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ESTIMATING AND INCORPORATING PARAMETER UNCERTAINTY WHEN RETURNS OF ATLANTIC SALMON ARE DERIVED FROM ANGLING CATCHES

by

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ABSTRACT

A non-parametric method, the "bootstrap", was used to estimate the error of several parameters used to estimate returns of Atlantic salmon using angling catches and derived exploitation rates. The variance of the estimated returns was calculated using a simulation technique which facilitated the incorporation of the uncertainty of the various parameters. The data from the 1990 assessment of Atlantic salmon in the Margaree River were used to compare the results of the simulation technique with the previously published estimated returns. The simulation technique provided confidence intervals for the estimates which were narrower than the previously published ranges of returns. The "bootstrap" technique and simulation are useful methods for estimating and incorporating uncertainty into the estimation of returns of Atlantic salmon but do not excuse inappropriate data. There must still be some form of rationalization for the assumption that the data are representative of the population.

RESUME

Les captures et les taux d'exploitation dans la pêche sportive du Saumon atlantique servent à l'estimation des retours aux rivières. Une méthode non-paramétrique, le "bootstrap", a servi à l'estimation des erreurs associés aux paramètres des captures et des taux d'exploitation. L'incertitude dans l'estimation des retours a été calculée avec une technique de simulation qui permettait d'incorporer les erreurs associées aux paramètres individuels. L'évaluation des retours de Saumon atlantique à la rivière Margaree de 1990 a été reprise afin de comparer les résultats de ces techniques avec ceux de l'analyse prise auparavant. La technique de simulation généra des intervalles de confiance beaucoup plus étroits que les étendues des estimés des retours calculées auparavant. La technique du "bootstrap" et la simulation sont des méthodes qui permettent d'intégrer l'incertitude dans les estimations des retours du Saumon atlantique. Il est cependant obligatoire d'apporter réfléxion sur la validité des paramètres utilisés dans la formule des retours .

INTRODUCTION

In many Atlantic salmon stock assessments, returns to the river are estimated using angling catches and derived or assumed exploitation rates. The formula is:

(1) Returns = Angling Catch / Exploitation Rate

Angling catches are often reported as a single number (see, for example, Claytor and Chaput 1988, Courtenay et al. 1991). Some angling catches, with associated parametric estimates of the variance, have been estimated using creel surveys (Chaput and Jones 1991). The exploitation rate (ER) is often given as a fixed value or as a range of possible values (most often just the extremes of the range are used) (see, for example Chaput and Jones 1991, Courtenay et al. 1991).

The estimates of both angling catch and ER are subject to error. Some recent assessments have attempted to estimate and incorporate some of this error into the estimates of returns but have been unsuccessful for the following reasons:

1 - parametric estimation of the error was not possible because the data were not suitable or the analytical techniques for estimating error were unfamiliar,

2 - ignorance of the analytical techniques for carrying the error estimates through the returns formula.

A good example of this particular problem, estimation of error and incorporation of the error in the returns formula, was the 1990 stock assessment of Atlantic salmon from the Margaree River (Chaput and Jones 1991). A marking program had been instigated to estimate the exploitation rate in the recreational fishery. The recreational catch had been quantified for part of the river. Unfortunately, the errors were only estimated for some of the parameters and were not carried through into the returns formula. The returns for 1SW salmon in 1990 were reported to have been somewhere between 123 and 2,696 whereas MSW returns were somewhere between 2447 and 27,181 (Chaput and Jones 1991, Table 11). These are ranges obtained using the lowest angling catch value divided by the highest exploitation rate estimate (results in the low estimate of returns) and the highest angling catch value divided by the lowest exploitation rate estimate (results in the high estimate of returns). They are not confidence intervals.

This document describes the application of a non-parametric method, the "bootstrap", for estimating the error of several of the parameters used in the estimation of catches and exploitation rates. It also provides an example of a simulation technique (also called 'Monte Carlo') for integrating both parametric and non-parametric estimates of variance into the estimate of returns. The technique was applied to the data from the 1990 stock assessment and the results are compared to those previously presented.

MATERIALS AND METHODS

The "Bootstrap" method involves drawing at random (with replacement) from the observed data and calculating the statistic of interest (Efron and Gong 1983). A large number of these bootstrap samples are drawn and from these the distribution of the statistic can be described, thus providing an estimate of the variance of the statistic or estimator of interest as well as non-parametric confidence intervals (Efron and Gong 1983). This technique was applied to the 1990 assessment data for Atlantic salmon from the Margaree River. The data used for estimating the parameters of equation (1), the method used for estimating the uncertainty, and the relationship between parameters are given in Table 1.

The uncertainty in the parameters, i.e. angling catch and exploitation rate, was incorporated in the returns equation in the following manner:

1. Select a value for each of the parameters, using either the known distribution information or a "bootstrap" estimate of the parameter.

2. Calculate the returns using the value for each of the parameters from step 1.

3. Repeat steps 1 & 2 a large number of times. In this analysis, 10000 replicates were generated.

4. From the distribution of the replicates, determine the expected value for the returns (use either mean or median) and the confidence limits around the expected value.

A listing of the simulation program is provided in Appendix A.

