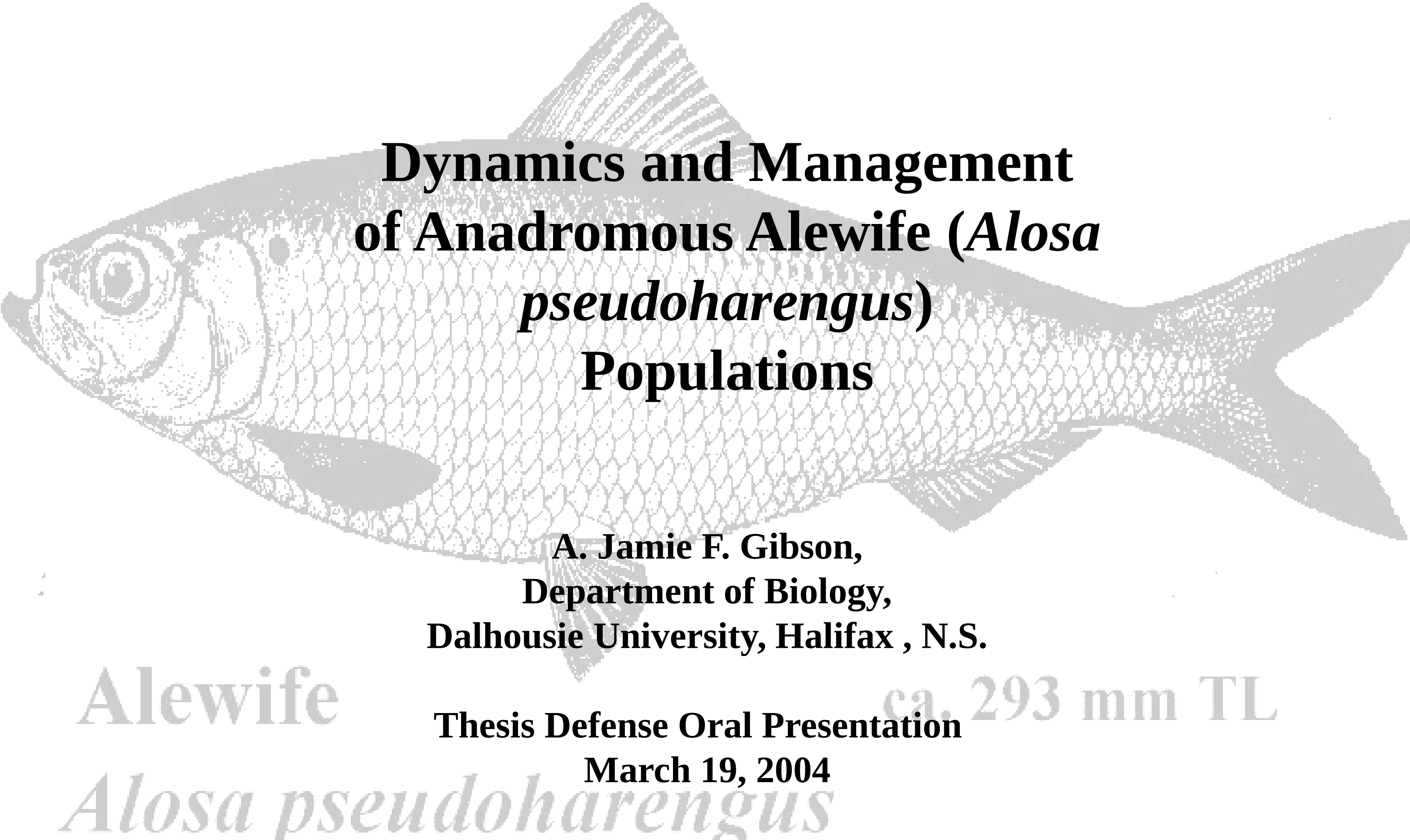
Dynamics and Management of Anadromous Alewife (*Alosa pseudoharengus*) Populations

A. Jamie F. Gibson,
Department of Biology,
Dalhousie University, Halifax , N.S.

Thesis Defense Oral Presentation
March 19, 2004



Why Study Alewives?

- Commercially Important:
  - support directed and bycatch fisheries (marine)
  - fished recreationally and commercially (freshwater)
- Biologically Important:
  - vector for nutrient transport
  - prey species in marine and freshwater environments
  - planktivore

Square net on the Gaspereau River

Objectives

- To conduct basic research about the population dynamics of anadromous alewife
- To use this research to develop assessment and management models for alewife populations

Why not use existing fishery assessment models?

- Alewife life history and fisheries differ from marine fish
  - e.g. in-river fisheries select on the basis of maturity
- Kinds of data typically collected also differ
  - larval indices, juvenile indices, adult counts at ladders
  - data is often intermittent (often not intended for assessment)
- Other human activities impact upon alewife populations
  - hydroelectric development, eutrophication

- Underlying Philosophy: Rather than attempt to force the data to fit an existing model, to develop a model of the process under study, adapt the model to the available data and estimate the parameters of interest

Thesis Overview

- Development of a population dynamics model for *Alosa*
  - many uses illustrated in the thesis
- Parameter estimation for the model
  - natural, fishing and turbine mortality rates, maturity schedules, reproductive rates, habitat carrying capacity
- Biological reference points for alewife fisheries
  - YPR, SPR, production model, simulation-based
  - decision-theoretic methods for deriving fishery reference points
  - evaluation of the methods for estimating BRP's using simulations
- Assessing the effects of hydroelectric development on alewife populations and fisheries
  - evaluating fish diversion systems, estimating turbine mortality, trade-offs between hydroelectric generation and fisheries yields

Chapter 2. A statistical, age-structured, life history based, stock assessment model for anadromous *Alosa*.

1) Mathematical representation of the life history of anadromous *Alosa*

2) The core of the model is a numbers-at-age array with an additional dimension to keep track of previous spawning history

3) The model is adaptable to data for individual populations and management questions
   - basis for stock assessment models and reference point estimation
   - simulation models
   - cumulative effects of fishing and turbine mortality

4) I show how model parameter estimates may be obtained using maximum likelihood

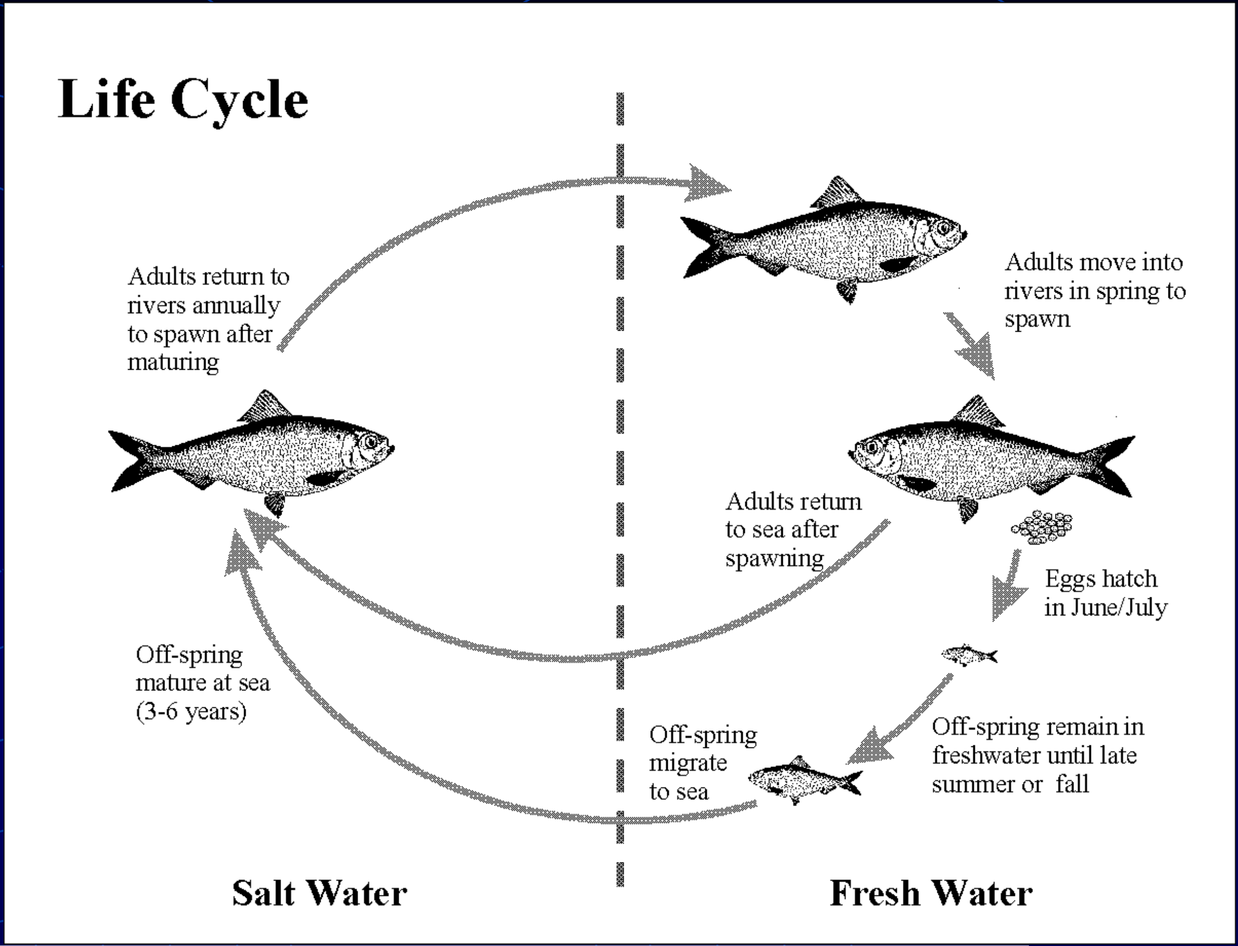
$$Q_t = \sum_{a,p} N_{t,\mathrm{f},a,p}(1-u_t)\, f_{a,p}$$

$$O_{t,s} = Q_t \mathrm{e}^{-g(Q_t)+\varepsilon_t}\, \upsilon_s$$

$$N_{t,s,a,0} = O_{t-a,s}\, e^{-T^{\mathrm{juv}}}\, m_{t-a,s,a}\, e^{-M^{\mathrm{juv}} a}$$

$$N_{t,s,a,p} = N_{t-p,s,a-p,0}\, e^{-\left(\sum_{k=t-p+1}^{t} F_k + T^{\mathrm{adult}} p + M^{\mathrm{adult}}_{s,a} p\right)}$$

use SSB as a proxy for the number of eggs and assume a Beverton-Holt model for density dependence in the early life stages



$$N_{t,s,a,p} = \begin{cases} \dfrac{\alpha SSB_{t-a}}{\left(1+\alpha SSB_{t-a}/R_0\right)}\, e^{-T^{\mathrm{juv}}}\, \upsilon_s m_{t-a,s,a}\, e^{-M^{\mathrm{juv}} a} & \text{if} \quad p=0 \\ N_{t-p,s,a-p,0}\, e^{-\left(\sum_{k=t-p+1}^{t} F_k + T^{\mathrm{adult}} p + M^{\mathrm{adult}}_{s,a} p\right)} & \text{if} \quad p>0 \end{cases}$$

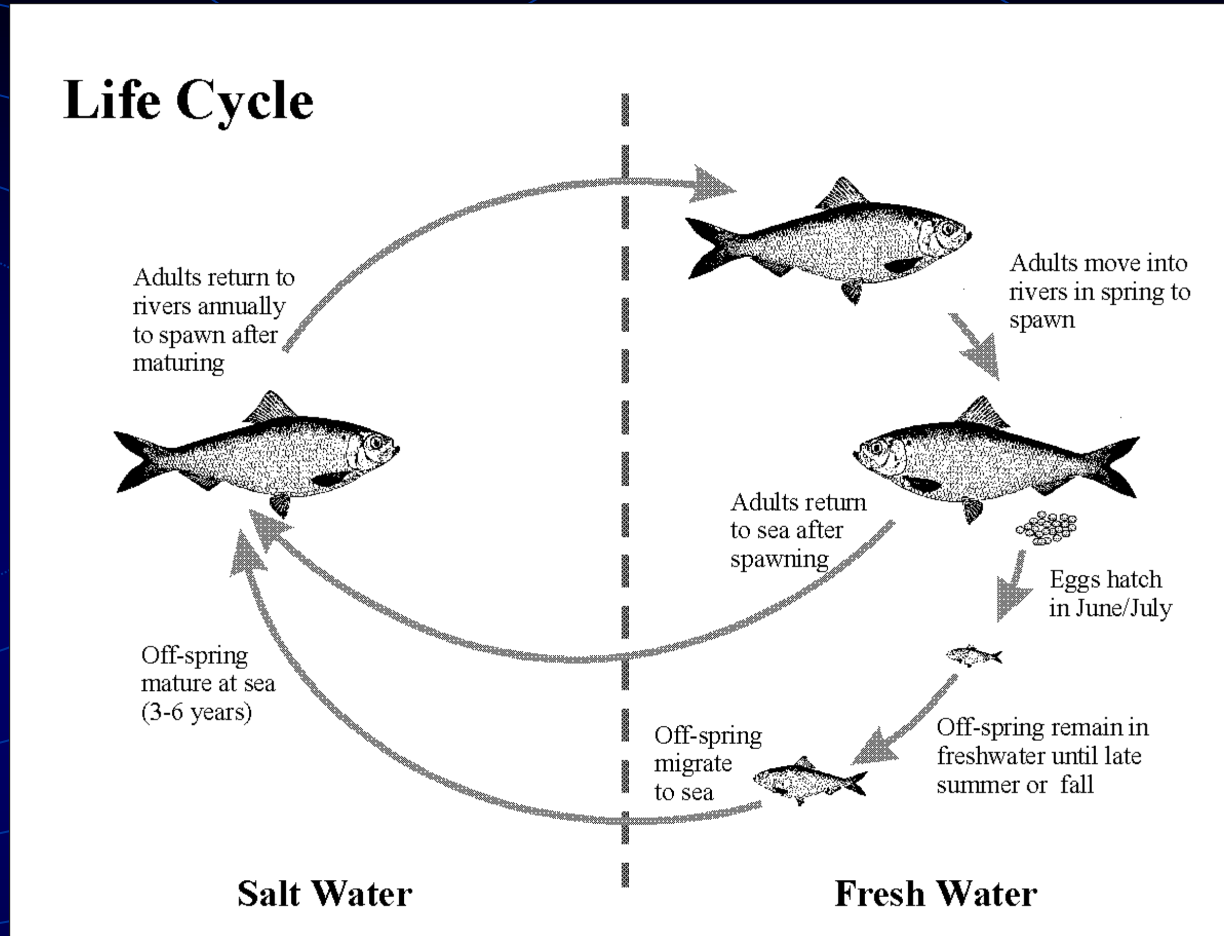
$$Q_t = \sum_{a,p} N_{t,f,a,p}(1-u_t) f_{a,p}$$

$$O_{t,s} = Q_t e^{-g(Q_t)+\varepsilon_t} \upsilon_s$$

$$N_{t,s,a,0} = O_{t-a,s} e^{-T^{juv}} m_{t-a,s,a} e^{-M^{juv} a}$$

$$N_{t,s,a,p} = N_{t-p,s,a-p,0} e^{-\left(\sum_{k=t-p+1}^{t} F_k + T^{adult} p + M^{adult}_{s,a} p\right)}$$

use SSB as a proxy for the number of eggs and assume a Beverton-Holt model for density dependence in the early life stages



$$N_{t,s,a,p} = \begin{cases} \dfrac{\alpha SSB_{t-a}}{\left(1+\alpha SSB_{t-a}/R_0\right)} e^{-T^{juv}} \upsilon_s m_{t-a,s,a} e^{-M^{juv} a} & \text{if} \quad p = 0 \\ N_{t-p,s,a-p,0} e^{-\left(\sum_{k=t-p+1}^{t} F_k + T^{adult} p + M^{adult}_{s,a} p\right)} & \text{if} \quad p > 0 \end{cases}$$

The Annapolis Tidal Generating Station

- On-line in 1985
- built to test the utility of the STRAFLO turbine
- runner diameter: 7.8 m
- discharge: 408 m^3/s
- speed: 50 rpm
- operating head: 1.4 to 6.8 m

Chapter 3. A logistic regression model for estimating turbine mortality at hydroelectric generating stations.

