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RELATIONSHIP OF COASTAL OCEANOGRAPHIC FACTORS TO THE MIGRATION OF FRASER RIVER SOCKEYE SALMON (Oncorhynchus nerka, W.)

by
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ABSTRACT

The majority of Fraser River sockeye salmon return to the river through the Strait of Juan de Fuca at the south end of Vancouver Island. From 1953 to 1973 the percentage of sockeye that returned by the northern passages between the island and the mainland has varied from 2% to 35%. Conditions that could force varying amounts of Fraser River water offshore at greater latitudes have been used to predict the percentage of fish using the northerly route in the years 1974 to 1976.

RÉSUMÉ

Le plus grand nombre des saumon sockeye retourné à la rivière Fraser par le détroit Juan de Fuca au bout sud de l'île de Vancouver. Le pourcentage de sockeye de l'anneé 1953 à 1973, retourné par les détroits nords à changé de 2% à 35%. Nous prédissons le pourcentage pour 1974 à 1976 par les conditions qui forcent de la terre l'eau de la rivière Fraser au total variable vers le nord.

INTRODUCTION

Effective management of the sockeye salmon (Oncorhyncus nerka) fishery of the Fraser River is dependent upon the capability to predict the abundance, timing and migration routes of these species. Royal and Tully (1961) noted that it is relatively simple to make compensating adjustments in fishing regulations for unexpected changes in abundance, provided that the timing of the runs is inherently consistent, as it is in most years, and that the routes of inshore migration follow a consistent pattern. If, however, the measurement of abundance from commercial catches in the initial phase of the fishery is confused by a delay in arrival, and/or a change in the route of migration, then the problem of managing the fishery becomes more complex.

Normally the bulk of the maturing Fraser River sockeye arrive off the west coast of Vancouver Island and approach the Fraser River around the south end of the island through Juan de Fuca Strait (Fig. 1). A small part of the population, averaging 16%, passes around the northern tip of Vancouver Island and approaches the Fraser River from the north through Queen Charlotte Sound and Johnstone Straits. However, radical departures from this normal pattern have occurred. For example, in 1957 a larger share of the population approached Vancouver from the north and a larger percentage (approximately 19.5%) returned through Queen Charlotte Strait. Also, the fish were slightly delayed, and migrated over a longer period of time. In 1958, the fish failed to appear off the west coast of Vancouver Island in its usual initial landfall, but arrived northerly of Vancouver Island in the Queen Charlotte Sound area. The fish then moved in a southerly direction with an estimated 35% of the total population entering Queen Charlotte Strait. The fish appeared in the fishery 10 days later, and over a longer period of time than was anticipated on the basis of previous catch records. These vagaries have been discussed by Royal and Tully (1961). They suggested that these anomalies were related to a change in surface circulation of the offshore waters, which was accompanied by the development of anomalously high temperature conditions off the southern British Columbia coast in 1957. These conditions intensified in 1958, with the warm water reaching its maximum northward extent in August 1958 (Tully et al. 1960).

Favorite (1961), using data gathered in August 1958 and 1959 noted the presence of three distinct tongues of dilute water extending seaward of Juan de Fuca Strait, Queen Charlotte Sound and Dixon Entrance. The tongue seaward of Queen Charlotte Sound extended further offshore in 1958 than in 1959. On the basis of these differences, he suggested that the seaward extent of dilute surface water may determine the location where homeward migrating salmon enter coastal waters. Also, the presence of clearly defined tongues normal to the coast suggests the absence of any appreciable northerly or southerly current along the Canadian coast. These hypotheses cannot be verified for other years when changes occurred in the migration paths (e.g., 1972, 34% returned by the northern route) because of the lack of a synoptic coverage of the area in this period. However, they do suggest parameters and mechanisms that should be investigated, if a predictive capability for the Fraser River sockeye fishery is to be developed. This ppaper presents the results of further research on this pressing requirement.

HYPOTHESES TESTED

Four hypotheses were tested, i.e., a greater percentage of Fraser River sockeye salmon will use the northern passages due to:

1. an avoidance of warm water (or the northern transport of adults as indicated by surface temperatures at a shore station on the west coast of Vancouver Island,
2. less southward displacement of young fish moving offshore resulting in corresponding displacements of the adults,
3. increasing convergence of coastal waters with displacement of Fraser River discharge to the north where it could act as a releaser to the adults,
    (a) as indicated by increased mean sea level along the west coast of Vancouver Island,
    (b) as indicated by varying north-south sea level differences along the east coast of Vancouver Island,
4. greater total amounts of Fraser River water diluting the offshore waters to the northwest of Vancouver Island.

DATA

Yearly percentages of salmon using the northern passages were supplied by the International Pacific Salmon Fisheries Commission through the courtesy of the former director, L. Royal, and of the present director, A. C. Cooper. There were two series, 1951 to 1968 and a revised series 1953 to date.

Sea levels and shore station temperatures were supplied by the Marine Sciences Directorate Pacific Region and Fraser River discharge by the Water Survey of Canada, Pacific Region. Ekman transport was computed from sea level pressure data (Wickett and Thomson 1973; previous numbers in series).

Fig. 2 was taken from Dodimead et al. (1963) and Dodimead (1968).

METHOD

A computer program for multiple regression was used to examine the hypotheses, taking two or three independent variables at a time (Lindsey 1971). A full linear equation with removal of coefficients likely to be zero is calculated.

RESULTS

A. Y=% 1951-1968

X_1= Ekman transport December (year n-2) to March (year n-1) along 140° from latitutde 45°N longitude 135°W.

X_2= June mean temperature at Amphitrite Point.

$R^2 = 0.83$ $F = 11.34$ $F_{.05} = 5.06$ $F_{.01} = 3.11$

Failed to predict large percentage in 1972.

B. Y = % 1953-1974

X_1 = Ekman transport December (year n-2) to March (year n-1) along 140° from 45°N 135°W.

X_2 = February to June mean sea level at Tofino.

$R^2 = 0.22$ $F = 5.50$ $F_{.05} = 4.49$ $F_{.01} = 8.53$

Only the coefficient for X_2^2 was significantly different from zero.

C. Y = % 1953-1974

X_1= February to June mean sea level at Tofino.

X_2= Difference in sea level between Alert Bay and Point Atkinson May to June.

