Stock-Recruit Relationship for Multi-Sea-Winter Salmon
from the Margaree River, N.S.

by

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ABSTRACT

This study describes a stock-recruit relationship for multi-sea-winter (MSW) salmon from the Margaree River, derived using estimates of returns based on angling and commercial catches for the years 1947 to 1992. Since 1947, escapements and returns of salmon to the Margaree River have varied by more than 10-fold. The Ricker model provided the best fit of four models examined. Bootstrap estimates of various function parameters included: spawners for maximum recruitment = 1974, spawners for maximum net gain = 1352, maximum recruitment = 4584, maximum net gain = 2937. The current conservation level target for the Margaree River of 1036 MSW salmon, based on 2.4 eggs/m^2 of spawning and rearing habitat, is 31% lower and just outside the 90% confidence interval from the bootstrap estimate of the spawners for maximum net gain. The estimated returns and escapements were derived using assumed values for the exploitation rates in the recreational fishery. The combined effects of annual variation in exploitation rates and error in the estimates of angling catches would weaken the predicted stock-recruit relationship. However, the biases resulting from such measurement errors should be of little concern given the wide range of spawning stocks and returns observed over the time series.

RESUME

La relation entre le nombre de géniteurs et celui des recrues est évaluée pour le stock de Saumon atlantique rédibermarin de la rivière Margaree. Les niveaux de recrutements et de géniteurs, estimés avec les captures dans la pêche sportive, ont varié de plus de 10 fois depuis 1947 à 1992. L'ajustement des données était le meilleur pour l'équation de recrutement de Ricker. Les méthodes de "bootstrap" ont servi à l'estimation des divers paramètres de la courbe de Ricker : géniteurs pour recrutement maximal = 1974, géniteurs pour le gain net maximal = 1352, recrutement maximal = 4584, gain net maximal = 2937. Le niveau cible de géniteurs pour la rivière Margaree, calculé selon 2,4 oeufs/m^2 d'habitat de frai et d'élevage, est inférieur de 31% et à l'extérieur de l'intervalle de confiance à 90% de l'estimation de la relation de parents-recrues. Les estimations de recrutements et de géniteurs ont été obtenus en supposant un taux d'exploitation fixe dans la pêche sportive. La variabilité temporelle de ce taux d'exploitation et les incertitudes dans les estimations de captures affaiblissent la relation de géniteurs et de recrutements. Le biais, attribuable à ces incertitudes, serait inconséquent compte tenu des grandes variations dans le nombre de retours et de géniteurs observées durant la période d'étude.

INTRODUCTION

The Margaree River Atlantic salmon resource has been assessed using a target spawning requirement based on 2.4 eggs/m² of spawning and rearing habitat area. On that basis, a total of 6.714 million eggs are required to seed the river; this represents approximately 1036 multi-sea-winter salmon (MSW) and 582 one-sea-winter salmon (1SW). The latter are required to provide a one-to-one sex ratio on the spawning grounds (Chaput et al. MS 1992a). River-specific refinements to the ecological derivation of the spawning requirement (Elson 1975) are difficult; habitat production estimates for the Margaree River are not available and surveys to reassess the quality and quantity of habitat would only address part of the equation. Alternatively, stock-recruitment relationships (statistical approach as per Elson 1975) can provide a river-specific spawning target.

This document describes a stock-recruit relationship for MSW salmon from the Margaree River. MSW salmon refer to salmon which have spent 2 or more years at sea before spawning and are generally fish of fork length greater than 63 cm. Angling and commercial catches were used to derive estimates of returns and escapements of MSW salmon for the years 1947 to 1992. A total of four relationships describing stock and subsequent recruitment were examined: linear with intercept; linear through the origin; Beverton-Holt; and Ricker functions. The Ricker function was analyzed in greater detail. Bootstrap methods were used to derive joint confidence intervals for the estimates of maximum recruitment, the stock levels generating maximum recruitment, the maximum net gain (recruits - parents), and the number of parents generating the maximum net gain.

MATERIALS AND METHODS

The estimates of spawning escapement (parent stock) and returns to the Margaree River (recruitment) were obtained using the commercial and recreational fisheries data for Atlantic salmon of the Margaree River for the years 1947 to 1992, excluding 1958 to 1960. The following assumptions and adjustments to the data were made:

1. Only MSW salmon returns and escapements were considered in this analysis. Current target egg depositions for the Margaree are based on eggs from MSW salmon only. The Margaree River stock is principally a MSW salmon stock with the proportion of MSW salmon in the total returns exceeding 75% in most years (Chaput et al. MS 1992a).

2. The lag between spawning escapement and returns was assumed to be 5 years based on a smolt age of 2 years and a MSW sea age of 2 years. MSW virgin spawners in Margaree were between 70% and 80% of smolt age 2 in 1987 and 1988 (Claytor and Jones MS 1990). Repeat spawners have made up less than 15% of the MSW returns to the river in recent years.

3. Catches from the commercial fisheries in Districts 2 & 3 of Zone 6 (Fig. 1) were considered to be either 100% or 30% Margaree River origin. In 1983, the commercial catch of MSW salmon in Districts 12 & 13 (Fig. 1) was estimated to have been approximately 30% Nova Scotia origin fish (Claytor et al. 1987). The commercial fishery in District 2 was estimated to have been composed of approx. 30% Margaree origin salmon for the years 1948 and 1949 (Marshall MS 1982). The annual variation in the proportions of Margaree origin fish in the commercial catch was unknown. All commercial catches were considered to have been composed of MSW salmon and were converted to numbers using a constant of 5 kg per MSW salmon.

4. Angling catch data for the years 1947 to 1986 were those collected by DFO Conservation and Protection personnel (Chaput and Claytor 1988). Angling catches for the years 1958 to 1960 were reported as total catch of 1SW and MSW salmon for summer and fall combined and were not used in the analysis. For the years 1987 to 1991, MSW angling data were those obtained by creel surveys on the river (Chaput et al. MS 1992a).

