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The Contribution of Estuaries to the Offshore Winter Flounder Fishery in Rhode Island

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Abstract

The winter flounder, **Pseudopleuronectes americanus** (Walbaum), has been found to be one of the important demersal fishes of Rhode Island. The contribution of particular breeding areas and the significance of shallow estuarine environments to the offshore flounder fishery were studied by means of markrecapture population estimation procedures. The adult breeding population in one salt pond (Green Hill Pond; Charlestown, Rhode Island) was inventoried. In addition, an estimate of the offshore population as well as the population of juvenile winter flounder in another salt pond was obtained. On the basis of the juvenile population estimate, it was found that about 25 per cent of the total recruits to the offshore fishery were contributed by two shallow lagoons. An estimate of the mortality rate from egg to juvenile (Age I) was also made indicating a survival of about 18 individuals from each 100,000 newly hatched eggs. It was concluded from the projected population estimates that a significant contribution to the fishery was derived from the shallow estuarine environments.

INTRODUCTION

THE PURPOSE OF THIS PAPER is to provide preliminary quantitative information on the numerical abundance of some life history stages of the winter flounder, *Psuedopleuronectes americanus* (Walbaum), in Rhode Island. Bigelow and Schroeder (1953), Perlmutter (1947) as well as Warfel and Merriman (1943) have summarized much of the available information regarding the life history of this species. However, with the exception of work by Dickie and McCracken (1955) in Nova Scotia, little quantitative information is yet available concerning the vital statistics of adult populations.

The above-mentioned authors indicate that movements by adult winter flounder are restricted to relatively short seasonal migrations. Usually, migration to shoal breeding grounds by adults is followed by a movement (dispersal) into deeper offshore waters as water temperatures increase. It is submitted that rational management of a fishery of this type is highly dependent upon estimates of the magnitude of adult stocks in defined areas as well as estimates of the contribution of recruits from specific breeding areas. The ability of breeding adults to return to specific breeding sites in large numbers has already been demonstrated (Saila, 1961).

Estimates of mortality during early life history stages are also necessary for a better understanding of the fishery. Although Pearcy (1960) provided estimates of mortality in his substantial contribution to the early life history of winter flounder in a Connecticut estuary, comparisons with this data are desirable. Fecundity data can be utilized to provide estimates of the mortality rate from egg to juvenile if the following additional information is available from a defined area: (1) the numerical strength of the adult population, (2) the numerical strength of the population of juvenile fish, and (3) the adult sex ratio.

In this study the fecundity of winter flounder has been estimated, and population estimates of the breeding adults as well as juvenile winter flounder in defined areas have been made. These data, in addition to published sex ratio observations have been utilized for an estimate of early stage mortality. The population estimates are also considered with reference to the importance of estuaries in maintaining winter flounder stocks. The role of estuaries as production and nursery areas for several kinds of fishes has been discussed by Thompson (1961) in a qualitative sense, but quantitative data pertaining to any species utilizing estuaries have been largely unavailable to date. The results of this study are directed toward a quantitative evaluation of estuaries with specific reference to winter flounder.

MATERIALS AND METHODS

Fecundity. Specimens collected for fecundity studies were obtained with an experimental otter trawl from Narragansett Bay, Rhode Island and Massachusetts on January 11, 1958. Total lengths were taken to the nearest millimeter on a flat measuring board, and weights (including gonads) were taken on dietetic scales to the nearest two grams.

The procedure for estimating fecundity involved: (1) removal of gonads from mature females, (2) preservation in a suitable medium to break down ovarian connective tissue and membranes, (3) dilution of free ova to a known volume with water, (4) removal of aliquots, and (5) counting aliquot samples. Gonads were removed and weighed on a triple-beam balance to the nearest 0.1 gram. They were preserved in labelled jars containing modified Gilson's fluid (Simpson, 1951). After ovarian tissue had broken down sufficiently to permit easy separation of eggs by gentle manipulation with the fingers, the eggs were washed in fresh water. Estimates of the number of eggs in the ovaries of each fish were made from sub-samples of 1/1205 each. The eggs were placed in special calibrated cylinders used for measuring particle size distribution of soil suspensions and were stoppered with a rubber ball. Shaking was continued until apparently random distribution was achieved, and a one millileter aliquot was quickly removed with a Stempel pipette. The sample was spread on absorbent paper placed over a transparent plastic grid (12 x 12 cm) ruled into one centimeter squares. The grid was illuminated and the entire sample was enumerated with a hand tally counter under magnification of a large hand lens. At least four replicate samples were counted from each pair of ovaries.