The 1990 Margaree River assessment data were used. The methods are similar to those described by Chaput and Jones (1991) with the addition of variability estimates for several of the components when the data were appropriate. Some additions and changes to the 1990 method include:

1 - Creel catch estimates for summer and fall seasons from index pools were expanded to total river catch using the logbook catch proportion data for summer and fall separately. Chaput and Jones (1991) used the ratio of effort at index pools to total effort based on angler counts at 32 pools to weight the creel catch for the summer and tag recapture proportions to weight the fall creel catches. Fall creel catches were also weighted using the tag recaptures and bootstrap estimates of the variability of the tag recapture proportions were included.

2 - In the 1990 assessment, the estimates of tag retention rate were based on the mean number of days to recapture multiplied by the tag loss rate determined experimentally. This analysis used the median, rather than the mean, days to recapture because the distribution of recaptures was skewed towards shorter recapture times (for ex. the median days to recapture for 1SW was 4.0 whereas the mean days to recapture was 10.9).

RESULTS

The distributions and some statistical descriptors of several of the parameters of interest are presented in Fig. 1 and Table 2. The distributions of most of the parameters were skewed (Fig. 1). The median and the 5 and 95 percentiles stabilised after about 2000 simulations although more complex parameters, such as the returns, took as many as 4000 to stabilize (Table 2).

The estimates of catch proportions, catch, and returns based on the 1990 assessment methods and the present logbook data weighting methods are summarized in Table 3. The logbook proportions for fall MSW catch from index pools were identical to the proportion based on tag returns (Table 3). The proportion of fall 1SW catch from index pools based on logbook data was higher than that based on tags but the distributions were very wide for both.

The estimates of returns for summer, fall, and combined, using the median of the distributions, are similar to the estimates from the original assessment but the confidence intervals are much narrower than the ranges provided in the 1990 assessment (Table 4).

DISCUSSION

The "bootstrap" method is a non-parametric technique which can be used to quantify the standard error of estimators other than the mean, for example the median (Efron and Gong 1983). It requires that the data set represent a **random** sample from an unknown probability distribution.

> "One thing is obvious about the bootstrap procedure: it can be applied to any statistic, simple or complicated..." (Efron and Gong 1983).

The technique was used to estimate the uncertainty in some of the parameters of the returns function including:
- catch at index pools as a proportion of catch at all pools based on the logbook data,
- tag returns from index pools and other pools, and
- median days to recapture in the angling fishery.

The appropriateness of the individual parameters in the returns formula must be considered. The question is not whether the "bootstrap" technique should be used to obtain an estimate of variance but whether the estimator is valid. In this analysis, for example, logbook data were used to expand creel catch estimates from selected pools to total river catch. Was this appropriate? The assumption was that the catches at index pools relative to catches from other pools by the logbook anglers was similar to the catch distribution of the angling population. The catch of the logbook anglers is a sample of the catch of the angling population but not necessarily a random sample because only a proportion of the logbooks mailed out every spring are returned. The recaptures of tagged fish represented another sample of the catch distribution by the angling population. A comparison of the proportion estimates from these two samples gives some support to the assumption that the logbook data are reprensentative of the angling population. The estimates of MSW catch proportions from logbooks were nearly identical to those obtained using the index pool distribution of tag recaptures. The similarity was less for the 1SW catch proportions although the confidence intervals of each overlapped the estimates. The logbook data for 1990 were more useful than the tagging data because:
- the tag proportion data were not available for summer 1990 catches;
- the tagging data sets were of smaller sample size than the logbook data sets; and
- the tag reporting rates may not have been similar for local anglers, other resident (provincial) anglers and non-resident anglers.

I have additional confidence in the representativeness of the logbook data because individuals returning logbooks include locals residents of the Margaree area, residents of Cape Breton, residents of Nova Scotia and nonresidents from Canada and the U.S.A.

Estimating the uncertainty in the estimated returns by Monte Carlo simulation eliminated the confusion associated with providing ranges for the returns of 1SW and MSW salmon. The best estimates of returns were not different but the confidence intervals around the estimates were much narrower than the ranges presented in the 1990 assessment. The management advice forthcoming from the assessment would not have been different had the simulation technique been used for the original assessment. The criticisms received from user groups, regarding the uncertainty in the returns might have been less severe, however, had the confidence intervals been presented instead of the ranges.

In this analysis, as few as 500 replications were sufficient to obtain stable descriptors of the distribution of some parameters. For other parameters, 4000 replications were required. The number of replications to be performed should be determined by the behaviour of the parameter distributions in that the number of replications are sufficient when the median and the percentiles of interest stabilise (J. Hoenig, DFO, St. John's, NFLD, pers. comm.).

The "bootstrap" technique and simulation are useful methods because they allow the estimation of uncertainty for numerous parameters and the incorporation of this uncertainty into the final outcome. These techniques do not, however, excuse inappropriate data and the appropriateness of the data, i.e. a random sample from some albeit unknown probability distribution, must be considered.

