# STOCK-RECRUIT RELATIONSHIPS FOR ATLANTIC SALMON FROM WESTERN ARM BROOK, NEWFOUNDLAND

by

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## ABSTRACT

The data series of Atlantic salmon adult returns, adult escapement, and smolt enumerations for 1971 to 1992 from Western Arm Brook, Newfoundland, were used to model the adult-to-adult and adult-to-smolt stock-recruit relationships. The parameters of the Ricker-type stock-recruit functions were estimated using the linear approximations and bootstrapping of the original data provided estimates of: the stock level for replacement, the stock level for maximum recruitment, and the stock level for maximum net gain of adults. The Ricker function was a good model of the adult-to-smolt relationship but the adult-to-adult relationship was poorly modelled. The principal result from the analysis was that the number of spawners required to produce the maximum recruitment of adults back to the counting fence was 527 fish, less than half the 1073 fish required for maximum smolt production. The estimate of recruitment of adults did not account for removals in the commercial fisheries but the spawners required for maximizing adult recruitment would probably not change substantially if estimates of removals by the commercial fisheries were considered.



## RESUME

Les dénombrements de la dévalaison des saumoneaux et de la montaison des adultes du Saumon atlantique à Western Arm Brook, Terre-Neuve, pour les années 1971 à 1992, ont servis à évaluer la relation entre le nombre de parents et celui des recrues. L'approximation linéaire des équations de recrutement de Ricker a servi à l'estimation des paramètres des fonctions. La méthode de "bootstrap" a permis d'évaluer les niveaux de recrutement maximal, de reproducteurs pour générer le recrutement maximal et le rendement maximal. L'ajustement des dévalaisons des saumoneaux par rapport aux géniteurs était bon, mais l'ajustement pour le recrutement des adultes était faible. Les résultats démontrent que le nombre de géniteurs requis pour maximiser la production des saumoneaux était égale à 1073 saumons tandis que le nombre de géniteurs requis pour maximiser le recrutement des adultes est 527 saumons, moins de la moitié celui pour maximiser la production des saumoneaux. L'estimation du recrutement des adultes ne considère pas les captures commerciales, mais le nombre de géniteurs requis pour maximiser le recrutement des adultes ne serait que faiblement affecté par la considération de ces captures.

## INTRODUCTION

The data series of smolt and adult enumeration from the counting fence at Western Arm Brook (WAB), Newfoundland, provides a unique opportunity for examining the stock-recruit relationships from adult to smolt and adult to adult. The number of spawners that generates maximum smolt production may not be the same as that which results in maximum recruitment of adults back to the fence. Some of these data have previously been examined by Chadwick (1987) and this paper extends the analysis using the additional years.

## MATERIALS AND METHODS

Smolts and adults were enumerated at the counting fence in WAB for the years 1971 to 1992. Systematic sampling of about 1% of the smolt run was also conducted at the fence to estimate year class strength. Adult escapement was adjusted for fish entering the river after the fence had been removed as per Mullins and Jones (MS 1992). The recruitment values for the adults does not account for any exploitation in the commercial fisheries.

The adult recruitment to the fence for the corresponding spawner escapement was estimated by lagging the returns to the counting fence by 6 years. The dominant smolt age of a cohort is 4 years although 3 and 5-year old smolts have made up as much as 40% of a given cohort. During the time series studied, more than 99% of adult returns to the fence were one-sea-winter of age.

Ricker stock-recruit functions were fitted to the adult-to-smolt data and the adult-to-adult data (Table 1) using the linear derivation outlined by Ricker (1975) and SAS regression procedures (SAS 1989). A total of 2500 bootstrap replications were used to quantify the variation of the Ricker parameters and the associated values for spawner replacement (adult-adult function), spawners for maximum recruitment (as adults for the adult-adult relationship, as smolts for the adult-smolt relationship) and estimates of maximum recruitment (adults or smolts) (Ricker 1975).

## RESULTS

The linear fit of the Ricker function was suitable for both the adult-smolt and the adult-adult functions. Spawner escapement explained 56% of the total variation in year-class strength of smolts but only 7% of the variation in numbers of adults returning to the fence 6 years later (Table 2, Fig. 1). The diagnostics of the linear fit indicated that the adult returns for the 1973 escapement had both a high residual and high influence (Fig. 2). The 1979 year class of smolts had the highest influence value of the adult-smolt data series (Fig. 3).

