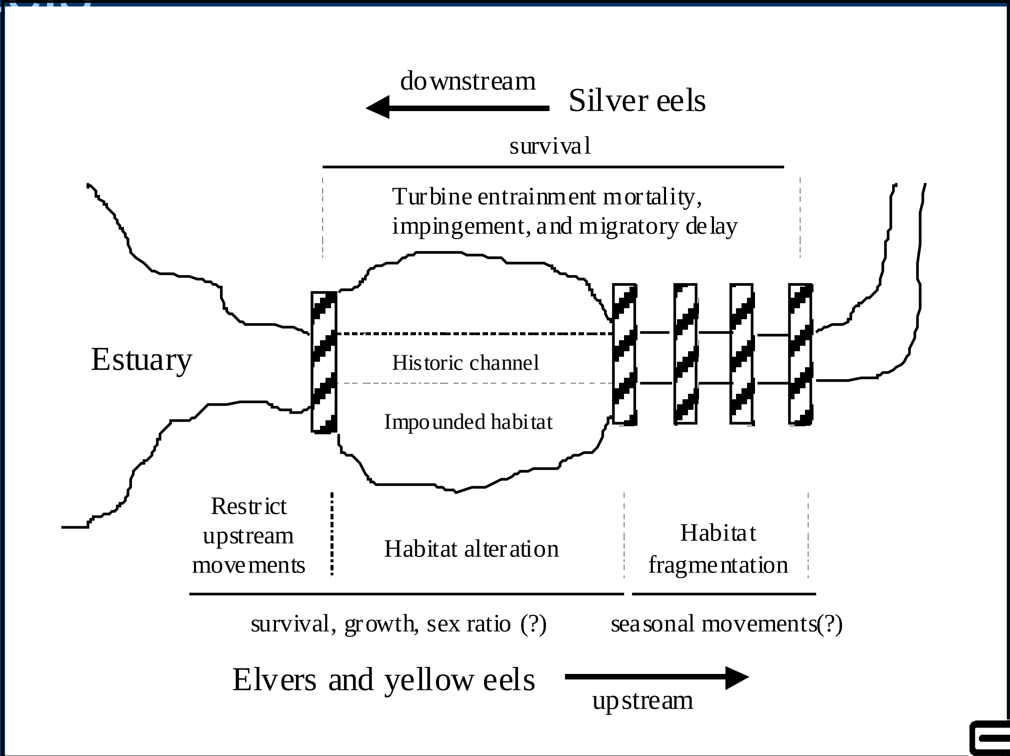
- American eel (*Anguilla rostrata*) Scoping Study (1999) – review of life history, stock status, population dynamics, and hydroelectric impacts

- Passage and protection of downstream migrating eels at hydroelectric facilities (2001) – overview of downstream migratory behavior (all species), engineering and operational factors influencing injury and mortality during turbine passage, and effectiveness of physical and behavioral passage technologies

Project Sponsors

- EPRI Project Manager Dr. Douglas Dixon
- Allegheny Energy Inc., Dominion, Hydro-Quebec, Exelon Generation Company, U.S. Department of Energy - Hydropower Program, New York Power Authority, Duke Energy, and Ontario Power Generation Inc

Modes of Hydroelectric Project Impact on Eels



Options for Protecting Downstream Migrating Eels

1. Reduce mortality of eels passing through turbines
2. Direct eels away from operating turbines
3. Prevent eels from entering operating turbines
4. Stop operating turbines when eels are passing
5. Trap and transport eels around projects

Option 1 – Reduce Turbine Mortality

- Variable magnitude of mortality (*A. anguilla* and *rostrata)* – from low of 6% (NIMO, 1995) to high of >50% (Monten, 1985); most commonly 20% to 30%
- Examples of factors influencing mortality:
  -- turbine type (Kaplan higher; Francis lower)
  -- eel size
  -- location of entry to turbine
  -- turbine load levels
  -- distance between vanes and runner blades
- Examples of factors affecting mortality estimation
  -- handling challenges
  -- abnormal behavior in response to anesthesia, handling and marking
  -- differing day and night behavior
  -- inefficient post-passage recovery
  -- lethal internal injuries not visible

Option 1 – Reduce Turbine Mortality (Continued)

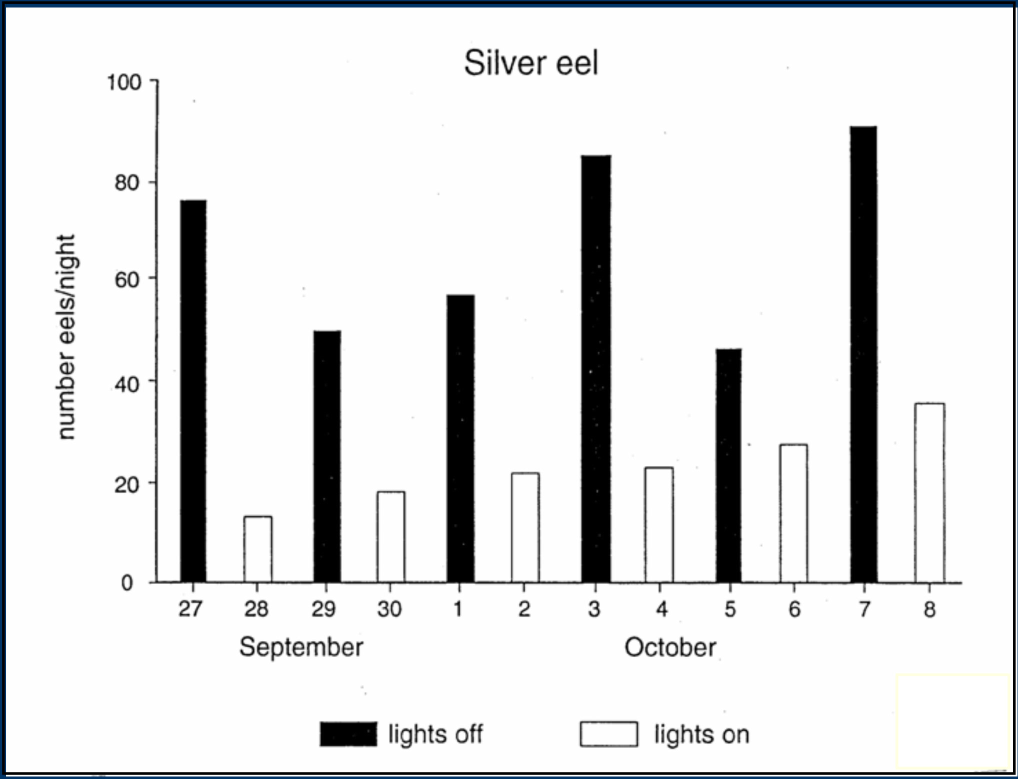
- Pros: -- Direct and definable benefit
  -- Least complicated
- Cons: -- Difficult to precisely quantify benefit
  -- May not be feasible from engineering perspective
  -- May have high, prohibitive cost (e.g., installation of new fish-friendly turbines)
- Needs: -- Development of standardized mortality testing procedures to improve comparability of results
- EPRI may fund testing of small eel-friendly turbine in 2006

Option 2 – Direct Eels Away from Turbines (Behavioral Methodologies)

- Light
- Sound
- Air Bubbles/Water Jets
- Electricity
- Induced flows and by-pass facilities

Option 2 – Light – Examples of Some Positive Diversion Results

- Lowe (1940’s, 1950’s) – 70%-90% diversion in small stream
- Hadderingh et al. (1992) – 64% to 94% avoidance in lab; 66% diversion at hydrofacility; 73% to 85% diversion in small river



Number of silver eels caught behind the light barrier with and without the operation of the light barrier at Haandrik Hydropower Station 1988. (From Hadderingh et al. 1992.)

Option 2 – Light – Uncertainties and Limitations

- Numerous studies, both lab and field, showed no response, including to strobe lights
- Effectiveness often unpredictable, influenced by many factors: water quality (turbidity), water velocity, light quality, light intensity, light configuration, logistical constraints (e.g., fouling), and eel life stage
- Numerous logistical challenges to effective deployment and high cost (NYPA presentation)

Option 2 - Sound

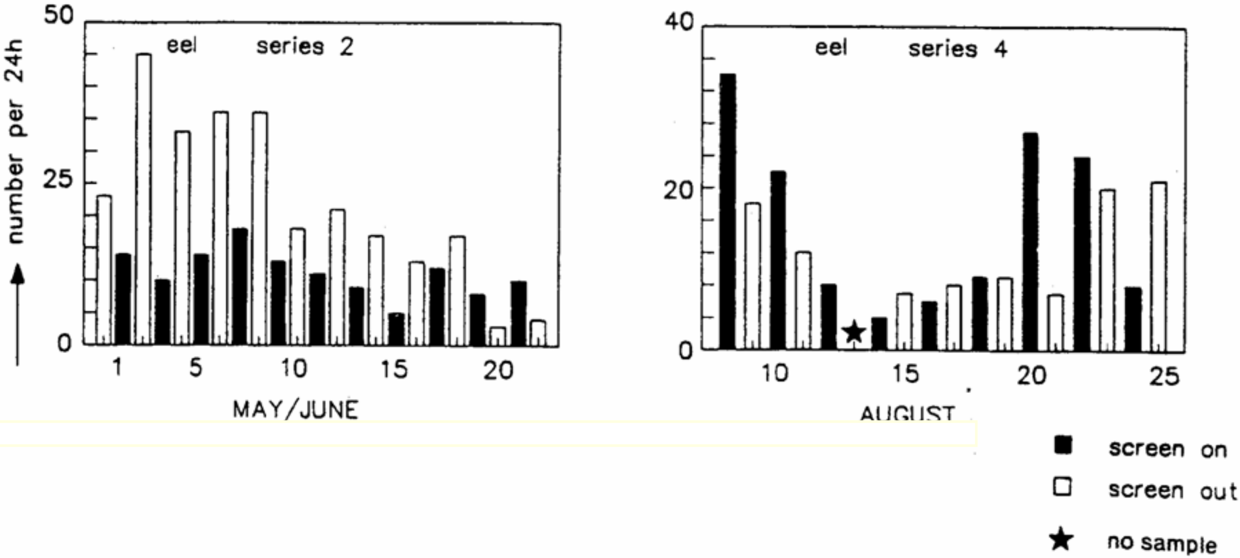
- Popper and Carlson (1998) conclude usefulness of sound for controlling fish behavior is limited; most effective with clupeid species
- Sand et al (2000; 2001) showed positive eel response to infrasound (11.8 Hz)
- Infrasound results promising, but has limited range and logistical challenges

Option 2 – Air Bubbles and Water Jets

- Adam and Schwevers (1997) found no lasting response of eels to air bubbles and water jets; rapid habituation
- Least supported mitigation option

Option 2 -- Electricity

- Eels very sensitive to electricity
- Some successful diversion of eels using electric fields and screens, but results not consistent (Hadderingh and Jansen, 1990)
- Numerous logistical challenges to installation in a manner that would guide rather than stun downstream migrating silver eels (in contrast to upstream migration of species such as salmon and Asian carp)
- Represents an option that has potential because of eel responsiveness, but with many obstacles to successful implementation



Numbered eels captured per 24 hours with electric screen on and off.
(From Hadderingh and Jansen 1990)

Option 2 – Induced Flows and Bypass Facilities

- Induced flows for guidance (e.g., Coutant and Whitney 2000) not tested on eels
- Examples of inconsistent results in diverse bypass studies
  - -- Haro et al (2000) had 10 of 13 radio-tagged eels pass through turbines rather than over dam or through bypass
  - -- Shultze (1999) reported eels passing through turbines until 50% of flow passed over dam
  - -- Of 15 eels tracked by Durif et al. (2002), 10 passed over the dam, 1 passed through the turbines, and 4 used a bottom bypass, but during a storm event
  - -- Travade (2001) reported 30% to 50% of eels using a deep bypass where 3 cm spaced bar racks blocked turbine intakes (update this session)
  - -- Legault et al. (1999) reported 12% of silver eels used small bypass

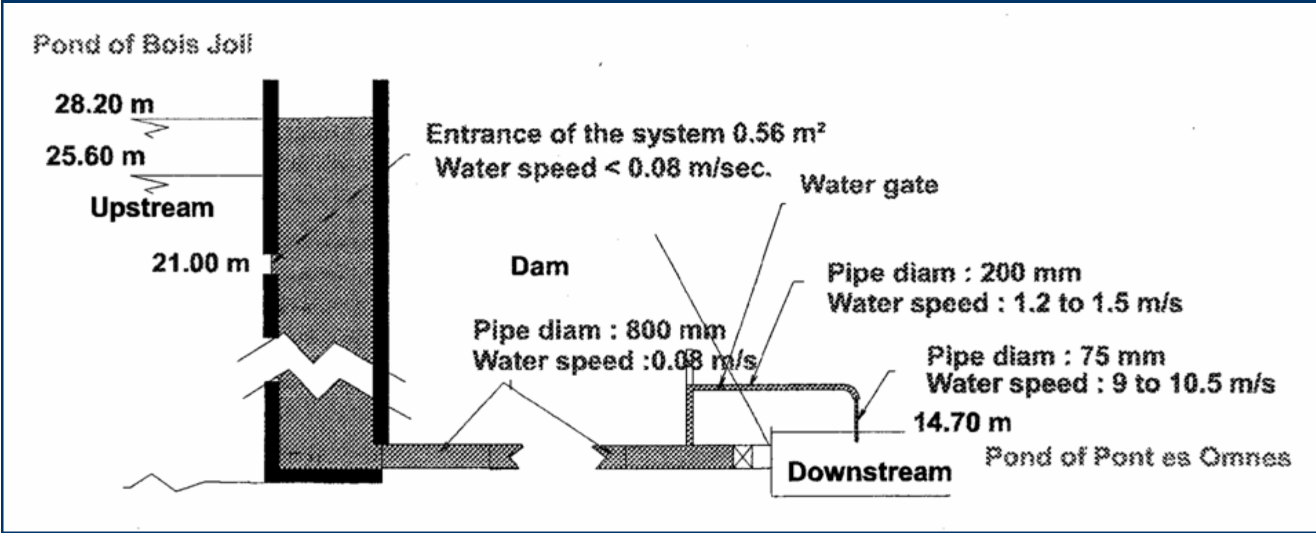


Diagram of an eel bypass system in Fremur, France. (From Legault et al. 1999)

Option 2 – Induced Flows and Bypass Facilities (Continued)

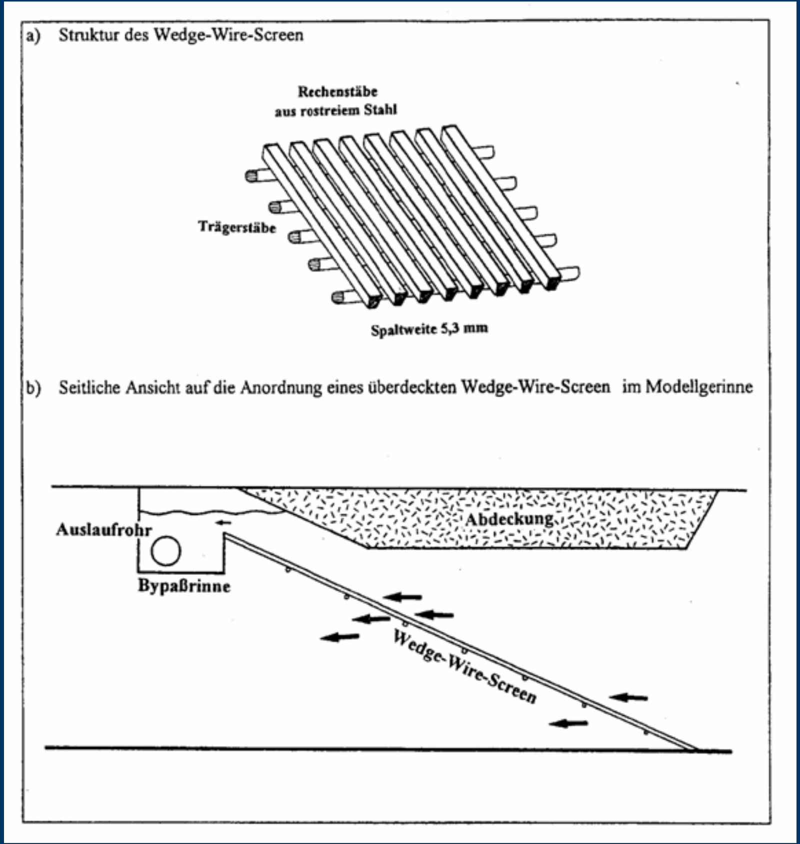
- Majority of studies suggest eels move downstream with main flow of river
- In absence of barrier at turbines, effectiveness of bypass flows by themselves, such as for salmonids, likely to be limited

Option 3 – Blocking Turbine Passage

- Primarily screening/bars, but includes angled louvers that divert eels
- Alternatives include flat screens, angled screens, wedge-wire screens, angled bar racks, angled louvers

Option 3 – Eel Response to Screens and Bars

- Behavioral response of silver eels to screens and louvers relatively unique; no visual response, only to physical contact
- Eels most frequently attempt to force their way through barriers perpendicular to flow, often causing injury
- Eels easily impinged by flows >1m/s
- Angled, rather than perpendicular, screens can be effective in diverting eels
  - -- 40° vertically angled wedge-wire screen diverted eels into a bypass with no mortality (Schultze, 1999)
  - -- Alden studies presented in this session



Structure of a Wedge-Wire Screen and its arrangement in the model channel. (From Adam and Schwevers 1997)

Option 3 – Blocking Turbine Passage (Continued)

- Physical barriers may be effective if angled (to guide rather than block)
- Engineering requirements and, thus, cost may limit their use to smaller projects
- Lab studies require field verification; EPRI studying eel behavior as they approach louvers in field

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EPRI

Option 4 – Project Shutdown During Eel Migration

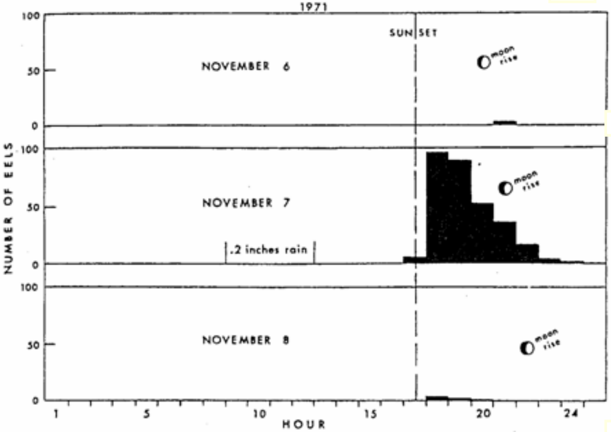
- The only option that ensures absolute protection
- Creates potential for very substantial impact to project power generation as well as on power grid if shutdowns widespread
- Effectiveness dependent on accuracy in predicting eel migration

Option 4 – Project Shutdown During Eel Migration (Continued)

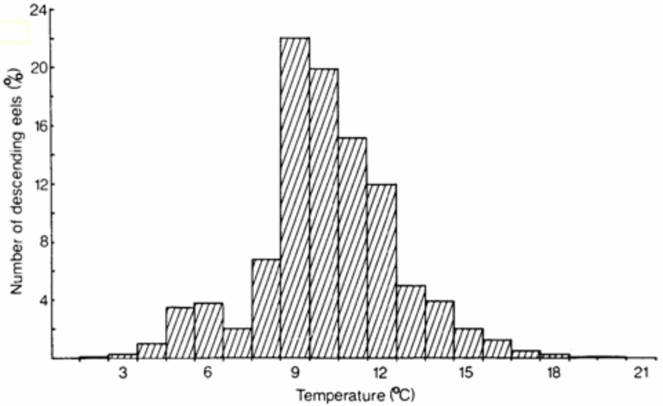
- Predictability and duration of out migration clearly varies with stream/river size

  -- Migration triggers in small rivers and streams most commonly include precipitation events and or increases in discharge, with moon phase and temperature acting as gating parameters

  -- Migration in small rivers and streams often has relatively short duration



Hourly counts of eels migrating downstream through a fishway in the Annaquatucket River in 1971 recorded by an electronic counter over 3 days. Lunar phase is shown. (From Winn, et al. 1975)



Percent silver eel descent (N = 36,494) at temperatures from 2 °C in the River Imsa during 1974-84. (From Vρllestad, et al. 1986)

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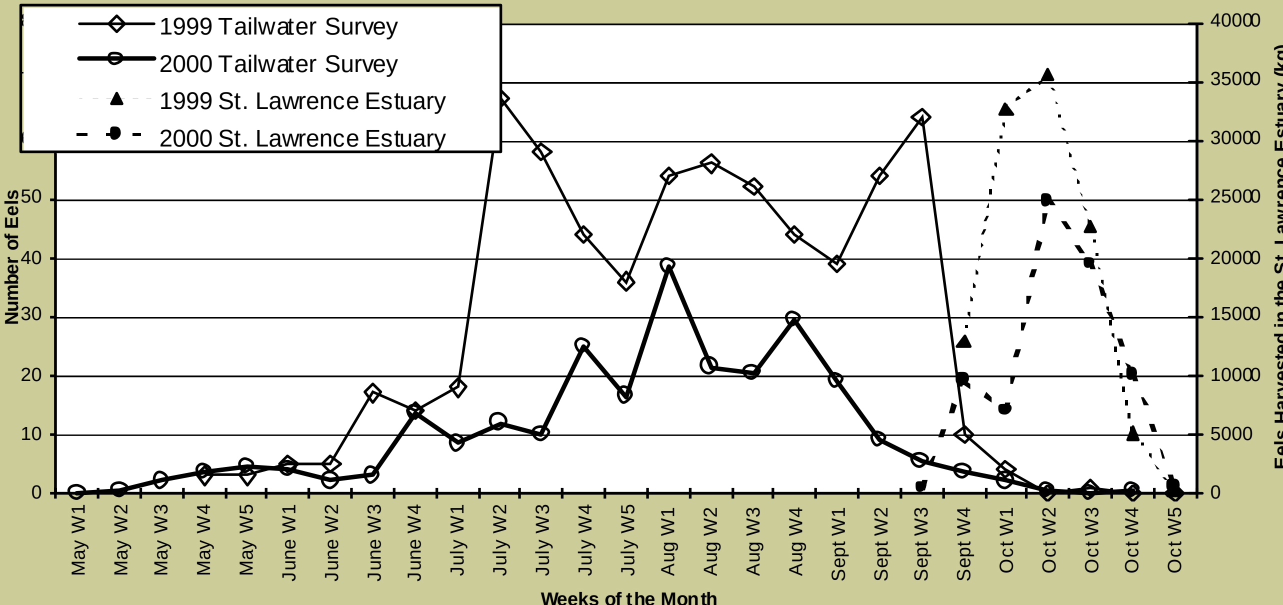
Option 4 – Project Shutdown During Eel Migration (Continued)

- Predictability and duration of out migration clearly varies with stream/river size

  -- Migration in upper portions of large rivers does not appear to be pulsed or triggered (upper St. Lawrence River, following figure)

  -- But migration out of lower portions of large rivers may be similar to patterns shown in small rivers and streams (i.e., Verreault et al. 2002)



Number of eels collected weekly per collection day of effort at the International St. Lawrence Power Project Harvest in the St. Lawrence Estuary for 1999 and 2000. (Estuary data provided by G. Verrault, 2001: G. Verrault, La Société de la faune et des parcs du Québec, Government of Quebec, personal communication to Kevin McGrath, New York Power Authority, March 2000; cited in Kleinschmidt Associates, 2001.)

Option 4 – Project Shutdown During Eel Migration (Continued)

- Attempts to develop accurate models to predict eel migration have not been consistently successful

  -- Hvidsten (1985) conducted multivariate correlation analyses that explained 9% to 68% of migration variability

  -- Euston et al (1997) explained 19.8% of variability with a regression model

  -- Haro will report on another predictive model

  -- model development is limited by absence of accurate long-term data sets and concurrent records of all potentially important environmental variables

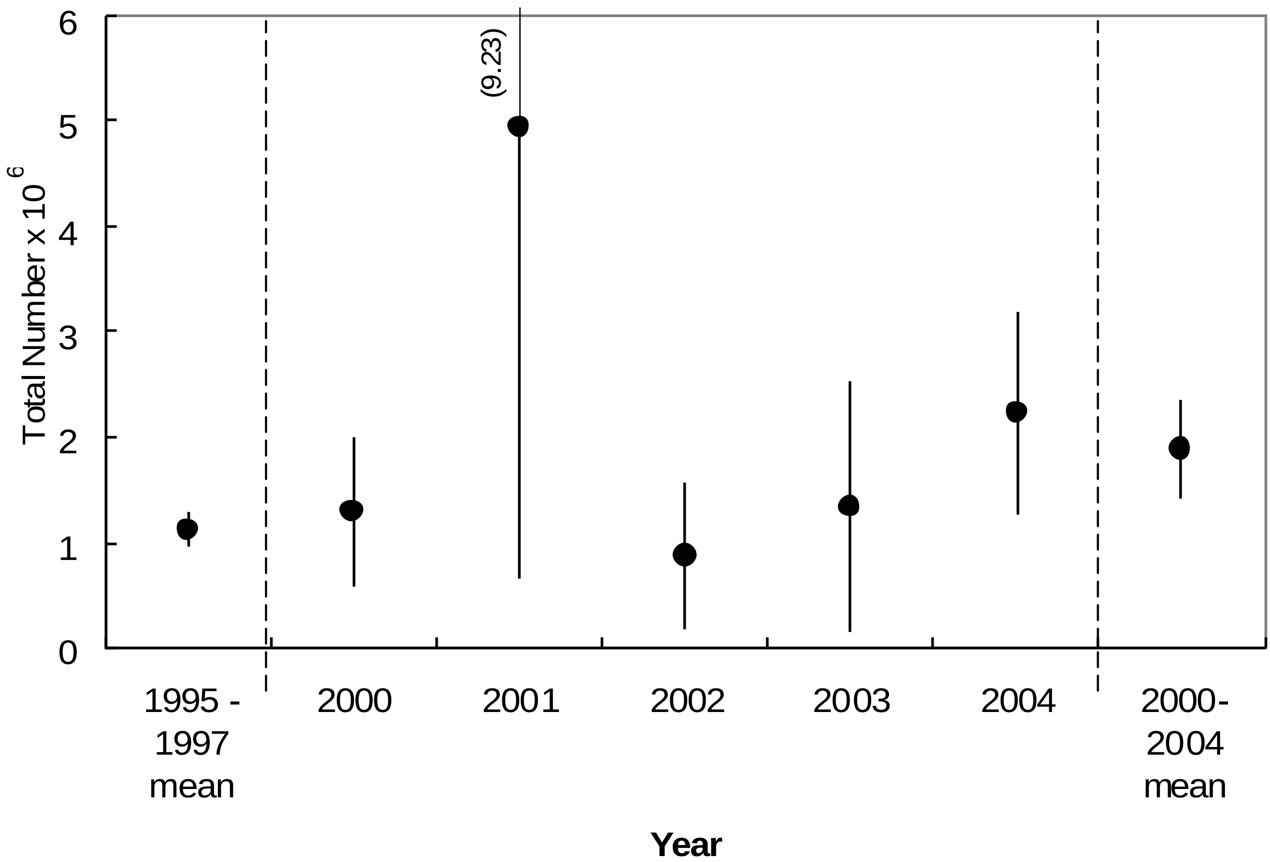
- Option 4 has been applied (night only) at some hydroelectric projects where project owners and fisheries managers have achieved compromises regarding risks to eels and risks to project financial viability.

Option 5: Trap and Transport

- Pros:
  - -- Efficient in systems where eels have to pass multiple projects
  - -- May be feasible option where other alternatives are infeasible (e.g., site and project characteristics, cost)
  - -- May be most feasible in small streams and rivers
- Cons:
  - -- Setting trapping times subject to same uncertainties as with plant shutdowns
  - -- Difficult to ensure capture of high percentage of run
  - -- Gear deployment challenges (e.g., net anchoring, fouling)
  - -- Unknown effect of interrupting normal downstream migratory behavior
- Employed by RWE Energie in Moselle River, Germany

Overview

- Light, infrasound, and barriers combined with bypasses all have potential as effective mitigation measures
- Project shutdown guarantees eel protection, but benefits to eels have to be weighed against impact on generation output of the project
- Site- and project-specific characteristics will determine which mitigation methodology will be most cost-effective for providing the degree of protection to out-migrating eels that is desired.
- Size of the St. Lawrence River provides very unique challenges



Total Number x 10^6
0
1
2
3
4
5
6
(9.23)
1995 - 1997 mean
2000
2001
2002
2003
2004
2000-2004 mean
Year

Downstream eel passage in Maine

Gail Wippelhauser

Maine Department of Marine Resources


Heather
Perry

The problem

- Characterization of Maine's hydropower dams
  - Number
  - Rated capacity
- Habitat range of eels
- Degree of overlap

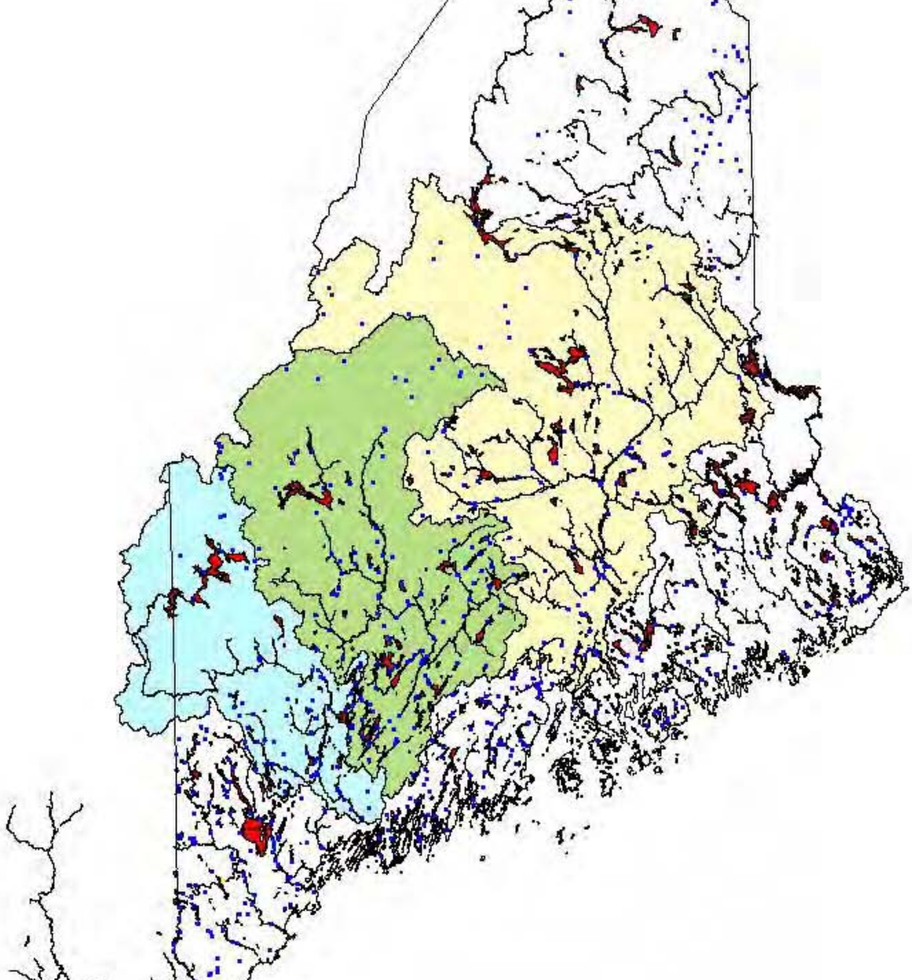
The solutions

- Determined on a case-by-case basis
- Dam removal
- Shutdown (cease generation)
  – Studies to determine timing
  – Real-time information
- Physical exclusion
  – With or without bypass or gates
  – With or without limited shutdowns
- Bypass alone


Heather Perry

Hydropower facilities in Maine

- 125 licensed hydropower facilities
  - 40 are rated for $\leq$ 1000 KW
  - 37 are rated for 1100-10,000 KW
  - 21 are rated for > 10,000 KW
- Approximately 94 facilities are within historic range of American eel



Dam removal

- Two dams have been removed
  - Edwards Dam
  - Smelt Hill Dam


Head-of-tide dam on Kennebec River
Environmental impacts on 10 native diadromous species
Upstream anadromous passage too costly

Head-of-tide dam on Presumpscot River
Flooded in 1996

Dam removal

- Five dams are proposed for removal

  – Fort Halifax Dam
    - First dam on the Sebasticook River (largest tributary in Kennebec watershed)
    - Upstream anadromous passage too costly

  – Madison Electric Works
    - First dam on Sandy River (tributary of Kennebec River)
    - Upstream anadromous passage too costly

Dam removal

- Penobscot River Restoration Project
- Settlement to purchase three dams because of environmental impacts on 10 species of diadromous fishes
  - Proposed removal of Veazie (head-of-tide dam) and Great Works (second dam)
  - Proposed decommissioning of Howland (first dam on the Piscataquis River, tributary of the Penobscot)

Great Works

Howland

Shutdowns

- Saccarappa, Mallison Falls, Little Falls, Gambo, Dundee on the Presumpscot River
  - 8 hours per night for 8 weeks and 3-year study
  - entirely for downstream eel passage
- Damariscotta Mills
  - July 1-November 30
  - for downstream clupeid and eel passage


Heather
Perry

Shutdowns

- Anson and Abenaki on the Kennebec River
  - Targeted shutdowns using hydroacoustics to identify downstream migrating eels
  - Efficiency standards

Exclusion

- American Tissue
  - Shutdowns for 2 years; currently exclusion
  - Punch plate and open deep gate
- Benton Falls (proposed)
  - Intake overlay with 1” spacing
  - Surface bypass (for clupeids)
- Burnham (proposed)
  - Trash racks currently have 1” clear space
  - Provide gate for for egress


American Tissue
DANGER
deep gate

Exclusion

- Orono and Stillwater
  - Trash rack with 1” clear opening and gated surface and deep discharge
- Milford
  - Trash rack with 1” clear spacing on upper 12’’ and gated deep discharge

Bypass

- Medway
  - Vertical slot with bellmouth weir

Conclusions

- Downstream eel passage - 9 years old
- Downstream eel passage measures are variable
  - depends on when project was relicensed
  - depends on the community of species
  - depends on the geography of the site
- Efficacy of measures unknown

Simulation of Migration and Passage of American Eels at Riverine Barriers

Alex Haro, Ted Castro-Santos

S. O. Conte Anadromous Fish Research Center, Biological Resources Division, U. S. Geological Survey, Turners Falls, MA

Lia McLaughlin

U. S. Fish and Wildlife Service, Red Bluff, CA

Kevin Whalen

Bureau of Land Management, Washington D.C.

Gail Wippelhauser

Maine Department of Marine Resources, Augusta, ME

Problems in Downstream Eel Passage:

- High turbine mortality rate for eels
- Limited effectiveness of mechanical barriers (screens, racks, louvers)
- Limited effectiveness of conventional behavioral barriers (light, sound)
- Specifics of downstream migration not well understood (run timing, environmental correlates)

USGS

Turbine Mortality Rates for Eels (percent)

Kaplan

23.8	Desrochers 1994
26.5	NYPA 1998
37	NIMO 1996
>25	Hadderingh & Bakker 1996
20-50	Berg 1986
>50	Monten 1985
90 - 100	Mitchell & Boubee 1992

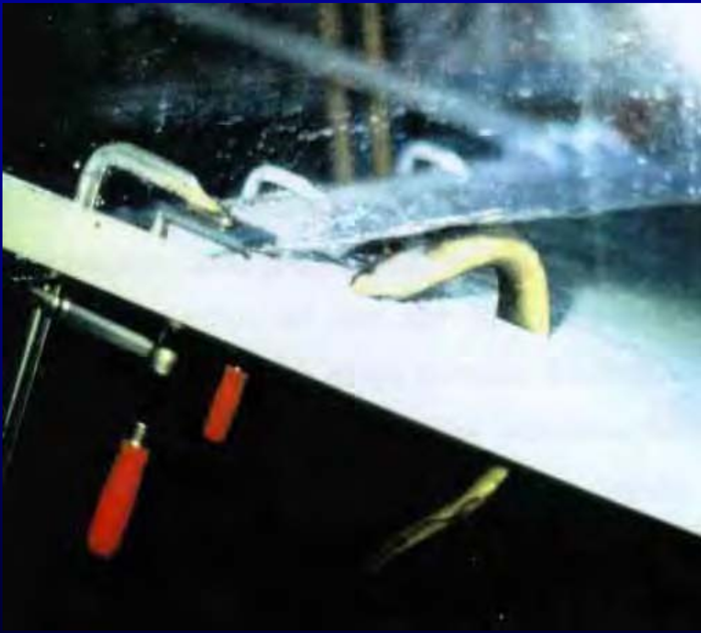
Francis

15.7	Desrochers 1994
6	NIMO 1995
9	RMC 1995
47 - 76	Mitchell & Boubee 1992

Photo: Desrochers 1995

USGS

Responses to vertical and angled (vertically) bar racks

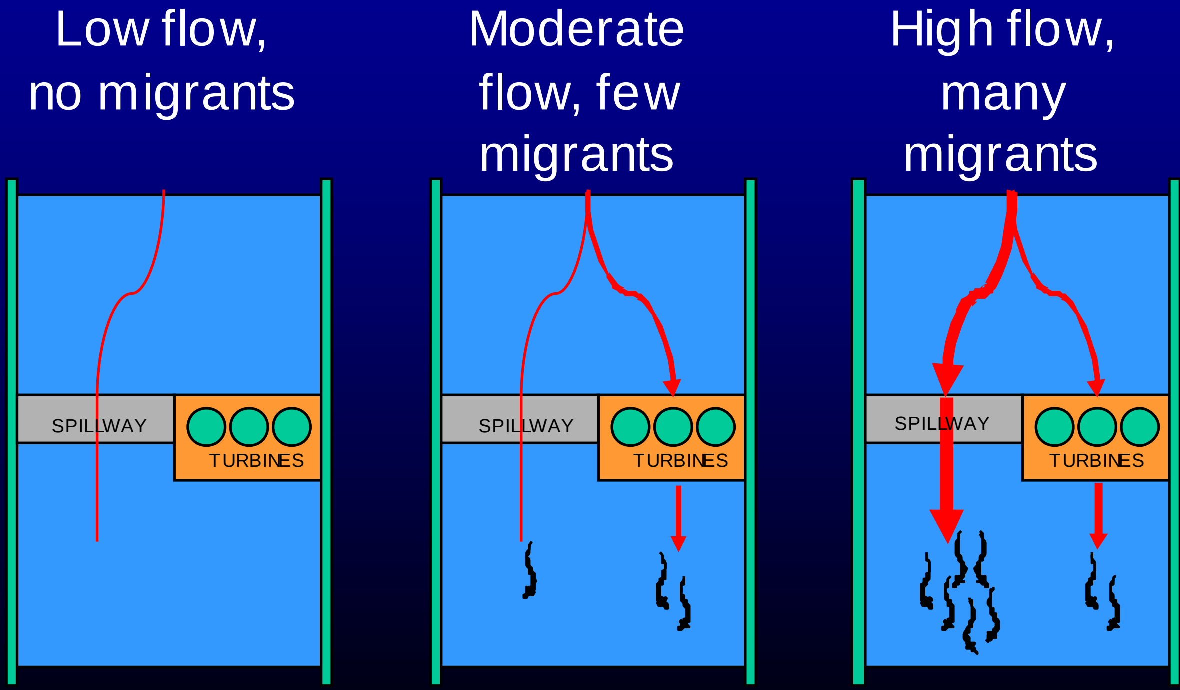


Photos: Adam and Schwevers 1997

Operational Alternatives for Downstream Passage of Eels

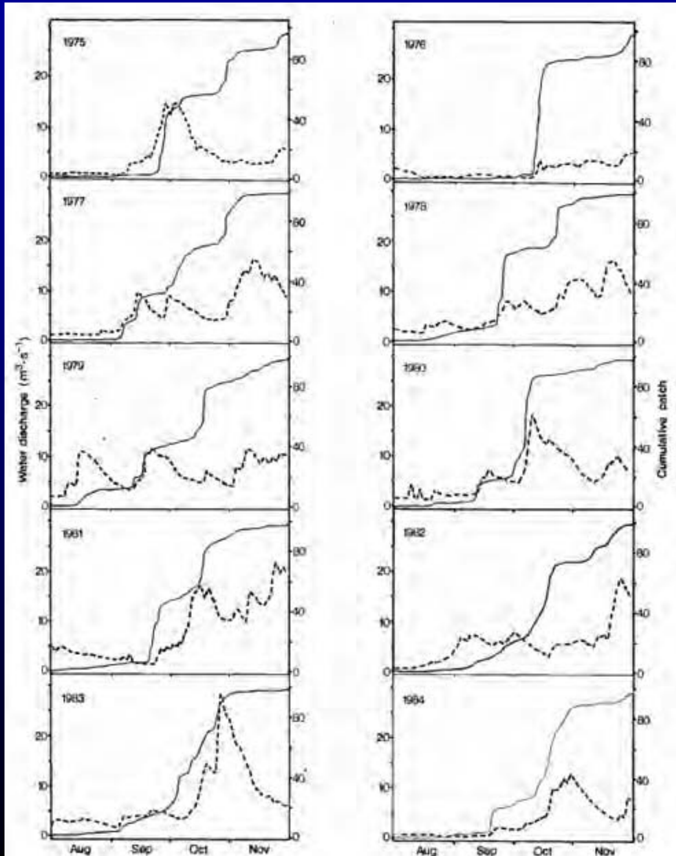
- Can we predict patterns of downstream migration?
- How much can total run mortality be reduced by modifying project operation?