The angling season for the years 1947 to 1961 closed on Sept. 30 whereas in subsequent years, the angling season closed on Oct. 15. The angling catches for the years 1947 to 1961 were adjusted to a theoretical Oct. 15 closure on the basis of the proportion of the total fall angling catch represented by the catch in September using data for 1962 to 1984. The model was:

$$\text{Prop (Sept.}_i / \text{Fall}_i) = \text{alpha X September}_i + \text{Beta; i} = 1962 \text{ to } 1984$$
$$\text{alpha} = 0.00382, \text{ beta} = 0.259, \ R^2 = 0.529,$$
$$H_o: \text{Slope} = 0, P < 0.05; \ H_o: \text{Intercept} = 0, P < 0.05$$

For the years 1947 to 1961, if the September catch was $<=$ 100 MSW salmon, the derived linear model was used to estimate the October catch. If the September catch was greater than 100, the October catch was estimated to have been 0.25 of the total fall catch had the angling season been open to Oct. 15 (October catch = September Catch/(0.75)-September Catch).

5. Total returns for a given year were calculated as the sum of the commercial catch and the in-river returns. In-river returns were estimated from the angling catches. For the years 1947 to 1989, the exploitation rate for summer angled MSW salmon was assumed to be between 0.206 and 0.379 (mean of 0.29) whereas, for fall angled fish, the exploitation rate was assumed to vary between 0.09 and 0.27 (mean of 0.18) (Chaput et al. MS 1992a). Returns in 1958 to 1960 were not estimated. For 1990 and 1991, inriver returns were those reported by Chaput et al. (MS 1992a). Returns in 1992 were estimated from the catches at the index trapnet fished in the Margaree estuary between June 16 and Oct. 14, 1992 and a preliminary calculation of 0.18 catch efficiency for the trapnet.

6. Parent stock size (escapement) for a given year was calculated as in-river returns minus angling harvest. Since returns for 1958 to 1960 could not be estimated, the escapements of 1953 to 1955 and 1958 to 1960 were not used in the analysis. For the years 1947 to 1978, the annual angling catches were subtracted from the in-river returns to estimate escapement. For the years 1979 to 1983 (Chaput and Claytor 1988), hook and release regulations were in effect for all MSW salmon angled prior to Sept. 1, therefore, escapement of MSW salmon was calculated as in-river returns minus the sum of 5% of the summer angling catch (assumes 5% mortality of MSW fish due to hook and release practices) and 100% fall angling catch. For 1984, hook and release regulations also were enforced for the fall, therefore escapement was calculated as inriver returns minus summer catch minus 5% fall angling catch. For the years 1985 to 1991, escapements were calculated as inriver returns minus 5% of the angling catch (Chaput et al. MS 1992a). In 1992, the escapement was estimated as equal to 99% of the return (20% exploitation rate times 5% hook and release mortality equals 1% mortality).

Stock-Recruit Relationships

Two recruitment data sets were considered; the first assumed 100% of the commercial catch was Margaree origin salmon whereas the second assumed that only 30% of the catch was of Margaree origin. The following functional relationships were examined, for the two data sets separately:
1 - recruits as a linear function of parents, with intercept,
2 - recruits as a linear function of parents, forced through the origin,
3 - Ricker type function of recruits on parents,

4 - Beverton and Holt function of recruits on parents.

All the models were fitted using SAS REG procedures (SAS 1989) with the Ricker and Beverton-Holt functions fitted using the linear transformations given in Ricker (1975). The appropriateness of the models was evaluated using two groups of criteria:
    1 - the goodness of the linear fits of the models, and
    2 - the goodness of the back-transformed fits (Ricker and Beverton-Holt functions).

For each of these groups, residual analyses were performed including:
    1 - proportion of the total variance explained,
    2 - whether the residual errors were normal with mean 0 and constant variance,
    3 - analysis of influential observations, (high leverage, high deleted studentized residual), and
    4 - analysis of the fit of the recent years (1985 to 1992 return years) when the commercial fishery was closed which removed a large portion of the returns estimate uncertainty associated with the proportion of the commercial catch which was Margaree origin.

Bootstrap estimates of the Ricker function parameters were obtained by selecting with replacement 35 parent/recruit observations from the observed parent/recruit values of 1947 to 1987 spawning years (excluding 1953 to 1955 and 1958 to 1960).

RESULTS

Since 1947, escapements of MSW salmon to the Margaree River have varied from 293 to 3993 fish (Table 1). Returns to the river from these escapements have varied between 1066 and 11144 fish if all the commercial catch is considered Margaree salmon. Otherwise, at 30% Margaree origin salmon in the commercial catch, returns have varied between 618 and 11144 MSW salmon (Table 1).

Of the four functions fitted, the Ricker model provided the best fit to both sets of data (Table 2, Fig. 2). The proportion of the explained variation in recruits due to the parent stock size was maximum and the average error in predicted returns to the Margaree River for the years when the commercial fishery was closed was minimal (Table 2). Analysis of the residuals indicated that the assumptions for the linear fit of the Ricker model were appropriate (Fig. 3). The Beverton-Holt function gave low average residuals for the recent years, however, the explained variation was small and the error distribution of the linear-fit was not normal (Fig. 4).

On the basis of the explained variation in recruitment and the distribution of the residuals in recent years when the fishery was closed, the data set which assumed that 100% of the commercial catch was Margaree origin MSW fitted more closely a Ricker function than did the data set which assumed that only 30% was Margaree origin (Table 2, Fig. 2). The linear model (with intercept) had a smaller average residual error for recent years, but again, the intercept term was large (1374) and significantly different from 0.0 (P = 0.004), which is biologically inappropriate.