Population Estimates. Estimates of the population of breeding adults and the juvenile population in a defined area were of the multiple census type (Ricker, 1958) in which fish were marked and added to the population over a period of time during which samples were taken and examined for recaptures. The major assumptions involved in this type of population estimate, the possible sources of error and their correction are discussed in connection with the results of individual estimates. Strictly speaking, the method requires a constant population with no recruitment or mortality. However, corrections can be made for major sources of error in estimation. The estimate of the population of adults in the offshore fishing area was made in a manner similar to that described by Walburg (1953). Details of the procedure and confidence limits are also described in the results.

Green Hill Pond (adult breeding population estimate). The estimate of the breeding population of adults was made during the period November 7, 1957, to March 13, 1958, in Green Hill Pond, Charlestown, Rhode Island. This shallow lagoon has a maximum depth of slightly more than 2 meters and a surface area of 475 acres. A narrow channel connects Green Hill Pond to Charlestown Pond which is connected to Rhode Island Sound by a similar channel. Thus, ingress and egress of fishes is possible from offshore waters. The gear for capture consisted of a small otter trawl fished from an outboard motor boat. The trawl had a mouth opening of approximately 18 feet and was hung with ¾-inch-square mesh throughout. Most of the bottom of the pond was free of major obstructions and was suitable for trawling. Only short tows of less than 10 minutes' duration were made in order to keep the fish in good condition. Peterson type tags were attached to the nape region of initially captured fish for purposes of identification. Only fish in apparently good condition were tagged and released. The total number of fish marked for this estimate was 488. These fish had an average total length of 302 mm and an average weight of 348 grams.

Charlestown Pond (juvenile population estimate). Estimates of the juvenile winter flounder population were made in Charlestown Pond during the period of July 22-October 27, 1960. The surface area of Charlestown Pond is about 1560 acres, and it has a maximum depth of slightly more than 3 meters. The gear for capture consisted of an otter trawl similar to the one described for the adult population estimate. Much of the bottom of this pond was also suitable for trawling, but the trawl areas were restricted to water of about 2 meters depth or greater. Marking was achieved by removal of one or both of the pectoral or ventral fins with bone cutting forceps. The sampling period extended over enough time to insure recapture of a significant number of the juvenile fish. The mean total length of the sample of 4134 fish was 227 mm and the mean weight was 170 grams. The mean weight was calculated from a length-weight relationship for this species (Berry, 1959), since only lengths were obtained in the field. Examination of the length-frequency distribution of the captured fish by 5 mm class intervals indicated a unimodal distribution. The modal value on the length-frequency distribution compared favorably with the expected size for Age I winter flounder. The observed modal length was 215 mm versus a calculated length of 207 mm for Age I (Berry, 1959). Although a few fish which did not fall in this group were undoubtedly encountered, the error introduced in this manner was believed to be small. Thus, the juvenile population estimate is considered to be an estimate of Age I winter flounder in the pond.

Rhode Island Sound (offshore population estimate). The recoveries of tagged fish in the offshore fishery for winter flounder can be used for a population estimate for a given year if catch statistics for the period under consideration are also available. The latter data were available from the Biological Laboratory, U.S. Fish and Wildlife Service, Woods Hole, Massachusetts. Tag returns were processed and rewards were paid by the above-mentioned agency. The offshore fishery consists of a fleet of about 40 small otter trawlers. Tagged fish used for the Green Hill Pond population estimate as well as additional tagged fish released at an earlier date in 1957 were utilized. A total of 493 individuals tagged during 1957 were involved in the population estimate.

RESULTS

Fecundity. Fecundity estimates were made for 46 mature winter flounder. The results of the estimate indicate that the fecundity of Rhode Island winter flounder varies from 193,000 eggs for a 249 mm fish to 1,340,000 eggs for a fish of 428 mm (Table 1). The grand average was 610,000 eggs for a mean fish length of 334 mm. A measure of the accuracy of the fecundity estimates is given by the coefficient of variation (C). It was found to be 9.38 per cent for a series of 12 samples taken from the same pair of ovaries. The observed variation is higher than the sampling variation for egg counting by essentially similar procedures obtained by Simpson (1951) and Bagenal (1957). They reported sampling variation on the order of 5 per cent for plaice and long rough dab eggs. The fecundity range reported herein compares favorably with the range of values (500,000-1,500,000) given by Bigelow and Schroeder (1953) with the exception of the lower limit.