1) Separation of mortality caused by passage through a turbine from mortality associated with the capture and handling is a fundamental issue

2) I present a method that allows separation of these sources of mortality by varying the duration of the net deployment.

3) Estimates of acute turbine mortality for 12 species of fish at the Annapolis Tidal Generating Station ranged between 0% and 23.4%.

Monitoring Fish Passage in the Tailrace at the Annapolis TiGS

Chapter 4. Effectiveness of a high-frequency sound fish diversion system at the Annapolis Tidal Generating Station, Nova Scotia.

1. I evaluated the effectiveness for 11 species
2. I demonstrated the importance of modeling the process that determines the rate of passage (environmental variables + the on/off status of the diversion system)
3. I used maximum likelihood and quasi-likelihood to fit the models
4. System was 42% to 48% effective for *Alosa*; but not effective for 7 other species

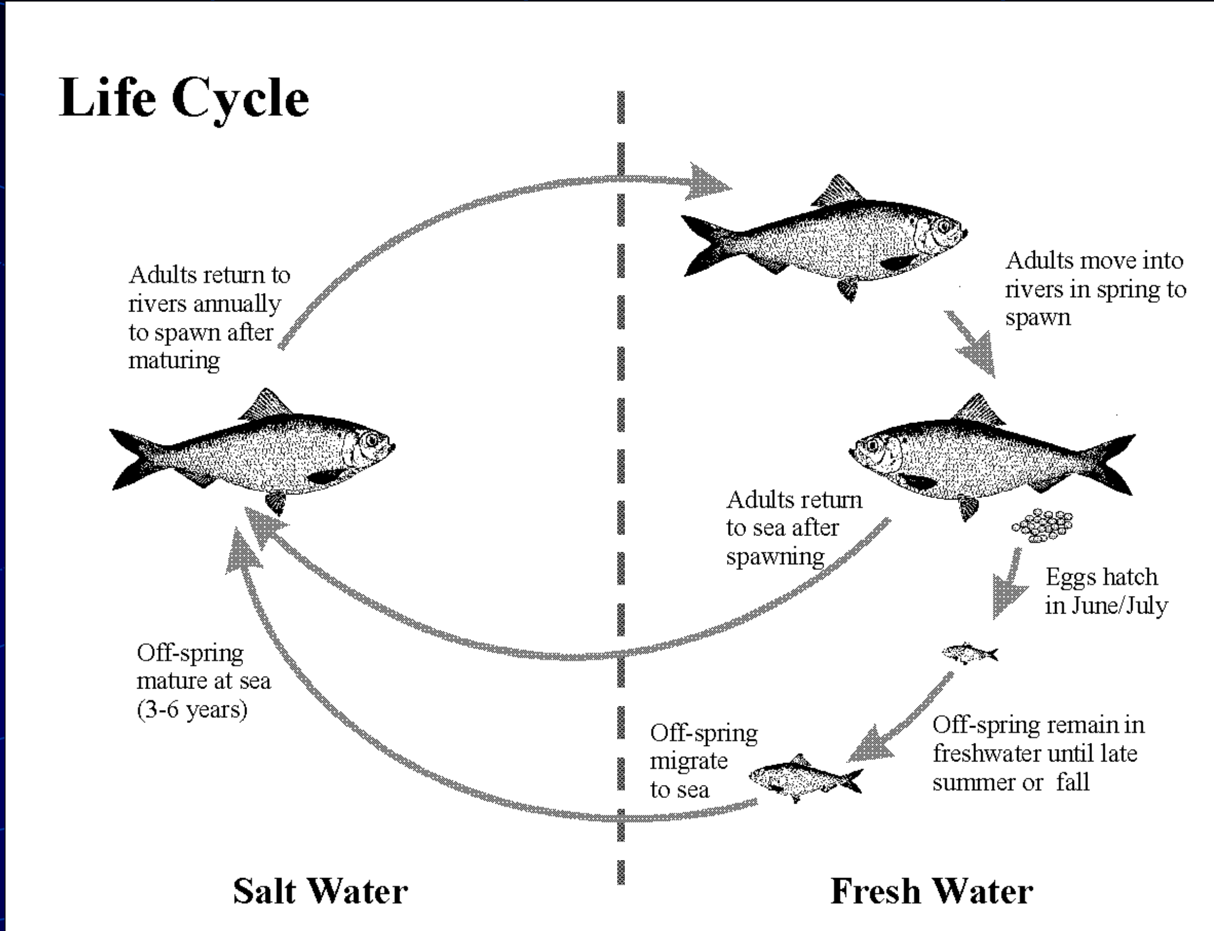
Monitoring Fish Passage through the New Fishway

$$Q_t = \sum_{a,p} N_{t,f,a,p}(1-u_t)\, f_{a,p}$$

$$O_{t,s} = Q_t \mathrm{e}^{-g(Q_t)+\varepsilon_t}\upsilon_s$$

$$N_{t,s,a,0} = O_{t-a,s} e^{-T^{\text{juv}}} m_{t-a,s,a} e^{-M^{\text{juv}} a}$$

$$N_{t,s,a,p} = N_{t-p,s,a-p,0}\, e^{-\left(\sum_{k=t-p+1}^{t} F_k + T^{\text{adult}} p + M^{\text{adult}}_{s,a} p\right)}$$



use SSB as a proxy for the number of eggs and assume a Beverton-Holt model for density dependence in the early life stages

$$N_{t,s,a,p} = \begin{cases} \dfrac{\alpha SSB_{t-a}}{\left(1+\alpha SSB_{t-a}/R_0\right)} e^{-T^{\text{juv}}} \upsilon_s m_{t-a,s,a} e^{-M^{\text{juv}} a} & \text{if} \quad p = 0 \\ N_{t-p,s,a-p,0}\, e^{-\left(\sum_{k=t-p+1}^{t} F_k + T^{\text{adult}} p + M^{\text{adult}}_{s,a} p\right)} & \text{if} \quad p > 0 \end{cases}$$

Chapter 5. A meta-analysis of the habitat carrying capacity and the maximum lifetime reproductive rate of anadromous alewife in eastern North America.

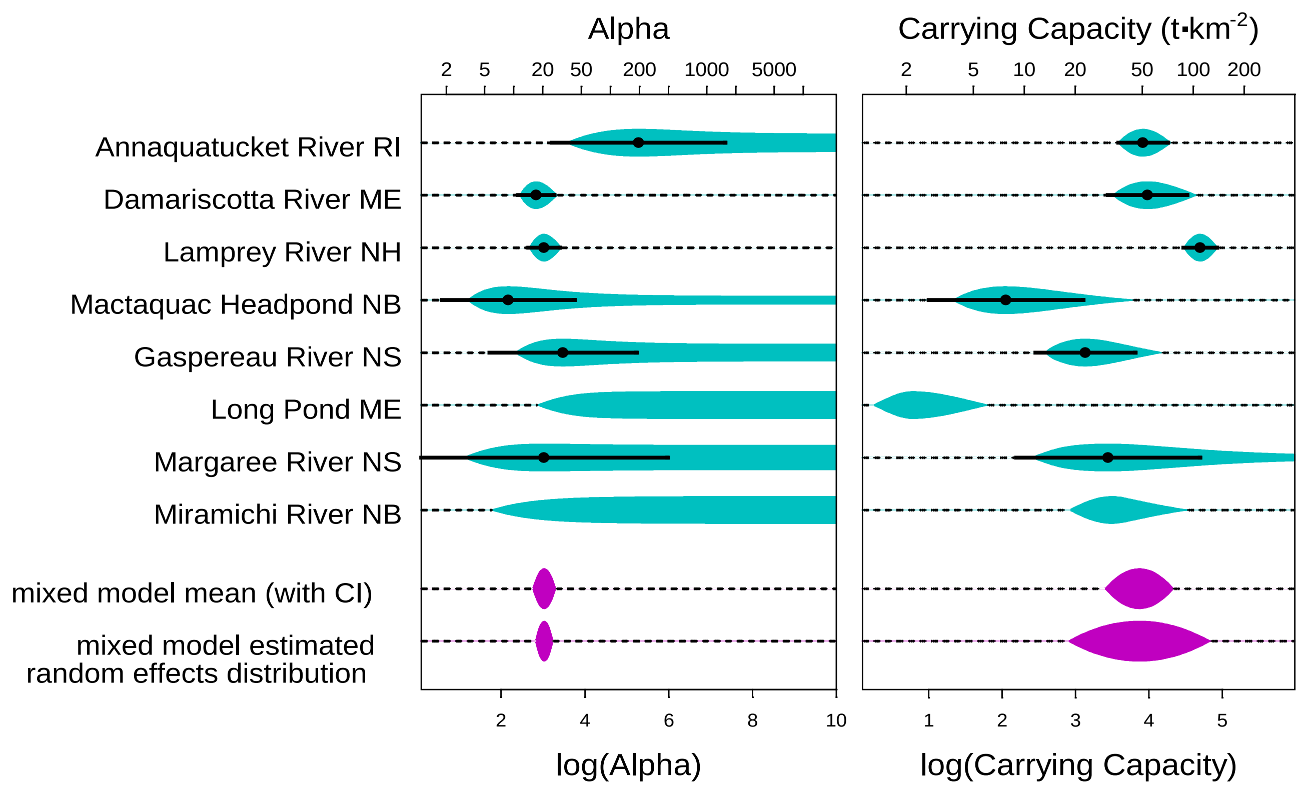
1. I carried a meta-analysis of the dynamics of eight anadromous alewife populations to determine:
   - their habitat carrying capacity
   - their maximum lifetime reproductive rate
   - whether depensation occurs at low abundance

2. I used mixed effects models for this analysis based on methods developed by Myers and Barrowman

A Meta-Analytic Summary of the Population Dynamics of Anadromous Alewife

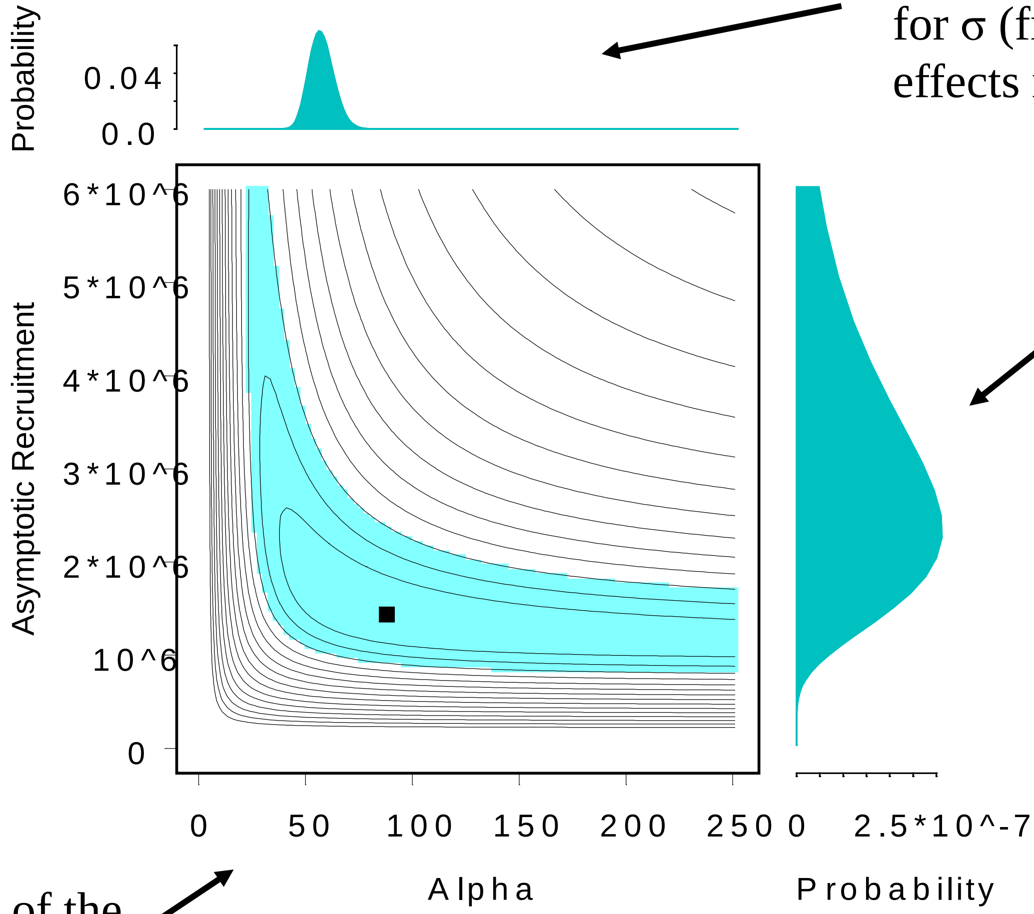
- At low population sizes and in the absence of anthropogenic mortality, 1 spawner can produce about 20.7 recruits throughout its life

- The carrying capacity for alewife is about 50 t/km^{-2} of nursery area



*Mactaquac Excluded

Gaspereau River Alewife



probability distribution for σ (from the mixed effects model)

probability distribution for R_0 (from the mixed effects model)

probability of the data given α and R_0

Chapters 5 and 6. Biological reference points for alewife fisheries

1. I calculated several fishery reference points for 4 alewife populations in Atlantic Canada.
   - YPR, SPR, production model, simulation-based and decision-theoretic BRP's

2. I compared reference point performance using Monte Carlo simulations.
   - simulated populations
   - simulated SR data

3. I showed that variability in age-at-maturity has little effect on selection of a reference *F* for alewife using Monte Carlo simulations.

4. I concluded that exploitation rates around 40% are not unreasonable for most alewife populations.

Three Methods of Estimating Reference *F*'s from SR Data

Most Common Method:

Use the MLE's of the spawner-recruit parameters to estimate F_{msy} using a production model.

