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Effects of diurnal variation in availability upon estimation of redfish numbers and biomass from stratified-random bottom trawl surveys

by

L. S. Parsons and D. G. Parsons
Department of Environment
Fisheries and Marine Service
Biological Station
St. John's, Newfoundland

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Introduction

In recent years stratified-random sampling has been increasingly accepted as a primary tool for assessing relative abundance of demersal stocks of fish. Research vessel surveys by the Newfoundland Biological Station up to 1971 were based upon the standard line method of surveying as described by Pinhorn (1971). Since 1971, surveys to the Grand Bank and St. Pierre Bank areas have utilized the stratified-random method of surveying as described in Grosslein and Pinhorn (1971). Pinhorn and Pitt (1974) have presented the results of these surveys for the 1971-73 period. To a large extent, the emphasis in these surveys has been placed upon depths normally frequented by cod, haddock, American plaice and yellowtail, with by far the bulk of the fishing sets occurring at depths of less than 150 fathoms. Some results have been presented for redfish (Pinhorn and Pitt 1974) but it has been realized that, to a large extent, these surveys have only sampled a small fraction of the redfish populations.

In attempting to extend these surveys to adequately sample redfish as well, consideration had to be given to the well-known diurnal vertical migrations of redfish as documented by Steele (1957), Konstantinov and Scherbino (1958), Templeman (1959) and Sandeman (1969). The extent of such migrations has been dramatized by the recent development of a midwater trawl fishery for redfish in the Gulf of St. Lawrence and, to a lesser extent, in Division 3P. In 1973 approximately thirty percent of the redfish catch in 3P was taken by midwater trawl.

This paper presents the results of a special stratified-random otter trawl survey of Subdivision 3Ps undertaken in June 1974 with comparative day-night fishing to assess the effects of diurnal variation in availability of redfish (Sebastes mentella) to the otter trawl upon estimation of redfish numbers and biomass, and examines the implications for redfish abundance estimation.

Materials and Methods

This study was undertaken during a June 1974 cruise by the A. T. Cameron to Subdivision 3Ps with comparative day-night fishing at depths ranging from 101 to 300 fathoms. The stratification scheme previously reported for 3Ps (Pinhorn 1972) was modified such that strata were drawn up on the basis of the following depth contours: 101-150, 151-200, 201-300 and 301-400 fathoms (Fig. 1).

In eleven of the total sixteen strata fished, a minimum of two (and generally more) randomly selected stations were fished both day and night. Sets designated as day sets were generally fished during the period from about one hour after sunrise to about one hour before sunset, night sets during the period from about one hour after sunset to about one hour before sunrise. The fishing pattern was such that in some instances a day set at a station occurred prior to the night set and in other instances vice versa.

All tows with the 41-5 otter trawl, with codend lined with 1/4" - 1 1/8" nylon mesh, were 30 minutes in duration.

Where time permitted, additional unreplicated day sets were fished at other randomly selected stations within a particular stratum. Because of operational requirements, it was not possible to carry out comparative day-night fishing in all strata. Five of the sixteen strata fished were fished only during daylight hours. Results for these strata are included in the overall estimates based on day sets but not in the day-night comparisons which are based only on stations where sets were replicated.

Results

Comparison of Day-Night Numbers and Biomass Estimates

Stratified mean numbers and weights (kg) per standard set and relevant statistics for replicated day-night sets are presented in Tables 1 and 2 for selected demersal species. Stratified mean numbers of redfish (Sebastes mentella) caught per standard set for day and night replicates are depicted in Figure 2.

There was a more than three-fold difference in stratified mean numbers of redfish caught during replicated day and night fishing (1328.6 versus 399.3; Table 1). The mean number for replicated daylight sets was outside of the 95% confidence limits for the stratified mean number caught at night and similarly the mean number caught at night was outside of the 95% confidence limits for the replicated day sets. The 95% confidence limits for the estimated mean number per replicated day set were considerably narrower (± 40% of the mean) than those for the estimated mean number per replicated night set (± 177% of the mean). For all strata in which comparative day-night fishing was conducted the mean number of redfish caught in replicated day sets was substantially larger than the mean number caught in the replicated night sets (Fig. 2).

There was a significant four-fold difference in stratified mean weight of redfish caught in replicated day and night sets (281.4 versus 70.6 kg). The 95% confidence limits for the two means do not overlap. The confidence limits for the estimated mean weight per replicated day set were slightly narrower (± 37% of the mean) than those for the estimated mean weight per replicated night set (± 47% of the mean).

Only small numbers of other demersal species were caught on this cruise (Table 1); hence, no meaningful conclusions could be drawn about the effects of diurnal variation in availability of these species to the otter trawl.

A comparison of these results with estimates obtained from numbers and weights caught during day and night unreplicated sets in two selected strata 306 and 309* (Tables 3 and 4) on an earlier 1974 April cruise indicates a similar trend but differences for just these two strata were much less pronounced than those obtained when a greater range and number of strata were fished on the June cruise.

Size and Age Comparisons

The length distribution of both male and female redfish in standard day and night sets (Fig. 3) were significantly different at the 1% level (Kolmogorov-Smirnov two-sample test). A comparison of the percentage length compositions (Fig. 4) reveals that the redfish caught during a standard night set were proportionately smaller than those caught during a standard day set at the same stations. This trend was evident in the majority of individual strata in which comparative day-night fishing was conducted.

A plot of the numbers caught per standard night set as a proportion of the numbers caught per standard day set at each length interval (Fig. 5A) suggests a differential rate of diurnal migration off bottom with size. Proportionately fewer of the intermediate-sized fish--22 to 30 cm--remained on bottom at night.

An examination of the night-to-day ratios of numbers caught at each age (Fig. 5B and 6) suggests, as might be expected from the trend with size, a differential diurnal migration rate with age, with proportionately fewer redfish of intermediate age (8 to 14 years) being caught at night than at day. The diurnal migration rate of 8- to 14-year-old redfish is proportionately greater than that for younger and older fish.

*Boundaries of strata 306 and 309 were altered between April and June cruises.

From the ratio of night-to-day catches per standard set plotted against numbers caught per standard day set (Fig. 7) it would appear that there is no significant relationship between daytime abundance and proportional movemement off bottom during the night.