TABLE 1

FECUNDITY ESTIMATES OF 46 WINTER FLOUNDER TAKEN ON JANUARY 11, 1958 FROM NARRAGANSETT BAY, RHODE ISLAND AND MASSACHUSETTS

TL (mm)	Wt. (g)	Gonad Wt.(g)	Egg Count				Fecundity
			1	2	3	4	
322	487	98.4	398	431	344	363	463,000
357	500	121.5	548	558	513	533	648,000
626	272	60.7	225	239	249	221	282,000
399	960	248.2	958	943	877	937	1,119,000
365	646	78.0	484	487	492	462	580,000
389	886	215.8	817	861	815	827	1,000,000
341	550	149.1	751	639	686	637	817,000
353	584	129.3	596	577	526	542	675,000
392	1003	215.6	960	987	989	1015	1,189,000
365	687	150.4	725	734	723	687	864,000
408	953	208.7	755	641	669	710	835,000
381	792	205.4	818	842	852	752	983,000
359	619	154.0	596	556	578	535	682,000
311	392	56.2	486	503	457	379	549,000
298	380	65.2	296	286	277	304	349,000
268	291	46.5	286	275	279	245	327,000
249	210	28.2	155	161	176	149	193,000
278	268	39.0	242	207	286	201	282,000
295	369	44.4	272	277	286	278	335,000
356	633	123.8	514	588	501	495	631,000
310	506	105.5	630	596	681	596	754,000
315	443	85.9	340	297	310	318	381,000
359	691	188.6	879	880	879	841	1,049,000
325	507	133.0	569	602	625	613	725,000
356	670	186.7	798	801	804	760	952,000
344	627	216.2	600	695	669	684	798,000
346	555	125.4	542	601	536	529	665,000
300	382	72.2	301	315	310	324	376,000
			284	281	279	267	—
			208	290	312	259	—
288	334	87.5	332	357	352	361	422,000
337	540	150.4	543	552	564	524	657,000
332	440	93.7	265	296	290	277	340,000
320	445	120.0	511	515	524	448	601,000
343	525	92.0	377	345	356	362	434,000
296	375	80.9	424	418	417	413	504,000
319	422	83.4	313	289	272	284	348,000
344	584	125.4	431	468	528	470	571,000
282	294	68.0	273	275	284	254	327,000
280	280	47.0	227	190	147	164	219,000
359	649	173.0	681	682	748	699	846,000
364	667	163.0	642	699	772	715	852,000
428	1051	276.0	1070	1141	1263	974	1,340,000
355	580	179.7	635	581	655	636	754,000
343	553	143.8	578	589	608	586	711,000
296	359	86.6	331	332	341	347	406,000
347	538	85.0	280	270	228	241	306,000
338	544	132.6	615	566	547	586	696,000

Scatter diagrams showing the dependence of fecundity upon weight (Figure 1), total length (Figure 2), and gonad weight (Figure 3), appear adequate to suggest that the form of relationships between fecundity and length as well as gonad weight are not linear, but that the fecundity-weight relationship is approximated by a straight line. Further, the apparent proportional increase in scatter with increasing fecundity in Figures 2 and 3 suggest a logarithmic transformation to overcome this difficulty.

From the measurements of fecundity (F), total length (L), weight (W) and gonad weight (G) it was desired to estimate the dependence of the first set (F) upon the others. For a problem of this nature a multiple regression equation can be fitted where:

$$F = F_0 + B_1 (L-\bar{L}) + B_2 (W-\bar{W}) + B_3 (G-\bar{G}).$$

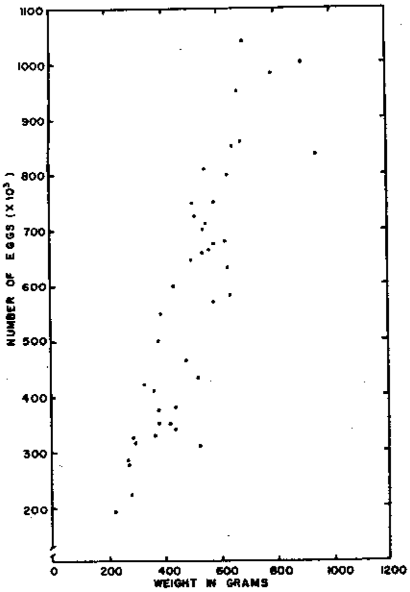

FIGURE 1. The relationship of weight (W) on fecundity (F) for 46 winter flounder.

