Lecture 16: Tag-Return Models

Estimation of Total Survival or Mortality (Review)

Estimation of Fishing and Natural Mortality (New material)

Augmentation with Telemetered Animals

Overview

Fisheries Stock Assessment and Management. Note many of these ideas apply generally to other taxa where models are used.

Introduction to Tag-Return Models (Review)

Tag-Return Model Advances

- **Age-Dependent Models**
- **Models Which Allow some Catch & Release**

Striped Bass Example

- **Age Independent Analysis**
- **Age Dependent Analysis**

Telemetry Methods and their combination with Tag-Return Models

Fisheries Stock Assessment and Management

Traditional Approaches

Mathematical models used to predict stock size under different levels of fishing --based on catch by age data over a series of years for a fishery plus information on recruitment of young fish.

Independent indices of abundance used "to tune" the predictions.

Very complex process with many subtypes of models. Also complex political and social issues involved when managing the fisheries.

One Weakness

Natural mortality is often poorly known. The old joke goes that M=? evolves into M= .2----Oh M is really equal to 0.2 !!!

Our Approach

Use tag returns from known cohorts of released fish to estimate M and see if it varies by age and time. (We will also get independent estimates of fishing mortality by age and time as well) .

Use these estimates to improve stock assessments.

Fisheries Stock Assessment

Field based estimates of parameters or "guesses"

↓

Build Fisheries Population Model

↓

Validate & Refine Fisheries Model ← Age & time dependent F & M from tag-return data

↓

Predict Fishing Impacts on stock for different values of F & M

Original Brownie Tag Return Model: Fates Diagram.

- → Survives (S) GOES TO NEXT YEAR
- → Harvest, reported ($f = u\phi\lambda$) DATA
- → Remainder (1-S-f) NO DATA

NOTE- CANNOT ESTIMATE u, the exploitation rate without additional information on ϕ (tag induced mortality) and λ (tag reporting rate). We will come back to this later.

$$\hat{u} = \frac{\hat{f}}{\hat{\phi}\hat{\lambda}}$$

Matrix of tag recoveries

R_{ij}= the number of tags recovered in year j from fish tagged in year i

i	Number tagged in year i	Expected recoveries in year j: j=1	2	3	4
1	N_1	R_{11}	R_{12}	R_{13}	R_{14}
2	N_2		R_{22}	R_{23}	R_{24}
3	N_3			R_{33}	R_{34}

Model structure where survival (S) and recovery (*f*) are year specific

i	Number tagged in year i	Expected recoveries in year j: j=1	2	3	4
1	N_1	$N_1 f_1$	$N_1 S_1 f_2$	$N_1 S_1 S_2 f_3$	$N_1 S_1 S_2 S_3 f_4$
2	N_2		$N_2 f_2$	$N_2 S_2 f_3$	$N_2 S_2 S_3 f_4$
3	N_3			$N_3 f_3$	$N_3 S_3 f_4$

S_i is the annual survival rate
f_i is the annual rate at which tags are recovered
(Brownie et al. 1985)

Estimation Motivation

i	No tagged in year i	Expected (Observed) Recoveries j=1	2
1	N_1	$N_1 f_1$ (R_{11})	$N_1 S_1 f_2$(R_{12})
2	N_2		$N_2 f_2$ (R_{22})

$$N_1 f_1 \approx R_{11} \qquad N_1 S_1 f_2 \approx R_{12}$$

$$\hat{f}_1 = R_{11} / N_1 \qquad N_2 f_2 \approx R_{22}$$

$$\hat{f}_2 = R_{22} / N_2$$

$$\hat{S}_1 = \frac{R_{12} / N_1}{R_{22} / N_2}$$

Tagging Likelihood

The likelihood for tag return models is based on products of independent multinomial distributions.

Not presented here but the likelihoods are given in many of the papers cited later.

Assumptions of the Brownie Models

- **Sample is representative of population**
- **No tag loss**
- **No tag-induced mortality**
- **Year of tag recovery is correctly tabulated**
- **Fates of tagged fish are independent**
- **Homogeneous survival and recovery rates within each age class and year**

Lake Trout Example Brownie Models

- Tag-return study on lake trout originally analyzed by Youngs in early 70's and then reported in detail by Youngs and Robson (1975).
- Study was in Cayuga Lake in New York. This led to modeling work by Robson and then the Brownie Models soon afterwards.
- Hoenig et al. (1998ab) also used this data to illustrate aspects of their instantaneous rates formulation.

MARK Demonstration Last Time

- Use Brownie et al. Recoveries Option
- Input File
- PIM Structure
- Lake Trout Example 5 years
- I went through the summary Slides and then showed you how to do it in MARK. You will have a homework on this material.

5-Year Data Set MARK Example

Table 3. Recapture data from a tagging study of lake trout (*S. namaycush*) described by Youngs and Robson (1975).

