RELATIONSHIP BETWEEN SEDIMENT CHARACTER AND SEX SEGREGATION IN ENGLISH SOLE, *PAROPHRYS VETULUS*[1]

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ABSTRACT

English sole, *Parophrys vetulus*, were collected by otter trawl in the nearshore zone of Puget Sound, Washington, during two surveys conducted in 1981–82 and 1984. Stations in both surveys were distributed across a broad range of sedimentary environments. Sex segregation by English sole was strongly associated with the grain-size characteristics of bottom sediments. This association was persistent across a variety of sampling conditions, including different years, seasons, embayments, and depths. Fish age did not appear to influence the observed association. Results of this study provide the first documentation of the influence of sediment character on sex segregation by a pleuronectid, and suggest that this relationship should be considered in future studies of English sole and, perhaps, other pleuronectids as well.

Sex segregation by fishes of the family Pleuronectidae (i.e., righteye flounders) has been documented for numerous species from the United States (Alverson and Chatwin 1957; Fadeev 1970; Alton 1972), Europe (Rae 1965), and Asia (Moiseev 1953; Kovtsova 1982). These patterns have been related to such factors as geographic location, depth, season, and age of fish. However, because most of these observations have been made while fishes were being collected for other purposes, the underlying reasons for the observed patterns are poorly understood.

Several studies have documented sex segregation in English sole, *Parophrys vetulus*, a pleuronectid found in nearshore areas along the west coasts of the United States and Canada (Hart 1973). In describing the catch of the English sole fishery in Hecate Strait, British Columbia, Ketchen (1956) noted that considerable sex segregation takes place, particularly during the summer months. In a study of the population characteristics of this species in Puget Sound, Holland (1969) found a difference of 18% between the percentages of males in the populations from two locations. Because both of these accounts were largely anecdotal, no evaluations of the observed patterns were made.

One factor that has yet to be evaluated with respect to sex segregation by pleuronectids is the character of bottom sediments. Because pleuronectids live in close association with the sea floor, it might be surmised that the characteristics of that environment exert a differential influence on the distributions of the two sexes. Additional support for this hypothesis comes from the fact that the influence of sediment character on the overall distribution (i.e., both sexes pooled) of several pleuronectids has been well documented (Ketchen 1956; Alverson et al. 1964; Feder et al. 1974; Pearcy 1978; Scott 1982; Becker 1984).

In this paper, I evaluate patterns of sex segregation by English sole in relation to the character of bottom sediments in nearshore areas of Puget Sound, WA. This study provides the first determination of how sediment character influences sex segregation in a pleuronectid. In relating sediment character to sex segregation in English sole, I also evaluate the potential influences of depth, season, and fish age on the observed relationships.

METHODS

English sole were sampled during two independent surveys conducted in several embayments of Puget Sound in 1981–82 and 1984. The relationship between sex segregation and sediment character was evaluated separately for each survey. Although the two surveys differed with respect to such variables as station locations, sampling times, and sample sizes, the basic collection and analytical methods used in both surveys were similar.

In both surveys, the sex ratio of the English sole captured at each station was represented by the proportion of the sample comprised of males (i.e., male proportion). Sediment character at each station was represented by the percentage (by weight) of the

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grain-size distribution comprised of fine-grained material (i.e., <0.063 mm in size). This variable was used as an index of sediment character because many physical, chemical, and biological characteristics of sedimentary environments covary with the grain-size distribution (Buchanan 1984).

During 1981–82, English sole were collected from 15 May to 6 July 1981 at 12 transects in Commencement Bay, Elliott Bay, and Sinclair Inlet (Fig. 1). Fishes also were collected during three additional time periods (23–24 November 1981; 8–9 March 1982; 30–31 August 1982) to evaluate seasonal patterns at three stations in Commencement Bay (CB-1, CB-4, and CB-5; Fig. 1). These stations were selected to represent a gradient of sediment grain size. Although the seasonal sampling occurred over a 2-yr period, it was assumed that interannual variation was not sufficiently large to obscure major seasonal patterns.