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Table 1. Estimating returns of Atlantic salmon to the Margaree River for 1990. Boldtype indicates parameters which change value for every repetition.

$$\textbf{RETURNS (1SW; MSW)} = \frac{\textbf{CATCH (1SW; MSW)}}{\textbf{EXPLOITATION RATE (1SW; MSW)}}$$

$$\textbf{CATCH (1SW; MSW)} = \frac{\textbf{Est. Creel Catch from Index Pools (CCI)}}{\textbf{Proportion of Catch from Index Pools (PCI)}}$$

EXPLOITATION RATE (1SW; MSW) = Tags Recaptured / Tags Available

$$\textbf{Tags Recaptured} = \frac{\text{Tags Returned Voluntarily (1SW; MSW)}}{\textbf{Reporting Rate (RR)}}$$

Tags Available (1SW; MSW) = Tags Placed X **Proportion Retained(PR)**

Combining the various equations for 1990 gives:

$$\textbf{RETURNS (1SW; MSW)} = \frac{\textbf{CCI (Summer)}}{\textbf{ER (Summer) X PCI (Summer)}} + \frac{\textbf{CCI (Fall)} \text{ X Tags Placed X } \textbf{PR X RR}}{\textbf{PCI (Fall)} \text{ X Tags Recaptured}}$$

Solve **RETURNS** a large number of times to generate the distribution from which the Confidence Limits can be determined.

Table 1 (cont'd).

The data sources for the parameters in the 1990 simulation were:

```
CCI ---> 1SW summer assumed distribution N(135, 2601)
         1SW fall assumed distribution   N(33, 441)
         MSW summer assumed distribution N(192, 3844)
         MSW fall assumed distribution   N(533, 24180)

PCI ---> variability simulated using bootstrapping.
         Using logbooks:
         summer   N = 20   1SW prop.   27/40 =  0.68
                           MSW prop.   29/55 =  0.53
         fall     N = 22   1SW prop.   20/32 =  0.63
                           MSW prop.   20/50 =  0.40

         Using tag returns from angling fishery:
         fall              1SW prop.    7/13 =  0.54
                           MSW prop.    6/16 =  0.38
ER --->  Estimated for fall only.
         Assumed for summer, uniform distribution between
         0.206 and 0.379 for both 1SW and MSW.

RR --->  Bootstrap estimates of RR for 1990 estimated from:
```

$$RR = \frac{\dfrac{\text{Tag Recaptures from Index Pools (1SW + MSW)}}{\textbf{Creel Catch Estimate at Index Pools (1SW + MSW)}}}{\dfrac{\text{Tag Recaptures by Logbook Anglers (1SW + MSW)}}{\text{Logbook Catch (1SW + MSW)}}}$$

Nonbootstrap value = (13/566) / (3/82) = 0.62

Note: Logbook catch of 82 is updated value from that reported by Chaput and Jones (1991).

PR = 1 - (Tag Loss Rate) X **Median Days to Recapture**

In 1990, tag retention experiment was performed. Of 18 fish marked and held for 21 days, 5 tags had been shed. Tag loss rate (per day) = 0.013.

Recapture data is bootstrapped to obtain median days to recapture.

1SW Recaptures: N = 13, Range 1 to 25 days, Median = 4 days
MSW Recaptures: N = 17, Range 0 to 20 days, Median = 6 days

Note: In the 1990 assessment, mean days to recapture were used (Chaput and Jones 1991)
1SW: Mean = 10.9 days
MSW: Mean = 7.7 days

Table 2. **Median, 5 and 95 percentile estimates for several parameters of the 1990 returns formulation relative to the number of replications performed.**

Replication		GSPROPL	GSIND	GSRIVL	GSRETL	MFPROPL	MFIND	MFRIVL	MFRETL	GRETL	MRETL	RR	ERSUM	ERGF	ERMF
100	**median**	0.647	127	193	656	0.392	527	1352	9952	978	11443	0.642	0.300	0.181	0.131
250		0.652	129	192	658	0.396	546	1354	9868	980	11343	0.616	0.297	0.189	0.138
500		0.667	132	198	674	0.400	540	1338	9772	966	11260	0.627	0.297	0.187	0.135
1000		0.674	133	200	668	0.405	538	1315	9697	968	11138	0.627	0.297	0.187	0.135
2000		0.677	134	201	680	0.404	533	1318	9742	986	11173	0.631	0.294	0.187	0.135
3000		0.676	135	202	691	0.404	531	1312	9731	996	11148	0.633	0.295	0.186	0.134
4000		0.677	136	202	690	0.404	530	1307	9738	996	11142	0.634	0.294	0.186	0.134
5000		0.678	135	202	690	0.404	530	1305	9744	995	11140	0.634	0.294	0.186	0.134
6000		0.678	135	202	690	0.404	530	1305	9744	995	11140	0.634	0.294	0.186	0.134
10000		0.677	135	203	693	0.404	530	1307	9752	997	11144	0.634	0.294	0.186	0.134
100	**perc5**	0.475	41	64	203	0.280	270	623	7209	469	8706	0.449	0.214	0.093	0.069
250		0.467	41	61	201	0.270	258	628	7261	440	8265	0.431	0.212	0.092	0.068
500		0.447	40	60	207	0.267	283	638	7213	429	8262	0.435	0.213	0.095	0.071
1000		0.442	52	74	262	0.264	288	628	6984	466	8140	0.439	0.215	0.100	0.075
2000		0.443	53	75	260	0.267	275	620	6885	467	8065	0.430	0.215	0.101	0.073
3000		0.442	54	80	265	0.265	277	634	6905	467	8067	0.428	0.215	0.100	0.072
4000		0.443	53	77	260	0.267	275	627	6899	451	8077	0.428	0.215	0.100	0.072
5000		0.444	53	77	259	0.265	275	629	6896	442	8077	0.428	0.215	0.101	0.072
6000		0.444	53	77	259	0.265	275	629	6896	442	8077	0.428	0.215	0.101	0.072
10000		0.442	53	78	259	0.264	275	630	6901	443	8073	0.428	0.215	0.101	0.072
100	**perc95**	0.879	219	375	1364	0.529	764	2251	14807	1721	16545	1.234	0.371	0.258	0.192
250		0.866	216	405	1488	0.536	795	2547	14666	1901	16139	1.242	0.368	0.277	0.198
500		0.862	220	399	1473	0.550	787	2431	14992	1880	16719	1.199	0.369	0.276	0.196
1000		0.859	218	391	1425	0.556	779	2406	15093	1851	16334	1.144	0.370	0.270	0.194
2000		0.862	218	383	1396	0.563	790	2407	14937	1874	16443	1.159	0.370	0.274	0.197
3000		0.861	220	386	1433	0.563	792	2407	15059	1852	16559	1.164	0.370	0.275	0.198
4000		0.862	220	384	1440	0.563	793	2397	15033	1879	16585	1.166	0.370	0.277	0.198
5000		0.860	220	383	1442	0.564	792	2398	15046	1878	16599	1.161	0.370	0.276	0.198
6000		0.860	220	383	1442	0.564	792	2398	15046	1878	16599	1.161	0.370	0.276	0.198
10000		0.858	220	383	1443	0.563	792	2369	15069	1880	16606	1.161	0.370	0.277	0.198