In this expression a unit increase in L causes an increase of B_1 in F, a unit increase in W causes an increase of B_2 in F, etc. In many cases the estimate of the dependent variable may be significantly improved by taking into account several independent variables. Although there is high intercorrelation among the independent variables this reasoning was followed in the analysis of the fecundity data.

A multiple regression of the common logarithms of total length (L), weight (W), and gonad weight (G) on fecundity (F) was performed. The resulting multiple regression equation:

$$\text{Log } F \text{ (thousands of eggs)} = 1.1272 + 0.7701 \log L - 0.04877 \log W - 1.7782 \log G$$

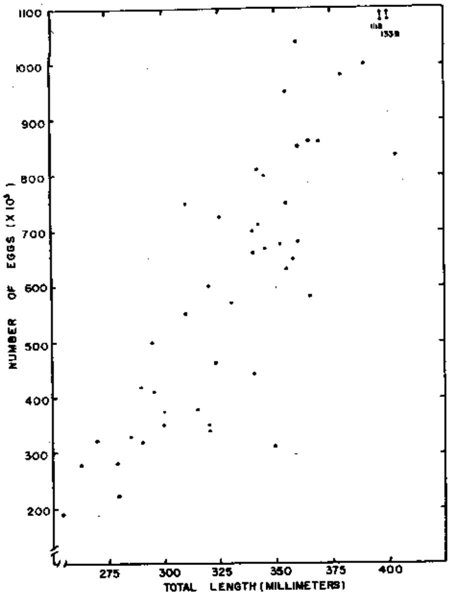

FIGURE 2. The relationship of total length (L) on fecundity (F) for 46 winter flounder.

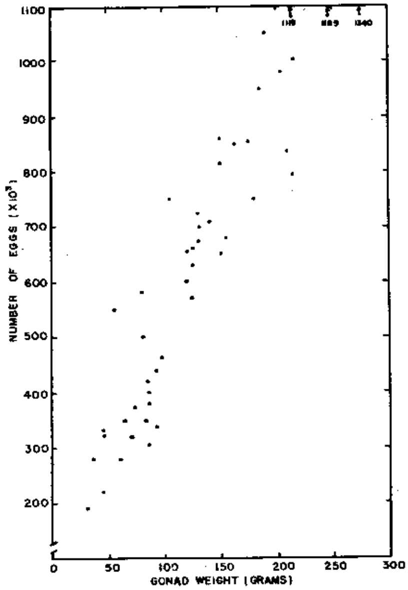

FIGURE 3. The relationship of gonad weight (G) on fecundity (F) for 46 winter flounder.

may be used to estimate the fecundity of winter flounder when real values are substituted for the independent variables. The variance ratio for testing the significance of the multiple regression coefficient was high ($F = 29.89$, d.f. $= 3,42$), and the coefficient of multiple correlation (R^2) was found to be 0.681.

Total length and gonad weight were then deleted from the analysis, and a simple regression equation for estimating the relationship between weight and fecundity was calculated. The resulting equation:

$$\text{Log } F = 2.6712 + 1.1383 \log W$$

is believed to be adequate for practical purposes in estimating winter flounder fecundity.

Green Hill Pond (breeding adult population estimate). Although multiple census techniques (Schnabel and Schumacher formulae) are useful in population estimation and have been frequently applied, it is important to be aware of possible sources of systematic error. The major systematic errors in a multiple census include those due to (1) fishing mortality, (2) natural mortality, and (3) recruitment.