The parameters of the Ricker function for the Margaree River MSW salmon stock, assuming 100% of the commercial catch was of Margaree origin, are as follows:

alpha   =   6.263
beta   =   0.00050
Parents for replacement   3669
    for maximum recruitment   2000
    for maximum net gain   1363
Maximum recruitment   4608
Maximum net gain   2955

Bootstrap estimates of the Ricker parameters and of the parent-recruit relationship are shown in Figures 5 to 7. The R^2 value of the linearly fitted Ricker function for 2500 bootstrap replicates had a median value of 0.54, ranging between 0.29 and 0.72 (5th and 95th percentiles). The stock characteristics are summarized below:

	Median	Percentiles		(Fig. #)
		5	95	
Parent Replacement	3637	2982	4464	(Fig. 5)
Parent for Max. Recruit	1974	1524	2602	(Fig. 5)
Maximum Recruitment	4584	3859	5514	(Fig. 6)
Spawner for Maximum Net Gain	1352	1091	1693	(Fig. 7)
Maximum Net Gain	2937	2437	3561	(Fig. 7)

DISCUSSION

The Ricker function parameters indicate that when 100% of the commercial catch is considered to be of Margaree origin, the recruit to spawner ratio is 6.3:1 whereas it is only 3.3:1 when the commercial catch is assumed to represent 30% Margaree origin fish. These values are neither high nor low compared to values suggested for other stocks; a recruit to spawner ratio of 3:1 for returns to the counting fence at Western Arm Brook (Newfoundland) after commercial exploitation (Chaput et al. MS 1992b); and between 3:1 and 12:1 for several north shore and Gaspé rivers of Québec (Côté et al. 1990).

The estimates of the returns and the escapements were derived using assumed values for the exploitation rates in the recreational fishery. The angling catches and the commercial catches have also been used without accounting for measurement error. There is undoubtedly annual variation in the exploitation rates and there is undoubtedly error in the estimated angling catches from the river. The combined effect of these unknowns on the derived stock-recruit relationship would likely be to weaken the relationship between the parental stock size and subsequent recruitment (Walters and Ludwig 1981). However, when the smallest stock size is at least 1/10th the largest spawning stock, Hilborn and Walters (1992) suggest that the biases resulting from the measurement errors of the spawning stock size will probably be of little concern. The stock size in the Margaree River analysis ranged between 293 and 3993, a factor of more than 1/13th.

Management of the Margaree River Atlantic salmon could be based on a number of potential targets: managing on the basis of a conservation target of 2.4 eggs/m^2; on the basis of a maximum recruitment target; or on the basis of maximizing surplus. Managing on the basis of a conservation level of 2.4 eggs/m^2, as outlined in CAFSAC Adv. Doc. 91/16, would require a total of 1036 MSW salmon. This target level of spawners would potentially still provide a harvestable surplus. Managing on the basis of maximizing the recruitment or managing to maximize the harvestable surplus have different target levels. Maximum recruitment could be obtained at a spawner level of about 2000 fish, ranging between 1500 and 2600. Deviations of as much as ±30% from the target level of 2000 fish (1400 to 2600) would still provide for potential maximum recruitment because these values are within the 90% confidence interval of the estimate. This target would provide a potential maximum recruitment of 4600 fish, ranging between 3900 to 5500 (90% confidence interval). Managing for maximum net gain would require that the target number of spawners be 1350 salmon (between 1100 and 1700 salmon). This

would maximize the net gain at about 2900 fish per year, ranging between 2400 and 3600. Deviations of ± 30% from the target level of 1350 fish would still be within the confidence interval of the estimated target.

How could these values be used to manage the resource? Once the management strategy is decided, the returns in the next year can be obtained from the Ricker stock-recruit function. On the basis of the returns estimate, the harvestable amount is obtained by subtracting the predicted returns from the target spawners. For example, in 1988, the estimated escapement to the Margaree River was about 1650 MSW salmon (Chaput et al. 1992a). The predicted recruitment from these spawners is 4990 salmon, ± 650 or 15% of predicted value (90% confidence interval). Assuming that the management decision is for maximizing recruitment, then the allowable harvest could be 2462, with a 90% confidence interval of ± 610 (25% of the median allowable harvest estimate). The confidence interval is calculated by fitting the estimated escapement into the bootstrap values of alpha and beta coefficients of the Ricker function.

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ACKNOWLEDGEMENTS

Table 1. Spawner and returns estimates used in deriving the stock recruitment function for the Margaree River multi-sea-winter Atlantic salmon stock.

Year	Spawners in Year i	Returns in Year i+5 Commercial=100%	Returns in Year i+5 Commercial=30%
1947	1685	4852	2307
1948	3358	7204	3386
1949	1839	5716	2852
1950	1744	4000	2282
1951	2093	2440	1167
1952	969	2833	1561
1956	486	2616	1089
1957	822	4534	2562
1961	344	3620	1711
1962	1306	3850	2051
1963	887	3538	1783
1964	1053	2515	1195
1965	993	3694	1892
1966	727	1393	730
1967	1009	2083	960
1968	828	2378	1071
1969	488	3394	1398
1970	901	2702	1060
1971	351	2630	1103
1972	373	3261	1453
1973	393	3131	1539
1974	436	1066	618
1975	293	2813	1421
1976	366	1819	1055
1977	538	2909	1484
1978	699	3292	1522
1979	363	1868	1001
1980	681	1452	1452
1981	618	3627	3627
1982	760	4033	4033
1983	657	1667	1667
1984	413	2297	2297
1985	1437	11144	11144
1986	3589	3484	3484
1987	3993	3372	3372

Table 2. Diagnostics of the stock-recruit functions for the Margaree River MSW Atlantic salmon stock based on whether all the commercial catch of Districts 2 & 3 is considered Margaree salmon versus only 30%.