GSPROPL = 1SW Summer Logbook Proportion from Index Pools
GSIND = 1SW summer, creel catch estimate from index pools
GSRIVL = 1SW summer catch from river using logbook proportion weighting
GSRETL = 1SW summer returns using logbook catch proportion weighting and assumed exploitation rate for summer (ERSUM)
MFPROPL = MSW Fall Logbook Proportion from Index Pools
MFIND = MSW fall, creel catch estimate from index pools
MFRIVL = MSW fall catch from river using logbook proportion weighting
MFRETL = MSW fall returns using logbook catch proportion
GRETL = 1SW summer returns using logbook catch proportions
MRETL = MSW returns for summer and fall, based on logbook proportions
RR = Reporting Rate estimate for tag recaptures
ERSUM = Exploitation rate for summer, assumed uniform between 0.206 and 0.379
ERGF = Exploitation rate for fall marked 1SW, derived
ERMF = Exploitation rate for fall marked MSW, derived

Table 3. Effects of using logbook data versus tag recapture data on the estimates of catch and returns of 1SW and MSW Atlantic salmon to the Margaree River, 1990.

			Using Logbooks	Using Tag Recap.
Proportion of catch at index pools				
1SW	summer	median	0.677	
		5%	0.442	
		95%	0.858	
	fall	median	0.647	0.538
		5%	0.455	0.308
		95%	0.815	0.769
MSW	summer	median	0.532	
		5%	0.313	
		95%	0.770	
	fall	median	0.404	0.375
		5%	0.264	0.188
		95%	0.563	0.563
Estimates of River Catch				
1SW	summer	median	203	
		5%	78	
		95%	383	
	fall	median	51	60
		5%	0	0
		95%	114	150
MSW	summer	median	359	
		5%	156	
		95%	705	
	fall	median	1,307	1,410
		5%	630	635
		95%	2,369	3,184
Estimates of Returns				
1SW	summer	median	693	
		5%	259	
		95%	1,443	
	fall	median	274	330
		5%	0	0
		95%	739	929
MSW	summer	median	1,239	
		5%	519	
		95%	2,614	
	fall	median	9,752	10,560
		5%	6,901	6,517
		95%	15,069	21,430

Table 4. Comparison of returns estimates obtained using the 1990 assessment method and the simulation method with bootstrap estimates of variability.