The calculated alpha parameters of the Ricker functions indicate that, at low stock abundance, each spawner produces 2.6 adult recruits back to the fence 6 years later (2 to 3.7 on the basis of the 90% C.I. from the bootstrap simulation). For smolts, each spawner generates 52 smolts (41 to 80; 90% C.I. from bootstrap replicates).

Both curves were flat-domed (Fig. 1). Spawners for replacement and spawners for maximum recruitment of adults back to the fence were similar, about 520 fish (Table 2, Fig. 4,5). Maximum net gain (recruits to fence - spawners) occurred at about 250 fish, with a net gain of 190 salmon. The maximum number of smolts is estimated at 20700 (90% C.I. of 13000 to 22600) and this is obtained at a spawner escapement of 1073 salmon (90% C.I. of 430 to 1500) (Table 2, Fig. 6).

## DISCUSSION

Adult recruits to the fence do not account for fish harvested in sea fisheries. The interception of salmon destined for Western Arm Brook has been estimated to be about 50% of the commercial catch in St. Barbe Bay, the bay into which Western Arm Brook empties (Chadwick and Claytor 1990). Commercial catches specific to St. Barbe Bay are not available. A recruits to the fence per spawner ratio of 3:1 is low considering that for the MSW salmon stock of the Margaree River, after accounting for commercial harvests, the value is 6:1 (Chaput and Jones MS 1992). Assuming that 30% of the local commercial catch was Margaree-origin salmon, the recruit to spawner ratio for was 3:1 (Chaput and Jones MS 1992). Chadwick (1987) estimated that each spawner in Western Arm Brook generated eight recruits when commercial harvests were included in the returns and, given the relationship for Margaree, inclusion of some portion of the commercial catch would provide for recruit:spawner ratios that are higher than the 3:1 derived for recruits to the fence.

The spawner to smolt function may not be a true Ricker function; compensation at high spawner escapements may not be real in Western Arm Brook given that a large proportion (67%) of the smolt production occurs in lacustrine habitat (Chadwick and Green 1985). The Beverton-Holt stock-recruit function did not fit the data at all. The numbers of smolt for a given cohort was strongly related to the parental stock. The variation in the number of adults recruiting to the fence was weakly related to the spawning escapement 6 years before. The relationship might have been stronger if the returns to the fence had been allocated to the appropriate cohort rather than assuming a 6 year lag.

The important point in this analysis is that maximum smolt production occurs at almost twice the spawner escapement required for maximum adult recruitment back to the fence. Target spawning requirements, which are based on the premise of maximizing smolt output, may, therefore, not provide maximum adult recruitment. In river systems where the largest proportion of smolt production occurs in fluvial areas, the discrepancy between the two spawner levels may not be as wide. There is reason to believe that compensation at sea is an important factor in the adult recruitment back to the river. Smaller smolts produced at high egg depositions appear to have lower sea survival (Chadwick 1987). It is not possible to test this hypothesis because there are no other river systems with comparable data series as that from Western Arm Brook.

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Table 1. Raw data used for deriving Ricker stock-recruit functions for Atlantic salmon from Western Arm Brook.

| Year-Class | Adult Escapement | Smolts Out | Adult Returns (Year+6) |
|---|---|---|---|
| 1971 | 427 | 8000 | 355 |
| 1972 | 205 | 6153 | 309 |
| 1973 | 351 | 13387 | 1578 |
| 1974 | 299 | 11298 | 465 |
| 1975 | 393 | 12344 | 489 |
| 1976 | 420 | 18088 | 463 |
| 1977 | 341 | 12754 | 1145 |
| 1978 | 285 | 8519 | 235 |
| 1979 | 1578 | 21973 | 223 |
| 1980 | 430 | 12915 | 252 |
| 1981 | 447 | 13805 | 438 |
| 1982 | 387 | 15901 | 423 |
| 1983 | 1141 | 20688 | 455 |
| 1984 | 120 | 9020 | 322 |
| 1985 | 168 | 12015 | 234 |
| 1986 | 252 | | 456 |