Model	Form	R-square	Residuals 1980-1987 Distribution	Average Error	Residuals 1986	1987
			Commercial catch assumed to be 100% Margaree origin MSW salmon			
Ricker	R = f(P) Log(R/P) = f(P)	0.197 0.534	4+, 4-	1458	-252	-24
Beverton-Holt	R = f(P) 1/R = f(1/P)	0.062 0.126	5+, 3-	1589	57	194
Linear (intercept)	R = f(P)	0.148	5-, 3+	2069	1778	2197
Linear (no-intercept)	R = f(P)	-	6+, 2-	2973	-4158	-5103
			Commercial catch assumed to be 30% Margaree origin MSW salmon			
Ricker	R = f(P) Log(R/P) = f(P)	0.138 0.349	7+, 1-	1979	791	834
Beverton-Holt	R = f(P) 1/R = f(1/P)	0.014 0.166	7+, 1-	2227	-1387	-1256
Linear (intercept)	R = f(P)	0.119	4-, 4+	1869	-306	-690
Linear (no-intercept)	R = f(P)	-	6+, 2-	2704	1595	2279
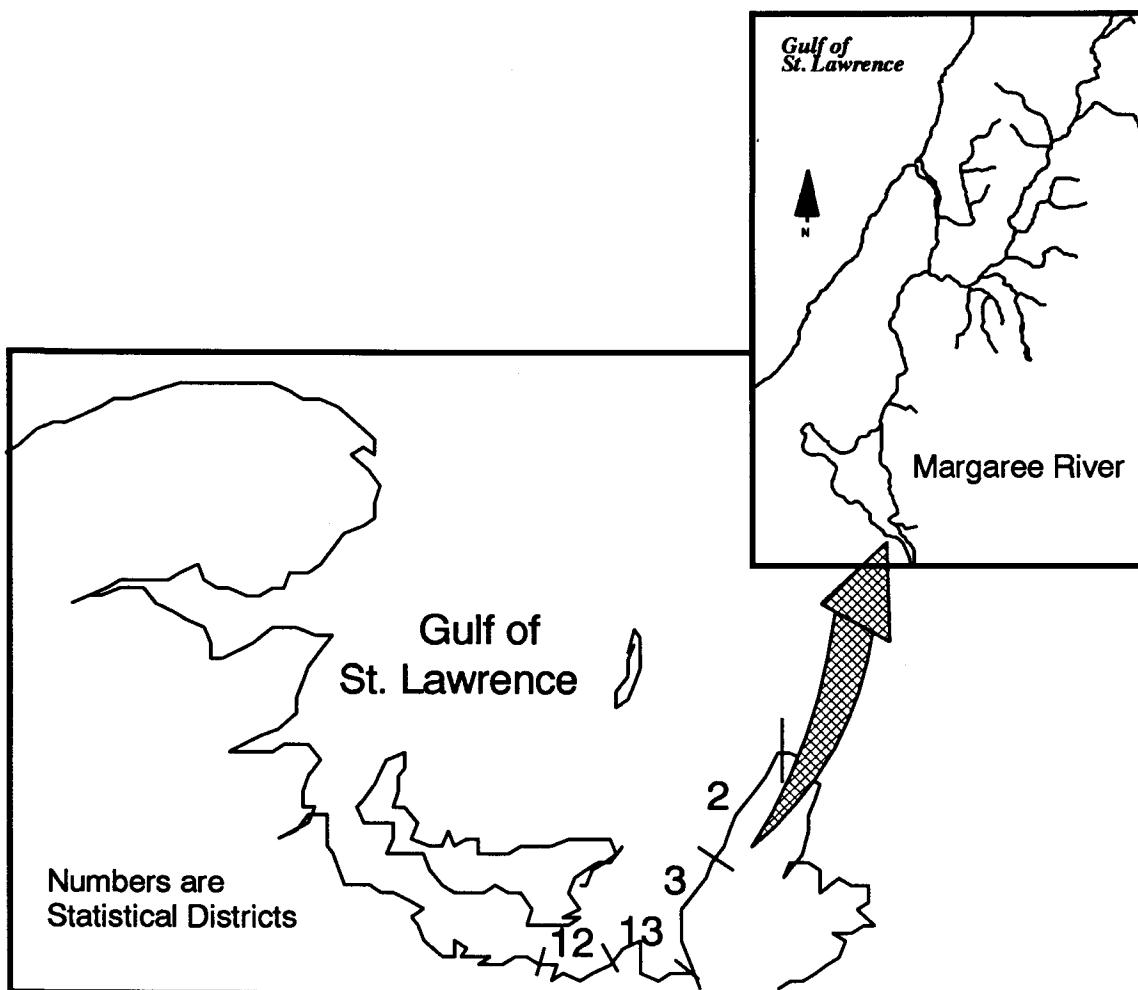
Figure 1. Location of the Margaree River relative to the Statistical Districts within Gulf Nova Scotia Salmon Zone 6.