	Returns	Statistical Descriptors		
From the 1990 assessment (Chaput and Jones 1991)				
			Range	
		Estimate	Low	High
1SW	Summer	504- 927	123	1627
	Fall	156- 469	0	1069
	Total	660-1396	123	2696
MSW	Summer	718-1320	254	2170
	Fall	5263-15789	2193	25011
	Total	5981-17109	2447	27181
From Bootstrapping and Simulation				
		Median	Perc 5	Perc 95
1SW	Summer	693	259	1443
	Fall	274	0	739
	Total	999	465	1880
MSW	Summer	1239	519	2614
	Fall	9752	6901	15069
	Total	11144	8073	16606

```
ERGF                                                             Cum.
Midpoint                                                         Freq
 0.000  |                                                            2
 0.015  |                                                            4
 0.030  |*                                                          29
 0.045  |*                                                          53
 0.060  |***                                                       112
 0.075  |******                                                    234
 0.090  |**********                                                436
 0.105  |*******************                                       817
 0.120  |**************************                               1328
 0.135  |**********************************                       2012
 0.150  |***********************************************          2958
 0.165  |****************************************************     3995
 0.180  |*********************************************************5126
 0.195  |*****************************************************    6177
 0.210  |******************************************************   7248
 0.225  |*************************************                    7985
 0.240  |************************************                     8698
 0.255  |************************                                 9185
 0.270  |****************                                         9506
 0.285  |***********                                              9731
 0.300  |*****                                                    9838
 0.315  |****                                                     9917
 0.330  |***                                                      9967
 0.345  |*                                                        9981
 0.360  |*                                                        9991
 0.375  |                                                         9997
 0.390  |                                                         9999
 0.405  |                                                        10000
        -----+----+----+----+----+----+----+----+----+----+----+--
            100  200  300  400  500  600  700  800  900 1000 1100
```

```
ERMF                                                         Cum.
Midpoint                                                     Freq
 0.005  |                                                        4
 0.015  |                                                       12
 0.025  |*                                                      38
 0.035  |*                                                      56
 0.045  |****                                                  130
 0.055  |******                                                248
 0.065  |*********                                             429
 0.075  |*****************                                     770
 0.085  |***********************                              1229
 0.095  |*****************************                        1805
 0.105  |*******************************************          2667
 0.115  |********************************************         3554
 0.125  |*****************************************************4618
 0.135  |**************************************************** 5660
 0.145  |************************************************     6616
 0.155  |**********************************************       7536
 0.165  |************************************                 8247
 0.175  |*****************************                        8832
 0.185  |********************                                 9237
 0.195  |****************                                     9564
 0.205  |*********                                            9743
 0.215  |******                                               9858
 0.225  |***                                                  9923
 0.235  |**                                                   9970
 0.245  |*                                                    9990
 0.255  |                                                     9997
 0.265  |                                                     9998
 0.275  |                                                    10000
        -----+----+----+----+----+----+----+----+----+----+---
            100  200  300  400  500  600  700  800  900 1000
                               Frequency
```

Figure 1. **Parameter distributions for the 1990 Margaree River simulation, for 10,000 replications. Acronyms as in Table 2.**

```
GSPROPL                                                          Cum.
Midpoint                                                         Freq
  0.165   |                                                         3
  0.195   |                                                         4
  0.225   |                                                        10
  0.255   |*                                                       23
  0.285   |*                                                       35
  0.315   |*                                                       63
  0.345   |**                                                     112
  0.375   |*****                                                  215
  0.405   |********                                               365
  0.435   |*********                                              543
  0.465   |*************                                          805
  0.495   |*******************                                   1184
  0.525   |************************                              1668
  0.555   |************************                              2156
  0.585   |******************************                        2761
  0.615   |********************************************          3649
  0.645   |*******************************************           4516
  0.675   |*******************************************           5369
  0.705   |**********************************************        3^R90
  0.735   |*****************************************             7119
  0.765   |******************************************            7955
  0.795   |***************************************               8736
  0.825   |*************************                             9239
  0.855   |*******************                                   9614
  0.885   |**********                                            9818
  0.915   |******                                                9945
  0.945   |**                                                    9979
  0.975   |*                                                    10000
          -----+----+----+----+----+----+----+----+----+-
              100  200  300  400  500  600  700  800  900
```

```
GFPROPL                                                                    Cum.
Midpoint                                                                   Freq
  0.165   |                                                                   6
  0.195   |                                                                   7
  0.225   |                                                                  14
  0.255   |                                                                  18
  0.285   |                                                                  26
  0.315   |*                                                                 52
  0.345   |***                                                              110
  0.375   |****                                                             189
  0.405   |*****                                                            297
  0.435   |*********                                                        477
  0.465   |*****************                                                808
  0.495   |**********************                                          1246
  0.525   |***************************                                     1784
  0.555   |**********************************                              2471
  0.585   |******************************************                      3311
  0.615   |********************************************************        4422
  0.645   |***************************************************             5440
  0.675   |*****************************************************           6506
  0.705   |*********************************************                   7406
  0.735   |**********************************                              8091
  0.765   |*******************************************                     8953
  0.795   |************************                                        9430
  0.825   |***************                                                 9722
  0.855   |********                                                        9879
  0.885   |***                                                             9945
  0.915   |**                                                              9976
  0.945   |*                                                               9996
  0.975   |                                                                9996
  1.005   |                                                               10000
          -----+----+----+----+----+----+----+----+----+-)))+----+-
              100  200  300  400  500  600  700  800  900  1000 1100
                                 Frequency
```