Table 2. Parameters and estimates from the Ricker stock-recruit functions for Western Arm Brook.

| Parameters | Ricker Adult to | | Median | Percentiles 5% | Percentiles 95% |
|---|---|---|---|---|---|
| R-square | adult | linear-fit | 0.66 | 0.16 | 0.88 |
| | | non-linear | 0.07 | | |
| | smolt | linear-fit | 0.62 | 0.32 | 0.83 |
| | | nonlinear | 0.57 | | |
| Beta | adult | | 0.00180 | 0.00146 | 0.00251 |
| | smolt | | 0.00093 | 0.00068 | 0.00229 |
| Alpha | adult | | 2.57 | 1.94 | 3.65 |
| | smolt | | 51.80 | 40.76 | 79.85 |
| Spawners for Replacement | | | | | |
| | adult | | 522 | 408 | 637 |
| Spawners for Maximum Recruitment | | | | | |
| | adult | | 527 | 435 | 653 |
| | smolt | | 1073 | 429 | 1470 |
| Maximum Recruitment | | | | | |
| | adult | | 555 | 398 | 684 |
| | smolt | | 20727 | 13076 | 22613 |

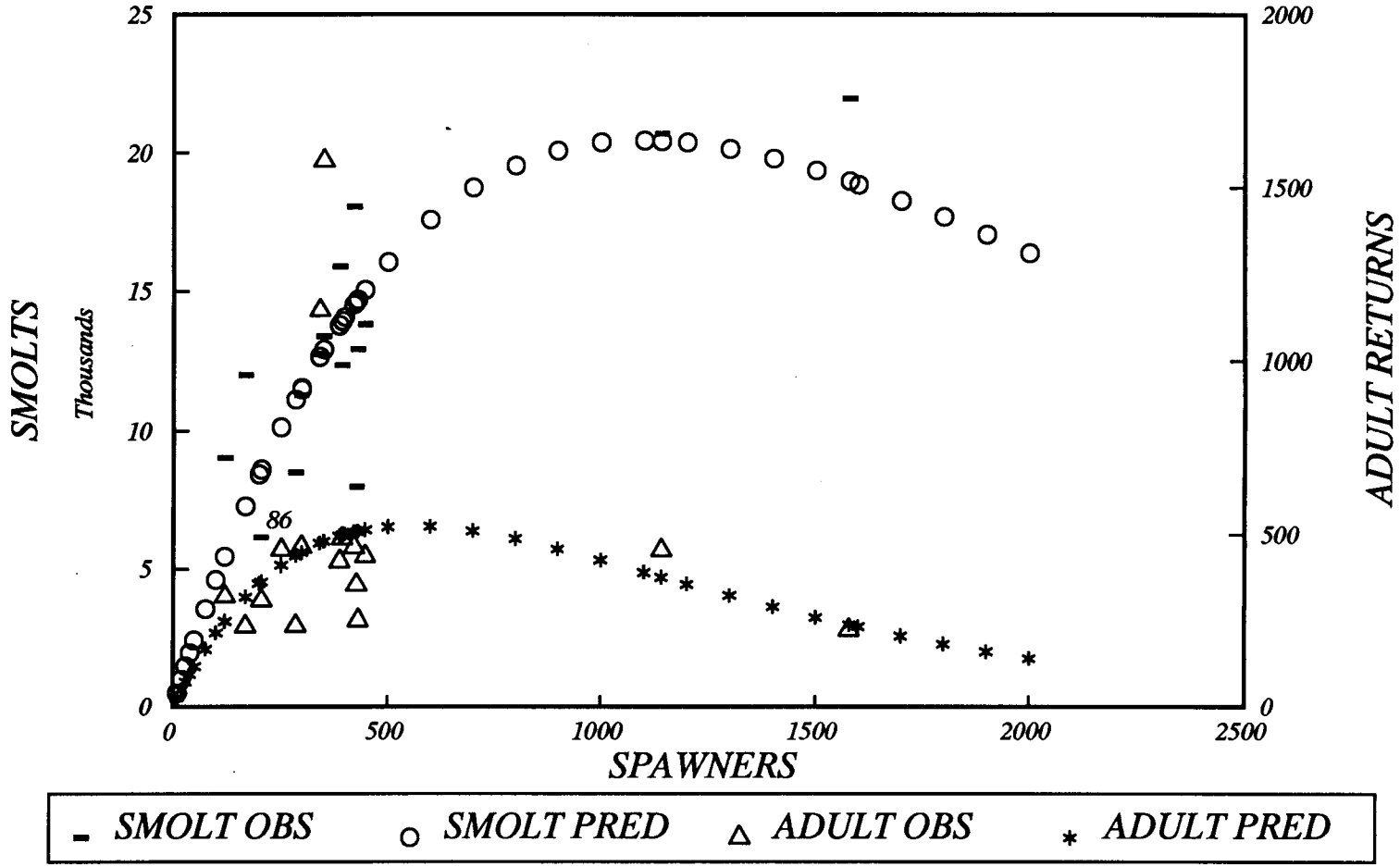


Figure 1. Ricker stock-recruit functions for adult-adult and adult-smolt for Atlantic salmon from Western Arm Brook, Newfoundland.