Relationships of migration timing, flow, and station operation



Vøllestad et al. 1986

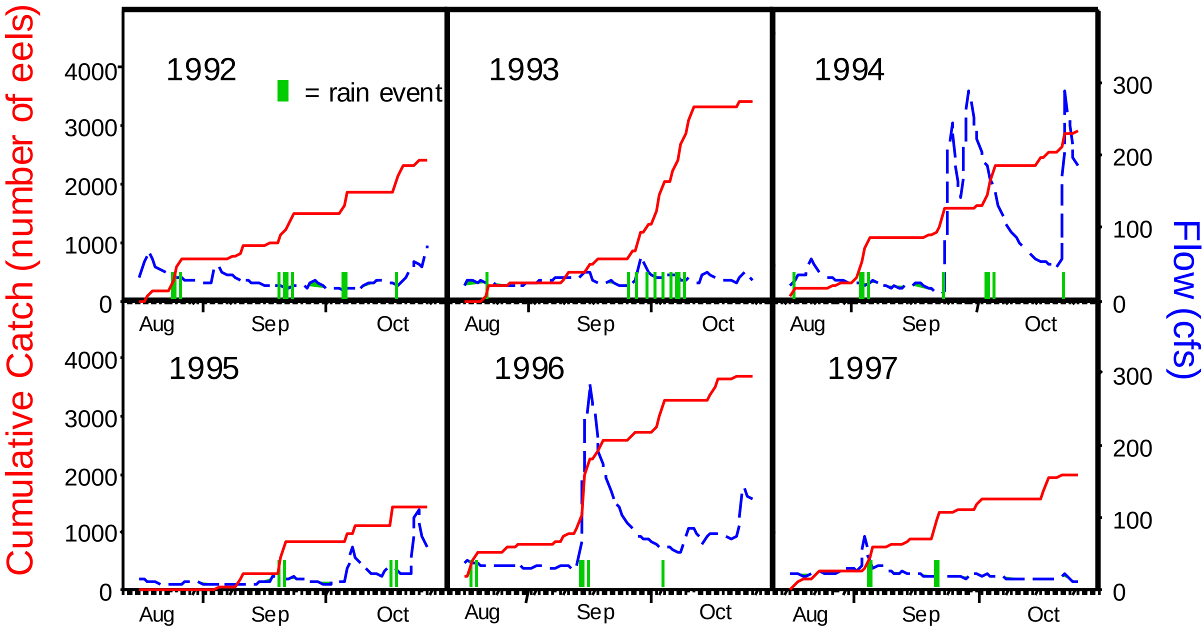
- Analysis of 10 year European eel weir catch dataset
- Start and duration of run correlated with mean water temperature and mean flow
- No significant relationships for *daily* rate of descent and any environmental variable



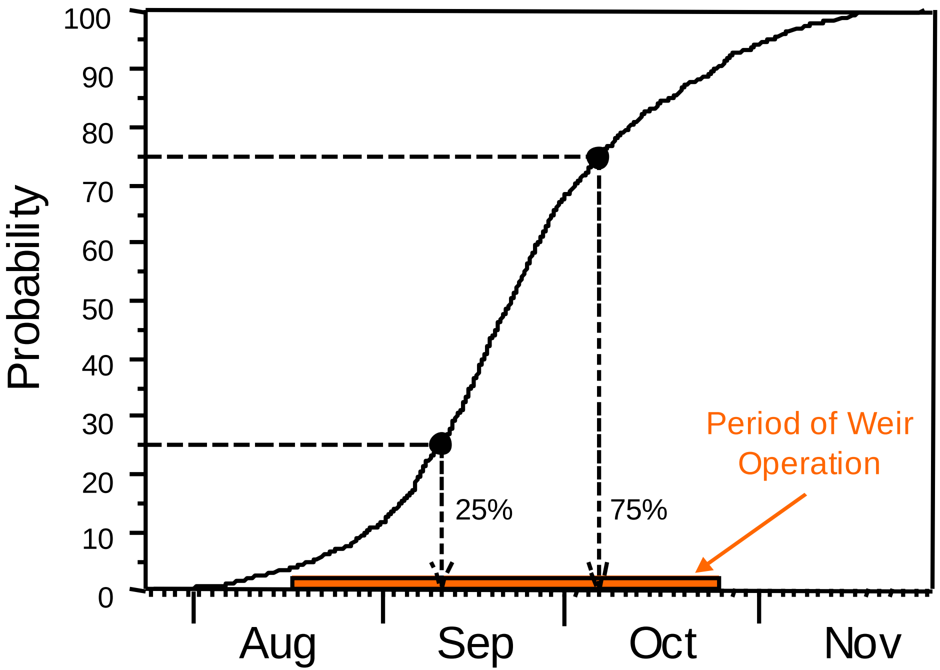

Silver eel weir in Maine

USGS

Six Year Catch Dataset from Maine Eel Weir



Probability Density Function for 1992-1997 Maine Eel Weir Data



Parameters for Simulation Model (*small* hydro project):

- Watershed Area = 145 mi^2
- Mean Annual Flow = 300 cfs
- Minimum Spill = 0,5,10,20,40,or 80 cfs
- Turbine Mortality = 25%
- Spill Mortality = 2%

Three Operational Scenarios:

Normal Operation

- Generate when flows are in excess of minimum spill

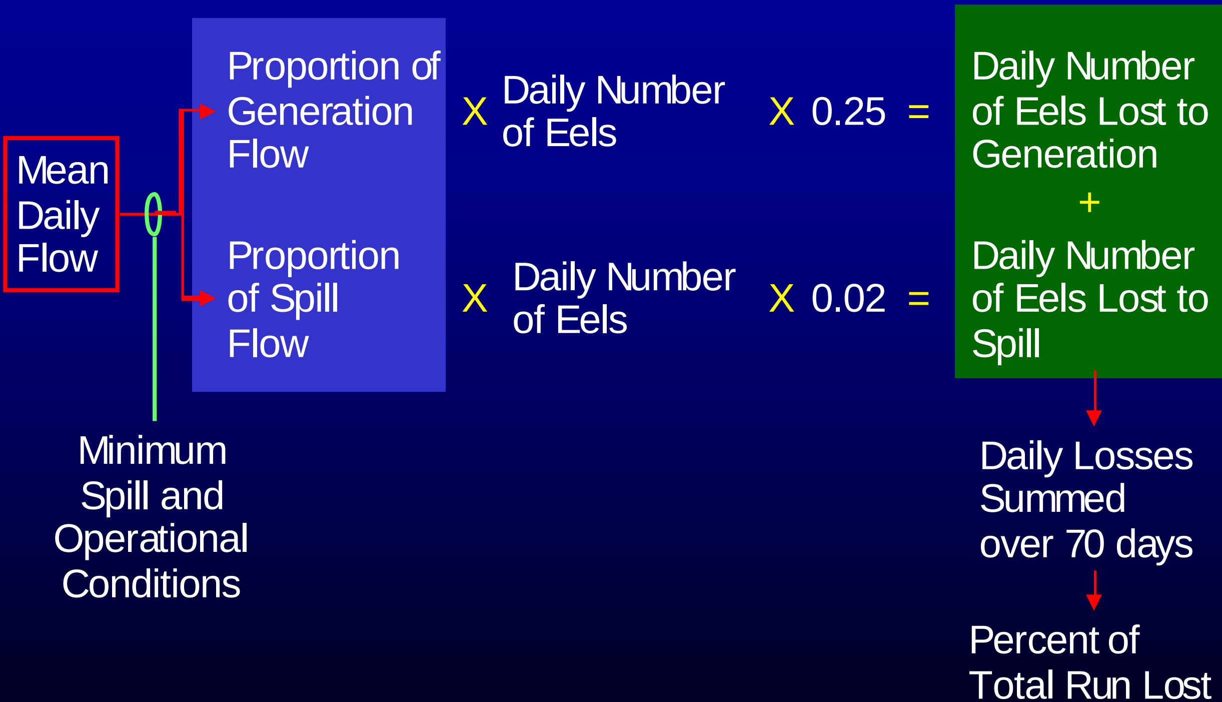
Narrow Window Operation

- Suspend generation between 10 Sept. and 6 Oct. (25%-75% PDF)

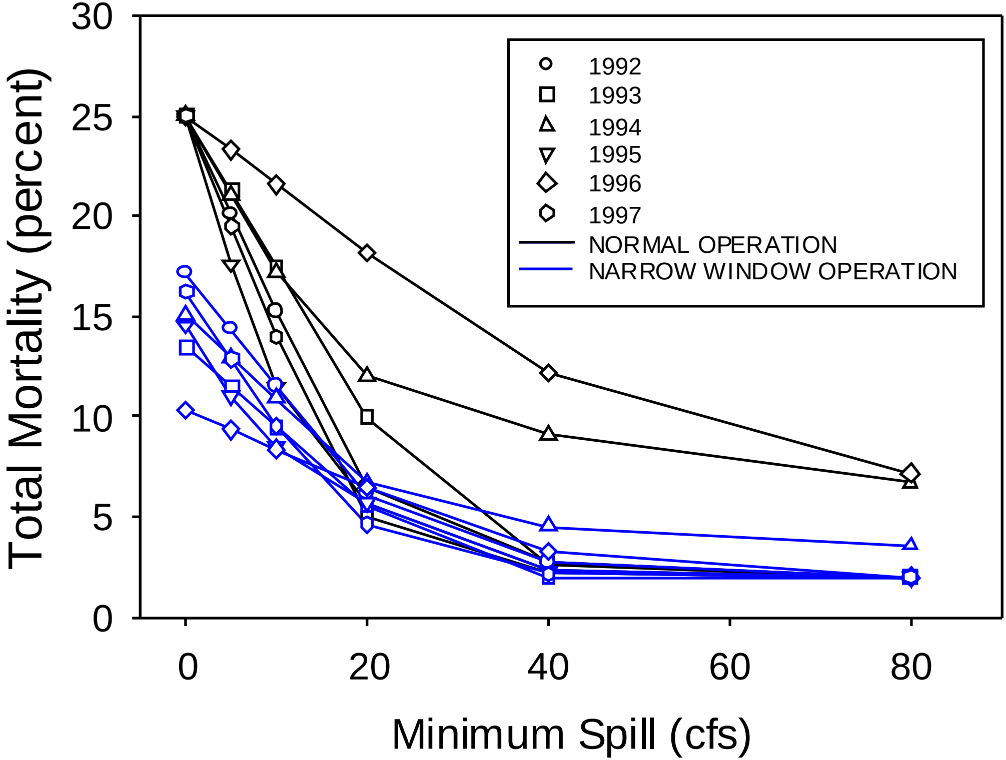
Rain Event Operation

- Suspend generation on days when rain event occurs

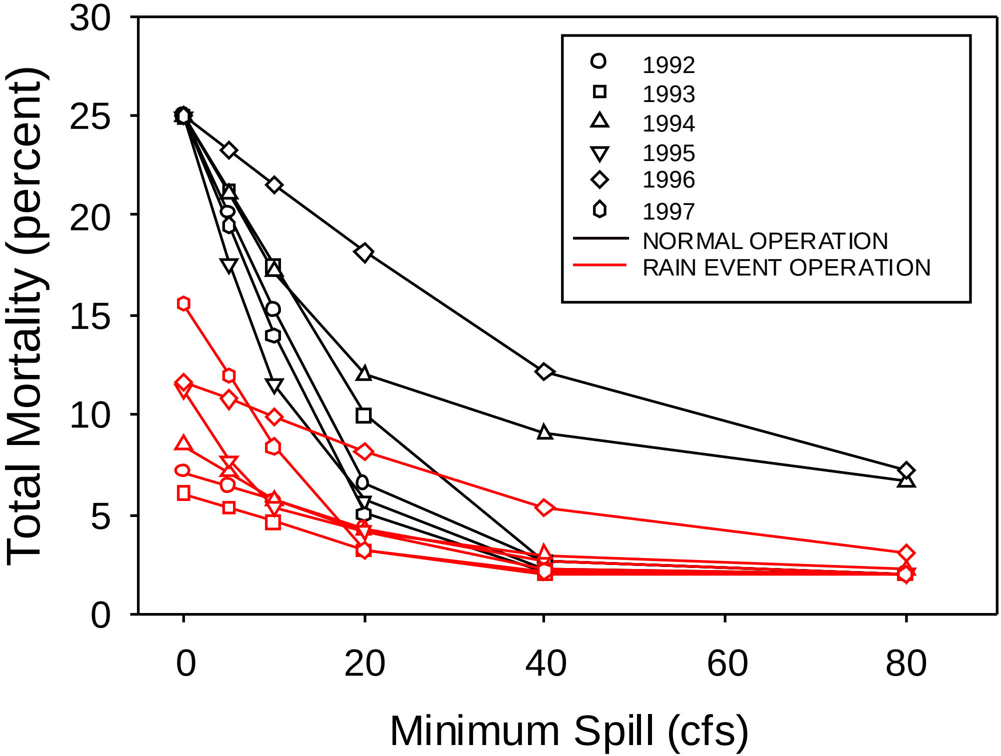
Simulation Model Design



Simulation results: Normal vs. Narrow Window Operation



Simulation results: Normal vs. Rain Event Operation



Conclusion:

- Reduction in total run mortality by modification of operation can be significant, *if patterns of migration can be predicted*

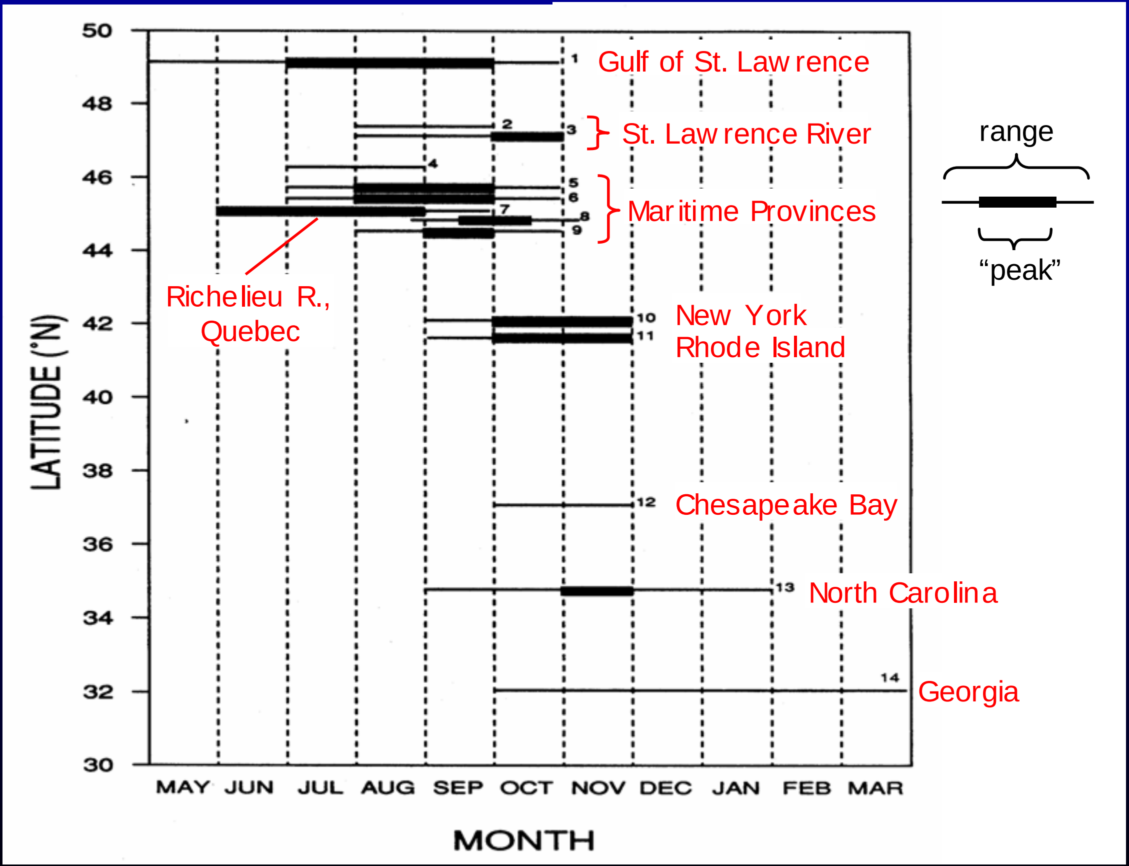
But -

- Modification of operation may not be practical or effective at some sites (e.g., large rivers, regulated or complex flows)
- Costs and benefits of structural versus operational mitigative techniques should be thoroughly evaluated

Assumptions Need to be Verified!

- *Route selection proportional to flow?*
- *Weir data from small streams representative of larger rivers?*
- *Spill and turbine mortality quantified?*
- *Migration timing and behavior consistent between sites?*

Local and geographic variation in run timing



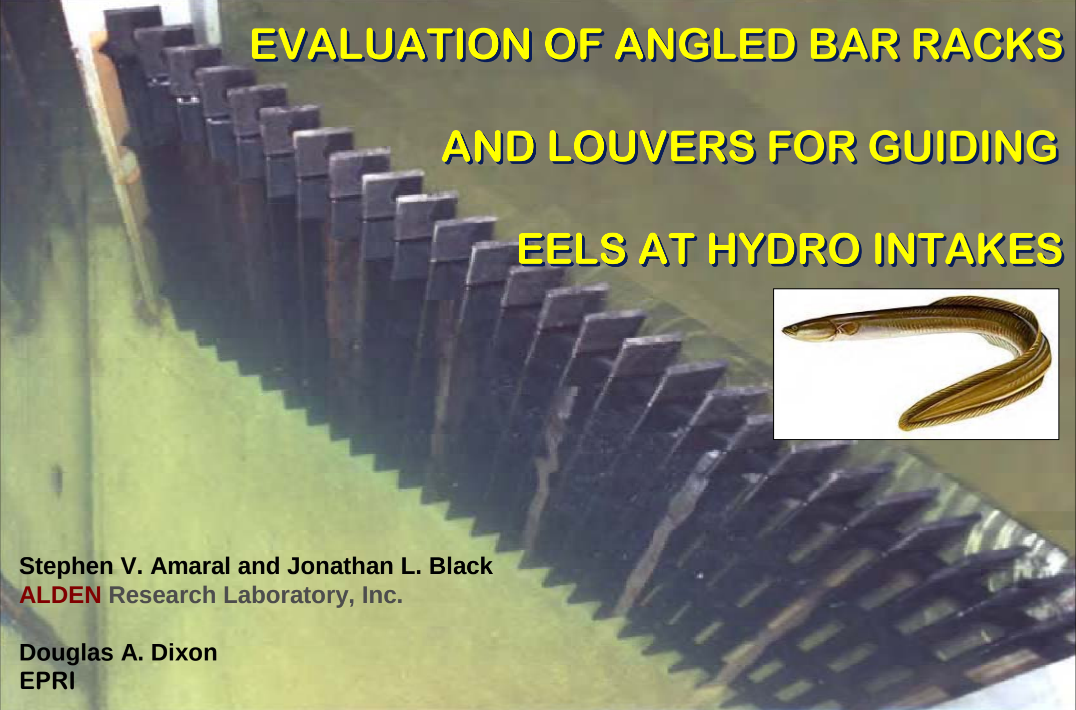
Assumptions about "safe" passage via spill!

USGS

Future Directions

- Improve understanding of migration timing and cues
- Investigate effect of river/project size on run characteristics
- Quantify mortality estimates (especially spill mortality)
- Refine predictive model designs

EVALUATION OF ANGLED BAR RACKS AND LOUVERS FOR GUIDING EELS AT HYDRO INTAKES



Stephen V. Amaral and Jonathan L. Black
ALDEN Research Laboratory, Inc.

Douglas A. Dixon
EPRI

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Wisconsin DNR

US Fish & Wildlife Service

Michigan DNR

Conte Anadromous Fish Research Lab

Hydrothane

BACKGROUND

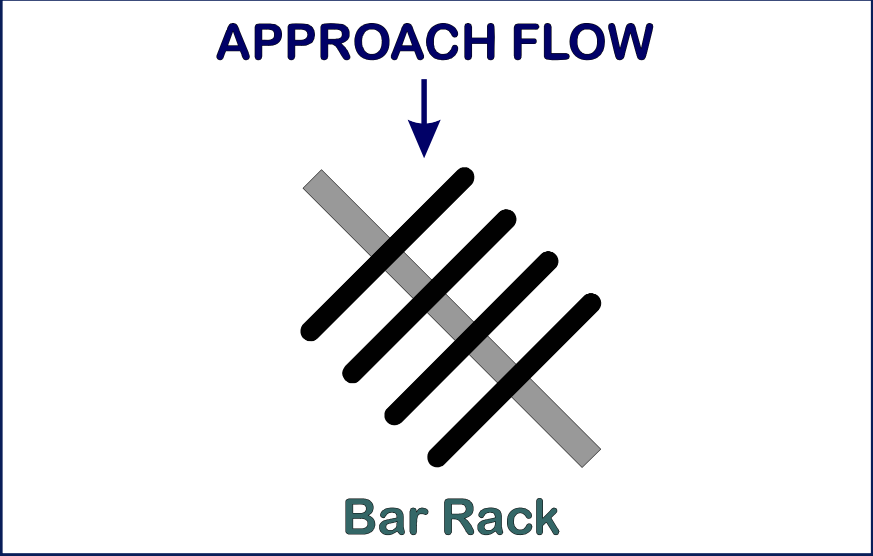
- Angled bar racks have been prescribed for use at many projects in Northeast
- Most bar rack field evaluations have been conducted with anadromous species and results have been mixed
- Louvers have been effective at guiding anadromous species at several sites
- Limited to no information for guidance of riverine species and the catadromous American eel

STUDY OBJECTIVES

- Quantitatively evaluate the ability of selected fish species to guide along various configurations of bar racks and louvers

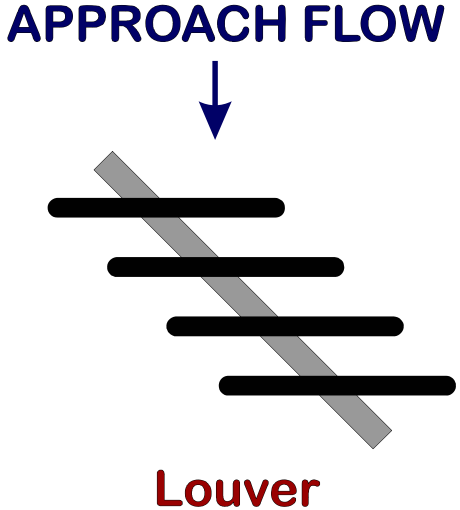
- Qualitatively evaluate fish behavior in the vicinity of the bar racks and louvers

METHODS *Slat Orientation*



METHODS

Slat Orientation



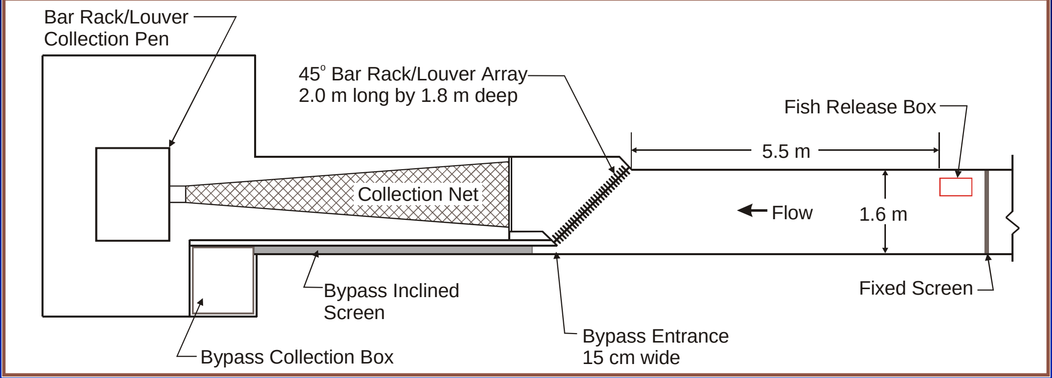
METHODS

Test Parameters

	1999		*2000*	
Parameter	*Bar Rack*	*Louver*	*Bar Rack*	*Louver*
Angle to flow	45^{o}	45^{o}	15^{o}, 90^{o}	15^{o}
Spacing (mm)	25, 50	50	50	50
Velocity (m/s)	0.3 – 0.9	0.3 – 0.75	0.3 – 0.9	0.3 - 0.9
Bypass depth	Full	Full	Full	Full
Fish release	Surface	Surface	Bottom	Bottom
Guide wall	No	No	Yes	Yes
Bottom overlay	No	No	Yes/No	Yes/No
Avg Length (mm)	558		568	

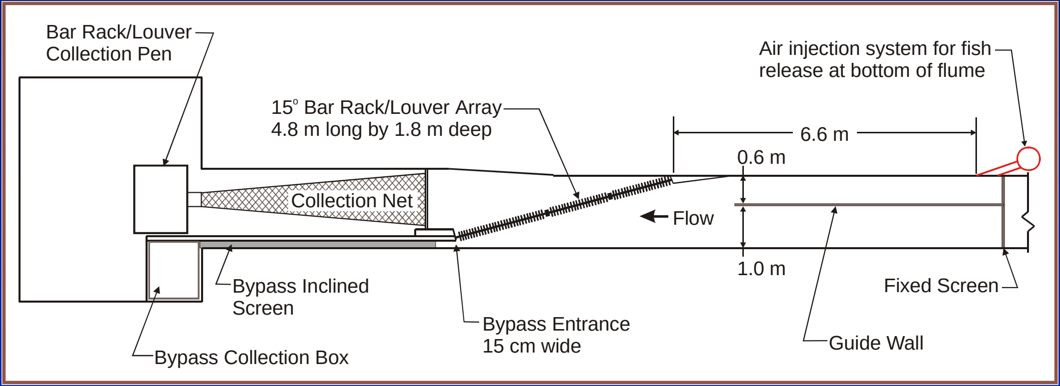
METHODS *Fish Testing Facility*

1999 Test Configuration



METHODS *Fish Testing Facility*

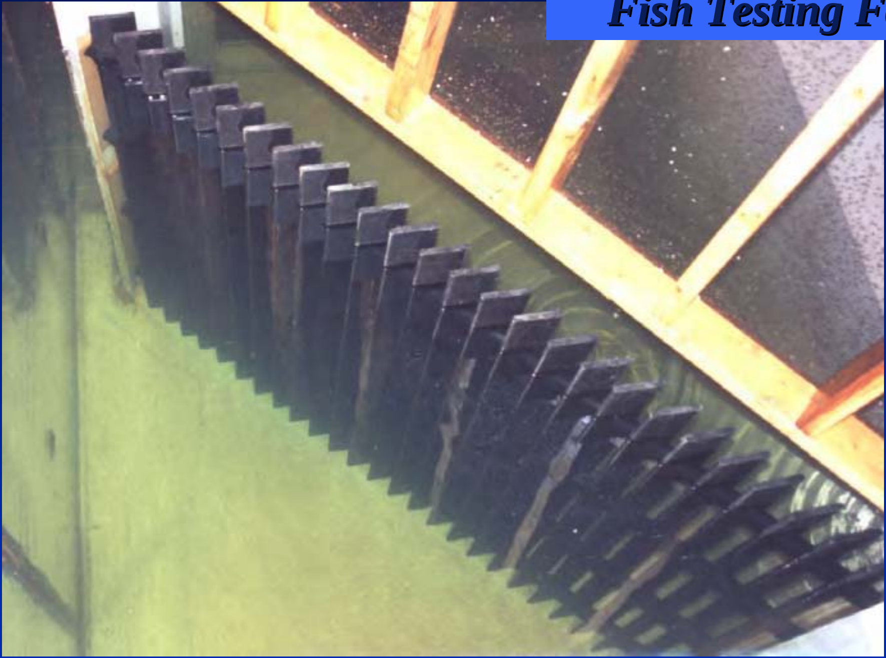
2000 Test Configuration



Fish Testing Facility

45^{o} Bar Rack and Bypass with Inclined Screen

Fish Testing Facility



45º
Louver

Fish Testing Facility

15º Bar Rack without Bottom Overlay

Fish Testing Facility

15° Bar Rack with
Bottom Overlay

RESULTS *American Eel*

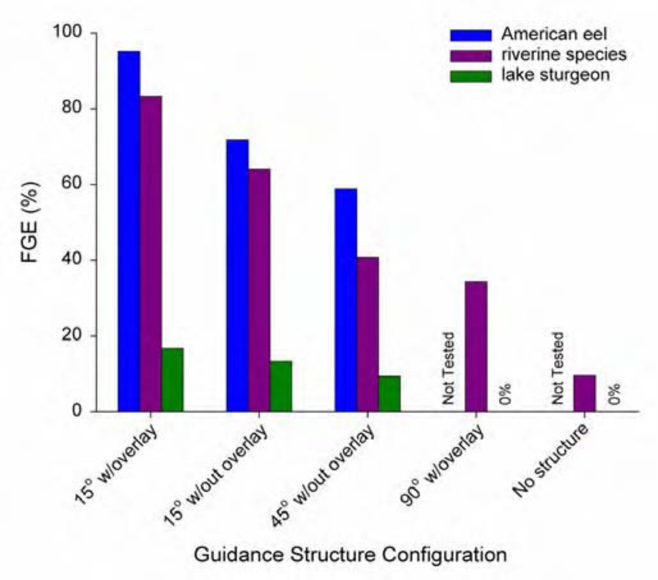
Approach Velocity (m/s)	Number of Trials (*N*)	Number of Fish Released	Percent Recovery	Mean Guidance Efficiency (%) (SE)
45º Bar rack with 25-mm spacing				
0.30	3	45	95.6	64.8 (8.0)
0.60	3	45	97.8	56.5 (7.0)
0.90	3	45	97.8	65.9 (12.0)
45 º Bar rack with 50-mm spacing				
0.30	3	45	97.8	72.5 (5.0)
0.60	3	45	90.0	57.8 (4.0)
0.90	3	45	97.8	53.3 (3.0)
45 º Louver (50-mm spacing)				
0.30	3	45	93.3	33.3 (2.0)
0.60	3	45	93.3	62.1 (4.0)
0.75	3	45	97.8	45.4 (4.0)

RESULTS *American Eel*

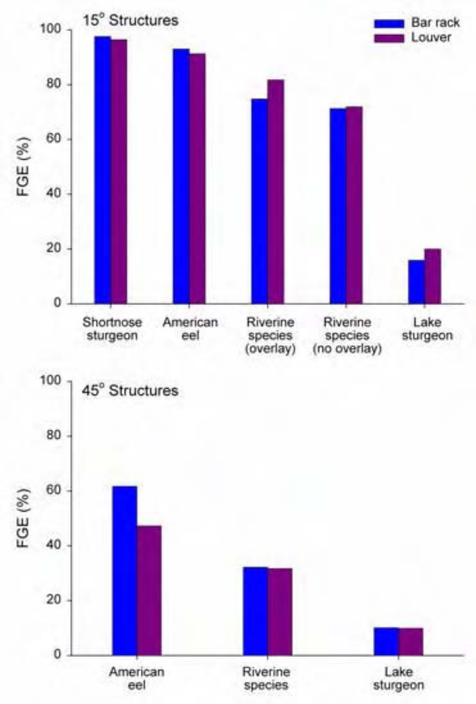
Approach Velocity (m/s)	Number of Trials (*N*)	Number of Fish Released	Percent Recovery	Mean Guidance Efficiency (%) (SE)
		15º Bar rack		
0.3	3	45	91.1	95.1 (3.0)
0.6	3	45	88.9	95.2 (4.0)
0.9	3	45	100.0	88.9 (4.0)
		15º Bar rack		
0.6	2	30	80.0	83.3 (0.0)
		15º Louver		
0.3	3	45	97.8	88.7 (4.0)
0.6	3	45	91.1	95.2 (2.0)
0.9	3	45	91.1	90.3 (2.0)
		15º Louver		
0.6	3	45	77.8	60.7 (4.0)

RESULTS *Fish Guidance Efficiency*

FGE by Guidance Array (0.6 m/s only)

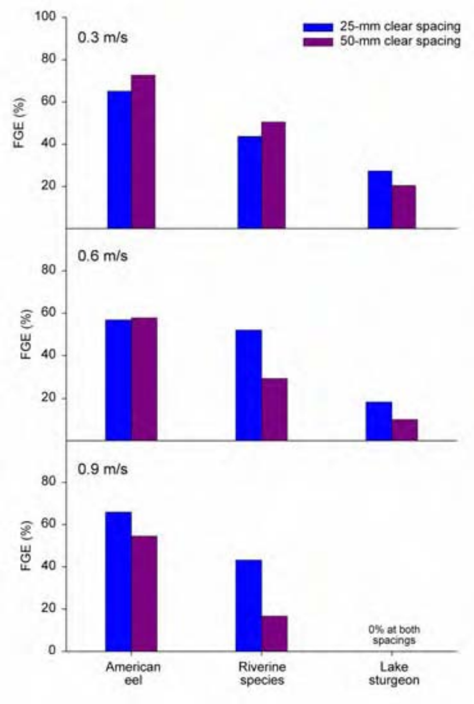


RESULTS *Fish Guidance Efficiency*



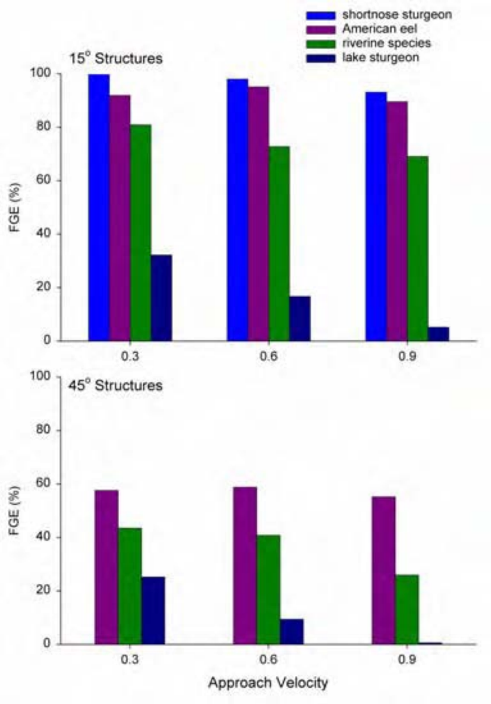
FGE by Slat Angle (0.6 m/s only)

RESULTS *Fish Guidance Efficiency*



FGE by Slat Spacing and Approach Velocity

RESULTS *Fish Guidance Efficiency*



FGE by Approach Velocity

Conclusions *Guidance Efficiency*

- No clear relationship between FGE and slat spacing
- FGE of the bar rack was greater than the louver at an angle of 45^{o}, but was comparable at 15^{o}
- FGE at the 15^{o} angle was greater than at the 45^{o} angle, especially with the bottom overlay in place
- There was no clear trend between FGE and approach velocity

Conclusions *Visual Observations*

- It appeared that eels were not aware of the guidance structures until contact was made
- Eels often approached racks head first, after contact they usually moved rapidly upstream
- Some eels were impinged, but this appeared to be controlled behavior

Biological Evaluation of a New Turbine Designed to Minimize Fish Injury and Mortality

Downstream Passage for American Eel

Steve Amaral, George Hecker, and Tom Cook
ALDEN Research Laboratory, Inc.

Acknowledgements

U.S. Department of Energy

Advanced Hydro Turbine Systems Program

Technical Committee Members

DOE (Oak Ridge and PNNL)

USCOE

NOAA Fisheries

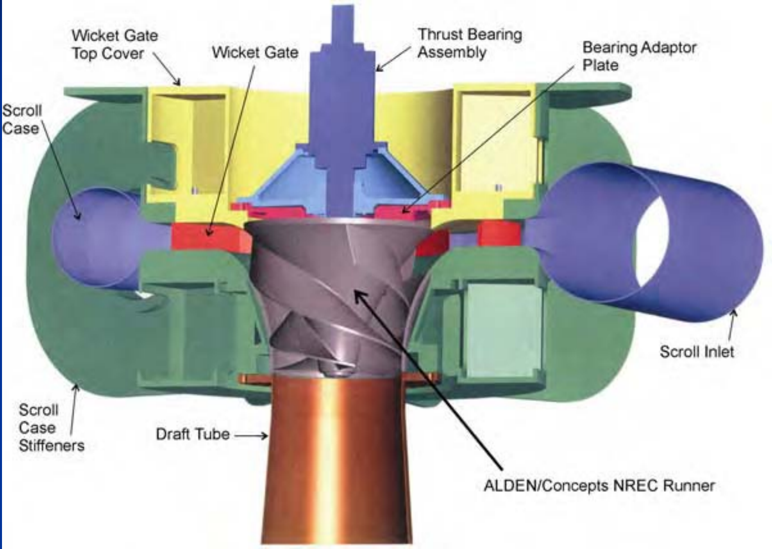
USGS

Industry Representatives

Biological Evaluation

- Turbine Design
- Study Parameters
- Study Methods
- Results
  - Turbine passage survival and injury rates
  - Effects of biological and engineering test conditions
  - Full-scale survival predictions
  - Turbine passage video observations
- Conclusions

Pilot-Scale Turbine



Study Parameters

No Wicket Gates rainbow trout	Test Series 1	◆ Effects of release depth
	Test Series 2/3	◆ Effects of turbine head ◆ Effects of fish size
Wicket Gates rainbow trout	Test Series 5/6	◆ Effects of turbine head ◆ Effects of fish size
Wicket Gates	Test Series 7	◆ Species evaluation
	Test Series 8	◆ Effects of fish size
	Test Series 9/10	◆ Effects of turbine efficiency

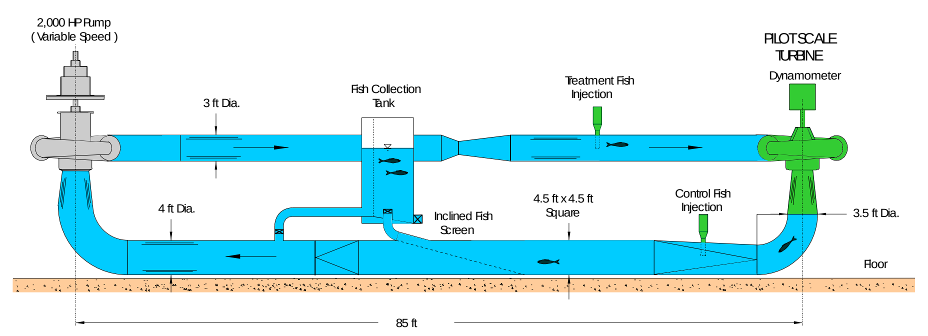
Study Methods

American Eel Test Conditions

Average FL (mm)	Head (ft)	Efficiency	Runner Speed (rpm)
249 431	40	BEP	240

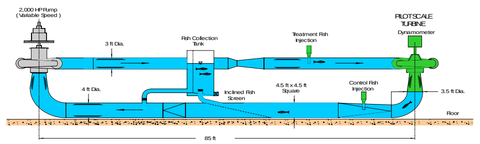
Study Methods

Pilot-Scale Test Facility



Study Methods

Pilot-Scale Test Facility



Study Methods

Fish Marking

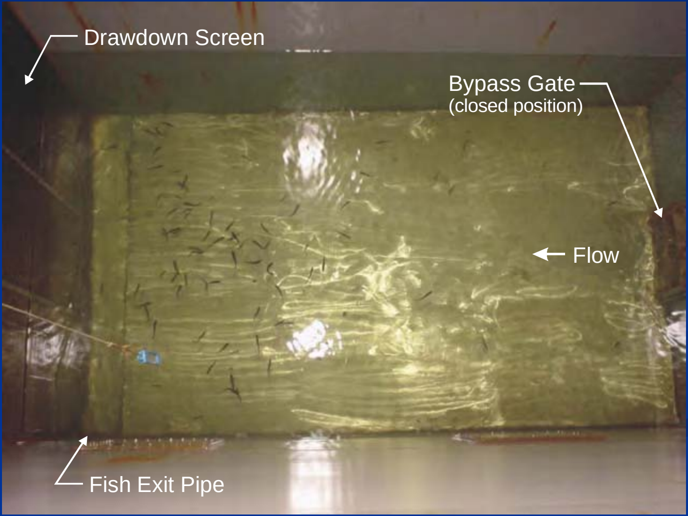
- New West POW'R-Ject marking gun
- 6 colors x 4 fins = 24 unique marks
- Anesthetized with clove oil solution
- Marked 2 days prior to testing
- Paired T/C groups held in same tank

Study Methods

Fish Release

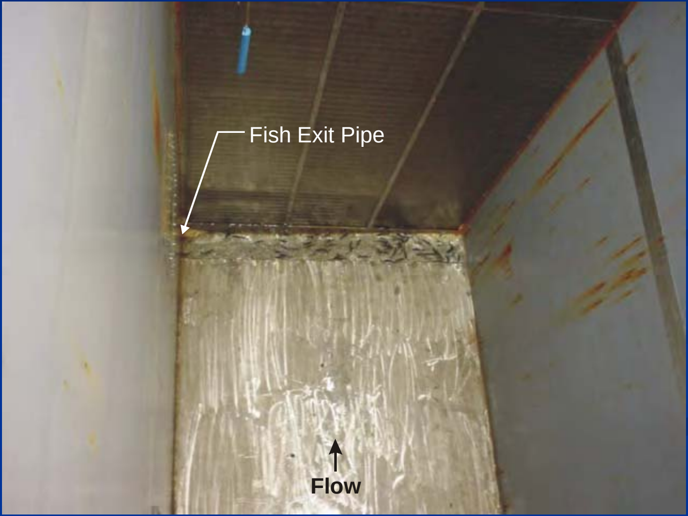
Study Methods

Fish Recovery



Study Methods

Fish Recovery



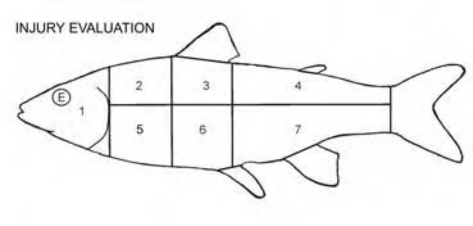
Study Methods

Fish Recovery

Study Methods

Injury Evaluation

- Bruising/hemorrhaging
- Lacerations
- Severed Bodies
- Eye damage



Study Methods

96-hr Delayed Mortality

Study Methods

Survival Analysis

- Nine replicate trials for each test condition
- 100 treatment and 100 control fish per trial
- Control and turbine survival rates were estimated for individual trials using MLE techniques
- Calculated pooled-replicate survival estimates and tested for significant differences among test conditions

Study Results

- Survival Estimates
  - Test data summary
  - Immediate (1 hr)
  - Total (1 hr + 96 hr)
- Injury Rates by Type
- Survival/Fish Length Relationship
- Predicted Survival for a Full-Scale Turbine
- Turbine Passage Video Observations

Study Results

American Eel Test Data Summary

40 ft Head - BEP - Wicket Gates Installed

Fish Size Group	Number of Trials	Test Group	Total Number of Fish Released	Mean FL and SD (mm)	Percent Recovered During Test of Release	Number Recovered Live	Number of Immediate Mortalities (1 hr)	Number of Delayed Mortalities (96 hr)
small	9	T	901	249 (23)	99.0	892	0	6
		C	902	249 (23)	96.0	866	0	2
		NM	--	--	--	6	0	0
large	9	T	894	429 (42)	90.2	804	2	20
		C	891	433 (41)	86.1	765	2	5
		NM	--	421 (26)	--	2	1	0

Study Results

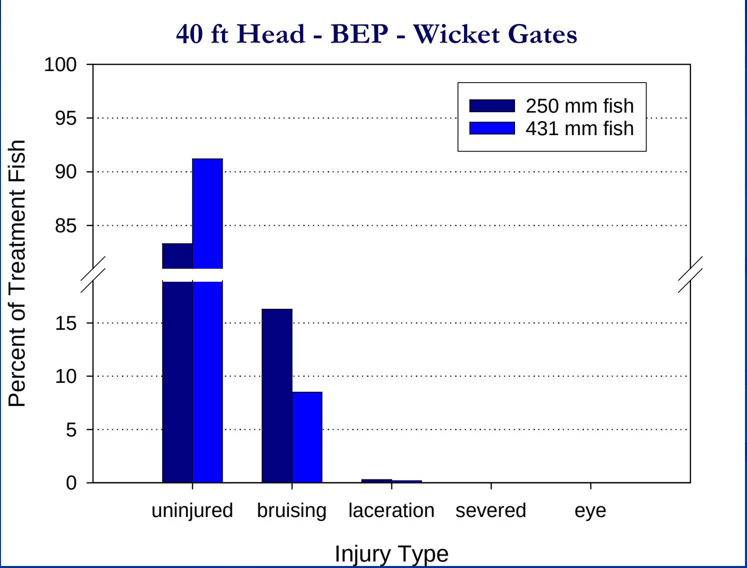
American Eel Survival Estimates

40 ft Head - BEP - Wicket Gates

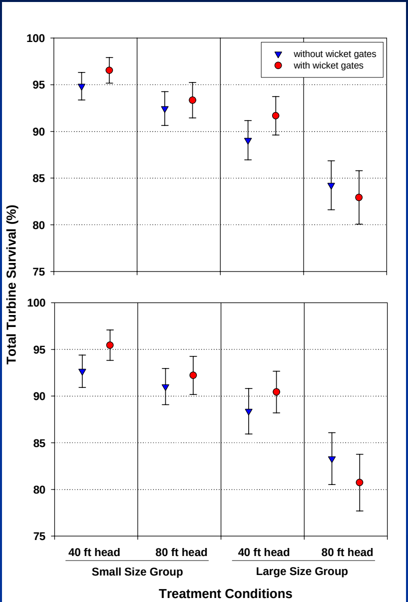
Mean Length (mm)	Immediate Turbine Survival (%) ± 95% CI	Total Turbine Survival (%) ± 95% CI
249	100.0 ± 0.0	99.6 ± 0.6
431	100.0 ± 0.5	98.2 ± 1.3

Study Results

American Eel Injury Rates



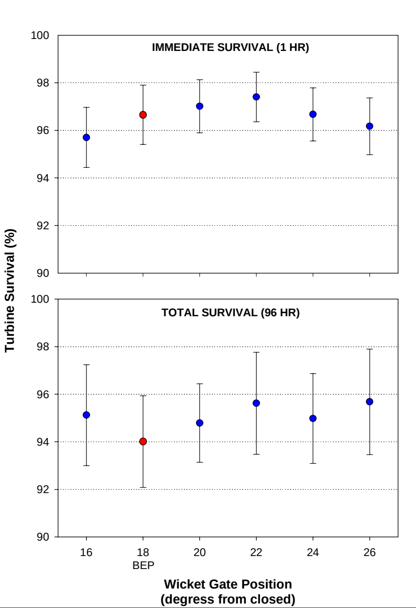
Study Results



Comparison of turbine passage survival with and without wicket gates

Rainbow trout
BEP

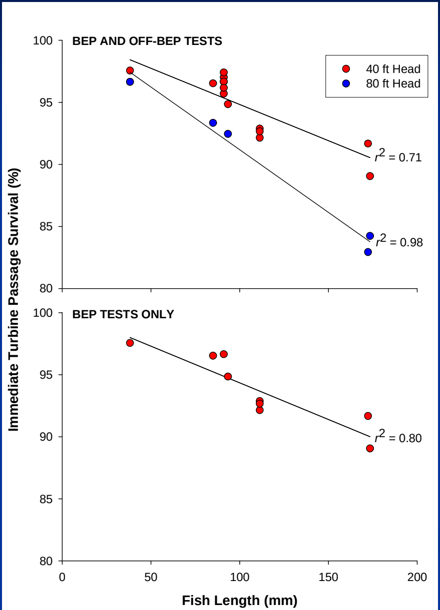
Study Results



Relationship between wicket gate opening and turbine passage survival for rainbow trout tested at 40 ft head

Wicket gate position of 18^{o} corresponds to estimated BEP of pilot-scale turbine

Study Results

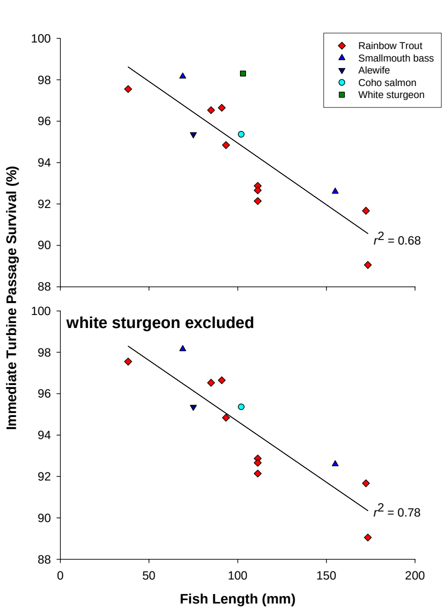


Relationship between fish length and turbine passage survival for rainbow trout

Includes data from tests with and without wicket gates

Off-BEP tests conducted at one wicket gate opening less than and four greater than BEP opening (degrees from closed position)

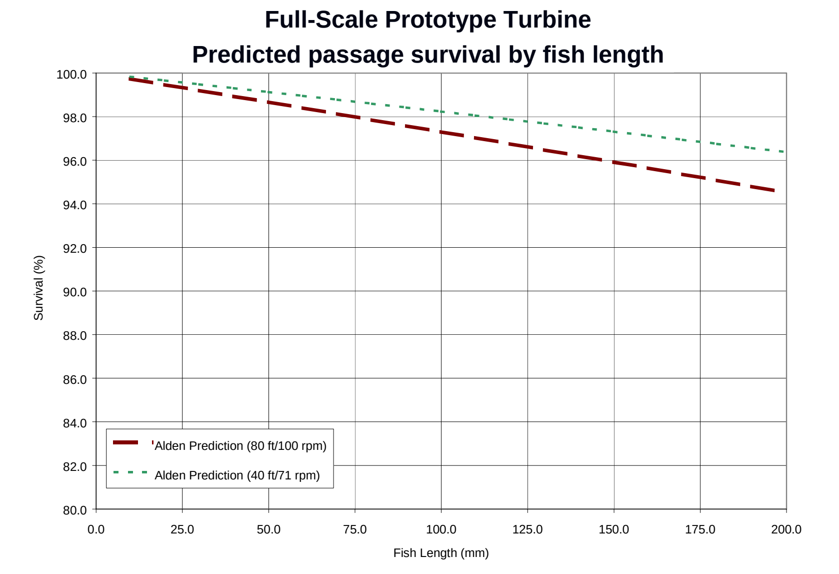
Study Results



Relationship between fish length and turbine passage survival

Data from tests with and without wicket gates at 40 ft head and BEP; excludes American eel test results

Study Results



Summary

Most comprehensive evaluation of direct turbine passage survival ever conducted in the history of the world

- Two operating heads
- Tests with and without wicket gates
- Six species with diverse morphologies and life histories
- Several distinct size groups for multiple species
- Six efficiency settings
- > 40,000 fish

Summary

All Species and Test Conditions

- No difference in survival rates with and without wicket gates
- Survival highly dependent on fish length – Except for American eel
- White sturgeon and American eel had significantly higher survival rates than other species
- No difference in survival rates among wicket gate positions (i.e., BEP and off-BEP openings)
- For live fish, injury and descaling rates were low (< 5% when control data are considered)
- Bruising was the most prevalent injury

Summary
American Eel

- Pilot-scale results for American eel (mean length = 249 and 431 mm)
  - Immediate survival (1 hr) = 100%
  - Total Survival (96 hr) > 98%
- Prototype Turbine (~ 4 m diameter, 100 rpm)
  - Eels over 1000 mm (40 inches) in length could experience passage survival rates of > 98%

What Next?