Year	No. tagged	No. recaptured in year				
		1	2	3	4	5
1960	1048	72	44	8	9	4
1961	844	—	74	30	20	7
1962	989	—	—	54	48	13
1963	971	—	—	—	74	24
1964	863	—	—	—	—	48

Lake Trout Example

Input File

```
/* Lake Trout 5 years only encounter
occasions=5, groups=1 */
recovery matrix group=1;
72 44 08 09 04;
74 30 20 07;
54 48 13;
74 24;
48;
1048 844 989 971 863;
```

5-Year Data Set MARK Example

MARK OUTPUT

Model	AICc	ΔAICc	AIC Weight	#Par
{S(.) f(t) PIM	4214.653	0.00	0.697	6
{S(t) f(t) PIM}	4216.366	1.71	0.296	9
{S(t) f(.) PIM}	4224.121	9.47	0.006	5
{S(.) f(.) PIM}	4228.690	14.04	0.001	2

5-Year Data Set MARK Example

The "best" Model Output

MARK OUTPUT MODEL 2 {S(.), f(t)}

Parameter	Estimate	Standard Error	Lower-Upper
Survival Rate			
1:S	0.5009476	0.0272329	0.44 -0.55
Recovery Rate			
2:f	0.0680325	0.0077309	0.054-0.084
3:f	0.0866865	0.0079505	0.072-0.104
4:f	0.0552708	0.0059030	0.044-0.068
5:f	0.0831900	0.0072744	0.070-0.099
6:f	0.0542069	0.0059756	0.044-0.067

Multiple Groups

MARK- can extend the analyses to multiple fixed groups (such as males and females.

Multiple Age Groups Models

MARK- can run multiple age class models. More complex as animals change ages over time.

Components of Mortality (Fishing and Natural Mortality)

Pollock et al. (1991)

Hoenig et al. (1998a and 1998b)

Hearn et al. (1998)

Many recent papers

We need to know tag shedding and tag induced mortality (ϕ) plus tag reporting rate(λ) to proceed

Estimation of Tag Shedding and Tag Induced Mortality (ϕ)

Double tagging

Study tag shedding by double tagging some animals. Fraction of animals retaining both tags versus only one tag provides information on tag loss rate of each tag type

assumes tags are lost independently.

Estimation of Tag Shedding and Tag Induced Mortality (ϕ)

Cage studies

Can be used for 2 purposes:

- assess immediate tag loss
- assess short term tagging & handling mortality

limitations are

- whether the fish are treated the same in the tanks as in the wild
- short term and small numbers usually involved

Reporting Rate (λ) Estimation Methods

Commercial and Recreational Fisheries

High reward tags

Twice a year tagging method (Hearn et al. 1998)

Creel surveys or Port samples

Commercial Fisheries Only

Planted tags

Observers plus catch

High reward tagging method

method involves:

- releasing batch of high reward tagged fish
- releasing batch of regular tagged fish
- computing the ratio of return rates of the two groups

$$\hat{\lambda} = \frac{regular \quad tag \quad return \quad rate}{reward \quad tag \quad return \quad rate}$$

assumptions are:

- all reward tags reported
- anglers behavior does not change

Note-Also used on wildlife species!!!!

All reward tags reported

Important that reward be high enough to ensure this assumption true. Nichols et al. (1991) variable reward study on mallards.$100 required. Taylor et al. (2006) study on snook in Florida found around $75 needed.

Reward needs to be on the tag.

Program needs to be well advertised.

Anglers behavior does not change

The reward tagging program may cause the reporting rate of regular tags to change. We recommend that if reward tagging cannot be throughout the study that one should assume different λ **’s for when reward tags are and are not present.**

Where Are We?

Have S from Brownie model; and given an estimate of ϕ and of λ, we can estimate u, the exploitation rate by:

$$\hat{u} = \hat{f} / \hat{\phi}\hat{\lambda}$$

$$Note - \text{Often assume } \varphi = 1.$$

However, the parameters would be better represented in the standard instantaneous rates formulation used in fisheries (Ricker 1975)

Instantaneous Rates Formulation

S -finite annual survival rate

f - finite annual recovery rate

u - finite annual exploitation rate

F -instantaneous rate of fishing mortality

M -instantaneous rate of natural mortality

Z -instantaneous rate of total mortality

λ –reporting rate of tags

Instantaneous Rates Formulation

Survival

First, in the additive model

$$S = \exp(-F-M) = \exp(-Z)$$

note S is invariant to timing of the fishery.

Instantaneous Rates Formulation

Exploitation

Continuous Fishery (Whole Year)

$$u = [1 - \exp(-F-M)][F/(F+M)]$$

Pulse Fishery (Very Short)

$$u = [1 - \exp(-F)]$$

Estimates for the Youngs 5 Yr Lake Trout Example Continuous Fishery (λ=0.2)

Parameter	Estimate	SE
F_1	0.58	0.08
F_2	0.69	0.07
F_3	0.42	0.05
F_4	0.65	0.07
F_5	0.40	0.07
M	0.11	0.04

Additional Assumptions for Instantaneous Rates Formulation to Separate Sources of Mortality

- **Fishing and natural mortality are additive**
- **Timing of fishing and natural mortality is known**
- **M is assumed to be constant over time**
- **The reporting rate (λ) is known or, more realistically, can be estimated accurately**

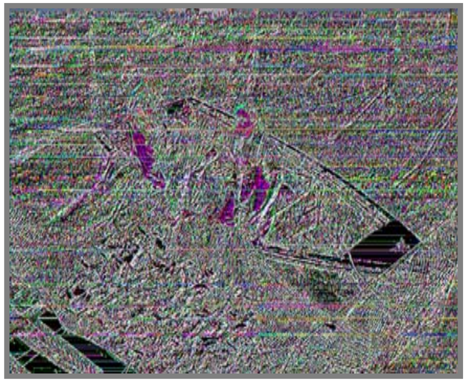
Striped Bass Research, Many co-workers. Honghua Jiang was my Ph D Student

Striped Bass

Morone saxatilis

Striped bass tagging program

Striped Bass an important anadromous fish on the east coast



Tag release and recapture data are exchanged between USFWS & other agencies

As of July 2004, 426,576 striped bass tagged; 75,930 reported recoveries

We will extend the tagging models to allow age dependence and catch and release fishing.