There was no significant difference in the sex ratios of the numbers caught per standard day and night set.

Overall Estimates From Day Sets

Stratified mean numbers and weights per standard day set and relevant statistics, based on the total daylight sets in all sixteen strata surveyed, are given in Table 5. Overall mean number per standard day set was 854.8 and mean weight 219.3 kg. This is considerably less than the mean numbers per set in the 1973 and 1965 redfish research surveys of 3Ps, using the standard line survey method,of 1266 and 2629 fish respectively. For comparison, the 1965 and 1973 surveys were post-stratified, using the strata boundaries of Figure 1, and estimates derived for the six strata fished in all three years. Stratified mean number per unit for these strata in 1974 (1998.3) was about 20% higher than the post-stratified mean number per unit for the 1973 survey (1667.5); both were considerably less than the post-stratified mean number per unit for the 1965 survey (3189.9)

Estimated numbers of redfish in Subdivision 3Ps were 449 million fish and the estimated minimum trawlable biomass was 115,000 metric tons. The 95% confidence limits for the numbers and biomass estimates were within $\pm$ 32% and $\pm$ 25 % of the respective means.

Greatest mean numbers and mean weights per standard day set were obtained in the 101-150 fathom strata, with centres of greatest abundance in the Hermitage Channel immediately east of Burgeo Bank and on the southeastern edge of St. Pierre Bank (Fig. 8). Mean numbers and weights per standard day set were considerably lower in the 151-200 fathom and 201-300 fathom strata, with the exception of the southeasternmost strata (318, 707 and 708) where redfish abundance was high at all depths surveyed.

Bottom temperatures at the stations fished ranged from 4.8 to 8.0^{o} C, the upper part of the range of preferred temperatures for redfish (Templeman 1959). Bottom temperature did not appear to be the principal factor determining centres of redfish abundance within the survey area, although at temperatures of less than 5.5^{o} C the numbers caught were invariably low (Fig. 9).

Eight- and nine-year-old redfish of the 1966 and 1965 year-classes accounted for 34% of the redfish caught in standard day sets; 60% were between the ages of 6 and 10 (Fig. 10). Since relatively small and young redfish

(16 - 25 cm and 6 - 10 years old) were predominant in the survey catches (Fig. 10), it would be expected from the well-known differential depth distribution of redfish with size (age) that the shallower strata (101-150 fathoms) fished would have the largest concentrations of redfish.

Discussion and Conclusions

The results of the comparative day-night fishing reveal consistent and substantial differences in mean numbers and weights of redfish caught per standard day and night sets for all strata in which replicated day-night fishing was performed. The resulting differences in estimates of redfish numbers and weights derived from the replicated day and night fishing are substantial enough to cast serious doubt upon any estimates obtained by random 24-hour fishing, as might have been expected from previous knowledge of diurnal variation in availability of redfish to bottom trawls.

To date most of the stratified-random bottom trawl surveys in the Northwest Atlantic have been predicated on the assumption that such effects will average out over long periods of 24-hour fishing at randomly selected stations within predetermined strata. An examination of trawling records of Newfoundland Biological Station spring stratified-random bottom trawl surveys in 3Ps during 1972-73, with classification of fishing sets by time of day, revealed an uneven diurnal distribution of fishing sets within particular strata (Fig. 11).

Depending upon the actual distribution of fish among the strata during any particular survey cruise, estimates of numbers and biomass for any species exhibiting pronounced diurnal variations in availability could be seriously biased by year-to-year or cruise-to-cruise changes in fishing pattern and nonproportional allocation of day and night sets among strata.

For this reason, unless reliable and consistent conversion factors between day-night catches of such species can be derived, a feat not possible to date*, estimates of numbers and biomass for redfish and other species exhibiting pronounced diurnal variations in availability to the survey gear should, for bottom trawl surveys, be derived only from stations fished during daylight hours. Because of the necessity to maximize the number of usable fishing sets per stratum, these considerations further suggest that for maximum efficiency stratified random bottom trawl surveys aimed at abundance estimation for such species should be conducted, insofar as circumstances permit, during periods when daylight hours are close to maximal.

We were fortunate in this respect that the survey reported here was conducted during the latter half of June and consequently sufficient numbers of stations were fished during daylight hours to enable us to derive estimates of redfish numbers and biomass from the daylight portion of the survey. The relatively narrow confidence limits (± 32% for the estimate of numbers and ± 25% for the estimate of weights; Table 5) are as good as any obtained in demersal fish surveys conducted by the St. John's Station and better than the precision of ± 50% generally attainable in such surveys (Grosslein 1971). For redfish there is a quite marked gain in precision with stratification according to time of day, with bottom fishing restricted to daylight hours. It appears that estimates based on stratified-random bottom trawling during daylight hours may indeed be useful for assessment of trends in redfish abundance, even though the actual estimates of numbers and biomass must continue to be regarded as minimal until such time as catchability factors can be determined. Scott (1971), in estimating abundance of groundfishes on the Scotian Shelf, used an overall

*In this study ratios of day-to-night catches in individual strata ranged from 1.8 to 24.7 for numbers and from 1.6 to 28.8 for weights.

catchability factor of 0.27 for redfish, obtained from Edwards (1968), which was based on component availability, vulnerability and areal/seasonal factors of 0.45, 0.75 and 0.80 respectively. This factor was virtually identical to that used for cod (0.28) in the same study. In view of the probable differences in the degree of diurnal variation in availability of cod and redfish to the otter trawl, these estimates must be regarded as highly subjective.

The results of our study also suggest a differential diurnal variation with size and age in availability of redfish to the otter trawl, with apparently greater proportions of the intermediate sizes and ages moving off bottom during the night. Sandeman (1969), in a detailed study of the diurnal variation in availability of different sizes of redfish during a series of alternate haul mesh selection experiments directed at redfish on the eastern part of the Grand Bank, found that the catchability of redfish varied with size with greater proportions of the smaller redfish being caught than of the larger. Our results indicate a variation with size (age) in the proportion of redfish becoming available to the bottom trawl during the night.