Figure 1 (cont'd).

```
GSRIVL                                                          Cum.
Midpo)nt                                                        Freq
      0  |**                                                     107
     50  |*******                                                462
    100  |***********************                               1629
    150  |******************************************            3737
    200  |**********************************************        6044
    250  |************************************                  7860
    300  |*********************                                 8914
    350  |***********                                           9466
    400  |*****                                                 9693
    450  |***                                                   9847
    500  |**                                                    9922
    550  |*                                                     9952
    600  |                                                      9976
    650  |                                                      9990
    700  |                                                      9994
    750  |                                                      9996
         --------+-------+-------+-------+-------+------
                400     800     1200    1600    2000
```

```
GFRIVL                                                                                     Cum.
Midpoint                                                                                   Freq
      0  |*****************************************                                          825
     12  |************************************                                              1551
     24  |**************************************************                                2560
     36  |*********************************************************************             3938
     48  |************************************************************************          5379
     60  |*****************************************************************                 6684
     72  |******************************************************                            7759
     84  |******************************************                                        8591
     96  |****************************                                                      9156
    108  |*****************                                                                 9496
    120  |**********                                                                        9703
    132  |******                                                                            9823
    144  |***                                                                               9881
    156  |**                                                                                9928
    168  |**                                                                                9958
    180  |*                                                                                 9972
    192  |*                                                                                 9982
    204  |                                                                                  9989
    216  |                                                                                  9992
    228  |                                                                                  9995
    240  |                                                                                  9995
         -----+----+----+----+----+----+----+----+----+----+----+----+----+----+--
             100  200  300  400  500  600  700  800  900 1000 1100 1200 1300 1400
```

```
MSRIVL                                                      Cum.
Midpoint                                                    Freq
     40  |**                                                  76
    120  |*********                                          543
    200  |**************************                        1852
    280  |******************************************        3947
    360  |******************************************        6043
    440  |******************************                    7565
    520  |*********************                             8608
    600  |************                                      9208
    680  |*******                                           9554
    760  |****                                              9740
    840  |**                                                9840
    920  |*                                                 9891
   1000  |*                                                 9942
   1080  |                                                  9960
   1160  |                                                  9969
   1240  |                                                  9982
   1320  |                                                  9986
   1400  |                                                  9992
         --------+-------+-------+-------+-------+--
                400     800     1200    1600    2000
                         Frequency
```

Figure 1 (cont'd).

```
MFRIVL                                                                              Cum.
Midpoint                                                                            Freq
   100   |*                                                                           27
   300   |***                                                                        110
   500   |*************                                                              424
   700   |******************************                                            1166
   900   |******************************************************                    2513
  1100   |**************************************************************            4074
  1300   |*****************************************************************         5700
  1500   |********************************************************                  7102
  1700   |**************************************                                    8051
  1900   |*******************************                                           8818
  2100   |*****************                                                         9251
  2300   |***********                                                               9517
  2500   |*******                                                                   9690
  2700   |*****                                                                     9809
  2900   |***                                                                       9875
  3100   |**                                                                        9928
  3300   |*                                                                         9953
  3500   |                                                                          9964
  3700   |*                                                                         9979
  3900   |                                                                          9985
  4100   |                                                                          9993
  4300   |                                                                          9995
  4500   |                                                                          9997
         --------+-------+-------+-------+-------+-------+-------+-------+-
                200     400     600     800    1000    1200    1400    1600
```

```
MRETL                                                 Cum.
Midpoint                                              Freq
     0  |                                                0
  1200  |                                                4
  2400  |                                                4
  3600  |                                                6
  4800  |                                                8
  6000  |*                                              33
  7200  |******                                        331
  8400  |*********************                        1370
  9600  |**************************************       3266
 10800  |*******************************************  5425
 12000  |***********************************          7150
 13200  |***********************                      8307
 14400  |**************                               9015
 15600  |********                                     9409
 16800  |*****                                        9646
 18000  |***                                          9796
 19200  |*                                            9869
 20400  |*                                            9924
 21600  |*                                            9955
 22800  |                                             9966
 24000  |                                             9975
        --------+-------+-------+-------+-------+---
               400     800    1200    1600    2000
                        Frequency
```

Figure 1 (cont'd).

APPENDIX A. SAS program listing for the 1990 bootstrapping and simulation.

```
** margar90.SAS   ESTIMATING TOTAL RIVER CATCH, ER, ETC. USING LOGBOOKS;
OPTIONS LINESIZE = 160 PAGESIZE = 90 NOCENTER;
LIBNAME A '[CHAPUT.MARGAREE.ASSESS91]';
/*FILENAME TAGS '[CHAPUT.MARGAREE]TAGS90.PRN';
DATA A.TAGG A.TAGS; INFILE TAGS; INPUT OBS TYPE$ TIME RGEAR$;
  IF TYPE = 'G' THEN OUTPUT A.TAGG;
  IF TYPE = 'S' THEN OUTPUT A.TAGS;
DATA A.GS; INFILE 'YCHAPUT.MARGAREE.ASSESS91]LOGGRIS.PRN';
  INPUT NAME$ 1-9 GSI GSO GS;
DATA A.GF; INFILE '[CHAPUT.MARGAREE.ASSESS91]LOGGRIF.PRN';
  INPUT NAME$ 1-9 GFI GFO GF;
DATA A.MS; INFILE '[CHAPUT.MARGAREE.ASSESS91]LOGMSWS.PRN';
  INPUT NAME$ 1-9 MSI MSO MS;
DATA A.MF; INFILE '[CHAPUT.MARGAREE.ASSESS91]LOGMSWF.PRN';
  INPUT NAME$ 1-9 MFI MFO MF;
RUN;*/

*****************************************************
  this is the simulation step
******************************************************;
proc iml;

  USE A.TAGG;* tag recapture file for grilse 1990;
  read all var _&um_ into tagl;* recapture times for grilse 1990;
  tagg = tagl[,2];* keeps only the days to recapture;
  tagrowg = nrow(tagg);* number of tag recaptures to work with;
  tg = j(tagrowg,1,0);* dimensions tag vector;
  tagtg = j(tagrowg,1,0);
*print tagg tagrowg tagtg tg;
  USE A.TAGS;* tag recapture file for MSW 1990;
  read all var _num_ into tag2;* recapture times for MSW 1990;
  tags = tag2[,2];* keeps only the days to recapture;
  tagrows = nrow(tags);* number of tag recaptures to work with;
  ts = j(tagrows,1,0);* dimensions tag vector;
  tagts = j(tagrows,1,0);

  use a.gs;* grilse summer logbook data;
  read all var _num_ into gsl;
  rowgsl = nrow(gsl);* number of logboks for suemer;
  zzgs=j(rowgsd,1,0);* dimensions the summer matrix;
  gslog=j(rowgsl,2,0);* ditto;

  use a.gf;* grilse fall logbook data;
  read all var _.um_ into gfl;
  rowgfl = nrow(gfl);* number of logbooks for fall;
  zzgf=j(rowgfl,1,0);* dimensions the fall matrix;
  gflog=j(rowgfl,2,0);* ditto;

  use a.ms;* MSW sumeer logbook data;
  read all var _num_ into msl;
  rowmsl = nrow(msl);* number of logboks for summer;
  zzms=j(rowmsl,1,0);* dimensions the sume%r matrix;
  mslog=j(rowmsl,2,0);* ditto;
```