Two Alternatives:

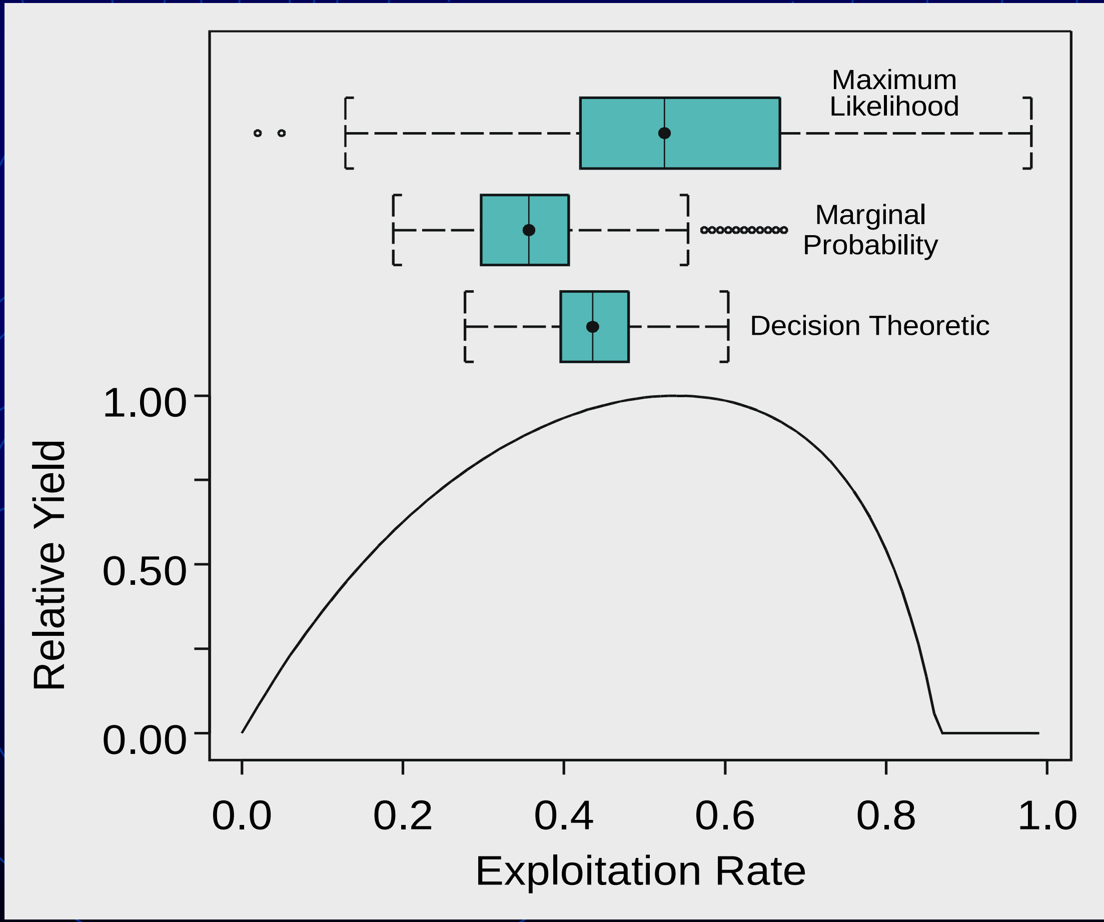
1. Using the mode of the marginal probability density for α (Ianelli and Heifetz 1995, Chen and Holtby 2002) to estimate a reference *F* using the production model (F_{marg}).

2. Maximizing the expectation of the yield (Brodziak 2002) given the uncertainty in the SR parameters ($F_{\mathrm{maxE[Y]}}$).

Comparison of F_{msy}, F_{marg} and $F_{\mathrm{maxE[Y]}}$ using Simulated Data

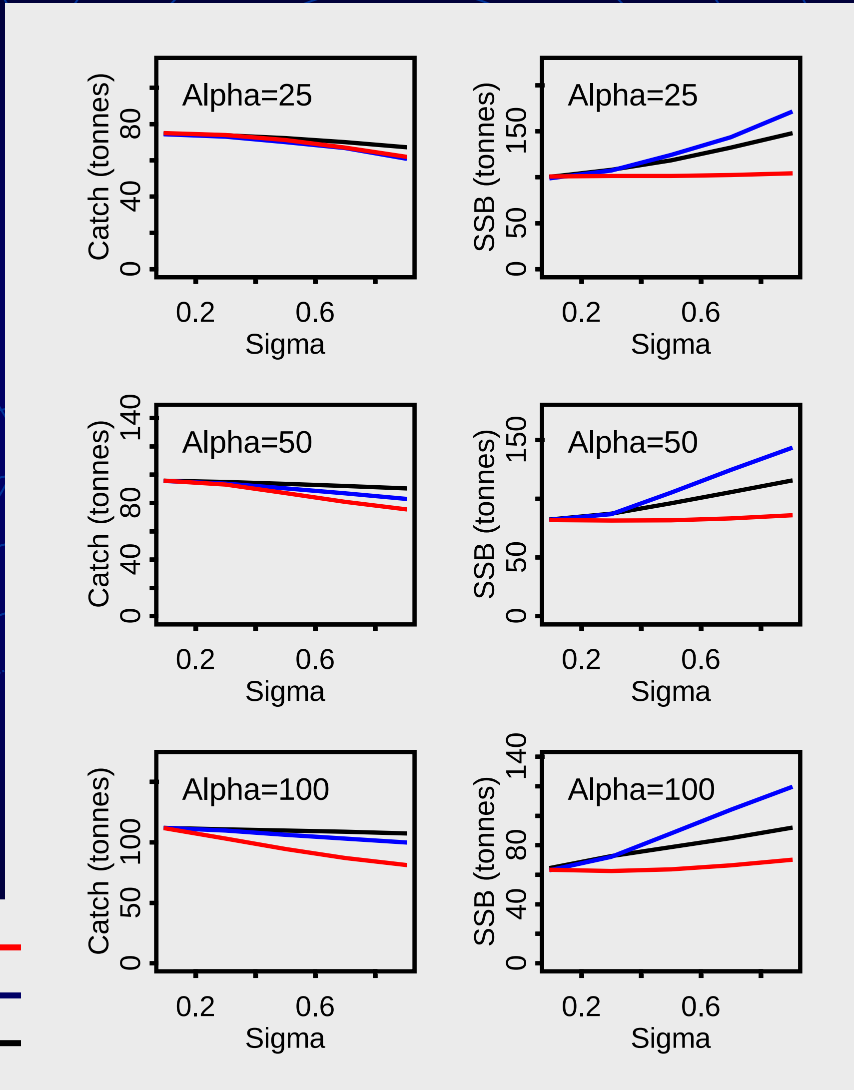
- I simulated 500 SR datasets for 5 levels of α and 5 levels of σ
- I estimated the 3 reference *F*'s and compared them with the known yield curve
- The ML method was least biased but at times leads to substantial over- and under-exploitation
- The decision theoretic BRP, $F_{\mathrm{maxE[Y]}}$ produces the least variable equilibrium yields

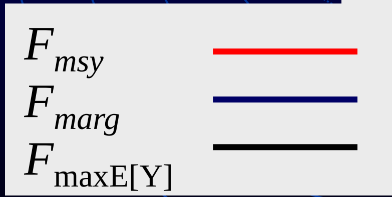
Simulation Results: Comparison of the Estimated Reference *F*'s and the Equilibrium Yield Curve for the α = 50 and σ = 0.9 Combination



Simulation Results: Comparison of the Mean Equilibrium Catches and Spawner Biomasses for Estimated Reference *F*'s

- For each simulated dataset, the equilibrium catch and SSB is calculated using the estimated reference *F* and the known population dynamics. The results are averaged for each α and σ pair.
- Differences increase with increasing σ
- F_{msy} produces catches and spawner biomasses that are lower than the other methods
- $F_{\mathrm{maxE[Y]}}$ produces the highest catches and spawner biomasses between F_{marg} and F_{msy}





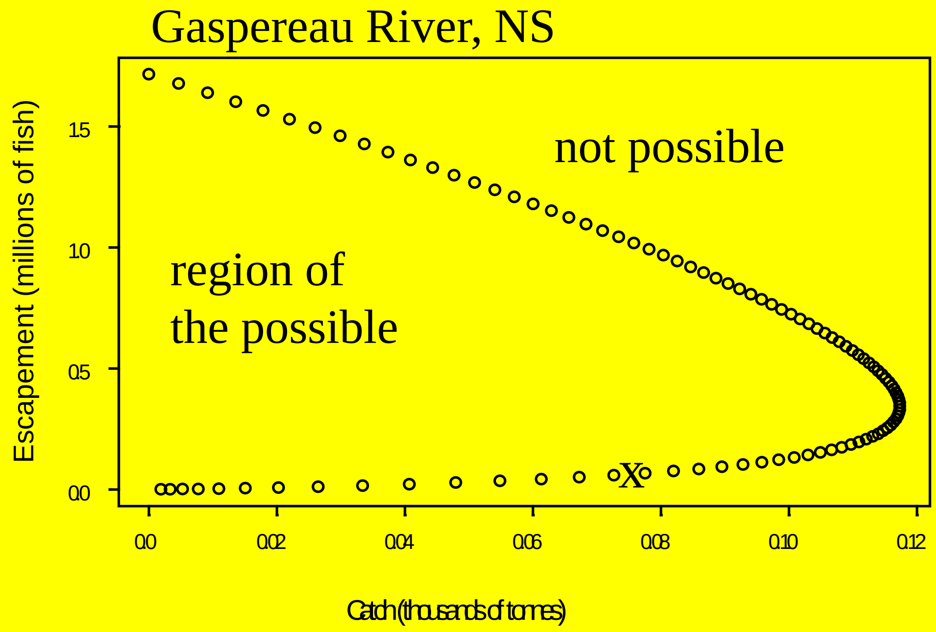
Evaluation of BRP's via Monte Carlo simulations using the life history model

-Each point represents the mean of 100 Monte Carlo projections over a 50 year period for each exploitation rate (1% increment).

-The best strategies fall on the frontier.

-Spawner abundances limit catch at low escapements

-A good strategy might be to target escapement around 0.4 to 0.5 million fish



Summary

- The population dynamics model presented in this thesis provides a flexible tool for stock and impact assessment

- Model applications in the thesis include:
  - life history parameter estimates for alewife
    - maximum reproductive rates, mortality rates, maturity schedules, habitat carrying capacity
  - methods for assessing effects of human activities (e.g. fishing and turbine mortality)
  - combining life history and effects of human activity:
    - assessment models
    - reference point estimation and evaluation
    - relationships between fisheries yields and other sources of human-induced mortality

Acknowledgments

- Funding provided by:
  - Nova Scotia Power Inc.
  - Department of Fisheries and Oceans
  - Nova Scotia Department of the Environment and Labour
  - Acadia Centre for Estuarine Research
  - NSERC (grant to RAM)

- Special thanks to RAM for fundamentally changing the way I approach science

MSY and its Associated Reference Points

- The MSY is firmly embedded in the management objectives of many organizations countries
  - The Magnuson-Stevens Fisheries and Management Act (1996) defines overfishing as an *F* that jeopardizes the stocks capacity to produce MSY
  - The United Nations Convention of the Law of the Sea (1982) directs coastal States to maintain or restore exploited populations to levels that can produce MSY
- Despite the above, the concept of MSY remains one of the most controversial topics in fisheries science
  - e.g. Larkin (1977): An Epitaph for Maximum Sustainable Yield

Criticisms of MSY

- Punt and Smith (2001) divide the criticisms of MSY into three categories:

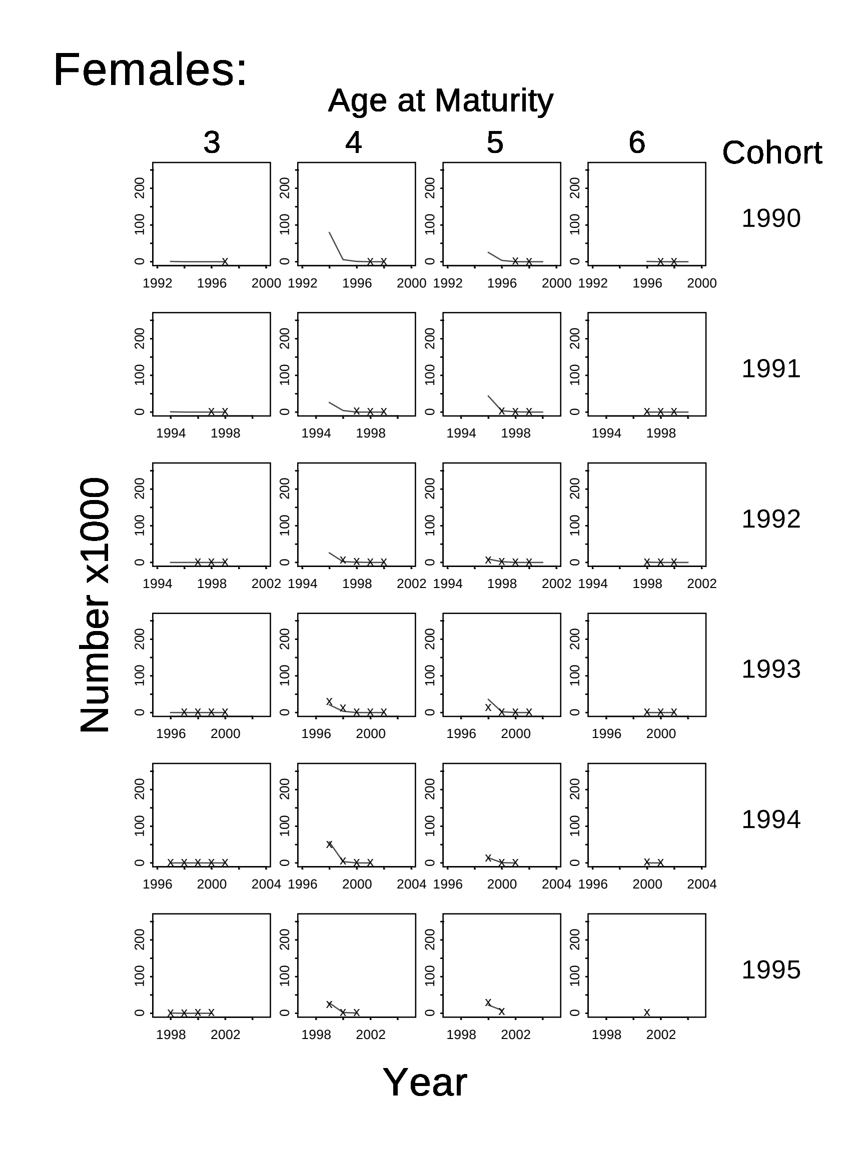
1. Problems with its implementation
   - not specific to MSY and therefore is not a valid criticism
2. Its appropriateness as a management objective
   - MSY is no longer considered a constant amount that can be removed from the ocean annually; it is now considered a long term average amount obtained through management of fishing mortality, spawning escapement and harvests (Punt and Smith 2001; Mace 2001)
3. Problems with its estimation
   - A valid criticism
   - Many datasets contain little information about MSY and F_{msy}
   - Hilborn and Walters (1992) point out that to estimate MSY you must exceed it, so as soon as you know what it is you're into stock rebuilding