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Table 1. Stratified mean number per standard set and relevant statistics for replicated day-night sets, A. T. Cameron Cruise 224, June 1974, in ICNAF Subdivision 3Ps.

Type of Set	Mean	Variance	Standard Deviation	Coefficient of Variation	95% Limits	
					Upper	Lower
			REDFISH			
Day-replicated	1328.6	48,312.0	219.8	0.17	1875.9	781.3
Night-replicated	399.3	6,934.0	83.3	0.21	1107.9	-309.3
			COD			
Day-replicated	2.5	1.8	1.3	0.54	6.7	-1.8
Night-replicated	7.8	18.4	4.3	0.55	19.5	-4.0
			HADDOCK			
Day-replicated	1.8	1.1	1.1	0.58	4.6	-1.0
Night-replicated	1.4	0.41	0.64	0.46	3.2	-0.39
			PLAICE			
Day-replicated	4.3	0.95	0.98	0.23	6.9	1.6
Night-replicated	2.2	0.19	0.43	0.20	3.3	1.1
			WITCH			
Day-replicated	15.4	8.7	3.0	0.19	22.4	8.3
Night-replicated	27.5	55.2	7.4	0.27	45.9	9.2

Strata Used for Diurnal Comparison: 306, 309, 310, 313, 316, 318, 705, 706, 707, 715, 716.

Table 2. Stratified mean weights (kg) per standard set and relevant statistics for replicated day-night sets, A. T. Cameron Cruise 224, June 1974, ICNAF Subdivision 3Ps.

Type of Set	Mean	Variance	Standard Deviation	Coefficient of Variation	95% Limits	
					Upper	Lower
			REDFISH			
Day-replicated	281.4	1746.1	41.8	0.15	386.7	176.1
Night-replicated	70.6	103.1	10.2	0.14	104.0	37.1
			COD			
Day-replicated	1.8	0.52	0.72	0.39	3.6	0.03
Night-replicated	3.3	2.6	1.6	0.50	7.8	-1.3
			HADDOCK			
Day-replicated	1.4	0.57	0.75	0.54	3.5	-0.71
Night-replicated	1.0	0.21	0.46	0.46	2.2	-0.15
			PLAICE			
Day-replicated	1.2	0.10	0.32	0.27	2.0	0.33
Night-replicated	0.56	0.01	0.12	0.21	0.86	0.26
			WITCH			
Day-replicated	4.6	0.98	0.99	0.21	7.0	2.3
Night-replicated	8.3	3.7	1.9	0.23	12.7	3.8

Table 3. Stratified mean numbers per standard set and relevant statistics for unreplicated day and night sets, Strata 306 and 309, A. T. Cameron Cruise 221, April 1974, ICNAF Subdivision 3Ps.

Type of Set	Mean	Variance	Standard Deviation	Coefficient of Variation	95% Limits	
					Upper	Lower
			REDFISH			
Day-unreplicated	811.3	99,157.0	314.9	0.39	1812.7	-190.0
Night-unreplicated	429.4	48,676.0	220.6	0.51	1104.5	-245.8
			COD			
Day-unreplicated	6.1	3.2	1.8	0.29	10.6	1.6
Night-unreplicated	2.2	1.3	1.1	0.49	5.4	-0.85
			HADDOCK			
Day-unreplicated	0.40	0.04	0.20	0.50	0.91	-0.12
Night-unreplicated	0.10	0.01	0.10	1.0	0.43	-0.22
			PLAICE			
Day-unreplicated	0.41	0.17	0.41	1.0	1.7	-0.90
Night-unreplicated	1.4	0.46	0.68	0.50	3.2	-0.52
			WITCH			
Day-unreplicated	31.1	39.0	6.2	0.20	46.5	15.8
Night-unreplicated	25.9	30.3	5.5	0.21	40.9	10.8

NOTE: Boundaries of strata 306 and 309 were altered between the April and June Cruises.

Table 4. Stratified mean weight (kg) per stnadard set and relevant statistics for unreplicated day-night sets, Strata 306 and 309, A. T. Cameron Cruise 221, April 1974, ICNAF Subdivision 3Ps.

Type of Set	Mean	Variance	Standard Deviation	Coefficient of Variation	95% Limits Upper	95% Limits Lower
			REDFISH			
Day-unreplicated	88.4	685.0	26.2	0.30	169.5	7.3
Night-unreplicated	46.4	302.1	17.4	0.37	100.9	-8.2
			COD			
Day-unreplicated	17.8	17.9	4.2	0.24	28.3	7.3
Night-unreplicated	3.0	1.4	1.2	0.40	6.3	-0.20
			HADDOCK			
Day-unreplicated	0.47	0.11	0.33	0.69	1.5	-0.54
Night-unreplicated	0.44	0.20	0.44	1.0	1.9	-0.97
			PLAICE			
Day-unreplicated	0.01	0.00	0.01	0.94	0.04	-0.02
Night-unreplicated	0.26	0.03	0.17	0.64	0.78	-0.25
			WITCH			
Day-unreplicated	11.3	3.9	2.0	0.17	16.2	6.3
Night-unreplicated	9.4	4.9	2.2	0.24	15.7	3.1

Table 5. Stratified mean numbers and weights (kg) per standard set and relevant statistics for total day sets--all strata, A. T. Cameron Cruise 224, June 1974, ICNAF Subdivision 3Ps.