X_3= Difference in sea level between Alert Bay and Point Atkinson in June

The coefficients for X_1^2, and $X_1 \times X_2 \times X_3$ were significantly different from zero.

$R^2 = 0.42$ $F = 6.17$ $F_{.05} = 3.74$ $F_{.01} = 6.51$

D. Y = % 1953-1973

X_1= February to June mean sea level at Tofino in feet.

X_2= April to June monthly mean discharge of the Fraser River in 10^5 cubic feet per sec totalled.

(a) Full linear equation $R^2 = 0.71$ $F = 7.18$ $F_{.05} = 2.90$ $F_{.01} = 4.56$

(b) Equation with X_1; X_2; X_1X_2 significantly different from zero.

$R^2 = 0.69$ $F = 11.70$ $F_{.05} = 3.29$ $F_{.01} = 5.42$

The data are given in Table 1. The limits on expected values are ± 11%. The equations predict reasonably well the values for 1974, 1975, and 1976. with indications that the 1977 value may be acceptable.

The equations developed under the last hypothesis are:

$$Y = 2264.232 - 441.605X_1 - 299.443X_2 + 15.17X_1^2 - 1.751X_2^2 + 46.823X_1X_2 \quad (1)$$

and

$$Y = 1356.381 - 198.586X_1 - 272.115X_2 + 40.241X_1X_2 \quad (2)$$

In order to make predictions earlier in the season, June values of X_1 and X_2 were dropped and the following equations computed:

$$Y = -2582.08 + 956.512X_1 - 642.833X_2 - 85.573X_1^2 - 11.797X_2^2 + 101.614X_1X_2 \quad (3)$$

$R^2 = 0.69$ $F = 6.64$ $F_{.01} = 4.56$ Limits = ± 12%

and

$$Y = 326.635 - 301.951X_2 - 6.798X_1^2 + 44.379X_1X_2 \quad (4)$$

$R^2 = 0.58$ $F = 9.25$ $F_{0.01} = 5.42$ Limits = ± 12%

All the coefficients of (4) are significantly different from zero.

The predicted and observed values for 1974 to 1977 are given in Table 1.

DISCUSSION

The hypotheses may be considered in a slightly different form. Three processes by which the salmon could be diverted are considered: (1) avoidance of warm water, (2) physical transport to the north, (3) release of migratory behavior combined with an east-west salinity boundary in the tongue of dilute water running out from Queen Charlotte Sound to the north of Vancouver Island. Assumptions are made that the physical factors chosen are good indices of the processes being examined. We will consider these assumptions first.

Coastal temperatures will rise with onshore transport but the winter southeast winds normally switch to the northwest as the summer high pressure is established. At this time high insolation can be accompanied by coastal upwelling that can cause the inshore temperatures to drop. This seems to have happened in 1972.

The discharge of Fraser River water through the northern passages is too complicated a process to be monitored by simple tidal differences (P. B. Crean, pers. comm.). Wickett and Thomson (1973) showed that mean monthly sea levels at Prince Rupert were closely associated with mean monthly

Ekman transport normal to the coast. Similarly, for 300 months following January 1946, 41% of the variance of mean monthly sea level at Tofino is associated with Ekman transport normal to the coast from 50°N 130°W. This is taken to mean that convergence and divergence of the upper layers of the coastal waters of Vancouver Island are reflected in changing sea levels.

The three processes now can be considered:

1. Temperature. Within the depths sockeye have been caught at sea (Manzer 1964) there can be a change from 15 C to 7 C in coastal water. I believe that horizontal temperature gradients in the areas in which Fraser sockeye are found are not a deterent to migration. There was a north-south tongue of 15 C water off the west coast of Vancouver Island in 1972, the second year with a large percentage use of the northern channels, though.
2. Physical transport. The transport parallel to the coast (140°) did not predict the 1972 value.

   I have seen no evidence to suggest that there was a massive northward transport into the Gulf of Alaska in any year following 1958. Transport of the fish is rejected.
3. The third process has much to recommend it. Brett and Groot (1963) state that sockeye can detect a substance at a dilution of $1:8 \times 10^{10}$. An average discharge of the river for 3 months of 171,000 cfs ($1\ ft^3 = 0.0283\ m^3$) is sufficient to dilute a stream of seawater 12 ft deep, 30 mi (1 nm = 1.85 km) wide and moving at 1 kt from 31.80‰ to 30.34‰. Such a drop is of the order that happens at Pine Island at the entrance of Queen Charlotte Strait (north end of Vancouver Island). It also produces enough water to cover an area 300 × 123 mi to a depth of 100 ft (1 ft = 0.308 m).

Favorite's (1961) view that there is little north-south transport in offshore waters (during the latter part of the migration, I would add) is acceptable. However, close to the shore there is certainly a northward current. Lane (1963) states that "the force of the wind results in deep mixing throughout the entire oceanic and coastal region except near shore where the large coastal discharge provides continuous renewal of brackish water and large stability. An onshore movement produced by strong southeast winds confines the brackish discharge from local estuaries to a narrow, northward flowing, alongshore stream. The relative intensities of wind and discharge determine the width of the brackish coastal water belt." Tully (1942) showed that in the approaches to the Strait of Juan de Fuca there is balance between a wake stream from the strait, which is directly related to the volume of land drainage, and the independent wind-driven currents, which are due to one of the two prevailing coastwise winds in the area. Trites (1956) found that normally the majority of Skeena River (northern B.C.) discharge turns to the right and moves north along the coast. Barnes, Duxberg and Morse (1972) state that the Columbia River plume also marks winter convergence and summer divergence of coastal waters (Fig. 2). The isohalines shown in Fig. 2 mostly confirm the final hypothesis. The year 1966 is the most abberant statistically and pictorially, for Fig. 2h is not helpful. Thirty percent of the variance remains unexplained.

CONCLUSION

The hypothesis that increasing the proportion of Fraser River water discharged into the ocean to the northwest of Vancouver Island increases the percentage of Fraser River sockeye salmon that migrate through the northern channels around Vancouver Island is accepted at this time.

ACKNOWLEDGMENTS

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Table 1. Data used in computing expected number of sockeye returning via Johnstone Strait.