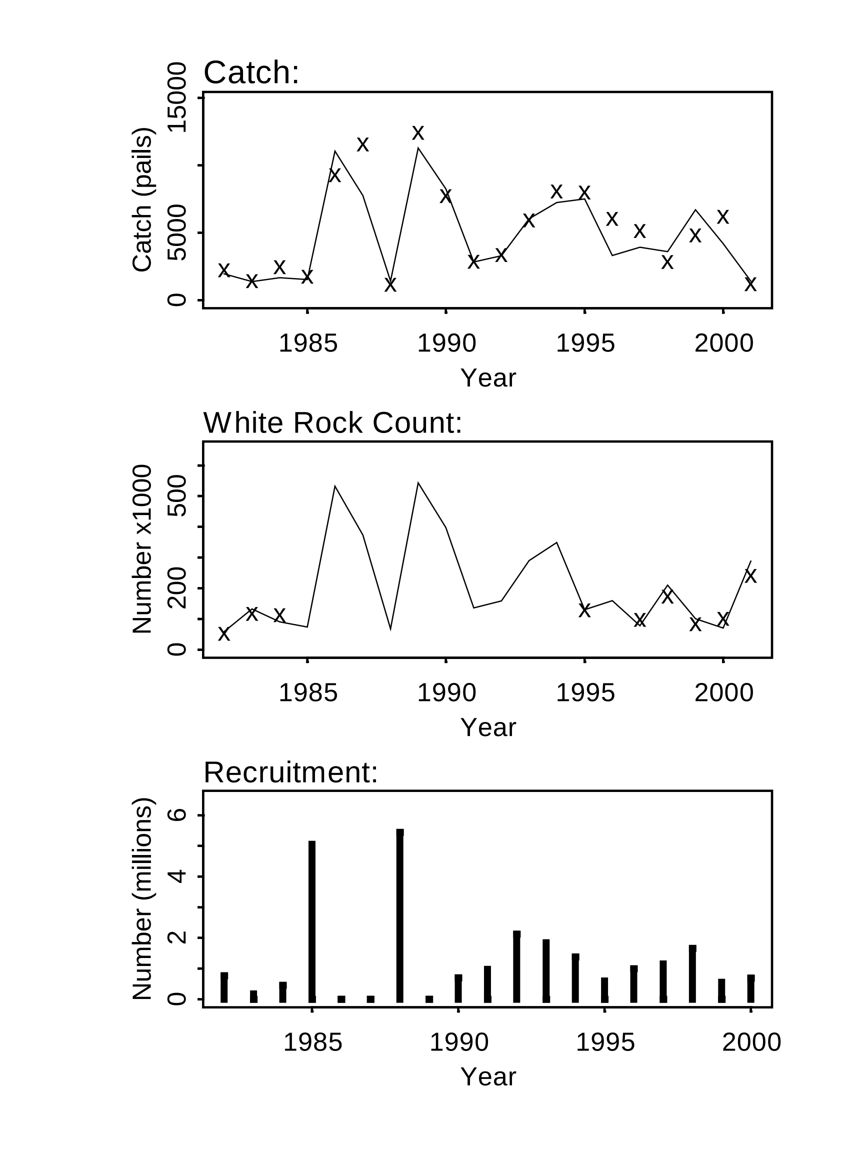
Chapter 5. Reference Fishing Mortality Rates from Noisy Spawner-Recruit Data (Preliminary Exam Essay)

Overview

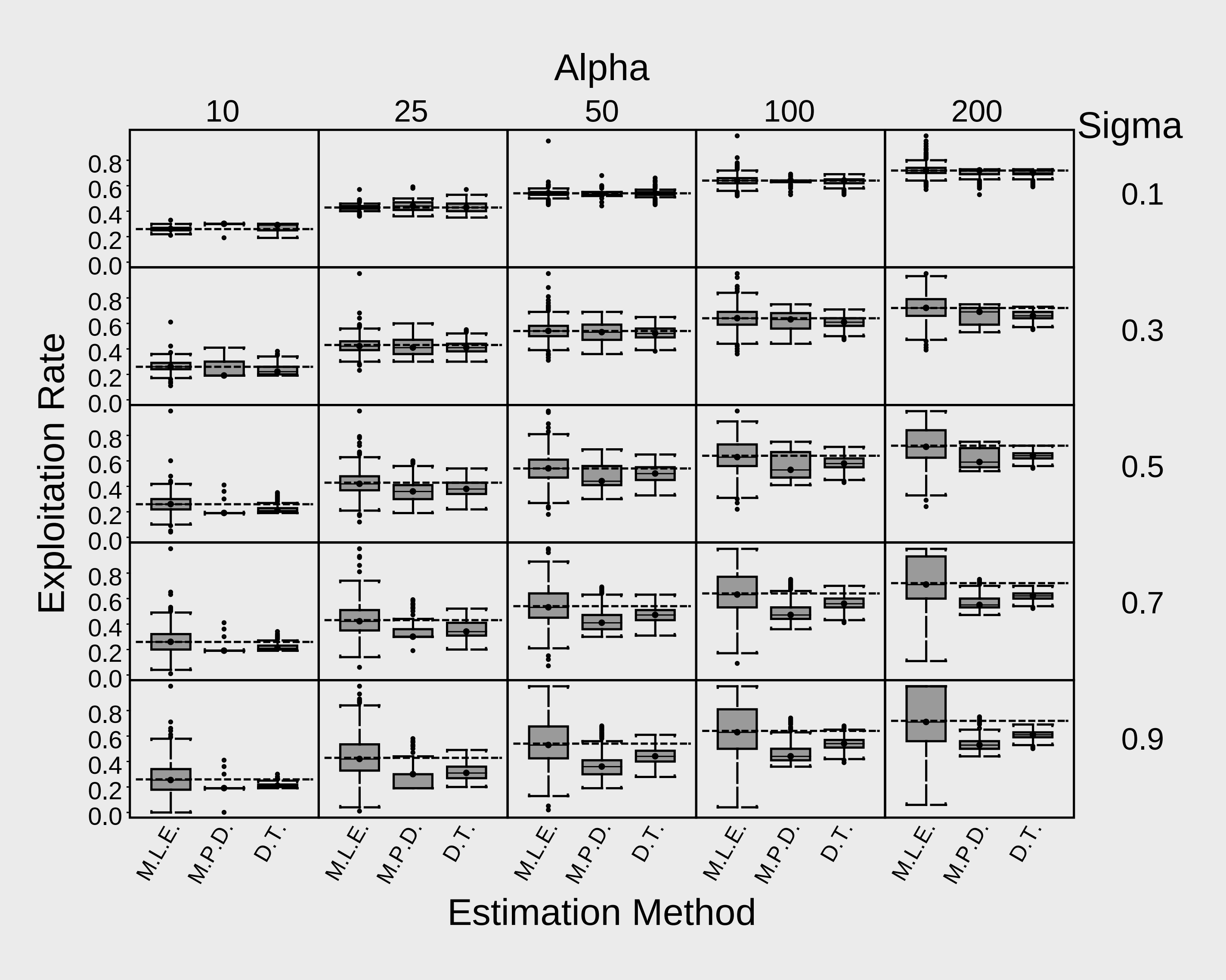
1. MSY and F_{msy}
2. Assessing uncertainty in F_{msy}
3. Methods of dealing with uncertainty in F_{msy}
   - alternative reference points that do not require an SR model
   - Bayesian and decision theoretic approaches to estimating reference F's
4. A comparison of maximum likelihood, marginal likelihood and decision theoretic approaches
5. Using data from other populations when estimating reference fishing mortality rates

Gaspereau River Alewife





Simulation Results: Comparison of the Estimated Reference *F*'s and the known Exploitation Rate that Produces MSY



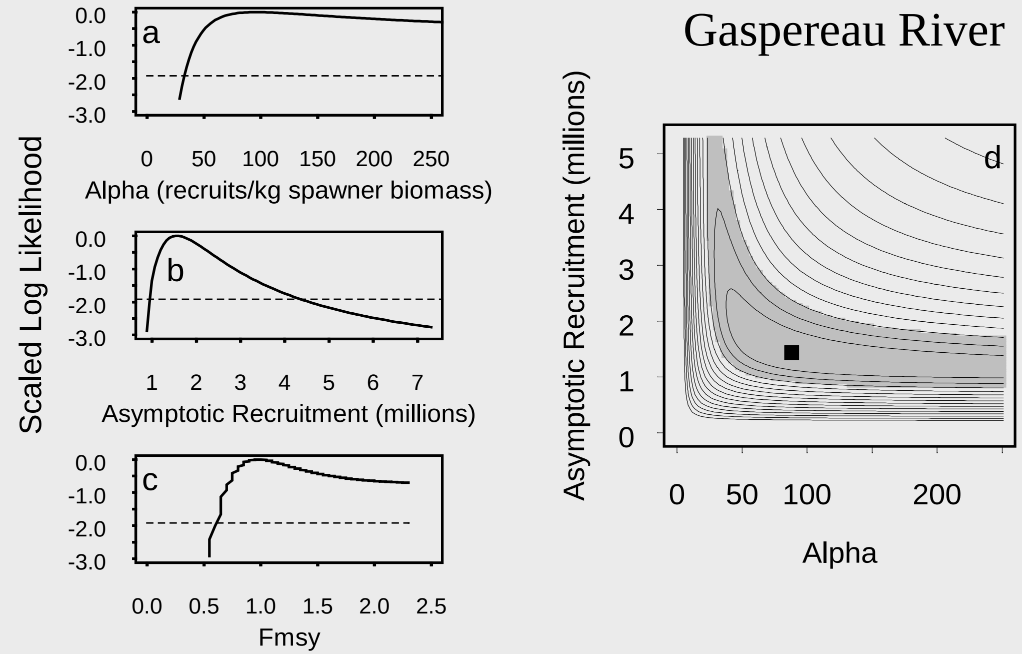
How Good are the Estimates of F_{msy}?

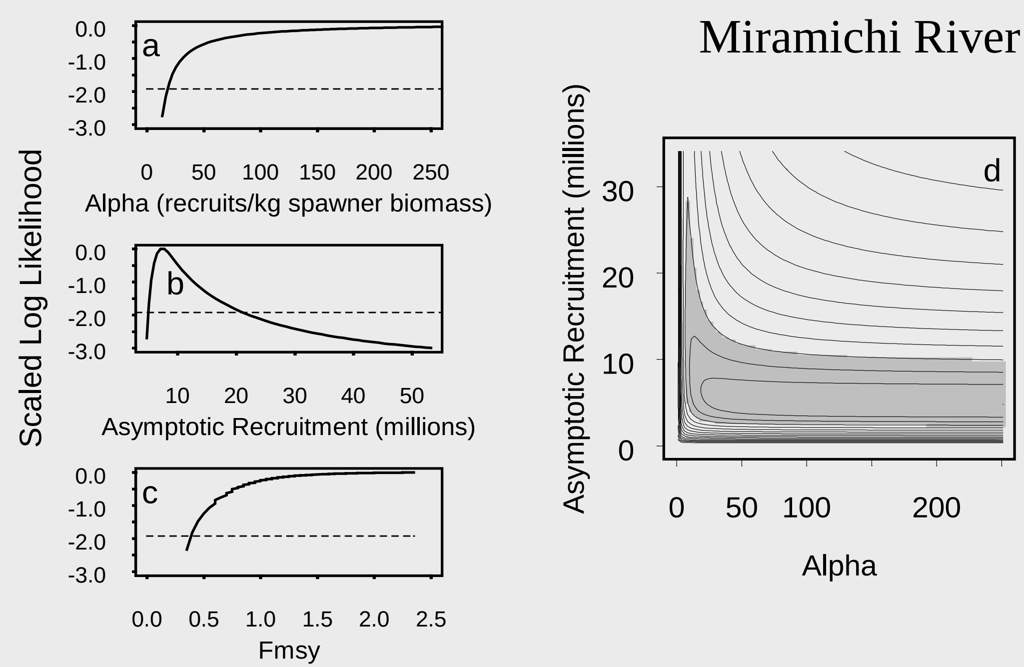
The Likelihood surfaces contain an "L" ridge along which parameter estimates are not significantly different

The data do not preclude the possibility of much larger recruitments than observed

Profile likelihoods indicate that the data contain little information about either α or F_{msy} other than a lower bound for a confidence interval

The data are more informative about R_0, although the confidence interval are wide





The Production Model

1. F_{msy} may be estimated in several ways:
   - Surplus Production Models
   - Delay Difference Models
   - Reviewed by Quinn and Deriso (1999)
2. I will focus on an age-structured production model with three components
   - A spawner-recruit component
   - A YPR component
   - A SPR component
   - MLE's of the SR parameters most often used
   - F_{msy} is found using a grid search over F

$$R = \frac{\alpha S}{1 + \frac{\alpha S}{R_0}} \quad \text{and} \quad S = SPR_{F=f} \cdot R$$

$$\frac{S^*}{SPR_{F=f}} = \frac{\alpha S^*}{1 + \frac{\alpha S^*}{R_0}}$$

$$S^* = \frac{(\alpha SPR_{F=f} - 1)R_0}{\alpha}$$

$$R^* = \frac{\alpha S^*}{1 + \frac{\alpha S^*}{R_0}}$$

$$Y^* = R^* \cdot YPR_{F=f}$$

Comparison of the Three Methods of Estimating Reference *F*'s from SR Data using Monte Carlo Simulations

Method:

1. I selected 5 levels for α and 5 levels for σ (a measure of the variability of the data around the fitted SR model). I assumed a constant *K*.

2. For a given α and σ, I randomly selected 20 spawner biomasses between 0 and the unfished equilibrium spawner biomass, using a uniform distribution.

3. For each spawner biomass, I randomly selected a recruitment from a lognormal distribution with its mean given by the SR model and σ as selected in 1.

4. I then fit the SR model to the simulated data and estimated F_{msy}, F_{marg} and $F_{\mathrm{maxE[Y]}}$ as previously shown.

5. For each α and σ pair, I repeated steps 2 to 4 a total of 500 times.

Alternative Methods of Estimating Reference *F*'s from SR Data

Two Alternatives:

1. Using of the mode of the marginal probability density for α (Ianelli and Heifetz 1995, Chen and Holtby 2002) to estimate a reference *F* using the production model (F_{marg}).

2. Maximizing the expectation of the yield (Brodziak 2002) given the uncertainty in the SR parameters ($F_{\mathrm{maxE[Y]}}$).

Both require a probability distribution for the SR parameters that may be obtained through an application of Bayes Theorem:

$$p(\alpha, R_0) = \begin{cases} \dfrac{L(\mathbf{R} \mid \mathbf{S}, \alpha, R_0) \cdot p(\alpha) \cdot p(R_0)}{\iint_{\Omega} L(\mathbf{R} \mid \mathbf{S}, \alpha, R_0) \cdot p(\alpha) \cdot p(R_0) \, d\alpha \, dR_0}, & \alpha, R_0 \in \Omega \\ 0 & \text{otherwise} \end{cases}$$

Alternative Methods of Estimating Reference F's from SR Data

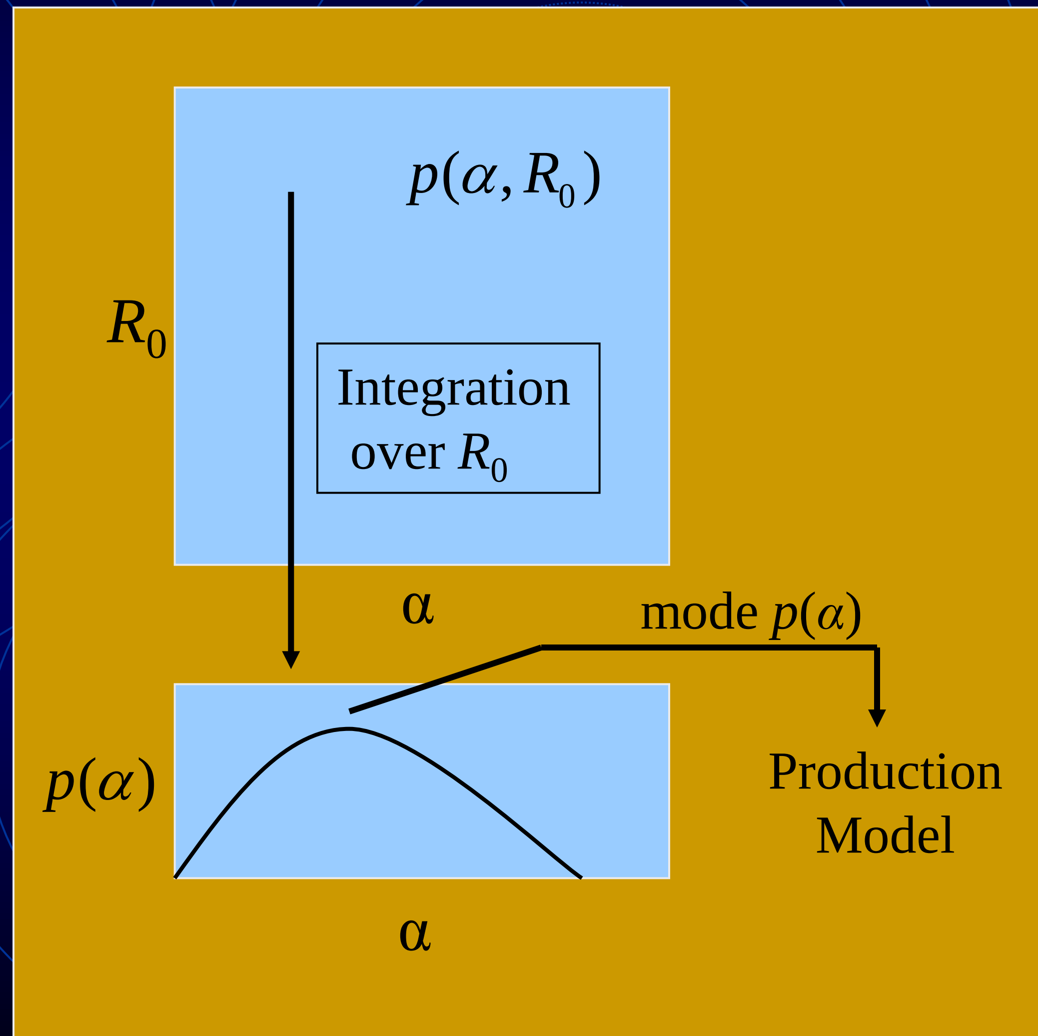
F_{marg}:

