THE ROLE OF ESTUARINE AND OFFSHORE NURSERY AREAS FOR YOUNG ENGLISH SOLE, *PAROPHRYS VETULUS* GIRARD, OF OREGON

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ABSTRACT

Our trawling studies confirm that age group 0 English sole are common in shallow waters along the open coast as well as in estuaries of Oregon. Both areas appear to be important nursery areas for this species. Metamorphosing English sole were recruited to Yaquina Bay over many months between November and June during the 5 years studied. Seasonal trends in abundance of these transforming fish were rather similar to both Yaquina Bay and open coastal stations. Transforming individuals, however, were found earlier in the fall and later in the spring and summer along the open coast than in Yaquina Bay.

Based on catch curves, the densities (no. m^{-2}) of juvenile English sole were much higher in Yaquina Bay than along the open coast. Transforming sole (20-25 mm) were an exception. They were sometimes most abundant at the open coast location. Increasing densities of 20-40 mm length fish in the Yaquina Bay catches were accompanied by decreased catches of this size group at the open coast site. This suggests immigration of a broad size range of both transforming and fully transformed individuals into Yaquina Bay.

English sole, *Parophrys vetulus* Girard 1854, is a major component of the catches in the northeastern Pacific trawl fishery, usually ranking second only to Dover sole, *Microstomus pacificus*, in annual landings off Oregon (Barss 1976[3]; Demory et al. 1976[4]). It ranges from Baja California to Unimak Island in western Alaska, with commercial quantities at depths of 128 m or less (Hart 1973). Tagging studies have revealed a series of relatively discrete stocks of English sole off California, Oregon, Washington, and British Columbia (Ketchen 1956; Forrester 1969; Jow 1969; Pattie 1969; Barss 1976 fn. 3).

Spawning of English sole is protracted, usually extending from September through April, and is often variable in seasonal intensity within and among spawning seasons (Budd 1940; Ketchen 1956; Harry 1959; Jow 1969; Laroche and Richardson 1979). Much of this variability among years may be related to upwelling and bottom temperatures (Kruse and Tyler 1983). Spawning concentrations of adult English sole were found in the fall off the central Oregon coast at depths of 70-110 m (Hewitt 1980).

English sole are fecund, producing 327,600-2,100,000 eggs, depending on the size of female (Ketchen 1947; Harry 1959). Eggs are pelagic and hatch in about 4½ d at 10°C (Alderdice and Forrester 1968). Larvae are often abundant during late winter and early spring in coastal waters of Oregon (Richardson and Pearcy 1977; Mundy 1984). Larval abundance may fluctuate greatly among years, possibly due to annual differences in ocean conditions (Laroche and Richardson 1979; Mundy 1984). The pelagic phase lasts 8-10 wk (Ketchen 1956; Laroche et al. 1982), and most individuals complete metamorphosis and acquire the morphology of benthic pleuronectids at 20 mm SL and 120 d of age (Ahlstrom and Moser 1975; Rosenberg and Laroche 1982).

While early larval stages are rarely found in estuaries (Misitano 1970; Pearcy and Myers 1974), transforming larvae and early juvenile stages of English sole are common in estuaries (Westrheim 1955; Smith and Nitsos 1969; Olsen and Pratt 1973; Pearcy and Myers 1974; Misitano 1976; Toole 1980; Bayer 1981) and shallow protected bays (Ketchen 1956; Kendall 1966; Van Cleve and El-Sayed 1969). Young English sole are known to utilize 13 estuaries along the Oregon coast and were absent in only 3 small estuaries surveyed along the southern Oregon coast.[5] Villadolid (1927, as cited by Misitano 1970) captured

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[3]Barss, W. H. 1976. The English sole. Oreg. Dep. Fish Wildl., Inf. Rep. 76-1, 7 p.

[4]Demory, R. L., M. J. Hosie, N. Ten Eyck, and B. O. Forsberg. 1976. Marine resource surveys on the continental shelf off Oregon, 1971-74. Oreg. Dep. Fish Wildl., 49 p.

[5]Report of estuary surveys, July-August 1972. Fish Comm. Oreg. Intern. Rep. GS-73-1, 14 p.

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0-age English sole in San Francisco Bay but not off the coast.

Based on the incidence of a parasitic infection, apparently acquired only in estuaries, and the absence of 0-age English sole in Demory's (1971) surveys off the northern Oregon-southern Washington coast, Olsen and Pratt (1973) concluded that estuaries are likely the exclusive nursery for English sole on the Oregon coast. Laroche and Holton (1979), however, captured 0-age English sole in shallow waters along the open Oregon coast, indicating that estuaries may not be the only nursery area for English sole off Oregon.

The main objective of our study is to evaluate the relative importance of estuarine and open coastal nursery grounds for young English sole off Oregon.

METHODS AND MATERIALS

Bottom trawl collections provided most of the information on the distribution and abundance of juvenile English sole. Collections were made in Yaquina Bay and along the open coast outside the bay. These were supplemented with extensive trawl collections farther to the north and south along the open coast and collections in other estuaries.

Fish were collected using a 1.52 m wide, 56 cm high beam trawl (see Krygier and Horton 1975) from the RV *Paiute* and from a 7.3 m dory. Additional collections with a 2.72 m beam trawl (Carey and Heyamoto 1972) were made on the RV *Cayuse*. To retain small, settling fish, fine-mesh (1.5-3.5 mm stretch) liners were used in the trawls. The 1.52 and 2.72 m beam trawls were fitted with a 1.0 or 2.0 m circumference wheel, respectively, and a revolution counter to estimate the area sampled (Carey and Heyamoto 1972; Krygier and Horton 1975). Tows were made at 0.7-1.0 m s^{-1}. Tow duration was normally 5-10 min on the bottom in estuaries and 10-20 min along the coast, usually at a 4:1 scope. Most tows were during daylight hours.

Collections for juvenile English sole were made in five different study areas (Fig. 1, Table 1):

ESTUARINE

1) Yaquina Bay: 1.52 beam trawl collections were made in lower Yaquina Bay from January 1970 through February 1972 by Krygier and Johnson (unpubl. data) and Krygier and Horton (1975) and supplemented by collections in 1977-79. Additionally, we used collections made by Myers (1980) with a 100 m beach seine (11.0 mm stretch mesh in the inner wing and bunt (Sims and Johnsen 1974)).

2) Other estuaries: The 1.52 m beam trawl was towed from a 7.3 m dory in four estuaries north and south of Yaquina Bay (Tillamook and Siletz Bays, 107.5 and 35.2 km to the north of Yaquina Bay and Alsea Bay and Umpqua River estuary, 21.3 and 105.6 km to the south). Each estuary was divided into seven equal-area portions from which we planned to take three random trawl collections (2 of the 21 trawls in the Umpqua River estuary were not completed).

COASTAL

3) Moolack Beach: 1.52 m beam trawl collections were made on a monthly or bimonthly basis in shallow (3-31 m depth) nearshore waters in a 1.0 km^2 area just north of Yaquina Head during 1977, 1978, and 1979. Moolack Beach is semiprotected by headlands to the north and south and offshore by a reef that rises from 15 m to 6 m.