Year	% Fraser sockeye in Johnstone Str.		Mean sea level Tofino Feb.-June ft.	Total of monthly mean Fraser River discharge at Hope for Apr., May, June $\times 10^5$ cfs
	observed	expected		
1953	9.4	10.4	6.83	4.205
1954	1.8	6.7	7.02	4.411
1955	9.1	16.6	6.65	4.501
1956	9.9	14.7	6.84	5.380
1957	19.5	21.9	7.00	5.834
1958	34.9	32.6	7.26	5.747
1959	14.7	13.2	6.88	4.890
1960	18.6	13.0	6.96	4.903
1961	16.4	21.1	7.15	5.346
1962	11.9	13.1	6.81	4.769
1963	11.12	10.0	7.02	4.653
1964	10.2	8.0	6.49	5.547
1965	10.3	13.5	6.73	5.190
1966	24.5	14.7	6.87	5.214
1967	25.0	20.1	6.95	5.905
1968	17.6	16.3	6.97	5.262
1969	15.0	13.6	7.04	4.943
1970	23.9	15.0	6.71	4.098
1971	11.6	15.1	6.86	5.389
1972	33.9	35.3	7.08	6.822
1973	8.9	12.5	6.80	4.466
1974	22.0	24.6(1) 25.45(2)[a] 25.4(3) 23.31(4)[a]	7.05	5.879
1975	9.0[b]	10.4(1)	6.83	4.20
1976	18.0	14 (1)	6.78	5.87
1977	11-12[c]	13.5(1)	6.75	4.49

[a] Number in bracket refers to equation used.

[b] Part-time strike.

[c] Preliminary August 10.

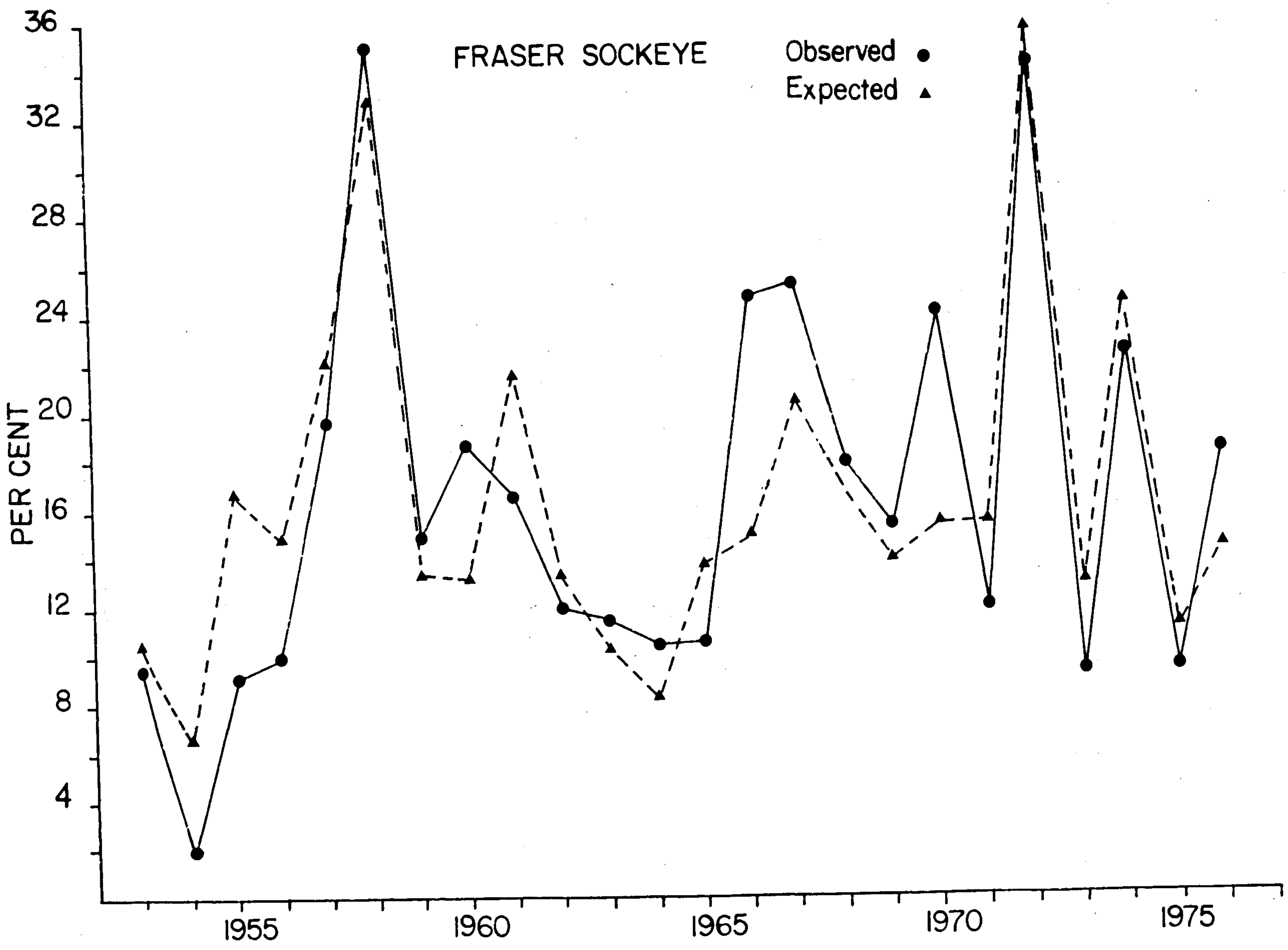


Fig. 1. Percentage of Fraser River sockeye salmon that returned by the northern passages around Vancouver Island and the percentage expected from regression. (Data courtesy of Int. Pac. Sal. Fish. Comm.)