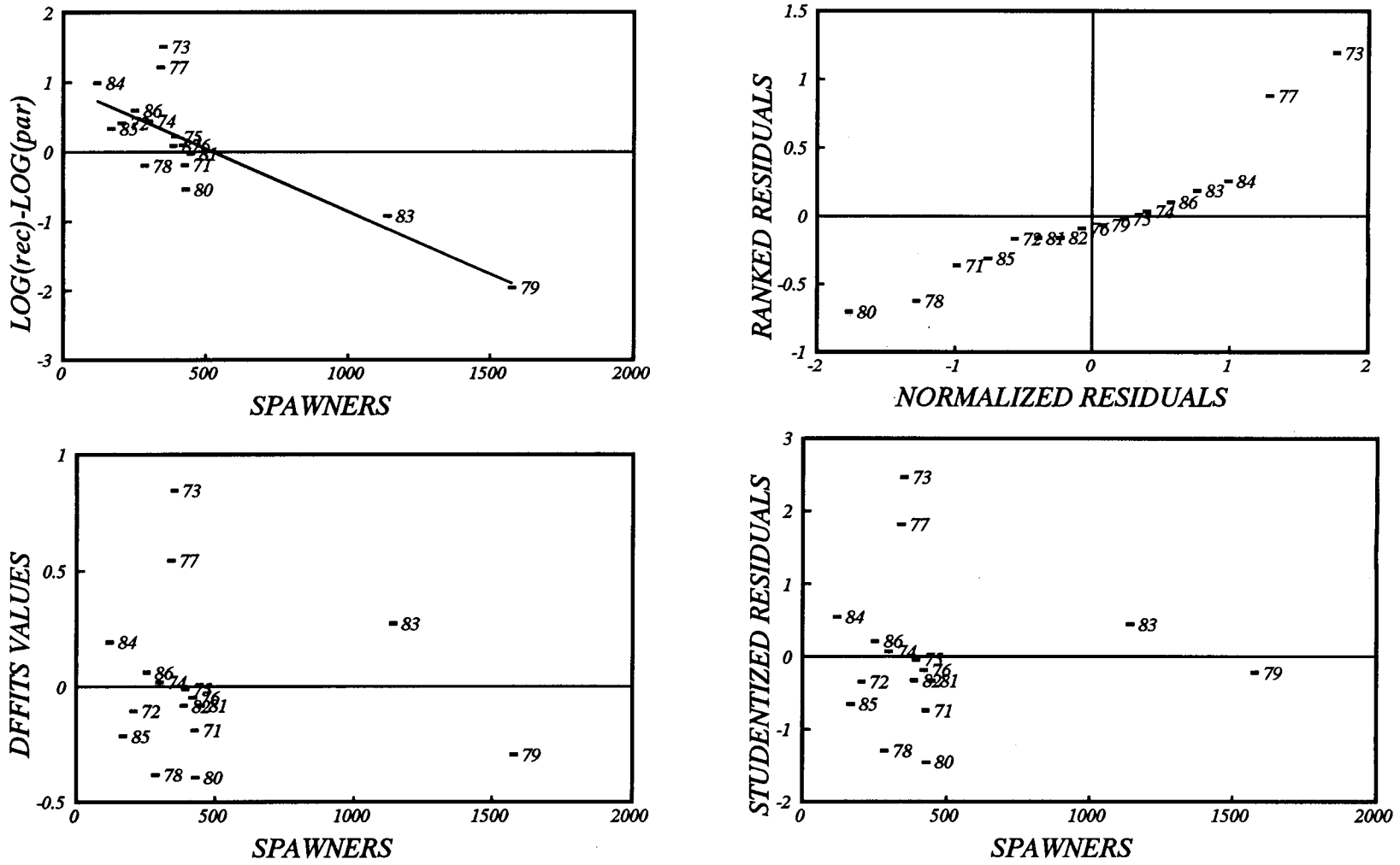


Figure 2. Diagnostics of the linear fitting of the Ricker adult-adult stock-recruit function for Western Arm Brook, Newfoundland.