4) Grid stations: Collections were taken with a 2.72 m beam trawl, approximately monthly, during 1978 at 1.9, 5.6, and 9.3 km (1, 3, and 5 nmi) offshore along lat. 44°41.6'N, 44°36.6'N, and 44°31.6'N. Thirteen collections were also made in this area with the 1.52 m beam trawl.

TABLE 1.—Summary of collections used in this study.

Area	Net type	No. trawls	Dates (sampling frequency)
Yaquina Bay	[1]1.52 m	178	16 Jan. 70-25 Jan. 71 (weekly or biweekly); 17 Feb. 71-25 Feb. 72 (bimonthly)
	[2]1.52 m	26	26 Apr.-28 June 77 (bimonthly)
	[2]1.52 m	96	1 Dec. 77-14 Sept. 79 (monthly to bimonthly)
	[2]2.72 m	8	16 Nov. 77, 1 Feb. 78, 27 Nov. 78
	beach seine	196	12 July 77-11 Nov. 78 (various: daily, biweekly, weekly, bimonthly)
Moolack	1.52 m	16	28 Apr. 77-23 June 77 (bimonthly)
	1.52 m	76	11 Jan. 78-24 Sept. 79 (bimonthly of monthly)
Grid	1.52 m	13	21 Apr. 77-27 June 77; 15 June 78-28 Sept. 78
	2.72 m	106	17 Nov. 77-25 Oct. 78 (monthly)
North-South	1.52 m	40	2 June 77-13 June 77, 15 June 78-21 July 78
	2.72 m	83	15 May 78, 27 June 78, 25 Oct. 78
Estuaries	1.52 m	82	8-12 May 78, 21 trawls each in Tillamook, Siletz and Alsea; 19 trawls in Umpqua

[1]Net liners 3.5 mm and cod end liner of 1.5 mm stretch mesh, 1970-72.
[2]Net liners 3.2 mm stretch mesh, 1977-79.

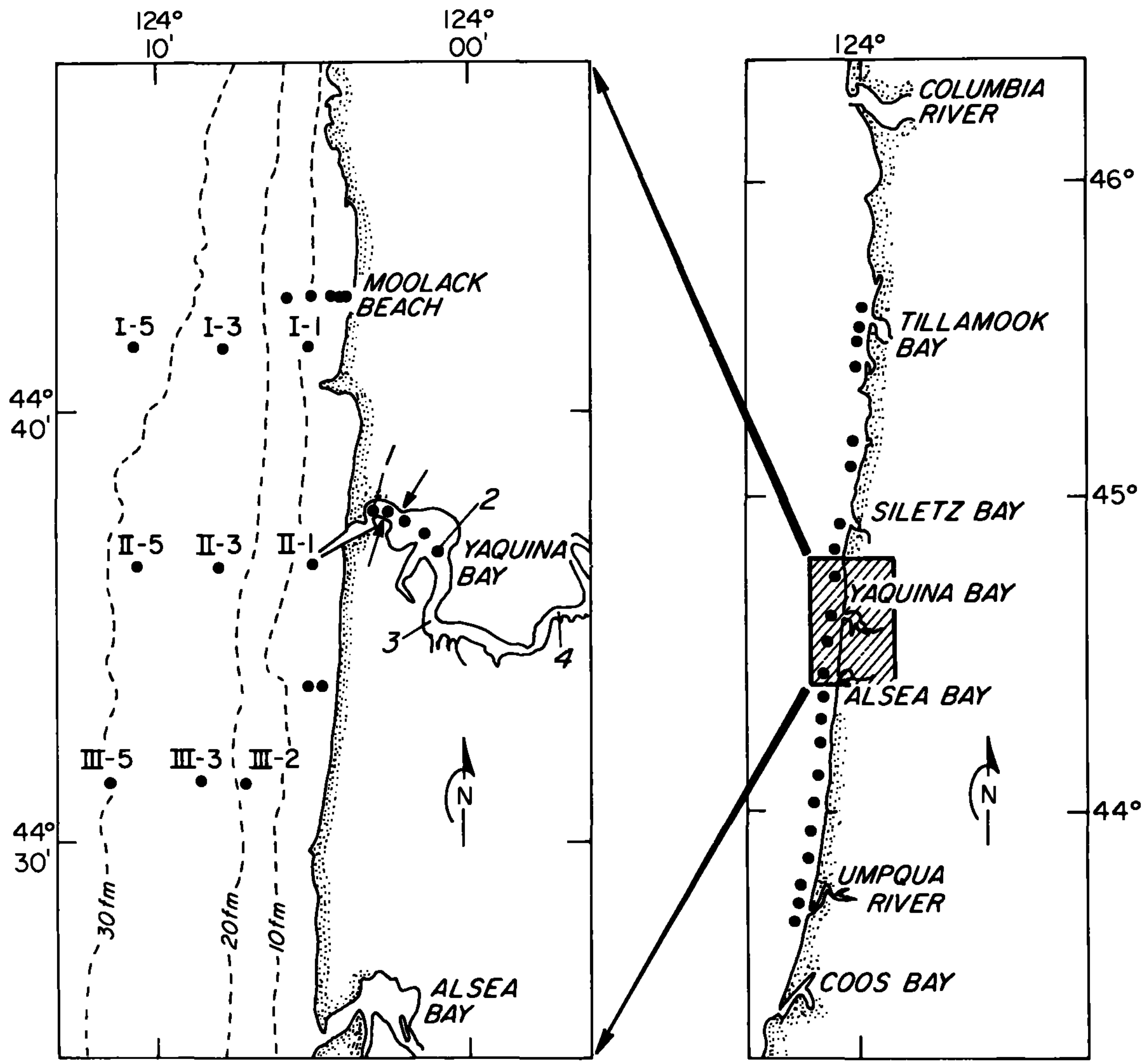


FIGURE 1.—Location of sampling stations in the North-South coastal survey (right) and at Moolack Beach, the grid stations I, II, III, and within Yaquina Bay (left). In Yaquina Bay the numbers 1-4 indicate locations of stations for sampling in 1970-72, the solid dots locations in 1977-79, and the arrows indicate seine stations in 1977.

5) North-south coastal survey: 1.52 m beam trawl collections were made from 111 km to the north (lat. 45°37.5′N) and 111 km to the south (lat. 45°36′N) of Yaquina Bay at 9.3 km intervals (Fig. 1) at depths of 9-18 m in June 1977 and May-October 1978.

Most samples were preserved in 5% Formalin[6] and seawater. In the laboratory, fish were identified, sorted, and standard length (SL) measured to the nearest millimeter. Nearly all English sole captured in Yaquina Bay were 150 mm SL or less and included 0- and I-age fish (Rosenberg 1982). We call these fishes "juveniles" in this paper.