We will use a subset of the tag return data collected in Maryland.

Extension to Allow Age and Year Dependent Models in F and M

- Earlier we have assumed that we have only adult fish tagged.
- Now we generalize to the situation where a range of ages (sizes) are tagged.
- Therefore fishing mortality may be age and time dependent.
- Natural mortality which we assumed constant before may have some degree of age and time dependence although our ability to allow for this is limited.

Extension to Allow Age and Year Dependent Models in F and M

Various models for the fishing mortality process are possible:

1. Full age and year dependence in Fishing mortalities. Theoretically one could do this but then there are many fishing mortality parameters.

2. Multiplicative (Separable) model ($F_{ya} = F_y \, Sel_a$) using selectivity to achieve some parsimony. This is our primary focus.

Extension to Allow Age and Year Dependent Models in F and M

The separable model $F_{ya} = F_y \, Sel_a$

- F_y , these are the fishing mortalities for the fish that are fully recruited to the fishery.

- $Sel_{a,}$ these are the selectivities and they depend on age but not on year. We typically assume that above a certain age (6 for striped bass) the selectivity is one

Extension to Allow Age and Year Dependent Models in F and M

Natural Mortality

Before we assumed constant but now we allow some variation due to age and calendar year. This will become clear in the examples which follow later.

Reporting Rate

Before we usually assumed constant over time and now we assume constant over age and year although if we had good enough special studies this is not necessary.

Extension to Allow Age and Year Dependent Models in F and M

Design Issues

There are trade offs involved in which ages should be tagged.

Younger fish may be easier to tag, and easier to age without substantial error.

Tagging a wide range of age classes gives better precision and allows a wider class of models to be fitted.

Extension to Allow Some Catch and Release Fishing.

- Motivated by Tagging Studies on Striped Bass Fisheries in VA and MD.
- We develop an alternative approach to Smith et al. (2000) CJFAS 57: 886-897.
- Tags are clipped and returned after first capture whether it is of a kept fish or a fish to be released. Thus there are two types of tag returns: kept or released .
- The implication of this is that we can think of the catch and release fishing as another force of mortality on the tags and use a generalization of the Hoenig et al. (1998) instantaneous rates models.

Some Catch and Release Fishing. Forces of Mortality on the Tags.

F_i is the force of fishing mortality

F_i^1 is the force of catch and release mortality on the tags

M is force of natural mortality

$$S_{i,\,tags} = \exp\{-(F_i + F_i^1 + M)\}$$

$$Z_{i,\,tags} = F_i + F_i^1 + M$$

The tag exploitation rate for kept fish is:

$$u_{i,\,tags}(kept) = [1-\exp\{-(F_i + F_i^1 + M)\}][(F_i)/(F_i + F_i^1 + M)]$$

The tag exploitation rate for released fish is

$$u_{i,\,tags}(rel) = [1-\exp\{-(F_i + F_i^1 + M)\}][(F_i^1)/(F_i + F_i^1 + M)]$$

Some Catch and Release Fishing. Likelihood Basis

Note that Normal tag-return data has just one return for each cohort in each year. Now we have the return separately for the kept and released fish.

This is basis of our product multinomial likelihood on the two types of returns of the tags.

We can get information on the mortality of the fish as derived parameters.

Some Catch and Release Fishing. Derived Parameters

Tag Survival and Mortality

$S_{i,\,tags} = \exp\{-(F_i + F_i^1 + M)\}$

$Z_{i,\,tags} = F_i + F_i^1 + M$

Fish Survival and Total Mortality (No Hooking Mortality)

$S_{i,\,fish} = \exp\{-(F_i + M)\}$

$Z_{i,\,fish} = F_i + M$

Fish Survival and Total Mortality (Hooking Mortality)

$S_{i,\,fish} = \exp\{-(F_i + M + \delta F_i^1)\}$

$Z_{i,\,fish} = F_i + M + \delta F_i^1$

where δ is the probability of hooking mortality.

MD Striped Bass Tag-Return Analysis

- Large MD Striped Bass Data Set based on fish aged 3 and above over the years 1991-2003.

- We did not attempt to estimate $\phi\lambda$ internally and instead assumed that $\phi\lambda = 0.43$. This was based on earlier reward tagging and other studies.

- We assumed an honest assignment by the angler of ‘kept’ or ‘released’ for the tagged fish and that $\phi\lambda$ was the same for the kept and released fish. **These are very big assumptions which we will return to later.**

- Age independent (age 6+) and dependent (all ages) analyses

MD Striped Bass Tag-Return Parameter Estimates

Age-Independent Analyses (Age 6+ Only)

Based on AIC

Two Period M Model

Table 3.2. Parameter estimates with standard errors in parentheses from fitting two-period M models (a) $(F_y, F'_y, M_{91-99}, M_{00-03})$ and (b) $(F_{91-94}, F_{95-03}, F'_y, M_{91-99}, M_{00-03})$ to adult (age 6+ years) striped bass data.