- Evaluation of relationship between fish survival and leading blade edge shape and thickness
- Turbine re-design to improve power output and efficiency
- Field installation and evaluation

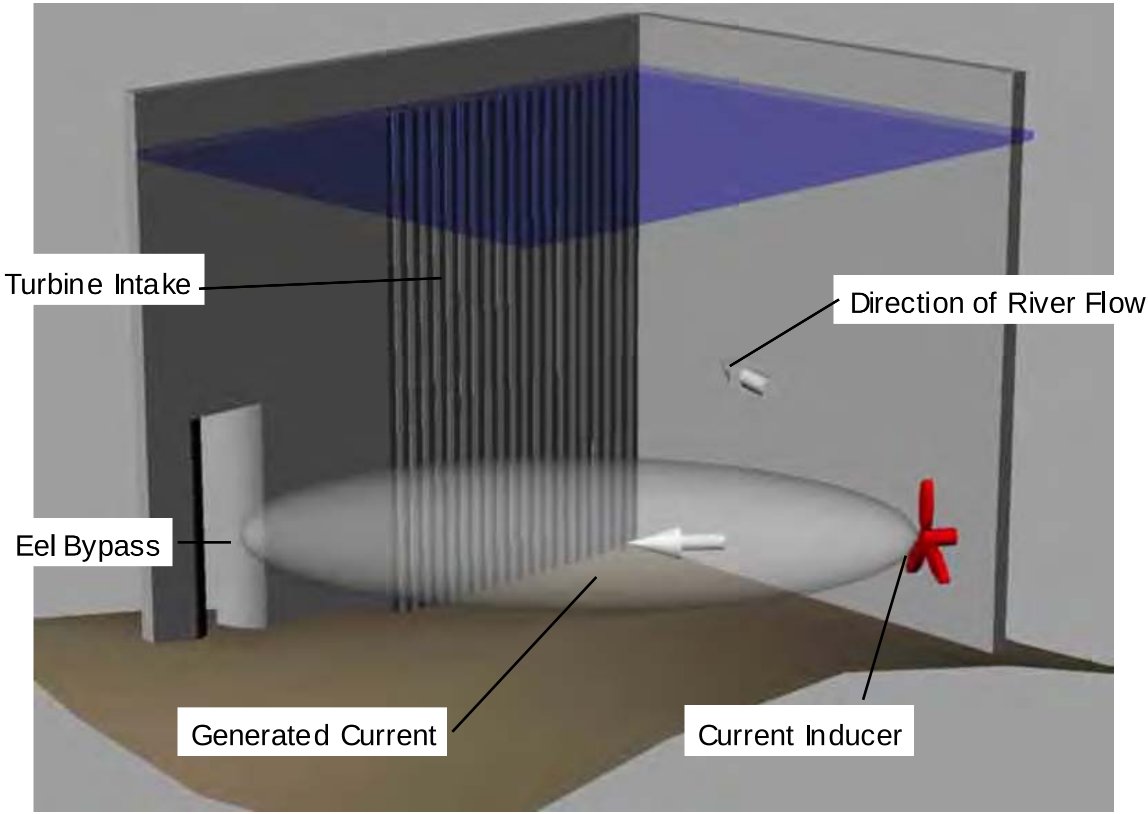
Mechanically Generated Currents to Facilitate Downstream Eel Passage at Hydroelectric Projects

Workshop on Methods of Safe Downstream Passage
for the American Eel

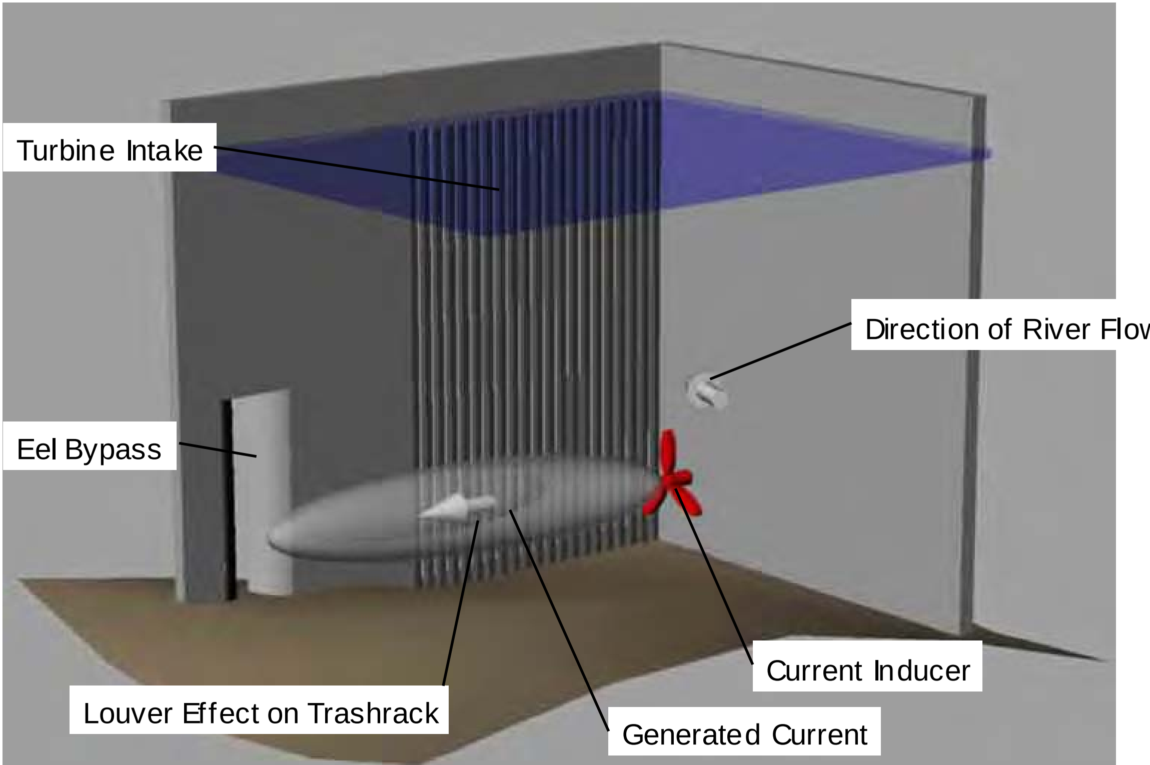
Poster Presentation by:
Eric Truebe
Lakeside Engineering, Inc.

February 17, 2005

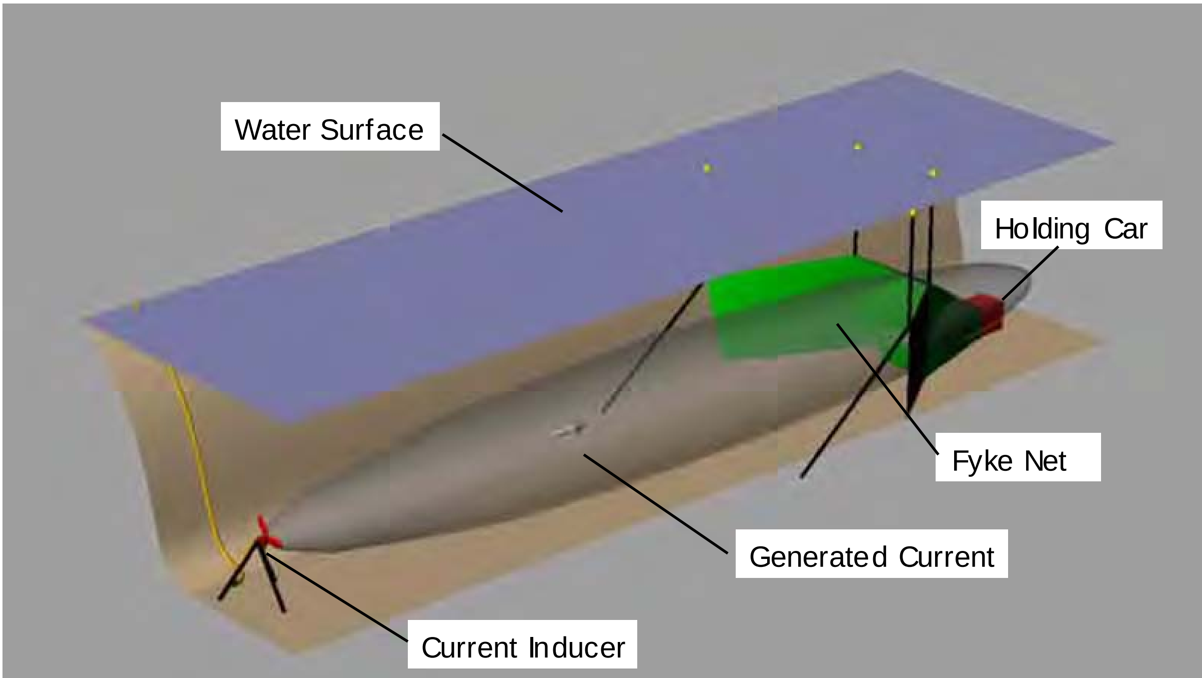
Mechanically Generated Currents to Divert Eels



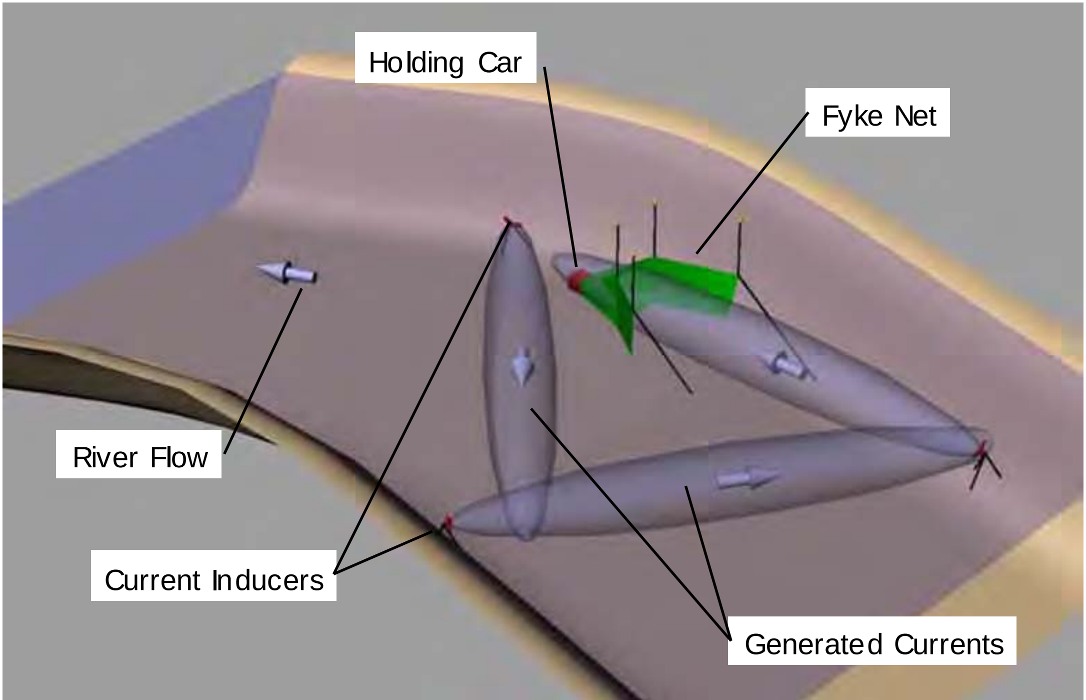
Current Inducer Creating Louver with Trashrack



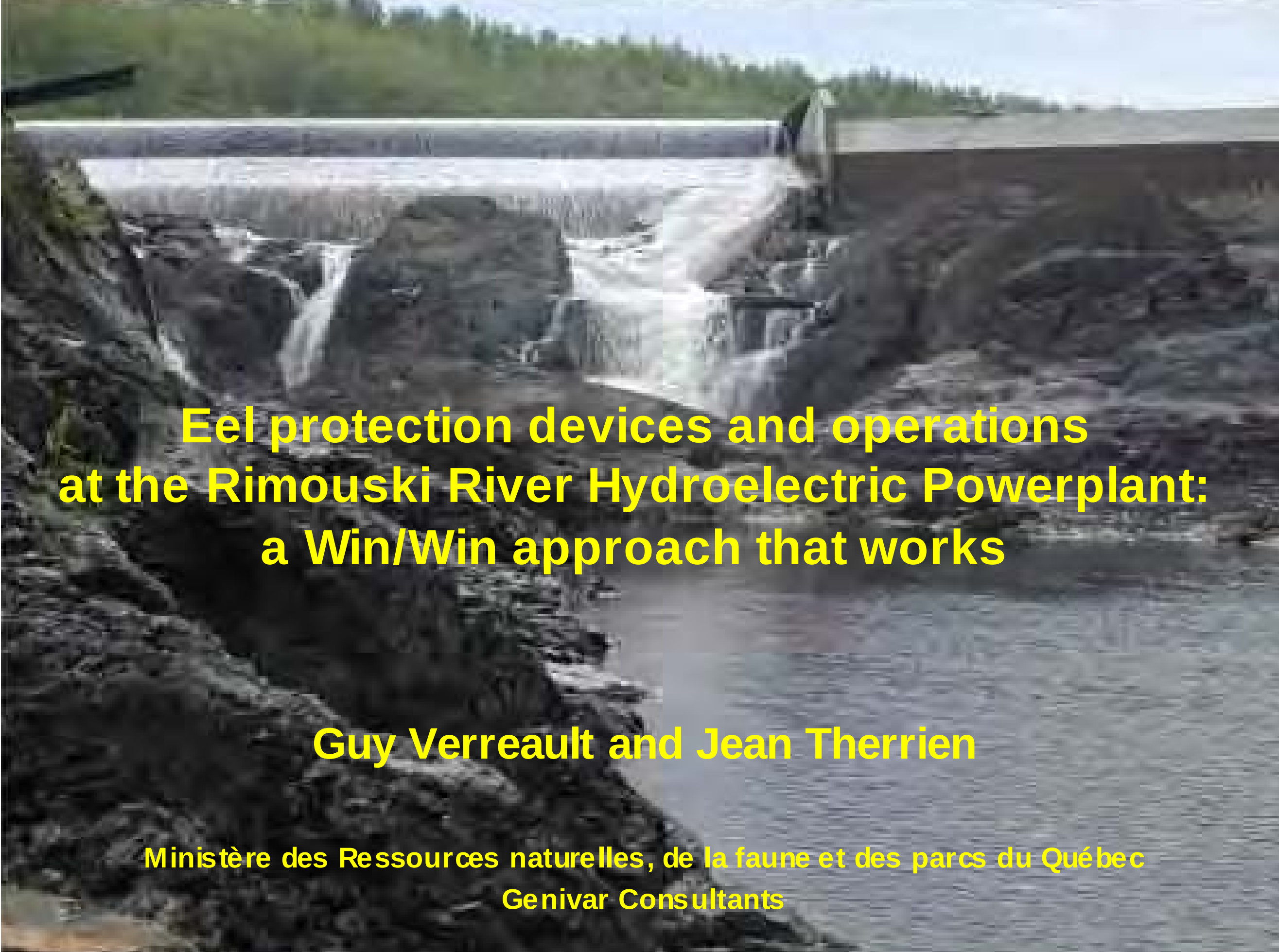
Mechanically Generated Currents Leading to an Eel Trap



Multiple Current Inducers Leading to an Eel Trap



Mechanically Generated Surface Currents Leading to Bypass



Eel protection devices and operations at the Rimouski River Hydroelectric Powerplant: a Win/Win approach that works

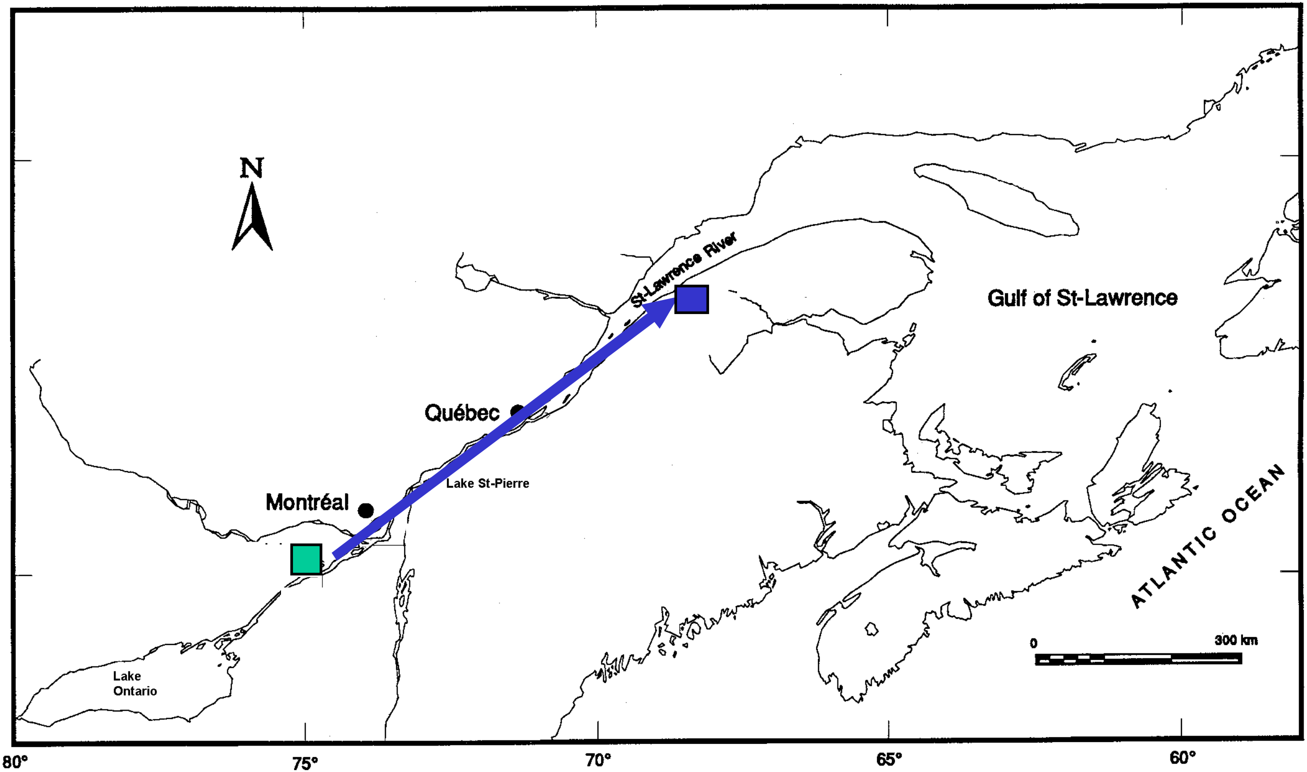
Guy Verreault and Jean Therrien

Ministère des Ressources naturelles, de la faune et des parcs du Québec

Genivar Consultants

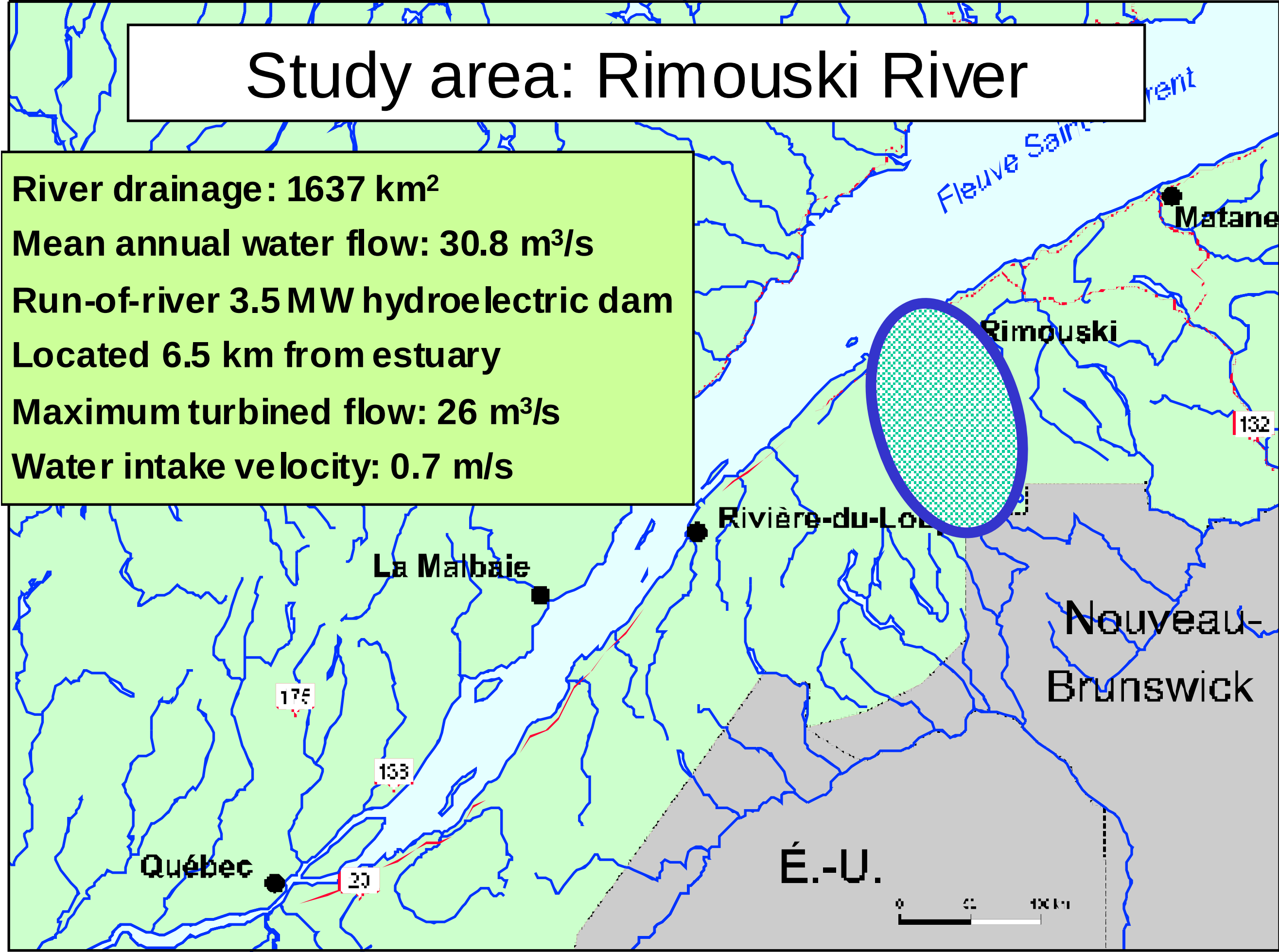
Introduction

- Research / licensing process
- Dam and hydropower plant rebuilt in 1996-1997
- Eel migration surveys (upstream and downstream) since 1994
- Salmon and eel upstream and downstream facilities
- Downstream device tested: bypass with light in 1997, and with screen in 1998
- Main task: eliminate turbine mortality without significant loss of electricity production

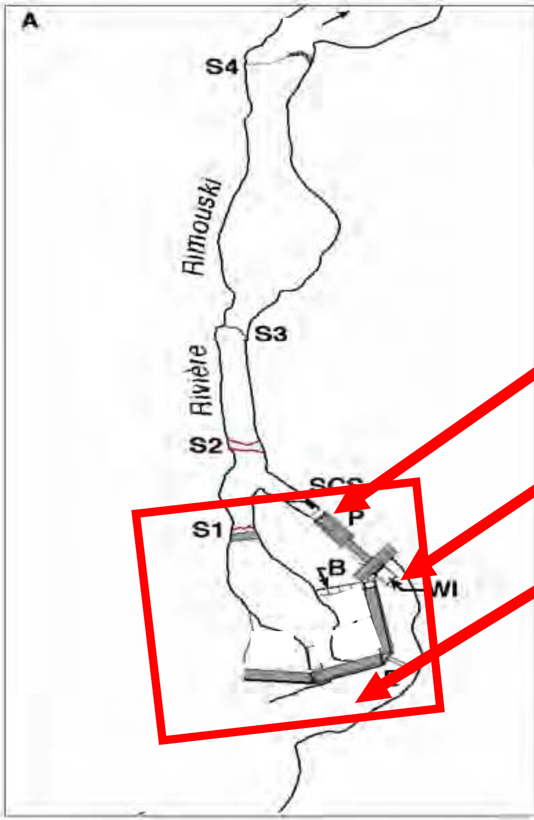

N
St-Lawrence River
Gulf of St-Lawrence
Québec
Montréal
Lake St-Pierre
Lake
Ontario
ATLANTIC OCEAN
0
300 km
80°
75°
70°
65°
60°

Study area: Rimouski River

- **River drainage: 1637 km²**
- **Mean annual water flow: 30.8 m³/s**
- **Run-of-river 3.5 MW hydroelectric dam**
- **Located 6.5 km from estuary**
- **Maximum turbined flow: 26 m³/s**
- **Water intake velocity: 0.7 m/s**



STUDY AREA - DAM VICINITY

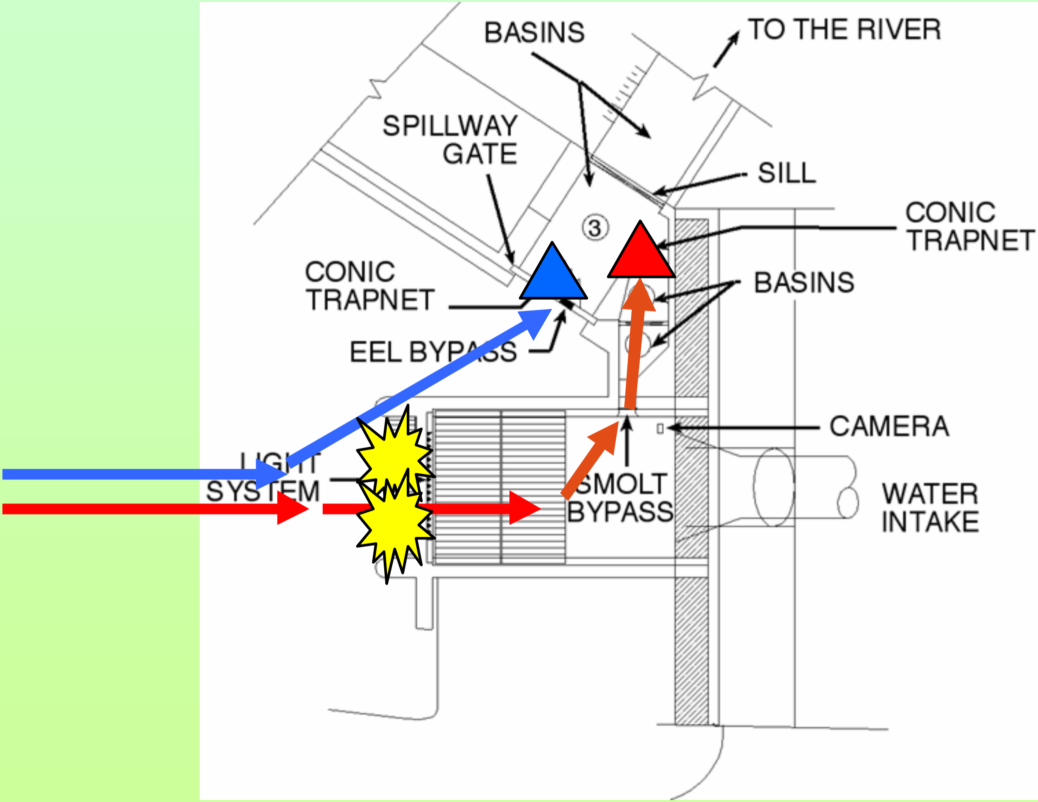


B	Basins
E	Estacade
P	Powerplant
SCS	Salmon catching system
S1 to S4	Sill (S1 in concrete)
WI	Water intake

Downstream device

- In 1997, three components: a light barrier, a bypass, and a fine grid (1 cm) inclined screen (effectiveness evaluation)
  - **Light device** (90 W submersible mercury bulbs, 40 Lux at 2 m with 30˚ angle) **in the water intake**
  - **Bypass in the wall of spillway gate**
  - **Fine grid (1 cm) inclined screen behind lighting barrier**
- In 1998, two components: a bypass and a fine grid inclined screen.

BYPASS PLAN VIEW




The results

Ligth avoidance device

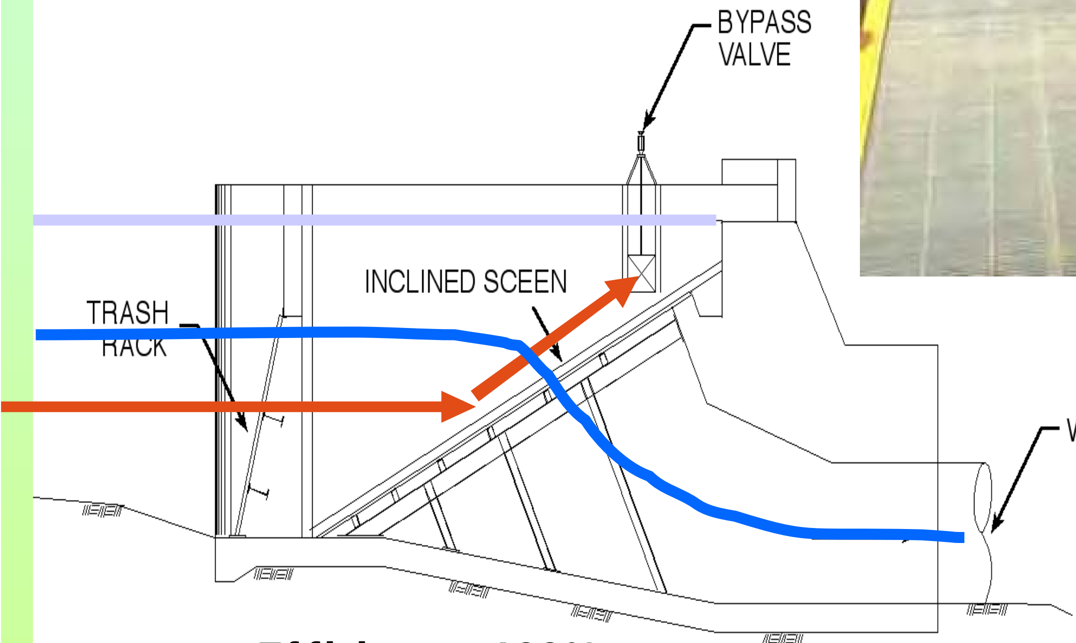
Sample	Device	Waterflow to device m³/s	Waterflow to turbines m³/s	Efficiency %
42	Halog	0.5 (7 eels)	4.7 (35 eels)	7.7
42	Halog	0.5 (7 eels)	9.0 (35 eels)	12.5
26	Halog + Hg	0.5 (0 eel)	8.8 (26 eels)	0

- Efficiency of the light system in 1997: 0 to 12.5%
- Unsufficient lighting on edges
- Backup screen diverted all migrants

Light avoidance behavior

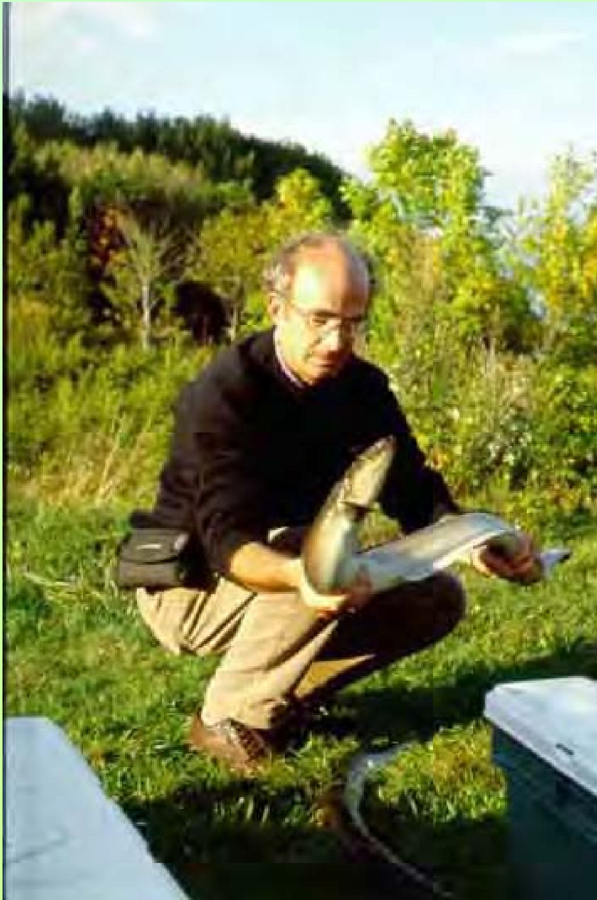
- Current velocity was not too fast (Taft, 1998)
- Water flow in the bypass was correct (0.5 m^3/s)
- Problem lies in:
  - Dark coloring of the water
  - Low intensity of lighting
- Behavioral barrier are not 100% effective with eel... (Hadderingh *et al*., 1992) and many other animals
- Field experiments may differ with laboratory observations

Experimental design: alternative diversion

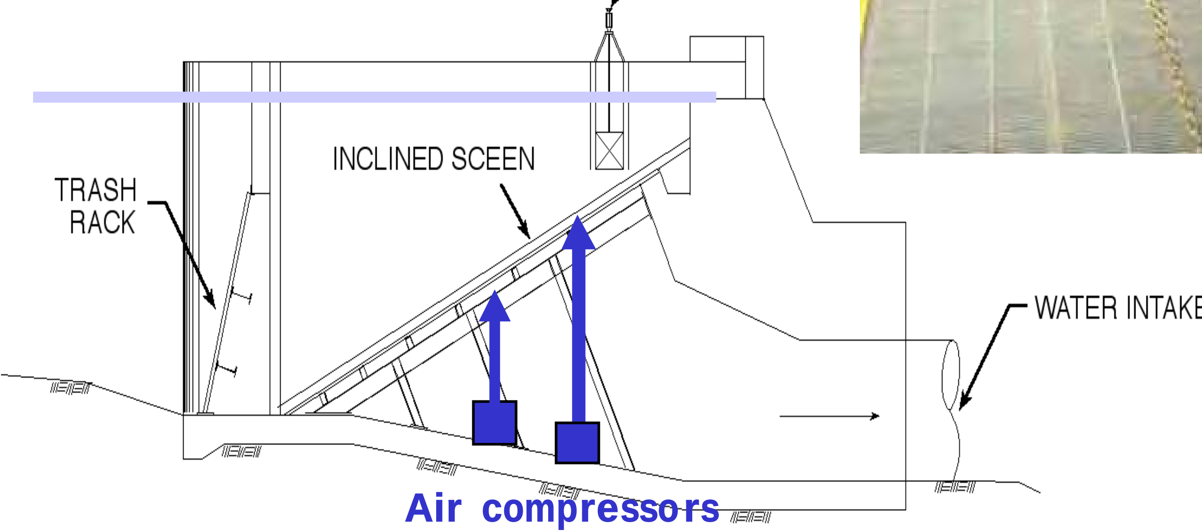


Efficiency: 100%

- Physical barrier tested the following year
- Total efficiency when adequately installed
- Minor adjustments required for total diversion
- Great concern with leaf clogging
- Physical barrier is effective in any water condition



Clogging with leaves and debris was of great concern



Conclusion

- **High survival rates could be achieved with simple device at small hydrodams**
- **Technical problems could be solved with imagination**
- **No significant loss in electricity production when protection devices are installed and well operated**
- **Moreover, strong involvement from dam operators is the main factor for a successful protection of downstream migrants**

Evaluation of bypasses to protect European silver eel (*Anguilla anguilla*) migrating downstream at small hydroelectric facilities in France

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C. DURIF, P. ELIE / Cemagref
M. LARINIER / CSP
M.L. BEGOUT-ANRAS / CNRS
S. SUBRA, P. GOMES / MIGRADO

Contents

- French experience on downstream bypasses combined to conventional trashracks for juveniles salmonids
- Test of a surface and a bottom bypasses at Halsou power plant (river Nive) and behaviour of Atlantic silver eels near the facility
- Test of a surface bypass at Baigts power plant (river Gave de Pau) for Atlantic silver eels

FRENCH EXPERIENCE ON DOWNSTREAM BYPASSES

COMBINED TO CONVENTIONAL TRASHRACKS FOR

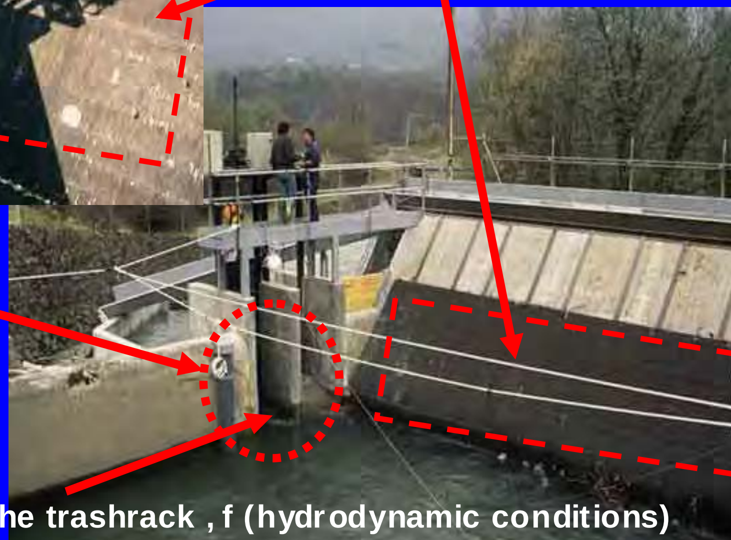
JUVENILES SALMONIDS

Downstream bypass for smolts : operating principle

Trashrack : behavioral repelling effe

Bar spacing < 3- 4 cm

Water velocity < 0.5 m/s

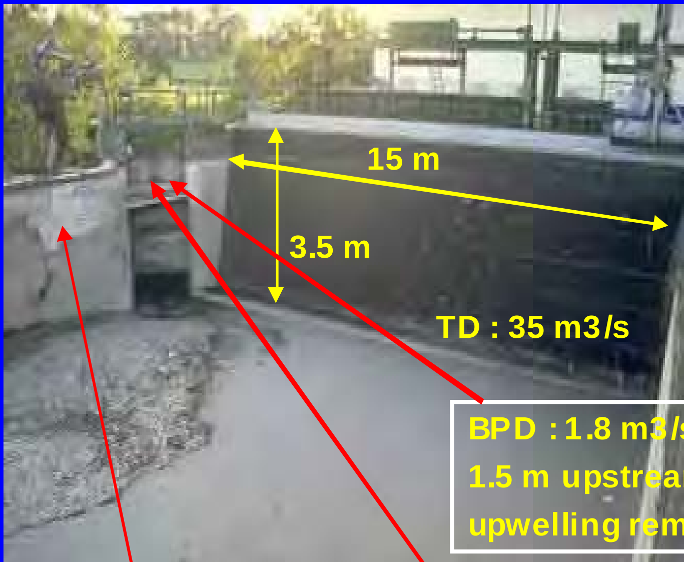


Surface bypass

discharge 2 to 10 % Q turbine

Bypass location = close to the trashrack , f (hydrodynamic conditions)

SOEIX (river Gave d'Aspe)

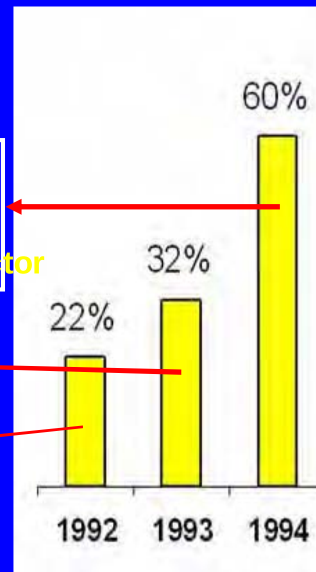


BPD : 1.8 m3/s
1.5 m upstream trashrack
upwelling removal by deflector

BPD : 0.8 m3/s
1.5 m upstream trashrack

BPD : 0.6 m3/s
6m upstream trashrack

Bypass efficiency



CAMON (Garonne river)

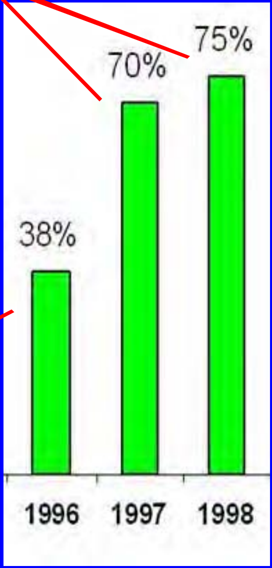
High efficiency achieved

by removing the upwelling

with a submerged

deflector plate

Bypass efficiency



Bypass included in the Trashrack

TD : 85 m3/s

BD : 2 – 3 m3/s

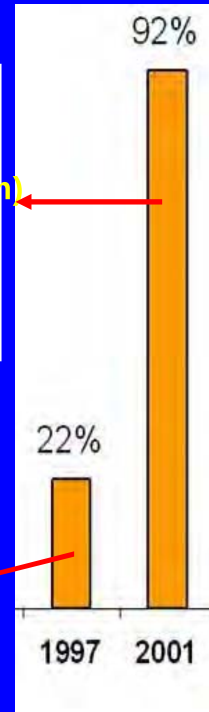
Low efficiency due to an upwelling near the bypass entrance