RESULTS

Variability of Catches

The variability of the number of juvenile English sole caught per m^2 in repeated trawls within the same area was low. Coefficients of dispersion ($s^2/\bar{x}$)

[6]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

were usually <0.1, indicating uniform distributions within the small areas (10-100 m^2) and short intervals of time (1-2 h) sampled. Variability was higher and coefficients of dispersion sometimes differed significantly (chi-square, <0.05) from a random (Poisson) distribution among different sampling depths at the same date ($s^2/\bar{x}$ = 0.36-1.65) and among different sampling dates within a single depth at Moolack Beach ($s^2/\bar{x}$ = 1.2-2.31). Coefficients of dispersion did not significantly differ from randomness either among the grid stations for the same sampling dates ($s^2/\bar{x}$ = 0.87-1.82) or among different sampling dates at the same station (0.94-1.97). In general, at the scale of sampling we used, juvenile English sole had even, nonpatchy distributions.

Gear Comparisons

To compare the relative efficiencies of the 1.52 m beam trawl from the *Paiute* and the 2.72 m beam trawl from the *Cayuse*, 14 pairs of trials were made at the same time, while the vessels trawled on parallel courses within 30 m of each other. No significant differences ($P > 0.05$; Mann-Whitney "U" tests, Tate and Clelland 1957) were found in the catch/m^2 of juvenile English sole <150 mm for any paired trawl comparison.

No significant differences were found in length-frequency distributions of *P. vetulus* captured in 10 of the 14 comparisons [Kolmogorov-Smirnov (K-S) test, Tate and Clelland 1957]. In the four pairs of tows that were significantly different (October 1978) the 2.72 m trawl caught more small (~20 mm SL) English sole per m^2 than the 1.52 m trawl, while both trawls caught similar proportions in the 46-100 mm size range.

Comparisons were made between the sizes of English sole in beach seine samples and midchannel trawl samples in Yaquina Bay on six different dates. Differences were significant (K-S test; $P <$ 0.05) for all comparisons because the beam trawl caught a much broader size range of fish, including individuals >40 mm which were rare or absent in the beach seine catches.

Trends in Catches and Sizes of Fish

Significant (H-test, $P \leq 0.05$) differences in catches/m^2 at different depths at Moolack Beach and the grid stations show that in general the abundance of juvenile English sole in offshore waters was greatest in shallow water and decreased with increasing depth. Average catches/10^{3}m^2 (±1 standard deviation) of English sole ≤150 mm were 16 (±20), 61 (±14), 43 (±75), and 10 (±12) at the 9, 9-17, 12-18, and 18-31 m stations off Moolack Beach, compared with only 3 (±3) and 2 (±3) at the 40 and 64 m I-3 and I-5 grid stations at about the same latitude.

Newly transformed, benthic English sole (<24 mm) were found at all depths sampled in the Moolack Beach area, but the highest proportion of these recently metamorphosed fish was found at depths <18 m. Within the depth zones sampled the proportion of small English sole <30 mm decreased with depth and fish >150 mm were only captured at depths deeper than 18 m (Fig. 2).

Juvenile English sole ≤150 mm were found along the entire 222 km coast sampled (Fig. 3). They were usually moderately abundant (≥0.01 m^2) between Siletz Bay and Alsea Bay, and near the Umpqua River and Tillamook Bay. Average catches, however, were higher off Moolack Beach than any other area, averaging 0.21 juvenile English sole/m^2, an order of magnitude greater than most other offshore areas or the grid stations. Moolack Beach was apparently a region of the open coast with exceptionally high densities of English sole.

Juvenile English sole were generally most abundant at the shallowest depths in these collections, corroborating more intense sampling off Moolack Beach and at the grid stations (Fig. 3). Average catches at depths of 18 m and 36 m decreased about an order of magnitude between May (0.026/m^2; SD 0.049) and October (0.003/m^2; SD 0.003).

Variations in Abundance of Settling Fish

In our samples, metamorphosis or transformation, as indicated by migration of the left eye and by body pigmentation, occurred between 14-26 mm. Most fish had completed metamorphosis by 23 mm. In Yaquina Bay, the metamorphosing individuals first appeared in November of 1971 and 1978 (the 1972 and 1979 year classes) and in January of 1971 and 1978 (1971 and 1978 year classes) (Fig. 4). (In this paper we designate year classes by the year that most juveniles settled to the bottom; e.g., products of spawning during the fall 1978-winter 1979 are called the 1979 year class.) Metamorphosing fish were present in Yaquina Bay until June (1970, 1978, 1979) or July (1971), but none was found after July during the four summer periods sampled.

Maximum densities of these metamorphosing fish were observed between March and May in 1970, 1971, and 1978, but between November and January in 1978-79. Densities were variable. Low densities