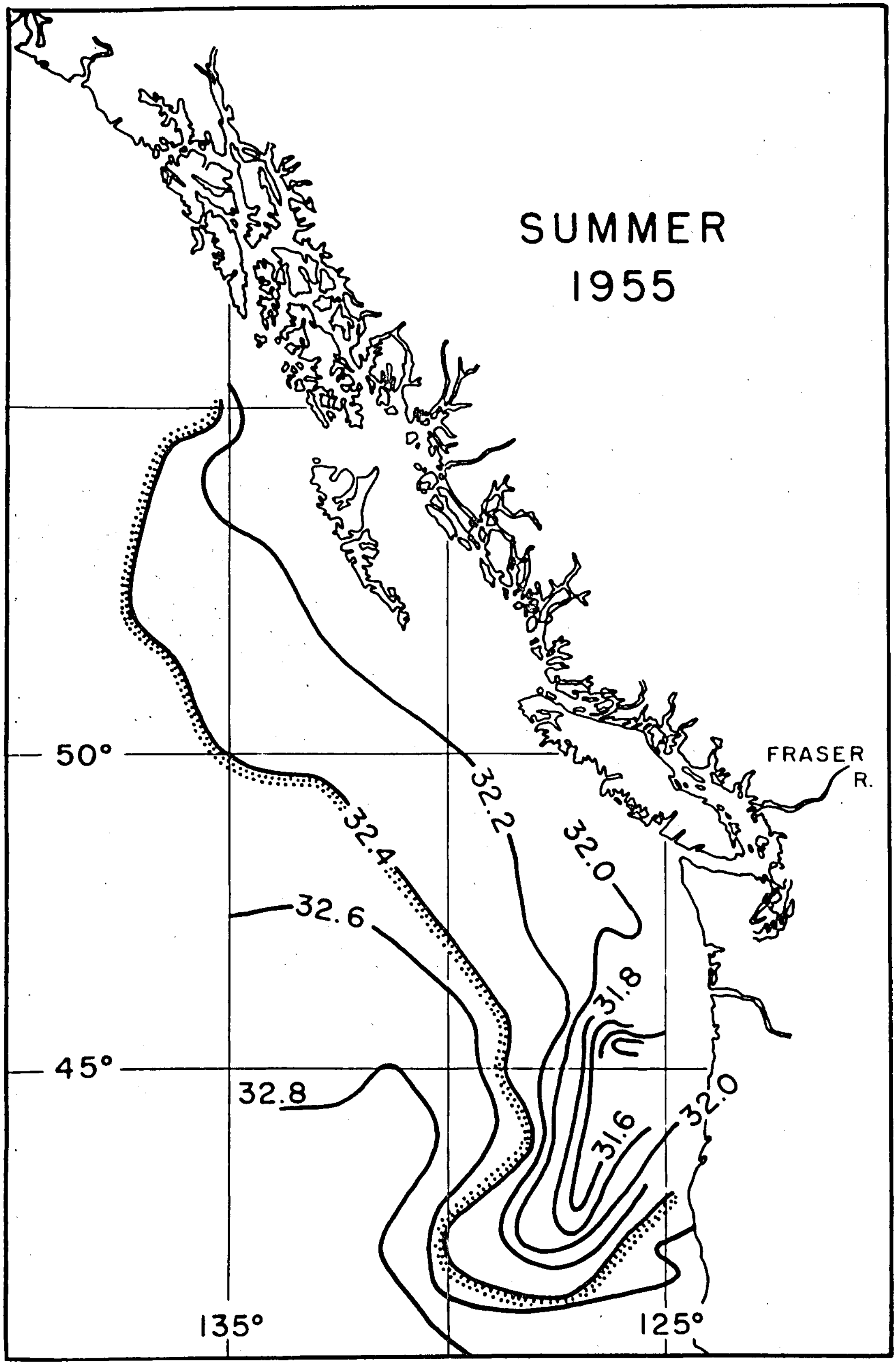


Fig. 2. Surface isohalines in the coastal waters of British Columbia, Washington, and Oregon during July and August. (a) 1955.