During the May–July sampling, English sole were collected at each transect during morning (07:00–09:30), midday (10:00–13:30), evening (20:30–23:30), and midnight (00:30–04:00). During the remaining sampling periods, fish were collected only during midday and evening. For each transect, results obtained for different periods of the diel cycle were pooled before male proportions were calculated. Sex determinations and evaluations of spawning condition were made for all English sole larger than 160 mm total length (TL). Age was not determined.

During 1984, English sole were collected from 4 to 9 June 1984 at 15 transects in Commencement Bay and at 2 transects in Carr Inlet (Fig. 1). Sampling was conducted during daylight hours (06:30–17:00) at all transects. Sex determinations and evaluations of spawning condition were made for all individuals larger than 225 mm TL. Age was determined by otolith analysis for all fish.

During both surveys, English sole were collected using a 7.6 m (headrope) Marinovich otter trawl having a body mesh of 3.2 cm (stretched) and a cod end liner mesh size of 0.8 cm (stretched). Trawling was conducted along isobaths at a constant vessel speed of approximately 2.5 knots.

During both surveys, bottom sediments were sampled using a modified van Veen bottom grab and the grain-size distribution of the top 2 cm of sediment was determined using standard sieve and pipette techniques (Folk 1968). During 1981–82, sediments were collected at five sampling points located at approximately equal distances along each transect. During 1984, sediments were collected at a variable number of stations located within 300 m from each transect.

The association between percent fine-grained sediment and male proportion of English sole was tested using Spearman's rank correlation coefficient (r_s). The association between station depth and male proportion was tested in the same manner. Differences in male proportion among age-classes of fish and among the seasonal sampling transects were tested using the G-test (Sokal and Rohlf 1981).

RESULTS

Station depth, percent fine-grained sediment, sample size, and male proportion at each transect from the 1981–82 and 1984 surveys are presented in Tables 1 and 2, respectively. During 1981–82, 4,430 English sole were sampled from stations ranging in depth from 8 to 36 m. Percent fine-grained sediment ranged from 5.8 to 92.1% and male proportion ranged from 0.20 to 0.91. During 1984, 1,007 English sole were collected from stations ranging in depth from 5 to 20 m. Percent fine-grained sediment ranged from 8.6 to 87.5% and male proportion ranged from 0.13 to 0.98.

The correlation between percent fine-grained sediment and male proportion of English sole was significant ($P \leq 0.01$; $r_s = 0.73$) for the May–July sampling of the 1981–82 survey (Fig. 2). This correlation was also significant ($P \leq 0.001$; $r_s = 0.80$) for the 1984 survey (Fig. 2). Correlations between depth and male proportion were not significant ($P > 0.05$) for either the 1981–82 ($r_s = -0.10$) or 1984 ($r_s = -0.04$) survey.

For the stations sampled seasonally in 1981–82 (CB-1, CB-4, and CB-5), heterogeneity of male proportion among stations was significant ($P \leq 0.05$) during all four sampling periods (Fig. 3). In all cases, male proportion was lowest at CB-5, highest at CB-4, and intermediate in magnitude at CB-1. This gradient of increasing male proportion was consistent with the gradient of increasing percent fine-grained sediment at the three stations (Table 1). The mean abundance of English sole at the three stations rose from a minimum level in March to a peak in May–July, and then declined through August to a level in November that was similar to that in March (Fig. 3).

For both surveys combined, 64 (1.2%) English sole were found to be in spawning condition. Twenty-four of those individuals were collected during March, to represent a spawning component of 14.8% during that month. The remaining 42 individuals were sampled between May and July to represent