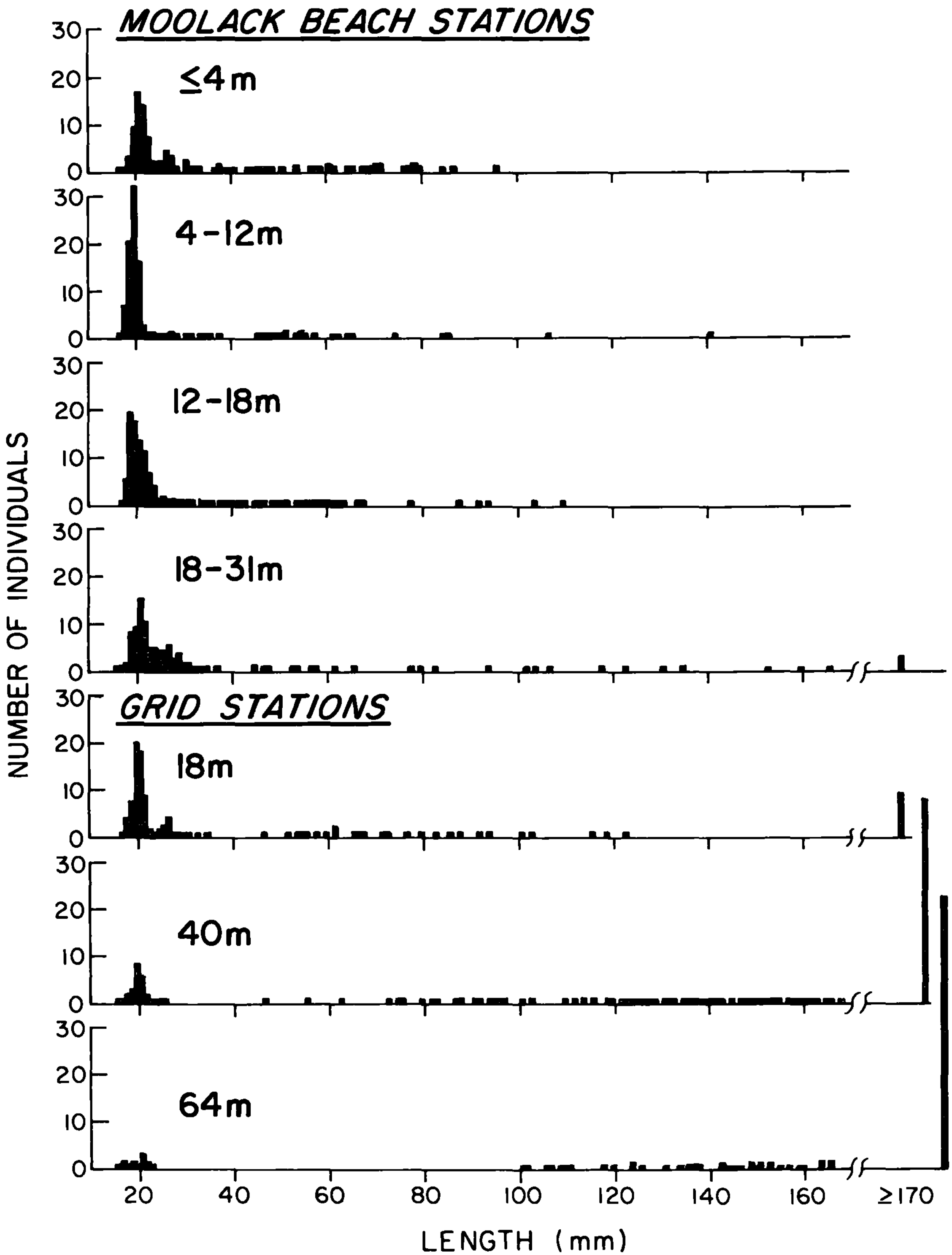


FIGURE 2.—Length-frequency distributions of juvenile English sole caught at different depths at the Moolack Beach (above) and grid stations (below).

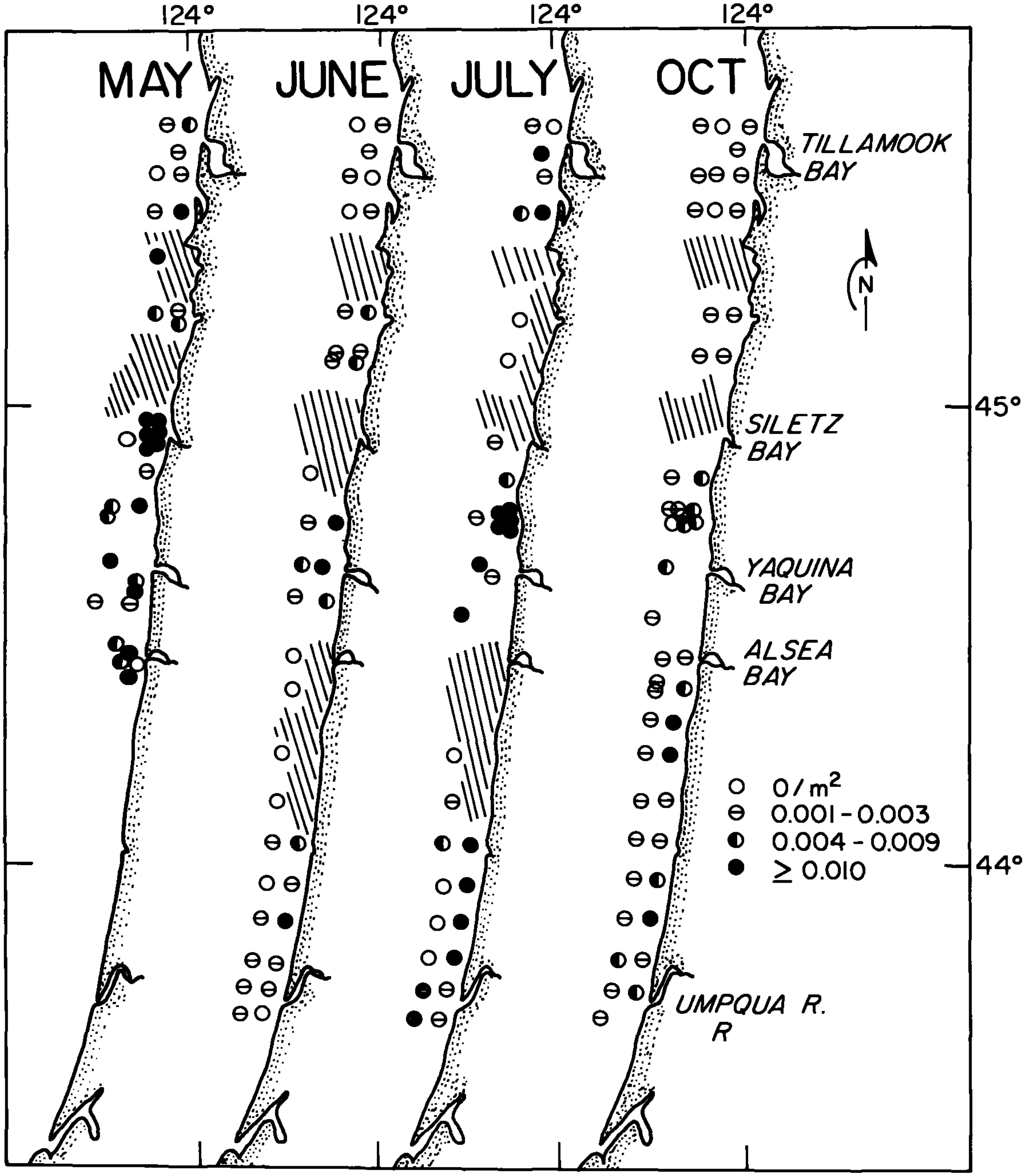


FIGURE 3.—Catches of juvenile English sole (<150 mm) along the open coast during May, June, July, and October 1978. Hatched areas indicate untrawlable grounds due to crab pots or rocky outcrops.