1. The marginal probability density for α is obtained by integrating over R_0 :

$$p(\alpha \mid p(\alpha, R_0)) = \int p(\alpha, R_0)\, dR_0$$

2. The mode of this distribution is an alternative estimate of α than can be used in the production model.

3. F_{marg} is then found using a grid search over F.



Alternative Methods of Estimating Reference F's from SR Data

$F_{\mathrm{maxE[Y]}}$:

1. For a given F , the expectation of the equilibrium yield is:

$$\mathrm{E}\left[Y^*(F)\right] = \int\int Y^*(F, \alpha, R_0)\, p(\alpha, R_0)\, dR_0\, d\alpha$$

2. $F_{\mathrm{maxE[Y]}}$ is the fishing mortality rate that maximizes this expectation:

$$F_{\mathrm{max\,E[Y]}} = \underset{F}{\operatorname{argmax}}\, \mathrm{E}\left[Y^*(F)\right]$$

3. This is a decision theoretic approach because it takes into account not only the probability of the SR parameters, but also their consequences (higher yields at higher levels of α and R_0)

Chapter 6. Biological reference points for alewife populations in Atlantic Canada. (in review)

- Biological reference points (BRPs) are indices, based on the characteristics of a fish stock and its fishery, that are used to gauge whether specific management objectives are being achieved.
- Provide the link between management objectives and stock assessment and provide a basis for risk analysis of management decisions

Comparison of Reference *F*'s Estimated Using Uniform Bounded Priors and Informative Priors Obtained from Meta-Analysis of Data from Similar Populations

In these examples, the prior for α is highly informative relative to the population-specific data or the prior for R_0.

As a result of this increased "certainty", the estimates of F_{msy}, F_{marg} and $F_{\mathrm{maxE[Y]}}$ are the same.

Reference Point	Gaspereau River	Miramichi River
Uniform Bounded Priors:		
F_{msy}	0.63	>0.99
F_{marg}	0.56	0.77
$F_{\mathrm{maxE[Y]}}$	0.61	0.68
Informative Priors:		
F_{msy}	0.56	0.53
F_{marg}	0.56	0.53
$F_{\mathrm{maxE[Y]}}$	0.56	0.53

Exploitation Rates Corresponding to the Reference *F*

ATC Exam Research Proposal

Compensatory Mortality in Anadromous *Alosa* Populations: Its Role in the Assessment and Mitigation of the Impacts of Hydroelectric Generation

Projects:

1. A meta-analysis of the life history and stock-recruitment parameters of anadromous *Alosa* stocks throughout North America.
2. A population model for American shad to examine the effects of the Annapolis Tidal Generating Station on the Annapolis R. shad stock.
3. An analysis of growth and survival of pre-migratory, young-of-the-year alewives in Gaspereau Lake, NS to look for evidence of density-dependence.

Why Alewives are Important

- Commercially:
  - support directed and bycatch fisheries along the eastern seaboard
  - fished recreationally and commercially in natal rivers
- Biologically:
  - food source
  - vector for nutrient transport from the ocean to inland lakes
  - can radically modify an ecosystem

Mactaquac Headpond Alewife

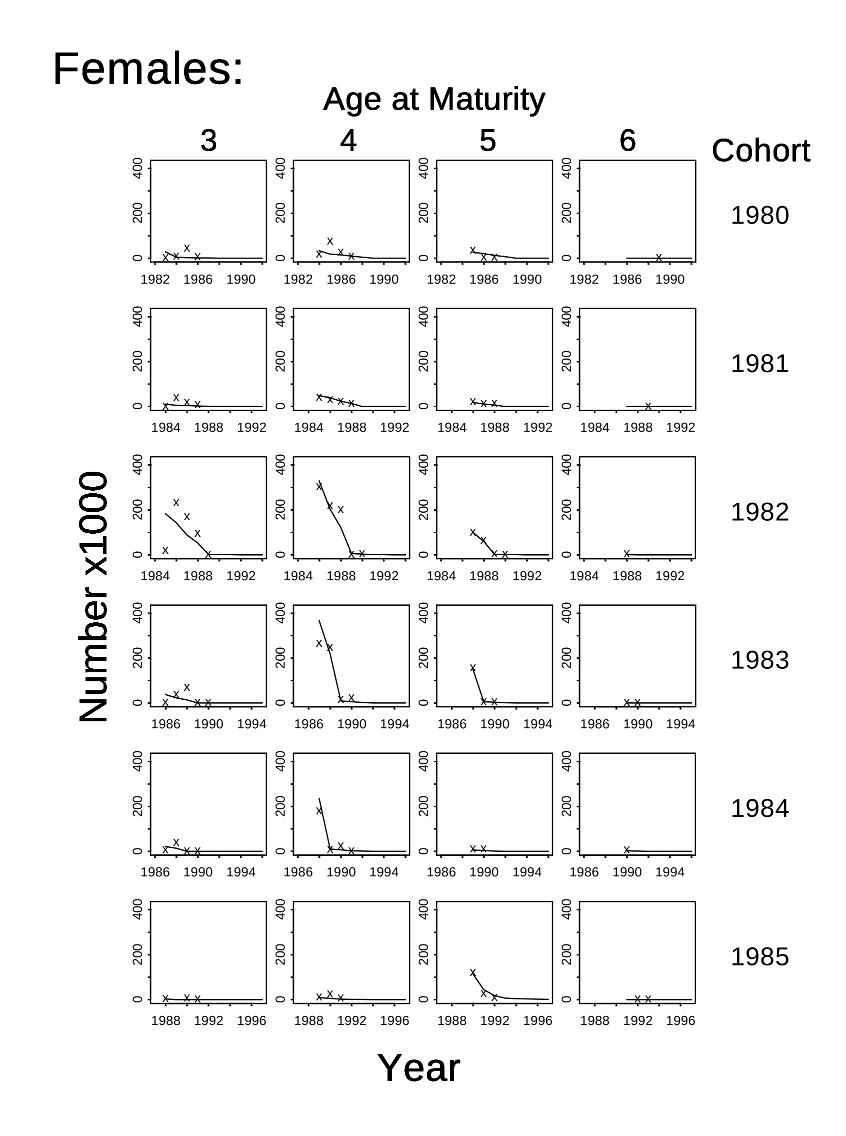
Data

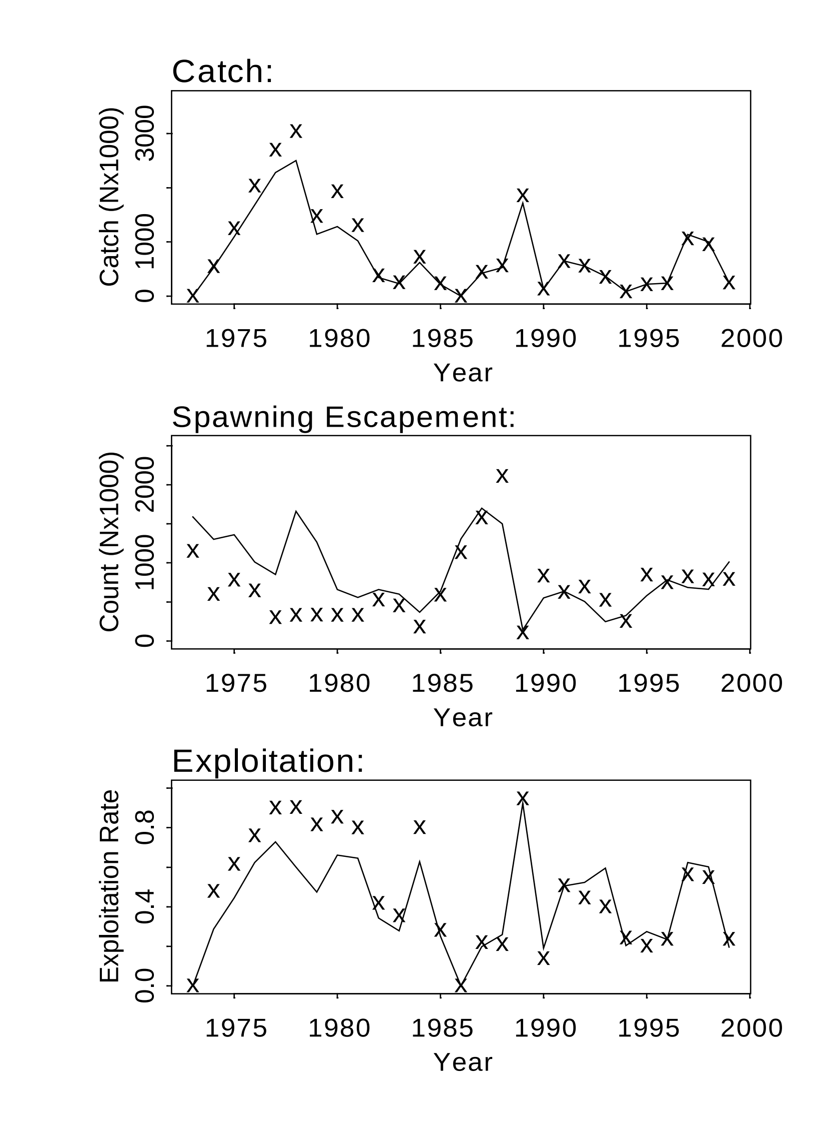
- Catch: 1973 –1999
  - number of fish
- Escapement Counts: 1968 – 1999
- Estimates for the run composition by sex, age and previous spawning history: 1973 –1999

Estimated Parameters

- The number of first time spawners by sex, age and year (216 parameters)
- Exploitation rates in each year (27 parameters)
- Adult natural mortality (1 parameter)
- 3 parameters to initialize the model
- Total: 247 parameters

Mactaquac Headpond Alewife





Margaree River Alewife

Data

- Catch: 1983 –2000
  - number of fish
- Estimates for the run composition by age and previous spawning history: 1983 - 2000
- Larval Index: 1983 - 1985, 1989 - 1991 and 1993 - 2000
  - used as a index of spawning escapement

Estimated Parameters

- The number of first time spawners by age and year (90 parameters)
- Exploitation rates in each year (18 parameters)
- Adult natural mortality (1 parameter)
- 4 parameters to initialize the model
- Larval catchability coefficient (1 parameter)
- Total: 134 parameters

Margaree River Alewife

Dynamics:

$$N_{t,a,p} = N_{t-p,a-p,0} e^{-\left(\sum_{k=t-p+1}^{t} F_k + M^{\text{adult}} p\right)}$$

$$C_{t,a,p} = N_{t,a,p} u_t$$

$$C_t = \sum_a \sum_p \left(N_{t,a,p} u_t\right)$$

$$I_t = q \sum_a \sum_p \left(N_{t,a,p} (1 - u_t)\right)$$

Likelihoods:

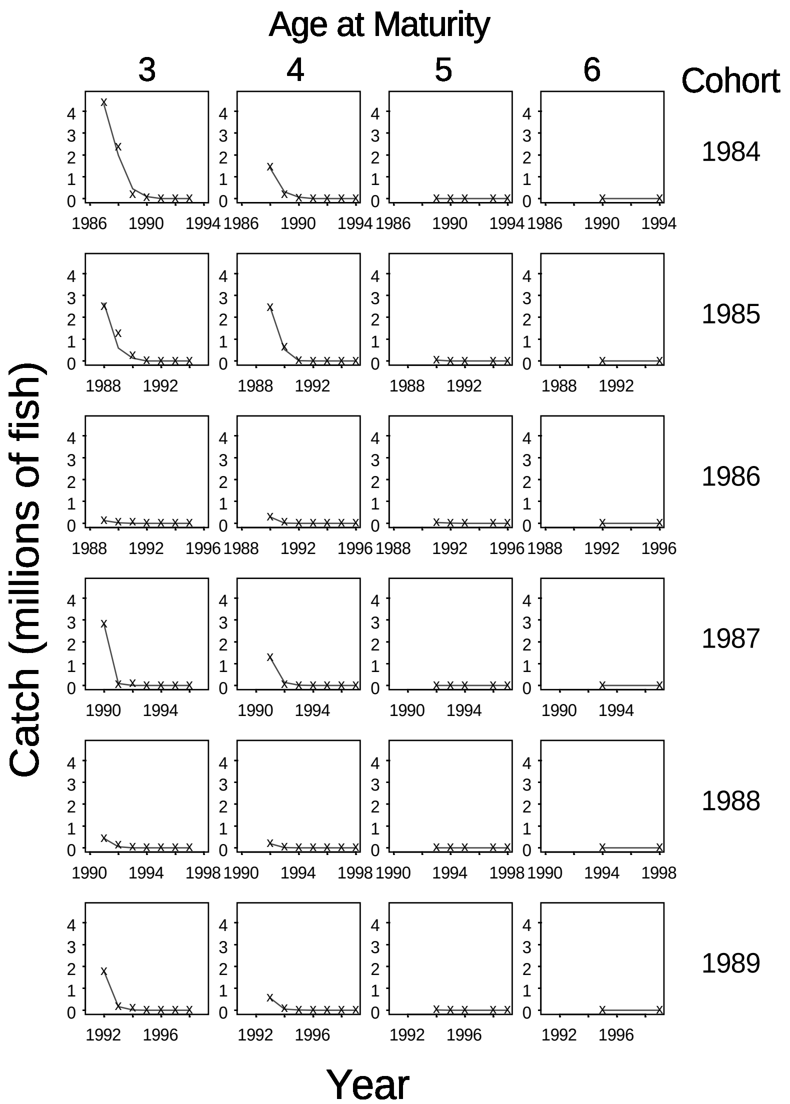
$$\ell_{catch} = -\sum_t (\ln C_t^{obs} - \ln C_t^{pred})^2$$

$$\ell_{composition} = -\sum_t \sum_a \sum_p \pi_{t,a,p}^{obs} \ln p_{t,a,p}^{pred}$$