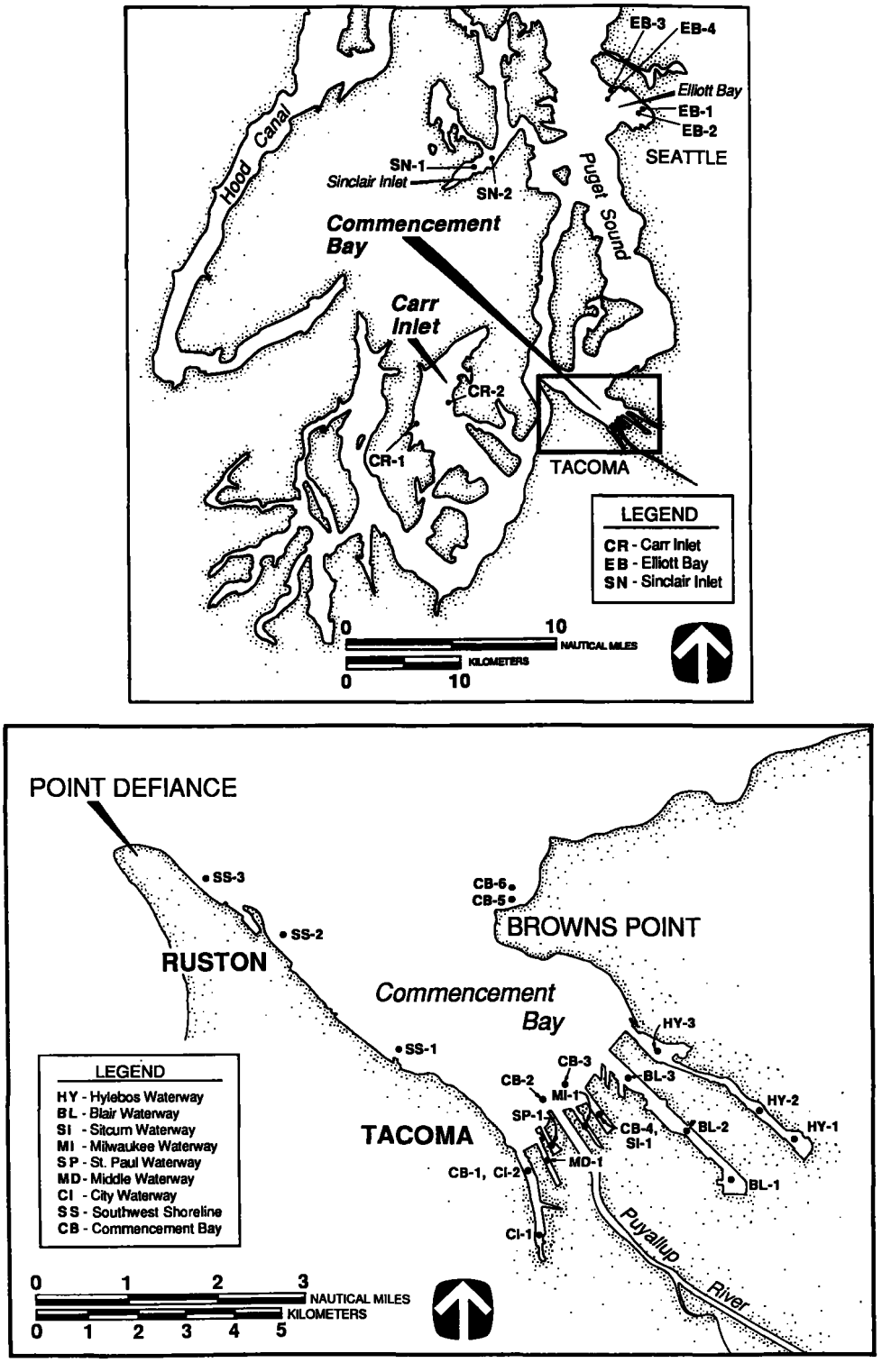

FIGURE 1.—Locations of transects sampled in 1981–82 (denoted by CB, EB, and SN) and 1984 (all remaining transects).

TABLE 1.—Characteristics of transects and samples of English sole during 1981–82.[1]

Station[2]	Depth (m)	Mean percent fine-grained sediment[3]	Sample size[4]				Male proportion			
			May–July	August	November	March	May–July	August	November	March
CB-1	10	27.1	655	249	65	90	0.83	0.74	0.58	0.57
CB-2	33	47.0	554				0.78			
CB-3	36	44.2	160				0.79			
CB-4	14	71.6	589	146	174	38	0.91	0.82	0.77	0.87
CB-5	13	7.6	181	67	68	35	0.55	0.64	0.44	0.20
CB-6	35	11.2	128				0.66			
EB-1	14	56.0	82				0.68			
EB-2	31	76.2	17				0.76			
EB-3	16	5.8	90				0.53			
EB-4	32	8.8	49				0.49			
SN-1	8	92.1	683				0.84			
SN-2	10	13.7	310				0.30			

[1]Sampling in May–July and November was conducted in 1981, whereas sampling in August and March was conducted in 1982.
[2]Locations of transects are presented in Figure 1.
[3]Each value is based on five replicate samples.
[4]All English sole were larger than 160 mm TL.