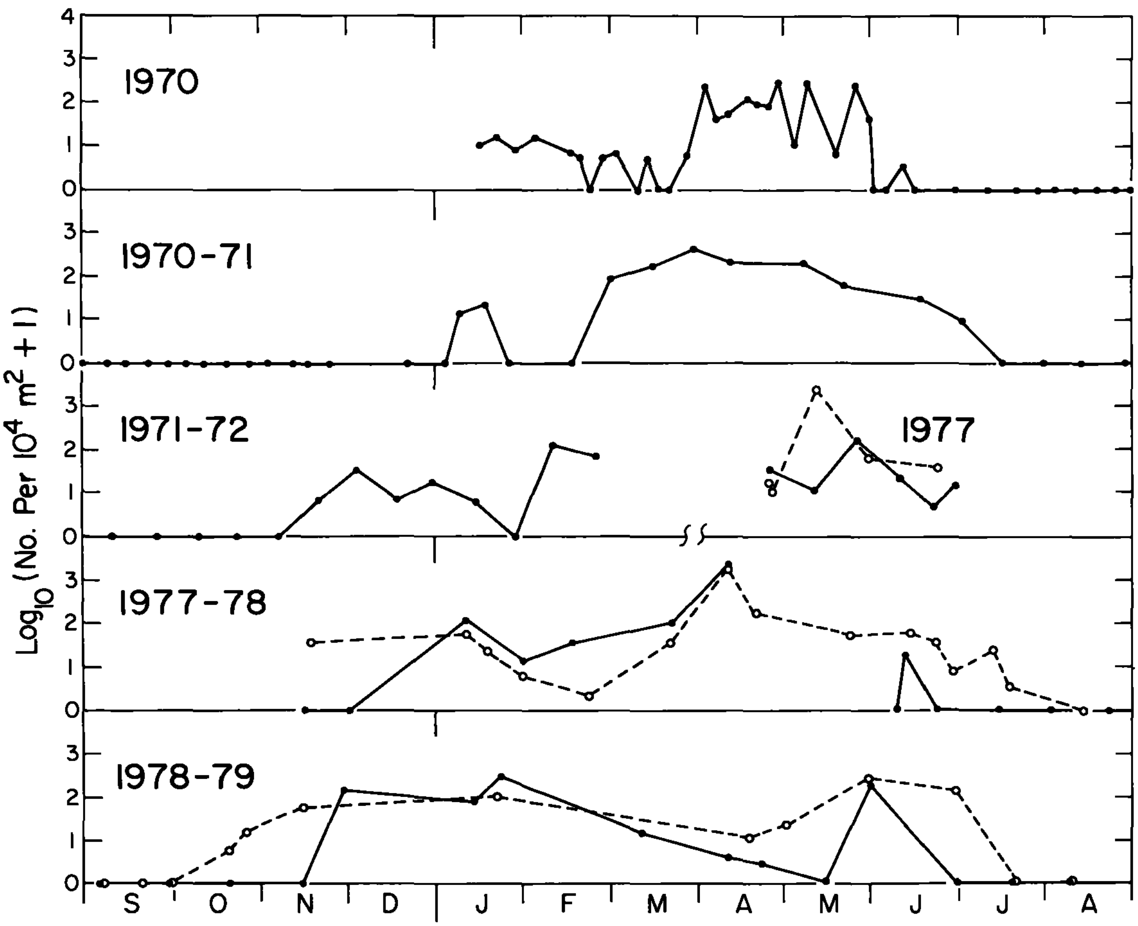


FIGURE 4.—Abundances of settling (<20 mm SL) English sole in Yaquina Bay for 1970-79 (solid line) and Moolack Beach for 1970-79 (dashed line).

occurred during March 1970, January and February 1971, 1972, and April-May 1979, suggesting seasonal variation in spawning activity of adults (see Kruse and Tyler 1983), mortality of planktonic stages, or movement of young into or out of the estuary.

Seasonal trends in catches of transforming English sole in Yaquina Bay and at Moolack Beach for 1978 and 1979 shows that fish ≤20 mm were found 1-2 mo earlier at Moolack Beach than in Yaquina Bay during both years (Fig. 4). Moreover, recruitment of the 1978 and 1979 year classes continued at Moolack Beach from 18 to 50 d after settling fish were no longer found within the estuary. To our surprise, similar densities of settling fish were caught in both areas. Seasonal trends were sometimes similar, suggesting a common source of larvae and similar processes affecting variations in recruitment of metamorphosing fish at both the open-coast and estuarine areas.

The catches/m^2 of age groups 0 and I English sole (20-150 mm) are plotted as catch curves for each 5 mm size group (Fig. 5) where

$$\text{no. m}^2 = \frac{\Sigma \text{ of the number of individuals in each 5 mm size group}}{\text{total area sampled in m}^2 \text{ during sampling periods in which year class occurred}}$$

Trends in the abundance of English sole were often

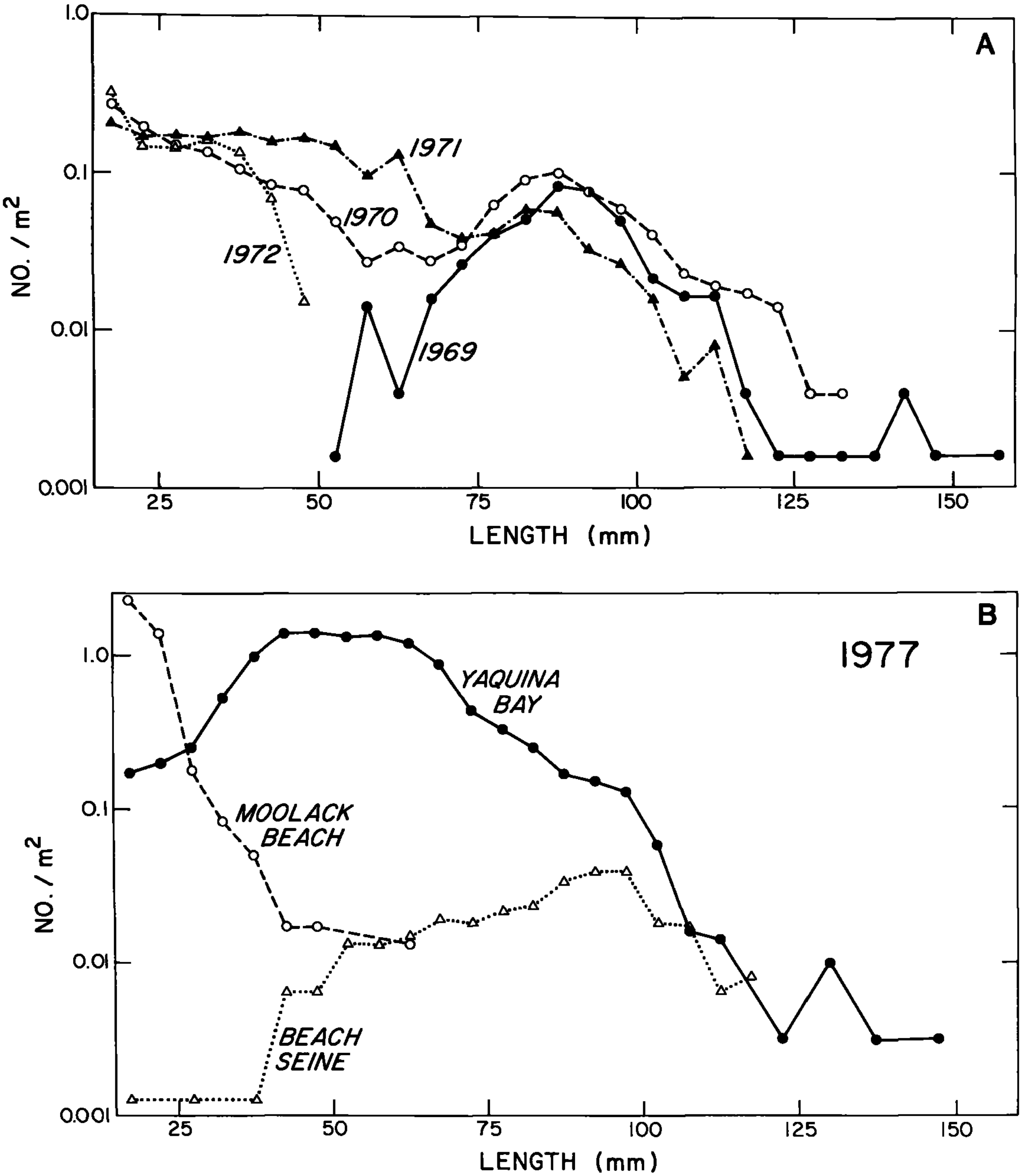
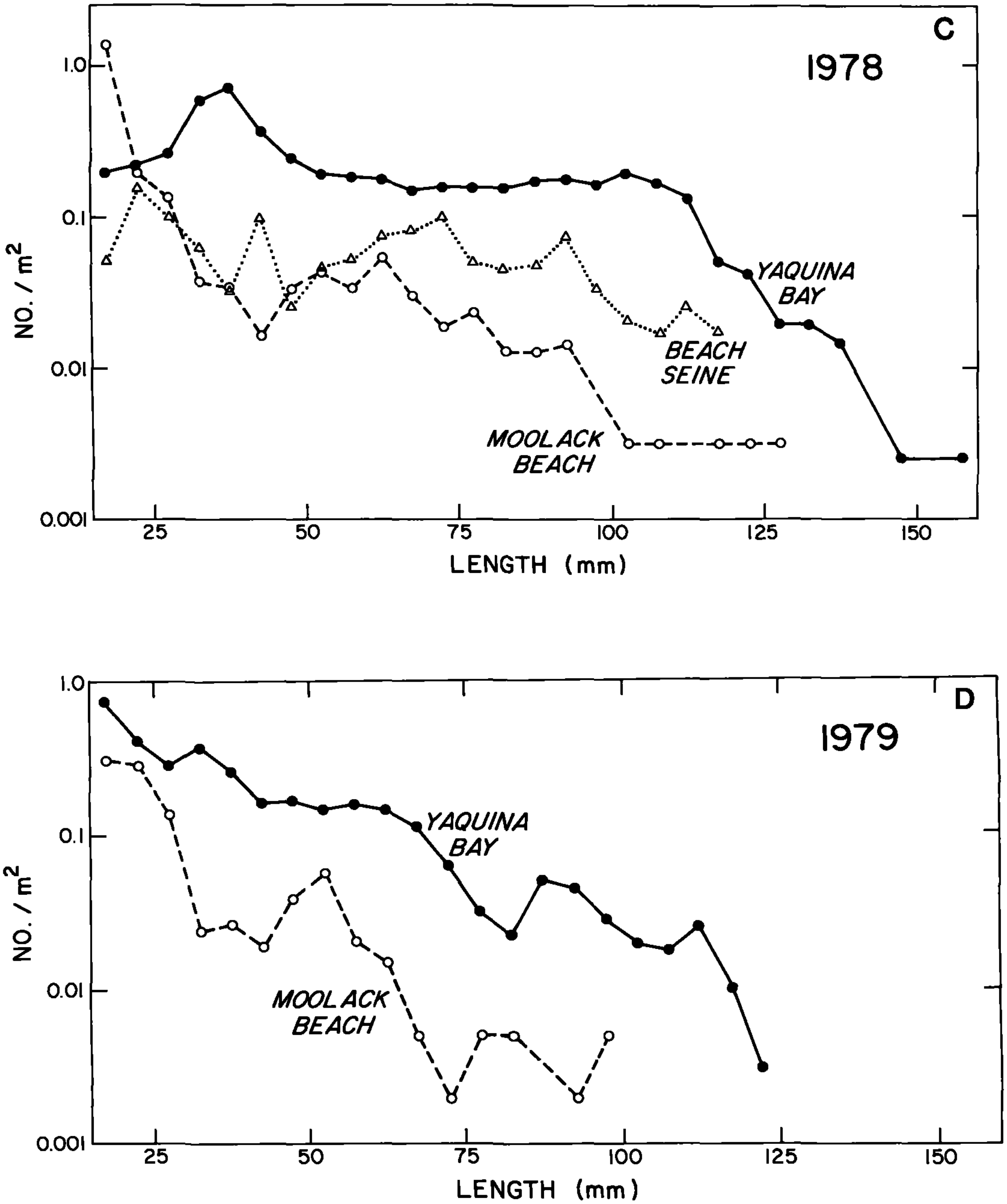