Parameter	(a)	(b)
F(91)	0.129 (0.019)	0.163 (0.009)
F(92)	0.175 (0.018)	0.163 (0.009)
F(93)	0.175 (0.016)	0.163 (0.009)
F(94)	0.159 (0.014)	0.163 (0.009)
F(95)	0.236 (0.017)	0.241 (0.009)
F(96)	0.206 (0.015)	0.241 (0.009)
F(97)	0.271 (0.021)	0.241 (0.009)
F(98)	0.297 (0.025)	0.241 (0.009)
F(99)	0.275 (0.026)	0.241 (0.009)
F(00)	0.213 (0.019)	0.241 (0.009)
F(01)	0.269 (0.026)	0.241 (0.009)
F(02)	0.204 (0.022)	0.241 (0.009)
F(03)	0.182 (0.037)	0.241 (0.009)
F′(91)	0.124 (0.019)	0.125 (0.019)
F′(92)	0.170 (0.018)	0.170 (0.018)
F′(93)	0.111 (0.012)	0.112 (0.012)
F′(94)	0.123 (0.012)	0.122 (0.012)
F′(95)	0.103 (0.011)	0.106 (0.011)
F′(96)	0.121 (0.012)	0.119 (0.011)
F′(97)	0.082 (0.011)	0.077 (0.010)
F′(98)	0.081 (0.012)	0.078 (0.012)
F′(99)	0.070 (0.012)	0.065 (0.011)
F′(00)	0.122 (0.014)	0.119 (0.013)
F′(01)	0.092 (0.013)	0.095 (0.013)
F′(02)	0.065 (0.010)	0.078 (0.011)
F′(03)	0.040 (0.013)	0.048 (0.015)
M_{91-99}	0.166 (0.009)	0.160 (0.009)
M_{00-03}	0.635 (0.058)	0.713 (0.038)

Change Adult (6+)

M=0.16 to 0.71

MD Striped Bass Tag-Return Parameter Estimates

Age-Dependent Analyses (Age 3+)

Two period and two age group M Model

Table 2. Parameter estimates with standard errors in parentheses from fitting the catch- and-release tag return models allowing age- and year-specific natural mortality and a selectivity model for fishing mortality to the Maryland striped bass data. Model (a) allows fishing mortality to vary by year $(F_y, F'_y, M_{Y\_91-98}, M_{Y\_99-03,} M_{A\_91-98}, M_{A\_99-03}, \ Sel_3, Sel_4, Sel_5)$ and Model (b) allows fishing mortality to be constant before and after 1995, when fishing regulations were liberalized $(F_{91-94}, F_{95-03}, F'_y, M_{Y\_91-98}, M_{Y\_99-03}, M_{A\_91-98}, M_{A\_99-03}, \ Sel_3, Sel_4, Sel_5)$. Reporting rates for both harvested and released fish were fixed at 0.43.

Parameter	(a)	(b)
F(91)	0.106 (0.014)	0.154 (0.007)
F(92)	0.163 (0.014)	0.154 (0.007)
F(93)	0.152 (0.011)	0.154 (0.007)
F(94)	0.162 (0.011)	0.154 (0.007)
F(95)	0.226 (0.013)	0.235 (0.007)
F(96)	0.190 (0.012)	0.235 (0.007)
F(97)	0.233 (0.015)	0.235 (0.007)
F(98)	0.244 (0.017)	0.235 (0.007)
F(99)	0.254 (0.019)	0.235 (0.007)
F(00)	0.260 (0.018)	0.235 (0.007)
F(01)	0.293 (0.022)	0.235 (0.007)
F(02)	0.230 (0.018)	0.235 (0.007)
F(03)	0.140 (0.022)	0.235 (0.007)
F'(91)	0.125 (0.016)	0.124 (0.016)
F'(92)	0.156 (0.013)	0.160 (0.014)
F'(93)	0.105 (0.009)	0.109 (0.009)
F'(94)	0.132 (0.010)	0.131 (0.010)
F'(95)	0.106 (0.009)	0.117 (0.009)
F'(96)	0.116 (0.009)	0.125 (0.010)
F'(97)	0.092 (0.009)	0.099 (0.009)
F'(98)	0.094 (0.010)	0.095 (0.010)
F'(99)	0.074 (0.010)	0.082 (0.010)
F'(00)	0.169 (0.014)	0.168 (0.014)
F'(01)	0.126 (0.013)	0.123 (0.012)
F'(02)	0.081 (0.009)	0.092 (0.009)
F'(03)	0.056 (0.012)	0.050 (0.011)
Sel3	0.663 (0.061)	0.627 (0.058)
Sel4	0.730 (0.044)	0.739 (0.044)
Sel5	0.967 (0.047)	1.000 (0.048)
MY_91-98	0.378 (0.021)	0.399 (0.021)
MY_99-03	0.836 (0.063)	0.858 (0.056)
MA_91-98	0.145 (0.009)	0.150 (0.009)
MA_99-03	0.673 (0.038)	0.645 (0.028)

Time Change

M = 0.40 to 0.85 Young (3-5)

M = 0.15 to 0.65 Adult (6+)

Key Assumptions

- Assumed that $\phi\lambda$ was the same for the kept and released fish. Also assumed that kept and released tagged fish were categorized accurately by the angler capturing the fish. Very big assumptions that really need more evaluation. However, the previous methods also depend on these assumptions as well

- Difficult to use reward tagging as we don't know for sure if fish were released or kept when the reward tag is reported. We only have what they tell us.