Fishing mortality in Green Hill Pond was considered to be negligible during the census period. Although occasional seining and fyke netting is done in the pond, none was directly observed during this period. Natural mortality during the sampling period was also assumed to be low and well within the limits of sampling error. Although Dickie and McCracken (1955) indicate that the winter period may be the "danger" period for this species in Nova Scotian waters, recent work by Pearcy (1960) in Connecticut does not confirm this. Pearcy estimated a constant mortality rate of about 8 per cent per month for Age I fish. The effect of natural mortality is to make the Schnabel type estimate less than the initial population size, assuming no other sources of error. No attempt was made in this study to correct for natural mortality.

Recruitment and immigration exert similar effects on population estimation. That is, a dilution of the population occurs with a resulting estimate of the population which is too great. Substantial emigration and natural mortality result in low estimates. The results of the previous year's fyke netting in Green Hill Pond indicate that immigration occurs into the pond for an extended period and at variable rates. This is then followed by emigration out of the area. DeLury (1958) shows that estimates of a population can be obtained by a multiple regression procedure correcting for immigration and emigration losses. However, constant rates are assumed in this procedure.

It can easily be seen from an inspection of the calculations for the conventional Schnabel and Schumacher type population estimates (Table 2) that the successive independent estimates of the population (C_tM_t/R_t) tend to increase over time, after which there is a significant decline noted in the last value of this column. Although this might be due to differential mortality of marked fish, the cold weather, careful handling and hardy nature of the winter flounder contribute to strengthening the assumption that this was not the case. Instead, observations on breeding biology (Saila, 1961) indicated a relatively prolonged period of migration to the breeding area and later movement out as the season progresses. The trend in the individual estimates was ascribed to immigration and the final decrease was probably due to emigration. Ricker (1958) has suggested a method for eliminating recruitment effects by calculating a linear regression between successive estimates of the reciprocal of the population (1/N) and the mid-points of successive sampling intervals. This procedure could also be applied to corrections for immigration inasmuch as both pheno-

TABLE 2

CALCULATIONS FOR SCHNABEL AND SCHUMACHER ESTIMATES (1957-8) OF ADULT WINTER FLOUNDER IN GREEN HILL POND, CHARLESTOWN, RHODE ISLAND, FROM TRAWL RECAPTURES

C_t	R_t	M_t	C_tM_t	M_tR_t	$C_tM_t^2$	R_t^2/C_t	C_tM_t/R_t
65	0	0	0	0	0	0	0
25	1	65	1625	65	105625	.040	1625
19	1	79	1691	89	150499	.053	1691
45	0	107	4815	0	515205	0	0
11	0	152	1672	0	254144	0	0
12	0	163	1956	0	318828	0	0
45	3	175	7875	525	1378125	.200	2625
61	3	217	13237	651	2872429	.147	4412
20	2	275	5500	550	1512500	.200	2750
59	1	293	17287	293	5065091	.017	17287
77	2	351	27027	702	9486477	.052	13514
49	1	426	20874	426	8892324	.020	20874
185	10	474	87690	4740	41565060	.541	8769
673	24		191249	8041	72116307	1.270	

mena result in dilution of the marked members of the population. The Y intercept of the regression line is the reciprocal of the population at time zero and provides an estimate of the population prior to migration. In this instance we are interested in the maximum size of the breeding population where both immigration and emigration occur. However, they do not appear to occur simultaneously or at constant rates, and the relationship between the reciprocal of the population and time is curvilinear (Figure 4). Thus in the relationship demonstrated, the best estimate of the maximum population is the point where the curve has a minimum slope. This point is where the estimate of the reciprocal of the population (1/N) is a minimum. The point on the Y coordinate corresponding to a minimum slope of the curve provides an estimate of the maximum population in the pond prior to emigration. Polynomials of successively high degree were fitted to the relationship between the reciprocal of population and mid-points of successive time intervals. It was found that a second degree polynomial minimized the standard error of estimate. The data and the results of fitting a quadratic equation to the relationship between the reciprocal of the estimated population and the mid-point of successive sampling intervals are shown (Table 3 and Figure 4).

The equation for the least squares quadratic equation of best fit from these data is:

$$y = 6.765 - 0.1531x + 0.00098x^2$$

The slope of the line (1) at any point can be found by differentiating:

$$1 = dy/dx = 0.00196x - 0.1531$$

The low point on the curve is obtained by making the derivative of the slope equal to zero:

$$d1/dx = 0.00196x - 0.1531 = 0$$

From this expression it is found that $x = 78$ and the reciprocal of the population $x10^4$ is 0.8835. This provides an estimate of 11320 breeding adults as the Green Hill Pond population. The above is believed to be a unique method to account for immigration and emigration losses in order to obtain an estimate of the population at its maximum.