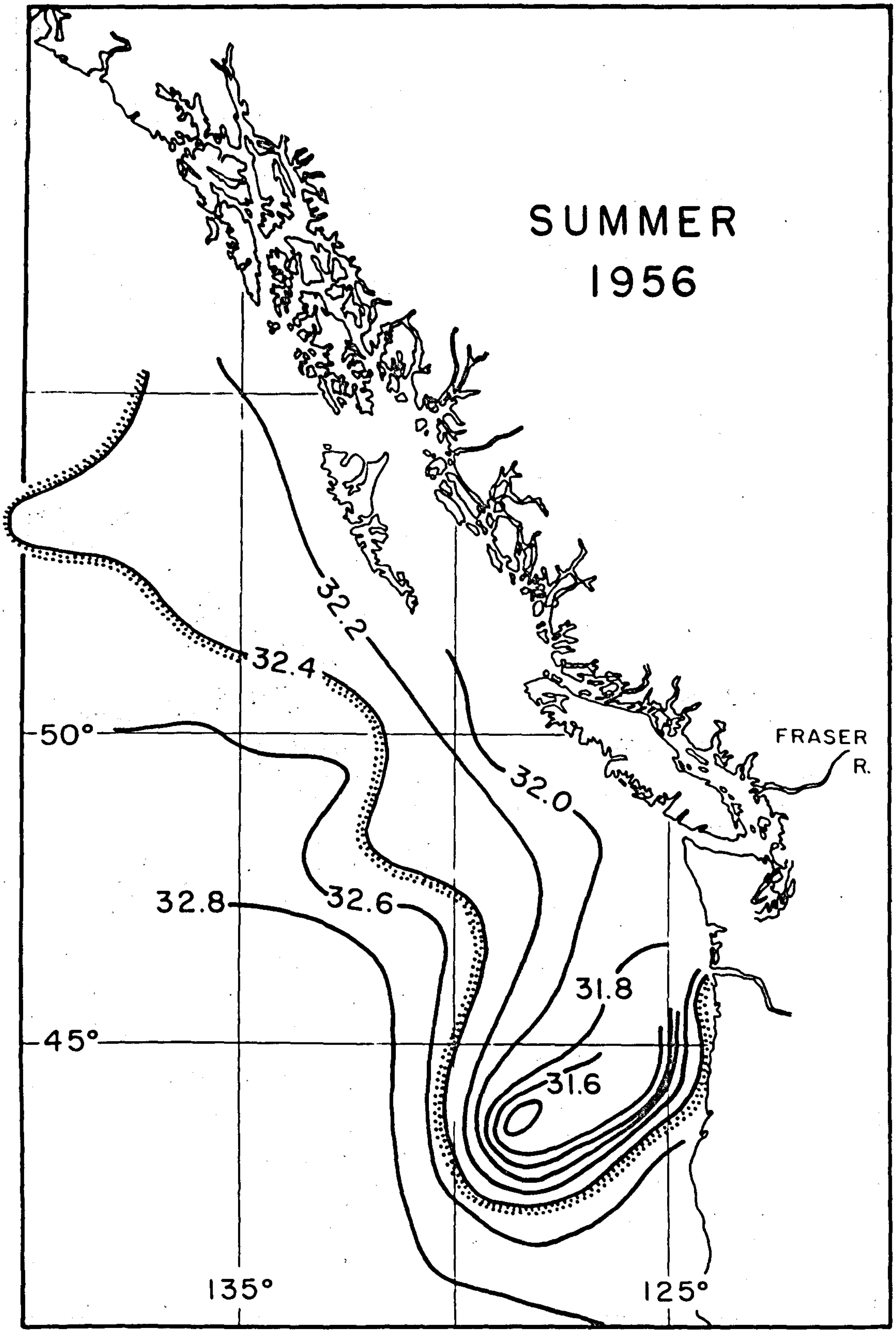


Fig. 2b

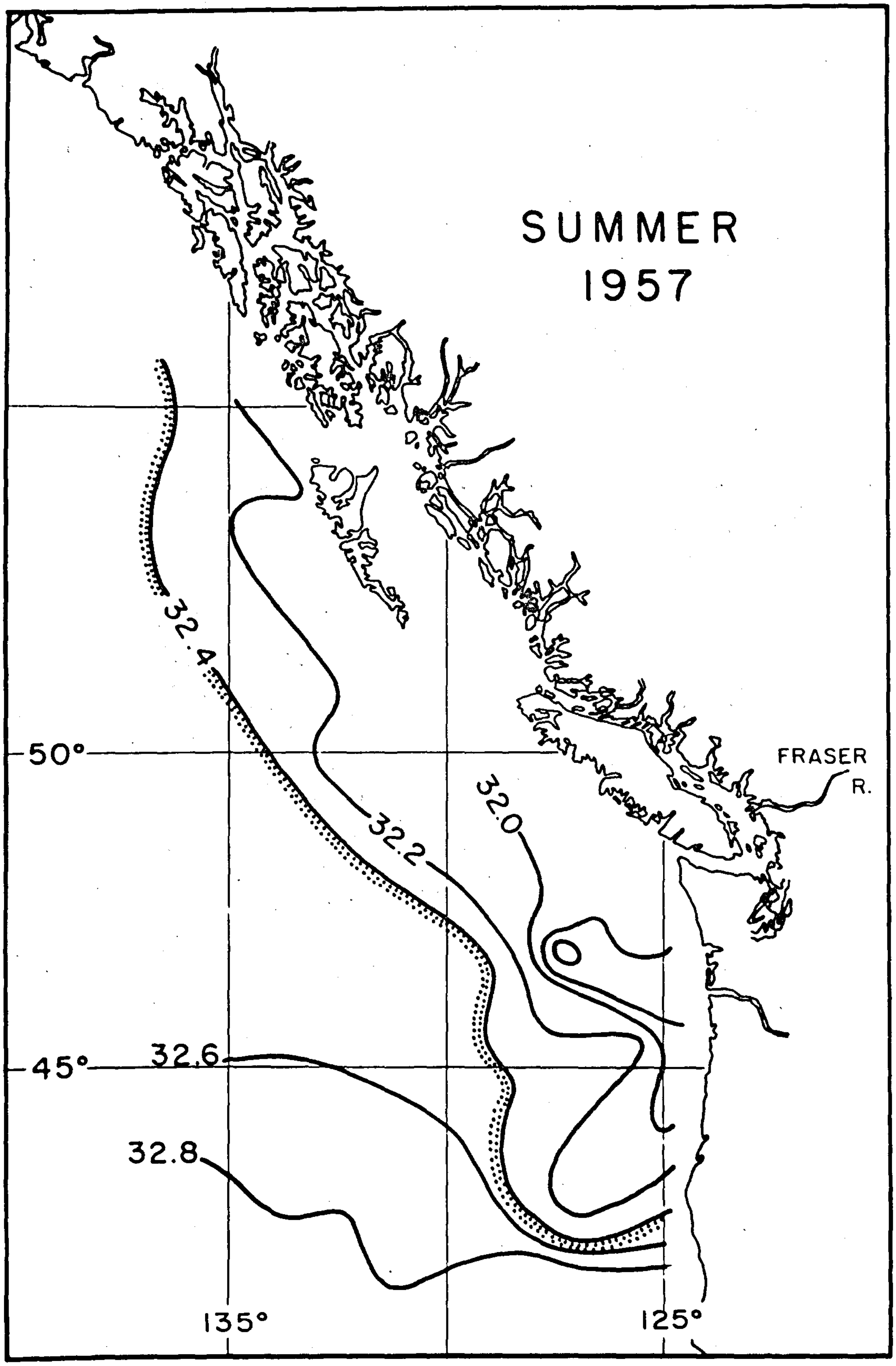