BAIGTS (Gave de Pau river)

Bypass

Good efficiency after changing the trashrack (3 cm) and increasing the bypass discharge (2.2 m3/s)

Bypass efficienc



Low efficiency due to large bar spacing (7 cm) and insufficient discharge in the bypass (0.6 m3/s)

CONCLUSIONS
for salmonids

- Surface bypass can be a simple solution to solve downstream migration problems for small scale power plants where 70 - 80 % efficiency is sufficient

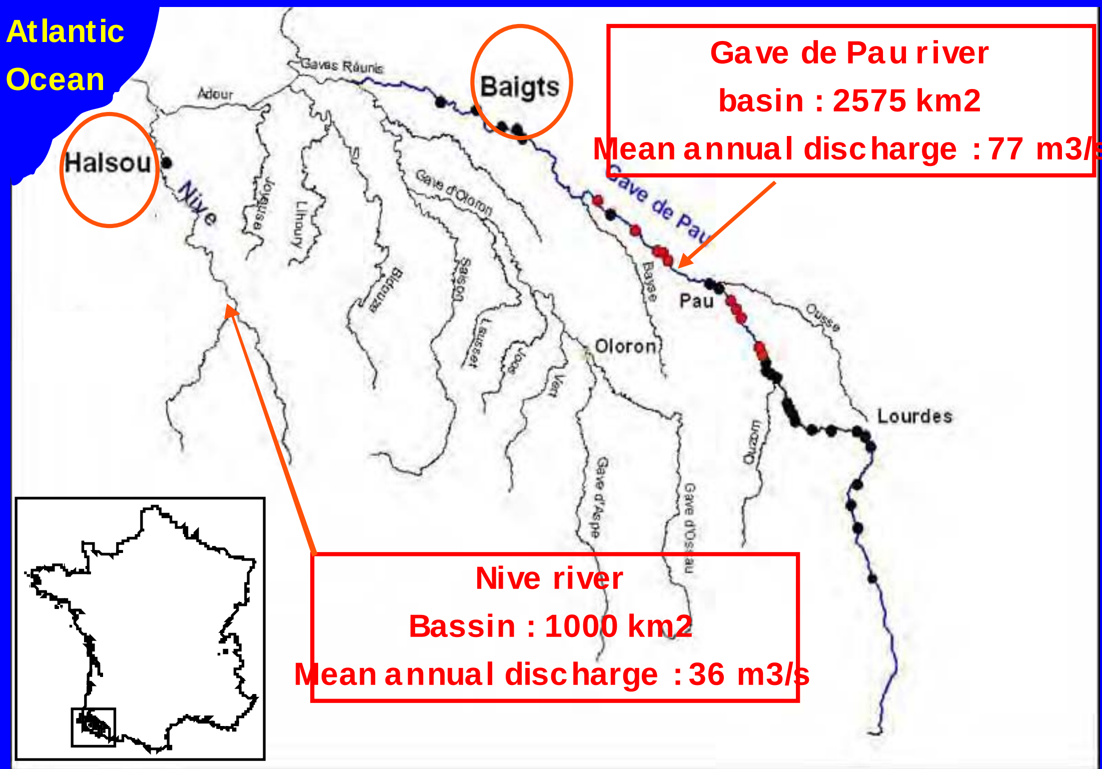
- Some criteria must be respected and several parameters carefully examined before designing a bypass :
  - Bar-spacing at trashracks < 40 mm
  - Water velocity < 0.5 – 0.6 m/s
  - Location of the bypass depends on flow pattern close to the intake
  - No upwelling near the entrance
  - Bypass discharge / turbine discharge = 2 - 10 %

Proposal studies for silver eel passage in France

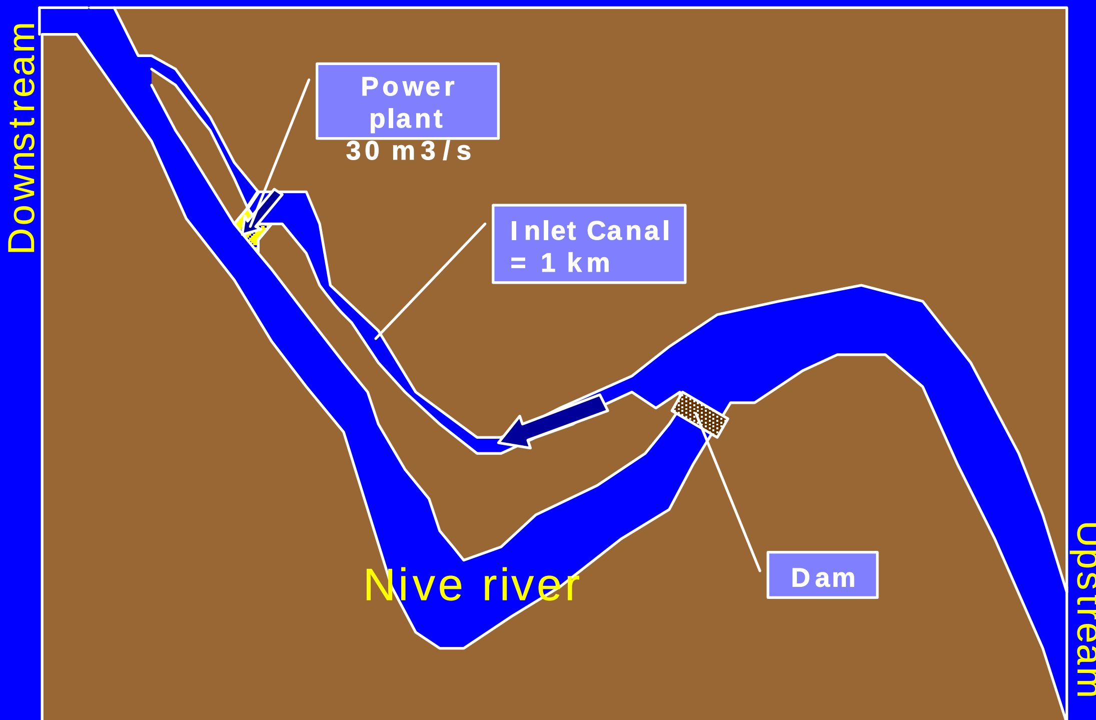
- Testing on sites the efficiency of bypasses similar to those used for salmon
- Comparing surface bypasses and bottom bypasses
- Analysing eel behaviour near hydroelectric facilities
- 2 sites selected :
  - Small plant « Halsou » to test surface and bottom bypasses
  - Larger plant « Baigts » to test surface bypass and to analyse eel bahaviour

Test of a surface and a bottom bypasses at Halsou power plant (Nive river)

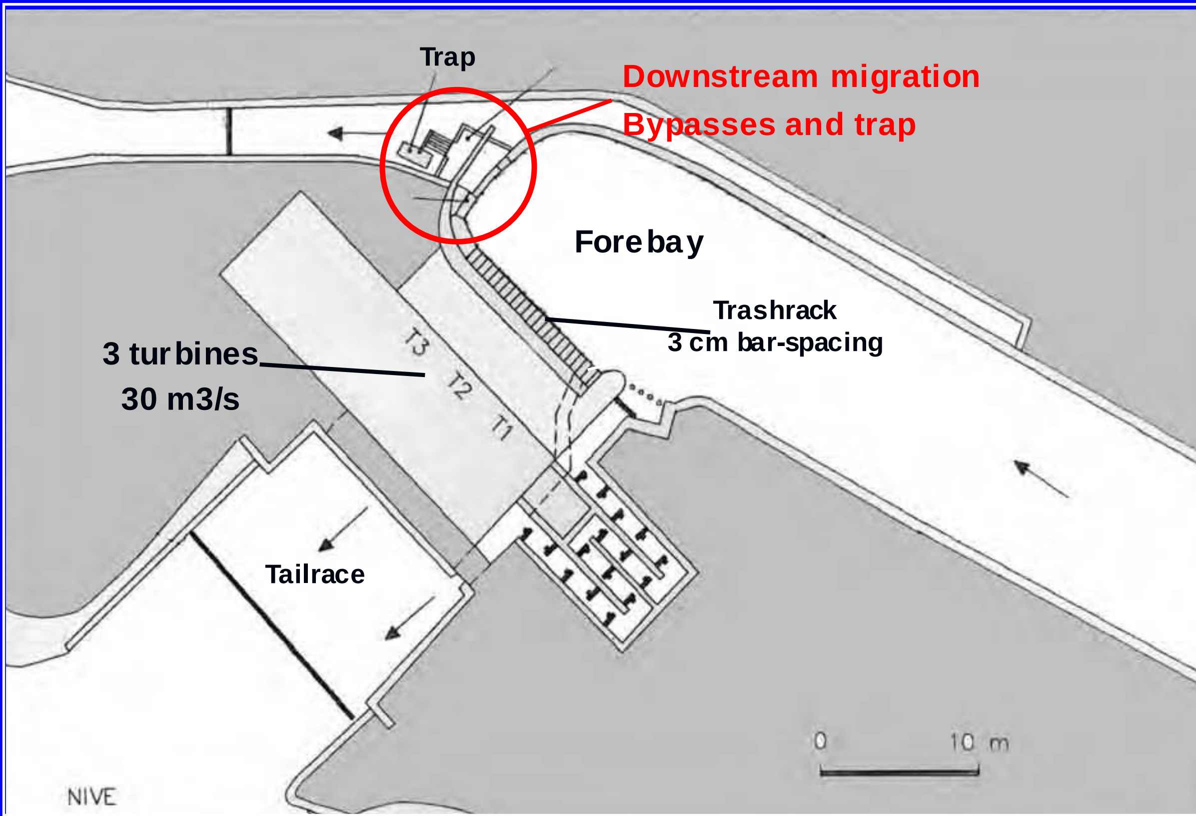
SITES LOCATION



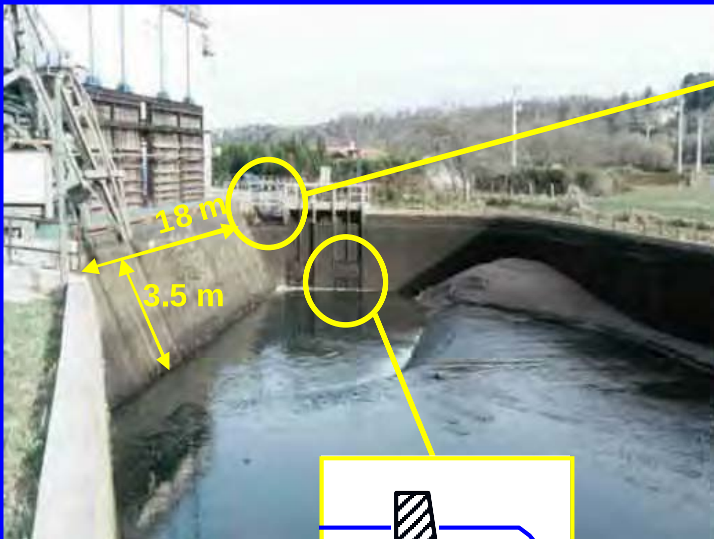
HALSOU Hydroelectric facility



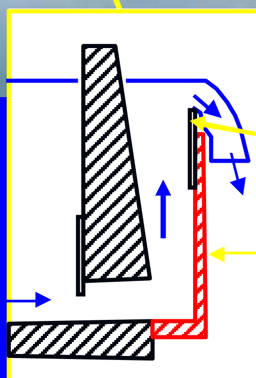
Halsou Power Plant



Forebay, trashrack and bypasses



Surface bypass
0.9 m width / 0.6 m3/s
2% TD



Bottom bypass
1.3 w x 0.5 h
0.6 m3/s
2% TD

Surface gate

Discharge Tower

Method

- Trapping naturally migrating silver eels downstream each bypass open alternately every other day

- Telemetry

  - Radiotracking of eels trapped and released in the forebay

  - Sonic tracking of some individuals with depth sensors

- Continuous record of environmental parameters : river discharge, temperature, conductivity, turbidity, atmospheric pressure, light intensity

- 3 studies conducted from october to december 1999, 2000 and 2001

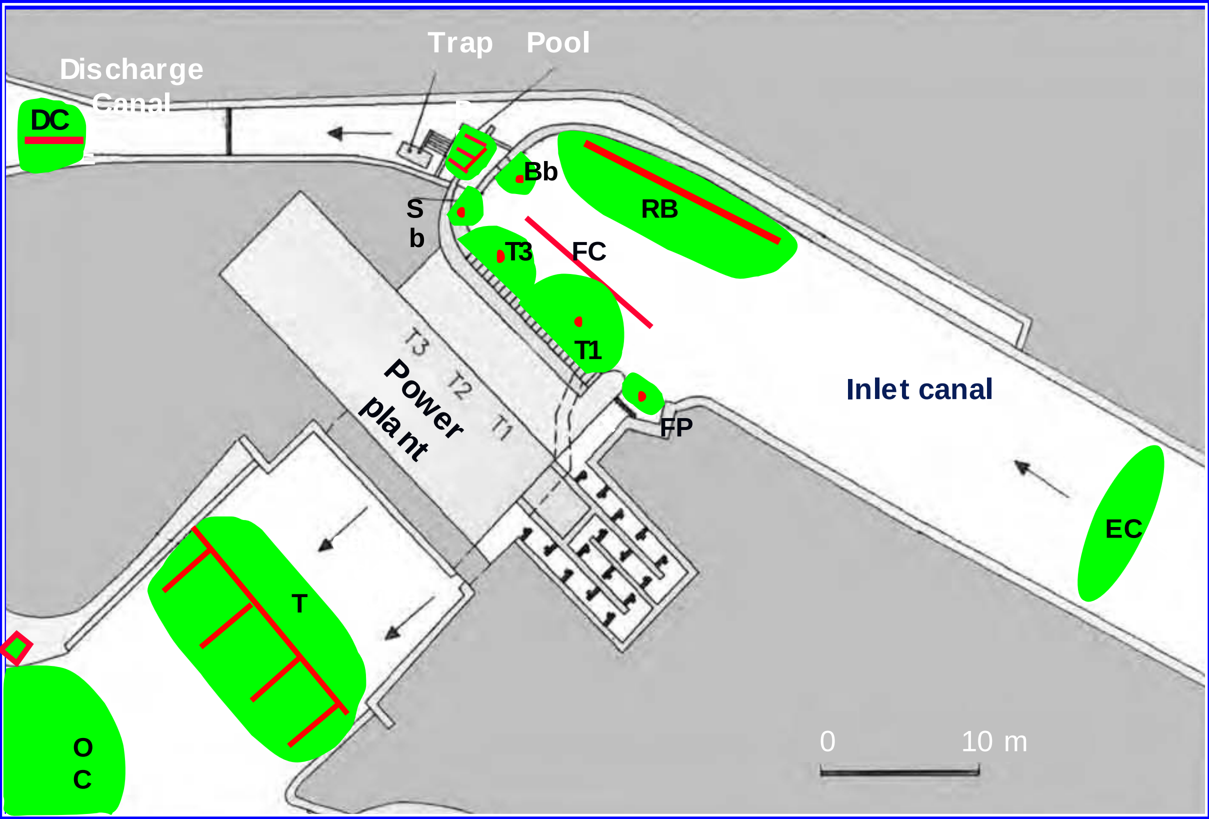
Bypasses and Trapping device

Radiotracking and acoustic tracking

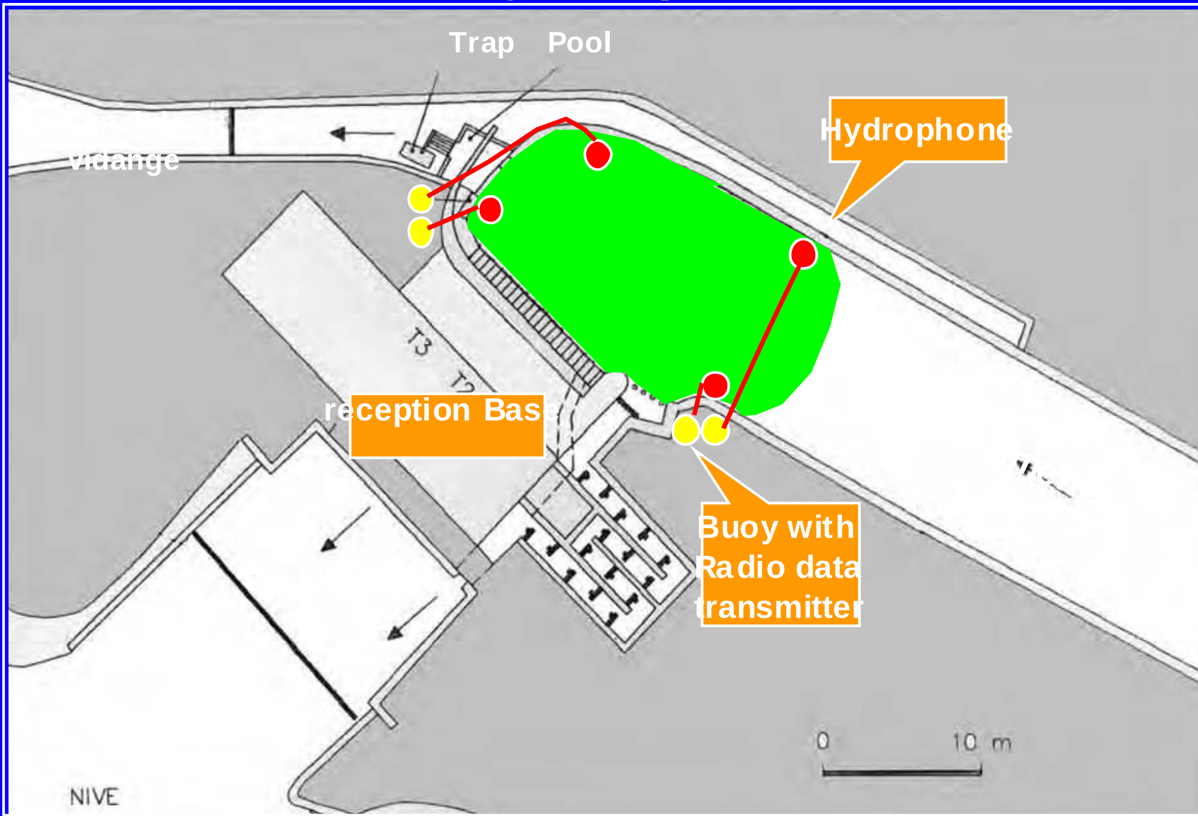
Radio transmitter : surgical implantation i the coelomic cavity.

Sonic transmitter with depth sensor : exter implantation on the eel back

Radiotracking recording zones



Hydrosonic tracking (VEMCO positioning System)



Automatic data recorders for radio and sonic telemetr

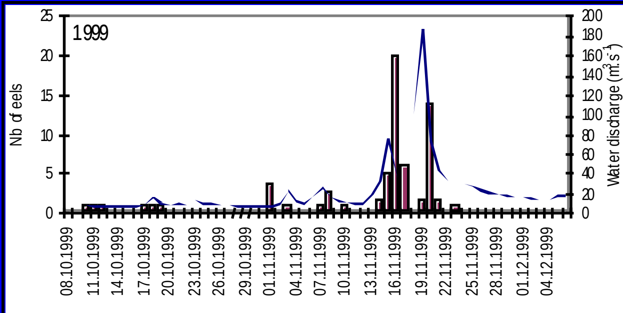
Radio tracking : ATS and LOTEK data collection systems

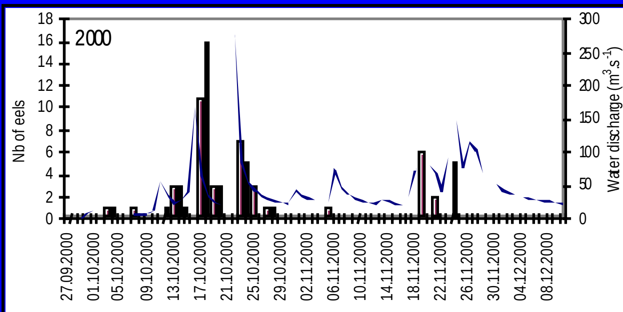
1 or 2 DCC for each zone

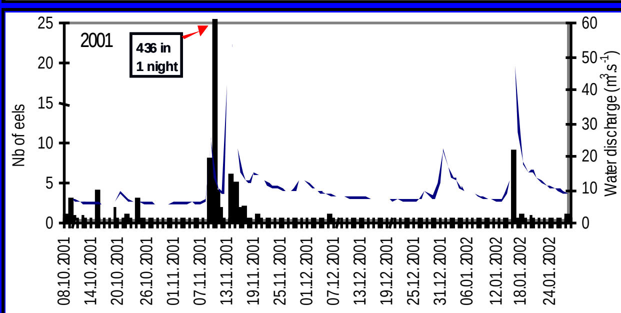
Sonic tracking : VEMCO

Continuous survey of the position in the forebay

Captures in the trap







1999

Number : 66
90 % during night (18h-8h30)
74 % during 2 picks : 5 days

2000

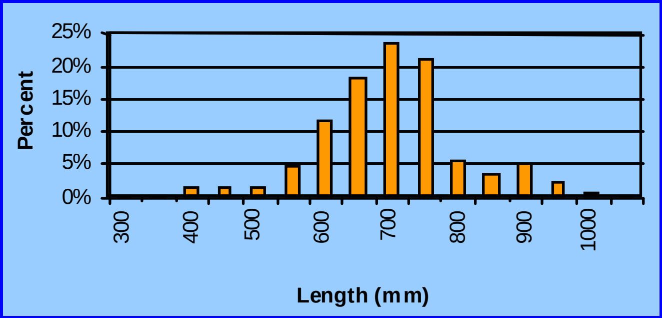
Number : 75
98 % during night (18h-8h30)
74 % during 2 picks : 8 days

2001

Number : 496
98 % during night (18h-8h30)
95 % during 3 picks : 8 days

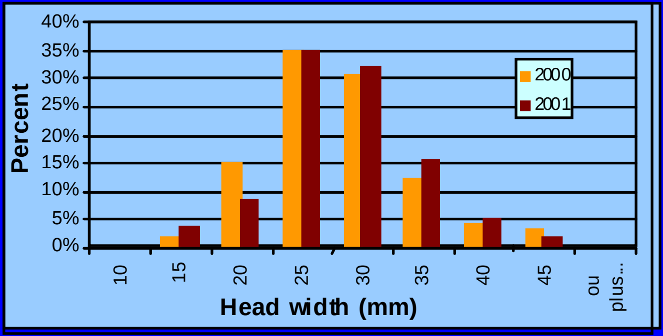
Captures linked to river discharge

Biometry



Length from 300 to 1003 mm

Mean length : 681 mm

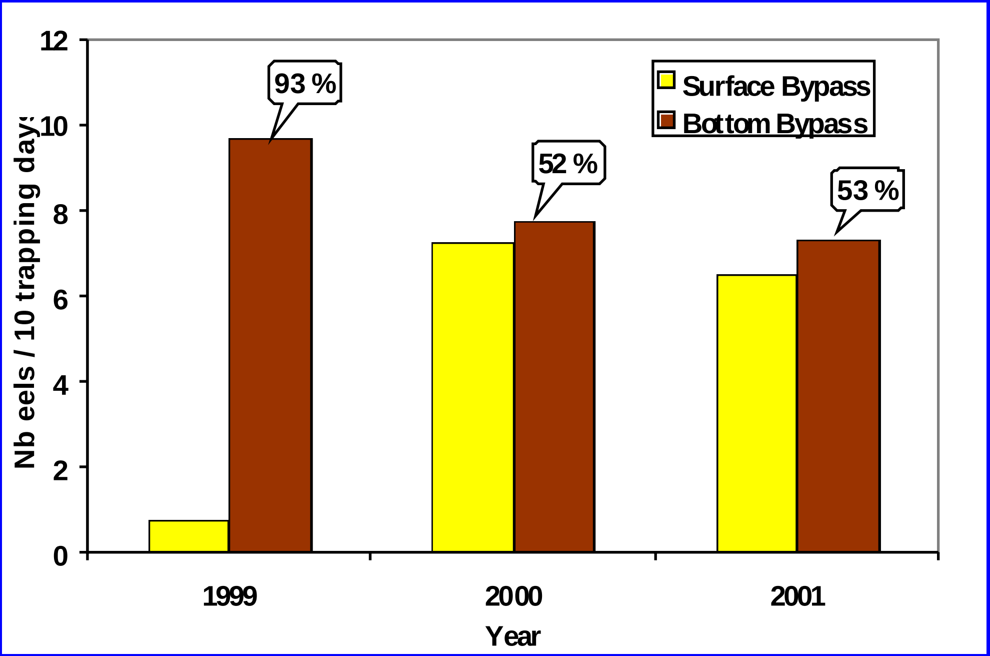


Head width from 13 to 45 mm

Mean width : 26,6 mm

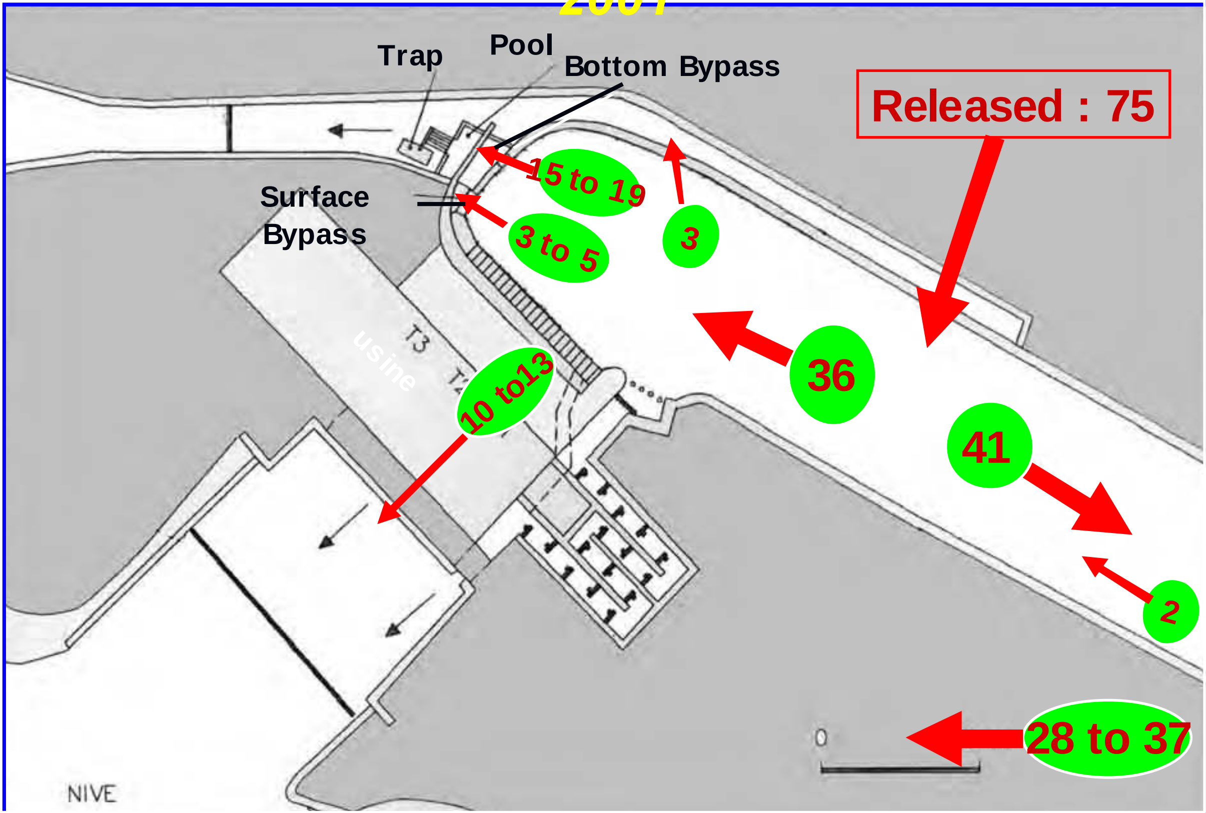
Passages through the Surface and Bottom Bypa

Corrected data - Number of Eels / 10 trapping days

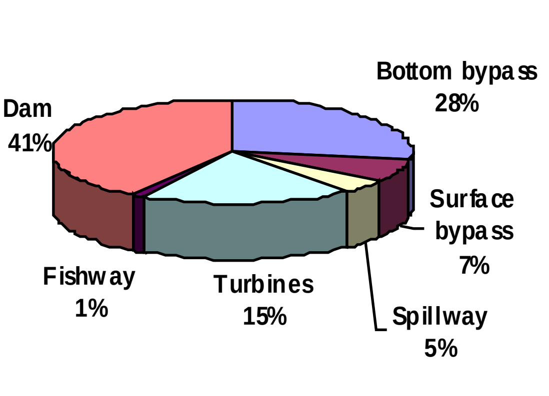


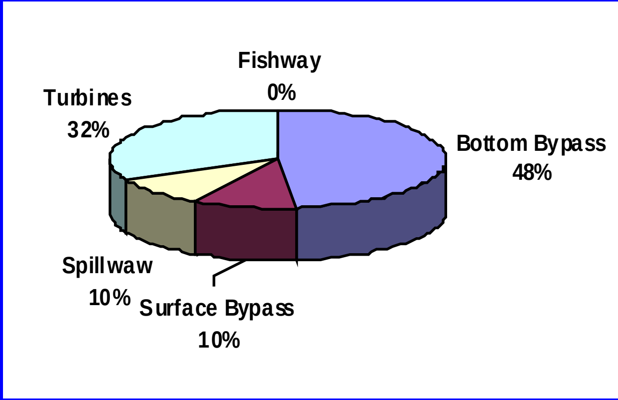
Difficult to compare SB and BB : bias due to clogging problems and characteristics of the run (peaks)

Radiotracking years 1999, 2000 et 2001



Quantification of eel passages by the various ways at the Halsou facility





Passages at the facility (Dam+PP)

Passage	Nb	%
Bottom bypass	15 to 19	23% to 30%
Surface bypass	3 to 5	5% to 8%
Spillway	3	5%
Turbines	10 to 13	13% to 17%
Fishway	0 to 1	0% to 1%
Dam	28	41%
TOTAL	64	100%

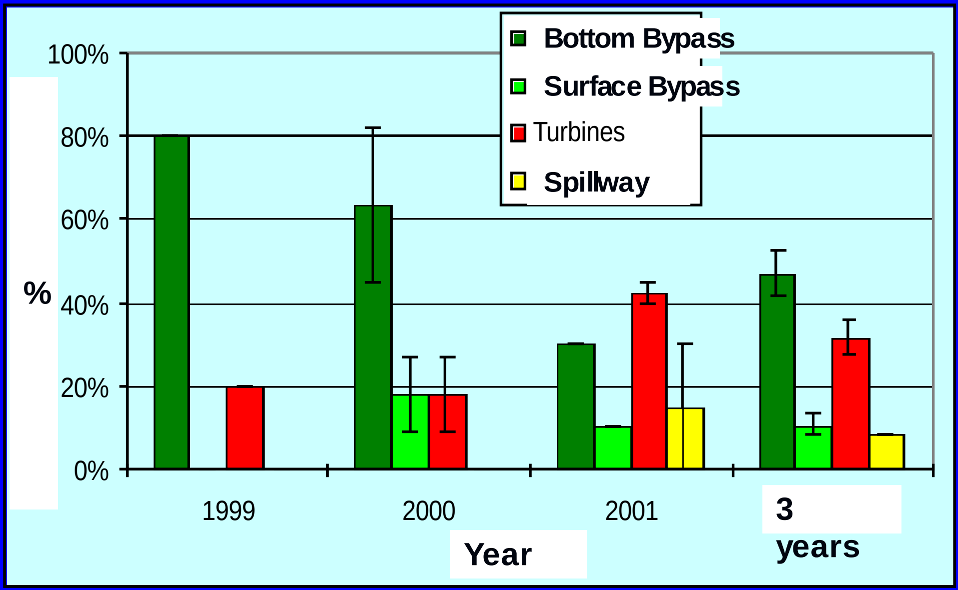
Passages at the power plant

Passage	Nb	%
Bottom Bypass	15 to 19	42% to 53%
Surface Bypass	3 to 5	8% to 14%
Spillwaw	3	8%
Turbines	10 to 13	28% to 36%
Fishway	0 to 1	0% to 3%
TOTAL	36	100%

Bypasses / power plant passages = 56 –

Mean value for the 3 years

Zones of Passage at the power plant for radiotracked eels in 1999, 2000 et 2001

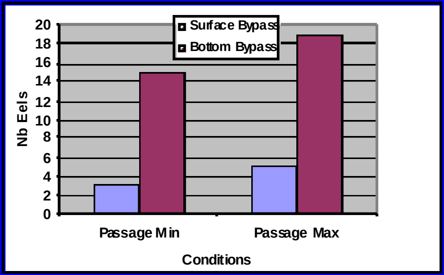


Passages Bypasses (Surface+ Bottom) / turbines = 56% à 65% mean 3 years

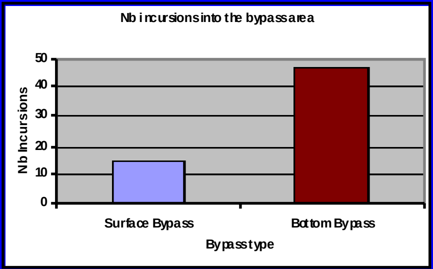
60% - 80% in 2000

40% in 2001

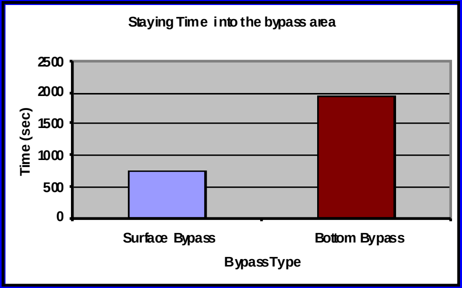
Comparison of Surface and Bottom Bypasses



Nb eels passed into the bypass



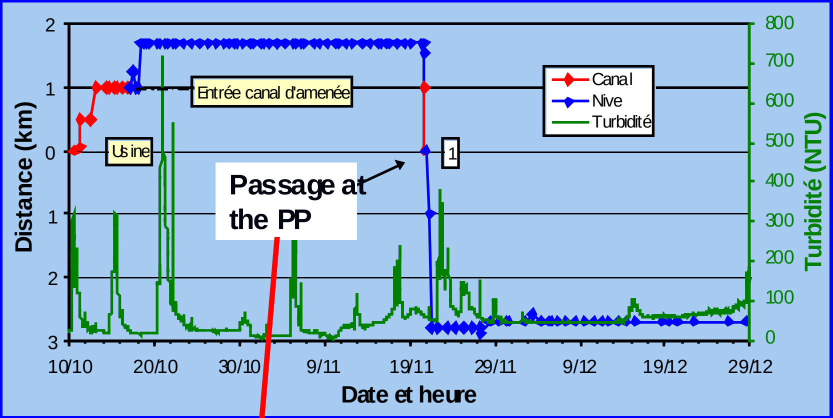
Nb incursions in the bypasses area (around 1.5

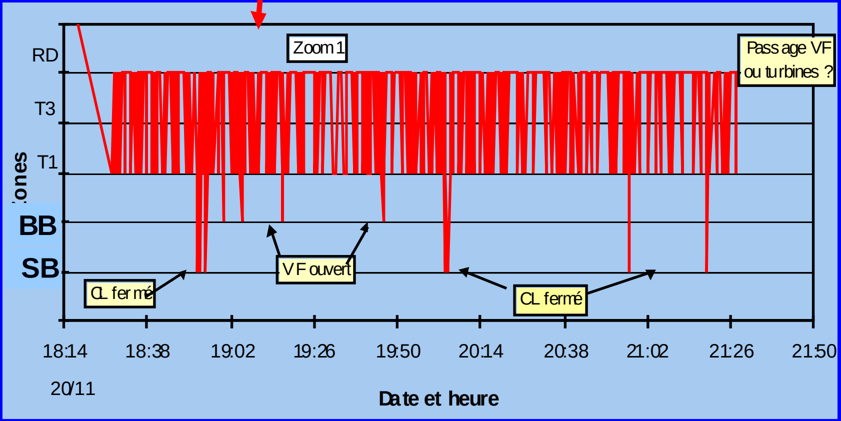


Total standing time in the bypasses area

Bottom Bypass 3 to 4 times more efficient than Surface Bypass

Movements of the eel N° 410





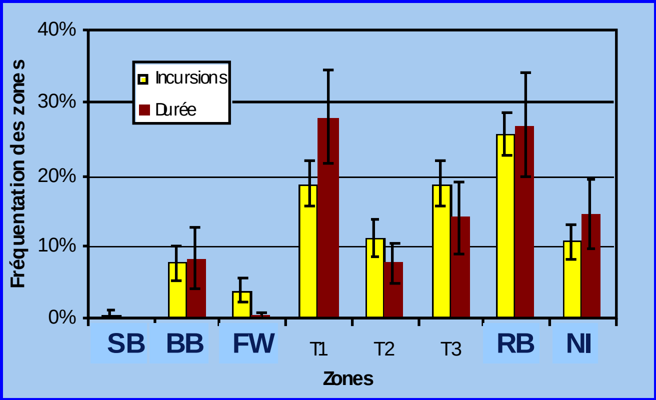
Example of eel tracking

Movements along the Niv

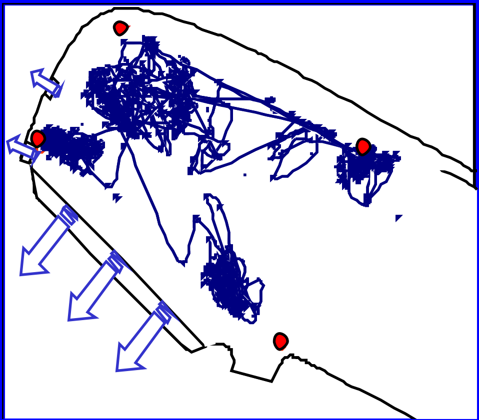
Behaviour in the foreba

Staying duration in the forebay : from 1 minute to 22 days

Eel behaviour in the forebay

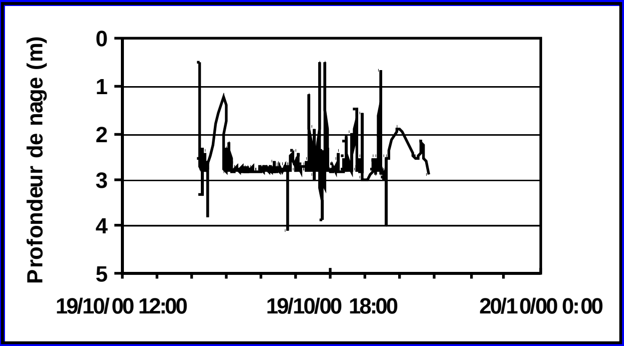


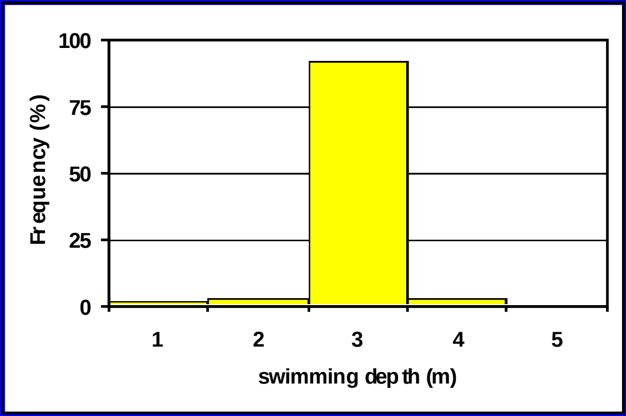
Radiotracking



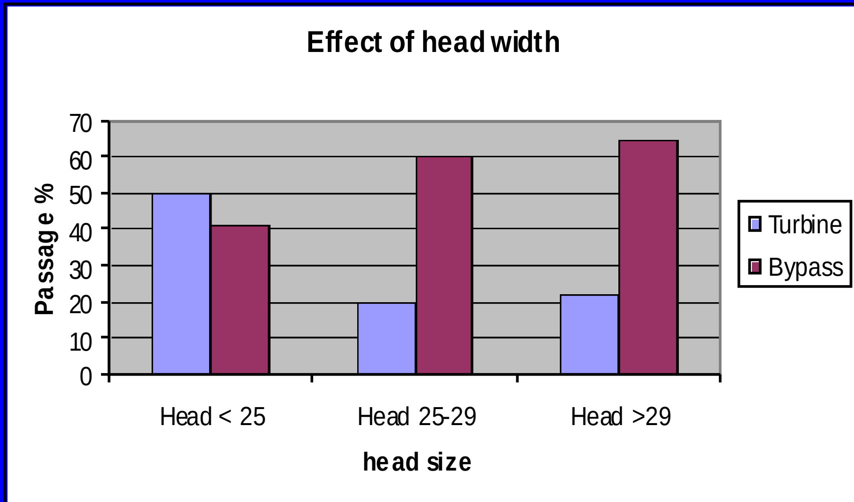
Sonic tracking

Swimming depth in the forebay
Sonic Tracking with depth sensor

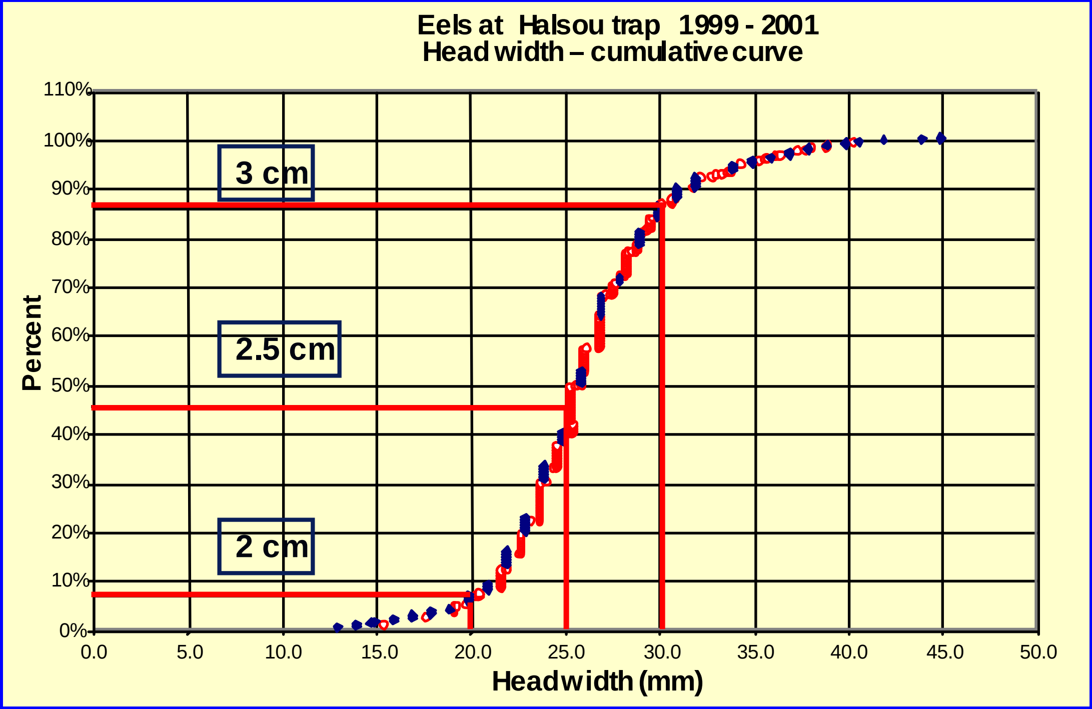




Effect of head width on bypasses efficiency



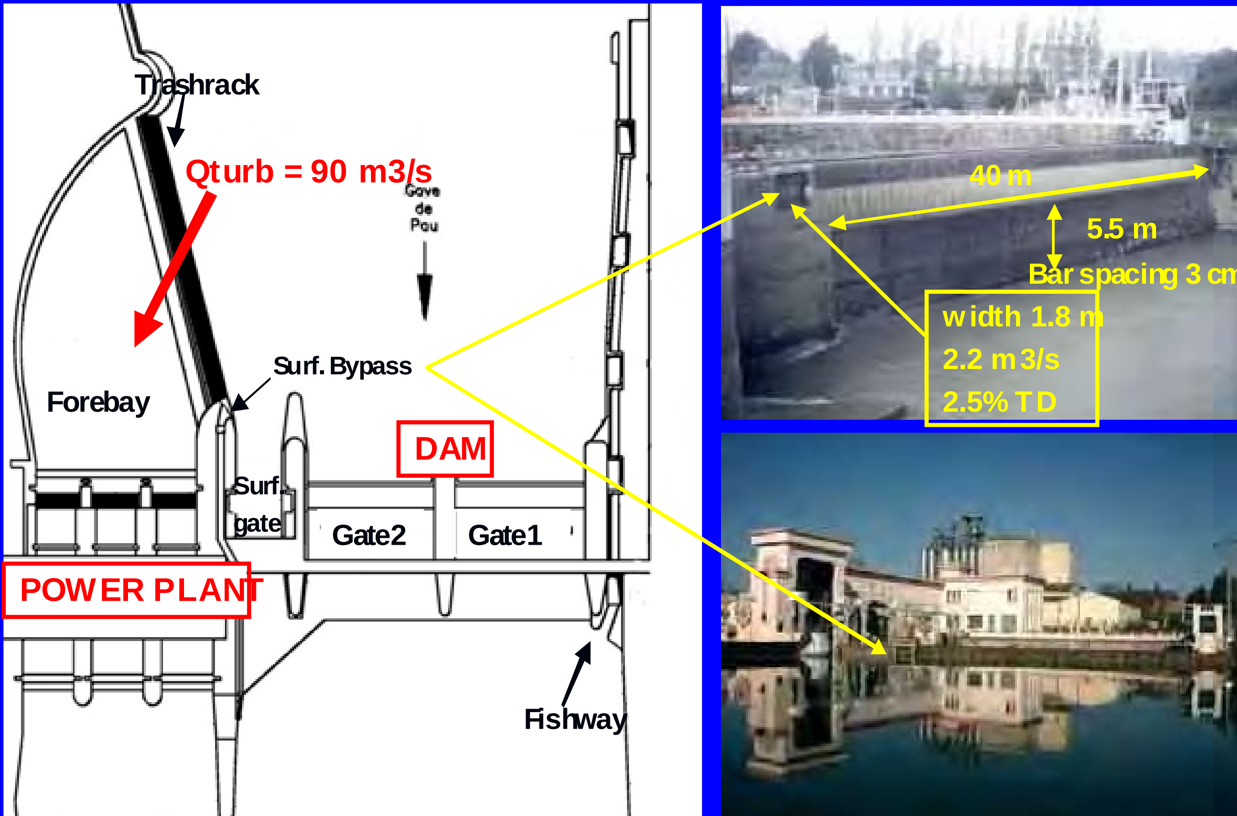
Trashrack permeability for silver eel population of the Niv