FIGURE 5.—Abundances of young English sole year classes as a function of length. (A) 1969-72, (B) 1977,

similar for the four year classes sampled between 1969 and 1972 in Yaquina Bay (Fig. 5A). Abundances of recently recruited individuals 20-45 mm in length were similar among the 1970, 1971, and 1972 year classes. The 1969, 1970, and 1971 year classes also increased in numbers/m^2 between 75 and 90 mm before declining to low catches at larger sizes. Abundances of small fish of the 1969 year class are low because this year class was only sampled in 1970, when most fish were >75 mm.

Catches/m^2 of the 1977 and 1978 year classes in Yaquina Bay were generally larger than the 1969, 1970, 1971, 1972, and 1979 year classes (Fig. 5A, B, C). The 1977 cohort differed from other year



(C) 1978, (D) 1979 year classes. Note that some curves are based on incomplete sampling of all seasons.

classes by having a large peak of abundance for 30-70 mm individuals, and the 1978 year class had much higher abundance of large (100-140 mm) individuals than other year classes.

Obviously the trends shown by these catch curves cannot be explained by mortality alone. Immigration of young benthic English sole into our sampling area of Yaquina Bay is suggested by the increased catches of 75-100 mm individuals of the 1970 and 1971 year classes and increased catches of 20 to 40-45 mm individuals of the 1978 and 1979 year classes.

Beam trawls catches at Moolack Beach for the 1977, 1978, and 1979 year classes and beach seine catches in Yaquina Bay for part of the 1977 year class and the 1978 year class indicate that the abundance of newly recruited, settling fish (<24 mm) of the 1977 and 1978 year classes was higher at Moolack Beach than in Yaquina Bay (Fig. 5B, C). These high catches at Moolack Beach were followed by a steep decline in catches to the 41-44 mm size class. English sole larger than 30 mm were consistently less abundant at Moolack Beach than in Yaquina Bay. Densities increased in Yaquina Bay concurrent with the steep decline of 20-44 mm individuals at Moolack Beach. These trends suggest immigration of young fish from the shallow waters of the open coast to Yaquina Bay over a range of sizes, from 20 to 40 mm.

Two peaks occurred in the beach seine catches of the 1978 year class: at 20-25 and 40-45 mm. The first peak coincides with the sizes that decreased markedly in abundance at Moolack Beach. The second peak coincides with low abundance of 40-45 mm fish at Moolack, and with a decrease in catches of these sizes of fish at the trawl stations in Yaquina Bay. These trends of trawl-caught fish suggest that immigration from Moolack Beach first occurred to the shallow waters of the bay and then to the deeper trawl stations. The peak in the catches of 40-45 mm fish at seine stations may be caused by immigration into these shallower waters of metamorphosed individuals from either the offshore areas or deep areas of Yaquina Bay.

Abundances and Sizes in Five Estuaries

Age-0 English sole were present in all five estuaries sampled with trawls during May and June 1978. The mean abundance of young English sole, which ranged from 0.7/m^2 in Tillamook Bay to 0.02/m^2 in the Umpqua estuary, generally decreased from the northern to the southern estuaries (Table 2). The exception was Yaquina Bay. It was latitudinally the middle estuary, yet abundance of English sole there ranked above that in Siletz Bay. No consistent relationship was observed between mean abundances and the area of estuaries, river flows, tidal prisms, or flushing times using the data of Choi (1975) or Starr (1979)[7].

A broad size range of fish was caught in Tillamook, Siletz, and Alsea Bays, while we caught few individuals larger than 36 mm in the Umpqua River estuary (Table 3). In Yaquina Bay, a higher proportion of large individuals (>65 mm) was found than in the other estuaries. A much broader range of sizes was captured in these estuaries than in open coastal areas on the dates sampled.