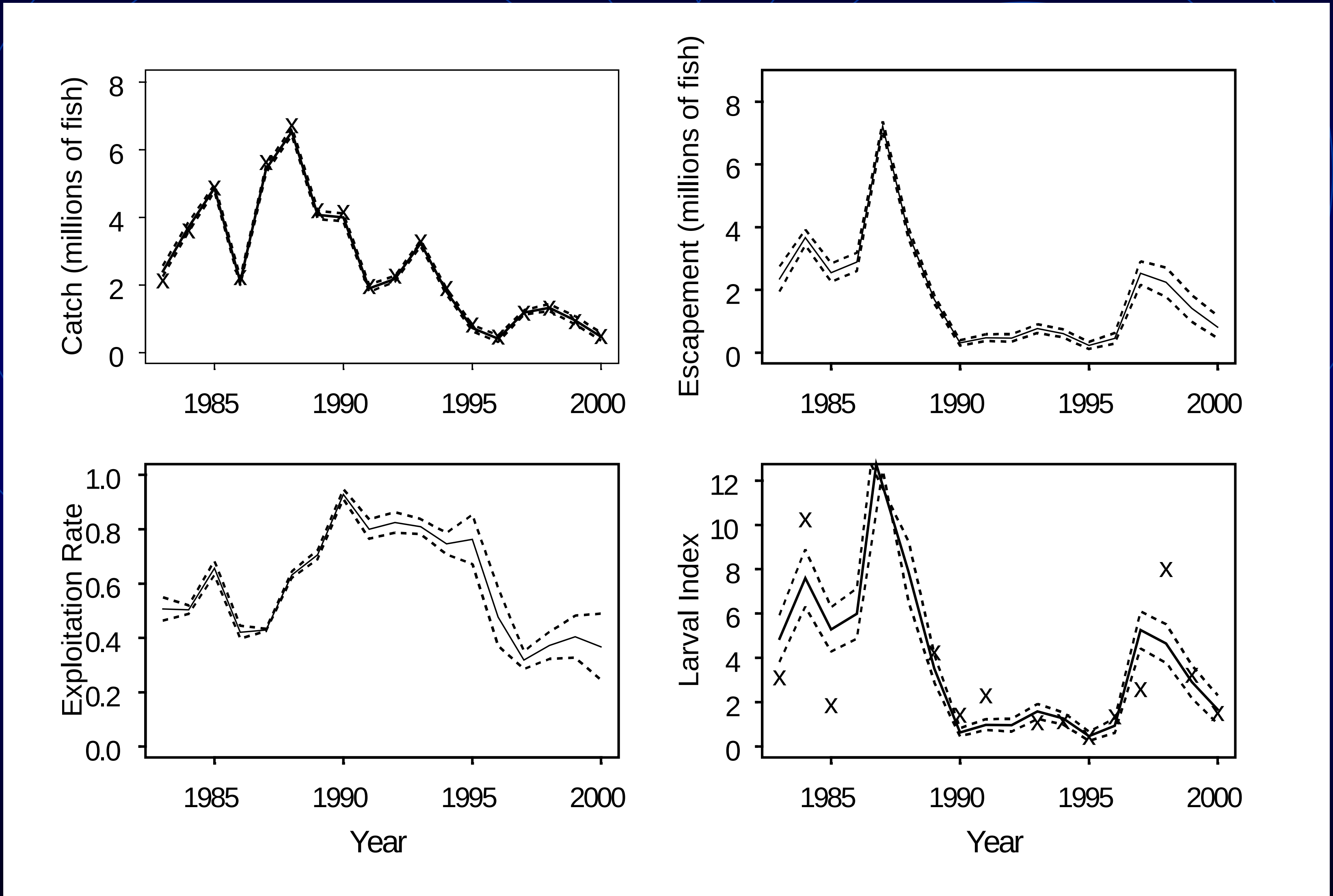
$$\ell_{larval} = -\sum_t (\ln I_t^{obs} - \ln I_t^{pred})^2$$

Objective Function:

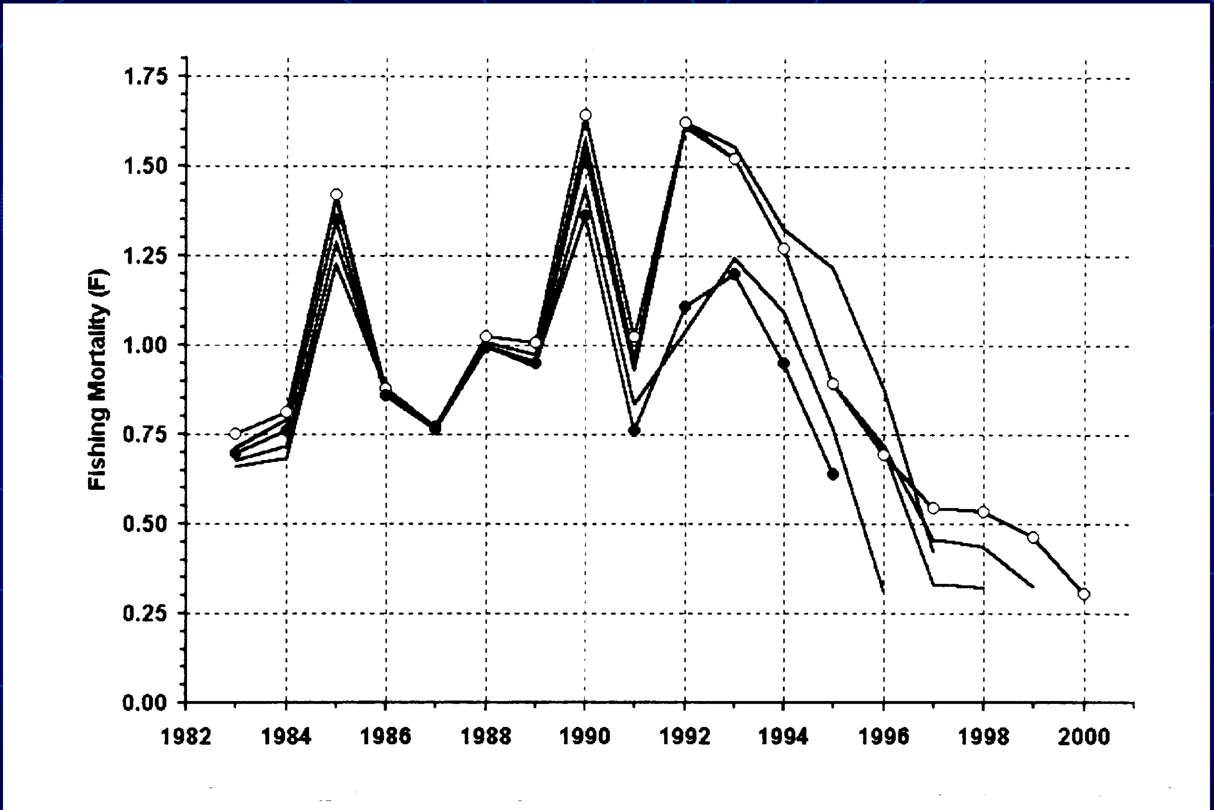
$$O.B.V. = -(\lambda_1 \ell_{composition} + \lambda_2 \ell_{catch} + \lambda_3 \ell_{larval})$$



Margaree River Alewife



Margaree River Alewife



-Chaput et al. 2001. CSAS Working Paper 2001/xxx

Margaree River Alewife

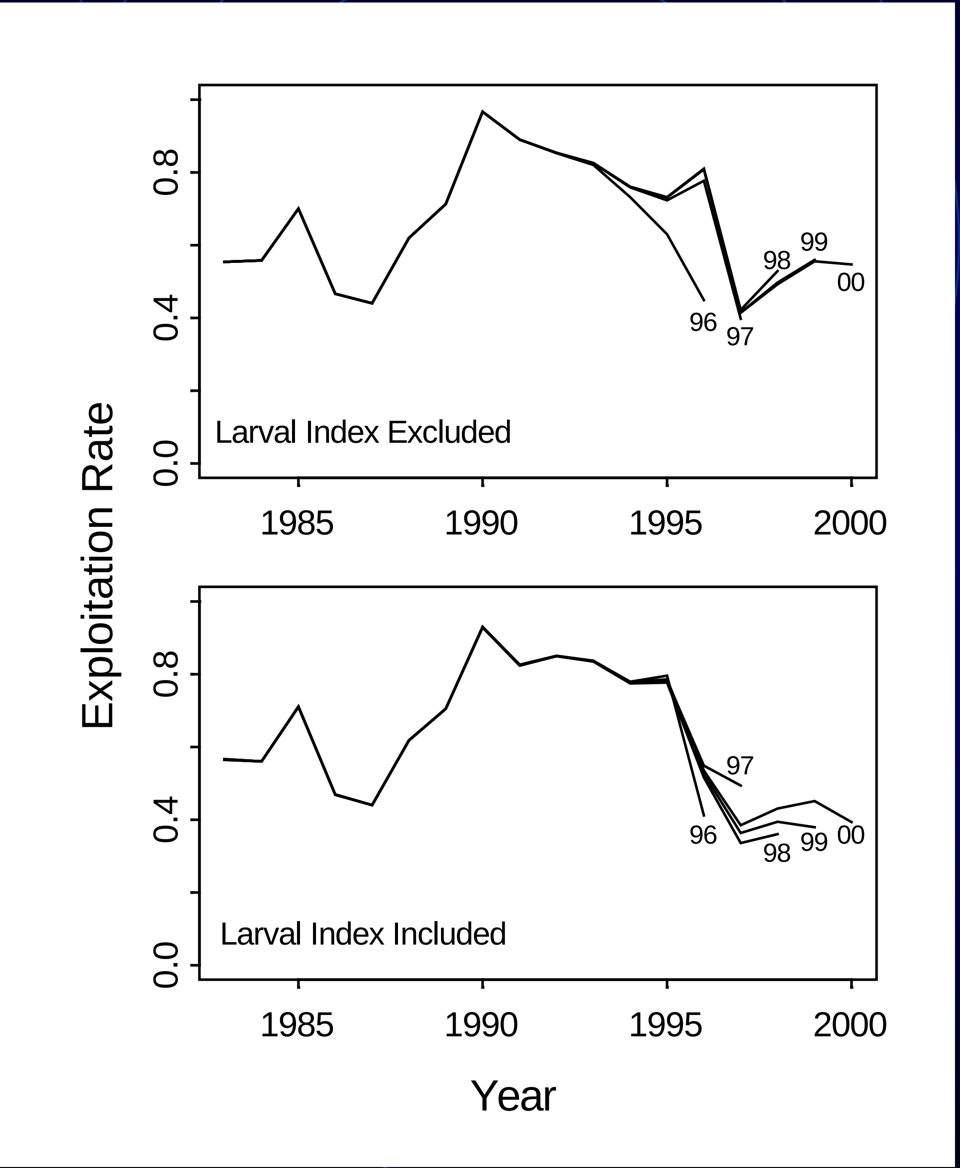
Utility of the Larval Index

- inclusion introduces a retrospective pattern

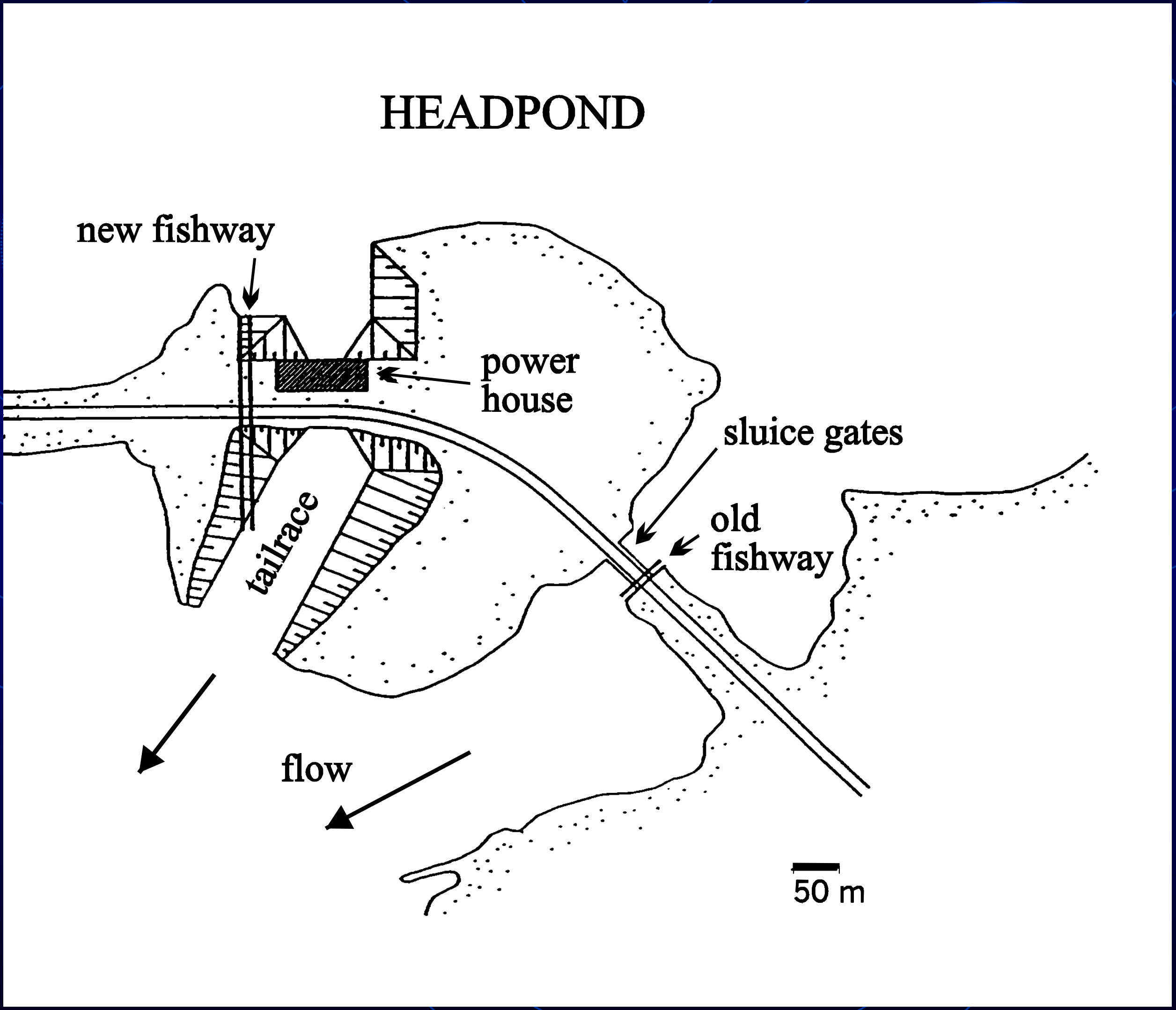
- produces estimates of SSB_t that are unrealistic when heavily weighted