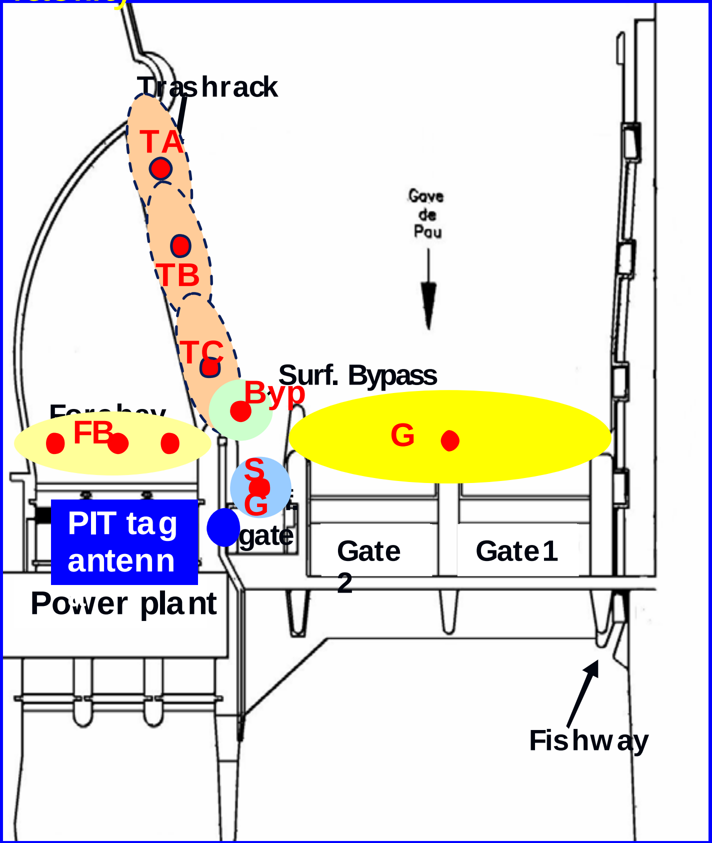
Due to head width, 90% of the population can pass through a 3.0 cm bar spacing trashrack, 50% through 2.5 cm and 10% through 2.0 cm

Test of a surface bypass at Baigts power plant (Gave de Pau river) and behaviour of silver eels near the facility

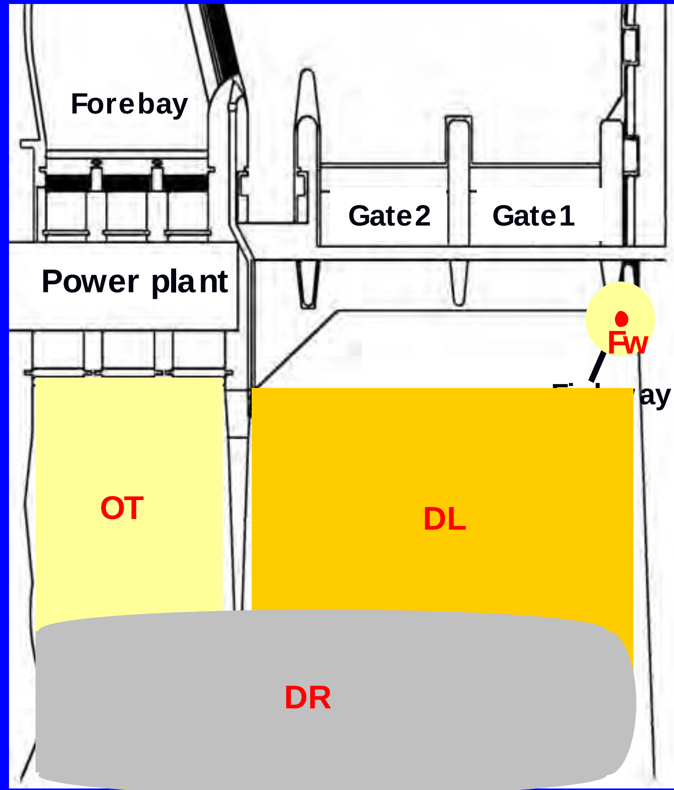
BAIGTS hydroelectric facility



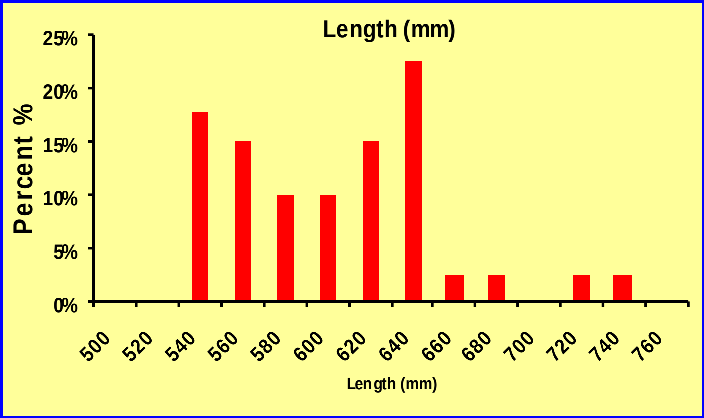
Radiotracking antennas for automatic recorders Upstream the facility



Radiotracking antennas for automatic recorders Downstream the



Characteristics of the 40 tracked eels

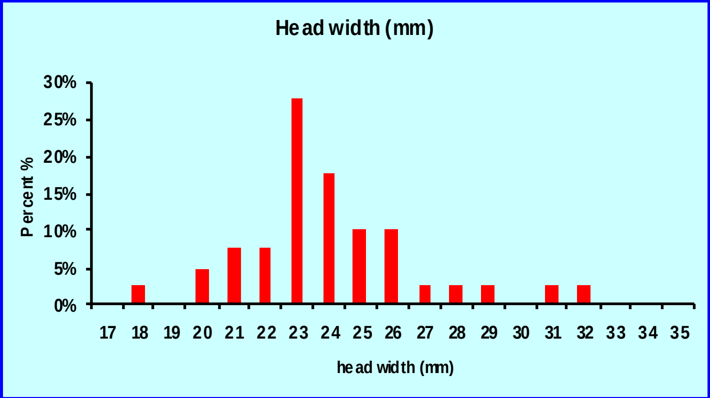


Imported from an other river (commercial fishery)

Released 3 km upstream the facilit

Length from 540 to 750 mm

Mean length : 610 mm

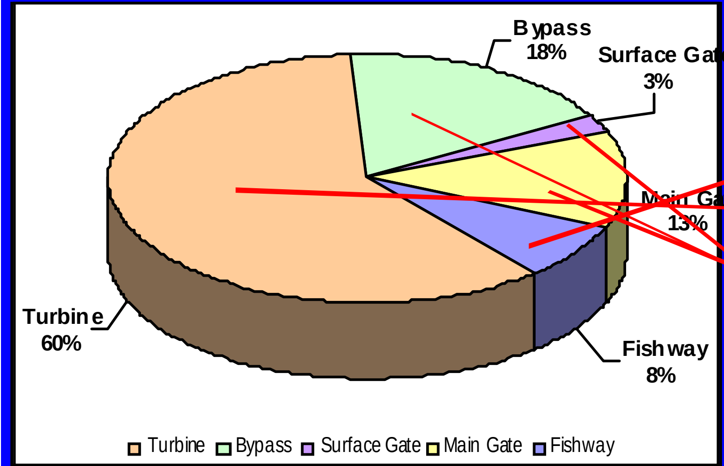


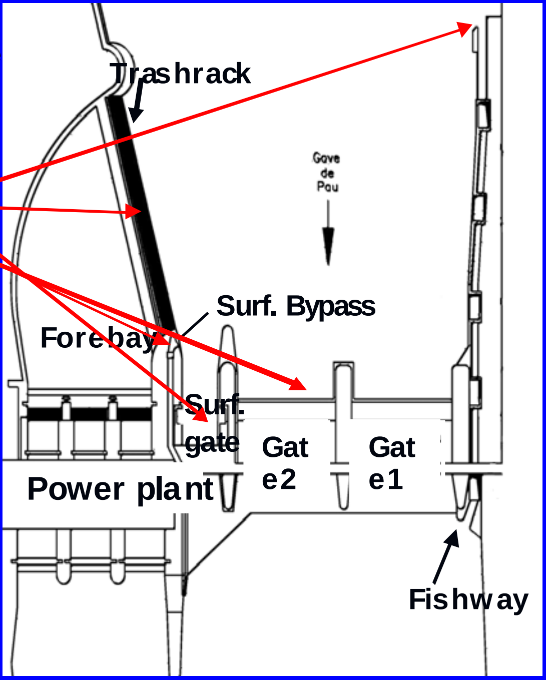
Head width from 18 to 32 mm

Mean width : 24,3 mm

Location of eel passages at the Baigts facility

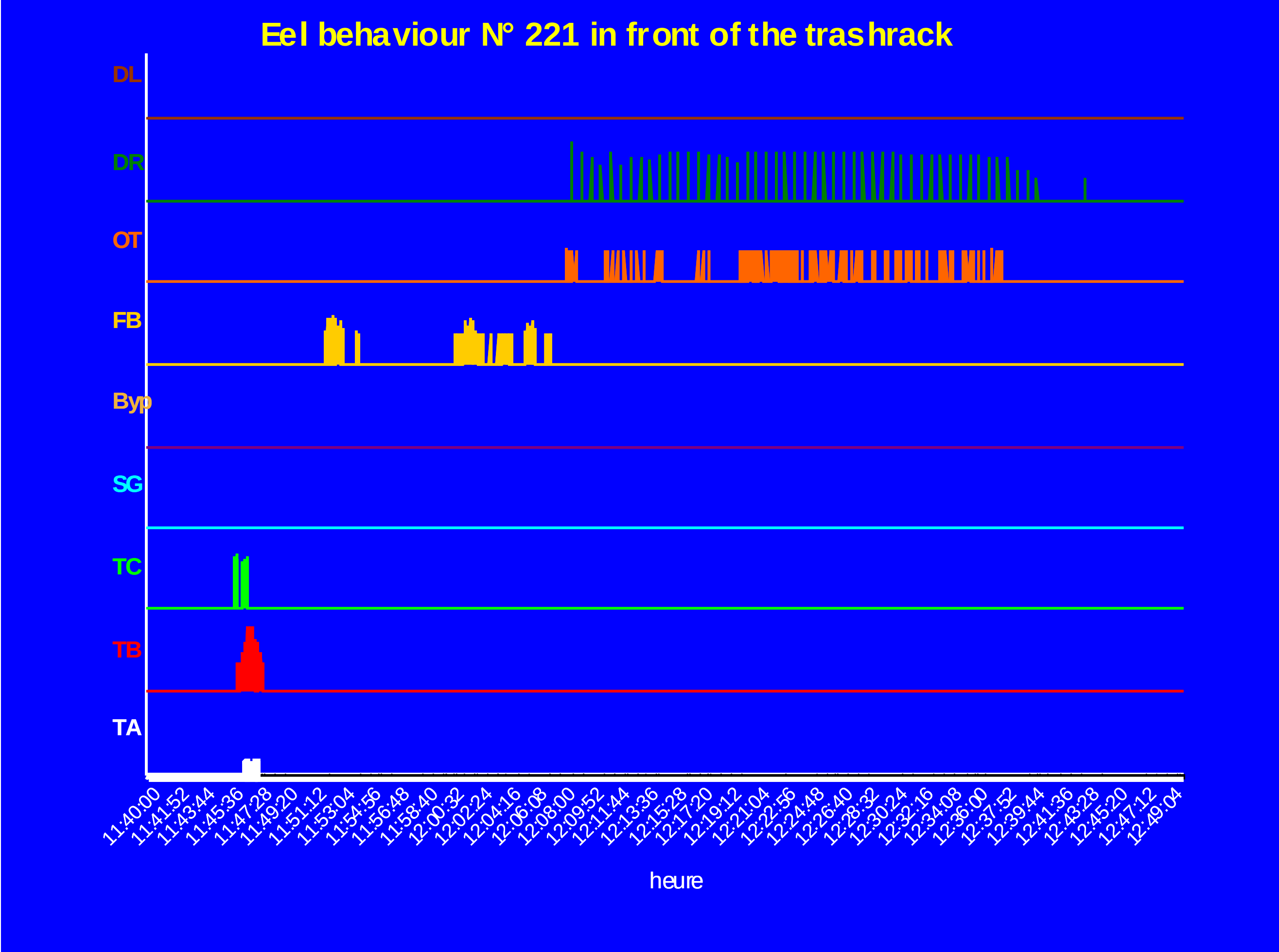
40 radiotracked eels





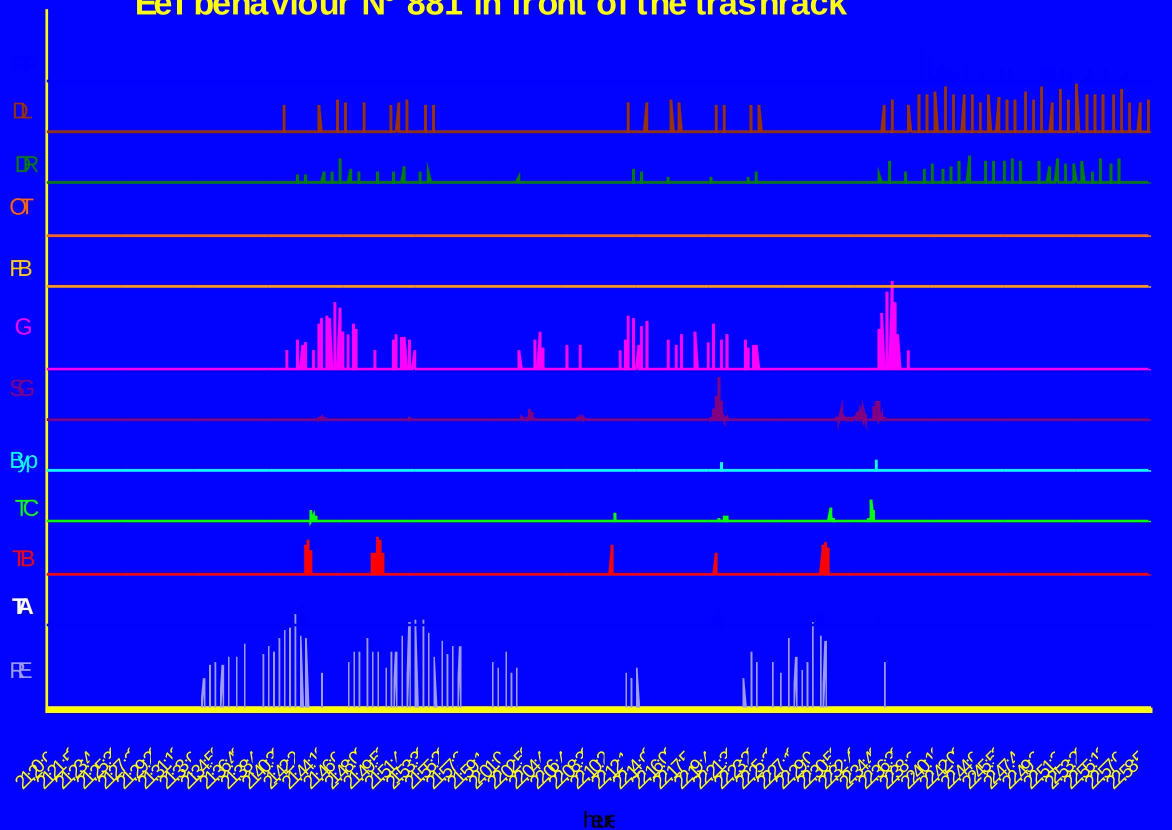
Passage	Nb	%
Turbine	24	60%
Bypass	7	18%
Surface Gate	1	3%
Main Gate	5	13%
Fishway	3	8%
TOTAL	**40**	**100%**

Bypass / (Turbine+Bypass) = 23%

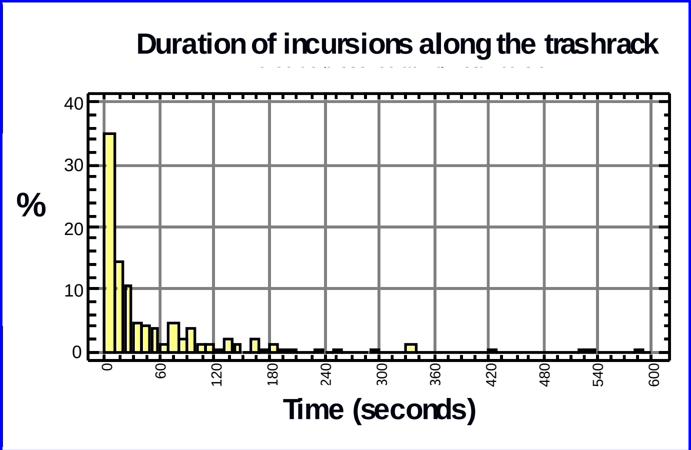


Eel behaviour N° 221 in front of the trashrack
DL
DR
OT
FB
Byp
SG
TC
TB
TA
11:40:00
11:41:52
11:43:44
11:45:36
11:47:28
11:49:20
11:51:12
11:53:04
11:54:56
11:56:48
11:58:40
12:00:32
12:02:24
12:04:16
12:06:08
12:08:00
12:09:52
12:11:44
12:13:36
12:15:28
12:17:20
12:19:12
12:21:04
12:22:56
12:24:48
12:26:40
12:28:32
12:30:24
12:32:16
12:34:08
12:36:00
12:37:52
12:39:44
12:41:36
12:43:28
12:45:20
12:47:12
12:49:04
heure

Eel behaviour N° 881 in front of the trashrack



Eel behaviour near the intake



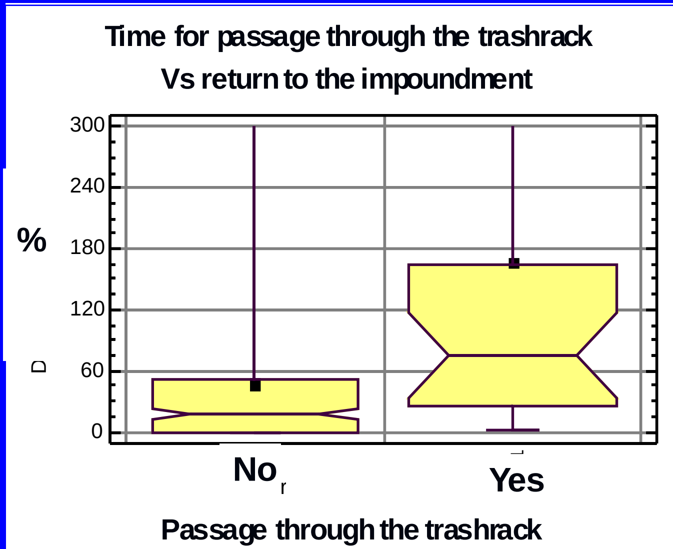
Duration of incursions from 5 sec to 10 minutes

35 % incursions are less than 10 sec

60 % incursions are less than 60 sec

→ mainly short incursions

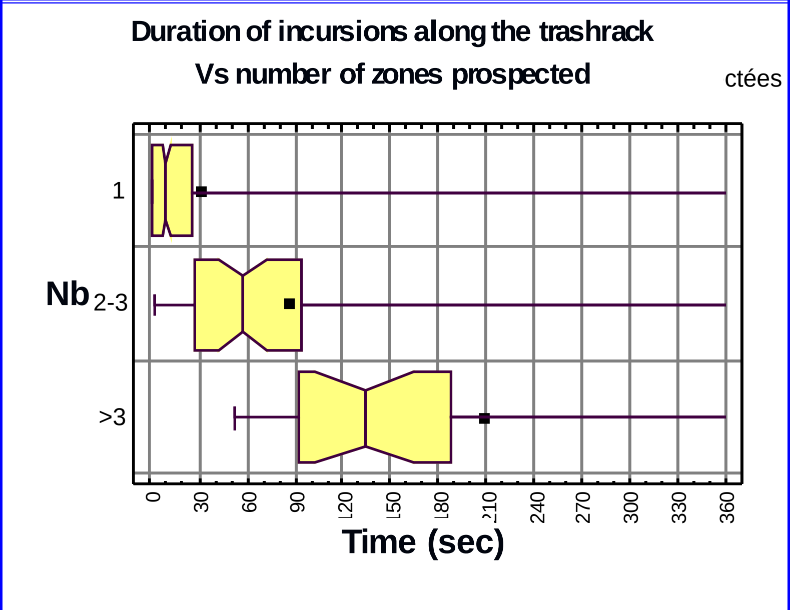
Eel behaviour near the intake



Time to pass through = longer than to return upstream

➡ **repelling effect of the trashrack ?**

Eel behaviour near the intake



When eels stay a long time near the trashrack they prospect several pa
of the trashrack → searching behaviour in front of the trashrack ?

CONCLUSIONS

- For small hydro plants, bypasses with a discharge of 2% to 3% of the turbined discharge located near the trashrack with 3 cm bar spacing could have a partial efficiency for adult eels : 20% to 70%
- A bottom bypass is 3 to 4 times more efficient than a surface bypass
- Passages through bypasses or turbines occurred mainly during the night
- Eels swim mainly near the bottom with short passages near the surface
- Trashrack repelling effect seems less efficient for eels than for smolts
- Eels make short incursions (several seconds) close the trashrack and return back upstream or they stay a longer time with displacements along the trashrack
- Improvement of bypases by using a smaller bar spacing (2 – 2.5 cm) can be considered on small plants, but to avoid the risk of impingement, this solution requires :
  - Water velocity less than 0.5 – 0.6 m/s (??) at the approach of the trashrack,
  - The installation of efficient bypasses with adequate location and discharge

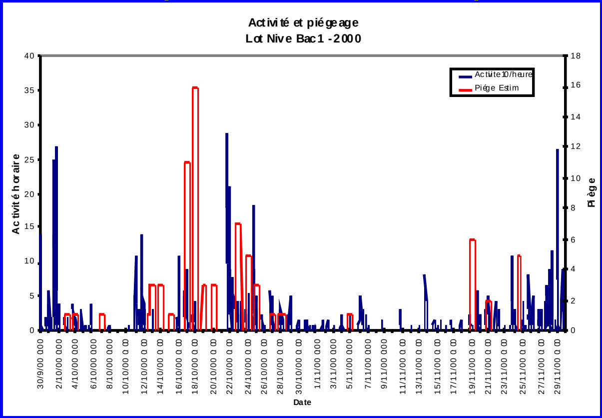
- Could be bypasses efficient for very large plants ?

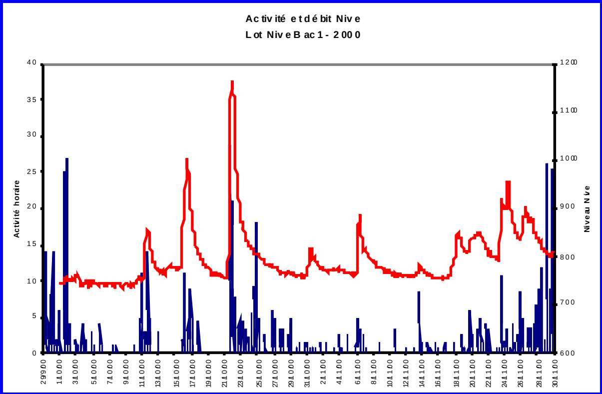

Thank you
and…
Sorry for my English

Trials of an Early Warning System

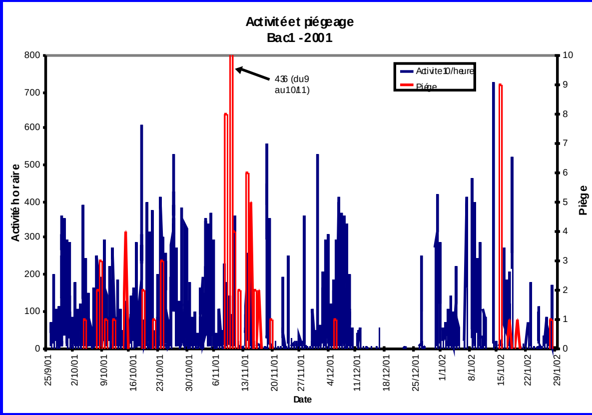
Results

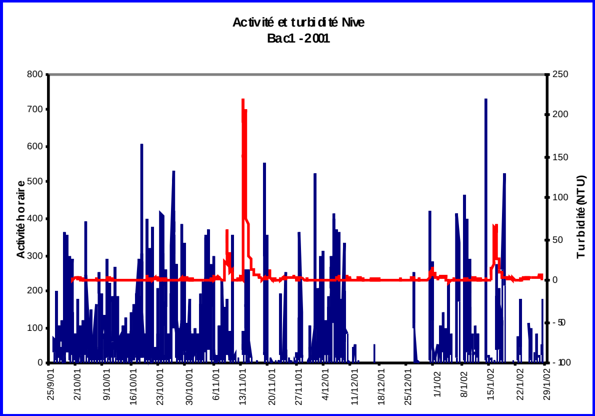
Eel activity linked to runs and env. param.



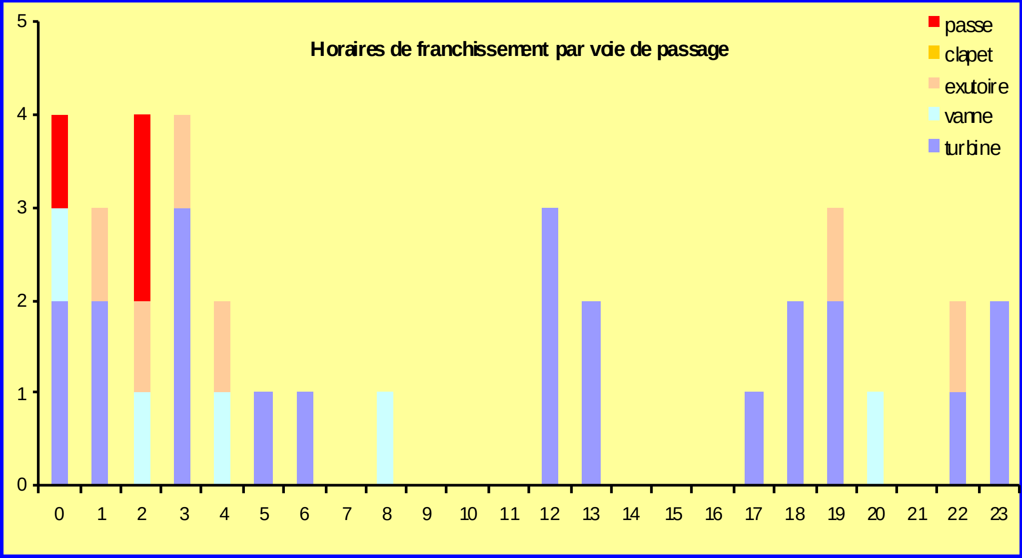


Eel activity not linked to runs and env. param.: para

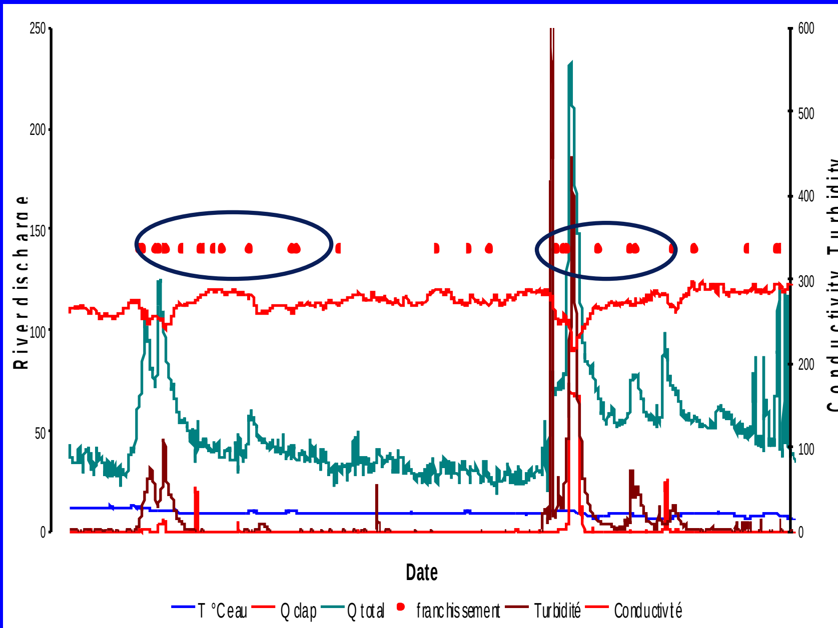




Conditions de franchissement



Eel passage at the power plant and environmental parameters



Main passages after an increase

of river discharge and turbidity

and decrease of conductivity

The main information in this presentation comes from the following papers:

- Gosset C., Travade F., Durif C., Rives J., Elie P., 2005. Tests of two types of bypasses for downstream migration of eels at a small hydroelectric plant. River Research and Applications. Accepted 04 March 2005.

- Durif C, Gosset C, Rives J, Travade F, Elie P. 2003. Behavioral study of downstream migrating eels by radio-telemetry at a small hydroelectric power plant. In: *Biology, Management, and Protection of Catadromous Eels*, Dixon DA (ed.). American Fisheries Society, Symposium 33: Bethesda, Maryland; 343-356.

- Larinier M, Travade F. 1999. The development and evaluation of downstream bypasses for juveniles salmonids at small hydroelectric plants in France. In: *Innovations in Fish Passage Technology,* Mufeed Odeh (ed.). American Fisheries Society, Bethesda, Maryland, 25-42.

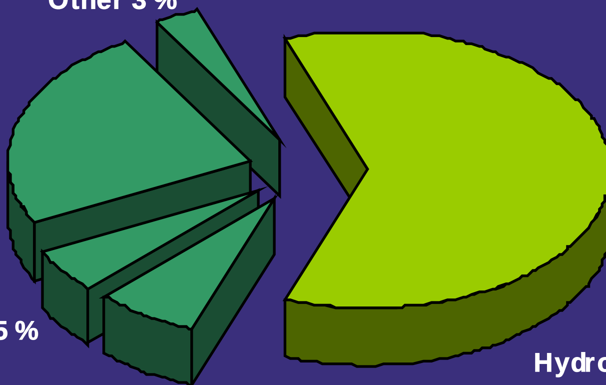
- Bégout-Anras M. L., Durif C., Gosset C., Rives J., Travade F., 2001. First results of a behavioural study on seaward migrating european eel, near the intake of a hydroelectric power station: comparison of radio and acoustic telemetry methods. Fourth conference on fish telemetry in europe, Trondheim, Norway, 26-30 june, 2001.

Status of Protection Measures for Downstream Migrant Eels in New Zealand

Jacques Boubée
Erica Williams

Electricity Generation in NZ

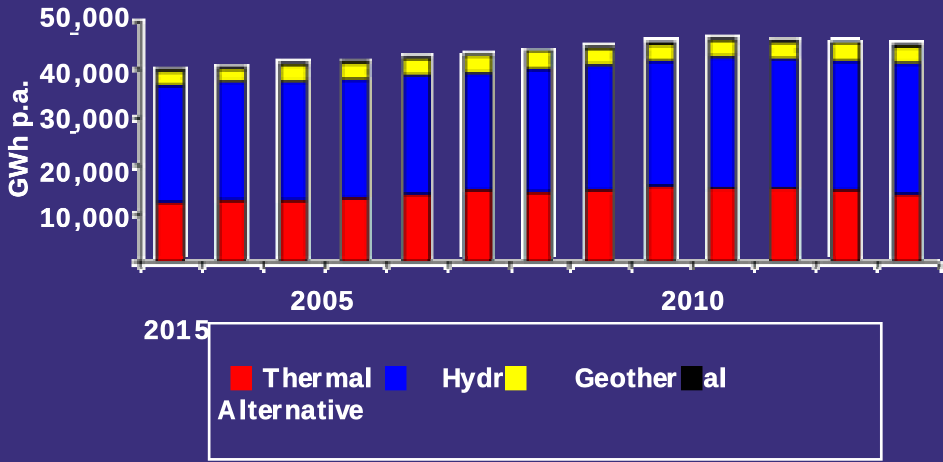
- NZ is highly dependant on hydro-power



Source: MED Energy Data File July 2003

Forecast Generation - NZ

- **Hydro generation is predicted to continue to be a significant source of energy - several new hydro schemes are planned.**



Source: MED Energy Data File July 2003

What are the Implications for Eels?

New Zealand Eel Species

Shortfin eel (*Anguilla australis*)

Max length: 1.1 m

Max weight: 3.0 kg

Habitat: lowland lakes & streams

New Zealand Eel Species

Longfin eel (*A. dieffenbachii*)

Max length: 2.0 m

Max weight: 10+ kg

Habitat: upland waters

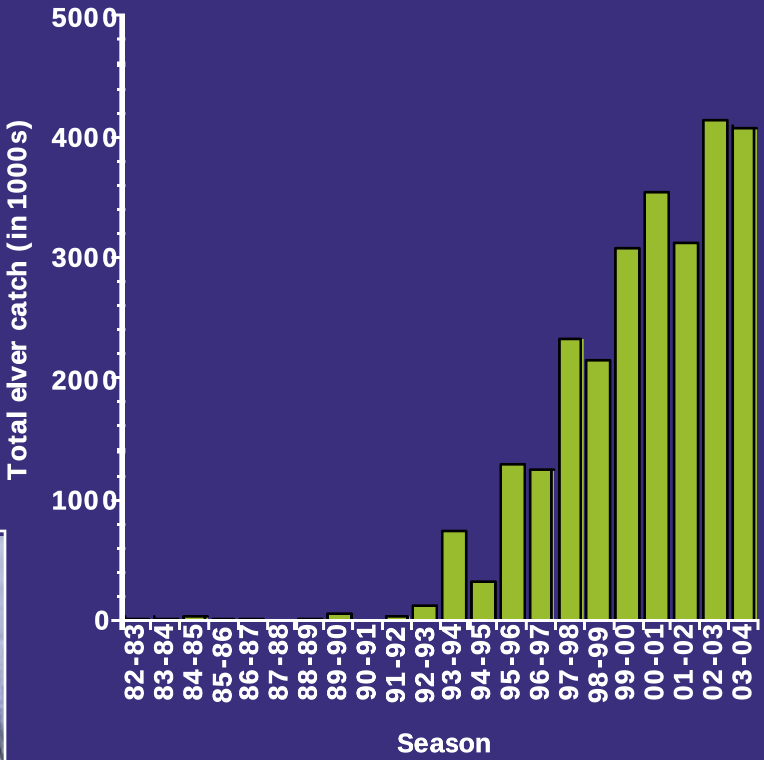
- **The most affected by hydro development.**

Habitat Upstream of Dams in NZ

- Hydro-electric dams are estimated to have blocked access to 35% of the total longfin eel habitat in NZ.
- The area affected is estimated to have been capable of sustaining a biomass of about 3,614 tonnes of longfin eels.
- Most of these are expected to be large females.

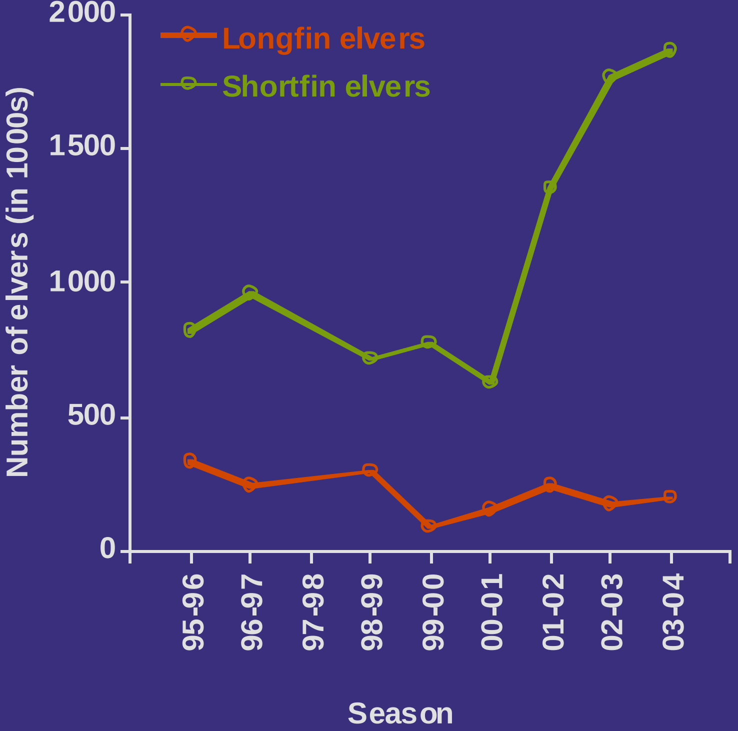
NZ Upstream Elver Transfers

- An increasing number of stations are implementing upstream transfer programmes for elvers.



Trends in Recruitment – no historical data

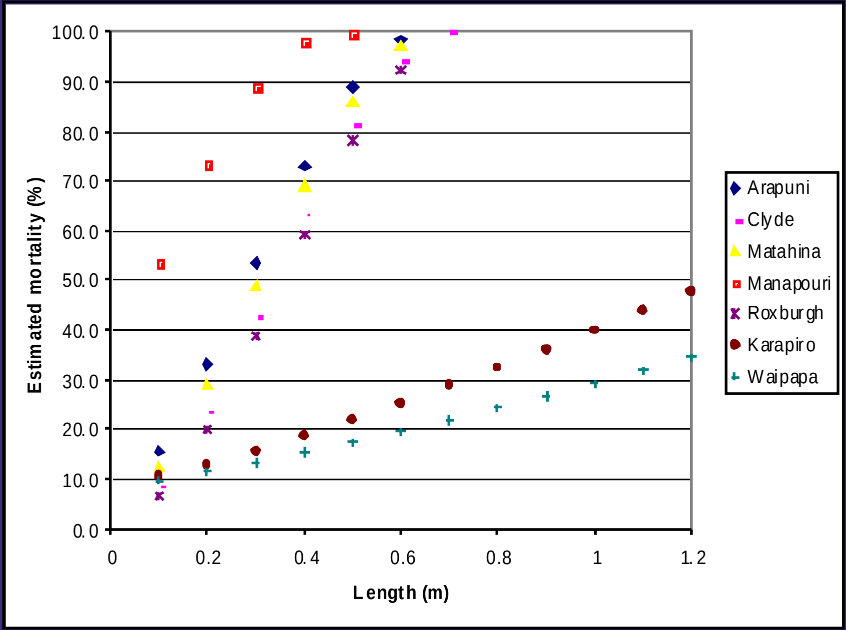
- Karapiro elver transfer



What about downstream migrants?

- The potential for a downstream passage problem will increase because of the elver transfer programmes and elver ladders/lifts that have been or are being installed.

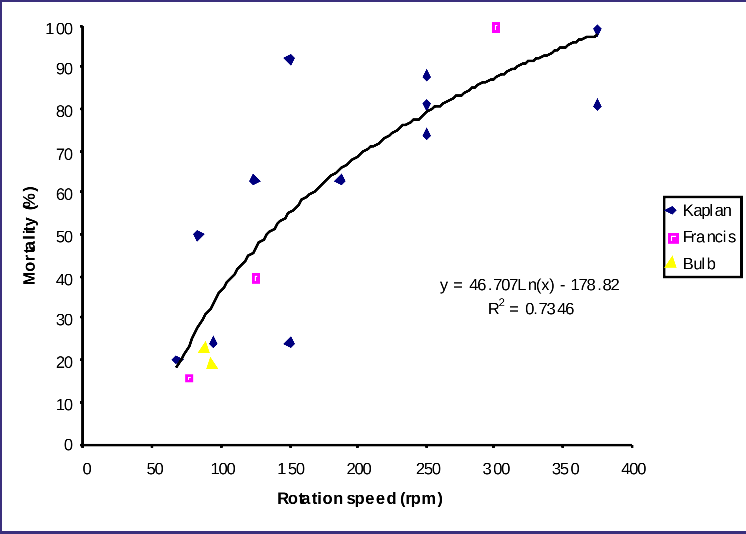
Turbine Mortality
– increases with eel length and height of dam



Predicted from Larinier and Dartiguelongue (198

Turbine Mortality

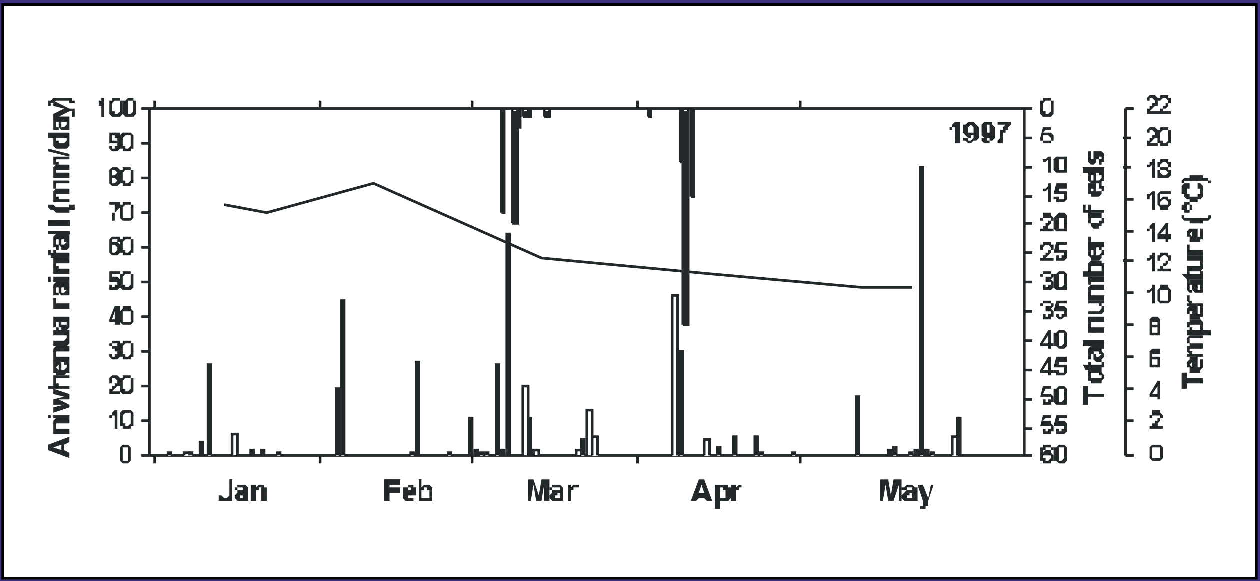
- highest for small turbines; increases with rotation speed



Data from Langon and Dartiguelongue (1997)

Studies

Timing of Downstream Migrations

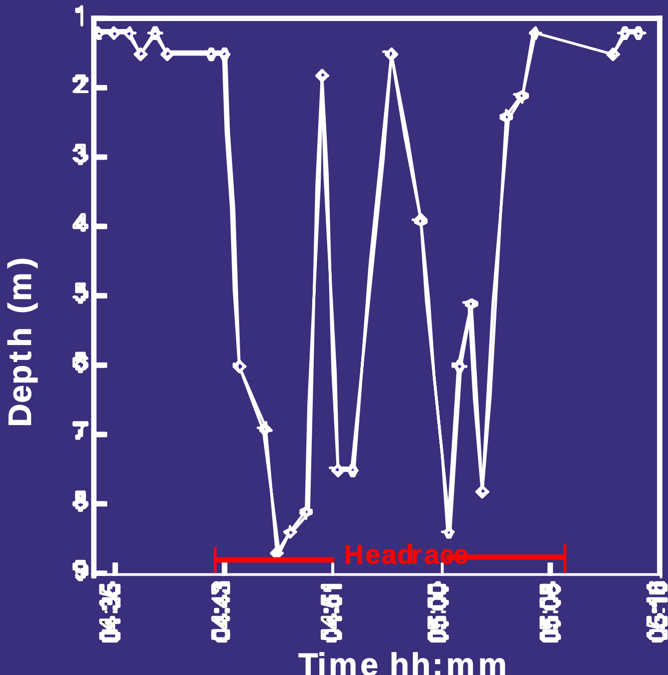


- **Migration occurs mainly in autumn after heavy rain.**

Studies

Migrant Eel Behaviour at Dams

Acoustic tracking of a migrant eel in front of the Patea Pw St intake



- Eels appear to search for an outlet in front of the intake, finally diving when passing.
- Eels are often seen swimming in the forebay (even in daylight) and so appear to be able to detect the intake.
- If unable or unwilling to pass, eels go back upstream and return during the next rain event.