TABLE 2.—Mean abundance and standard deviation of 0-age English sole in five estuaries north and south of Yaquina Bay and along the open coast between 9 and 37 m, April-June 1978.

Location	Date: 1978	No. of hauls	No./m^2	SD (s)
Estuary				
Tillamook Bay	8 May	21	0.715	0.916
Siletz Bay	9 May	21	0.184	0.206
Yaquina Bay	10 April; 12 July	6	0.332	0.251
Alsea Bay	10 May	21	0.059	0.075
Umpqua River estuary	12 May	19	0.016	0.037
Ocean Off				
Tillamook Bay	15 May; 17 June	12	0.005	0.013
Siletz Bay	16 May; 29 June	9	0.019	0.020
Alsea Bay	22, 29 June			
Umpqua River estuary	28 June	3	0.001	0.001
North of Newport	16, 23 May; 29 June	14	0.006	0.011
South of Newport	18 June	9	0.003	0.004

Growth

Despite prolonged recruitment of young English sole in Yaquina Bay (Fig. 4) distinct length modes were usually present for each sampling date. Growth rates in Yaquina Bay, estimated by following the progression of length modes of cohorts over time, were generally greatest (0.46-0.49 mm/d) during the late spring to early fall, while growth rates in winter were lower (0.26-0.32 mm/d) (Table 4). The growth rate from January to July 1970 was 0.47 mm/d, similar to the spring-fall estimates. Growth rates were estimated only for the spring-fall period off Moolack Beach. These were similar to those for Yaquina Bay fish but more variable, ranging from 0.28 to 0.42 mm/d.

DISCUSSION

Larvae of English sole are abundant in coastal waters off Oregon, ranking first among the flatfishes in some years (Richardson 1977[8]; Richardson and Pearcy 1977; Mundy 1984). Young larvae (<10 mm) of English sole are rare in estuaries of the Oregon-California coast as evidenced by plankton samples

[7]Starr, R. M. 1979. Natural resources of Siletz esturary. Oreg. Dep. Fish Wildl., Estuary Inventory Rep. 2(4):1-44.

[8]Richardson, S. L. 1977. Larval fishes in Ocean waters off Yaquina Bay, Oregon: Abundance, distribution and seasonality, January 1971 to August 1972. Oreg. State Univ. Sea Grant Publ. ORESU-T-77-003.

of only 6 larvae in 393 tows in Yaquina Bay (Pearcy and Myers 1974), 22 larvae in 84 tows in the lower Columbia River (Misitano 1977), and 4 larvae in 89 tows from Humboldt Bay (Eldridge 1970; Misitano 1970, 1976). However, young larvae are common in offshore collections (Porter 1964; Pearcy and Myers 1974; Laroche and Richardson 1979), and transforming larvae (19-22 mm) are frequent in collections from Humboldt Bay and the Columbia River estuary (Eldridge 1970; Misitano 1970, 1976). Thus young *P. vetulus* that enter estuarine nurseries do so as large transforming larvae or after completion of metamorphosis.

Our data confirm the above findings. We found that settlement of metamorphosing English sole to the bottom was common both in the Yaquina Bay estuary and at Moolack Beach along the open coast. Transforming individuals along the coast were caught in largest numbers/m^2 at depths of 16 m or less, but they were also captured at the deepest stations sampled (Fig. 2). Since small larvae were rare in Yaquina Bay (Pearcy and Myers 1974), these trends suggest movement into the bay of transforming larval stages. Boehlert and Mundy (in prep.)[9] have subsequently confirmed that small juveniles as well as transforming larvae of English sole recruit to Yaquina Bay.

Although densities of transforming larvae were sometimes higher at Moolack Beach than in Yaquina Bay, densities of juvenile fish >30 mm were usually over an order of magnitude higher in Yaquina Bay than at Moolack Beach, indicating either immigration into the bay from the open coast during or after metamorphosis, or dispersal or higher mortality rates of young along the open coast than in the estuary. Increasing densities in Yaquina Bay, concurrent with decreasing densities at Moolack Beach, suggest immigration into the bay over an extended range of sizes from 25 to 40 mm.

The mechanisms for such movements are not fully understood, but vertical movement of young fish off the bottom during periods of flood tide has been shown to effect transport into estuaries in several

TABLE 3.—Length distribution of English sole caught in the five estuaries, Moolack Beach and grid stations, 10 April-12 June 1978.

Location	No. of fish	Standard lengths (mm)														
		14-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	61-65	66-70	71-75	76-80	81-85	86-90
8:V:78 Tillamook	2,979	904	1,619	296	48	19	23	26	31	13	4	4	2			
9:V:78 Siletz Bay	673	242	256	72	36	13	13	21	14	5		1				
10:V:78 Alsea Bay	306	41	98	49	25	20	15	19	27	9	1		1			1
12:V:78 Umpqua River estuary	54	30	12	5	4			1						1	1	
10:IV:78 Yaquina Bay	163	46	16	1	6	11	11	11	23	18	11	6	2	1		
12:VI:78 Yaquina Bay	156	2	6	9	9	18	6	6	12	17	23	18	16	8	3	3
10:IV:78 Moolack Beach	221	209	9	3												
12:VI:78 Moolack Beach	24	5	12	5		1			1							
23:V:78 Offshore grid	47	42	5													

TABLE 4.—Growth of juvenile English sole estimated from modal progression of size-frequency histograms from catches in Yaquina Bay and Moolack Beach, 1970-79.

Area and date	mm/d (slope)	r^2
Yaquina Bay		
Jan. 1970-July 1970	0.46	0.98
Dec. 1971-Feb. 1972	0.26	0.92
Jan. 1972-Feb. 1972	0.32	0.91
Jan. 1978-Apr. 1978	0.31	0.91
Apr. 1970-Oct. 1970	0.46	0.96
May 1971-Oct. 1971	0.47	0.98
Mar. 1979-Sept. 1979	0.49	0.96
Moolack Beach		
Aug. 1978-Oct. 1978	0.41	0.98
May 1978-Oct. 1978	0.28	0.93
Apr. 1979-Sept. 1979	0.38	0.96
May 1979-Aug. 1979	0.42	0.99
June 1979-Sept. 1979	0.36	1.00

[9]Boehlert, G. W., and B. C. Mundy. Recruitment dynamics of the English sole, *Parophrys vetulus*, to a west coast estuary. Unpubl. manuscr., 16 p. Southwest Fisheries Center Honolulu Laboratory, National Marine Fisheries Service, NOAA, P.O. Box 3830, Honolulu, HI 96812.

flatfish species. Cruetzberg et al. (1978) suggested that immigration of plaice, *Pleuronectes platessa*, larvae is based on such a "selective tidal transport," and that starvation induces the swimming behavior resulting in transport by currents. De Veen (1978) concluded that juvenile sole (*Solea solea*) use tidal transport to enter the Wadden Sea in the spring. Metamorphosing larvae of the stone flounder, *Kareius bicoloratus*, also immigrate into estuarine nurseries with tidal currents; they were most abundant in plankton net collections during flood tides at night in an estuary of Sendai Bay, Japan (Tsurata 1978). Misitano (1976) captured metamorphosing English sole in a 1 m midwater trawl, especially after dark, in Humboldt Bay. Boehlert and Mundy (fn. 9) found that transforming English sole larvae were usually most abundant during flood tides at night in the moored plankton net that was nearest the bottom in the lower portion of the Yaquina Bay estuary and that recruitment to the bay was correlated with onshore Ekman transport.