Commercial Catch = 30% Margaree Origin MSW Salmon

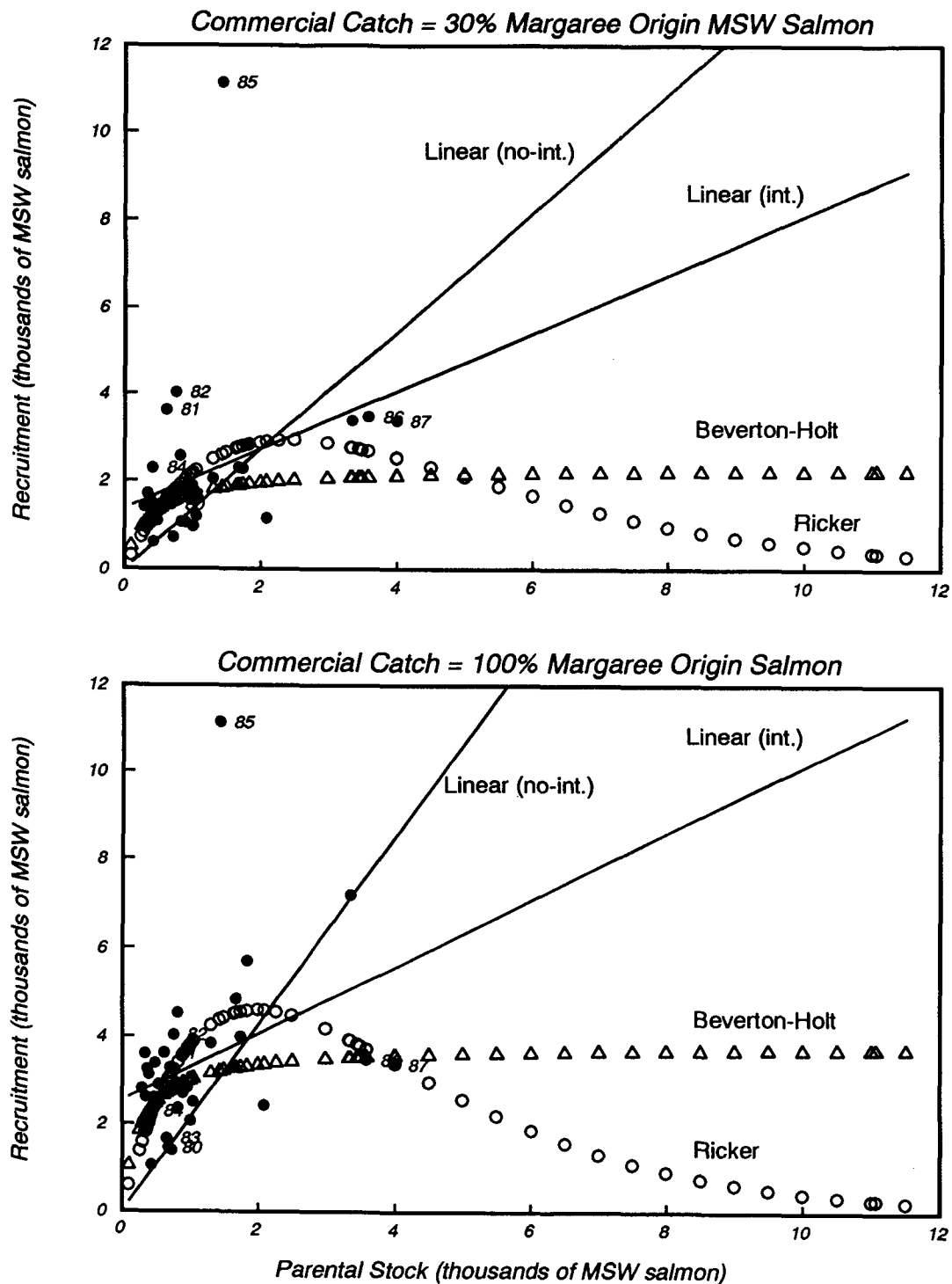## Commercial Catch = 100% Margaree Origin Salmon