Mean	Variance	Standard Deviation	Coefficient of Variation	Estimated Total for all Strata Fished	95% Limits Upper	95% Limits Lower
			NUMBERS			
854.8	18,499.7	136.0	0.16	449×10^6	592×10^6	306×10^6
			WEIGHT (kg)			
219.3	761.2	27.6	0.13	115×10^6	144×10^6	86×10^6

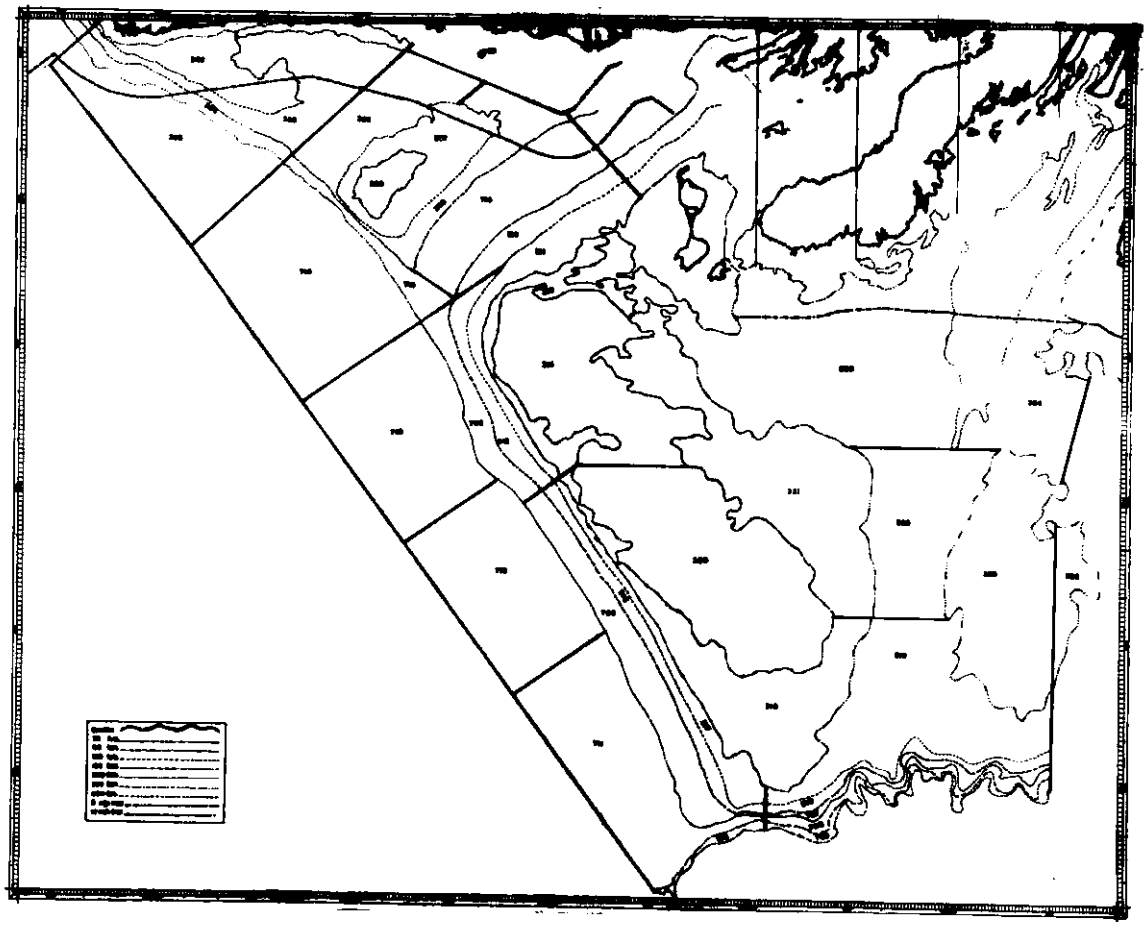

Fig. 1. Map showing strata fished on Canada (N) stratified-random cruise to Subdivision 3Ps, A. T. Cameron Cruise 224, June 1974.

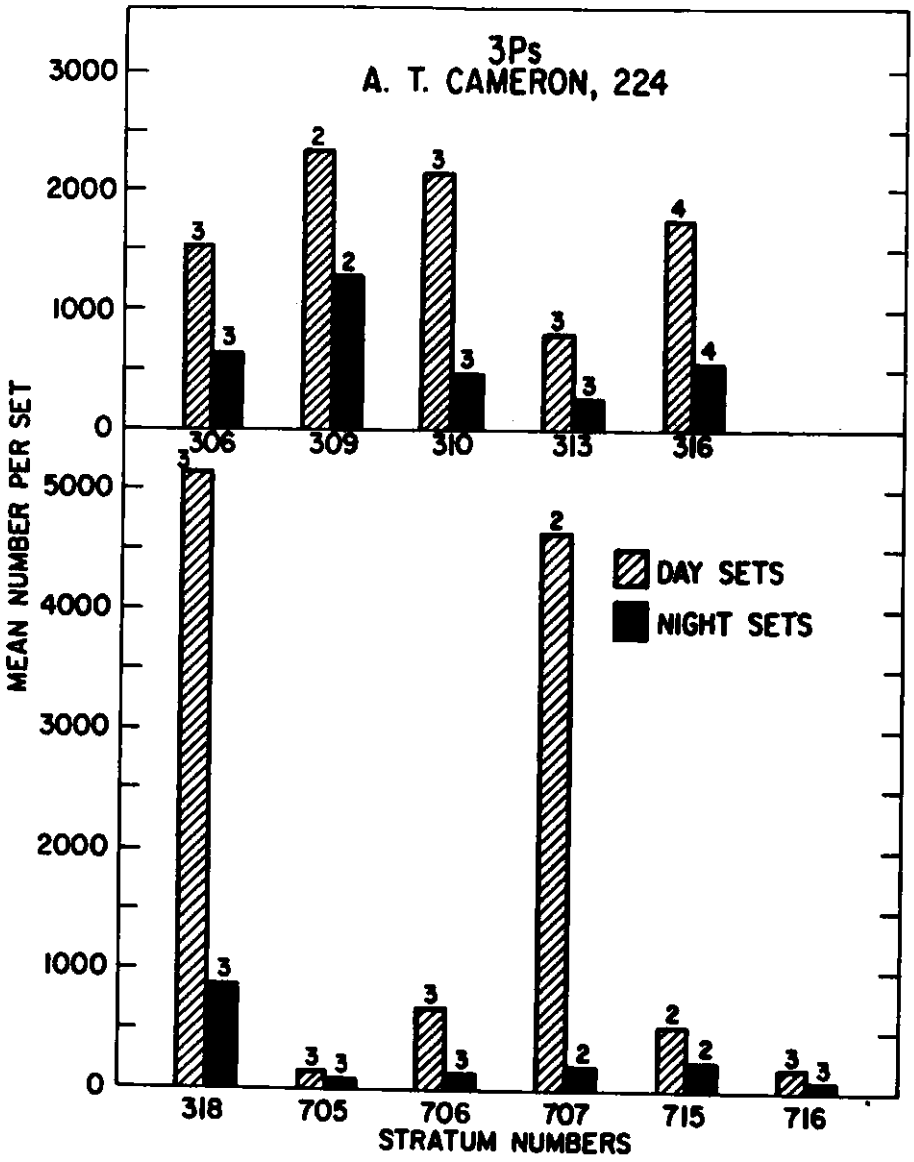

Fig. 2. Mean numbers of redfish (Sebastes mentella) caught per standard day and night set for each stratum in which comparative day-night fishing was conducted. (Numbers superimposed on each column represents the number of replicate sets fished in each stratum and category).