APPENDIX A (Cont'd)

```
  use a.mf;* MSW fall logbook data;
  read all var _num_ into mfl;
  rowmfl = nrow(mfl);* number of logbooks for fall;
  zzmf=j(rowmfl,1,0);* dimensions the fall matrix;
  mflog=j(rowmfl,2,0);* ditto;

  a1 = 1:2;
  a3 = 1:17;
  perm = 3000;* number of simulations;
  grilse = j(perm,17,0);* dimensions the grilse simulation matrix, all 0s;
****************************************************************;

do nperm = 1 to perm;* loop for the NPERM bootstrap replications;

****************************************************************
*** BOOTSTRAP THE RECAPTURE DATA TO ESTIMATE TAGS AVAILABLE ****
***                  FOR GRILSE                            ****
****************************************************************;
do h = 1 to tagrowg;* bootstrap sample created for tags grilse;
  do i = 1 to tagrowg;* selects with replacement one recapture from all;
   tg[i,1] = uniform(-1);
   end;
  ygt = rank(tg);* creates a vector corresponding to rank of random no.;
  ttg = tagg||ygt; * attaches rank vector to recapture data file;
  yy=min(ygt);* finds minimum rank, in case of ties;
  do j = 1 to tagrowg;
  if ygt[j,1]=yy then tagtg[h,1]=tagg[j,1];* keeps the obs with the min rank;
  end;
end;* one bootstrap sample completed;

*** calculating variable MEDTAGG the median value for grilse;
  y1 = rank(tagtg);
  if mod(tagrowg,2)<>0 then do; * n is an odd number;
     median = int(((tagrowg/2)+0.5));
     do i = 1 to tagrowg;
       if y1[i,1] = median then medtagg = tagtg[i,1];
     end;
  end;
  if mod(tagrowg,2)=0 then do; * n is an even number;
     med1 = tagrowg/2;
     med2 = tagrowg/2 + 1;
     do i = 1 to tagrowg;
       if y1[i,1] = med1 then medtag1 = tagtg[i,1];
       if y1[i,1] = med2 then medtag2 = tagtg[i,1];
     end;
     medtagg = (medtag1 + medtag2)/2;
  end;
** MEDTAGG  is the variable to keep, it is the median of one bootstrap
         sample for grilse      ***************;
```

APPENDIX A (Cont'd)

```
*******************************************************************
*** BOOTSTRAP THE RECAPTURE DATA TO ESTIMATE TAGS AVAILABLE ****
***                     FOR MSW                              ****
*******************************************************************;
do h = 1 to tagrows;* bootstrap sample created for tags MSW;
  do i = 1 to tagrows;* selects with replacement one recapture from all;
```