Figure 2. Margaree River MSW salmon stock-recruit functions assuming that either 30% or 100% of the commercial catch is Margaree origin salmon.
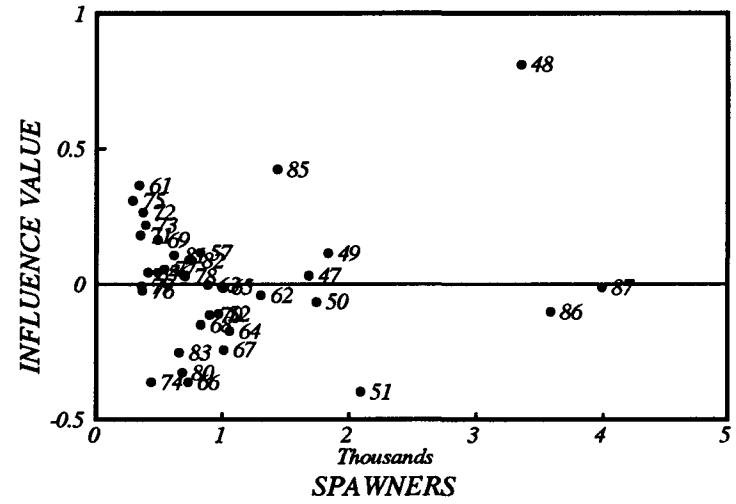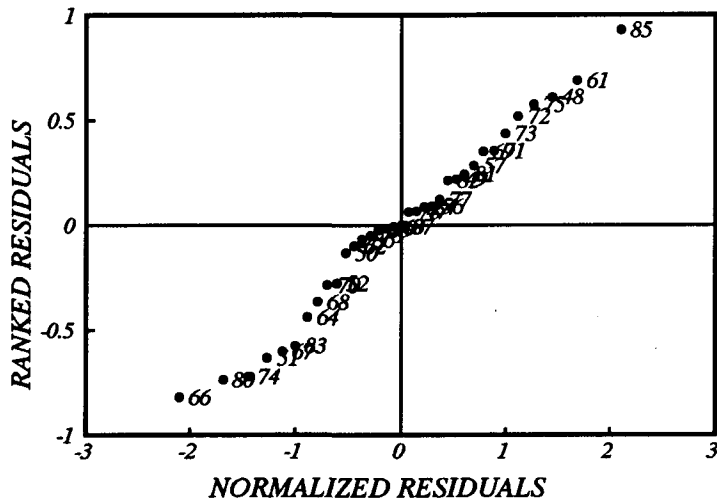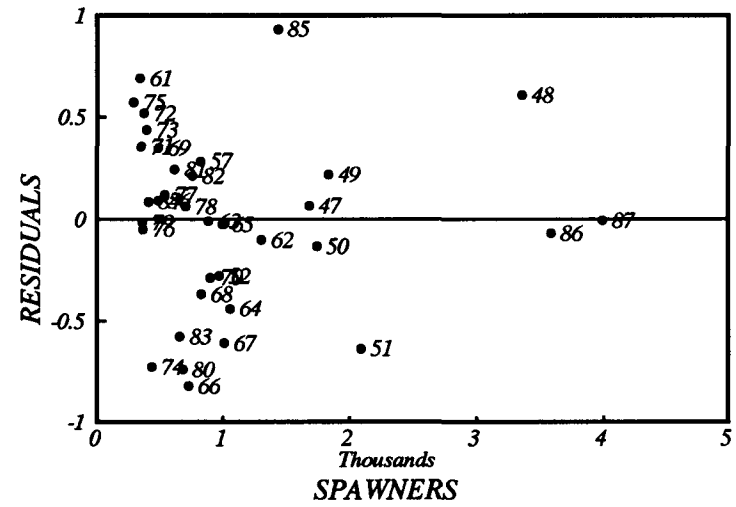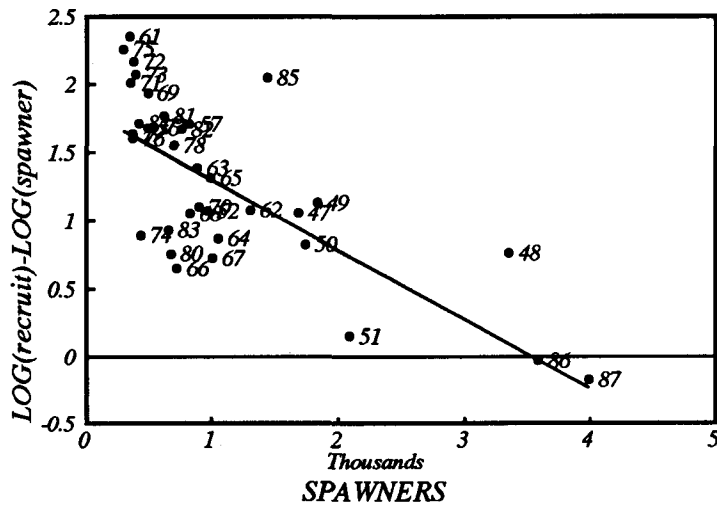
Figure 3. Diagnostics of the Ricker function linear fitting for the data set
which assumes that 100% of the commercial catch is Margaree-origin salmon.
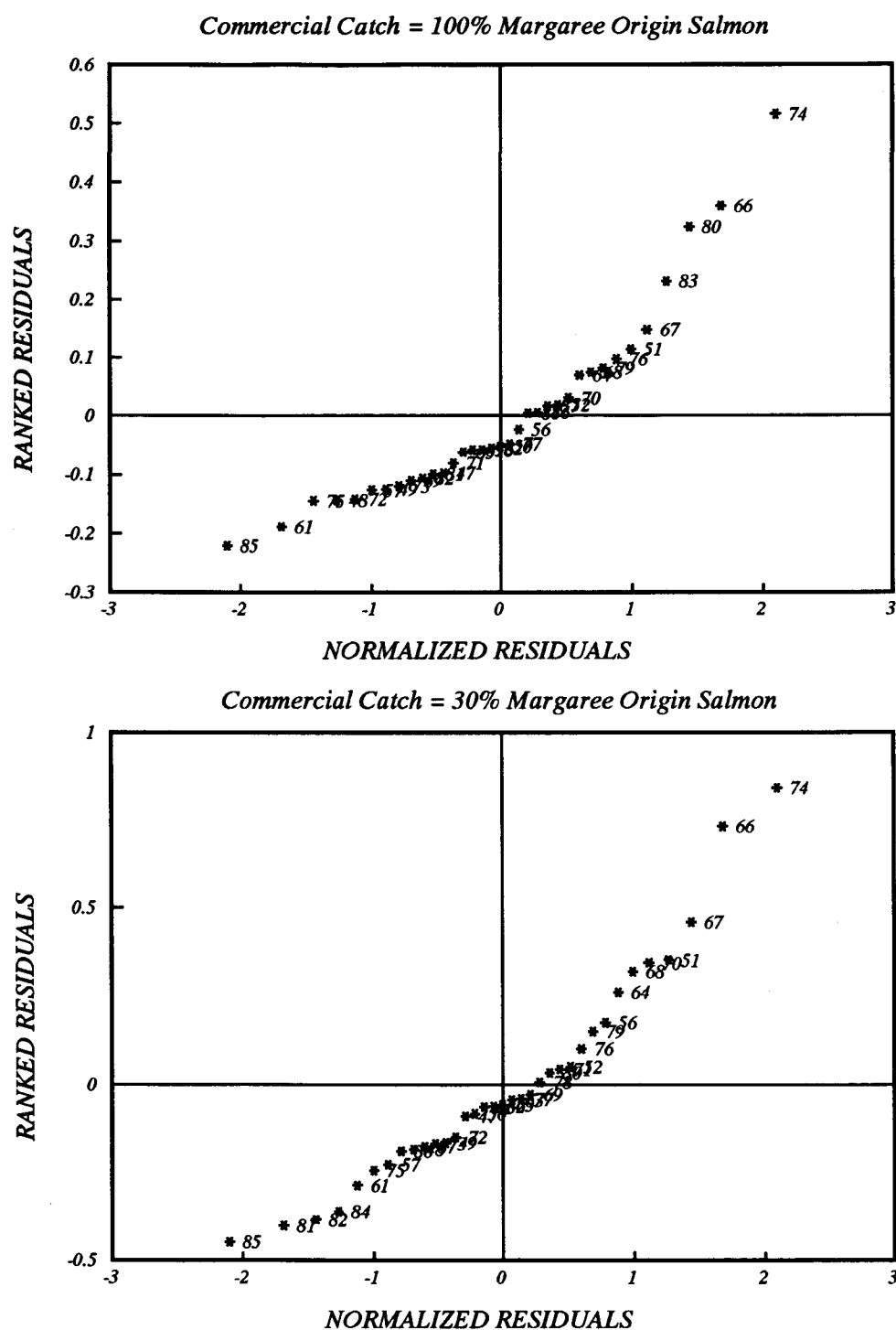The numbers represent the year of escapement.