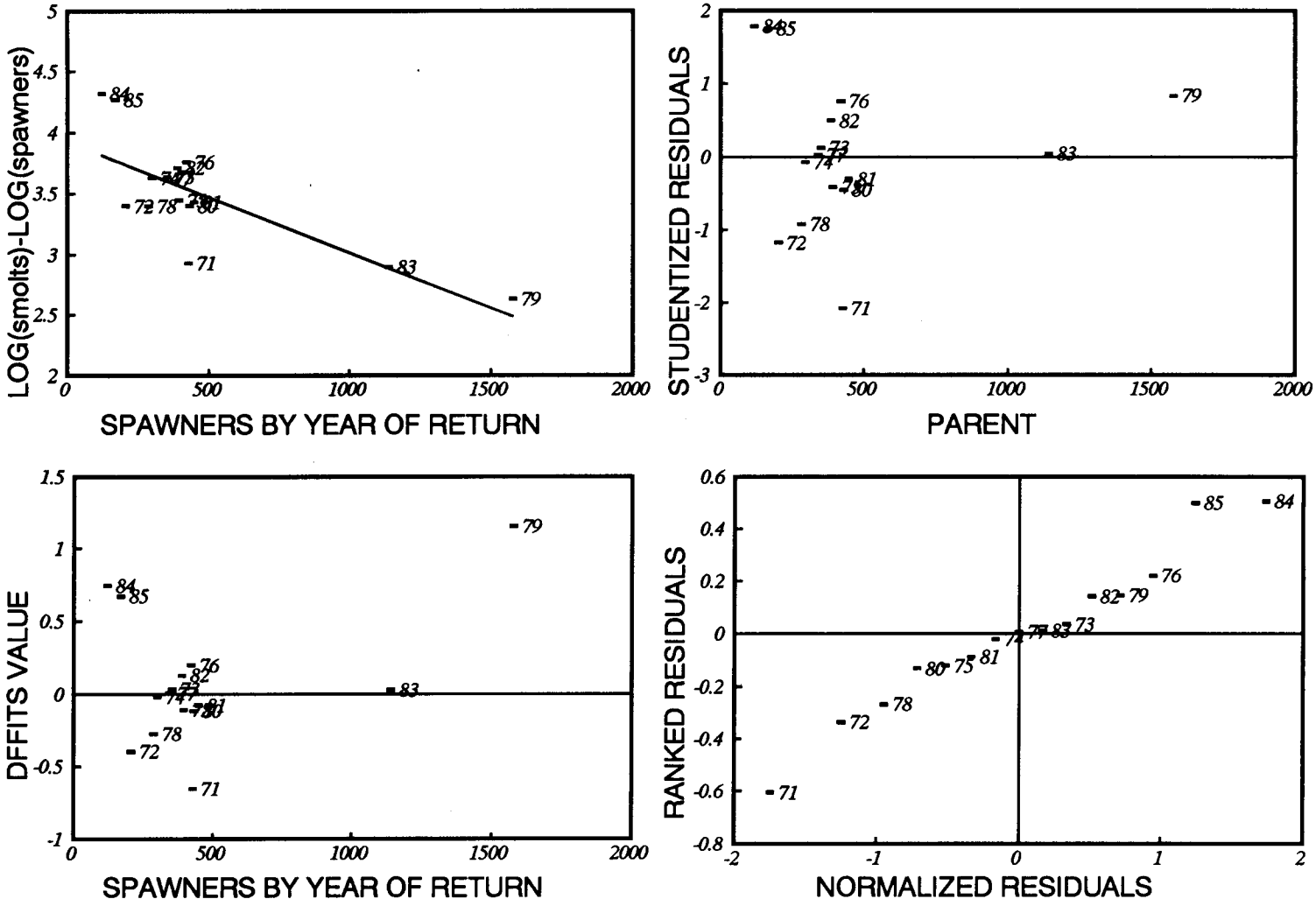


Figure 3. Diagnostics of the linear fitting of the Ricker adult-smolt stock-recruit function for Western Arm Brook, Newfoundland.