APPENDIX A (Cont'd)

```
   ts[i,1] = uniform(-1);
   end;
  ymt = rank(ts);* creates a vector corresponding to rank of random no.;
  tts = tags||ymt; * attaches rank vector to recapture data file;
  yy=min(ymt);* finds minimum rank, in case of ties;
  do j = 1 to tagrows;
  if tts[j,2]=yy then tagts[h,1]=tts[j,1];* keeps the obs with the min rank;
  end;
end;* one bootstrap sample completed;
*** calculating the median, variable MEDTAGS is the median value for MSW;
  y2 = rank(tagts);
  if mod(tagrows,2)<>0 then do; * n is an odd number;
     median = int(((tagrows/2)+0.5));
     do i = 1 to tagrows;
       if y2[i,1] = median then medtags = tagts[i,1];
     end;
  end;
  if mod(tagrows,2)=0 then do; * n is an even number;
     med1 = tagrows/2;
     med2 = tagrows/2 + 1;
     do i = 1 to tagrows;
       if y2[i,1] = med1 then medtag1 = tagts[i,1];
       if y2[i,1] = med2 then medtag2 = tagts[i,1];
     end;
     medtags = (medtag1 + medtag2)/2;
  end;
** MEDTAGS  is the variable to keep, it is the median of one bootstrap
           sample for MSW     ***************;

*******************************************************************
BOOTSTRAP SAMPLE OF RIVER CATCH FOR SUMMER GRILSE
*******************************************************************;
do h = 1 to rowgsl;* bootstrap sample created for summer logbook;
  do i = 1 to rowgsl;* selects with replacement one logbook from all;
   zzgs[i,1] = uniform(-1);
   end;
  y3 = rank(zzgs);* creates a vector corresponding to rank of random no.;
  xx=gsl||y3;* attaches rank vector to logbook data file;
  yy=min(y3);* finds minimum rank, in case of ties;
  do j = 1 to rowgsl; * finds the first occurence of minimum rank;
  if xx[j,4]=yy then gslog[h,a1]=xx[j,a1];* keeps the obs with the min rank;
  end;
end;* one bootstrap sample completed;
```

APPENDIX A (Cont'd)

```
****************************************************
BOOTSTRAP THE FALL GRILSE CATCH FROM THE RIVER
****************************************************;
do h = 1 to rowgfl;* same but this time for fall grilse;
  do i = 1 to rowgfl;
   zzgf[i,1] = uniform(-1);
   end;
  y4 = rank(zzgf);
  xxf=gfl||y4;
  yy=min(y4);
  do j = 1 to rowgfl;
  if xxf[j,4]=yy then gflog[h,al]=xxf[j,al];
  end;
```

APPENDIX A (Cont'd)

```
end;

loggs = gslog[+,al];* sums index and other catch for one bootstrap sample;
loggf = gflog[+,al];

****************************************************************
BOOTSTRAP SAMPLE OF RIVER CATCH FOR SUMMER MSW
****************************************************************;
do h = 1 to rowmsl;* bootstrap sample created for summer logbook;
  do i = 1 to rowmsl;* selects with replacement one logbook from all;
   zzms[i,1] = uniform(-1);
   end;
  y5 = rank(zzms);* creates a vector corresponding to rank of random no.;
  xxl=msl||y5;* attaches rank vector to logbook data file;
  yy=min(y5);* finds minimum rank, in case of ties;
  do j = 1 to rowmsl; * finds the first occurence of minimum rank;
  if xxl[j,4]=yy then mslog[h,al]=xxl[j,al];* keeps the obs with the min rank;
  end;
end;* one bootstrap sample completed;

****************************************************
BOOTSTRAP THE FALL MSW CATCH FROM THE RIVER
****************************************************;
do h = 1 to rowmfl;* same but this time for fall MSW;
  do i = 1 to rowmfl;
   zzmf[i,1] = uniform(-1);
   end;
  y6 = rank(zzmf);
  xxmf=mfl||y6;
  yy=min(y6);
  do j = 1 to rowmfl;
  if xxmf[j,4]=yy then mflog[h,al]=xxmf[j,al];
  end;
end;

logms = mslog[+,al];* sums index and other catch for one bootstrap sample;
logmf = mflog[+,al];
```

APPENDIX A (Cont'd)

```
****************************************************
BOOTSTRAP THE FALL GRILSE AND MSW TAG RETURNS BY POOL
****************************************************;
indexm = 0;
do i = 1 to 16; * 16 msw tags returned;
  xm = uniform(-1);
  if xm < 0.38 then indexm = indexm + 1;
end;
mftag = indexm/16;
indexg = 0;
do i = 1 to 13; *13 grilse tags returned;
  xg = uniform(-1);
  if xg < 0.54 then indexg = indexg + 1;
end;
gftag = indexg/13;

***************************************************************************
***     ESTIMATES CREEL CATCH BASED ON MEAN AND VARIANCE PARAMETERS     ***
***************************************************************************;
gsind = 135+(sqrt(2601)*NORMAL(-1));* simulates a creel summer catch from dist;

GFIND = 33+(SQRT(441)*NORMAL(-1));* simulates a creel fall catch from dist;

ersum = (uniform(-1)*0.173)+0.206;* simulates a summer ER from uniform;

msind = 192 +(sqrt(3844)*NORMAL(-1)); * simulates a creel summer catch for
                                        MSW;
mfind = 533 +(sqrt(24180)*NORMAL(-1)); * simulates a creel fall catch for
                                        MSW;

carrier=loggs||loggf||gsind||gfind||gftag||ersum||medtagg||logms||logmf||
                       msind||mfind||mftag||medtags;
*print carrier;
grilse[nperm,a3] = carrier[1,a3];* matrix with perm rows and columns
          corresponding catches from logbooks, catches from creel and summer;
FREE / tagg tagrowg tg tagtg tags tagrows ts tagts gsl rowgsl zzgs gslog
       gfl rowgfl zzgf gflog msl rowmsl zzms mslog mfl rowmfl zzmf mflog
       al a3 perm nperm grilse;
end;
print nperm;
create margar from grilse;
append from grilse;
close margar;
quit;
run;
proc append base = a.margar90 data=margar force;
run;
endsas;
```