- produces estimates of M^{adult} that are negative

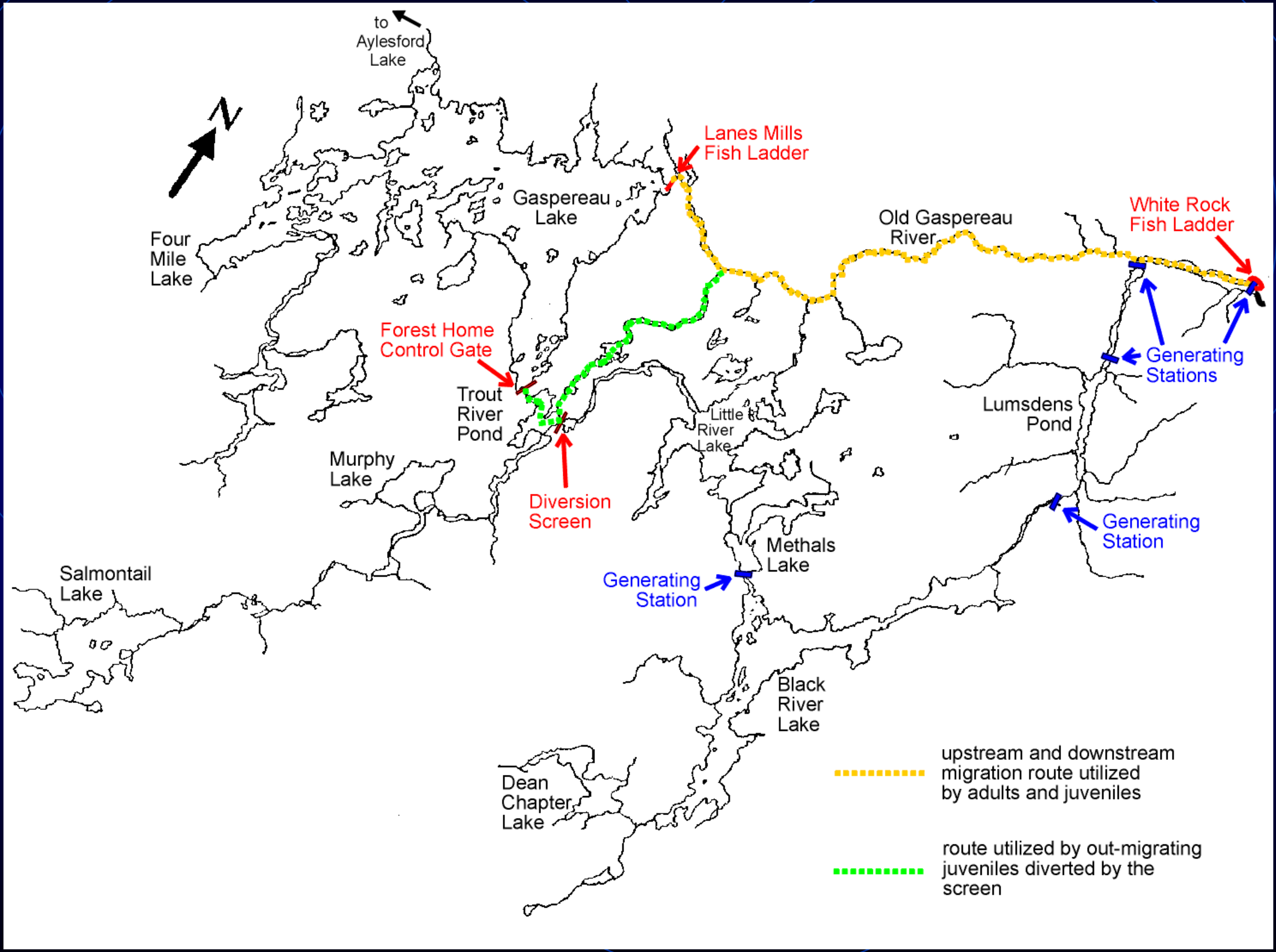
- lowers the estimates of u_t



The Annapolis Tidal Generating Station



Alewife Migration Routes in the Gaspereau River, NS



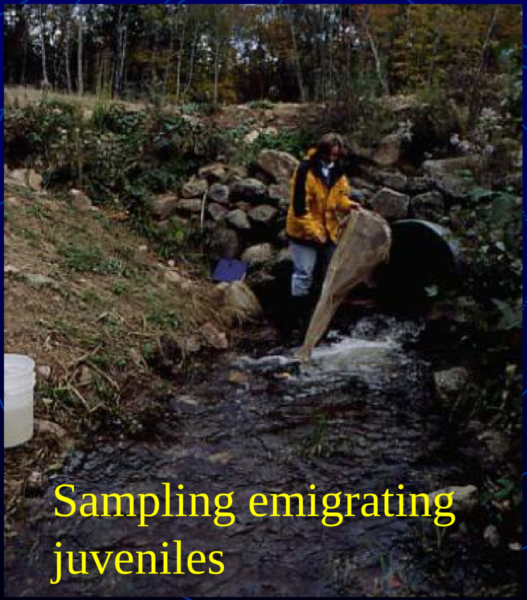
Where does alewife data come from?


Commercial landings


Biological sampling

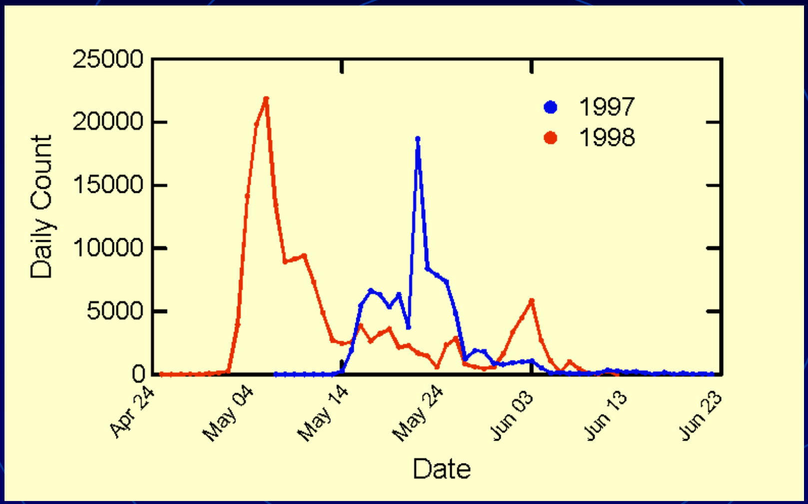

Counts at fish ladders


Seining for juveniles

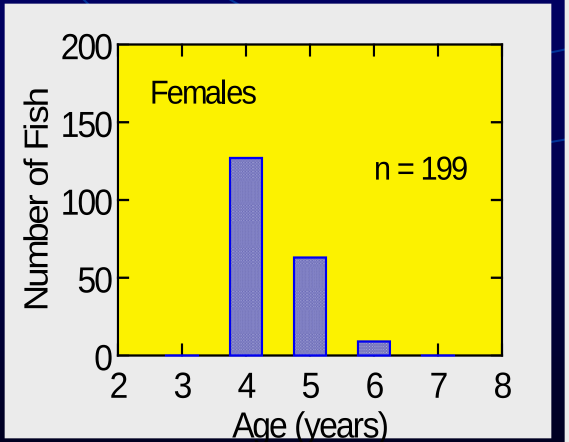

Sampling emigrating juveniles

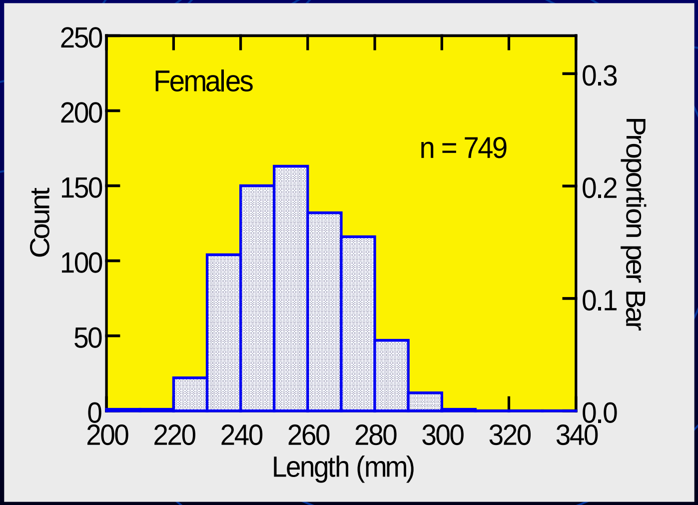

Larval sampling

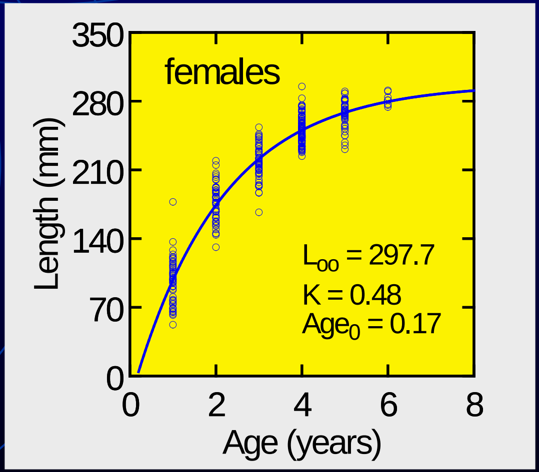
Gaspereau River Alewife Data Summaries



Year	Alewife Count	Catch (no. of fish)	Stock Size	Exploit. Rate (%)
2001	238,842	149,422	388,264	38.5
2000	98,883	754,585	853,468	88.4
1999	81,326	698,600	770,926	89.4
1998	171,639	372,400	544,039	68.5
1997	95,433	611,520	706,953	86.5
1995	126,933	954,960	1,081,893	88.3
1984	111,100	212,966	324,066	69.9
1983	114,800	150,408	265,208	56.7
1982	50,400	254,068	304,468	80.9
1970	60,527	480,000	540,527	88.9







Model Adaptations for the Gaspereau River Alewife Data

- Data are limited
- Set up model to estimate:
  - -the number of age-3 recruits in each year (20 parameters)
  - -maturity schedules (6 parameters)
  - -adult natural mortality (1 parameter)
  - -3 parameters to initialize the model
- Treat the exploitation rate as known
  - -calculated for years with escapement counts
  - - use mean for years when no data are available

Dynamics:

$$N_{t,s,a,0} = R_{t-a+3}\upsilon_s m_{s,a} e^{-M^{\text{juv}}(a-3)}$$

$$C_{t,s,a,p} = N_{t,s,a,p} u_t$$

$$C_t = \sum_s \sum_a \sum_p \left(N_{t,s,a,p} u_t\right)$$

$$E_{t,s,a,p} = N_{t,s,a,p}(1-u_t)$$

$$N_{t+1,s,a+1,p+1} = E_{t,s,a,p} e^{-M^{\text{adult}}}$$

$$SSB_t = \sum_s \sum_a \sum_p (E_{t,s,a,p} w_{s,a,p})$$

Log Likelihoods (non-constant portions):

$$\ell_{catch} = -\sum_t (\ln C_t^{obs} - \ln C_t^{pred})^2$$

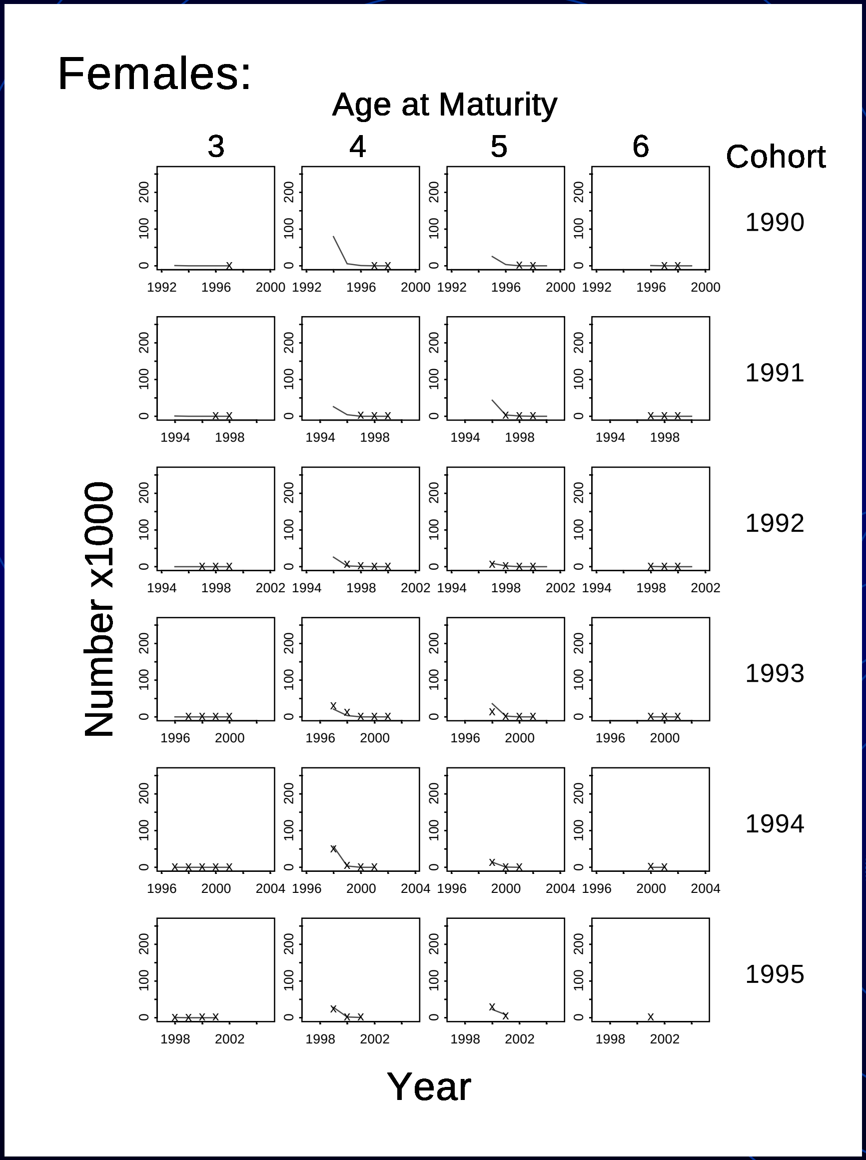
$$\ell_{composition} = -\sum_t \sum_s \sum_a \sum_p \pi_{t,s,a,p}^{obs} \ln p_{t,s,a,p}^{pred}$$

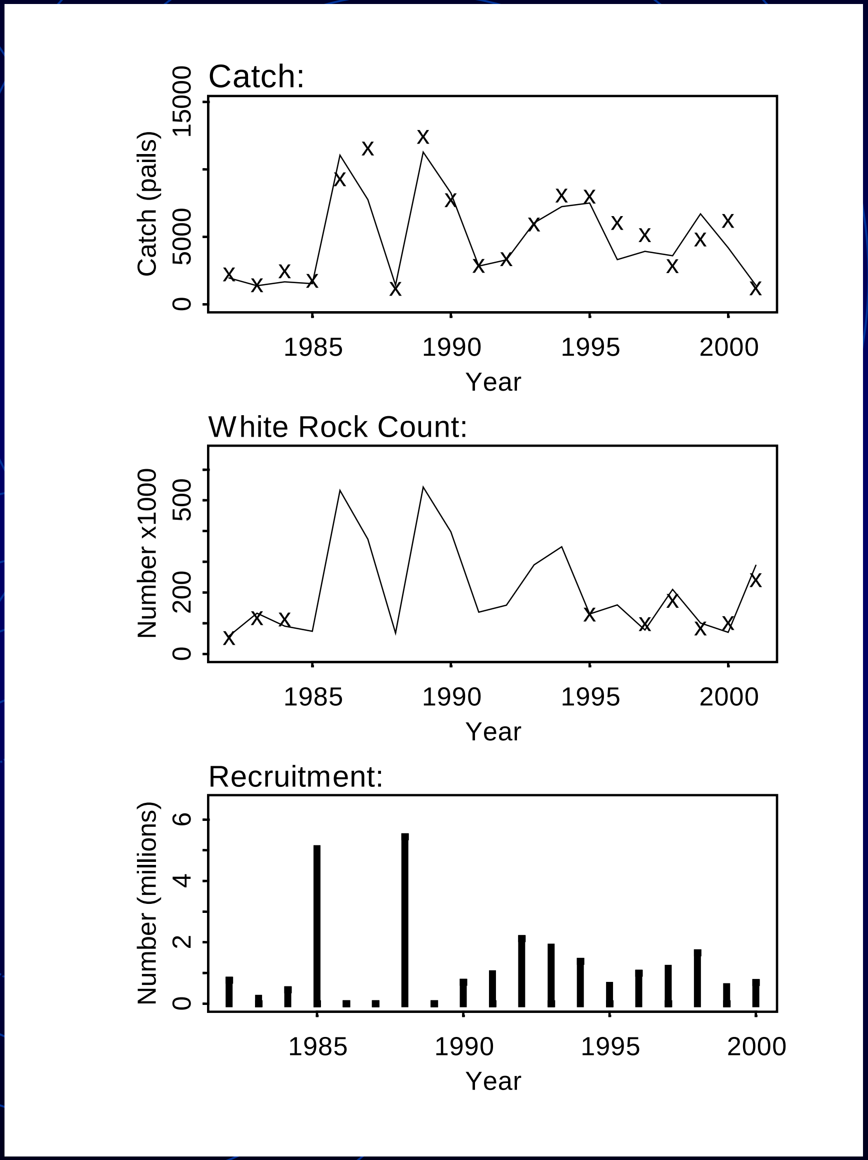
$$\ell_{escapement} = -\sum_t (\ln E_t^{obs} - \ln E_t^{pred})^2$$