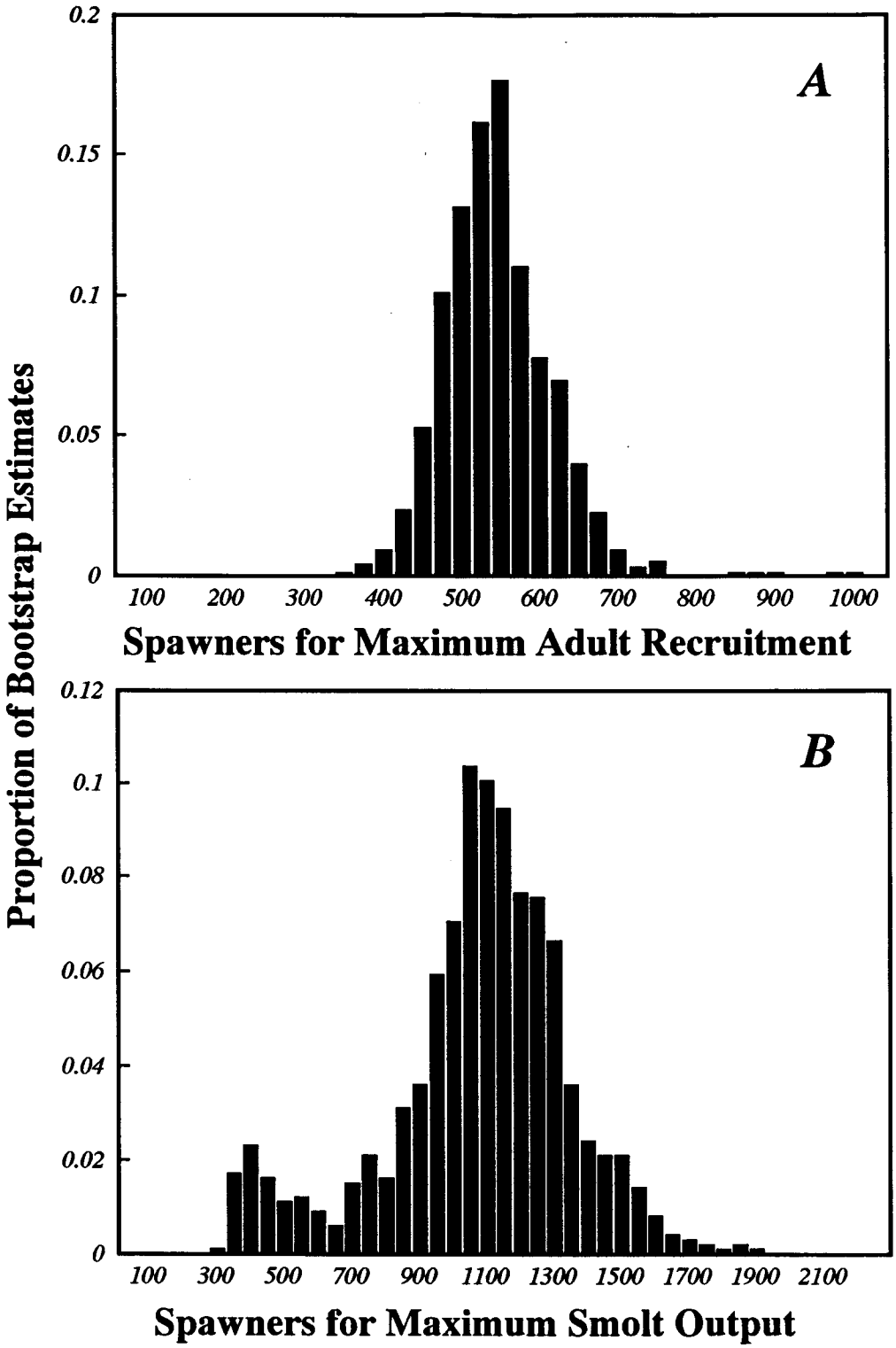


Figure 4. Spawners required to produce maximum recruitment as adults (A) or as smolts (B) for Atlantic salmon from Western Arm Brook, Newfoundland.