Targetted Netting and Increased Fishing Pressure

- Target migrants and transfer downstream (e.g. L. Manapouri).
- Increase fishing pressure upstream of barriers (e.g. Waikato R.) (Ideally also ban fishing downstream.)

Barrier nets

- Barrier nets with trap or bypass can be effective if the amount of drift material is low.
- Timing is critical.

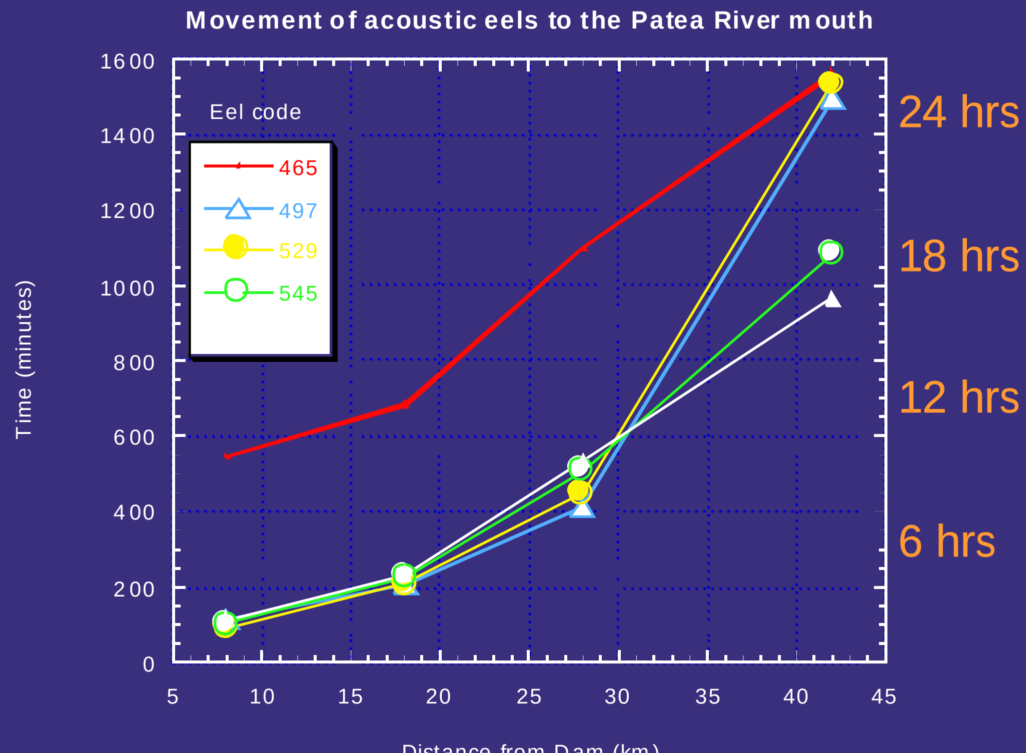
- Nets set during rain events.
- Very labour intensive.
- Only works well where macrophyte drift is absent.
- Cheap to install (NZ$10-15k), but high maintenance and running cost.

Spilling Over Dam

- Studies have shown that large numbers of eels can safely use an open spillway.
- Need to integrate migration timing, and station operation.
- No installation cost, but high fuel cost.

- Spillway opening of about 70 mm can be effective for eels if well timed and intake shut off or reduced.
- Efficiency? (Only 10% at one site where 3 x 2 hour targeted spills are made annually.)

Once Over Dam – OK?

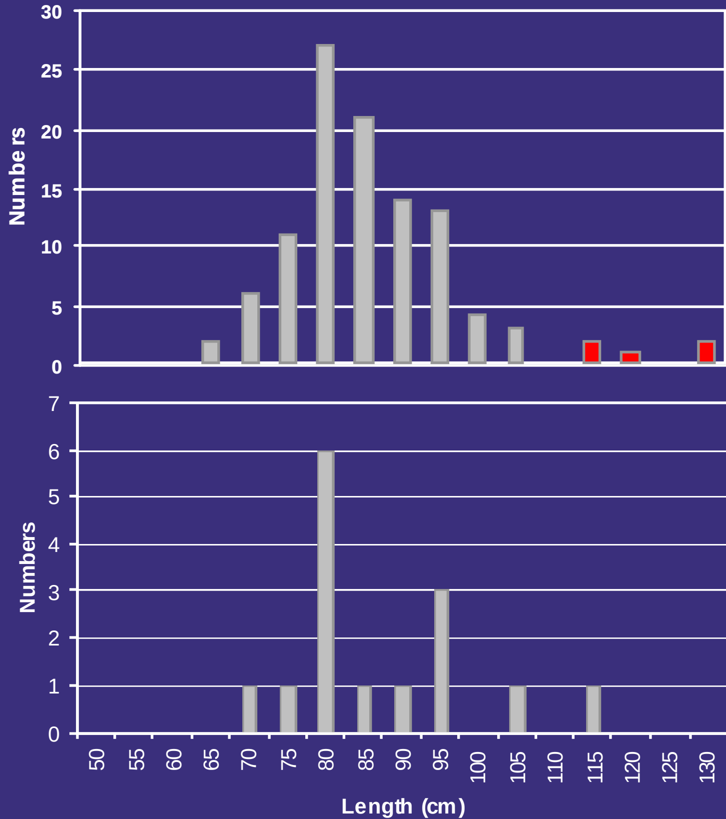


Small Diameter Bypass

Wairere Falls Ps

- Small 4.5 MW hydro station on a the “flashy” Mokau R.
- Trash rack spacing 30 mm.

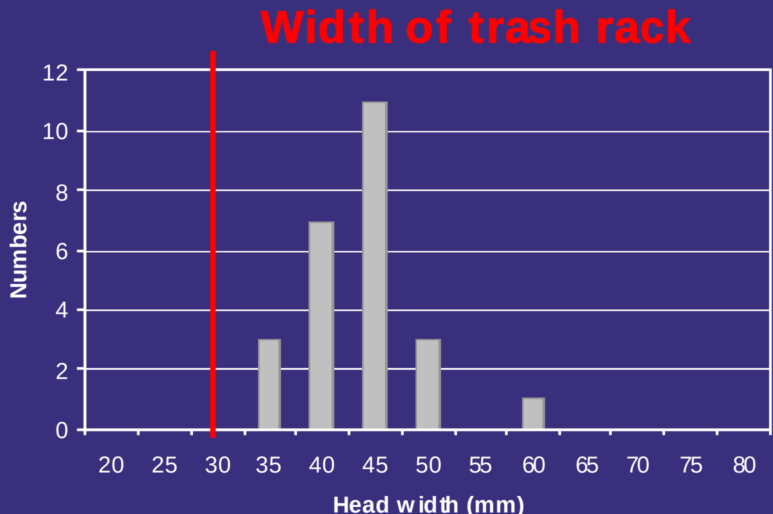
Size of Migrants



Length of migrant eels

Length of migrant eels found in turbine

Entrainment and Turbine Mortality



Body width of eels found in turbine

- How did these eels get through the 30 mm trash bars?
- A hole was found in the screens (and subsequently repaired).
- If the eels did find that hole would they find and use a small diameter bypass?

Small Diameter Bypass

- 2 x 100 mm bypass holes drilled through the dam.
- 0.6 m below water level and between two sets of screens.

Small Diameter Bypass & Spillway

- PIT antennae & readers/loggers installed on two of the six 7x3 m spillways in 2002 and on all six spillways in 2003.
- Also installed an antenna and reader/logger on the bypass.
- Tagged eels with 32 mm PIT in 2002 and 52 mm PIT in 2003 .

Small Diameter Bypass & Spillway

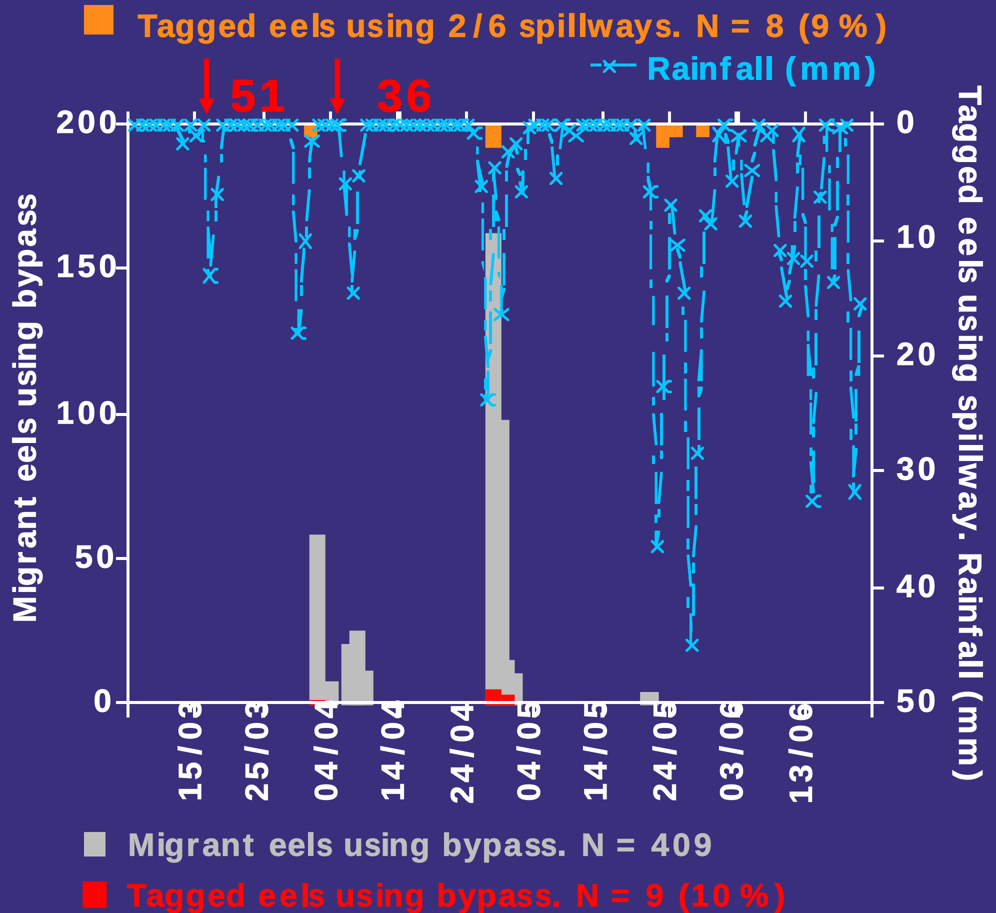
Used a net at the end of the bypass and counted the eels daily.

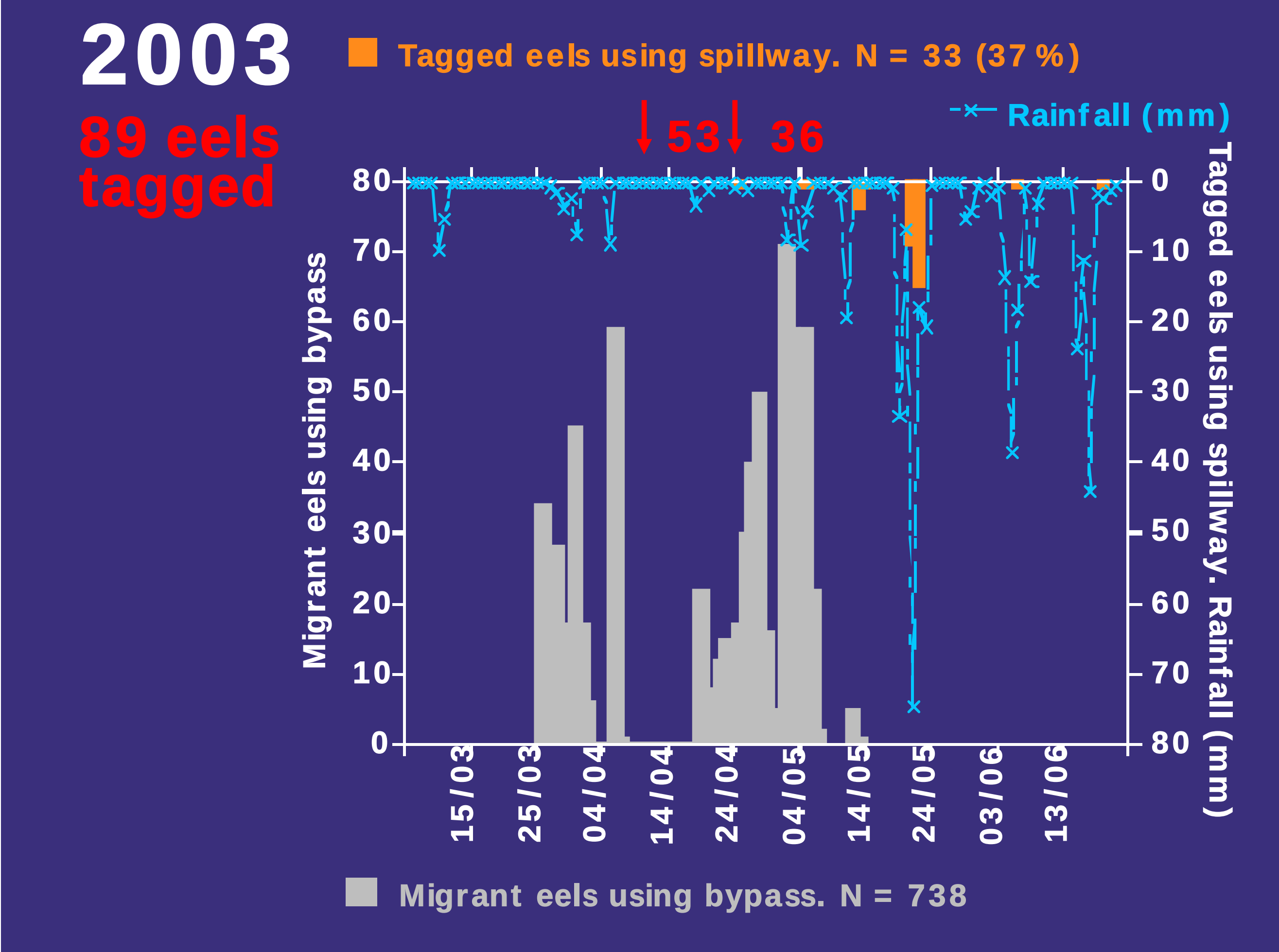
Small Diameter Bypass & Spillway

- **Spillways in flood**

2002

87 eels tagged





2003
89 eels tagged
Tagged eels using spillway. N = 33 (37 %)
Rainfall (mm)
53
36
Migrant eels using bypass
Tagged eels using spillway. Rainfall (mm)
0
10
20
30
40
50
60
70
80
15/03
25/03
04/04
14/04
24/04
04/05
14/05
24/05
03/06
13/06
Migrant eels using bypass. N = 738

Small Diameter Bypass & Spillway

- A proportion of the tagged eels were able to find and use the bypass when the spillway was not operating.
- Bypass efficiency ?
- Eels used the spillway preferentially when water level was over the spillway crest.

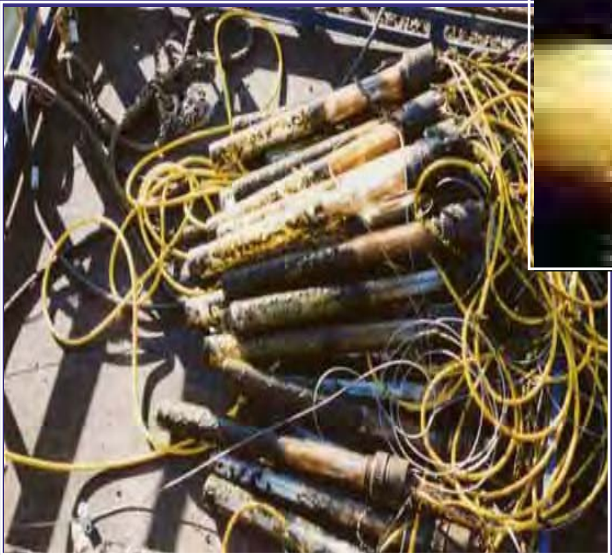
- Still get some impingement on the screens before spilling occurs.
- Will be installing two more bypasses and enlarge the existing one.

Protective Measures for Intakes

- Lights
  - Strobe lights reputed to work for eels and other species.
- Sounds
  - Marketed aggressively for some species but little done with eels (?)
- Electric fields
  - Useful on small schemes for upstream migrants. Several studies started for downstream migrants but no results published (?)
- Fine screening and reduced velocities
  - Will place severe restrictions on Ps operations. Very high costs.

Light trials

- KEMA Lights tested at the Huntly Power Station

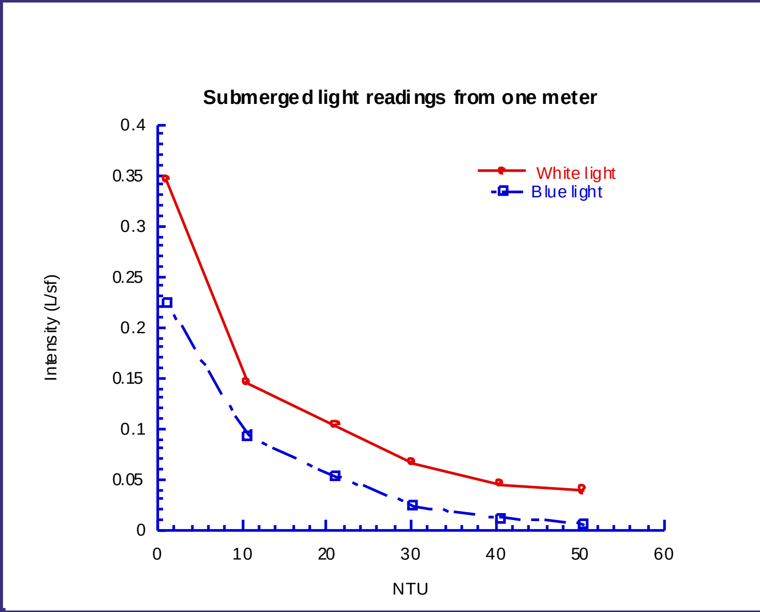


- Cost NZ$25,000 plus manpower.
- The glass case quickly became covered with algae and needed regular cleaning.

Lights

Light levels drop off very quickly with distance, especially if water is turbid.

- Given that eels move in floods and even during the day, light barriers are not the answer under NZ conditions.



Sound - Infrasound

? ? ? ? ? ? ? ?

Electricity

- We observed an avoidance response of the intake by connecting 12 volts DC to the screens.
- More work planned.


Questions
?

AMERICAN EEL LIGHT AVOIDANCE STUDY

Presented by Kevin McGrath

New York Power Authority

Coauthors and Collaborators

Scott Ault -- Kleinschmidt
John Skalski – U. of Washington
Carole Fleury -- Milieu, inc.
Alan Fairbanks -- Stantec

American Eel Workshop
February 2005
Cornwall, Ontario, Canada

Objective:

To determine whether outmigrating (silvering) eels avoid artificial light

Proof of Concept Study

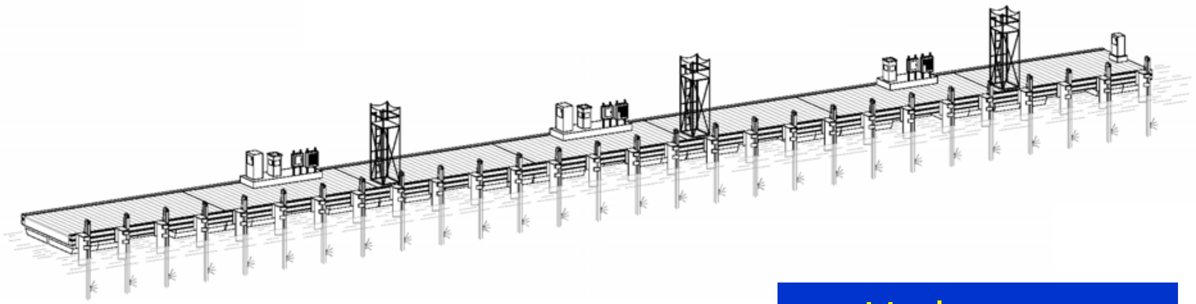
- Results of other eel light studies have shown differing and varying results
- This study was not an application at a hydro project
- Demonstration to show that light affects outmigrating St. Lawrence River eels under physical and hydraulic conditions similar to what exist at Moses-Saunders Power Dam and Iroquois Dam

Study Design

- Deploy underwater lights from an 80 m floating platform set 30° to the current to create a “wall of light”
- Randomly alternate sampling nights with “lights on” and “lights off”
- Conditions identical, except for light on and off, on the randomly alternated nights
- Determine avoidance by collecting eels in nets set downstream of the platform
- Observe eels in light field and document movement patterns

CM 1368_101_V01.fh8 (2003-08-05)

Platform Design



Underwater
Electric Cable

Approximately 600
meters in length

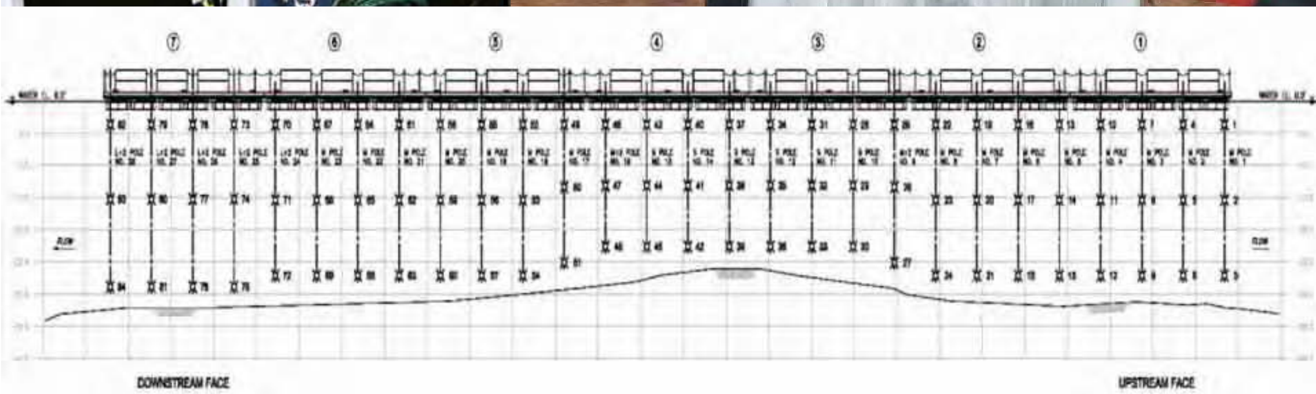
4,800 volts

Complete Platform 80 m Long

Light Array Platform Deployed Upstream of Iroquois Dam

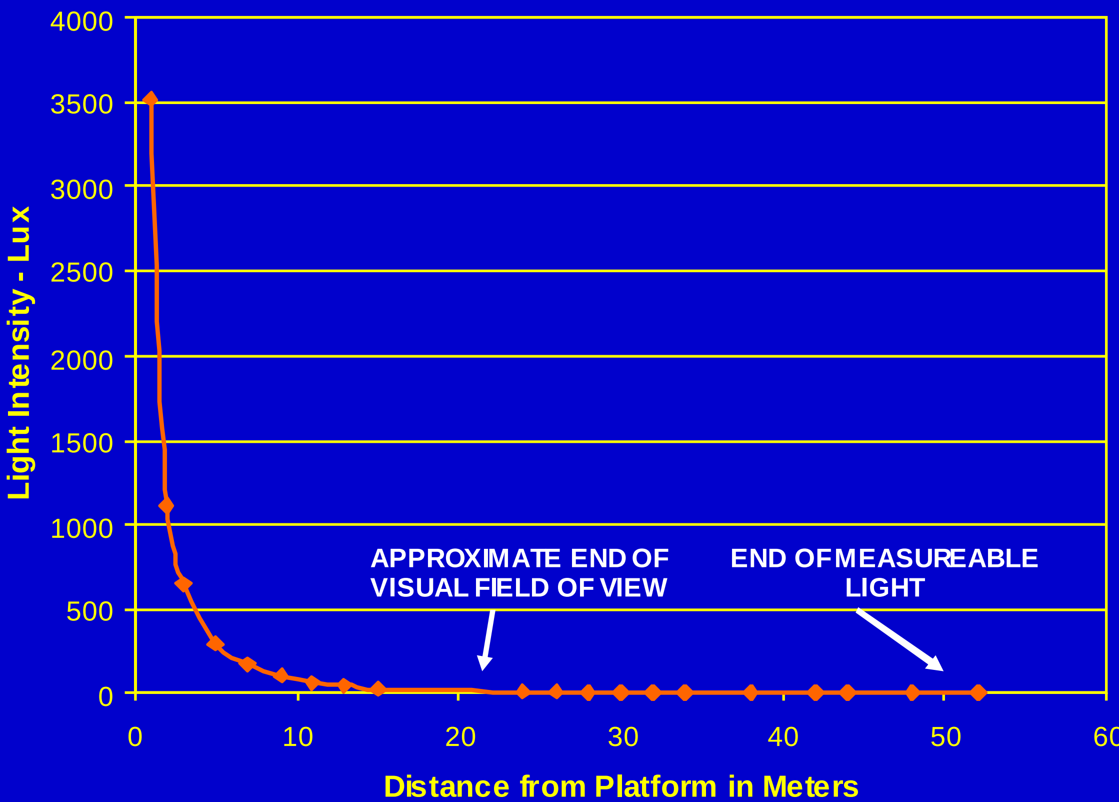

LIGHT


ROS Inc.
San Diego, CA
158 mm x 64 mm x 81 mm

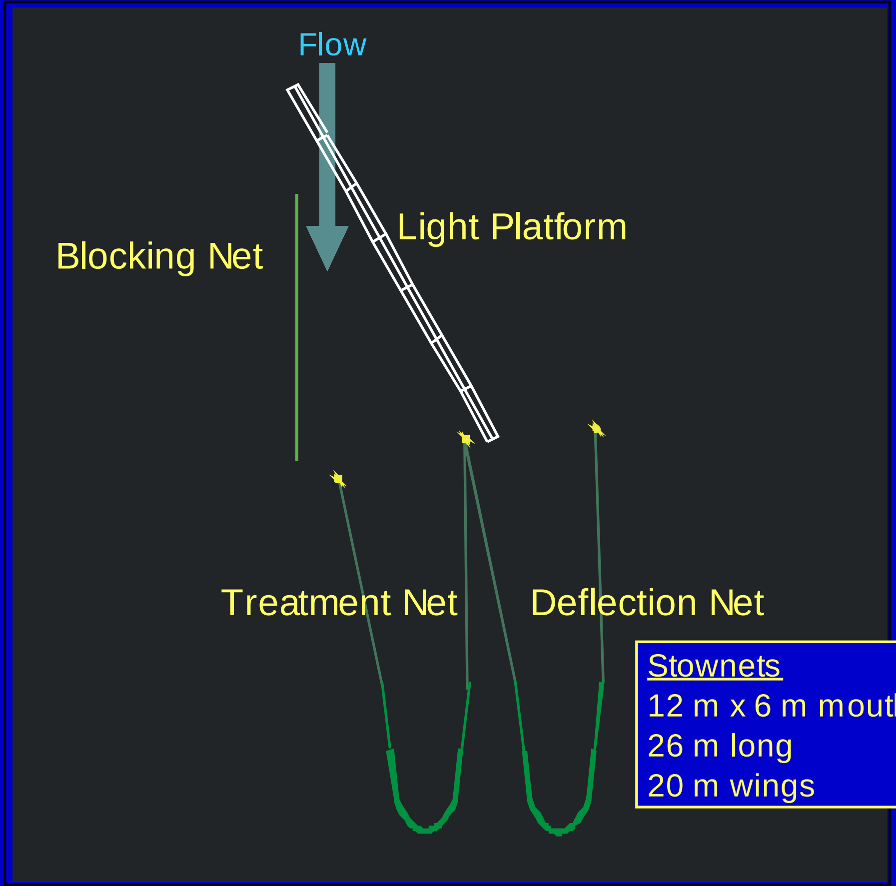

7
6
5
4
3
2
1
DOWNSTREAM FACE
UPSTREAM FACE


Area illuminated is approximately 52 m wide x 90 m long, surface to bottom
20-25 METERS

Light Intensity Field Measurements at Center of Platform



Collection and Blocking Net Arrangement



<u>Stownets</u>

12 m x 6 m mouth

26 m long

20 m wings


Collected Adult Eels:
Approximately 850 to
1100 mm in length

Statistical Design for Estimation of Light Avoidance

- Estimates are obtained by comparing the proportional number of eels in the Treatment Net between **Treatment (ON)** and **Control (OFF)** conditions

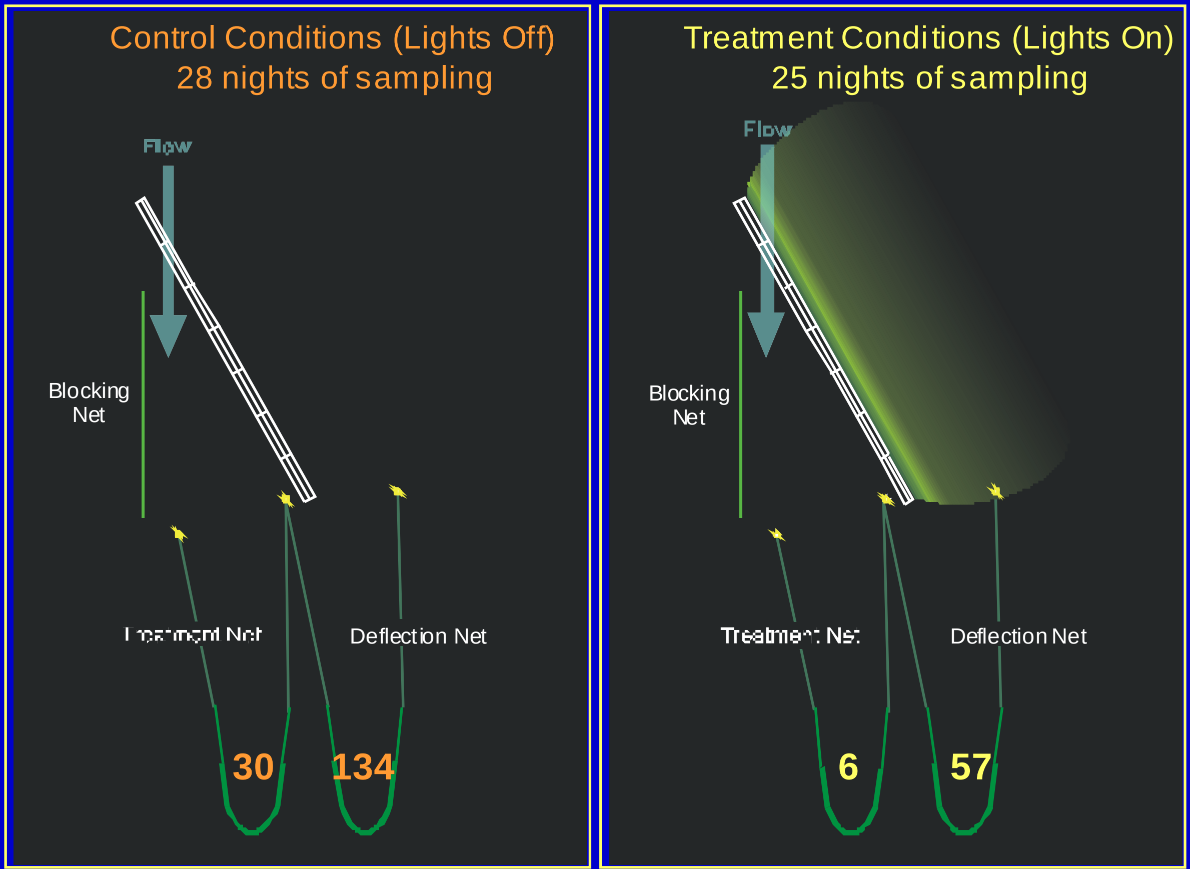
- The statistical design assumes that all factors, except for light, remain constant under both the **Control** and **Treatment** conditions.

- In the study, the only factor that changed between **Control** and **Treatment** conditions was **LIGHT**.

RESULTS

- 53 nights of sampling
  - July 24 to September 17, 2002
  - 25 nights with the lights on
  - 28 nights with the lights off

Collection of Eels Under Control and Treatment Conditions



Estimating Light Avoidance

$$\text{Probability an eel avoids the Treatment Net with LIGHTS ON} = 1 - \left(\frac{\text{Mean \# eels in Treatment Net with lights ON}}{\text{Mean \# eels in Treatment Net with lights OFF}} \right)$$

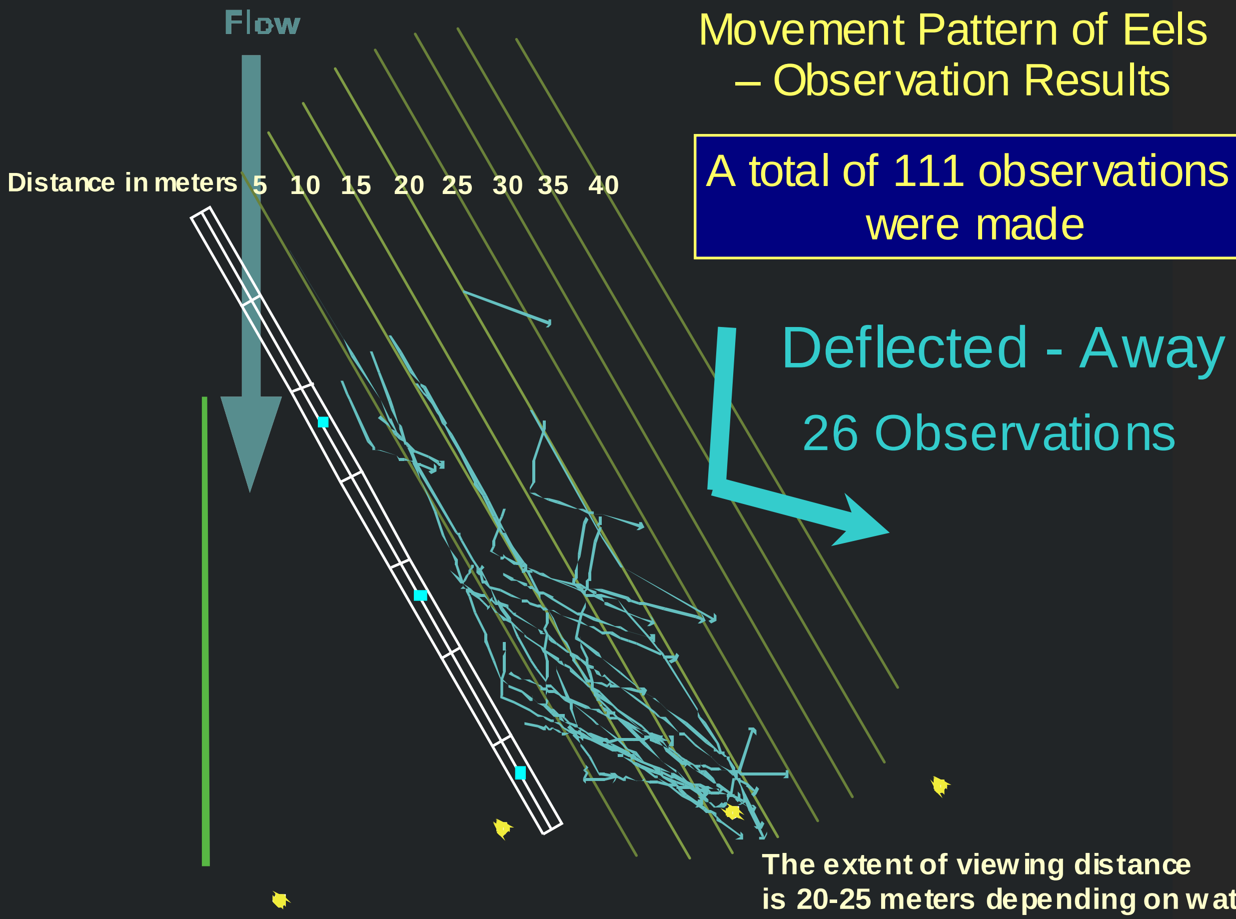
$$= 1 - \left(\frac{6 \text{ eels} / 25 \text{ nights}}{30 \text{ eels} / 28 \text{ nights}} \right)$$

Probability an eel avoids the Treatment Net with LIGHTS ON = **77.6%**

with a 90% confidence interval between 65.6% and 91.7%

Movement Pattern of Eels – Observation Results

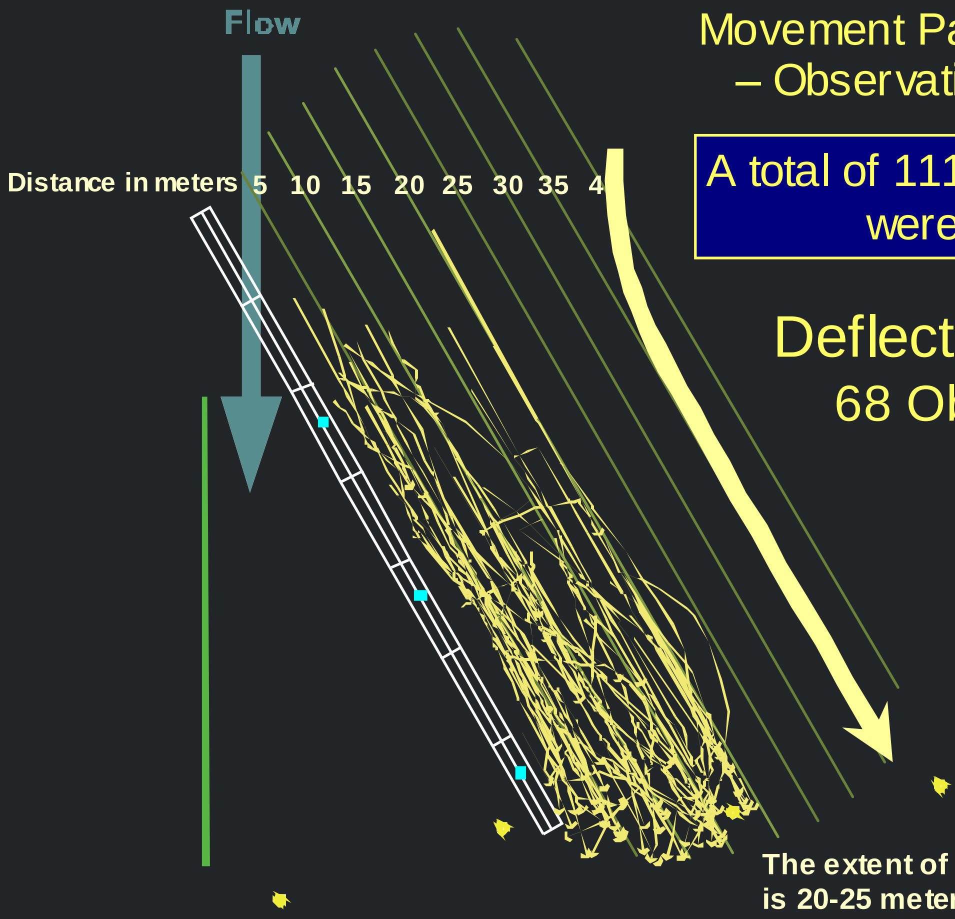
A total of 111 observations were made



The extent of viewing distance is 20-25 meters depending on water surface conditions and wind

Movement Pattern of Eels – Observation Results

A total of 111 observations were made



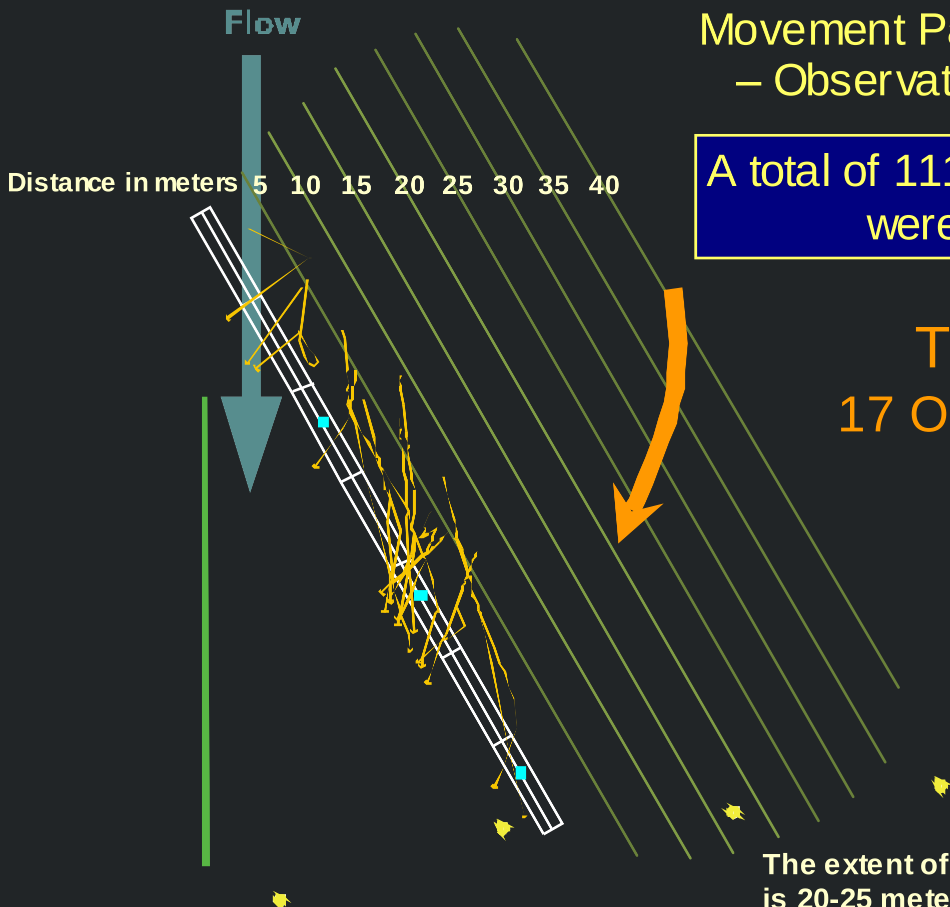
Deflected - Parallel

68 Observations

The extent of viewing distance is 20-25 meters depending on water surface conditions and wind