Fig. 2c

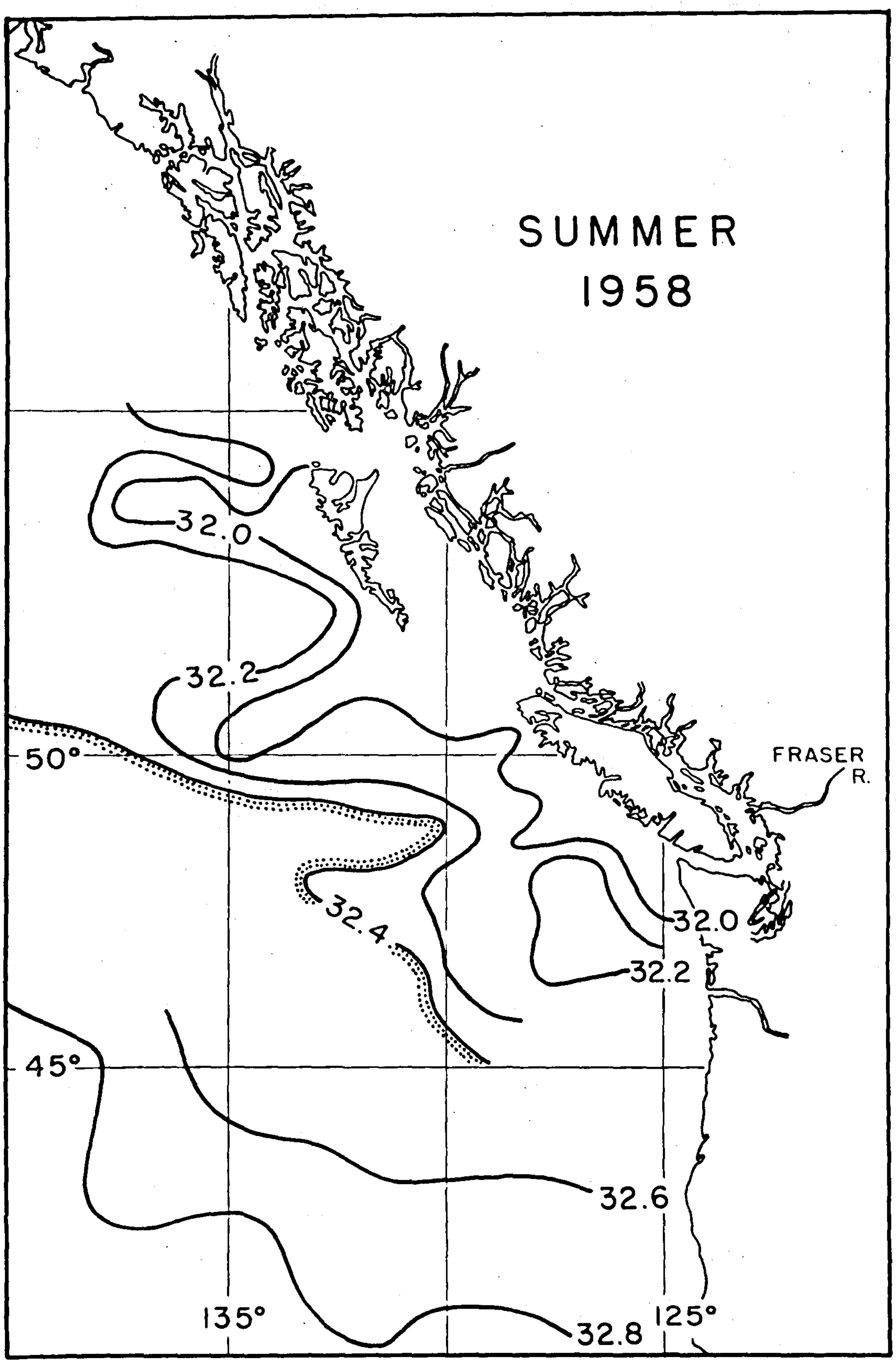
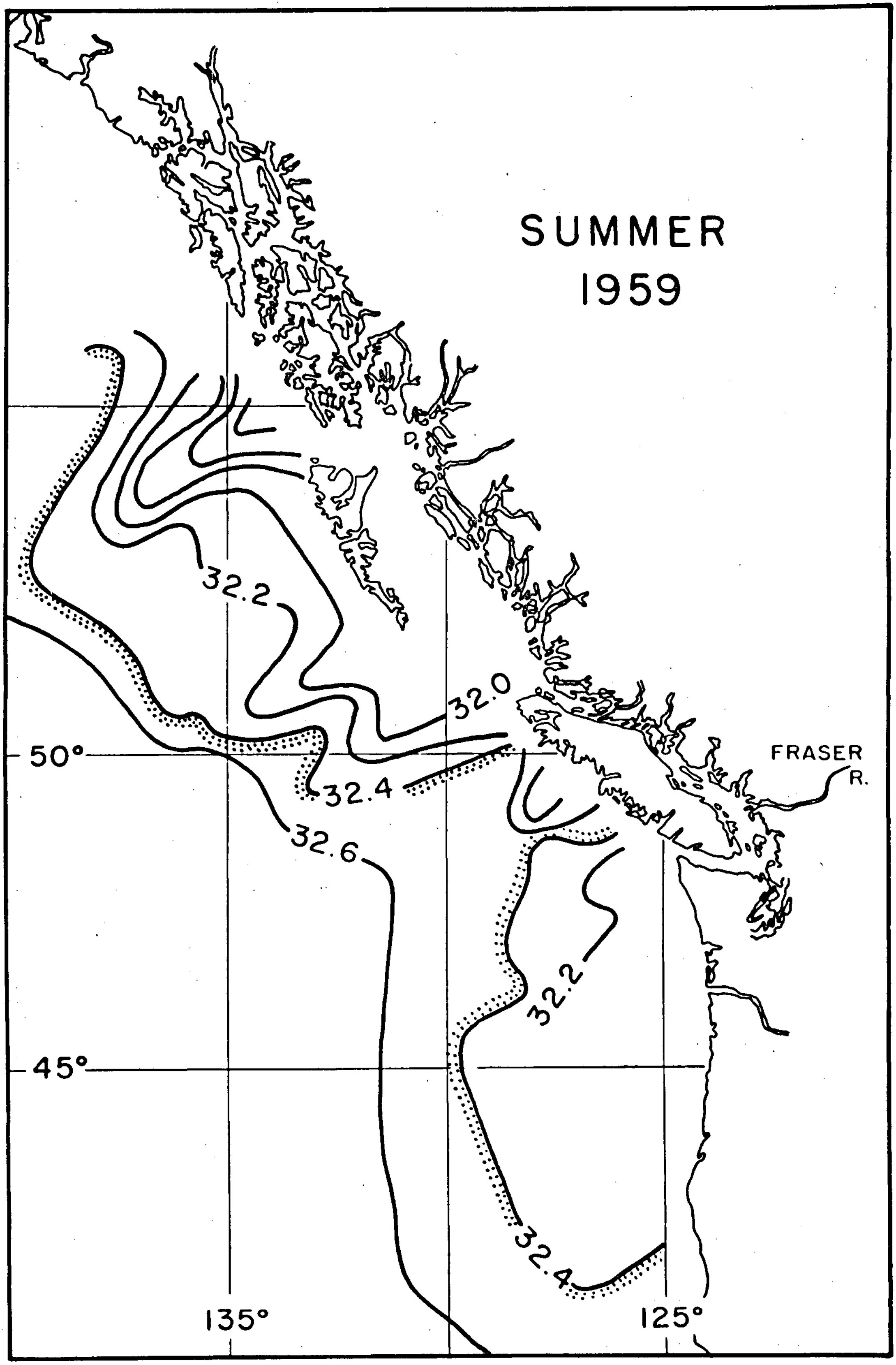