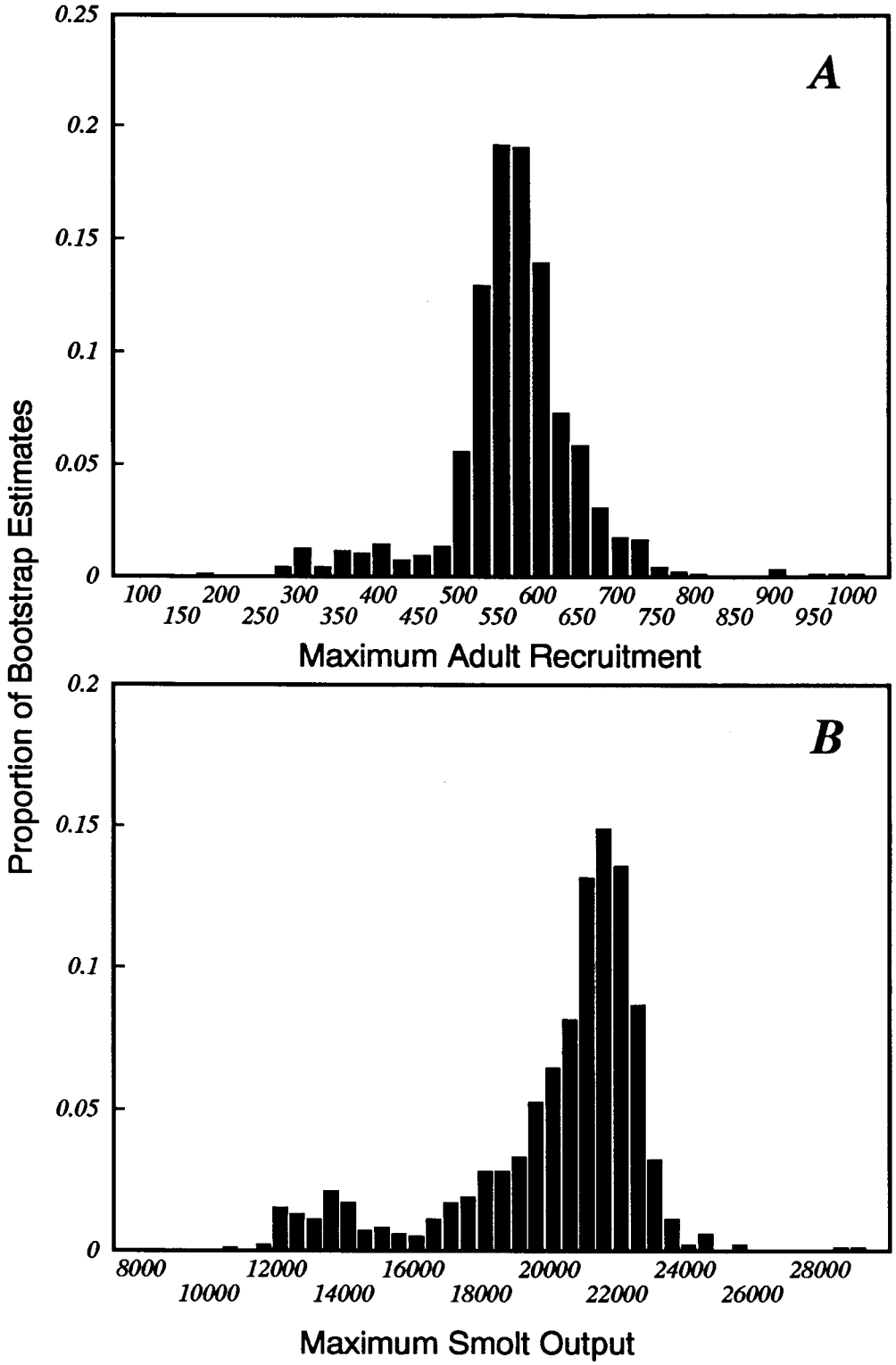


Figure 5. Predicted maximum recruitment from the Ricker functions as adults (A) or as smolts (B) for Atlantic salmon from Western Arm Brook, Newfoundland.