Movement Pattern of Eels – Observation Results

A total of 111 observations were made

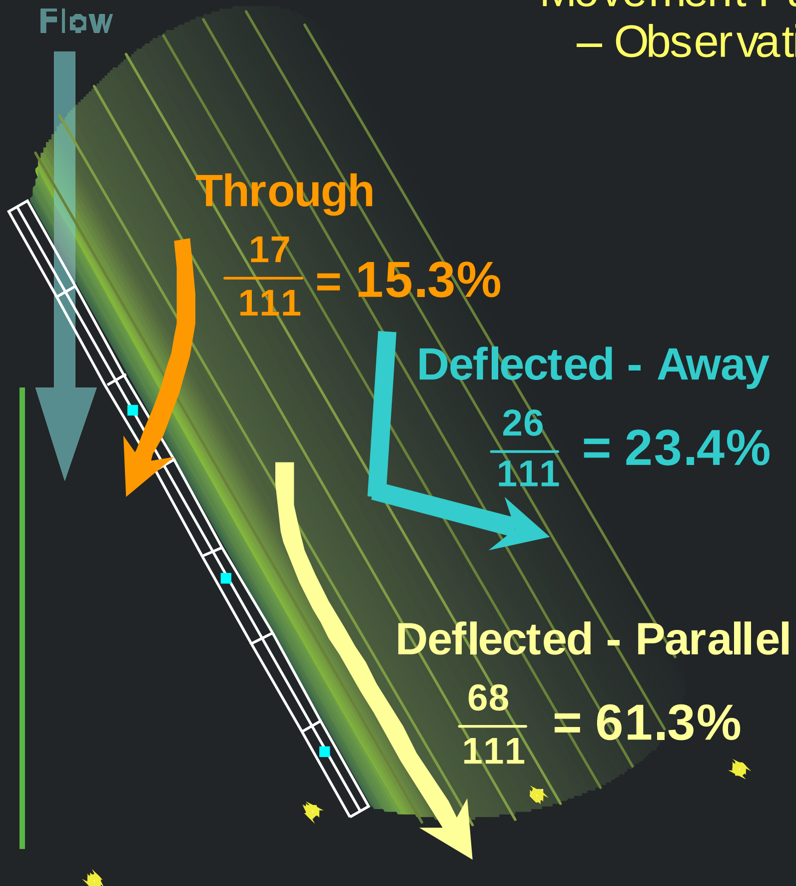


Through

17 Observations

The extent of viewing distance is 20-25 meters depending on water surface conditions and wind

Movement Pattern of Eels – Observation Results



WHAT IS KNOWN

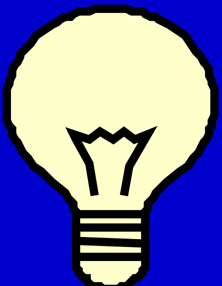
- Migrating eels avoid a 90 m long underwater "wall of light" set 30° to the flow in a current of approximately 0.6 m/s

- Based upon netting results 77% of the eels avoided the light field

- Based upon observational results 85% were able to modify their trajectory, avoiding the light field

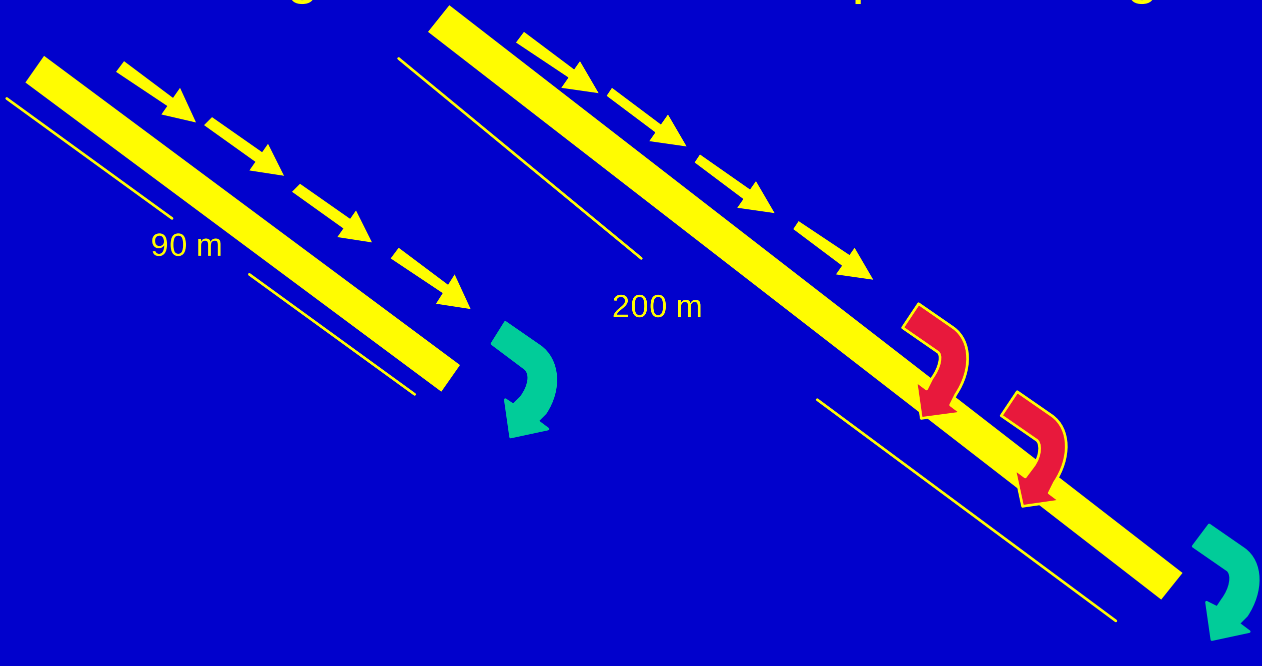
WHAT IS NOT KNOWN

- How changes in light intensity affect avoidance
- How changes in light frequency affect avoidance
- How increases in angle of the array affect avoidance
- How increases or decreases in current velocity affect avoidance

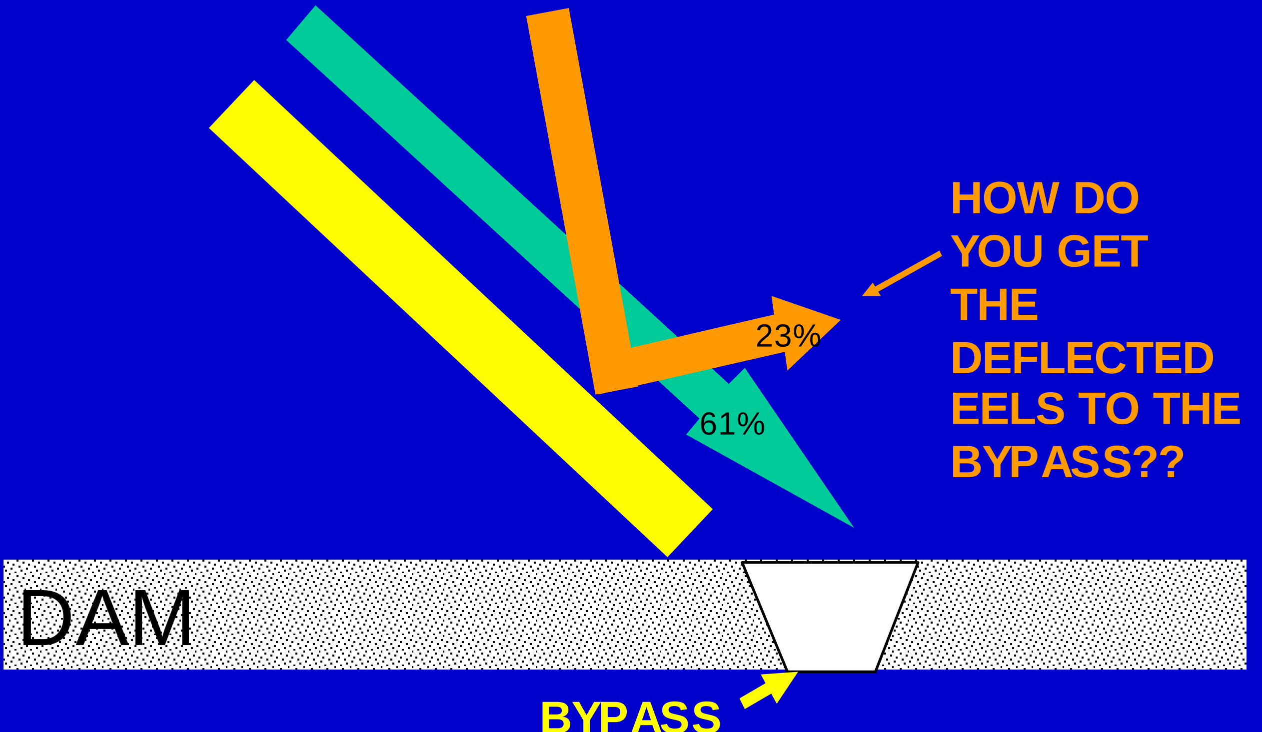


WHAT IS NOT KNOWN (Continued)

- Is there a linear distance along the array where eels no longer avoid but instead pass through



APPLICATION AT A HYDRO DAM IS LIKELY GOING TO PRESENT SOME CHALLENGES



New York Power Authority

Concept: Ault

Acknowledgements

- Kleinschmidt – Design, Engineering, Electrical, Construction, and Installation
  - Scott Ault, Joe Dembeck, Steve Day, Mike Hreben, Peter Bastian, and Steve Rule
- NYPA St. Lawrence Project
  - Electrical Department and Dan Parker
- Milieu – Light Platform and Data Analysis
  - Carole Fleury and Denis Desrochers
- Stantec (Beak) – Netting and Platform Installation
  - Alan Fairbanks
- Buffalo State – Great Lakes Research Center – Research Vessel
  - Capt. John Freidhoff
- U. of Washington – Biostatistican –Statistical Design
  - Dr. John Skalski

St. Lawrence-FDR Power Project

Moses-Saunders Power Dam

Collection Efforts for Downstream Migrating American Eel

Presented by Kevin McGrath

New York Power Authority

Collaborators

Kleinschmidt

Stantec Associates

Buffalo State College, Great Lakes Center

American Eel Workshop
February 2005
Cornwall, Ontario, Canada

Purpose for Collecting Downstream Migrating Eels

- For a large-scale telemetry study
- Evaluating the effects of artificial light on the behavior of outmigrating eels

Collection Gear

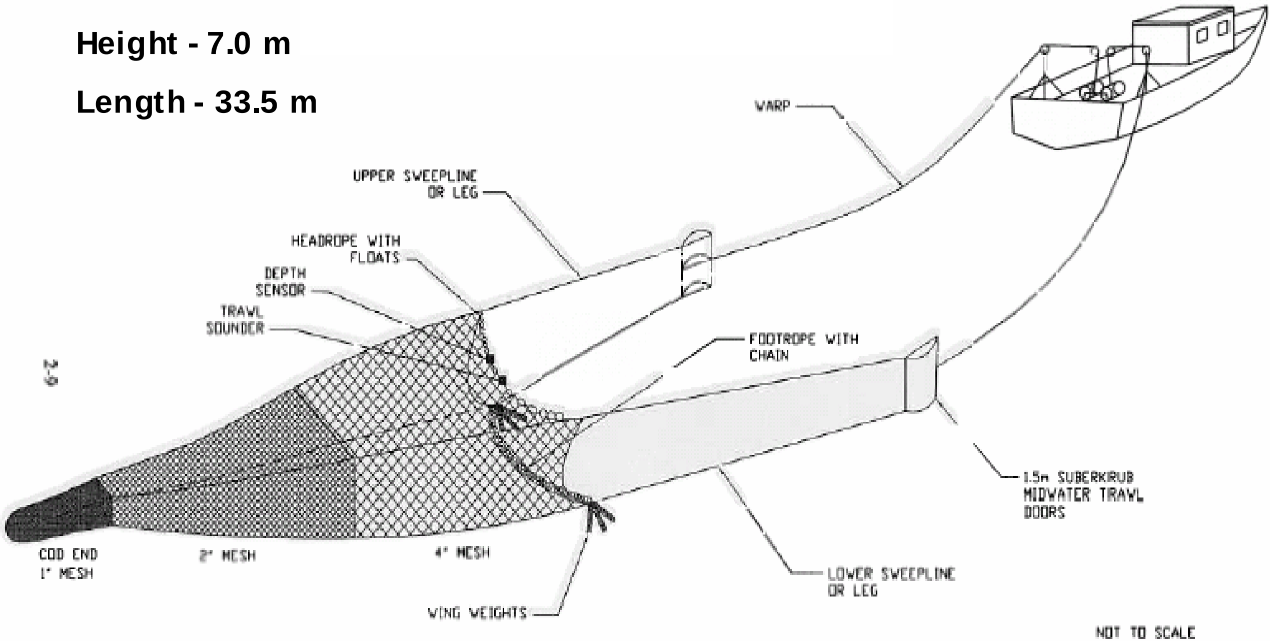
- Previous studies indicated that gear such as electrofishing, hoop netting, and eel pots were not effective at capturing maturing outmigrants
- Developed mid-water trawling techniques in 1999
- Used mid-water trawling upstream of the Moses-Saunders Power Dam in 2000 to collect outmigrants for large-scale telemetry study

Mid-Water Trawl

Width - 9.2 m

Height - 7.0 m

Length - 33.5 m



Trawl Vessel - Andrea Marie I

Length – 24 m

Beam – 7.3 m

Tonnage - 87

Hp - 500

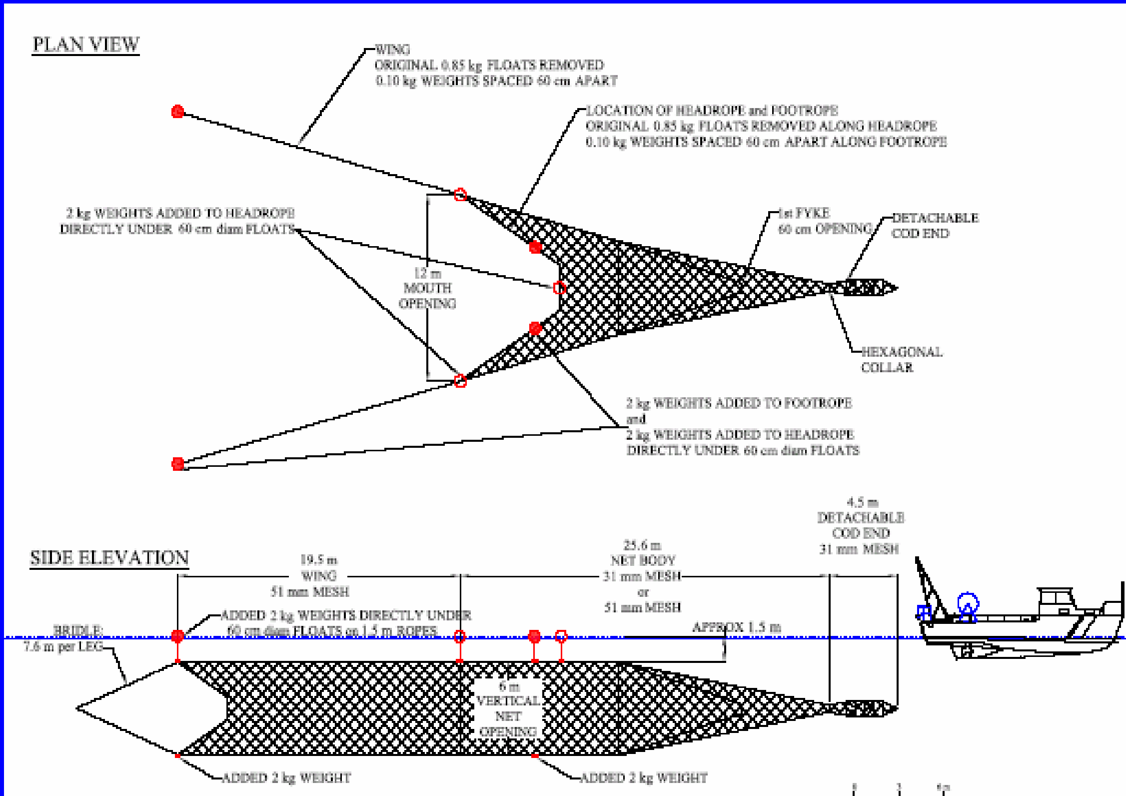
Collection Gear

- Because of limitations associated with trawling, stownetting techniques were developed in 2001.
- Limitations/concerns associated with trawling were:
  - Stress on collected eels associated with sampling at high velocities (approximately 2 m/s)
  - Requirement of large deep areas for maneuverability of towing vessel and to prevent net snagging
  - Intermittent nature of sampling (deployment and retrieval)

Collection Gear

- Basic stownet design - stationary trawl deployed from moorings to passively collect outmigrants
  - More continuous sampling approach then trawling
  - Cod end can be checked while main body fishes
  - Sampling velocities of approximately 0.6 m/s
  - Requires robust system of anchors and buoys
  - Requires large vessel to deploy and tend
  - Tends to get clogged with floating debris/vegetation
- Fished near Iroquois Dam

Stownet - Plan View and Elevation



RV Seneca and Stownet Buoys

Stownet Location Upstream of Iroquois Dam

Results

Effort and Cost for Eel Collection
Trawling vs. Stownetting

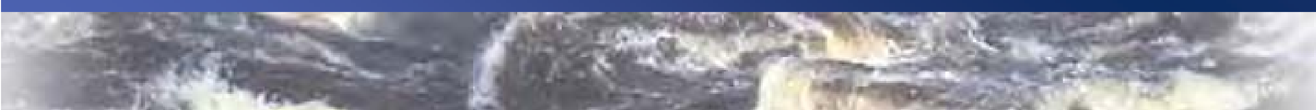
	2000 Intensive Trawling	2002 Stownetting Light Study
Number of Eels	155	159
Number of Sampling Nights	73	28
Number of Tows	389	NA
Hours Sampled	342	536
CPUE	0.45	0.30
Number of Nets	1	3
% of River Discharge Sampled	1.12	2.13
Program Cost	$165,000	$295,000

Une division d'Hydro-Québec

Eel Light Avoidance Study conducted at Les Cèdres Intake Canal (2004)

Richard Verdon
Hydro-Québec

Denis Desrochers and Carole Fleury
Milieu Inc.



Comparison of alternatives

TECHNOLOGY	ADVANTAGES	LIMITATIONS
AIR BUBBLE BARRIER	EASY TO INSTALL, RELATIVELY CHEAP	INEFFICIENT
ELECTRICAL BARRIER	EEL ARE VERY SENSITIVE TO ELECTRICAL FIELD	SENSITIVITY VARIES WITH EEL LENGTH. RANGE OF THE FIELD IS SMALL. DIFFICULT TO INSTALL AND MAINTAIN, HIGH SECURITY CONSTRAINTS
LOW FREQUENCY SOUND	EEL CAN DETECT LOW FREQUENCY SOUND. DEVICES ARE COMMERCIALLY AVAILABLE, E.G. SEISMIC SURVEYS	ARRAY OF SOUND GENERATORS WOULD BE COMPLEX TO INSTALL AND EXPENSIVES. POTENTIAL IMPACT ON LOCAL FAUNA

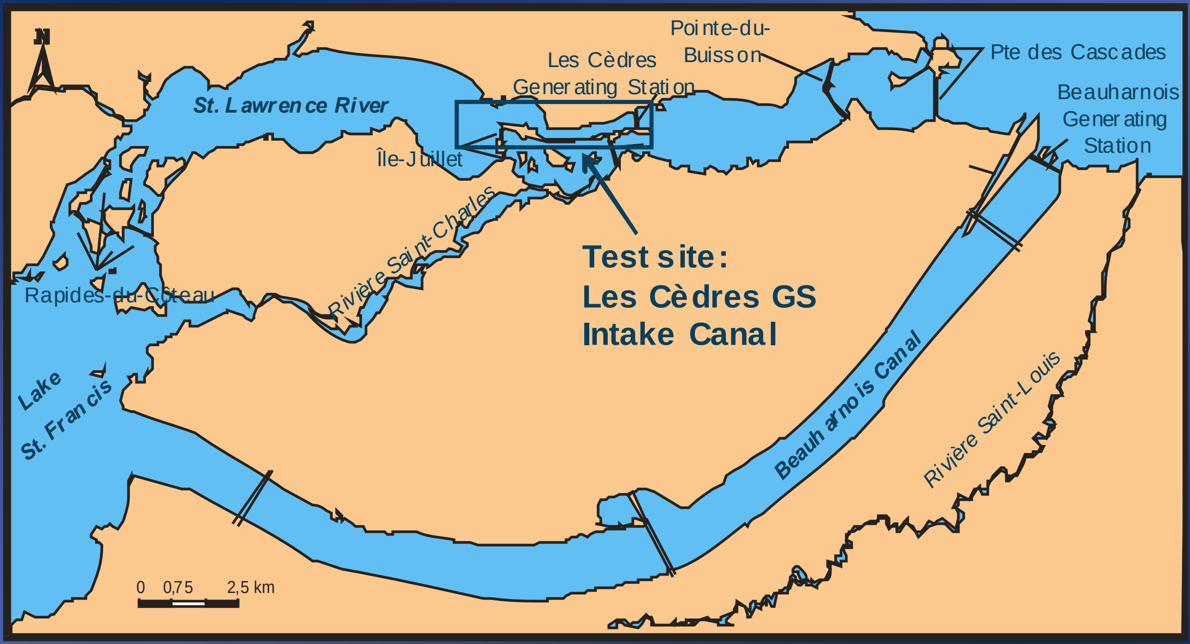
Comparison of alternatives (cont'd)

TECHNOLOGY	ADVANTAGES	LIMITATIONS
ULTRASOUND	DEVICES ARE COMMERCIALLY AVAILABLE	EELS ARE NOT VERY SENSITIVE TO HIGH FREQUENCY SOUND
INCANDESCENT AND FLUORESCENT LIGHT	MANY STUDIES HAVE SHOWN THE POTENTIAL OF LIGHT TO REPELL OR GUIDE EELS	MOST OF THE STUDIES AT SMALL SCALE. LARGE SCALE UNDERWATER ARRAY OF LIGHT WOULD BE EXPENSIVE AND DIFFICULT TO MAINTAIN.
LASER LIGHT	VERY POWERFULL. A SINGLE BEAM COULD THEORITICALLY BE PROJECTED OVER GREAT DISTANCE AND SWEEP THE WATER COLUMN	NO STUDY CARRIED OUT TO ASSESS EFFICIENCY

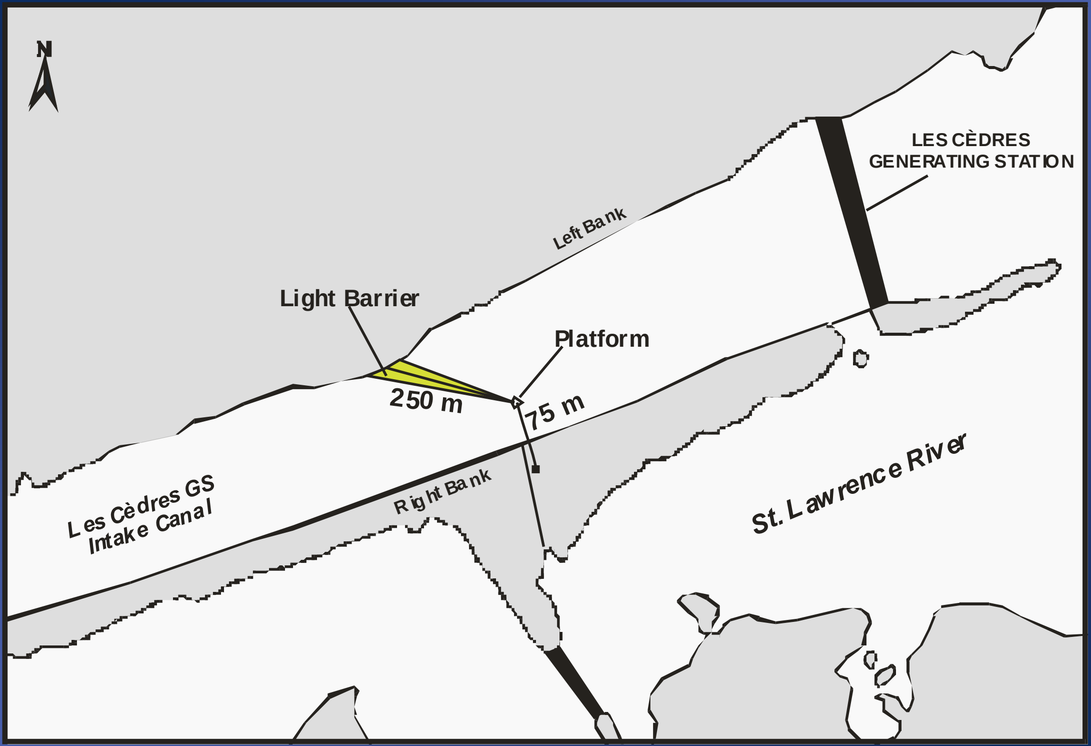
STUDY OBJECTIVE

To assess the potential of underwater laser light (40 watts, 532 nm) to guide eels over long distance in the St. Lawrence River

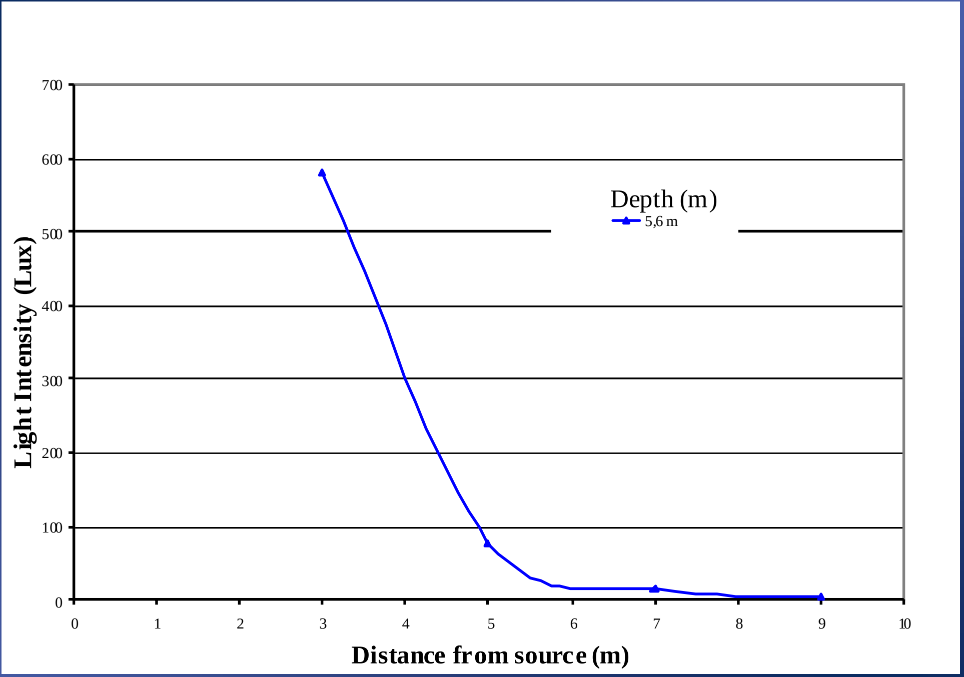
TEST SITE


N
St. Lawrence River
Les Cèdres Generating Station
Pointe-du-Buisson
Pte des Cascades
Beauharnois Generating Station
Île-Juillet
Rivière Saint-Charles
Test site: Les Cèdres GS Intake Canal
Rapides-du-Côteau
Lake St. Francis
Beauharnois Canal
Rivière Saint-Louis
0 0,75 2,5 km

LASER LIGHT TEST SITE AND SET UP



Laser light intensity at mid-depth

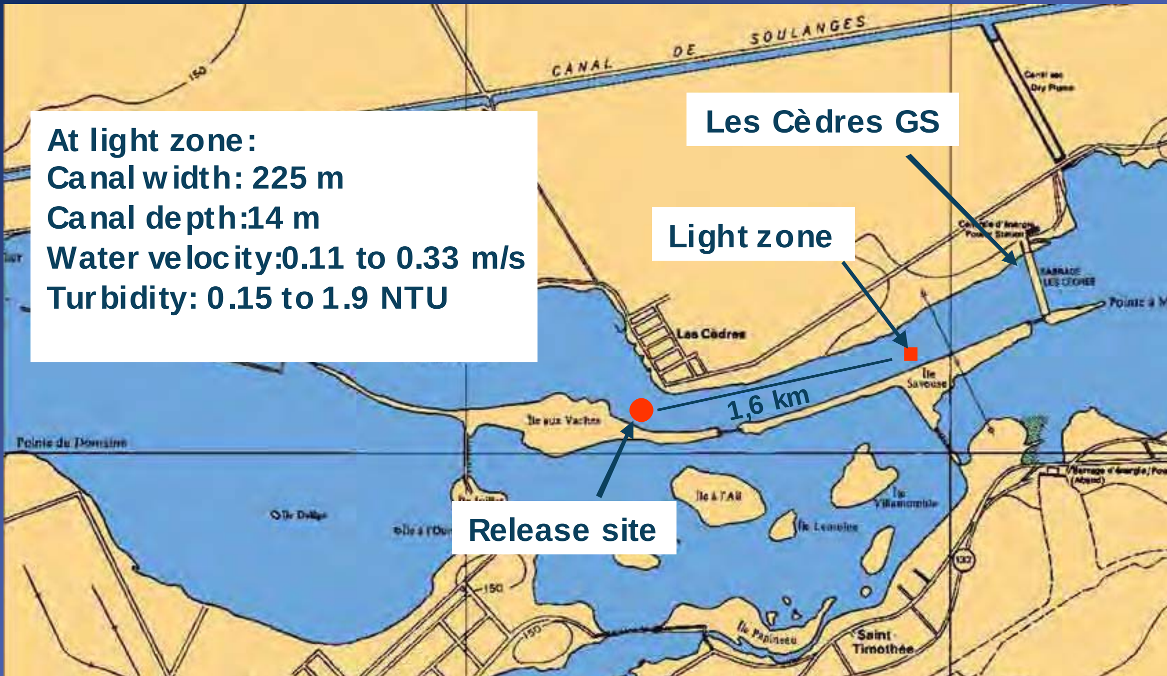


Light attenuation is rapid: Laser → Incandescent light

Methodology – light set up

- Two incandescent lights (12 000 Watts each) mounted above the water surface with a 32º angle
  - Half of days lights on
  - Half of days light off (randomly)
- Light Intensity Measurement (LI-COR SENSOR)
  - 1 to 30 meters from source
  - Along 6 axes
  - 3 depths: 2, 6, 10 m

LOCATION OF LIGHT ZONE AND EEL RELEASE SITE (LES CÈDRES INTAKE CANAL)



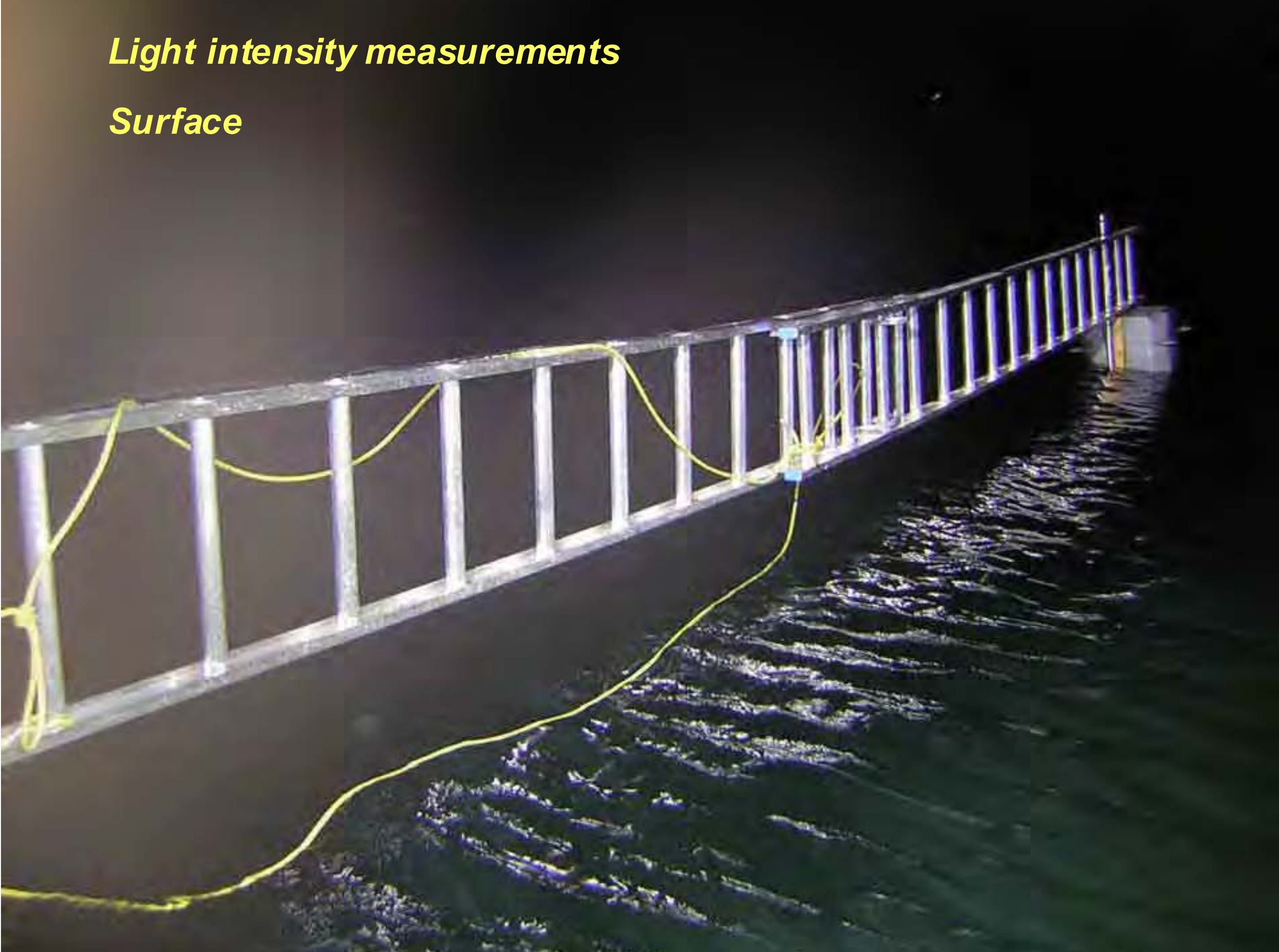
Light platform (without lights)

(3,65 m x 3,65 m)

12 kW Incandescent Lights on platform with 32º angle

Lights on

LI-COR underwater radiation sensor


Light intensity measurements
Surface

Methodology- eel monitoring

- Migrating eels purchased from commercial fishermen near Quebec City
- Eels (n = 210) were internally tagged with acoustic tags (HTI-795E) and released 1.6 km upstream of the light platform
  - Av. length: 940 mm (s.d. 68.3)
  - Av. weight: 1696 g (s.d. 403.4)
- Tag location accuracy
  - horizontal: ~ 1 m
  - Vertical: ~ 3 m
- Eels were released between Sept 11 and Oct.1

Acoustic Tag HTI-795E

Dimensions:

diam. 6,8 mm x length 21 mm

Weight:

1,5 g in air

0,8 g in freshwater

Duration:

17 days at 25°C – 21 days at 10°C

Frequency:

307 kHz

Detection Range:

300 m with 330° hydrophone

Pulse Width :

2 msec

Ping Rate:

Periods from 1003 to 1845 msec for the 210 tags of this study (3 or 5 msec separated periods)

Working table for handling


Irrigation of gills

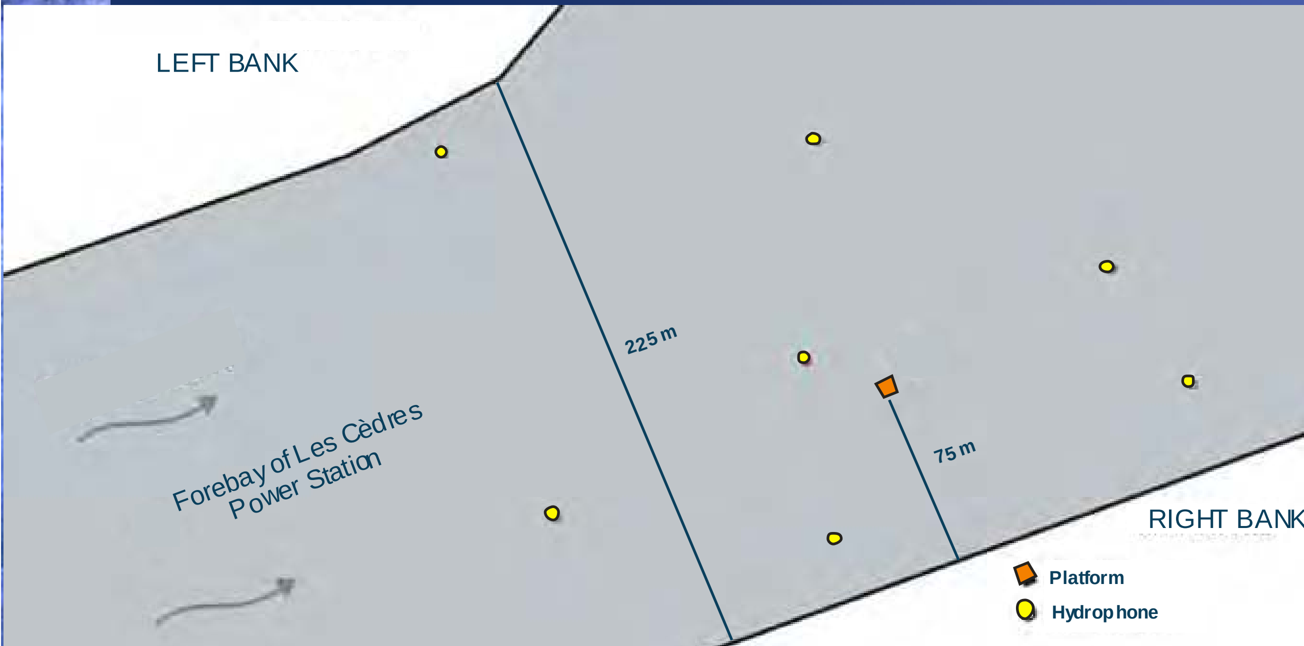

Abdominal
opening

Insertion of acoustic tag

One stitch to close opening

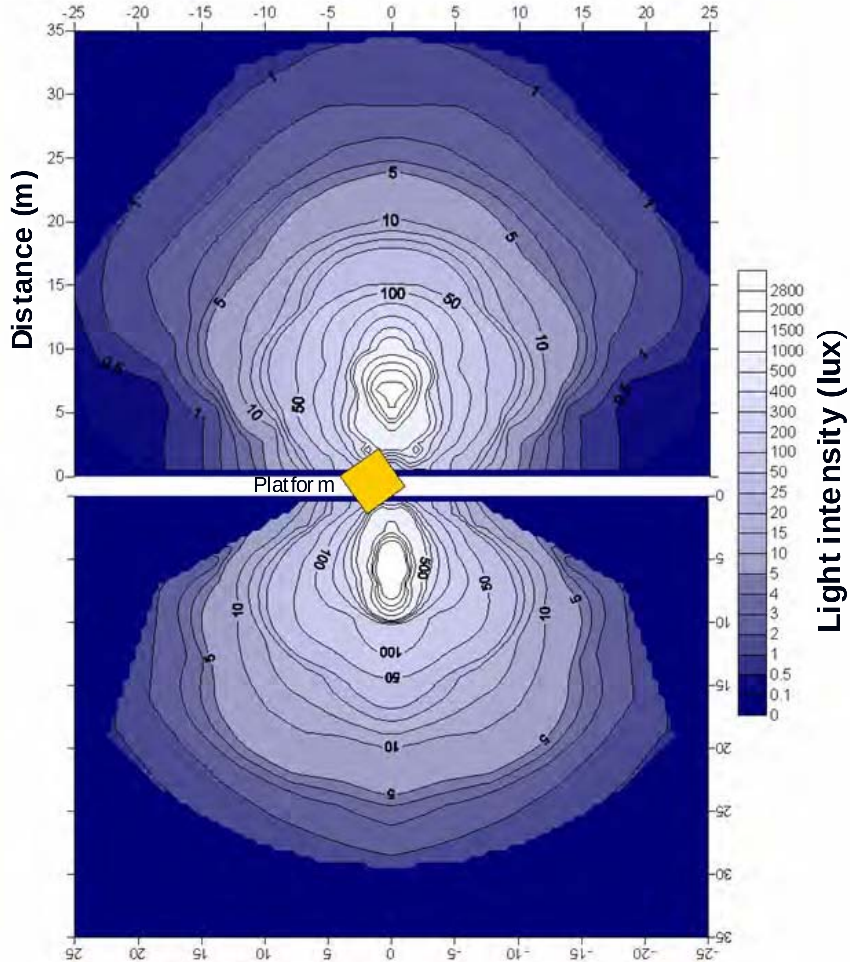
Installation of receivers

Location of receivers and light platform



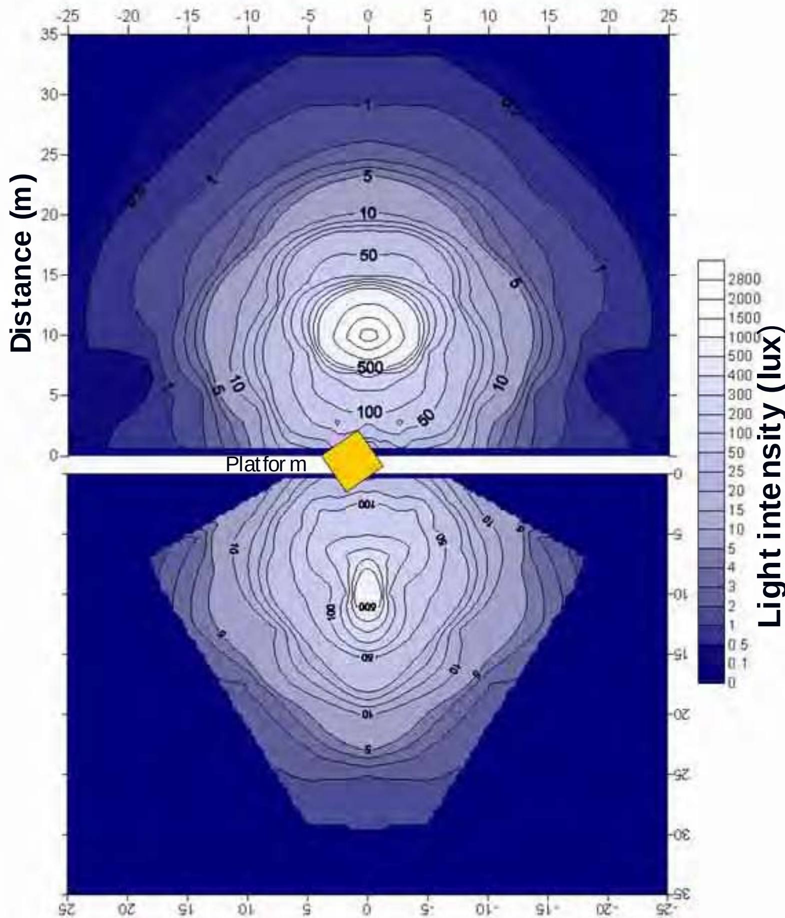
Light intensity depth: 2 m

(max. = 28 000 lux)



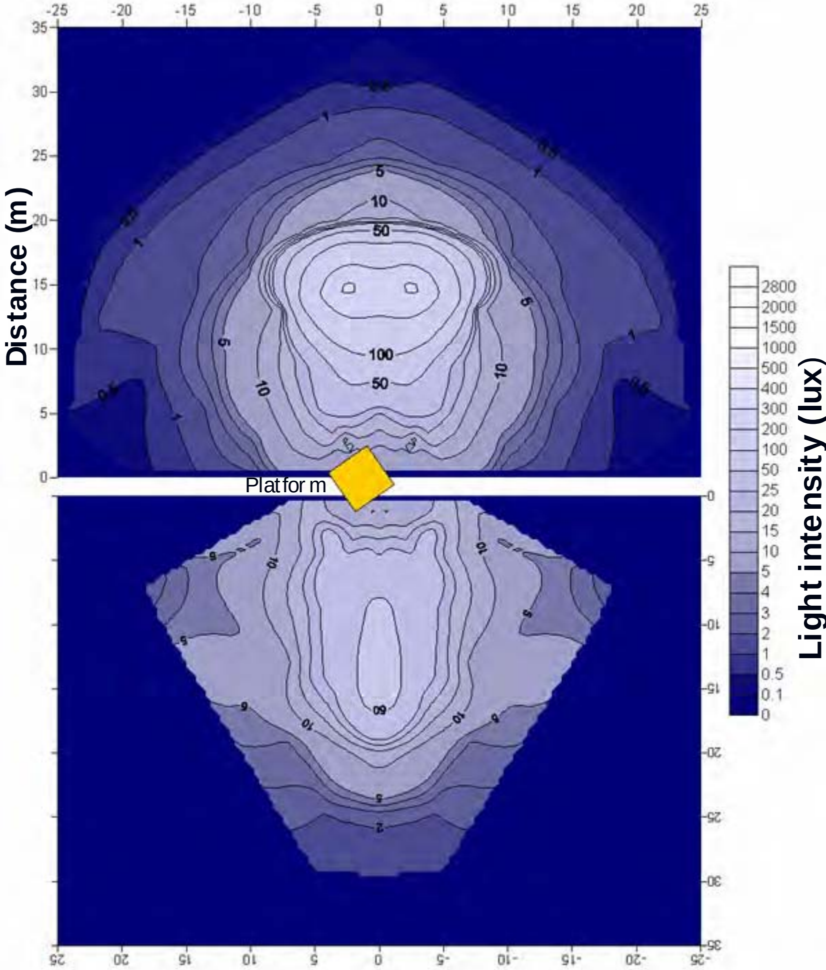
Light intensity depth: 6 m

(max. = 2 500 lux)