Our estimates of growth from modal progressions length-frequency histograms [averaging 0.40 mm/d (s = 0.10) for Yaquina Bay and 0.37 mm/d (s = 0.06) for Moolack Beach] were considerably higher than Rosenberg's (1982) estimates even for the same years (Table 4). Rosenberg studied growth of 0-age English sole using fortnightly otolith rings as an aging technique. He calculated that fish, 140-480 d of age, collected during 1978 and 1979 in Yaquina Bay and at Moolack Beach grew about 0.28 mm SL/d. Estimates of growth rates of juvenile English sole from length data by Westrheim (1955) in Yaquina Bay, as well as by Smith and Nitsos (1969) in Monterey Bay, and Van Cleve and El-Sayed (1969) and Kendall (1966) in Puget Sound were more similar to our estimates than those of Rosenberg (1982, table 2). The differences in apparent growth rates between length frequency and otolith measurements are difficult to explain. Avoidance of nets by larger sole (e.g., Kuipers 1975), emigration of larger fish out of the sampling area in the late summer, and prolonged immigration of small fish into the estuary, are likely. Any of these would result in an underestimates of growth by the length-frequency method (see Rosenberg 1982 for opposite explanations). Differential mortality of small fish (Rosenberg 1982) or methodological difficulties in analyzing otolith growth increments may also help explain the differences.

Our study confirms the observations of Laroche and Holton (1979) that small 0-age English sole are not found exclusively in estuaries along the Oregon coast, and that average sizes of English sole increase with depth at Moolack Beach. Laroche and Holton (1979) suggested that even low density or localized utilization of the extensive unprotected offshore areas along the coast could be an important factor in determining the English sole production off Oregon. To evaluate this possibility, we determined total areas within the range of our sample depths in the lower reaches of the five estuaries and multiplied these areas by the average catch/m^2 of 0-age English sole (<90 mm) to obtain an estimate of total number of young English sole in each estuary. The average catch was also determined from 47 collections between 9 and 36 m where we found highest catches of 0-age fish, along 448 km of the open coast from our May-June catches (Table 2). The average catch/m^2 of 0-age sole in the five estuaries usually was many times that along the open coast. But because of the large differences in areas, the estimate for total abundance of 0-age sole during the May-June period on the open coast was about 643 × 10^5, considerably higher than the estimate for the five estuaries, 140 × 10^5. Most of the fish caught during this period, however, were transforming or recently metamorphosed juveniles that could have entered estuaries later in the year. This may in part explain the 17-fold decrease in average abundance of small sole along the open coast between 16-23 May ($\bar{x}$ = 0.039, n = 18, s = 0.11) and 28-29 June ($\bar{x}$ = 0.002, n = 29, s = 0.004) in the vicinity of Tillamook and Siletz Bays. Our estimate of total abundance along the coast in June is 70 × 10^5, about half the estimate for the five estuaries about a month and one-half earlier. Because of our small sample sizes, lack of sampling in some estuaries and open coast areas, and temporal differences (and associated mortality) among samples, these estimates must be considered crude. Nevertheless, they suggest that shallow waters of the open coast are important initial settling areas for English sole and that both estuaries and the open coast are nursery grounds for fully transformed 0-age sole.

We need data on the growth and survival from estuarine and open coastal areas to evaluate their importance as nursery grounds and to assess their relative contributions to the commercially harvested and spawning population. Olsen and Pratt (1973) used parasites as indicators of English sole nursery grounds. The incidence of *Echinorhynchus lageniformis*, an acanthocephalan that they considered was acquired only in estuaries, averaged 29.9% in 0-age English sole <117 mm SL captured in Yaquina Bay and 28.5% in 0-age fish collected offshore at depths of 10-80 m near the entrance of Yaquina Bay during November and December, a period after most 0-age fish had emigrated from the bay. They concluded from these similar incidences of infection that there was no sizable influx of 0-age English sole to their offshore study area other than from estuarine nursery grounds. Their results imply that any 0-age fish that reside along the open coast during the spring and summer have much higher mortality rates than estuarine residents and do not contribute significantly to the offshore population of 0-age fish.

Growth rates of 0-age English sole from Moolack Beach and Yaquina Bay, however, do not support this hypothesis. They appear to be similar (Rosenberg 1982; Table 4). Our catch curves (Fig. 5C, D) also provide no evidence for grossly higher mortality rates at Moolack Beach. The total declines in abundances per m^2 are fairly similar for English sole 50-100 mm, presumably a size range that occurs after immigration into the estuary but before emigration of larger sizes out of the estuary in the fall.

The fact that 0-age English sole immigrate from offshore into estuaries where they are found in high concentrations suggests that this behavior is adaptive. Standing stocks and productivity of small benthic food organisms are undoubtedly higher in estuaries than along the open coast, but because of the higher concentrations of young flounder in Yaquina Bay than Moolack Beach (Fig. 5), competition for food probably results in similar growth rates in these two habitats. The rapid decreases in the estuarine densities of 0-age English sole during the fall and winter months are evidence of emigration out of estuaries to offshore areas. In Yaquina Bay, we found a decrease in density of 0-age fish in the late fall as well as a decrease in average size at this time. Frequently age-0 (20-55 mm) and age-I (75-115 mm) fish were both present in the winter, with the age-I fish disappearing entirely from catches in the spring. Westrheim (1955) and Olsen and Pratt (1973) also found decreases in catch per effort and average sizes of young English sole that indicated definite emigration from Yaquina Bay after October. Forsberg et al. (1975)[10] reported emigration of English sole from Tillamook Bay in early fall with few individuals remaining in November.

According to Bayer (1981), small English sole were common at intertidal stations in Yaquina Bay most of the year, but they were absent during November and were less common during other fall months. Toole (1980) also found that English sole disappeared from intertidal areas in early fall at an average size of 68 mm SL and subsequently resided in subtidal channels until they were about 120 mm SL in Humboldt Bay. He associated these different distributions with changes in feeding habits, and possibly with a reduction in intraspecific competition among small and large 0-age English sole. Indeed, emigration out of bays and estuaries in the fall may be related to limitations in the carrying capacity for high densities and standing stocks of young English sole.

We conclude that estuarine and offshore nursery grounds combine to significantly increase the survival and total population size of 0-age fish. Utilization of these two diverse habitats may also improve the chances for good survival of young fish from at least one habitat even when adverse conditions affect the other.

[10]Forsberg, B. O., J. A. Johnson, and S. M. Klug. 1975. Identification and notes on food habits of fish and shellfish in Tillamook Bay, Oreg. Fish Comm. Oreg. Contract Rep., 85 p.

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