The various estimates of the adult population in Green Hill Pond from the calculations in Tables 2 and 3 are summarized below:

1) Original Schnabel estimate —

$$\hat{N} = \frac{\Sigma(C_t M_t)}{R} = 7969$$

$$v(1/\hat{N}) = \frac{R}{(\Sigma C_t M_t)^2} \; 6.562 \times 10^{-10}$$

95 per cent range = 5516 — 14345

2) Modified Schnabel estimate —

$$\hat{N} = \frac{\Sigma(C_t M_t)}{R + 1} = 7650$$

Poisson limits, 95 per cent range = 5101-11577

TABLE 3

DATA FROM THE POPULATION ESTIMATE OF ADULT WINTER FLOUNDER IN GREEN HILL POND AND RESULTS OF FITTING A SECOND DEGREE POLYNOMIAL

Period (mid points of sampling intervals)	Reciprocal of population	Estimated reciprocal from quadratic
X	Y	Y
4.	6.154	6.168
6.	5.154	6.168
26.	3.766	3.447
30.	2.230	3.054
47.	3.533	1.733
50.	.5594	1.559
69.	.7175	.8659
72.	.4649	.8210
91.	1.1404	.9466

$$Y = 6.766 - 0.1531\,x + 0.0009799\,x^2$$

3) Schumacher estimate —

$$(1/\hat{N}) = \frac{\Sigma(M_t R_t)}{\Sigma(C_t M_t^2)} = 1.115 \times 10^{-4}$$

$$\hat{N} = 8969$$

$$\text{Standard error of } (1/\hat{N}) = \frac{s}{\sqrt{\Sigma C_t M_t^2}} = 2.002 \times 10^{-5}$$

95 per cent range = 6447 — 14728

4) Estimate adjusted for immigration and emigration —

$$\hat{N} = 11320$$

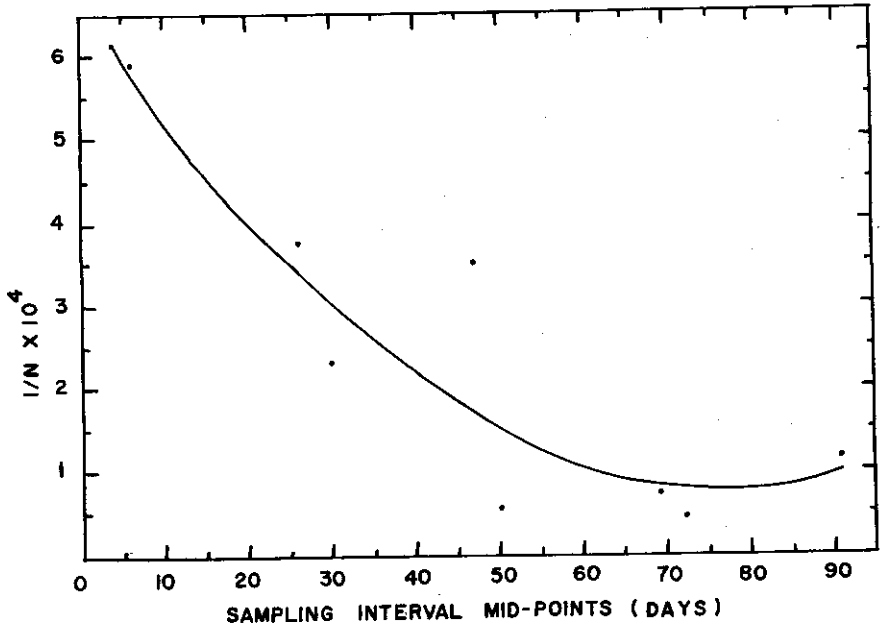

FIGURE 4. The relationship between the reciprocal of the population and mid-points of sampling intervals for the Green Hill Pond population data. A second degree curve has been fitted to these data.