TABLE 2.—Characteristics of transects and samples of English sole during 1984.

Station[1]	Depth (m)	Mean percent fine-grained sediment[2]	Sample size[3]	Male proportion
CR-1	18	14.5 (2)	60	0.28
CR-2	12	8.6 (2)	60	0.13
SS-1	9	18.2 (2)	59	0.29
SS-2	10	22.9 (6)	60	0.48
SS-3	20	8.7 (6)	60	0.35
CI-1	5	68.8 (4)	57	0.75
CI-2	9	58.2 (4)	52	0.73
MD-1	6	40.4 (2)	59	0.42
SP-1	5	48.9 (3)	60	0.77
MI-1	10	87.5 (5)	60	0.87
SI-1	12	73.8 (5)	60	0.98
BL-1	11	55.2 (1)	60	0.77
BL-2	12	74.3 (9)	60	0.88
BL-3	10	55.4 (6)	60	0.88
HY-1	9	68.1 (5)	60	0.45
HY-2	9	79.8 (7)	60	0.80
HY-3	9	61.1 (12)	60	0.73

[1]Locations of transects are presented in Figure 1.
[2]Number of stations used to calculate mean percent fine-grained sediment at each transect is given in parentheses.
[3]All English sole were larger than 225 mm TL.

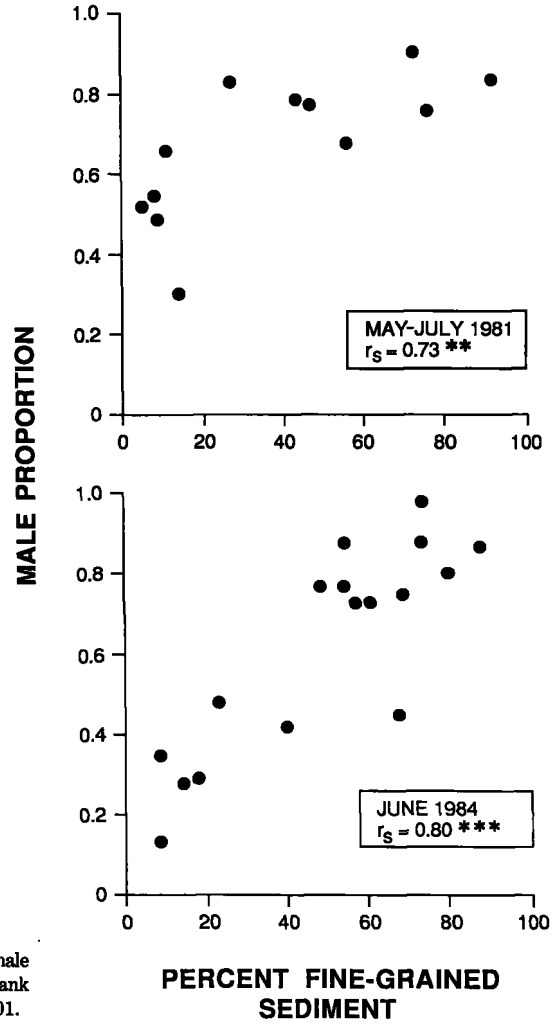

FIGURE 2.—Comparison of percent fine-grained sediment and male proportion of English sole populations using Spearman's rank correlation coefficient (r_s). ** = $P \leq 0.01$, *** = $P \leq 0.001$.