Fig. 2d



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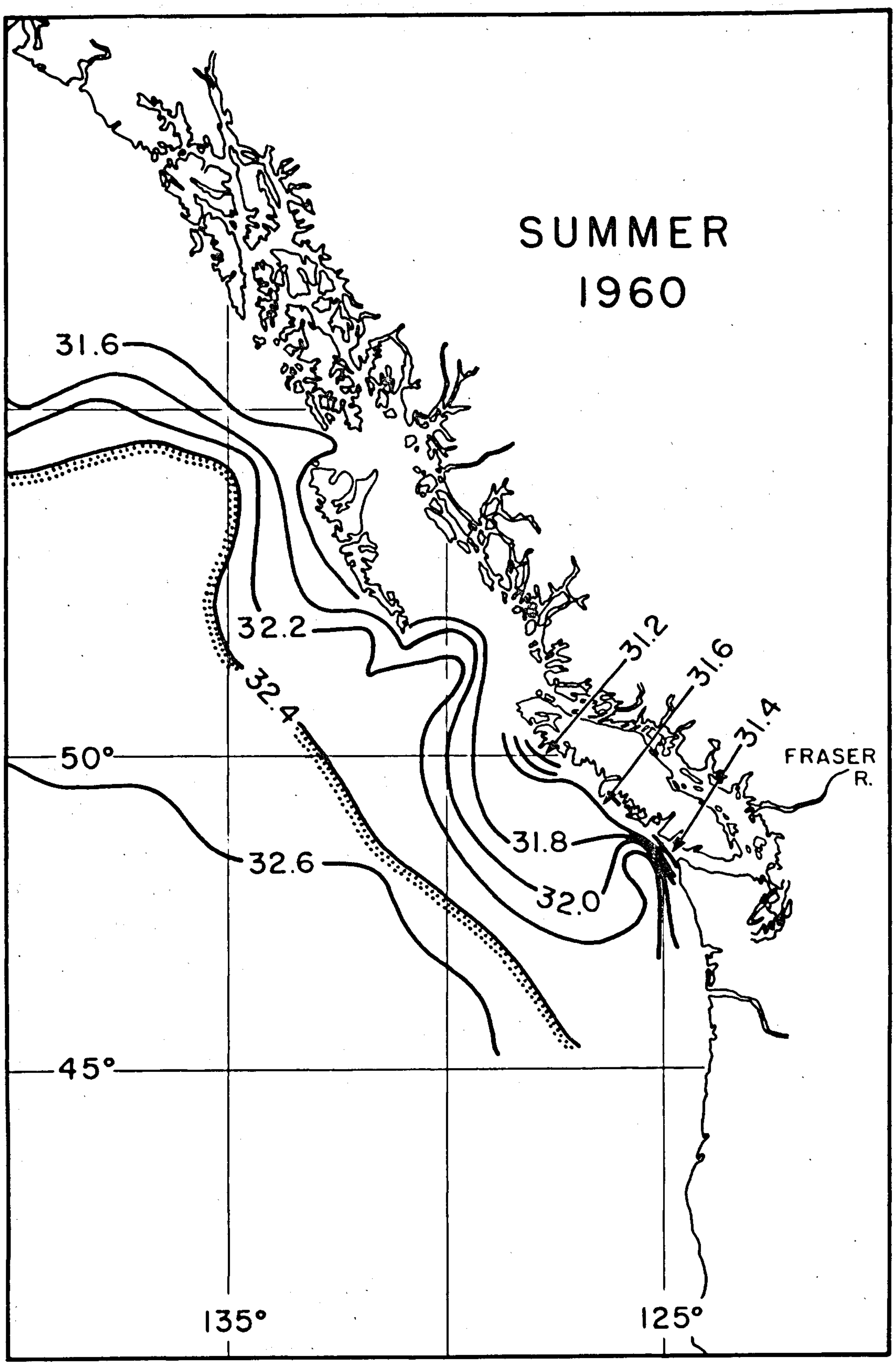
SUMMER
1960
31.6
32.2
32.4
50°
32.6
31.2
31.6
31.4
FRASER R.
31.8
32.0
45°
135°
125°