- What we need to help us is independent information on the relative rates of anglers keeping and releasing fish.One possible way to get this would be to ask a question on the Federal MRFSS access point survey or other angler surveys.

Conclusions and Future Work.

• Catch and Release now very common in fisheries and greatly complicates tag-return models. We have a useful framework but have much more to do.

• Need to obtain more information on the mortality of the released fish (hooking mortality).

• Age-dependence extension to model is important for striped bass fisheries. Allowing M to vary by age or year is very important.

•The results we have obtained are potentially very important for the management of striped bass and the stock assessments.

Combining Telemetry and Tag-Return Methods

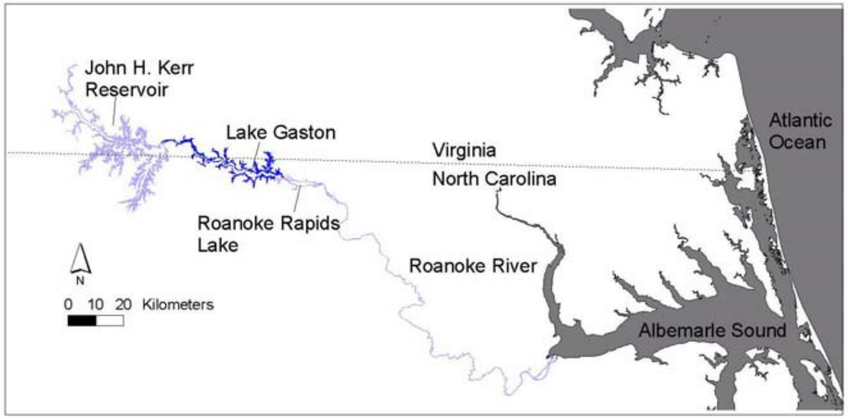
- Telemetry Only Example First
- Tag-return and Telemetry

  Simulations

TAFS Papers 2001, 2004

Telemetry Example: Striped Bass in Lake Gaston, North Carolina

- Total Mortality Z
- Fishing (F) and natural mortality(M)
- Hightower et al.(2001) TAFS



Field Methods

- Sonic telemetry
- Monthly searches of Lake Gaston, January 1997-December 1998
- Analysis limited to fish alive and in lake one month after surgery

Interpretation of Telemetry Data

- If located:
  - assumed to be alive if movement was detectable between searches
  - assumed to be natural death if relocated at same site on consecutive searches
- If not located:
  - Present but missed?
  - Harvested?
  - Transmitter failure?
  - Migrated downstream through turbines?

Modeling Approach

- Model described number of relocated fish on each occasion
- Decreases in relocated live fish provides indirect information about F
- Relocations of dead fish provide direct information about M

Model Structure

- Model describes first relocation for each telemetered fish in release R_i and We Build Likelihood in SURVIV based on expectations like those below
- Expected live relocations at time i+1

$=R_i \exp(-F_i-M_i)\ p_{i+1}$

- Expected live relocations at time i+2

$=R_i \exp(-F_i-M_i)\ (1-p_{i+1}) \exp(-F_{i+1}-M_{i+1})\ p_{i+2}$

- Expected natural death relocations at time i+1

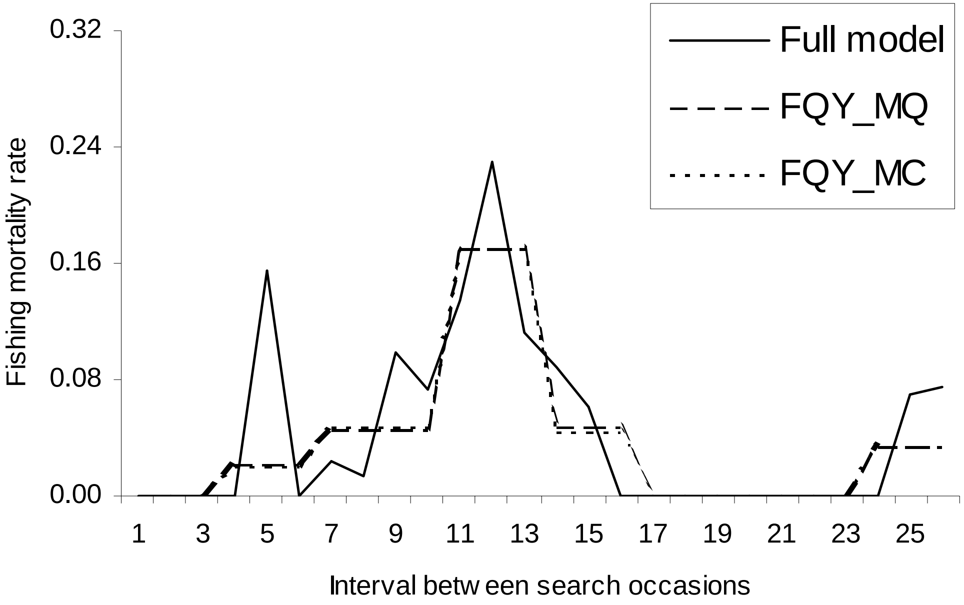
$=R_i\ [M_i\ /\ (M_i + F_i\ )]\exp(-F_i-M_i)\ p_{i+1}$