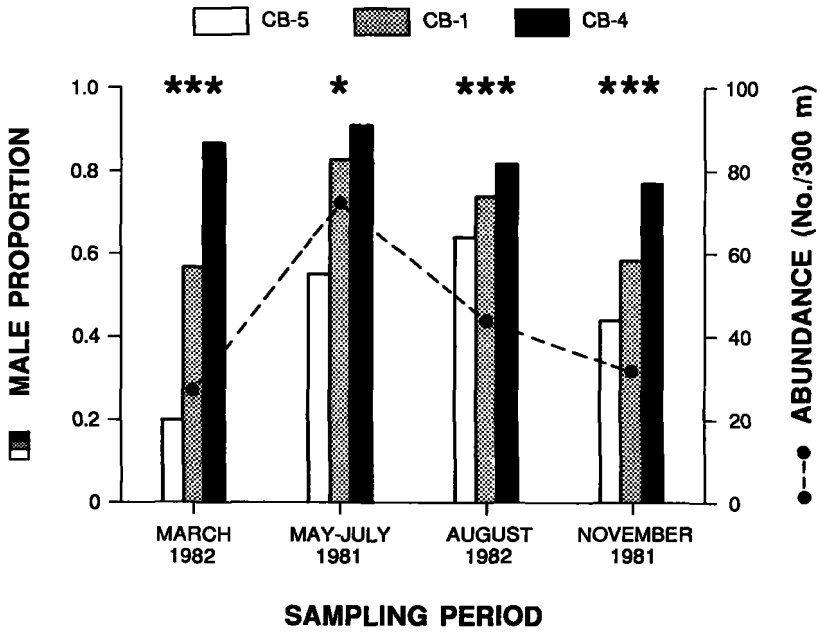

FIGURE 3.—Comparisons of male proportion of English sole populations at three Commencement Bay stations during four sampling periods using the *G*-test. Mean abundance of English sole at all three stations is plotted for each sampling period. The values of percent fine-grained sediment at Stations CB-5, CB-1, and CB-4 were 7.6%, 27.1%, and 71.6%, respectively. * = $P < 0.05$, *** = $P < 0.001$.

a spawning component of 0.9% during that period. No fish were found to be in spawning condition during August and November.

For English sole aged 3–10 years old during the 1984 study, male proportion for each age-class ranged from 0.50 to 0.66 (Fig. 4). However, the heterogeneity among age-classes was not significant ($P > 0.05$). Nineteen fish aged 2 or >10 years old were not included in this analysis because sample sizes by age-class were too small.

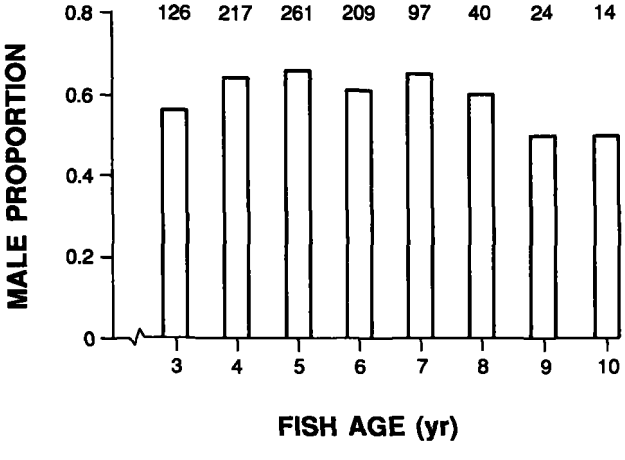

FIGURE 4.—Comparison of male proportion among age-classes of English sole collected in 1984. Sample size is presented above each bar.

DISCUSSION

Results of this study demonstrate that sex segregation by English sole in nearshore areas of Puget Sound is strongly associated with the grain-size distribution of bottom sediments. In addition to the results of statistical analyses, the strength of this association is demonstrated by its persistence across a variety of sampling conditions. For example, the association was found in two independent surveys conducted 2–3 years apart. Furthermore, the 1981–82 survey represented an analysis of large-scale patterns across three embayments, whereas the 1984 survey focused on small-scale patterns within a single embayment. The association between sex segregation and sediment grain size also persisted across seasons and across a range of depth.