Objective Function:

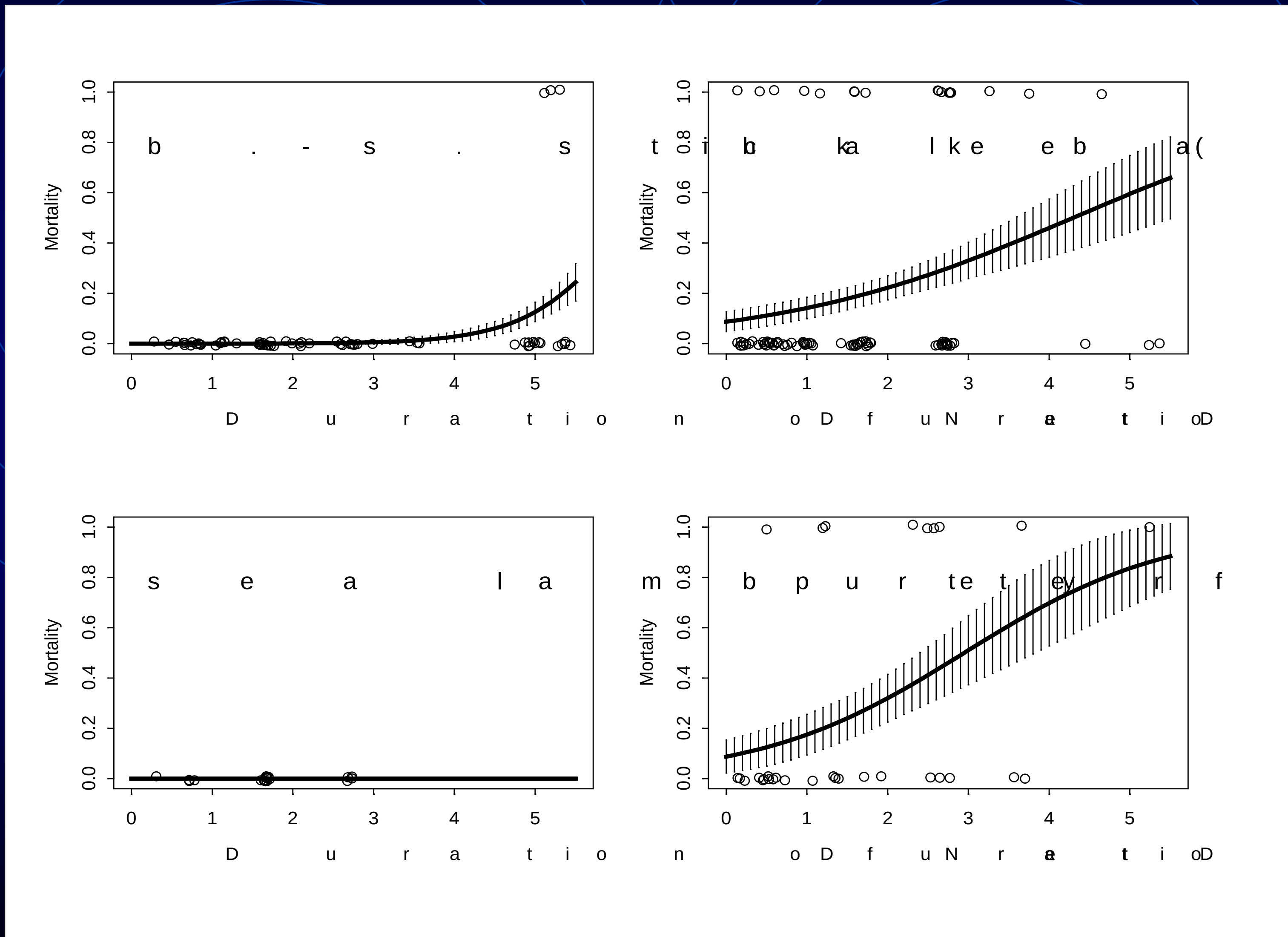
$$O.B.V. = -(\lambda_1 \ell_{composition} + \lambda_2 \ell_{catch} + \lambda_3 \ell_{escapement})$$

Gaspereau River Alewife

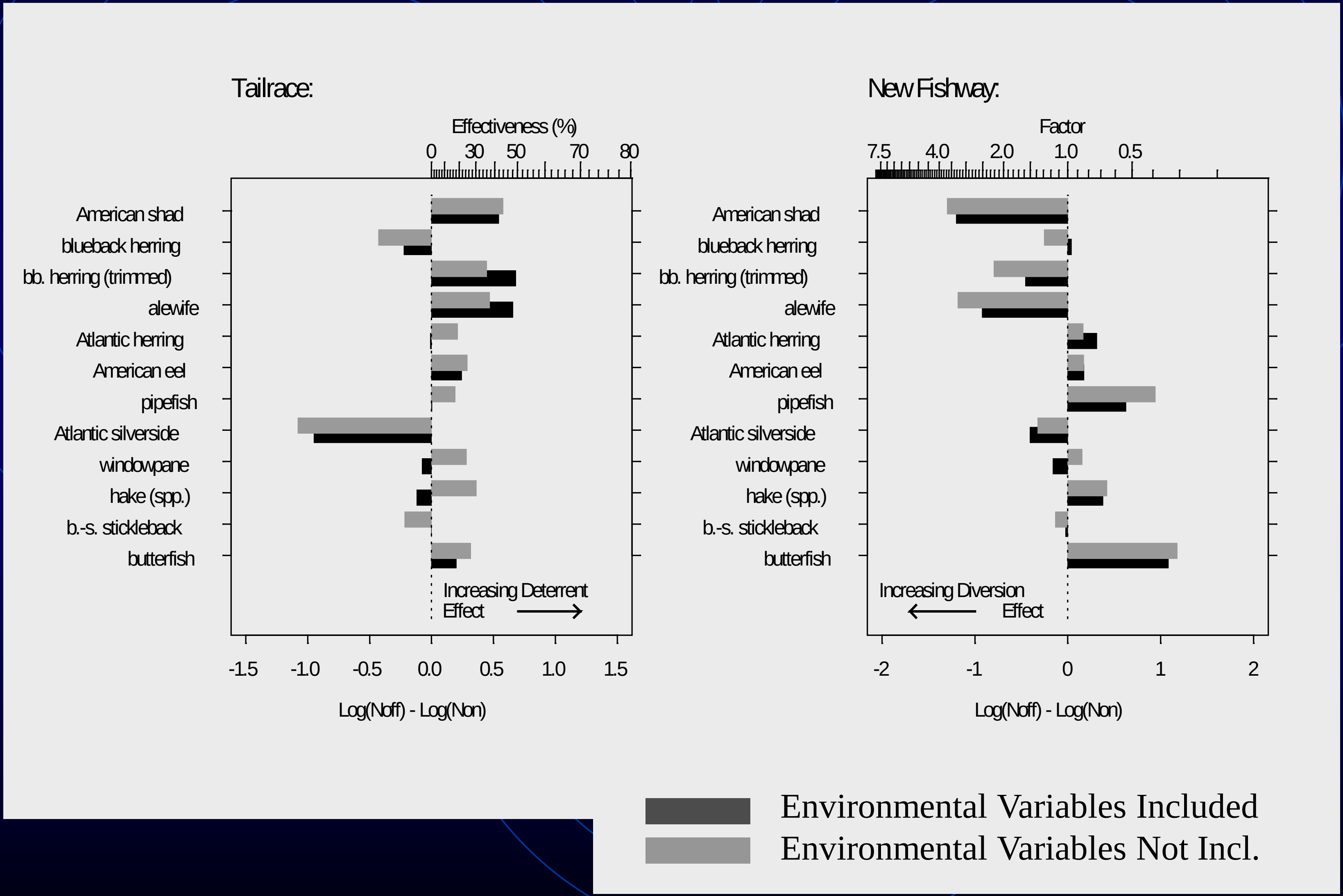




Acute Mortality of Fish as a Function of the Duration of the Net Deployment



Effect of Including Environmental Variables when Evaluating a Fish Diversion System



Chapter 5. Estimating fishery reference points from noisy spawner-recruit data

Options:

1. Ignore the uncertainty
   - possible (but not responsible) for the Gaspereau River example, but not in the case of the Miramichi River
2. Use an alternative reference point
   - example: SPR-based reference points $F_{35\%}$
   - not really satisfactory because the appropriate percentage can only be chosen with reference to stock productivity (the SR relationship)
3. Find an alternative method for estimating a reference F given the SR data
4. Make inferences about the SR parameters based on experience with similar populations
   - Myers and colleagues have developed meta-analytic methods for estimating probability distributions for SR parameters at some higher organizational level such as the species
   - These distributions can be used as priors in Bayesian analyses of the SR relationship or to assess the plausibility of parameter estimates obtained by analysis of population-specific data

Reference Point Summary

Researchers have several options for estimating reference F's given noisy SR data:

1. Ignore the uncertainty

   - not satisfactory given that many data sets actually contain very little information about α or F_{msy}
   - simulations show that populations many be highly under- or over-exploited if the MLE of F_{msy} is arbitrarily used

2. Use an alternative reference point

   -not satisfactory because the appropriate reference point must be chosen by comparison with the stock productivity (the SR relationship)

3. Use one of the alternatives presented here

   - in my simulations, $F_{\mathrm{maxE[Y]}}$ could be estimated for all datasets, never exceeded F_{crash}, and produced yields that were higher than F_{marg}

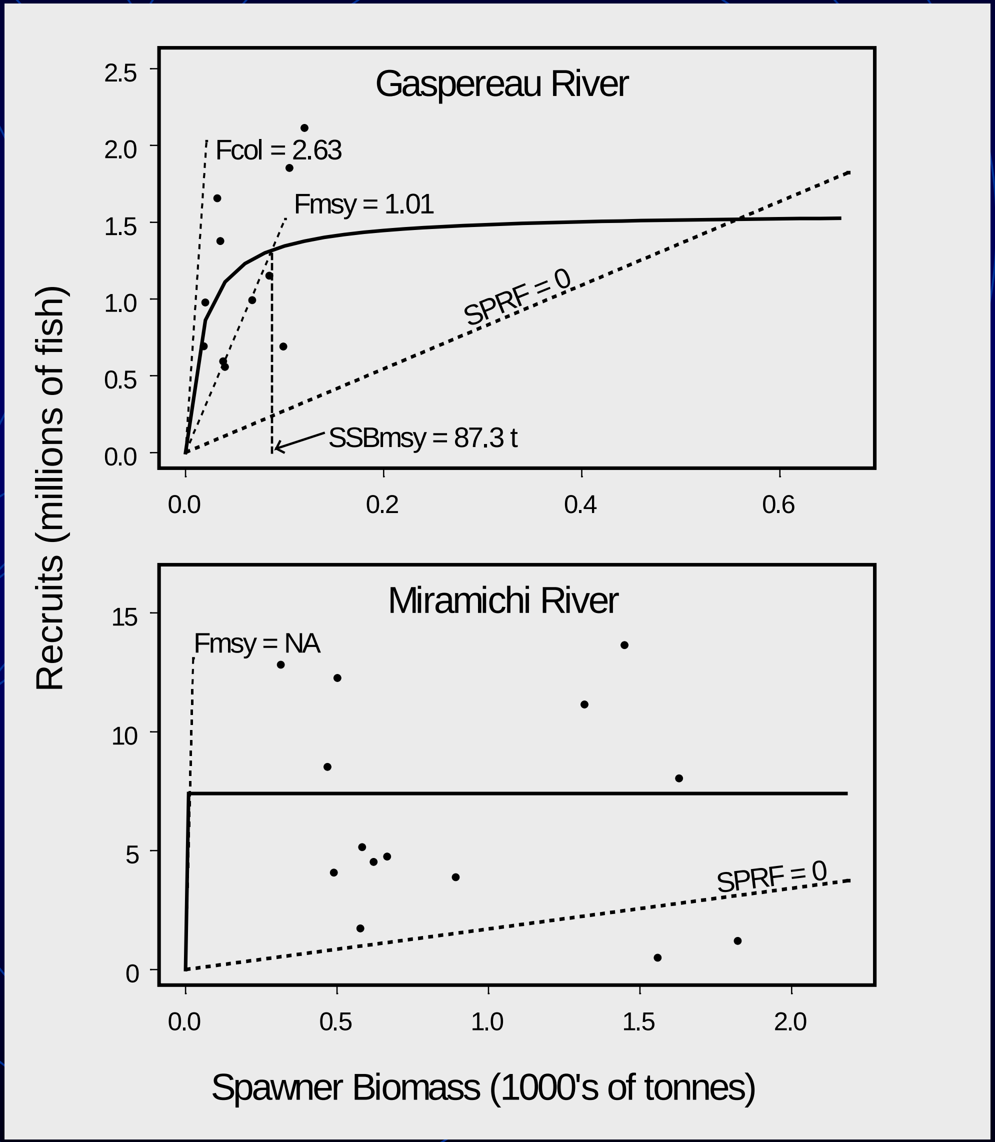
4. Obtain priors for the SR parameters via analysis of data from similar populations.

   - priors may be used to assess the plausibility of SR parameter estimates or incorporated directly into the reference point estimation process

Reference Points for two Alewife Populations obtained from a Production Model

1. Gaspereau River:
   - a plausible estimate of F_{msy} may be obtained
   - most the observed spawning biomasses are below SSB_{msy}
   - at least the estimate of R_0 is questionable

2. Miramichi River:
   - The estimates of α and F_{msy} are essentially infinite
   - The fit implies that an SSB of 10kg can produce the same number of recruits as an SSB of 10,000kg
   - Clearly, these estimates are not believable



Comparison of Reference *F*'s for 2 Alewife Populations

1. Plausible estimates of F_{marg} and $F_{\text{maxE[Y]}}$ could be obtained for the Miramichi River population, whereas its estimate of F_{msy} was essentially infinite.
2. The estimates of F_{marg} and $F_{\text{maxE[Y]}}$ were less than the estimate of F_{msy} and are intuitively appealing because they are precautionary.

Reference Point	Gaspereau River	Miramichi River
F_{msy}	0.63	>0.99
F_{marg}	0.56	0.77
$F_{\text{maxE[Y]}}$	0.61	0.68

Exploitation Rates Corresponding to the Reference *F*

Which reference point is better?