Light intensity depth: 10 m

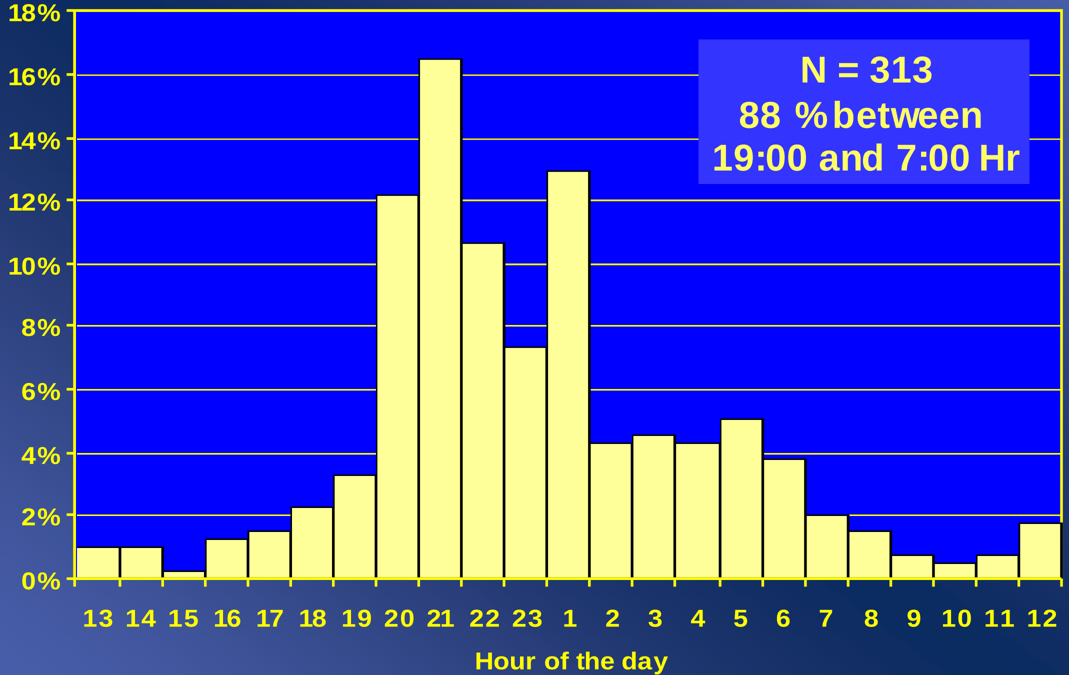
(max. = 332 lux)



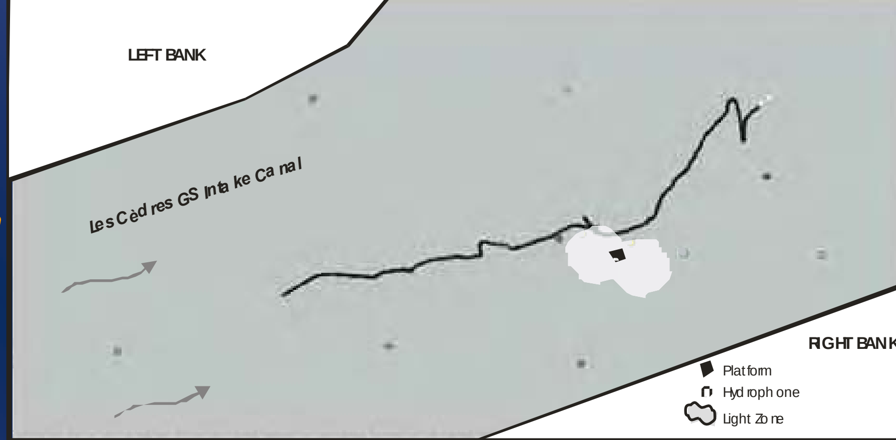
Detected Eels: n = 136
Paths: n = 313

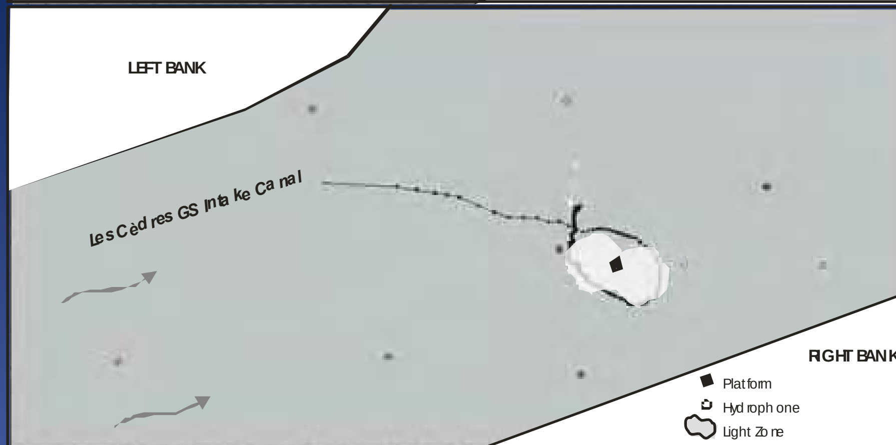
	Lights ON	*Lights OFF*	*Total*
Night (19:00-7:00)	134	142	*276*
Day (7:00:19:00)	23	14	*37*
	157	156	*313*

Hour of Detection



Examples of trajectory– lights on





Eels detected in the light zone

Light intensity zone (lux)	Lights on N		Lights off N		% avoidance
1-10	24		16		
11-100	16	66,7%	10	62,5%	- 6,7%
101-1000	6	25,0%	6	37,5%	33,3%
>1000	4	16,7%	4	25,0%	33,3%

CONCLUSIONS

- **Because of suspended particulate matter downstream of Lake St. Francis, laser light is rapidly diffracted and does not offer potential to guide eels over large distance**
- **The effect of incandescent light with a 32º angle above the water surface is limited**
  - Partial avoidance (33 %) seems limited to >100 lux
- **Limited number of observations limits the interpretation of data**
- **Results suggest that efficient light barrier in the St. Lawrence would need a dense array of high intensity lights**

Many thanks to:

- Alex Haro and Leah Brown, from S.O. Conte Anadromous Fish Research Center, for loan of equipment and technical assistance
- Kevin McGrath, from NYPA, for loan of equipment
- Staff from Milieu, Les Cèdres GS and Beauharnois GS

Eel stocking in the Upper Richelieu River and Lake Champlain a fisherman-scientist-manager partnership

Pierre Dumont and Guy Verreault

Faune Québec

Georges-Henri Lizotte

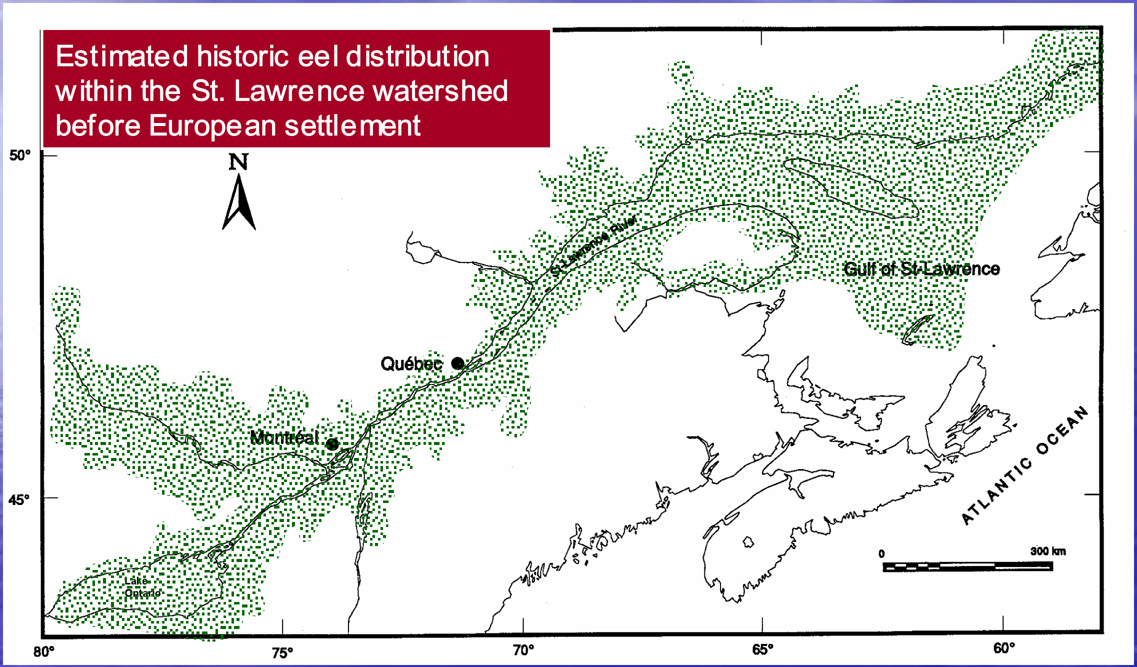
Association des pêcheurs d'anguilles et de poissons d'eau douce du Québec

André Dallaire

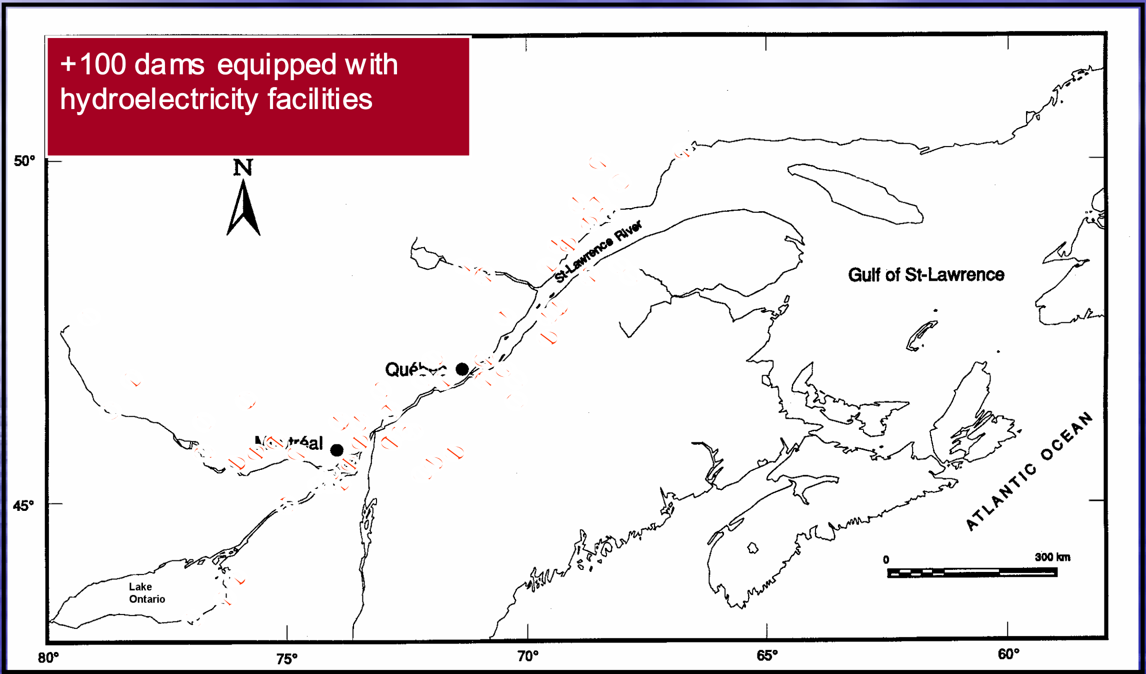
Faculté de médecine vétérinaire

Université de Montréal

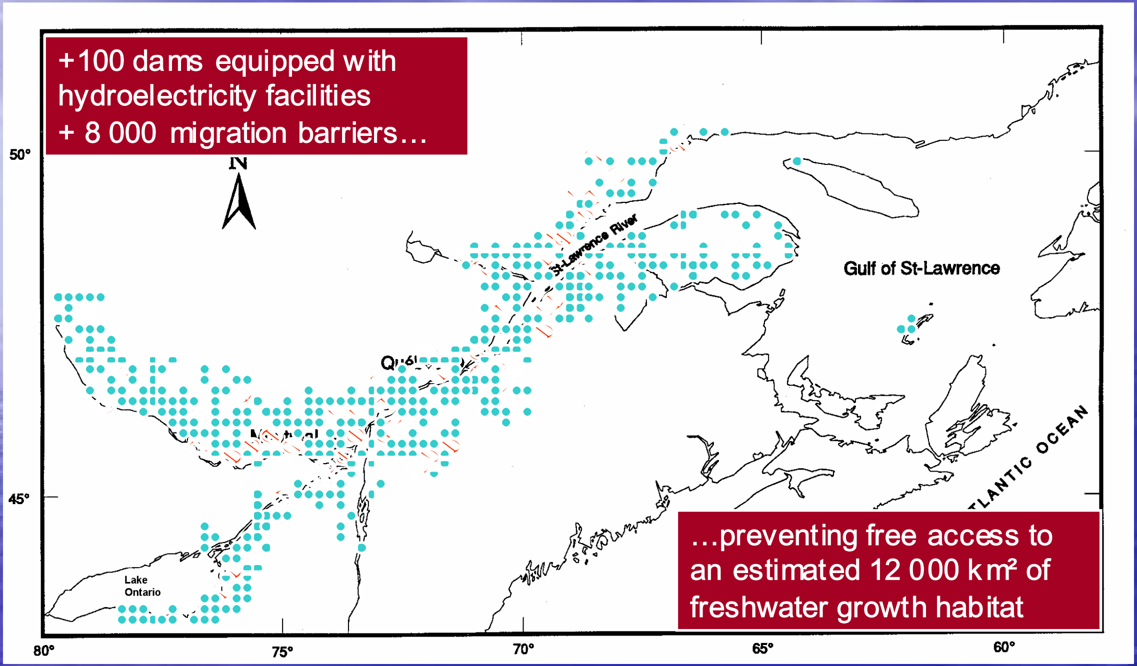
Preliminary remarks



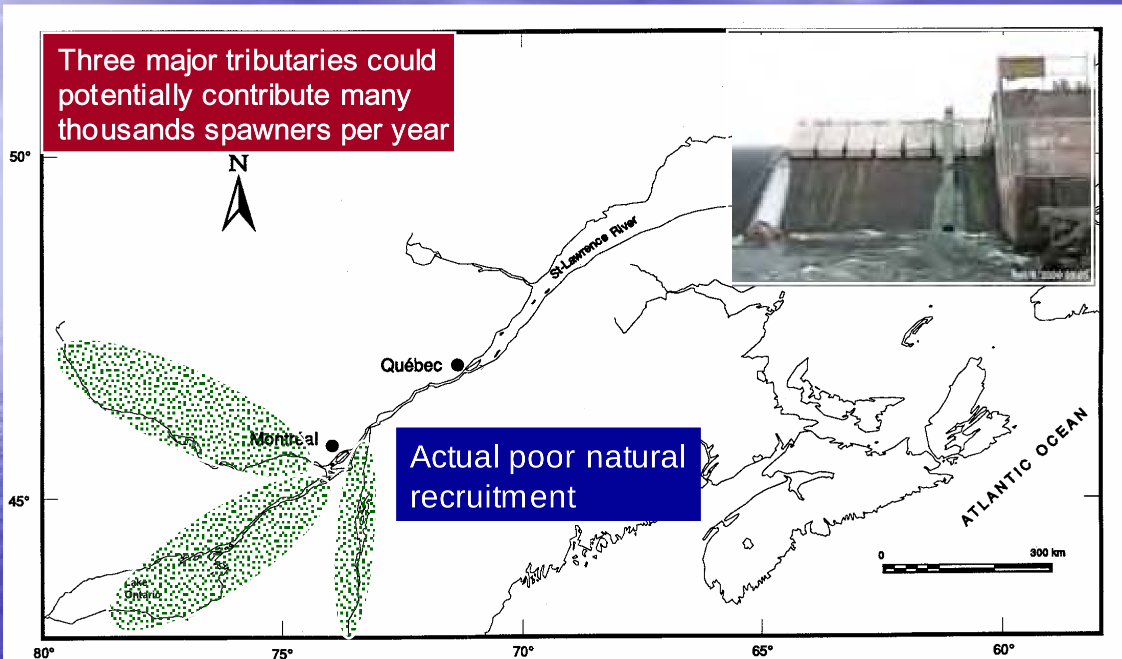
Anthropogenic barriers



Anthropogenic barriers



Three major tributaries could potentially contribute many thousands spawners per year

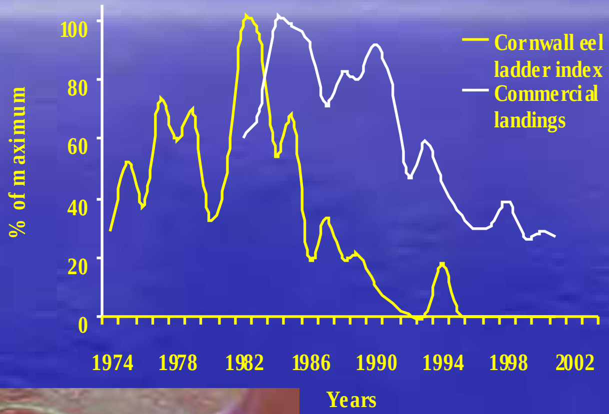


Actual poor natural recruitment

Eel stocking

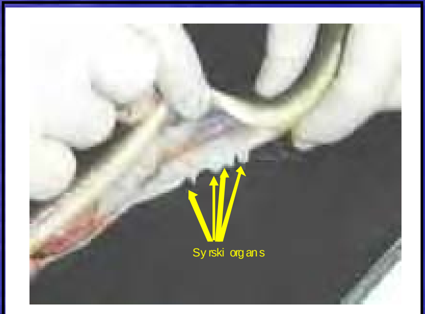
- In Eurasia : a way to rapidly increase local stock in a growth habitat facing poor natural recruitment
- In North America : a practice limited to a few experimental trials, never used to compensate low recruitment

Québec commercial fishermen are faced to a dramatic decline of eel landings and recruitment



1999 : a first reaction of the Association des pêcheurs d'anguilles et de poissons d'eau douce du Québec

- 40 000 elvers translocated from the Bay of Fundy to lac Morin (400 ha)
- In an eel-free watershed in South-eastern Québec

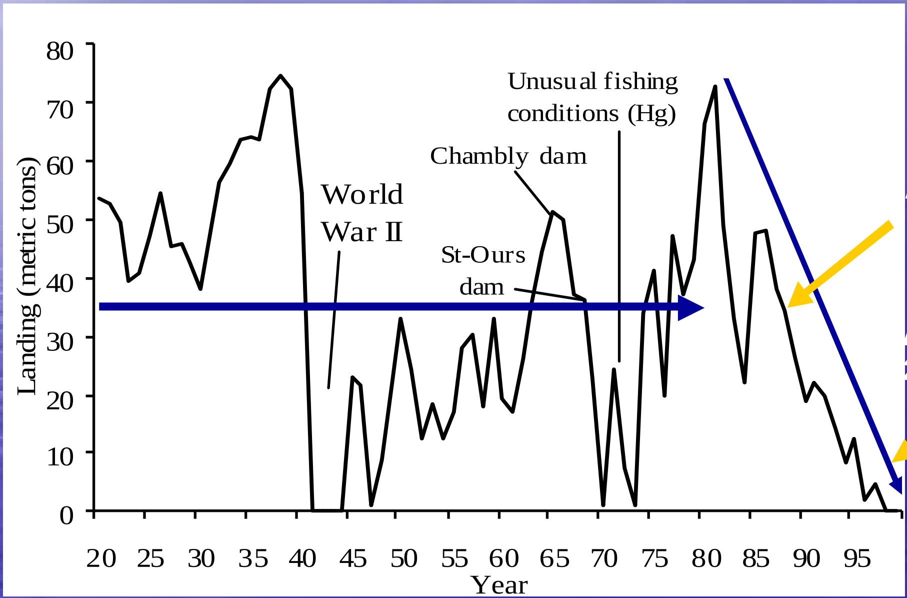


- After four years of monitoring :
  - Eel is well established
  - Movements in the outlet and tributaries were limited
  - Growth rate was very fast
  - **Males were exceptionally present in high proportion**

In 2003, a second reaction of the APAPEDQ : the Richelieu River-Lake Champlain watershed

A large deep and narrow oligotrophic lake (1140 km²) bordering Québec, New York and Vermont

This secular fishery collapsed within 15 years



Average weight 1497 g

Average weight 2244 g

Decline was partly related to the rebuilding of two old cribworks dams in the 1960s without replacing fishways

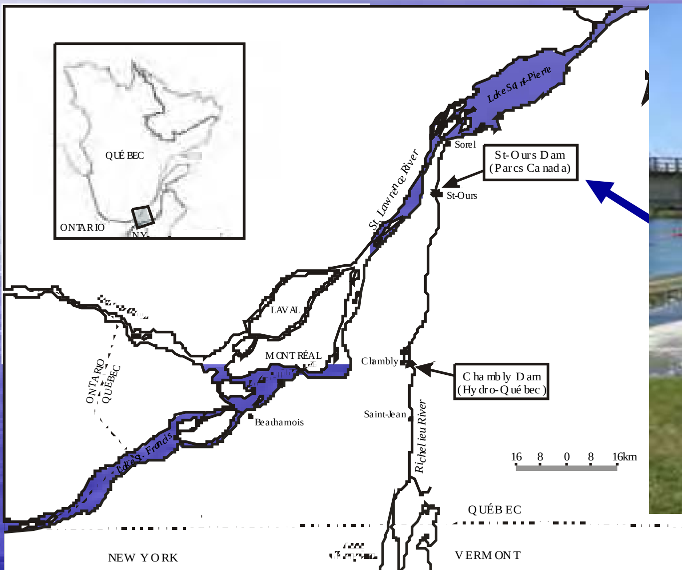


FIGURE 2 — Location of the study area.

Fishways were retroffited to enhance eel recruitment

- An eel ladder in Chambly (1997)

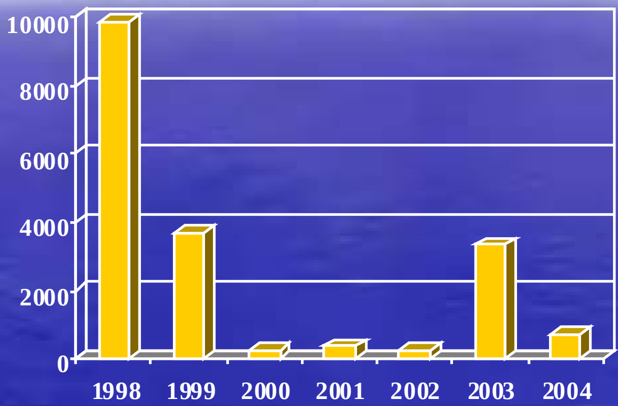
- An eel ladder and a multispecies fishway in Saint-Ours (2001)

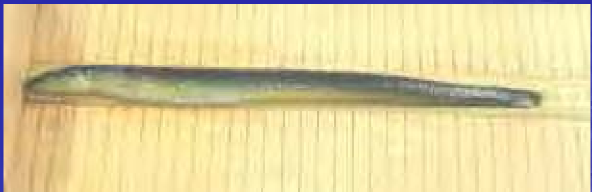
Ladder efficiency is high…

- > 60 % in Chambly

…but the number of young eels ascending the river remains too low

- To support an emigration averaging 35 000 silver phase females per year, many hundred thousand of these yellow eels (TL ~ 40 cm; age 4-6) are required yearly





The APAPEDQ project

- **Annual transfer of 0.5 to 1 million elvers from the Atlantic Coast during the next 10 years**
  - To accelerate the restoration of American eel
  - In a watershed historically recognized as an excellent eel pasture
  - With a main outlet free of turbines

- **The project received the support of :**
  - Faune Québec
  - and of the U. S. federal and state agencies involved in Lake Champlain Fisheries management.
- **In 2003, according to the new National Code on introductions and Transfers of Aquatic Organisms in Canada :**
  - A risk analysis was performed
  - Submitted to an expert committee

- **Winter 2004 : the project was accepted but conditions were imposed to prevent the introduction of diseases and parasites**
  - Pathological examination of a subsample must be made prior to the transfer looking for :
    - The presence of the Nematode *Anguillicola crassus* recently introduced in North America from Europe or Asia
    - Any other sign of disease and parasites
  - Elvers must be caught in water of salinity > 15 $^{o}/_{oo}$

Spring 2004 : the project is interrupted

- Histological signs suggesting a viral disease were observed during the preliminary test

- Supplemental tests were made in summer 2004
  - Evaluation by transmission electron microscopy
  - Viral isolation

- The hypothesis of viral infection was not supported by the results

- *Anguillicola crassus* has never been observed

A new trial in spring 2005, submitted to the same conditions

What is expected…

- A survival rate between 3 to 5 % after 10 years in Lake Champlain

- An annual stocking of 0.5 million elvers would yield 15 000 to 25 000 migrating eels after 10 years

- Historical emigration (35 000 adults) would be obtained with an annual transfer of 1 million elvers

➡ **if eel migrates…**

Monitoring…

- Biological observations
  - Presence of marks (oxytetracycline)
  - Growth : will likely be temporarily accelerated
  - Sex ratio : male production is now expected in Lake Champlain

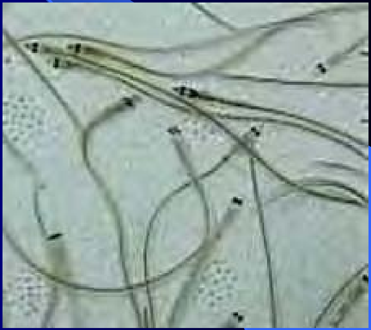
- Exhaustive pathological examination

- Capture-recapture experiments made in the 1970s and 1980s in three bays of Lake Champlain will be repeated

- Stocked eels contribution to the migrating silver phase run will be measured

‘Biological’ approaches to compensate for losses of silver eels to turbine mortality

Brian Knights
University of Westminster



POSSIBLE USES OF 'BIOLOGICAL' RATHER THAN 'TECHNICAL- PHYSICAL' SOLUTIONS

FUNDAMENTAL AIMS:

- Ensure production of sufficient [FEMALES] to compensate for turbine mortalities
- POSSIBLY ALSO gain wider extra benefits of stock restoration, maintenance or enhancement?

POSSIBLE METHODS

- *Trap silver eels upstream and transport/release downstream*
- *Aquaculture production and release*
- *Stocking*

NB to significantly enhance the whole species would require stocking on an ENORMOUS scale!!! (Knights, Jessop, Winemiller, etc)

MAIN CHALLENGES

- Solutions must be biologically and economically cost-beneficial
- Lack of experience and long-term robust studies

HOW MANY [SILVER FEMALE] EELS NEED TO BE COMPENSATED FOR?

From annual estimates for LO-SLR system (e.g. Caron, Verreault *et al.*, 2003) :

- **Spawner emigrants** **~ 0.5 x 10^6 eels**

  [99% ♀ @ 1.25 kg ~ 625 t ~ 5 x 10^{12} eggs]

- **Mortality**

  ~ 40% to turbines [+ 20% to fisheries, cumulative total ~ 50%]

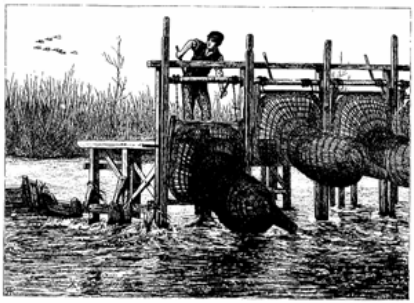
  ~ 0.2 x 10^6 eels ***[250 t, ~ 2 x 10^{12} eggs]***

- **And losses elsewhere in North America…….???**

UPSTREAM TRAP-AND-DOWNSTREAM TRANSPORT

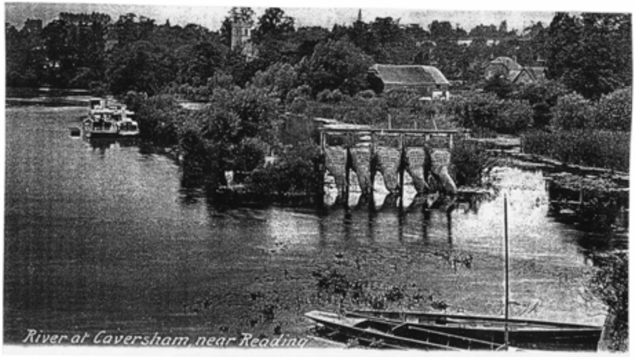
- **PRACTICALITIES**
- **How & where to capture downstream spawner migrants?**
  - **optimally, where most abundant and concentrated, e.g. via traps across lake or tributary exits or across main rivers**
  - **e.g. Toome and Portna eel weirs at the exit of Lough Neagh (363 km^2) and main River Bann, N.Ireland, capturing ~ 150 t of silvers/year**

Not efficient enough!!!!!



And certainly not

- ❑ Trawling
- ❑ LO fisheries (catch yellow eels)



SILVER EEL TRAP-AND-TRANSPORT

- **PRACTICALITIES**
  - Finding suitable trapping sites
  - Construction
    – *Iroquois Dam? IMPOSSIBLE!*
  - Handling, transport & release – 250+ t per year???
  - Release site(s) - nearer to the sea, avoiding fishing areas!

- **COSTS – RELATIVELY VERY HIGH?**
  - Capital costs???
  - Labour and other running costs?
  - Holding, transport and releasing facilities?

- **INDICATIVE [*MINIMUM?!?*] 'RUNNING' COSTS**
  - Based on current GB best export (+ transport) value for female silver eels of £7 kg^{-1} ~ 20 $CDN per eel
  - Thus for 0.2 x 10^6 LO-SLR eels
  - Total cost ~ 4 x 10^6 $CDN per year (*in perpetuum*)

SILVER EEL TRAP-AND-TRANSPORT

- **RISKS? – RELATIVELY VERY HIGH?**
- **Inefficient capture**
  - **L. Neagh/R. Bann 2 major weir traps - 150t y^{-1} ~ 50%**
  - **Moselle River, Germany – silver eels fykenetted, but only 1.5 – 4.6 t per year, efficiency unknown**
- **Incidental mortalities**
- **Negative effects on spawner behaviour, growth, maturation and emigration?**

- **CONCLUSION = NOT VIABLE ON EFFICIENCY, FINANCIAL OR RISK GROUNDS**

AQUACULTURE

- **INSURMOUNTABLE HURDLES**
- **Costs**
- **'Economic' production relies on very high densities – and this produces MALES that stop growing at < 40-45 cm**
  - **Solutions?**
    - **capture enough wild female yellow eels to grow on or**
    - **use hormone treatments (e.g. Tzchori *et al.*, 2004)**

    ⇒ not feasible or acceptable

- **CONCLUSION = NOT VIABLE**

  [but growing-on may be a component of stocking?]

STOCKING

- **EUROPEAN EXPERIENCE [Knights & White, 1997: EA, 2005]**
- **FISHERIES oriented**
  - **East European & Swedish lakes and coastal waters**
  - **L. Neagh yellow long-line and silver eel trap fisheries**
- **Ecologically oriented**
  - **Majority of programmes poorly planned and executed, with inadequate long-term post-stocking monitoring!**

- **KEY COMPONENTS for LO-SLR SPAWNER COMPENSATION**
- **Female spawners needed, i.e. low final densities (< 1 eel 100m^{-2})**
- **Source(s) of stocking material**
  - **From locations where recruitment exceeds carrying capacity *(cf ICES/EIFAC WGEEL suggestions for Europe)***

$\Rightarrow$ *Nova Scotia/Bay of Fundy & N Carolina/Florida*

STOCKING

- **Sites for stocking**
  - **Where eels are absent or at very low densities**
  - **Suitable productivity and carrying capacity**
  - **Safe eventual escapement**

- **Sites**
  - **Estuarine/coastal waters and coastal rivers?**

    ⇒ **but generally well recruited + high dispersal**
  - **Lakes – low dispersal = strong contenders**

    ⇒ **Lake Champlain!??**
  - **Rivers deep in large catchments – not well studied, but strong contenders – especially if lakes are present**

    Eel density declines with distance upstream & distance from ocean migration pathways⇒ % females increase (density dependent sex

STOCKING

- **Stocking density**
  - **To achieve < 1 eel 100m² to maximise female production (males may dominate initially – e.g SE Sweden lake study by Wickstrom)**
  - **Typical lake stocking rates 100-350 glass eel/elvers ha^{-1} yr^{-1} [ditto for rivers??]**
  - **Scatter stock in spring/summer**

- **Yields v. stocking in lakes (& rivers?)**

➢ ***Low productivity & survival & female spawner scenario***

  - **Stock @ 200 glass eel ha^{-1} y^{-1} for a yield of ~ 10 kg ha^{-1} y^{-1}**
  - **For each LO-SLR spawner ~1 kg, need 20 glass eels per spawner per year/**
  - **To compensate for 0.2 x 10^6 spawners @ 1 kg each, need to stock 4 x 10^6 glass eels $year^{-1}$ (i.e. ~ 0.6 t)**
  - **Minimum area = 20,000 ha (200 km²)**

STOCKING

- **Availability of glass eels?**
  - **N. American glass eel catches ~ 1 - 4 t year^{-1} ✓**

  OR use SLR dam eel ladder yellow eels?????

- **Availability of stocking area(s)?**

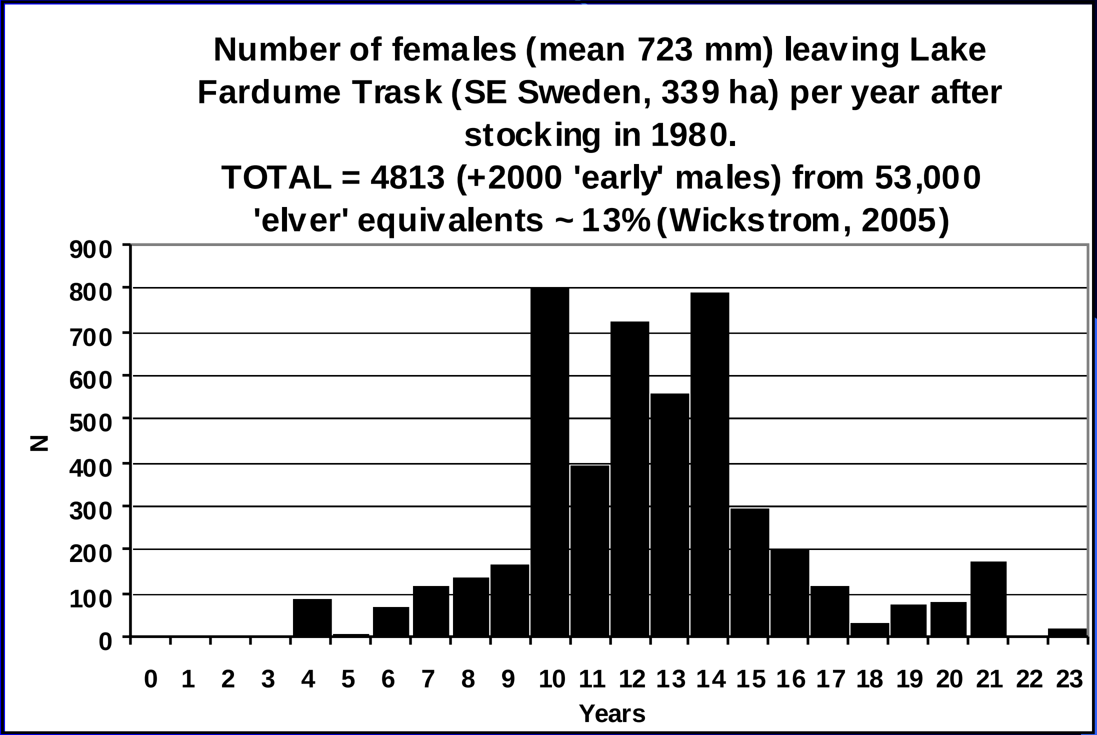
Lake Ontario	**19,604 km^2**
Lake Champlain	**1140 km^2 ✓**

- **INDICATIVE COSTS**
  - **@ approx. 180 $CDN per kg for 0.6 t;-**
  - **Total glass eel cost = 108,000 $CDN per year (+ labour, transport, etc costs)**
  - **Needs to be repeated every ? years**

- **CONCLUSION = LOOKS VIABLE??**

⇒ ***Main drawbacks = long timescale and beware of overstocking??***

STOCKING


Number of females (mean 723 mm) leaving Lake Fardume Trask (SE Sweden, 339 ha) per year after stocking in 1980.
TOTAL = 4813 (+2000 'early' males) from 53,000 'elver' equivalents ~ 13% (Wickstrom, 2005)
900
800
700
600
500
400
300
200
100
0
N
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Years

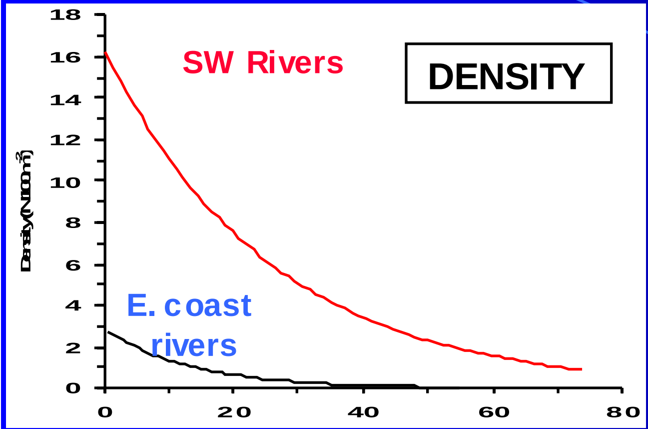
STOCKING – elsewhere, including under-populated rivers

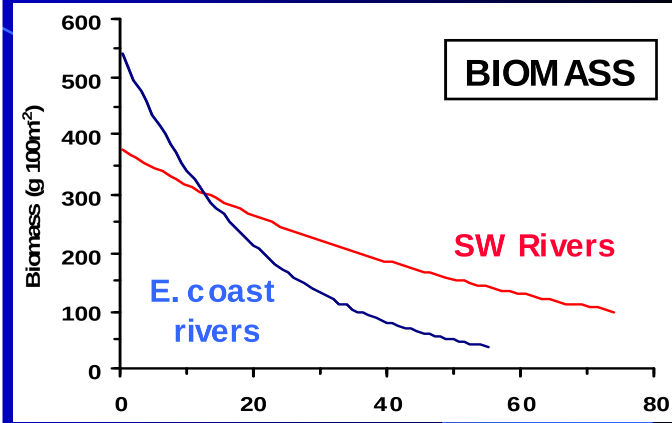
ATLANTIC SEABOARD (Busch, 1999)

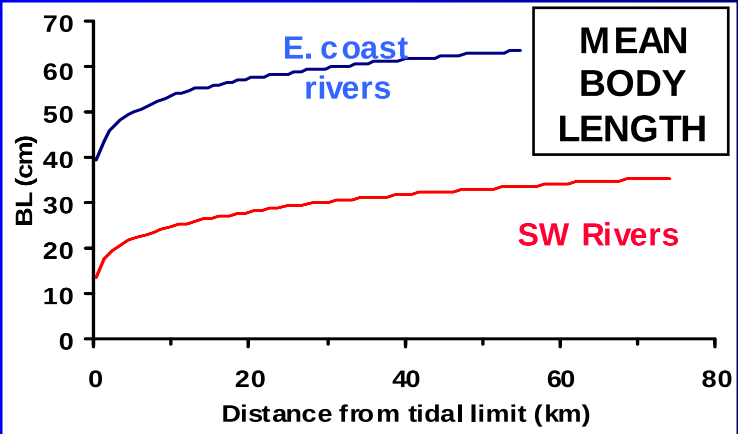
- conservative estimates;-

		@ N $100m^{-2}$	~ N eels
Estuaries	377,754 km^2	0.01	10^7
Coastal rivers	11,095 km^2	2.0	10^9
‘Open’ rivers	330 km^2	1.0	10^6
‘Restricted’ rivers	2454 km^2	1.0	10^8

RIVERS IN ENGLAND

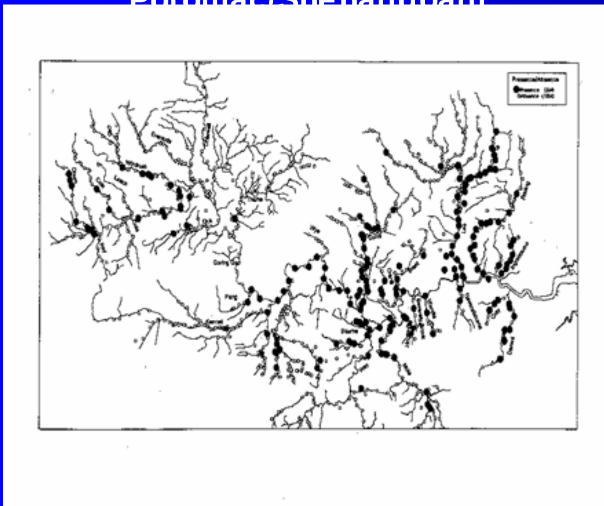


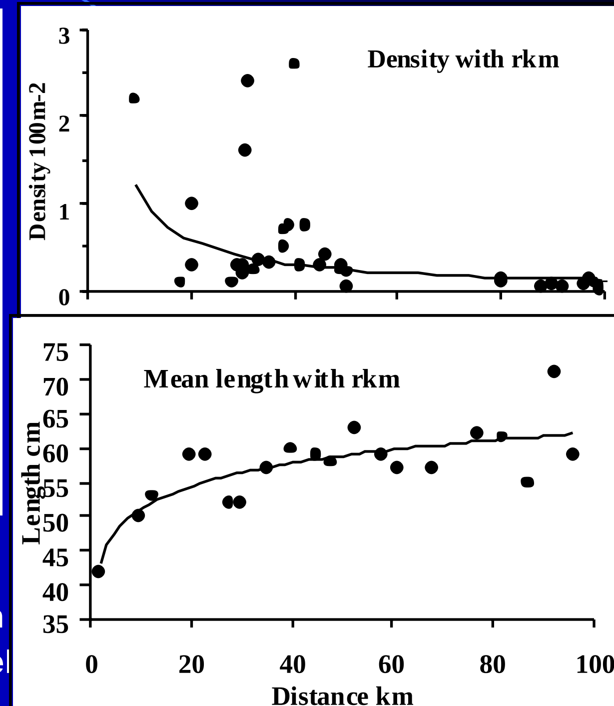




STOCKING

- e.g **Thames catchment** (ditto rivers like the Potomac/Shenandoah)





- Females dominate > 10-20 rkm
- Many up-river sites with NO eel
- Pockets of LARGE FEMALE stocked eels > 80-250 rkm

STOCKING

RISKS?

- **Lack of seed stock**
- **Impacts on local recruitment**
- **Incidental mortalities**
- **Disease transmission/need for health checks/quarantine**
- **Negative impacts on ecology of stocked waters**
- **Poaching**
- ***[Natural recovery of recruitment and populations]***

- **LARGE spawners produced highly vulnerable to turbine mortalities**

  ⇒ escapement may not be significantly increased, especially at ~ 40+% mortality?

- **MAJOR DRAWBACK = LONG (DECADAL) TIMESCALES!!!**

  (conduct some studies on use of yellow eels from the eel ladders?)

- **OVERALL**

  LO-USLR STOCKING COMPENSATION = MODERATE RISK??

IN CONCLUSION – PERSONAL VIEWS

- ‘Technical-physical’ & ‘retrofit’ solutions are not viable
- BUT developments must be encouraged in the long term for future use
- Of the ‘biological’ solutions, stocking (funded by the power companies) is the most viable, despite the long time scale

- And finally, is the focus on the LO-SLR stock too narrow??

IN CONCLUSION – PERSONAL VIEWS

- **Eel 'SUPERFUND' programme**
- **Assess value of lost spawners (commercial, 'willingness-to-pay', costs of other protection/mitigation options)**
- **Set up a fund to finance other eel & environmental projects in less risky/shorter payback time Atlantic Seaboard areas (e.g. Susquehenna, Sebasticook/Kennebec, etc programmes for salmonids, shad, sturgeon, etc)**
- **Benefits = coordinated & effective programmes involving monitoring, provision of passes, stocking, environmental improvements, etc**

  (cf Atlantic States Marine Fisheries Commission and American Eel Management Board initiatives)
- ***Also, aquaculture & research into artificial propagation should be encouraged to relieve fishery mortality in the long term!!!!!!***