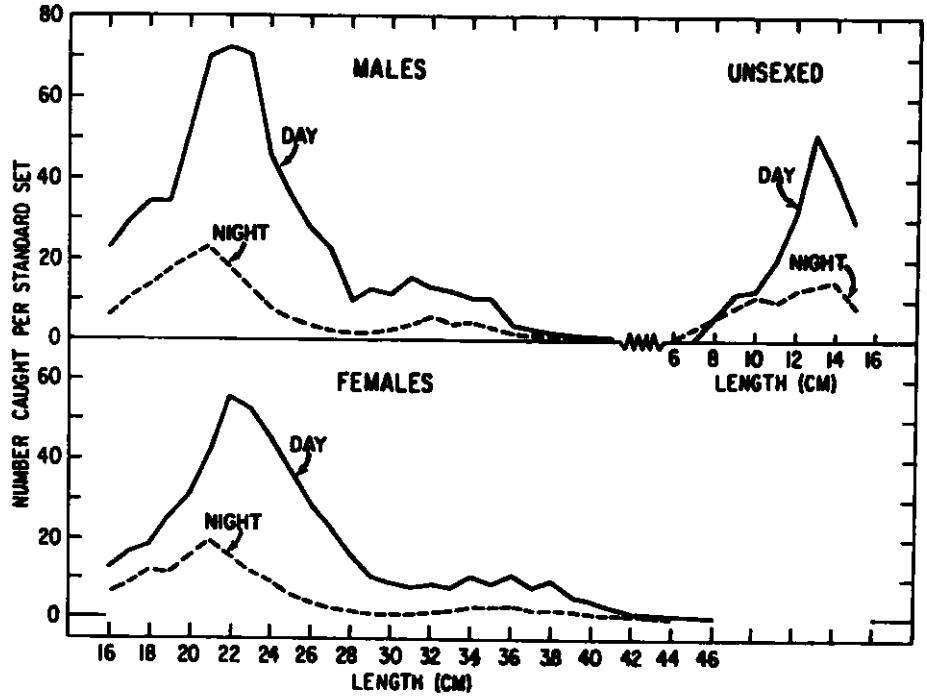

Fig. 3. Length distribution of redfish (Sebastes mentella) caught per standard day and night sets (based on replicated fishing).

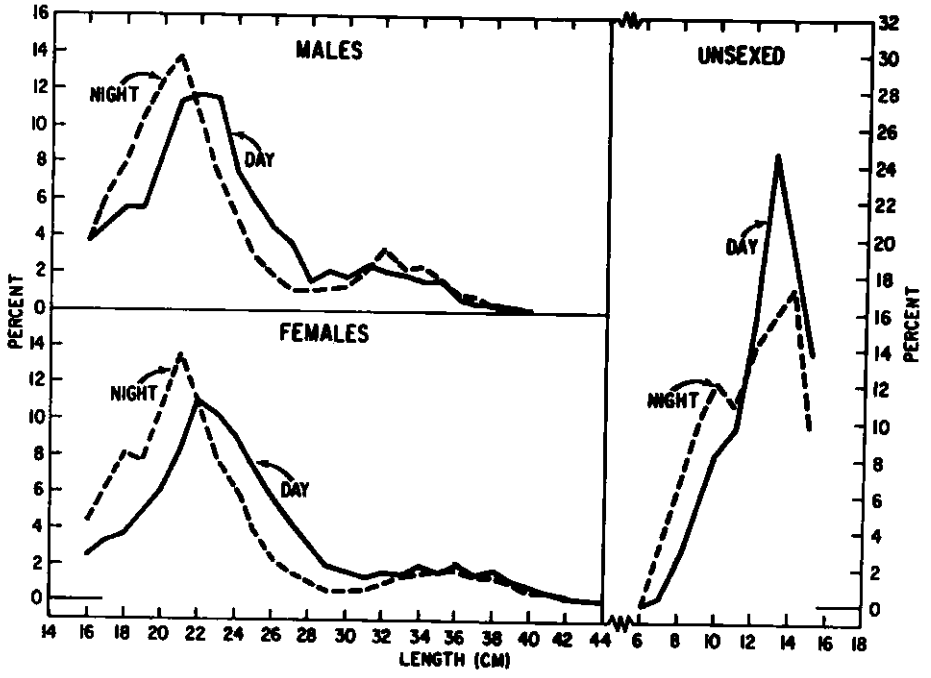

Fig. 4. Percentage length composition of redfish (Sebastes mentella) per standard day and night set (based on replicated fishing).