Model Assumptions

- All animals behave independently with respect to relocation and survival probabilities
- All telemetered fish have an equal probability of surviving to the next occasion
- All telemetered fish have an equal relocation probability (whether alive or dead)
- Probability of transmitter failure or shedding is negligible
- Fish leaving the study area were harvested or migrated downstream through the turbines
- Fish located repeatedly at the same site died of natural or hooking mortality
- Natural mortality occurred immediately prior to the first relocation at final site occupied by that fish

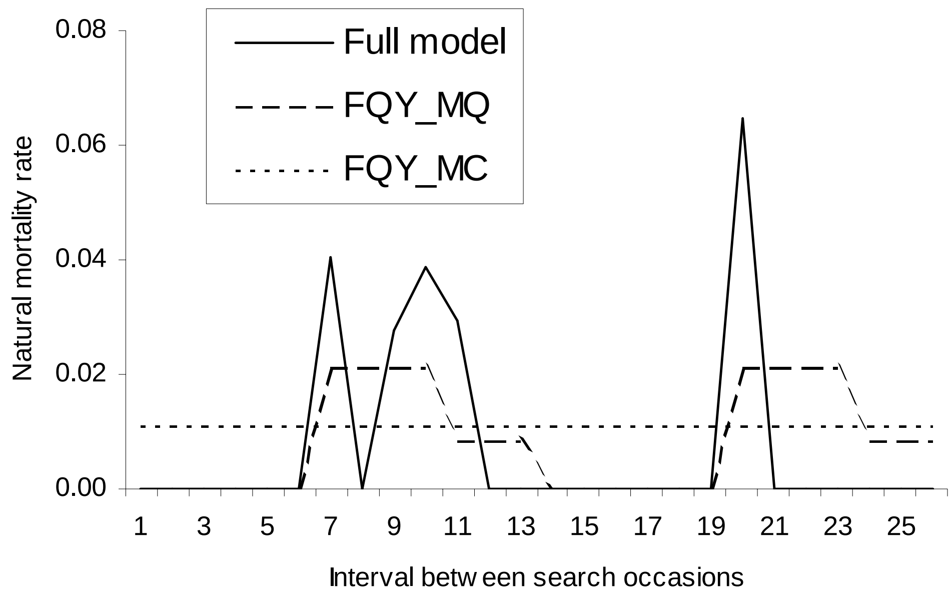
Fishing Mortality Rates

- 51 telemetered fish over two years
- 30 harvested and 6 natural (non-harvest) mortalities a 2 migrated downstream
- Annual Fs 0.3-0.7
- Fs highly seasonal
- Relative SEs 18-54%
- F includes any undetected emigration



Natural Mortality Rates

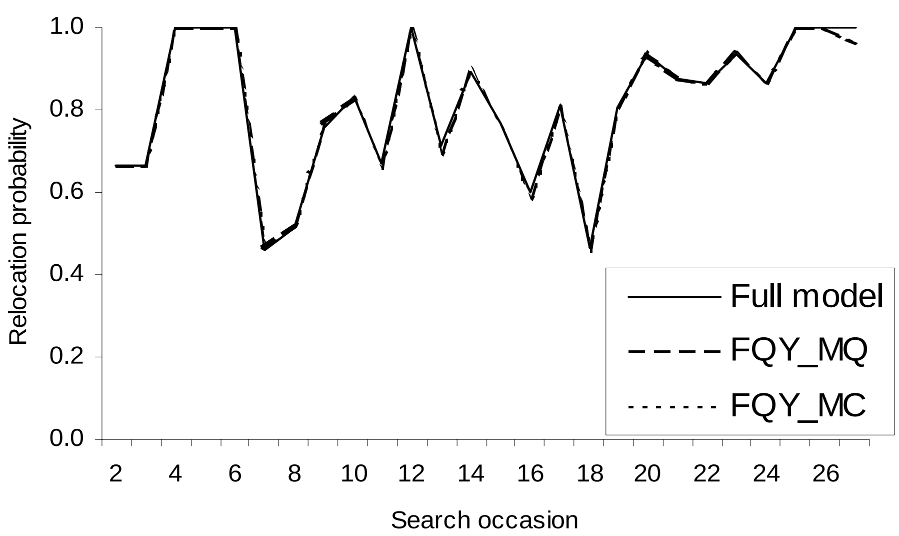
- Annual M=0.14
- Evidence of seasonality
- Relative SEs 24-33%
- M includes hooking mortality (catch-and-release)



Precision for F's and M similar to conventional tagging studies with large sample sizes!!!

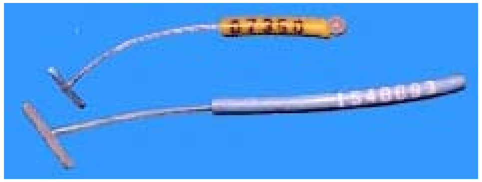
Relocation Probabilities

- Estimated probs highly variable with low values in year 1
- Estimates insensitive to assumptions about M and F
- When designing studies try and ensure relocation probability is near 1