Figure 4. Normalized residuals versus ranked residuals for the Beverton-Holt models assuming 100% or 30% of the commercial catch is Margaree origin fish. The numbers next to the symbols represent the year of escapement.
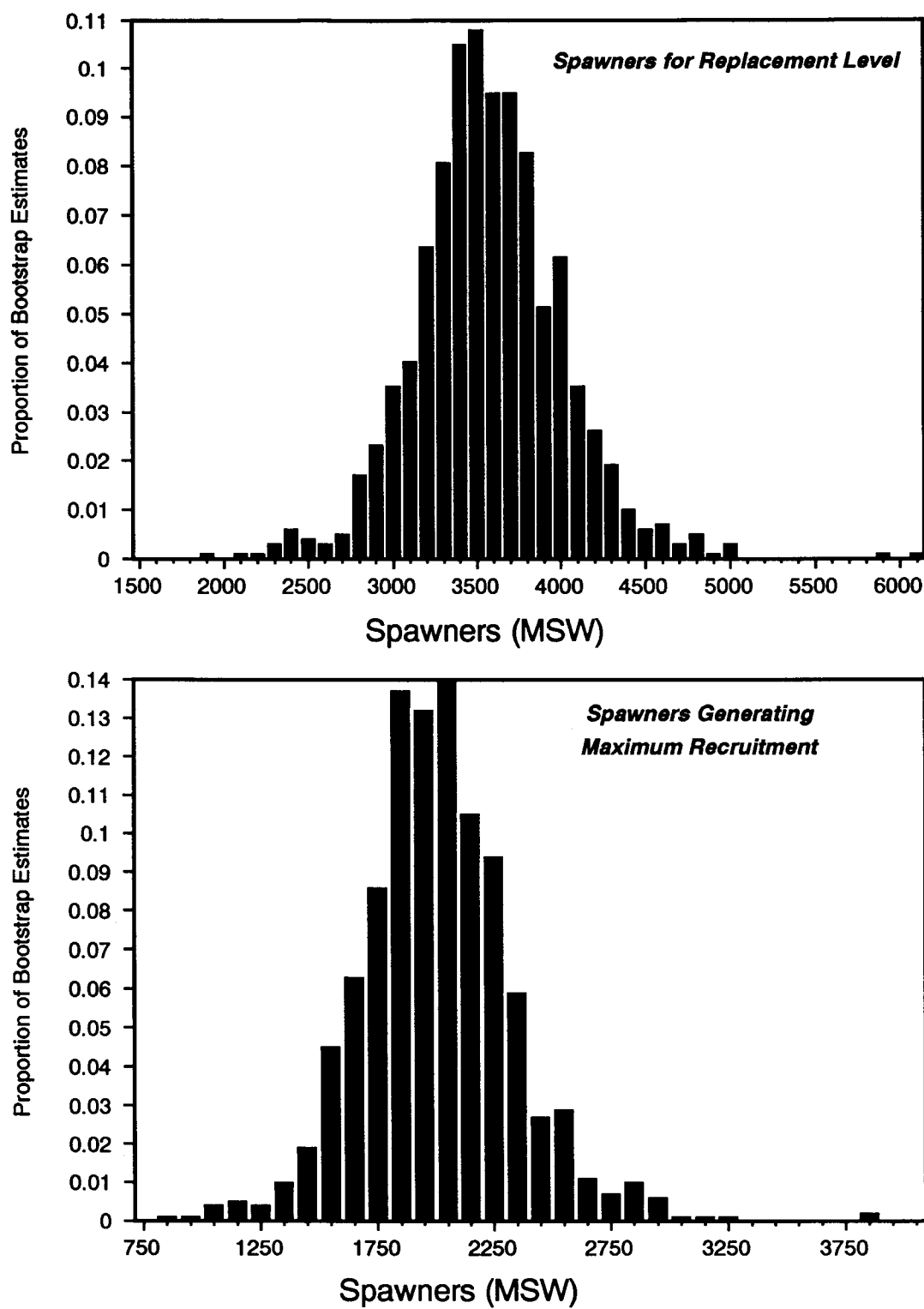
Figure 5. Distribution of spawners for replacement and spawners for maximum recruitment from bootstrap estimates of Ricker function parameters.