Inspection of the above population estimates indicates clearly that differences among the first three estimates are small. However, the population estimate which is adjusted for immigration and emigration is considerably higher, and it is apparent that the conventional population estimation procedures are biased toward a low value if one is interested in the estimate of the maximum size of the population during a period when immigration and emigration are occurring at different times during sampling. These data demonstrate the desirability of considering possible sources of error and carefully defining the required population estimate. The population of 11320 adults is considered the most realistic estimate of maximum population size. From this estimate a calculated standing crop of 23 adults per acre (18 pounds per acre) based on a mean weight of 348 grams is obtained.

Charlestown Pond (juvenile population estimate). Three estimates of the population of Age I winter flounder are possible from the calculations shown in Table 4. Before considering the estimates individually, the possible sources of systematic error are again examined. Fishing mortality for this size group was neglible, although occasional sport fishing took place in the pond during the population estimation period. Natural mortality, estimated by Pearcy

TABLE 4

SCHNABEL AND SCHUMACHER ESTIMATES (1960) OF JUVENILE WINTER FLOUNDER IN CHARLESTOWN POND, CHARLESTOWN, RHODE ISLAND FROM TRAWL RECAPTURES

C_t	R_t	M_t	C_tM_t	M_tR_t	$C_tM_t^2$	R_t^2/C_t	C_tM_t/R_t
59	0	0	0	0	0	0	—
303	0	59	17,877	0	1,054,743	0	—
278	3	362	100,636	1,086	36,430,232	.032374	33545
521	0	637	331,877	0	211,405,649	0	—
276	0	1158	319,608	0	370,106,064	0	—
273	1	1434	391,482	0	561,385,188	.003663	391482
513	3	1706	875,178	5,118	1,493,053,668	.017543	291726
222	4	2216	491,952	8,864	1,090,165,632	.072072	122988
378	6	2434	920,052	14,604	2,239,406,568	.095238	153334
511	12	2806	1,433,866	33,672	4,023,427,996	.281800	119489
269	7	3305	889,045	23,135	2,938,293,725	.182156	127006
344	6	3567	1,227,048	21,402	4,376,880,216	.104651	204508
66	1	3905	257,730	3,905	1,006,435,650	.015151	257730
168	4	3970	666,960	15,880	2,647,831,200	.095238	166740
212	5	4134	876,408	20,670	3,623,070,672	.117924	175252
	52		8,799,719	149,770	24,618,974,203	1.01781	

(1960) at 8 per cent per month for juvenile winter flounder is not considered in this estimate. Since no trend in the estimates of C_tM_t/R_t is evident, no correction was made for recruitment or natural mortality. The effect of natural mortality is to make the Schnabel estimate slightly less than the initial population size, and recruitment would make the estimate too high. It is appreciated that corrections for the estimated mortality rate or a new estimate of natural mortality are possible (DeLury, 1951). However, these are not considered at this time.

A summary of the estimates of the juvenile population (Age I) in Charlestown Pond is shown below. The formulae, which are similar to those presented previously, are not indicated.

1) Original Schnabel estimate —

$\hat{N} = 169{,}225$

95 per cent range = 131,418 — 237,569

2) Modified Schnabel estimate —

$\hat{N} = 166{,}032$

Poisson limits, 95 per cent range = 125,926 — 219,499

3) Schumacher estimate

$\hat{N} = 164{,}474$

95 per cent range = 162,048 — 204,540

From the above data, it is concluded that about 165,000 winter flounder (Age I) were present in Charlestown Pond. This gives a standing crop of 106 fish per acre or 39 pounds per acre assuming a mean weight of 170 grams per individual. This is equal to approximately 4.37 grams per m². This standing crop is more than three times as high as the value of 1.44 grams per m² calculated by Pearcy (1960). It indicates a higher productivity for Charlestown Pond compared to the Mystic River Estuary in Connecticut. Indeed, this standing crop exceeds the net production of 3.4 grams/m^2 cited by Pearcy. Jefferies (personal communication) indicates that the overall productivity of Charlestown Pond is very high. These data substantiate his observations.