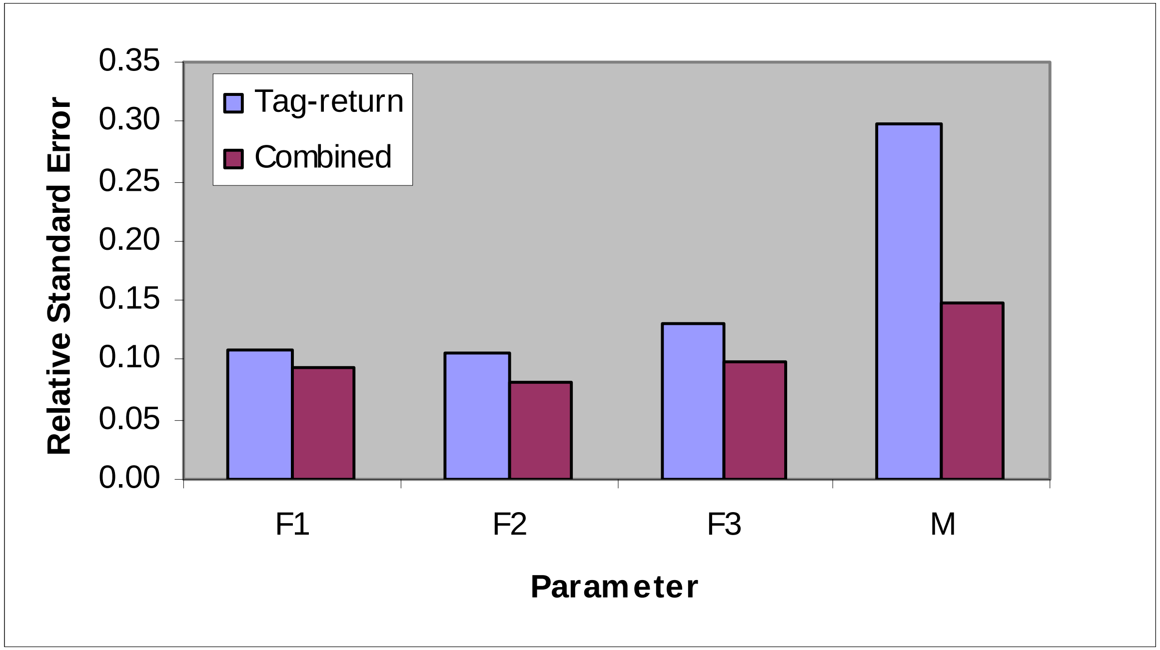
Combining Telemetry and Tag-Return Methods

- **We write down a combined likelihood and calculate MLE's as for the two individual approaches**
- **Information about tag reporting rate not required**
- **Our simulations show that it blends the strengths of each individual method**
  - **Many (500/yr?) conventional tags**
    - **Less informative**
    - **Inexpensive (<$1)**
    - **Results affected by reporting rate**
  - **Few (50/yr?) transmitters**
    - **More informative**
    - **Expensive (~$250/tag)**
    - **Unaffected by reporting rate**
    - **Labor intensive**



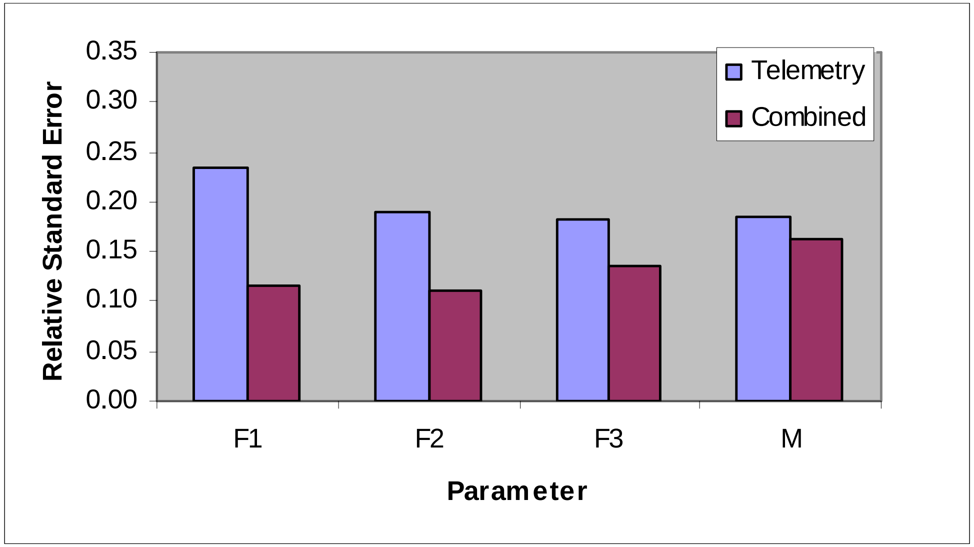
Combining Telemetry and Tag-Return Methods

- If reporting rate 100% (or known):
  - Moderately better estimates of F from combined method than tag-return method
  - Substantially better estimate of M than tag-return



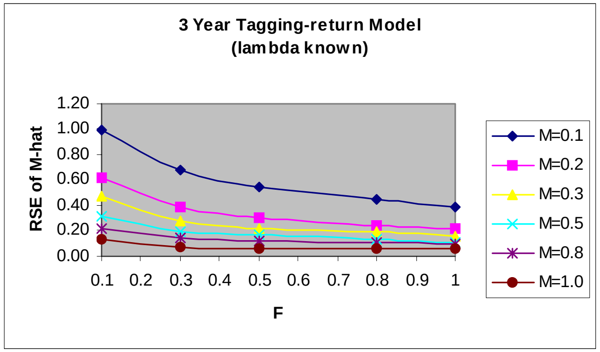
Combining Telemetry and Tag-Return Methods