Fig. 2f

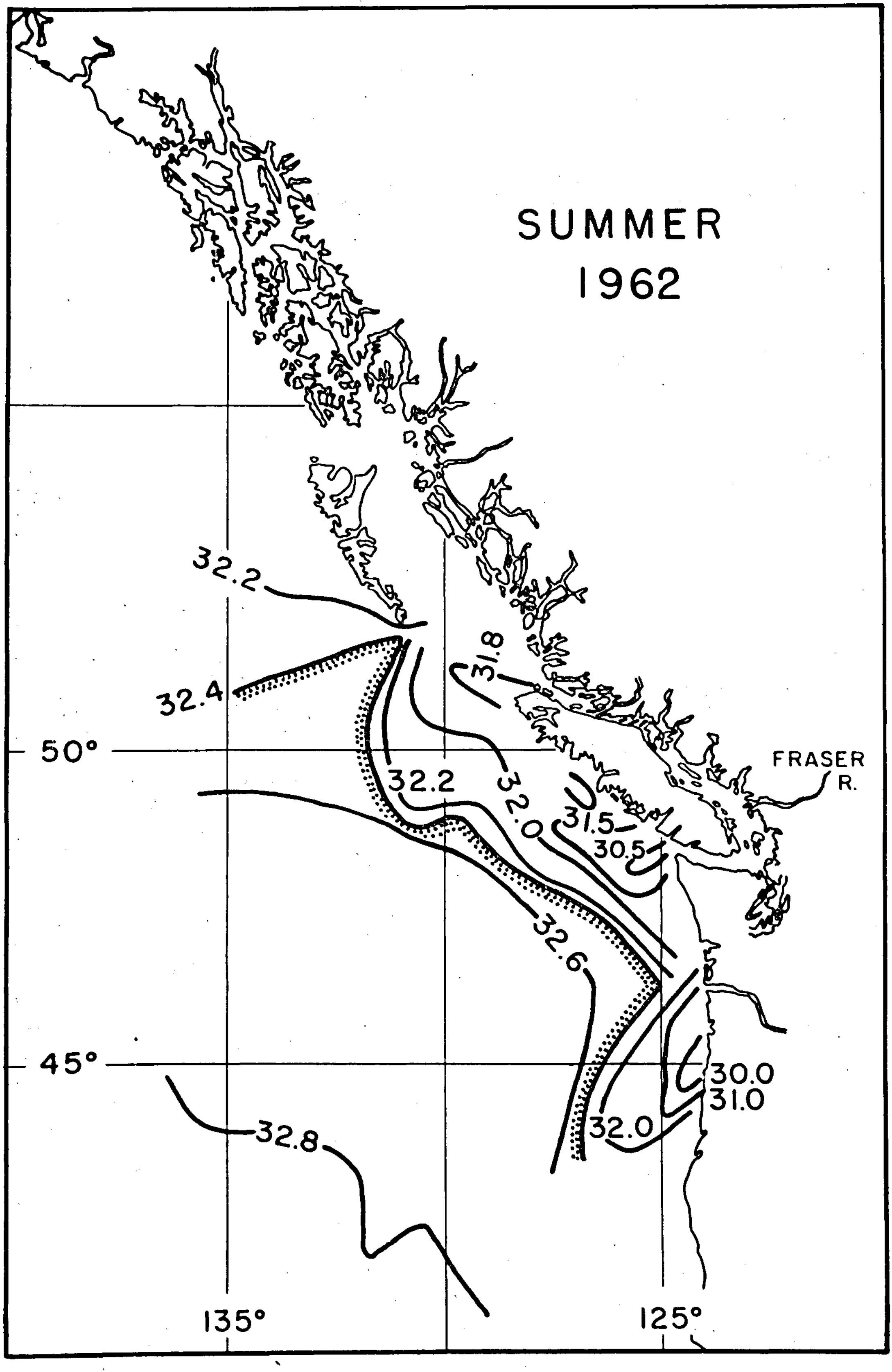
SUMMER
1962
32.2
32.4
31.8
50°
FRASER R.
32.2
32.0
31.5
30.5
32.6
45°
30.0
31.0
32.0
32.8
135°
125°

Fig. 2g

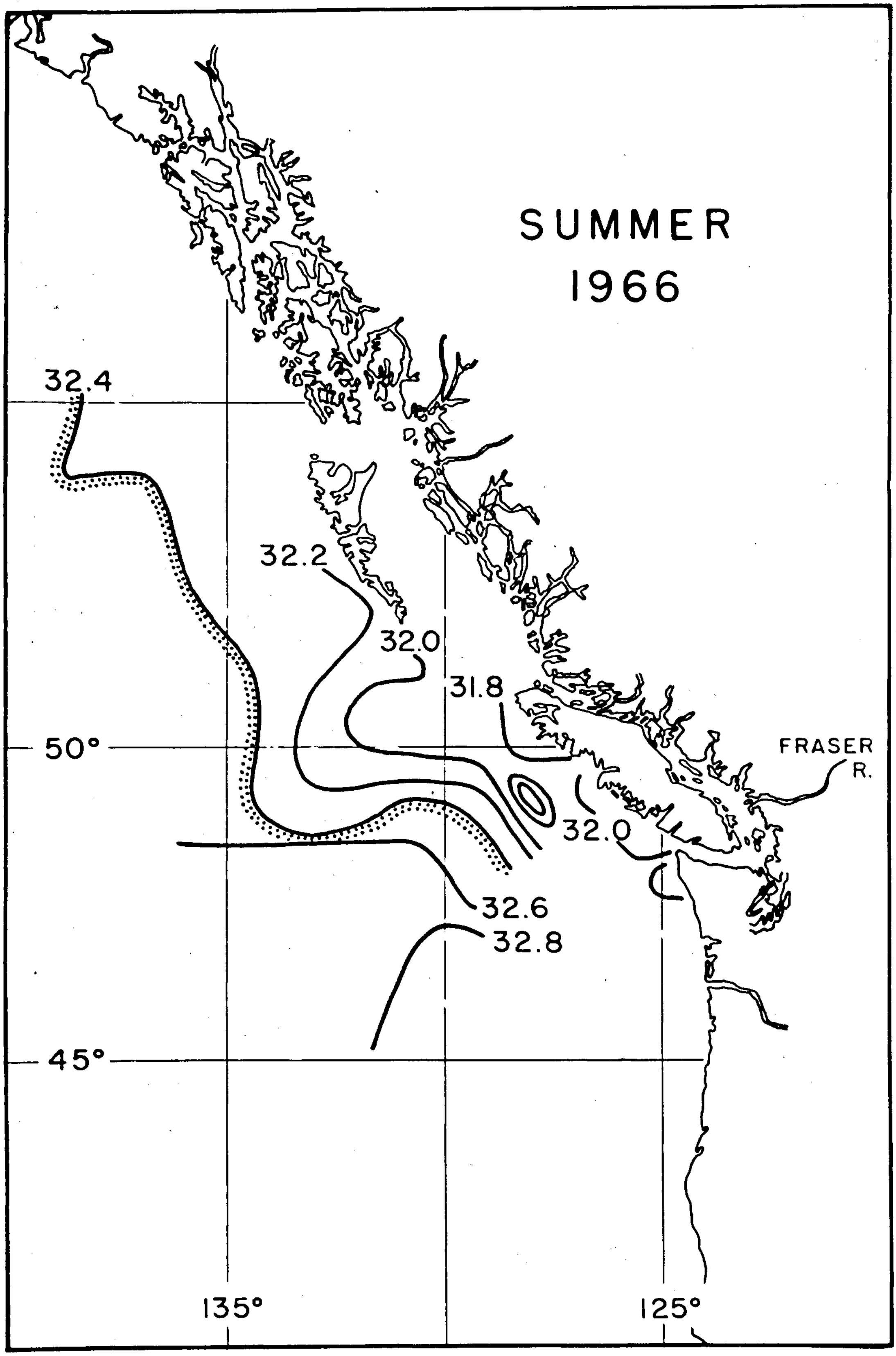

Fig. 2h May-June