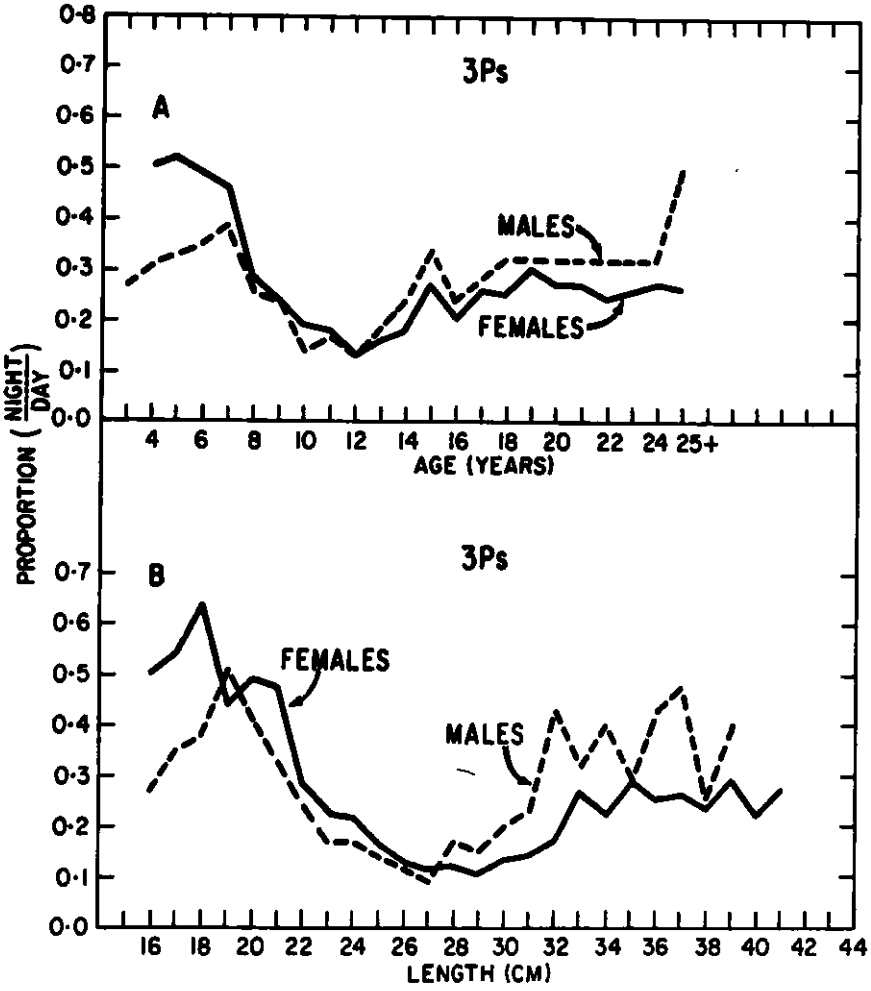

Fig. 5. Numbers of redfish caught per standard night set as a proportion of numbers caught per standard day set in relation to length (A) and age (B).

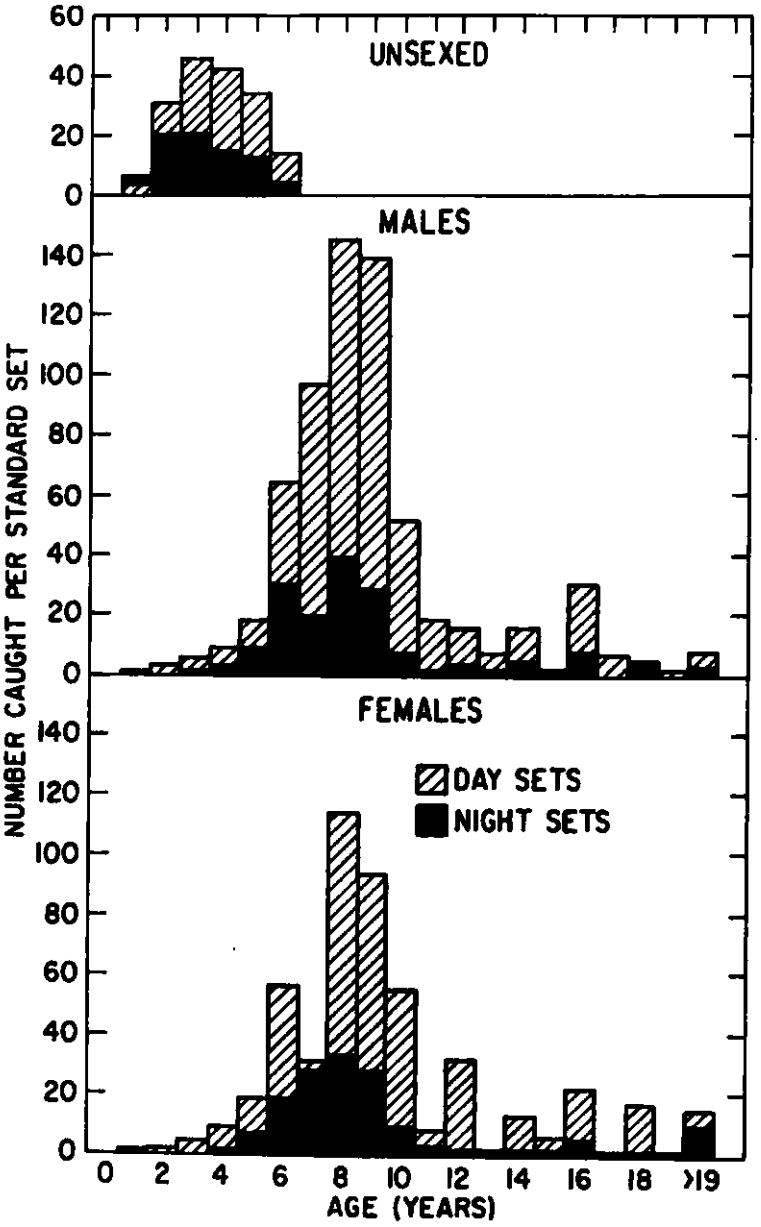

Fig. 6. Numbers of redfish caught at each age per standard day and night set (based on replicated fishing).

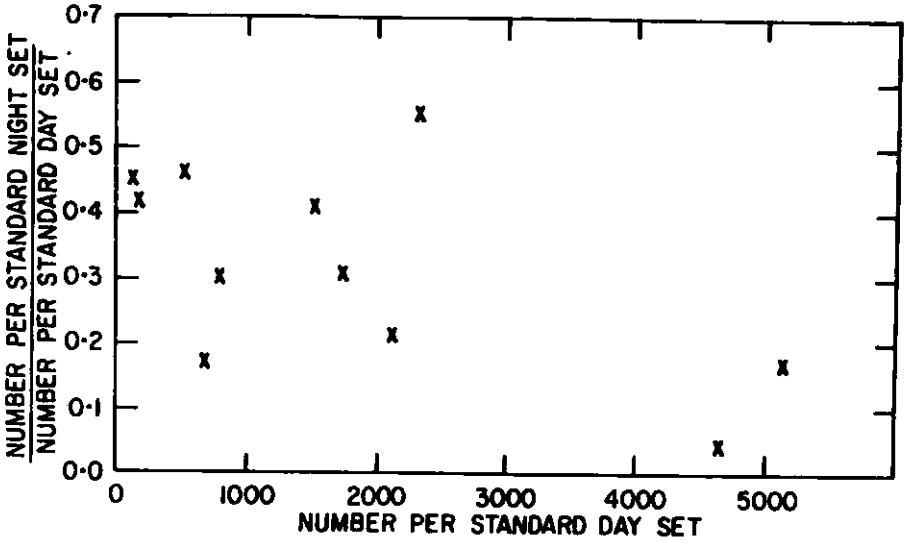

Fig. 7. Ratio of night-to-day numbers of redfish caught per standard set plotted against numbers caught per standard day set.