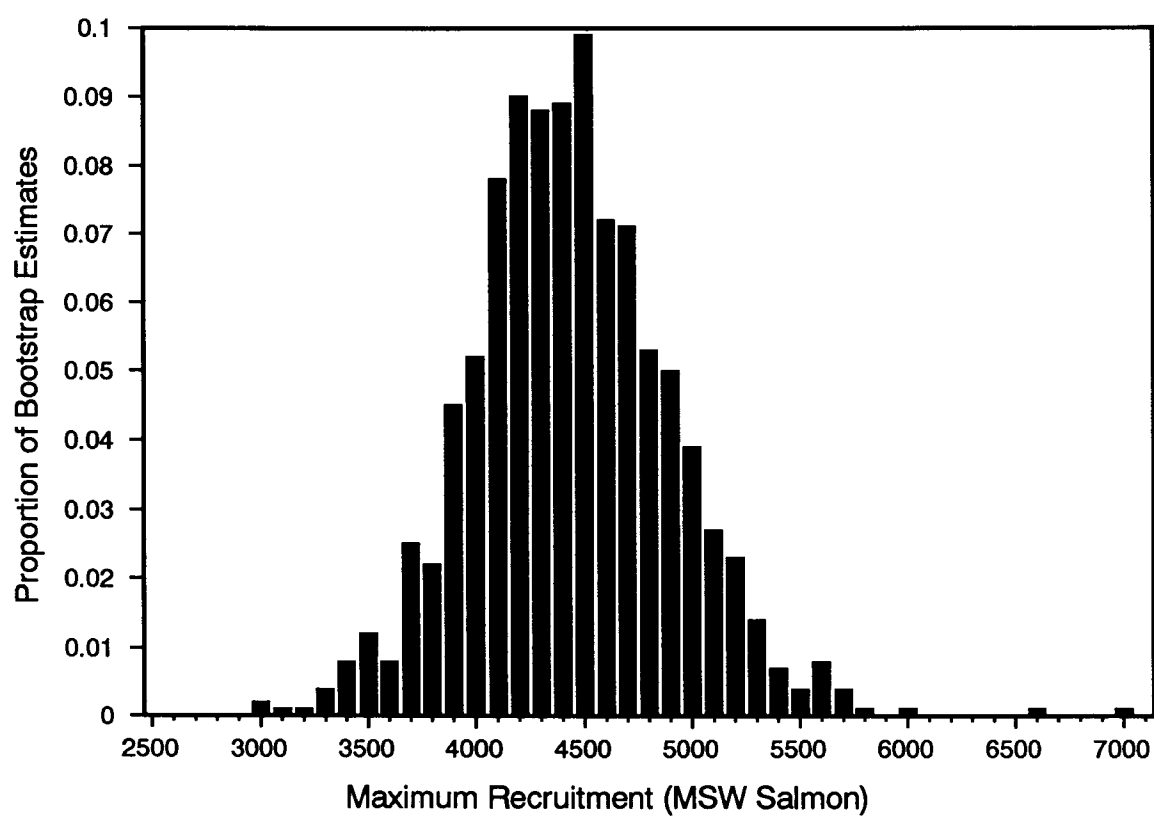
Figure 6. Distribution of maximum recruitment prediction from bootstrap estimates of Ricker stock-recruit function parameters.
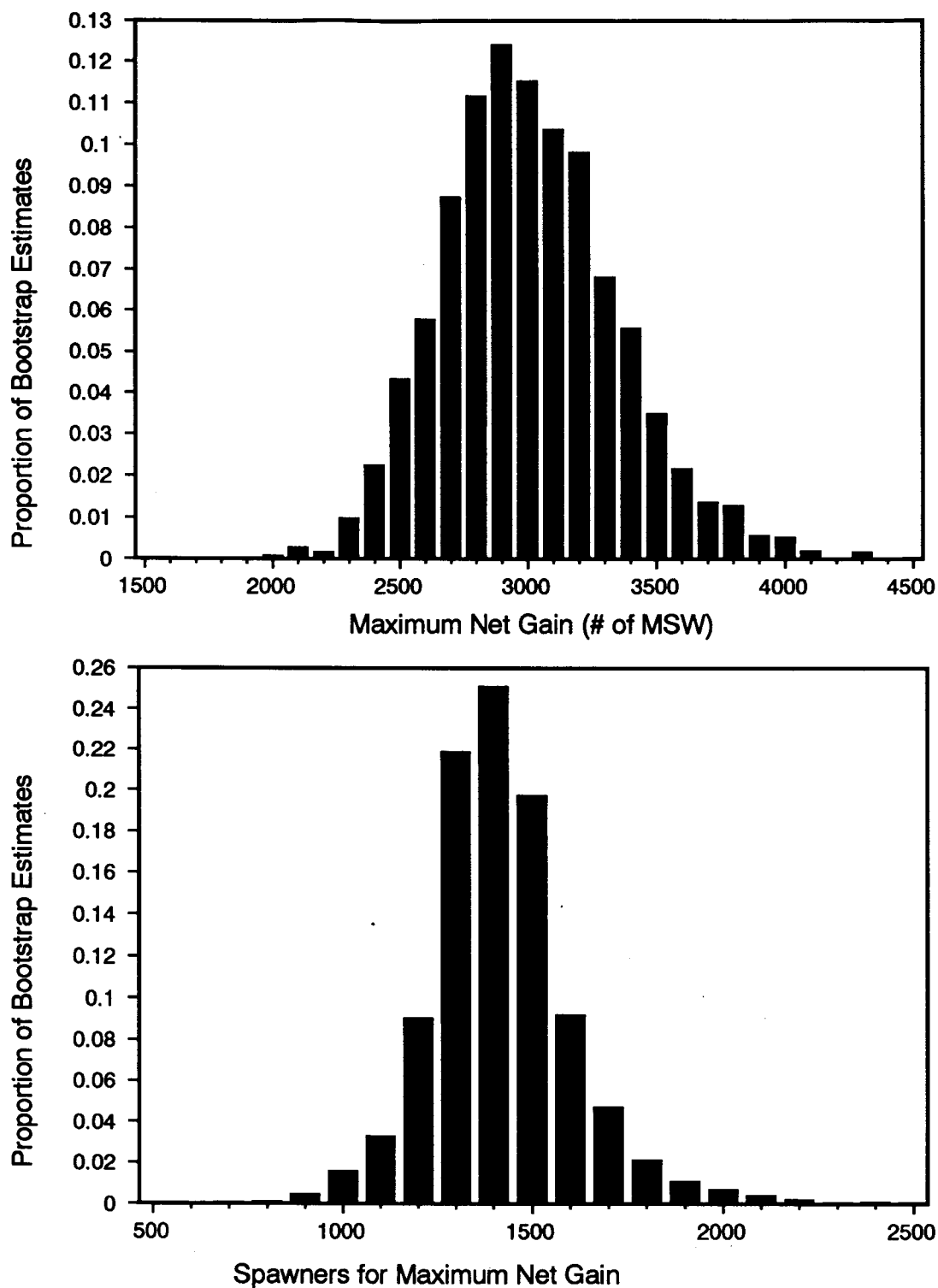
Figure 7. Estimate of number of MSW salmon spawners for maximum net gain and maximum net gain expected from the Margaree River MSW Atlantic salmon stock.