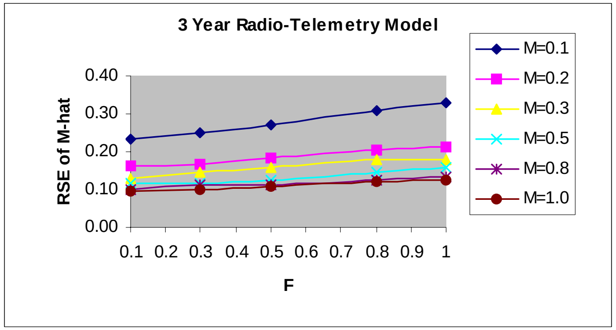
- When reporting rate is unknown:
  - Tag-return model cannot be used
  - Combined model provides substantially better estimates of F than telemetry alone
  - Slightly better estimate of M than telemetry alone

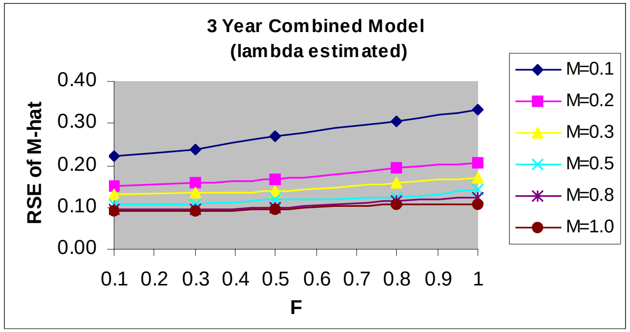


Combining Telemetry and Tag-Return Methods

- F affects model performance
- To estimate M:
  - Tag-return model works best when F high
  - Telemetry model works best when F is low
  - Combined model also works best when F is low

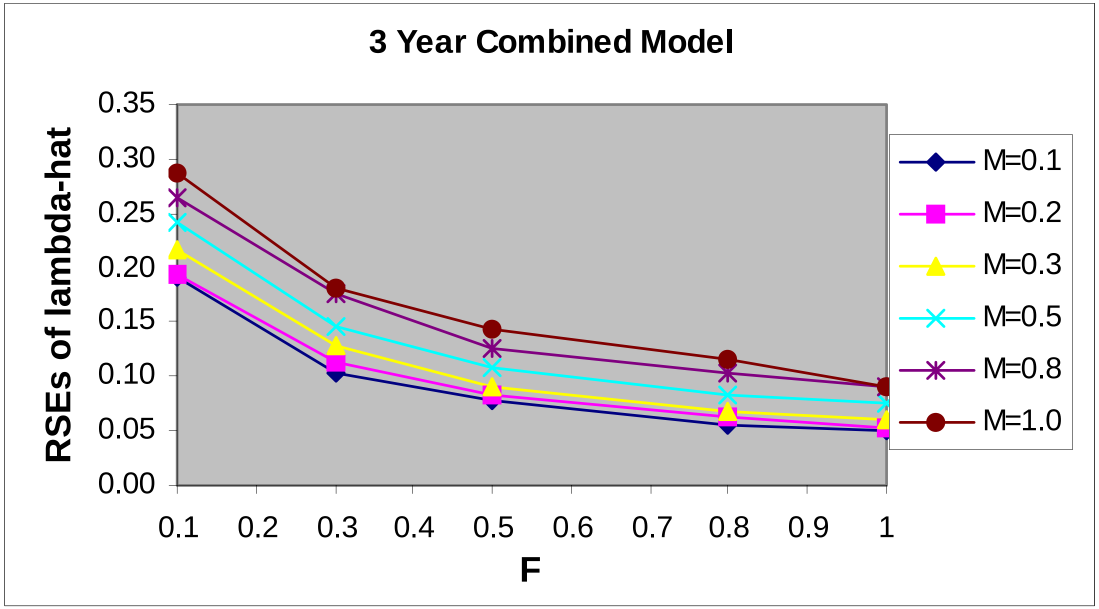






Combining Telemetry and Tag-Return Methods

- Tag-reporting rate can be estimated with combined approach
- Precision of estimate increases as F increases, M decreases



Combining Telemetry and Tag-Return Methods

- **Telemetry Methods Useful for:**
  - **Estimating Z and individual rates (F, M)**
  - **Determining timing, location, and sources of mortality due to different fisheries**
- **Tag-Return Methods Useful for:**

  -Estimate Z without reporting rate

  -Estimate individual rates (F, M) if reporting rate available (High Rewards, Observers, Planted Tags)
- **Combined Telemetry and Tag-Return Method Blends Strengths of Conventional Tag-Return and Telemetry Approaches**

Reminder: Mathematical and Statistical Modeling in Fisheries Stock Assessment:

Field based estimates of parameters or "guesses"

↓

Build Fisheries Population Model

↓

Validate & Refine Fisheries Model ← Age & time dependent F&M from tag-return data

↓

Predict Fishing Impacts on stock for different values of F & M

Lecture Summary

• Instantaneous rates tag-return models are a very useful source of additional information on fishing & natural mortality to input to fisheries stock assessment models.

• Age-dependent extensions to tag-return models are very important. There are both design and analysis issues to consider.

• Catch and release fishing needs to be allowed for in the models.

• Designs combining telemetry tags & regular tags gives more robust and precise estimates! Nate Bacheler recent field test on a red drum fishery in NC.

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