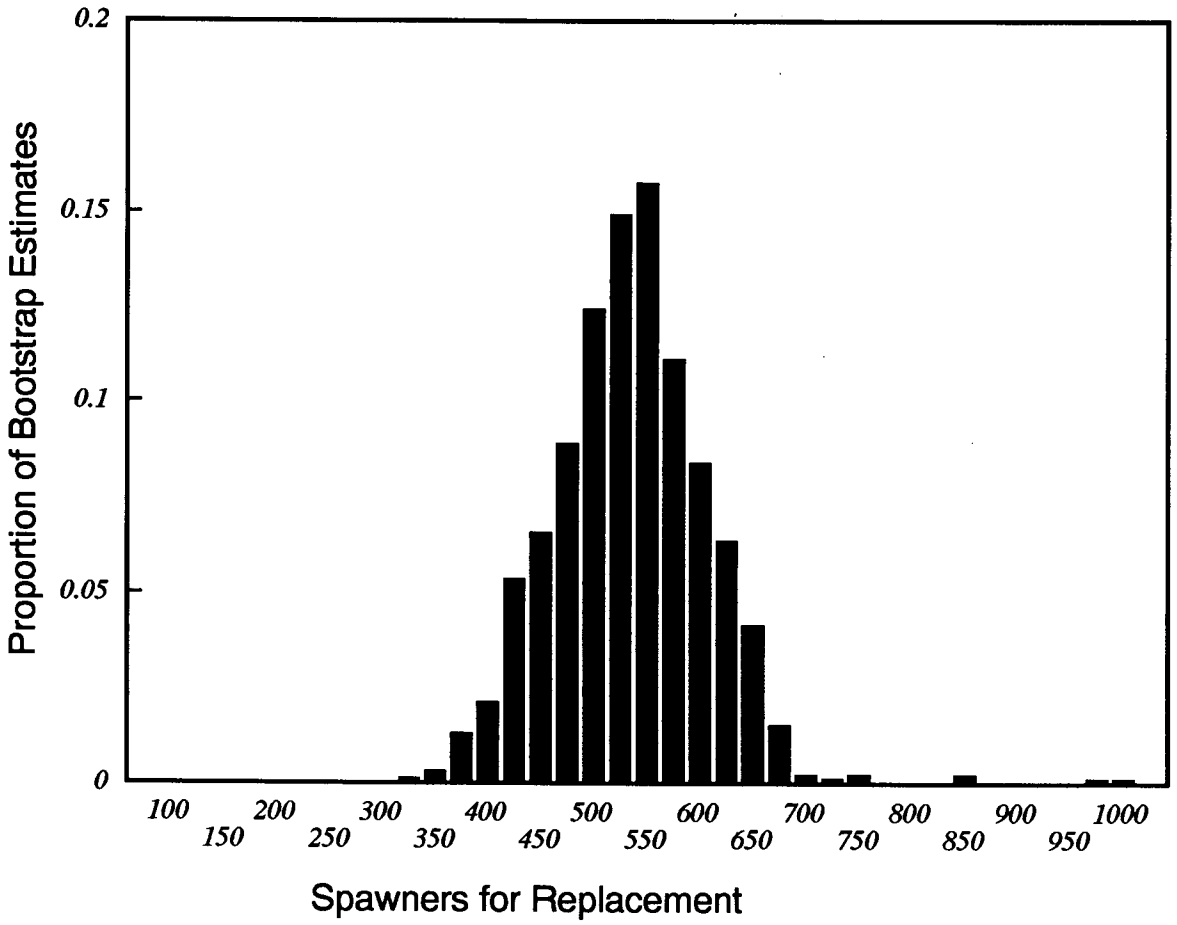


Figure 6. Spawners required for replacement level adult recruitment for Atlantic salmon from Western Arm Brook, Newfoundland.