Although a significant association was found between sediment grain size and male proportion of English sole, a variety of factors that covary with sediment grain size may have been partly or totally responsible for this association (Lagler et al. 1977; Moyle and Cech 1982). Examples of physical/chemical variables that often covary with grain size and may influence fish distributions include depth, current speed, turbidity, and dissolved oxygen. Examples of biological factors include the composition of prey assemblages and the distribution of predators. Although results of this study demonstrated that depth did not influence the observed association between sediment grain size and male proportion, further experimentation is required to identify the factor or suite of factors that directly influences sex segregation in this species.

Despite the fact that depth did not influence the patterns of sex segregation identified for English sole, the range of depth considered in this study (5–36 m) is a small fraction of the total range occupied by this species (0–550 m; Hart 1973). It therefore is possible that depth-related sex segregation in this species may be observed if a wider range of depths were examined. For example, considerable sex segregation by depth was found for Dover sole, *Microstomus pacificus*, off the west coast of the United States when a large depth range (110–440 m) was evaluated (Hagerman 1952; Alton 1972).

Based on results of the 1984 survey, no relationship between age and male proportion in English sole was evident. It therefore is unlikely that age influenced the observed relationship between male proportion and sediment grain size. A decline in male proportion with increasing age has been found for several pleuronectids (Rae 1965; Kovtsova 1982). Because most of the fish examined in this study were relatively young (<8 years old) compared with the maximum age of 15–17 years sometimes reached by individuals of this species (Ketchen 1956; Holland 1969; Van Cleve and El Sayed 1969), consideration of older fish may alter the patterns observed in this study. Although sample sizes for fish aged 9–10 years were relatively small in this study, male proportion in those age groups (0.50) was lower than that observed in all younger age groups (0.57–0.66).

The season of sampling did not alter the observed relationship between male proportion and sediment grain size. This relationship remained intact despite the fact that the mean abundance of English sole changed substantially throughout the seasonal cycle. The observed seasonal changes in mean abundance are consistent with the seasonal pattern of migration exhibited by adults of this species and most other pleuronectids. That pattern includes a migration to deeper water in the fall for overwintering and spawning, and a return migration to shallower water in spring for feeding throughout the summer (Ketchen 1956; Alverson et al. 1964; Roff 1982). It is unlikely that spawning substantially influenced the observed seasonal patterns of sex segregation in English sole, because the largest percentage of fish in spawning condition during any season was <15%. However, sex segregation in relation to spawning in pleuronectids has been documented for several species (Moiseev 1953; Alverson and Chatwin 1957), and may influence sex segregation in English sole when a substantial percentage of the population is in spawning condition.

Results of this study suggest that the influence of sex segregation should be considered when characteristics of English sole populations are compared among habitats that differ with respect to sediment character. Patterns based on population characteristics capable of exhibiting a dependence on sex (growth, condition, disease prevalence, tissue contamination) could be strongly biased if differences in the sex ratio among stations are not considered. This concern should probably be extended to studies of other pleuronectids, because the relationship between sex segregation and sediment character is unknown for most species.

Although the reasons for the observed patterns of sex segregation in English sole are unknown, a potential explanation is that different energetic needs induce male and female fish to utilize different habitats. Female English sole grow to a larger size than males and mature at an older age (Ketchen 1956; Holland 1969; Van Cleve and El-Sayed 1969; Hart 1973). In addition, fecundity in females is proportionate to individual size (Ketchen 1956; Hart

1973). These patterns are found for numerous pleuronectids and are thought to allow females to outgrow predators and maximize fecundity (Roff 1982). Female English sole may therefore select different habitats than males to support their differential reproductive requirements. Because many characteristics of benthic macroinvertebrate assemblages (i.e., the primary prey of English sole) are related to sediment character (Gray 1974; Rhoads 1974; Pearson and Rosenberg 1978), selection of habitats that differ in sediment grain size provides females with different prey spectra and energetic potentials than are available to males. In addition, differential habitat selection would reduce the potential of competition for food between sexes.

In summary, sex segregation by English sole was strongly associated with the grain-size characteristics of bottom sediments. This association was persistent across a variety of sampling conditions, including different years, seasons, embayments, and depths. Fish age did not appear to influence the observed association. Results of this study provide the first documentation of the influence of sediment character on sex segregation in a pleuronectid, and suggest that this relationship should be considered in future studies of English sole and, perhaps, other pleuronectids as well.

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