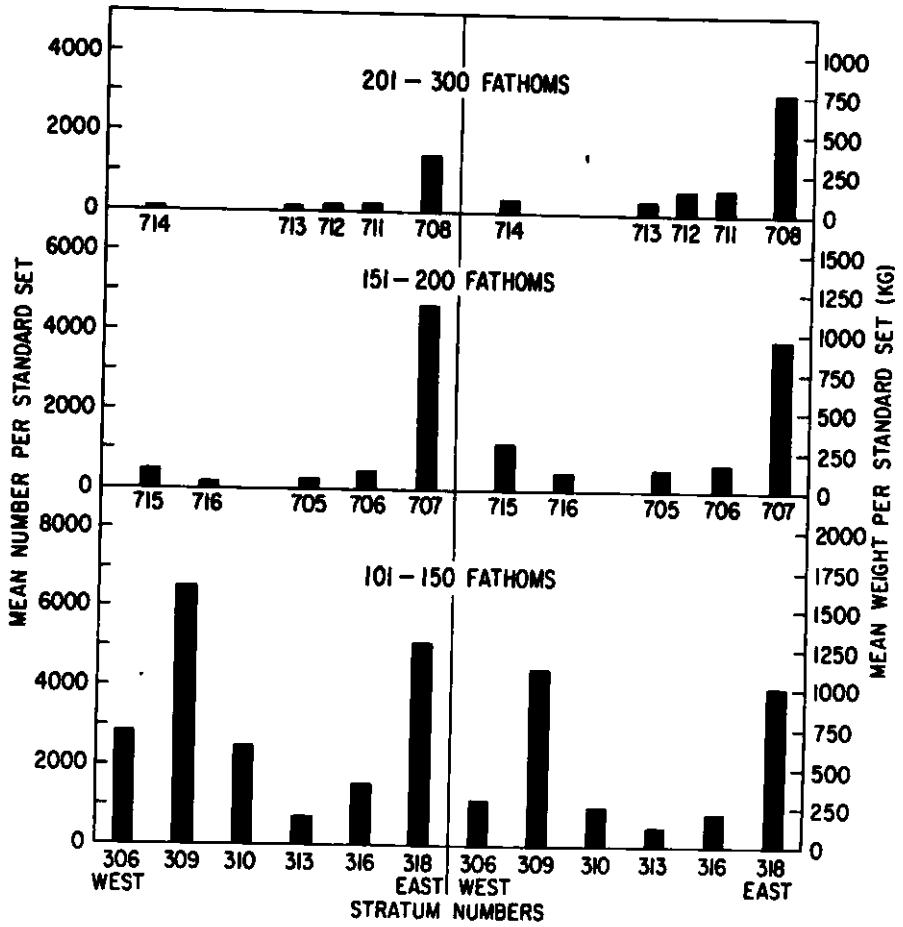

Fig. 8. Mean numbers and weights per standard day set--all strata (based on total day sets fished).

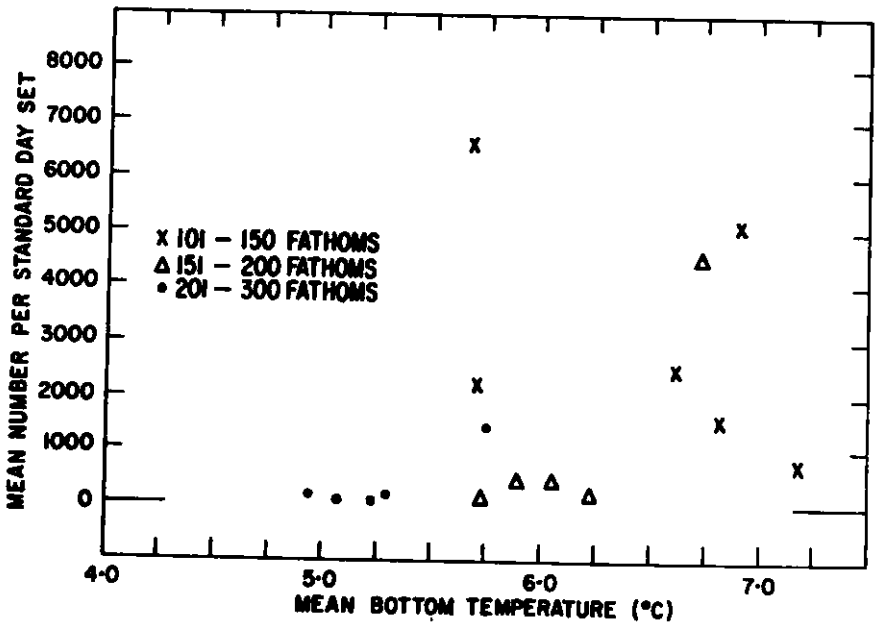

Fig. 9. Mean number of redfish per standard day set plotted against mean bottom temperature in each stratum.