Rhode Island Sound (offshore population estimate). To obtain an estimate of the total population during one year, the winter flounder tagged in Green Hill Pond during 1957 were utilized. An estimate of the offshore population in only those parts of Rhode Island Sound into which significant numbers of winter flounder had dispersed was desired. Saila (1961) has indicated that the dispersal of tagged Green Hill Pond fish does not deviate significantly from a random distribution if fishing effort is taken into consideration. Of the 493 individuals tagged during 1957, 61 were recovered from specific code areas in Rhode Island Sound illustrated by Saila (1961). An estimate of the total population in these code areas in 1958 can be made in the following manner.

$$N = nt/s$$

where:

n = total (1958) catch in the defined areas = 659,634 pounds

t = total fish tagged in 1957 = 493

s = total number of tagged fish recovered in the defined areas during 1958 = 61.

Substitution in this formula gives an estimate of 5,331,140 pounds of winter flounder. If it is assumed that the average weight of the individual fish is 348 grams (the same as the average for tagged fish at initial capture) a total of 6,870,000 individuals is obtained.

A formula derived by Chapman (1948) for obtaining 95 per cent confidence limits of the population estimated above is as follows:

$$(\overline{N},\underline{N}) = nt/s^2 \left[s + 1.9208 \pm \sqrt{(s + 1.9208)^2 - s^2 \left(1 + \frac{3.8416}{n}\right)} \right]$$

$\overline{N}$ = upper limit = 6902256 pounds.

$\underline{N}$ = lower limit = 4095796 pounds.

Applications of this population estimate to evaluate the contribution of estuaries follow in the interpretation and discussion of results.

INTERPRETATION AND DISCUSSION

Juvenile Mortality. An attempt was made to utilize available results to estimate the total mortality from newly hatched egg to juvenile (Age I). The following information was available:

(1) Fecundity (calculated from fecundity — weight relationship for an average weight of 348 grams).

$$\log F = 2.6712 + 1.1383 \log W$$

$$F = 366{,}700 \text{ eggs.}$$

(2) Numerical strength of adult population — 23 per acre.

(3) Numerical strength of juvenile population — 106 Age I fish per acre.

(4) Adult sex ratio — 70 per cent females (Saila, 1961).

Scott (1929) reports a range of 33-73 per cent for successful hatching of winter flounder eggs under laboratory conditions. If a conservative value of 10 per cent for successful hatching is assumed under field conditions, a figure of 587,000 newly hatched fish per acre is obtained (0.10 x 366,700 x 16). Survival to Age I is then merely the ratio of newly hatched fish to juveniles adjusted to a common unit area.

$$s = N_t/N_0 = 106/587{,}000 = 0.000181$$

Pearcy (1960) has calculated a life table for juvenile winter flounder and reports 44 survivors to Age I per 100,000 newly hatched larvae. This is somewhat higher than the 18 survivors obtained in this study if the above is calculated on the same basis. However, it should be appreciated that these estimates are subject to large sources of error. Further, Pearcy (1960) has already demonstrated that mortality is highest in the newly hatched larvae and that the mortality rate declines over time. In this study a constant rate was assumed for survival after hatching.

Contribution of Estuaries to the Offshore Fishery

Since an estimate of the adult population is available in offshore areas into which Green Hill Pond fish have been known to disperse, some indications of the contribution of the Green Hill-Charlestown Pond areas to the maintenance of the fishery are available. It has been estimated that the offshore population consists of approximately 6,870,000 individuals. If it is assumed that the average weight of individuals caught by the fishery is the same as the average weight of breeding adults, a total of at least 861,000 recruits are required to sustain the fishery at its present level without any allowance for natural mortality. If the number of juveniles produced in Charlestown and Green Hill Ponds is calculated on the basis of 106 Age I fish per acre, a figure of 215,710 is obtained. The contribution of the two areas (Charlestown Pond and Green Hill Pond) is about 25 per cent of the recruits required to maintain the offshore fishery. If we consider all the shallow water areas on the coast of Rhode Island it is conceivable that the entire offshore fishery in the areas designated could be supplied with adequate numbers of recruits from shoal breeding areas on the coast. It is concluded from these data that the importance of estuaries is sufficiently high to virtually eliminate this offshore fishery if these breeding grounds were to be destroyed.

It should be appreciated however, that winter flounder are taken from other areas than those from which a population estimate has been obtained. One of the major problems remaining in a better understanding of winter flounder biology is a definition of the source(s) of recruits for the entire fishery.

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The Ivory Barnacle, Balanus eburneus, as a Biological Indicator in Brackish Waters of South Florida

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