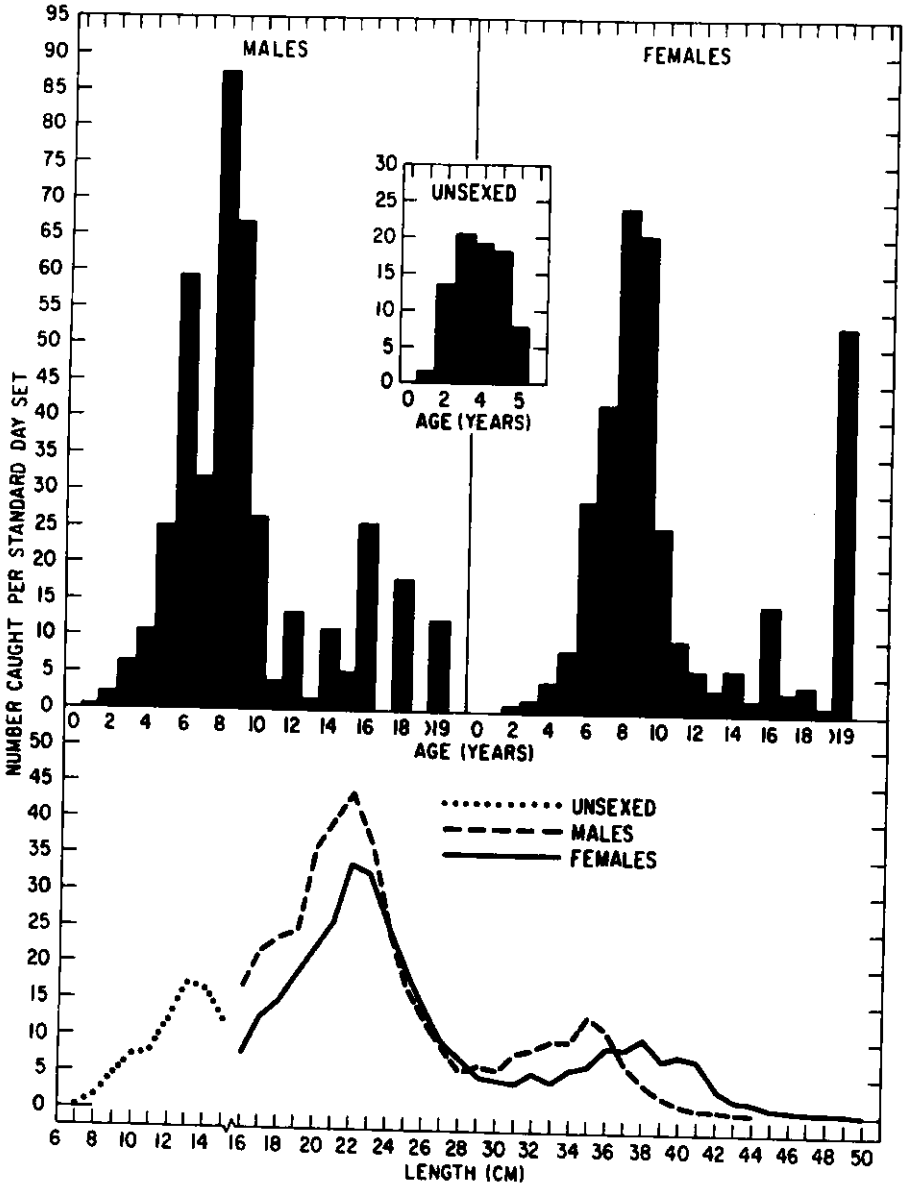

Fig. 10. Numbers caught at each length (A) and age (B) per standard day set--all strata and all day sets combined.

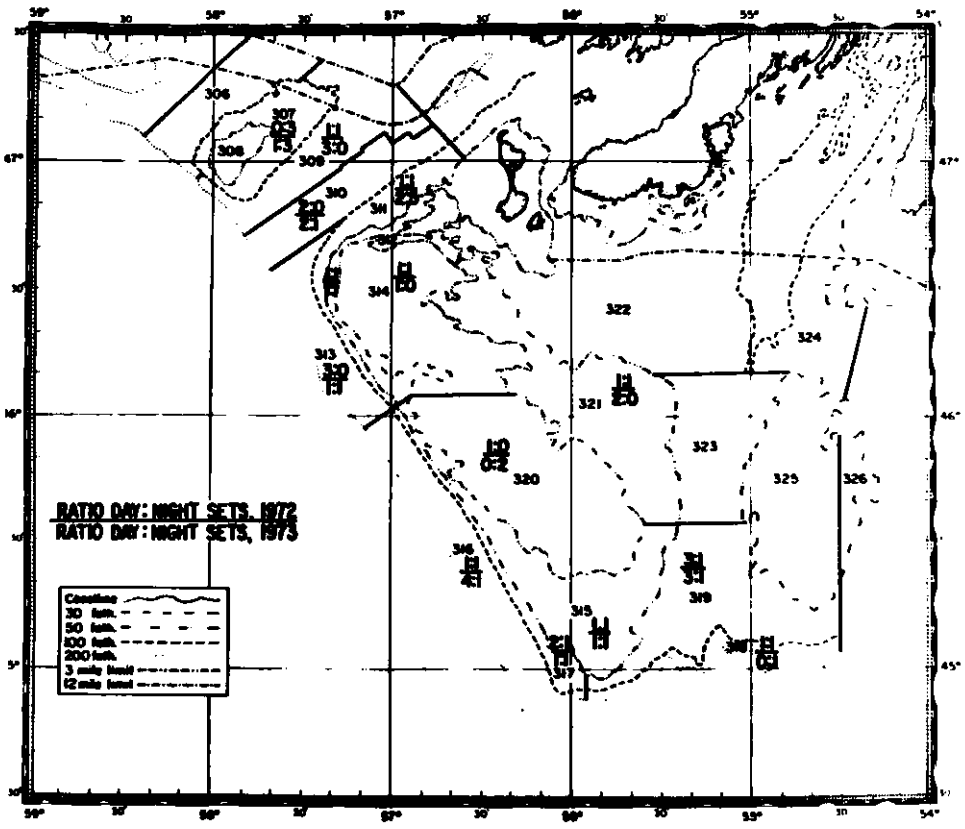

Fig. 11. Ratio of day-to-night sets in each stratum fished on Canada (N) stratified-random cruises to Subdivision 3Ps, 1972 and 1973. In each stratum, upper figures represent ratio of day-to-night sets in 1972 cruise; lower figures represent ratio of day-to-night catches in 1973 cruise.